PRODUCT LIFECYCLE MANAGEMENT

Assessing the industrial relevance

PLM-SP3, 2007

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EDITORIAL

This collection of papers constitutes the proceedings of the 4th International Conference on Product Lifecycle Management (PLM'07) held in northern Italy during the 11-13th July 2007 and organized in a joint initiative by the PLM Cluster of Politecnico di Milano and the University of Bergamo. The conference was hosted by the newest Italian technology park, KilometroRosso, located in Stezzano, between Milano and Bergamo.

Since their first edition in Bangalore in 2003, the objective of this conference series is to bring together researchers and practitioners involved in product innovation, product development and product delivery in one forum to share their viewpoints on new product innovation, lifecycle management, and supply and service chain. As the interest around this conference demonstrated, PLM is becoming more and more relevant both in the industrial and in the scientific world. Many industrial experiences are available nowadays in the world, and many of them establish connections with research initiatives.

More than 140 papers arrived and 85 of them were accepted and published in this book, after a severe peer-review process. The selected papers cover a broad spectrum of PLM topics and are organized in four main streams, presented in the eleven chapters of this book:

- *Management issues in PLM*: Organizational issues (Chapter 1), Business issues (Chapter 2) and Industrial experiences (Chapter 3).
- *Technical and integration issues in PLM*: Data exchange (Chapter 4), Tools (Chapter 5), Interoperability (Chapter 6) and Knowledge engineering (Chapter 7).
- *PLM support for product lifecycle phases*: Concurrent development and engineering (Chapter 8), Middle and end of life issues (Chapter 9), Lifecycle engineering and assessment (Chapter 10).
- Plus an ad hoc stream dedicated to the European FP6 project *Promise* (Chapter 11).

On behalf of the co-chairs of the conference, of the organizing committee and of the program committee we thank all the authors for their valuable contributions. We also thank the reviewers and the members of the conference program committee for their support in bringing this book to reality. Organizations that participated in the product showcase, sponsors and the local organizing committee (especially KilometroRosso people) are thanked for their help and support for making PLM07 a successful event. Finally, we wish to thank Michela Benedetti for supporting the preparation of this book and of the electronic proceedings.

Marco Garetti, Sergio Terzi, Peter D. Ball, Soonhung Han
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Chapter 1

Organizational issues

Applying a benchmarking method to organize the product lifecycle management for aeronautic suppliers

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Abstract: This work treats about the instantiation of the organisation of aeronautic part suppliers in order to attend the main Brazilian customer, who recently has been changing its concept of Product Lifecycle Management. This experience is showed in terms of a benchmarking method description, which is used for measuring cost structures, processes and technological performance of those enterprises. The benchmarking method provides the enterprises with strategic information, which will lead to highest competitiveness. One result of this benchmarking analysis is summarised in more than 100 benchmarking figures describing the performance of the aeronautic suppliers showing new organisational and technological strategies to be adopted. Other result is the information and knowledge documentation that will support the improvement of the Brazilian aeronautic supply chain organisation. Finally, another important result of this work is the attitudinal behaviour the entrepreneurs had during the application of the questionnaire and analysing the benchmarking results. They identified problems that can be solved immediately with the experiences and "best practices" of others. Additionally, common problems were identified that could be solved by joining competencies and efforts in a co-operative way.

Keyword: Benchmarking Methodology, Supply chain management, PLM.

1 Introduction

According with Eversheim and Weber (2000), supply chain external boundary conditions are high pressure of time and cost as well as high quality standards caused by fierce competition, new technological developments and lack of qualified personnel. Because of these conditions suppliers work environment is always in turbulence.

To minimise this work environment turbulence, some concepts, philosophies, techniques, methods and tools are being used. One of these methods is benchmarking, that is used for measuring cost structures, processes and technological performance of enterprises, and to provide them with strategic information, which will lead to highest competitiveness (Kiesel, 2001). In the present paper is showed how a benchmarking method can help to organise the implementation of a new Product Lifecycle Management (PLM) concept for aeronautic suppliers. PLM is an integrated business approach to manage the creation, validation, dissemination and application of engineering data throughout an enterprise. According to Subrahmanian and collaborators (2005), PLM is a strategic approach for creating and managing an organisation's product-related intellectual capital, from its conception to retirement. As information technology (IT) undertaking, supporting PLM entails the modelling, capturing, exchanging and using information and data in all PLM decision-making processes.

But, which are the information to be managed in a supply chain? How to organise fundamental information in an organisation? The authors of the present work believe that benchmarking is a good alternative to aid those questions.

2 Benchmarking

Learning from the practices of others is part of human nature. This principle are intuitively applied at home, at work, in the society. Benchmarking follows this same basic principle, trying to systematise and apply it in organisations with the purpose to supply them with strategic information.

Benchmarking is a continuous and systematic process to evaluate products, services and processes against competitors, or renowned organisations considered world leaders in their field (Spendolini, 1993; Zairi and Leonard, 1996). The working definition is the search for industry best practices that lead to superior performance. According to Zairi and Leonard (1996), benchmarking is used at the strategic level to determine performance standards considering four corporate priorities: customer satisfaction, employee motivation and satisfaction, market share and return on assets and at the operational level to understand the best practices or processes that help others achieve world-class performance.

The benchmarking method here presented is divided basically in three phases, respectively:

- Phase 1: identification of the best practices in one specific technological and organisational area;
- Phase 2: interpretation and discussion of the technological and organisational performance parameters with the group of entrepreneurs;
- Phase 3: planning actions to increase lower performance parameters of the group and of each enterprise, and apply them.

Many benchmarking projects fail in the phase 1 because of the non-definition of right comparison metrics.

Strategies in supply chain demand the adoption of systematic and methodical approaches in order to ensure adequate responses for processes organisation. This leads to the question: what are trends and success factors in supply industry, and how can they be helpful in finding successful strategies? (Eversheim and Weber, 2000). To answer these questions a benchmarking method has been developed to measure the performance of suppliers around the world. One of the most complete databases, created from the application of numerous European benchmarking projects, is the one co-ordinated by the

“Aachener Werkzeug– und Formenbau”, a partnership between the Fraunhofer Institute for Production Technology (IPT) and the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH – Aachen (Eversheim, 2001). Based on that experience, and adapting it to the Brazilian market reality, a specific benchmarking method was developed for Brazilian aeronautic suppliers of machined parts.

3 The project for Brazilian aeronautic suppliers

This benchmarking project was an initiative of Brazilian aeronautic suppliers of machined parts, which wanted to compare and evaluate their technological resources and processes, identifying the “best practices”. There were analysed more than 70 organisational and technological characteristics of 30 Brazilian suppliers of aeronautical machined parts. The metrics of each company were compared with the other enterprises and some of them with the *Centro de Competência em Manufatura – Instituto Tecnológico de Aeronáutica* (CCM-ITA) database. Then, it was possible to identify the group weakness and competencies in order to attend the main Brazilian customer, who recently has been changing its concept of Product Lifecycle Management.

This specific method was divided in four steps:

- Step 1 – Information Acquisition: It was developed a questionnaire for information acquisition. The information was verified and analysed after the visit of CCM/ITA consultants, whom in cooperation with employees from each company validated the filled questionnaire.
- Step 2 – Inform the general results: Based on the filled questionnaire it was developed some benchmarking figures analysing the worst, best and mean metrics of the group and of each enterprise. The overall group performance were presented in a general meeting. In that meeting the suppliers could recognise the group weakness and contribute with suggestions of new benchmarking features.
- Step 3 – Analysis of results: For each enterprise was prepared e confidential report showing his profile. The profile compared the individual results to the respective worst, best and mean performance.
- Step 4 – Action: After the individual analyses it was proposed planning actions to increase lower performance parameters of the group and of each enterprise. The proposal is being applying and its results are being monitoring.

To analyse the technological performance parameters, the “analysis of pairs” method was applied (Gomes and Vallejos, 2004). It is used to verify, considering a certain context, the number of prevalent qualitative parameters, where it is not possible to establish a comparison numerically. In that way it is possible to establish a ranking of weights for certain technological characteristics.

To exemplify this method to analyse technological characteristics of CNC milling machines, it is possible to link some parameters, as listed below: 1. Spindle power and speed; 2. Machining area; 3. CNC; 4. Work piece pallet; 5. Tool changer; 6. CAM interface; 7. Number of machines per operator; 8. Integrated measuring system; 9. etc.. Regarding to analysis in the table 1, when comparing in that case, for example, the CNC to work piece pallet, the CNC was chosen. With the information of Table 1 it is possible to establish a ranking of weights for certain technological characteristics (Table 2).

Table 1 Matrix for the "analysis of pairs" method considering a specific context (CNC, roughness process, etc.) for milling machines.

	1	2	3	4	5	6	7
1. Spindle power and speed							
2. Machining area	1						
3. CNC	1	2					
4. Work piece pallet	1	2	3				
5. Tool changer	1	2	3	5			
6. CAM interface	1	2	3	6	6		
7. Number of machines per operator	1	2	3	7	7	6	
8. Integrated measuring system	1	2	3	8	5	6	7
9. etc.							

Table 2 Ranking of weights for certain technological characteristics.

Characteristics	**Number of citations in the "analysis of pairs"**	**Characteristic 's weights**	**Characteristic 's usefulness**	**Weight x Usefulness**
1	7	5	2	10
2	6	4	2	8
3	5	4	2	8
4	0	1	0	0
5	2	2	1	2
6	4	3	2	6
7	3	3	2	6
8	1	2	1	2
Total				42

For the calculation of the weight for the qualitative parameters the following equation can be used:

$$\text{Weight} = [4(N_i\text{-}N_{min})/(N_{max}\text{-}N_{min}) + 1] \quad (1)$$

For usefulness the criteria are: 0 – they don't use the characteristic, 1 – they use it sometimes, and 2 – they use it frequently.

Considering the characteristic's weight and usefulness is obtained a total value that is divided by the maximum factor acquired for that analysis. This result is multiplied by 5 to obtain the technological factor.

4 Results

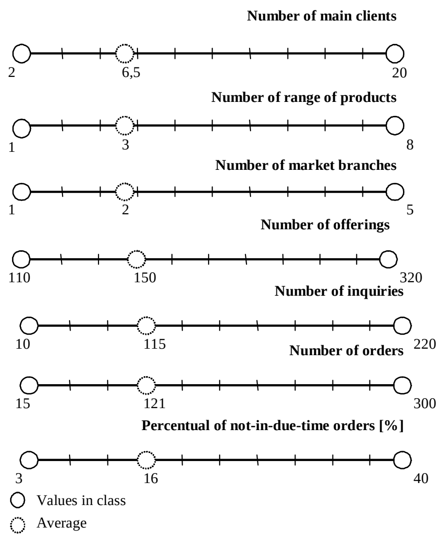
The result of this benchmarking method is summarised in benchmarking figures that describe several technological parameters measuring the organisational and technological performance in relation to the supply chain process. Below are presented some of those figures as an example.

4.1 The organisational structure

The organisational structure was developed gradually and non-planned, grooving mainly by the demand of the main client, a Brazilian aeroplane manufacturer. The manufacturing supply chain model is vertical, characterised by a low order variation and few range of products. There is a low difference between the number of enquiries and offerings in relation to number of orders handled. Even so, there are strong challenges for reduction of the manufacturing lead-time (figure 1).

Entrepreneurs have the perception that is necessary to improve the investments in information and communication technologies (ICT). It is notary the absence of Brazilian governmental support with politics to invest in that sector.

Figure 1 Organisational structure of supply chain management.



The benchmarking results show the good relation between the percent of the cost for personnel and the total cost that firstly means the idea of competitive companies. However the transgression between total cost and turnover is very close, which inhibits the decision for new investments. There is no perspective for a turnover ramp-up due to low values of capital and current assets and also due to low business cooperation, normally found out in industrial clusters. The companies are focused on the machining process with intensive application on process planning, NC programming, metal cutting, finishing and final assembly, but normally without emphasis on the PLM integration concept. The main client buys basically hours from suppliers (figure 2).

The low grade of automation and of process planning can be verified with the poor investment in IT. There is no digital information regarding to process planning, process control and tool service. For aeronautic suppliers of machined parts, the costs for machining and for raw-, auxiliary material, operating supplies are highest. Even so the low investment in the last 2 years, mainly in machine tools, denotes the poor support from Brazilian Government for special financing in the aeronautic sector.

4.2 Resources

In terms of milling machines, the group is characterised as having mainly conventional NC machining centers (72), which are not indicated for high remove rates of material, special case for aluminium parts machining.

The number of High Speed Cutting (HSC) machines is low (9) and with only 3 5-Axis-HSC machine tools it becomes restricted the orders with features of free form surfaces. About 1/3 of cluster shop-floor capacity is focused on rotational parts (figure 3).

Figure 2 Organisational information of supply chain management

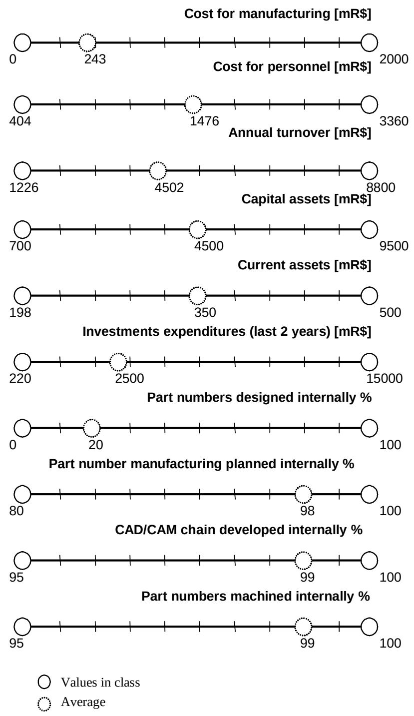
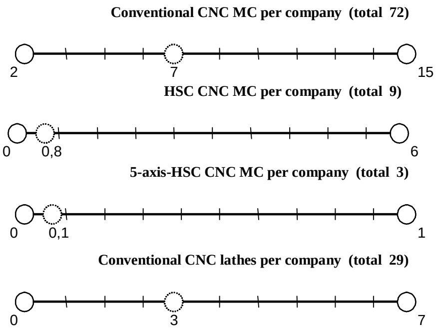


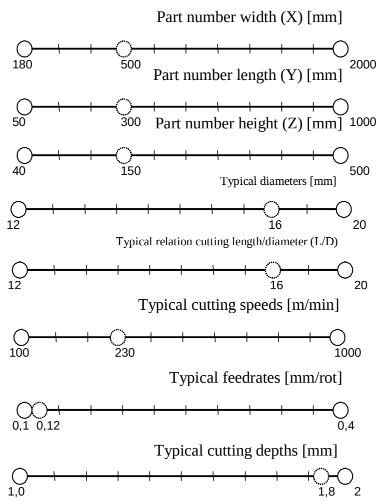
Figure 3 Mean profile of cluster milling machine.



The machined parts have typically prismatic geometries and are normally structural components of aeroplanes, basically without complex surfaces and having aluminium as material, which allows the application of small length and large diameter cutting tools.

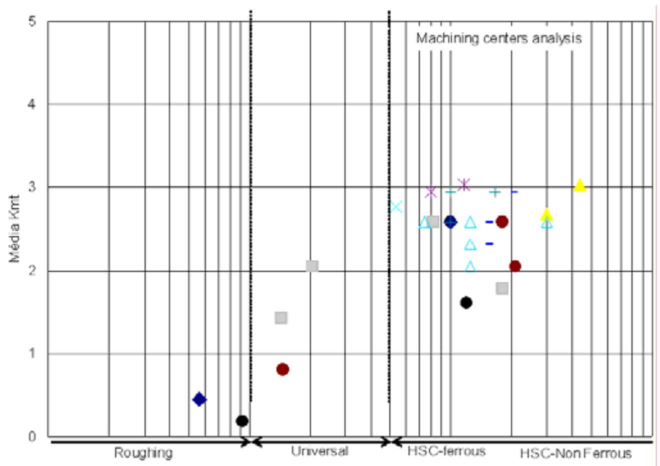
Even so, the low collected cutting parameters denote a poor knowledge on the machining process and also the need to up-grade the machine-tool shop floor (figure 4).

Figure 4 Typical parts dimensions and cutting parameters.



The used CAD/CAM systems can be considered as "high-end" software. However they are not used as expected, due to also the low personnel knowledge on the process. The technological grade of machine tools belonged to the aeronautic cluster studied is low. It was measured using the "analysis of pairs" method presented and verified a score of 2,5, which is typical used in machine-tools for steel (figure 5). Therefore, even the investments to qualify personnel in the group without the investments in resources like milling machines; emphatically the hoped efficiency optimisation would be not found out.

Figure 5 Characterisation of the aeronautic cluster milling machines.



5 Conclusions

Strengths and weaknesses of a Brazilian supply chain of aeronautic machined parts were identified through the application of a benchmarking method.

Major potentials for improvement concerning the organisational information consist in:

- A new management culture considering the PLM approach is necessary,
- The establishment of an efficient CAD-CAM integration to fulfil the customer requirements to increase NC-usage and
- A continuous investments in new state-of-the-art machinery, like HSC and HSC-5-axis Machines, and automation to keep an efficient shop floor.

The analysed information with respective call for actions can result in a potential increment of global competitiveness. A first step should be a conception of a new culture of PLM approach, looking for the integration of the best practices, impacting direct on the time-to-delivery, main costs and quality of manufactured products.

Important is that the new PLM approach is being proposed by the main aeronautical Brazilian customer. The authors of the present work believe that have contributed to identify important information to organize and structure a basis for this PLM approach.

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Metrics – The business intelligence side of PLM

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Abstract: In this paper we are proposing an ontology based approach to use the information base of PLM systems to support project analysis and management of development processes. At first, we will give a quick overview of generic engineering processes and involved IT-Systems followed by an analysis of common pitfalls and shortcomings. The paper however is focused on presenting meaningful metrics for the evaluation of PLM-data in a project management context based on a semantic integration model. After giving a short oversight of semantic web technologies we will introduce our approach based on these techniques. We use semantic maps to translated technical information supplied by a PLM-system into meaningful key figures to bridge the gap between technical and organizational data. Then we introduce PERMETER, a “semantic radar system” to pierce the thick mist of product complexity using ontologies and metrics. We will conclude with a summary and an outlook on further activities.

Keywords: Metrics, Ontology, Semantic Web, PLM, Project Management

1 Introduction: Measuring Performance in Engineering

Product development is a challenging research area for its creativity, complexity and its intricate management demands. It’s performance directly affects any company’s market success because in today’s fast and global markets, only an innovative product line and competitive prices secure survival and growth.

But how is performance in a development context rated? Classic definitions of performance such as “work performed per time” fail because it is difficult and impracticable to assess the impact of an idea in product development. Only long after a new product has been introduced into the market the economic success of a new idea can be measured by the revenue it creates. Up-to-date measures are needed that reflect the status of the development project in financial and temporal terms, the product maturity and any critical issues.

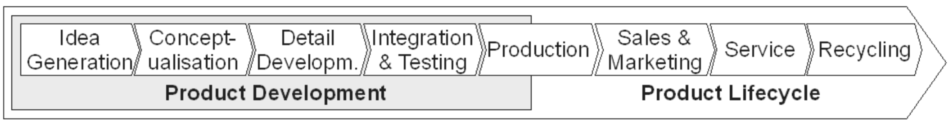
The importance of this issue becomes clear if we consider the high rate of overstretched or failed development projects ([1] [2], [3]), the lack of suitable solutions can be found in the very special nature of product development. Firstly, innovation activities can cover a wide range of activities from “applied projects to competency-building programs to basic research explorations" [4]. This calls for distinct, goal-oriented measures. Secondly, products and innovations brought to the market today are the result of many experts working together in a somewhat structured, however complex, dynamic and sometimes chaotic course of action: a development process often carried out in a global engineering network [5]. The third common trait of R&D and innovation processes is their intangibility caused by mostly virtual development methods (CAx-technology, [6]) or completely invisible products such as software, nowadays the driving force behind many innovations.

2 PLM - the Data Source

2.1 Engineering Processes

Accidental innovations such as the notorious story of the feeble superglue that conquered the world on the back of Post-it®-Notes[1] do happen, but most products brought to the market today are the result of day-by-engineering business and adhere to a strict specification sheet tailored to a target audience. To meet these requirements, many experts work together in a somewhat structured, but complex, dynamic and sometimes chaotic course of action: a development process. The development process goes through a number of phases which specific goals. The product lifecycle adds more phases that also provide valuable information for future developments. Each phase adds more detail and information to the product model ([7]). The content and sequence of phases depend of course on the industry sector under consideration and most sectors have developed their own best practice approach but a very generic model can be found in Figure 1.

Figure 1 Phases of product development and the product life cycle.



All development processes face the same challenges:

1. Dealing with technical complexity.
2. Understanding the interactions and dependencies between phases and partial models.
3. Determining the status of the project in terms of time, cost and quality for project management.

Common solutions such as Management Information Systems (MIS) fail to provide accurate information in such a setting because they are based on economic key performance indicators but are not geared towards capturing the many convolutions of a product development process. Here PLM-solutions are better suited as they capture complex products and their creation processes. They are a good base for operational controlling of a development project and also contain valuable information for strategic product decisions, but when it comes to status evaluation there is a gap between

[1] 3M, http://www.3m.com/us/office/postit

technological information and its sound economic interpretation. In this paper, we present metrics to bridge this gap and to come to new insights about one's products and processes.

2.2 IT-Standards and Business Objects

The IT support of engineering tasks is exceptionally good, for almost any task a CAx-solution exists. Despite the individual sophistication of these systems little research has been done on formally modelling and understanding development processes based on the actual observation of development activities, their dependencies and their (digital) results (= partial product models). Thus two additions are necessary: (i) a sound, flexible and integrated model of products and processes and (ii) an automatic transformation of technical qualities into economic key figures.

Addressing the first issue, PLM-systems offer a profound base of required data but are not yet sufficient to analyse the wealth of information they hold. PLM data exchange formats such as EDI, PDML or IGES focus on geometric information plus some metadata. The most prominent and comprehensive exchange format in the world of PLM however is STEP (Standard for the Exchange of Product Model Data), which will be used by the authors to build their proposed solution upon (see paragraphs 4 and 5). To address the second issue, the transformation of technical information into economic key figures, this paper introduces metrics for product data as described in paragraph 3. Here we focus on the information and metadata provided by STEP that has already been used in earlier works as a base for development project evaluation ([8], [9]). At the core of the basic STEP PDM Schema are products, being either a document or a part [10]. They are managed in the dominant structure of product development – the Bill of Material (BOM) with a number of specific relations to manage different product configurations.

2.3 The semantic gap – a question of interoperability

As stated earlier, there is a semantic gap between the information of PLM-systems and their economic evaluation. The severe deficit of PLM data structures is that they are primarily focused on technical processes, not so much on economical or organizational issues such as project management, interoperability between different system types (e. g. Integrated Software Development Environments, Project Management Systems and CAx-Systems) or benchmarking development methods. Typical questions are: Will the product be finished on time if I change this specification? Make-or-buy this component? What's the quota of re-used parts in my portfolio? To answer these questions, flexible metrics are necessary to evaluate PLM data. Following up on design decisions taking during the project or evaluating tools used may also give important strategic information for future endeavours. It may be possible to eliminate ineffective tests or promote the use of simulations instead of real world prototypes.

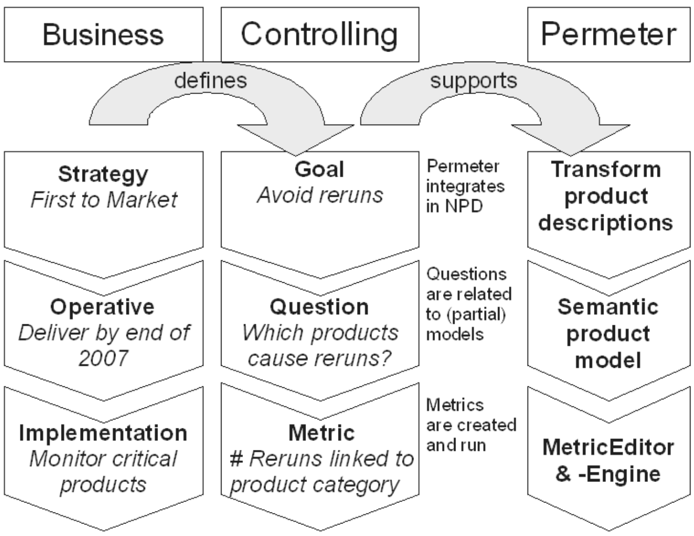
3 Metrics for Project Management

3.1 What is a Metric?

A metric is a measurement or calculation rule to assess *one* product or process quality ([11]). To derive metrics in the PLM setting, the Goal-Question-Metric approach from the TAME-project [12] is used. Metrics can be derived from business strategies by asking the according critical questions and answer with helpful metrics. This process is supported by the tool presented in section 5.

Metrics can be classified by a number of dimensions such as object of study, research goal, quality characteristic, … (see [13]), the most common one is the object of study, usually, one differentiates between product and process metrics, combined models give insight into the overall status of the project.

Figure 2 Permeter uses the GQM-Approach to link strategy to products.



3.2 Product Metrics based on the Bill of Material

As stated before, it is important to derive one's measurement methods/metrics from the current project context. There is no "one size fits all" metric set that can be used for every type of product or every new project, because the information that exists in a project and the specific properties of a product differ from one project to another. However there are some points of interest and patterns that can be applied to product measurement in general.

The reason why metrics are used is that there is an overflow of information in general and a lack of specific information (which is needed for a better understanding of project activities and their outcome) at the same time. To show some aspects of product measurement we use simple examples based on the evaluation of the BOM, useful to categorize products. A simple way to evaluate the complexity of a product is the length and size of the according BOM, determined by the depth of the product tree and the number of elements contained. The more components a product has, the more complex it is. This kind of metric can also be extended by evaluating the components properties. The most intuitive example is surely the weights of the components which can be simply added to calculate the expected weight of the product. More sophisticated metrics may weight the components by the number of documents associated to them or the even the release status of the associated documents and parts giving a clue to the maturity of the product.

The BOM can also be used to construct a component hierarchy tree which can be used to construct metrics based on tree graph theory. But effective metrics on the product hierarchy tree also depend on the ability to weigh its nodes, the parts and documents, in a meaningful way. This can't be done by PLM data alone. E.g. domain knowledge has to be applied to judge a components complexity. Ontologies are a promising way to overcome this semantic gap. Engineering domain ontologies can define their understanding of complexity on the basis of an abstract metric ontology. This is just one example for using ontologies to integrate information from different product related domains for metric purposes.

3.3 From product to process metrics

Making statements about the product is just the half way up to effective controlling of our projects. PLM provides administrative data that can link processes to products. But how can we benefit from this data? On the one hand processes can be used to evaluate components in a BOM. When we construct a product with lots of components that have lately been subjects of changes, we will likely have troubles with that product. – On the other hand we might use product metrics as sub metrics to estimate the effort needed for a modification of our product. A modification affects components that can have multiple dependencies to other components or might implement other requirements. The degree of dependency is another metric that might be described using ontologies in an elegant way. Project tasks can also be regarded as processes that can be related to products. These can help us to determine which products or product categories cause troubles for our projects and might eventually need a redesign. Product categories might even be outsourced which shows the strategic effect of product-to-process metrics.

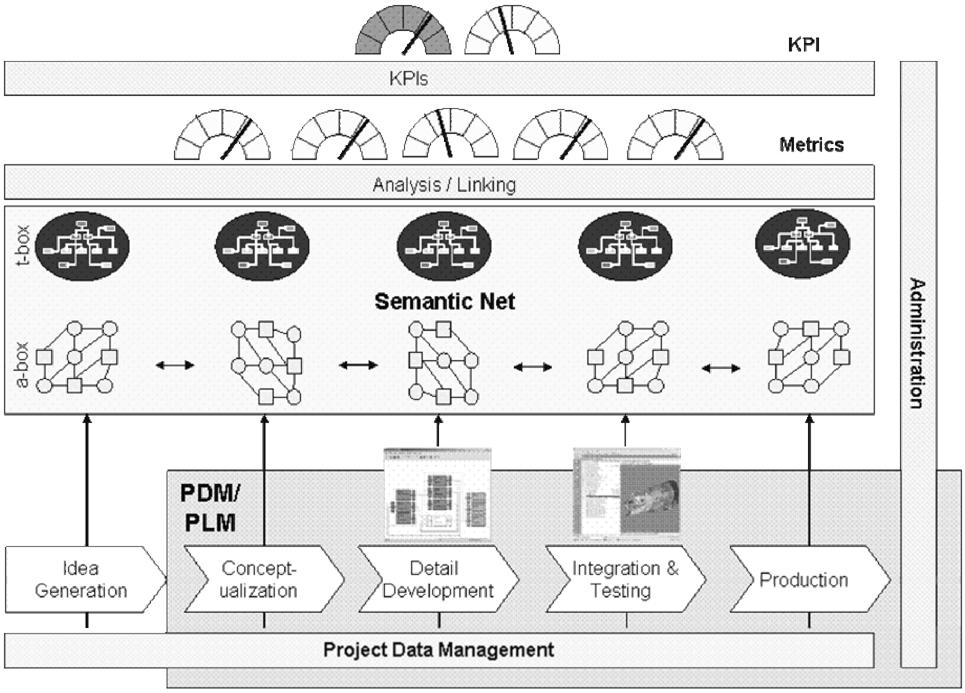
This is only a short insight in the features of metrics used on product data and PLM-Systems, a potential application in many engineering scenarios is e. g. the comparison and analysis of “as-designed” and “as-built” configurations (see [14]). Despite the potential they offer, one has to bear in mind that only careful selection of the right metrics has added value. No set of metrics or KPIs is an auto-pilot and measuring the wrong or partial properties can lead to overcompensation and failure.

4 A Performance Measurement Solution

4.1 Conceptual Overview

To implement the metrics described above, Figure 3 sketches the proposed solution for a phase-connecting framework of product development. Based on conceptual ontologies of project phases and the manual or (semi-) automatic interconnection between corresponding development artifacts during the development process, metrics for a project controlling dashboard and performance indicators can be derived.

Figure 3 Framework overview An extension of [15].



A closer look at Figure 3: At the bottom of the figure the data sources are sketched. In this example case these are five phases, four of them controlled by PLM. For each phase conceptual ontologies (t-boxes) define the types of artifacts created in this particular step of the development process. The figure displays them in the line labeled "t-box". PLM and project management ontologies provide the t-boxes for their context. In a specific project, the a-box is filled with corresponding instances; e. g. a specific part of a product is modeled as an instance of the concept "Part" as established by the t-box. This procedure is shown in the line labeled "a-box". A-boxes are created by a transformation process that converts documents like STEP-Files into semantic models.

In addition items of different phases are linked “horizontally” by manual or automatic linkage facilities. The semantic model established by these relations offers a representation of the development process not available previously. Dependencies and interrelations between individual phases and artifacts are made apparent.

Based on this integration, metrics and reporting tools find a semantically rich data source for analysis and to draw figures for a project management cockpit, as indicated on the top of Figure 3. Key figures are now derived from the project context and don't need to be interpreted in the isolated frame of a certain phase. To implement the surveillance and control functions, methods described in literature and research are applied as conceptual and process oriented metrics, to be later transformed into key performance indicators (KPI, see [16] and). They form a basis for up to date process monitoring that allows both measurement and active control.

4.2 Enabling Technology

Basis for the integration of the different models used to represent the development process as a whole are ontologies. Ontologies are models consisting of concepts (classes) and relations. The meaning of a concept is defined by human-readable descriptions that provide a common understanding. The usage of relations between classes is formally defined. E.g. for PLM we might define what a product is to us and how it can relate to the concept document. Further more an ontology can contain integrity and inference rules. A more detailed description is given by Gruber [17]. Ontologies have been a key approach in knowledge representation for years and methods to develop and testing them have matured. A language to describe ontologies is the Web Ontology Language (OWL) by the W3C. It has been developed by the W3C mostly for Tim Berners-Lee’s idea of the semantic web [18]. Although the semantic web didn't have a breakthrough yet, it's technologies are used in many domains e. g. medical informatics.

Semantic models based upon ontologies allow describing instances in sense of several domain ontologies at once. E.g. the semantics of requirements, products or abstract complexity can be put like layers over a common model. These semantics can also be defined by rules. This is a very elegant approach to classification. However this must be done by dedicated logic engines, called reasoners.

4.3 PR²ONTO: Ontologies for Products and Processes

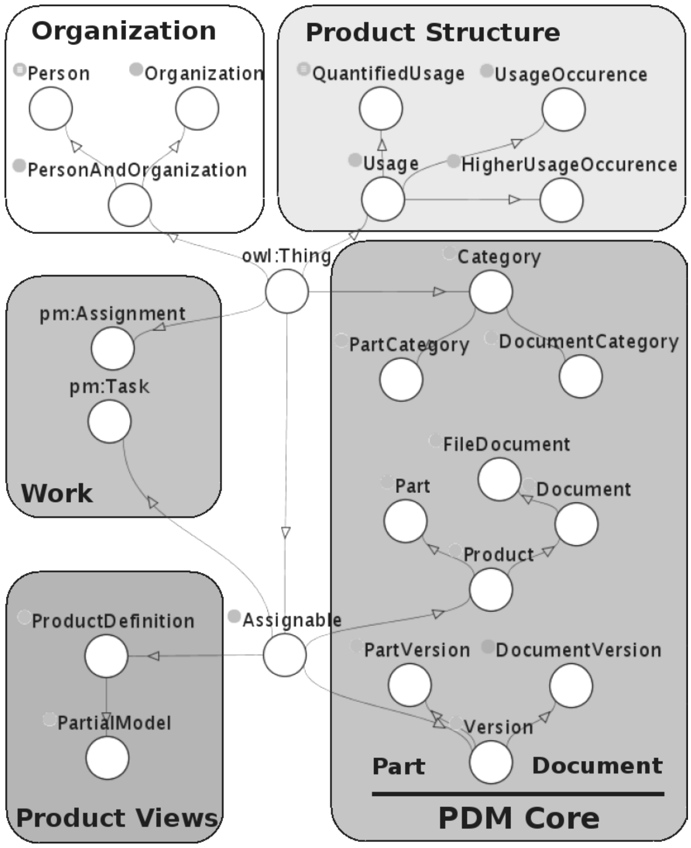
An ontology describing the development process must consist of several smaller ontologies that represent domain views on the product at different stages of the development. The set of domain ontologies needed to describe the product is project specific. In addition to these ontologies at the micro-product level, we assume that a PLM-based macro-view on the product is always necessary to characterize it in the context of the company. Some parts may come from a component supplier while others are self-made components that can be in the scope of the development process. Furthermore, we need to characterize the domain views to relate them to a development stage. Unfortunately this can be very complex when a domain ontology is applied in more than one development phase. To overcome this complexity we need PLM to classify the instances of the domain ontologies by their role in the development process. Our approach is to use a PDM/PLM ontology that will be part of the holistic product and development process ontology. This ontology is called PR²ONTO which is an acronym for PRoduct and PRoject ONTOlogy. It enables us to refine PLM data into semantic glue for the different views on the product regardless of their originating domain.

An overview of PR²ONTO organized in different scopes is shown in Figure 4. Ontologies allow objects to be instance of any number of classes as long as these are not declared explicitly as disjunctive. This aspect is important for understanding this ontology.

1. PDM Core gives the basics to represent parts and documents in term of PDM Schema and categorize them. The aspect of versioning is already included but not yet supported by the Permeter software (see following chapter). Later this will provide a basis for time-variant metrics, which we will discuss in the outlook.
2. Organization should be self-explanatory: These classes can also be used in conjunction with instances of “Assignable”.

3. Product Structure can be used to construct the different types of BOMs. The classes are derived from the PDM Schema.
4. Product Views provides the semantic glue between documents and parts. A domain model or a set of instances in a model define a part in a specific application domain and development stage and therefore provide a view. Views may also already be defined in the PLM data. The classes reflect these different kinds of views.
5. Work is set of classes imported from a project management ontology of Permeter. This allows use to relate products to project processes.

Figure 4 PR²ONTO provides a basis for a semantic integration of different domain models from an PLM approach based on the STEP PDM Schema.



5 A Tool for Product Metrics - PERMETER

In this chapter we give a short introduction to Permeter (http://www.permeter.de/), an application implementing the proposed framework that is able to handle all described steps like loading partial model specific project data from a PLM-System, establish relations between artifacts of different partial models, run metrics on the integrated product model and display the aggregated results in reports.

Permeter consists of three main user-perspectives. The first perspective is the Project Management Perspective, which depicts the organizational context of the development project. Here, all tasks, milestones and costs are collected and integrated with the product view, semantically bridging the technical and the commercial perspectives.

The second perspective is used to establish links between artifacts of different partial models. Permeter offers a specific editor as well as automatic linkage prototypes to create the model-spanning semantic web from PLM and other sources. Thus dependencies and interrelations between artifacts not available previously are made apparent improving surveillance, control and management of development processes through this model.

The third main functionality of Permeter is the analysis of the collected data via metrics. To define flexible metrics suited for the purpose, a metric engine, report editor and a visual editor to create metrics are part of Permeter.

Figure 5 Product development process and Permeter framework

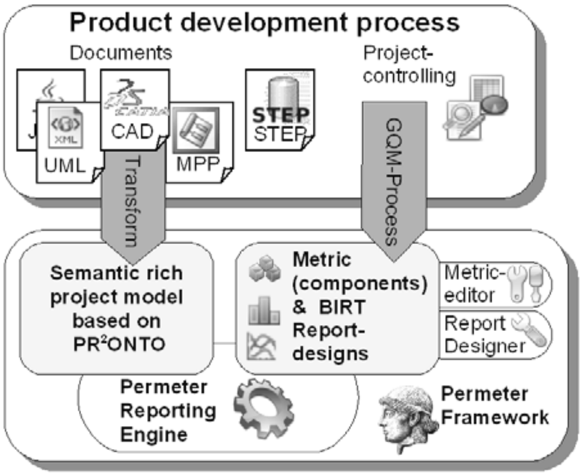


Figure 5 shows the analysis of a project with Permeter. Data from various file formats can be imported. E.g. STEP PDM files containing PLM data provide the semantic meta model. As mentioned above the semantic project model is created by linking instances from these sources on basis of PR^2ONTO.

The GQM process results in project specific metrics. These can be created using a dedicated metric editor by combining metric components and other metrics. Metrics can be put together in reports based on the Eclipse BIRT Framework. This metric concept is a flexible approach to create domain specific metrics in a quick and easy way.

6 Conclusion

We have illustrated that PLM-Systems are well suited for supporting engineering processes, but have limited capacities when it comes to performance measurement and project management tasks. This gap can be mended by metrics that evaluate product data gained from PLM systems in an economic or organizational context. To allow for flexibility and inter-domain interoperability, the metrics do not operate on "raw" PLM-data but have an intermediate semantic layer implemented by an ontology. A few simple examples have been given based on the BOM; more complex, context-specific metrics can be easily assembled as described in paragraph 5. So a continuous set of KPIs can be derived to assess strategic goals based on actual development data.

Since PLM-Systems track every change of the product, it is feasible to create time variant metrics that trace the product evolution, showing the effects of development decisions. In conjunction with other data sources the proposed solution Permeter becomes a powerful tool for both operative project management decisions and strategic or scientific evaluations of development processes, projects and methods.

Permeter 1.0 has already been completed and its concepts and implementation will now be tested in practice. Major automotive companies, both suppliers and OEMs, as well as a research consortium from the semiconductor industry plan to apply Permeter in their development projects.

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Supporting collaboration in product design through PLM system customization

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Abstract: This paper deals with the proposal of a framework for coordinating design process through a PLM (Product Lifecycle Management) system. Design coordination implies that project managers are able to structure their project, assign resources and define the schedule of the resulting tasks with specific objectives and performance criteria. In Small and Medium Enterprises (SMEs) the design process is generally described at a macro-level which does not fully correspond to the complexity of the real process. To improve design coordination in SMEs a method for analyzing informal collaborative practices is introduced in order to help modeling detailed but flexible design processes. Then these processes are implemented by using PLM technologies: multi-level workflows are implemented to control document workflows through synchronization tasks.

Keywords: Design coordination, design process management, PLM systems, workflows, collaboration

1 Introduction

Design coordination implies scheduling / planning tasks and resources management [1]. In main companies the product development process is formalised at a high level and project managers have to respect the general identified phases and milestones. They have autonomy to structure projects and tasks but respecting this general framework. In such a context, coordination of the information flows within design teams is generally managed through PLM basic processes centred on documents life cycle.

In SMEs, design process is also structured and especially when the company is involved in a quality management certification. But most of the time companies undergo external risks and collaboration between designers has a strong influence on the process

[2]. Flexibility is the main characteristic of design process in SMEs even if sometimes this situation leads to time consuming and a lack of coordination. In this context the formalization of information flows can lead to rigid processes that can disturb the operations of the company. When implementing a PLM system in an SME, we face two antagonistic problems: first to improve the level of formalization of information flows and second to keep a certain level of flexibility [3].

Our aim is to propose an approach that integrates these two problems in order to define flexible workflows based on the analysis of the collaboration among designers. In section 2 we focus on design coordination and PLM systems and we introduce the case study that will be developed all along the paper. Section 3 introduces a new approach based on collaboration analysis to increase the level of formalization of design processes. In section 4 we study the impact of this work on the implementation of PLM workflows dedicated to document management as well as design project coordination.

2 Design coordination and PLM systems in a SME

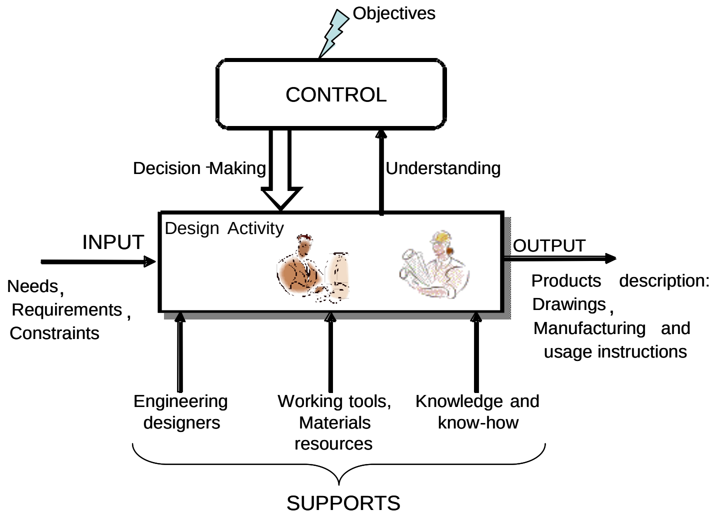
2.1 Design coordination

Today design projects depend on the ability to coordinate and to control the collaboration between the numerous actors participating in such projects: e.g. designers, experts from different disciplines and with different experiences, or external partners. Coordination and control of engineering design are part of a global approach for the development of new products which implies the need to identify the different situations occurring during the design process and the adequate resources to satisfy design objectives. In design project management, the control of the progress of design process can be defined as the understanding of existing design situations (in the real world) in order to evaluate them and take decisions that will modify and improve the future process, according to design objectives given by customer specifications or issued from the company strategy. The control problem here is a problem of decision-making to support designers in their activities [4] in order for them to achieve an objective in a specific context (figure 1).

Design activity has “input” and “output” information. Actors use the “input” in order to produce the “output”, to achieve their activity and they have “supports” namely: human and material resources and knowledge to help them in their work. For decision-making, project managers need to identify effective action levers which will influence collaboration thus increasing design performance.

In an SME design projects are generally different and require a specific study for each customer’s specifications. Most of the time, the small structure of the SME does not ensure project management in a routine way and leads to combine various responsibilities. Indeed there are not enough actors to fulfil each design role, so most of the actors have various design roles in a project. Consequently the role of informal relationships is very important in the SMEs in order that each design stakeholder may help each other without rigid formalities. Thus, the combination of various responsibilities and the informal relationships lead to a high level of workload because informal tasks are added to the official ones. Accordingly SMEs have to manage deadlines by setting an order of priorities on design tasks according to the objectives.

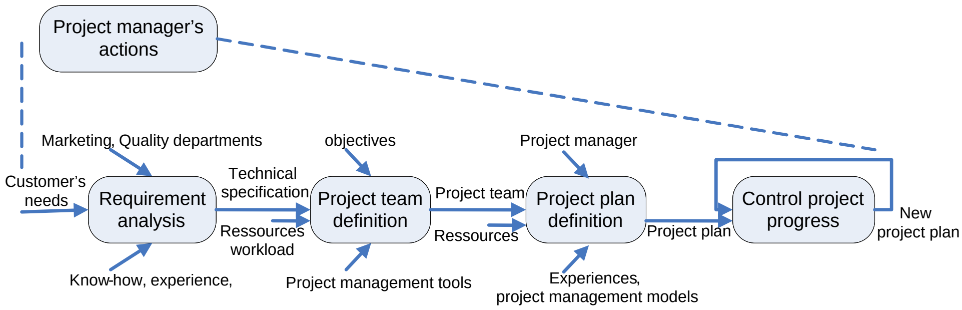
Figure 1 Coordination of design activities



Another point specific to SMEs is their project structures with a rigid formalization of their processes at a macro level and a very flexible non-formalization of the detailed processes which allows informal relationships into the project.

In this context, the project manager coordinates (figure 2) by analyzing the requirements from the customer, after which he defines the project team with its internal organisation [5]. He then defines the sub-phase of the project plan and activities in each sub-phase, next he defines a plan to control the project progress and finally he applies this control plan. Periodically he controls project progress and makes the adequate modifications according to the results and the design objectives.

Figure 2 Synthesis of the project manager's actions.



2.2 PLM systems and coordination

PLM (Product Lifecycle Management) systems are deployed within companies to support product data structuring and management throughout the product development process. They manage information through document management and especially product data evolution using predefined workflows [6]. Actual PLM systems integrate Internet-based technologies and offer groupware-like functionalities [7, 8] for collaboration among actors. Several PLM systems have recently introduced project management functionalities [9]. Most of the time these functionalities allow the formalization of tasks and milestones schedule. Nevertheless this project implementation reveals strong limitations [10] if correlated with design coordination. On the one hand the management of deadlines and the modifications of tasks sequences can be made dynamically.

On the other hand, it is not possible to ‘reuse’ predefined tasks sequences or to ‘redo’ specific ones as compared to workflow capabilities. Main limitation concerns the impossibility to drive documents life cycles from the tasks schedule. If a deliverable can be associated to a milestone, this only means that the end of the deliverable lifecycle must occur when the milestone is achieved, but no synchronization is possible before the lifecycle end. Consequently in the SME context we consider that there is no integration between macro-level project management and the micro-level document oriented process management, each level being managed through different technologies implementation. Nevertheless some PLM systems are able to manage workflow without associating them to documents: the proposed framework will be based on this assertion.

These considerations highlight the necessary flexibility of a design process in an SME. If the process is predefined at a global level as it is required by a PLM system, this is rather incompatible with actors from all departments working daily in a context of “mutual fit”. The processes of cooperation are quite unstructured and the confrontation of the various project teams’ points of view leads to informal and unofficial information exchanges [2]. When establishing a schedule in a SME it is an important issue to identify what must be really controlled and so predefined through a workflow, and what must be encouraged and not detailed. The management of the product development processes requires greater flexibility in the activities [11]. The coordination through PLM systems must be studied in order to integrate document workflows and to introduce flexibility into such workflows [12] for global project coordination.

2.3 Presentation of the case study

The industrial case study has been achieved in an SME which, some years ago, developed a new means of manufacturing structures using honeycomb sub-assemblies. This innovation confers lightness and significant vibration absorption on products whilst maintaining similar rigidity to steel. The company has captured several markets with products manufactured using its technology and consequently the number of employees grew from 4 to 40 over 10 years. Over this period the organisational structure and internal processes have not been formally revised. The objective of our study was to help the company to reorganise and to introduce the role of “design project manager” in order to manage further growth. In this context, problems of organisation, project management and relationships with suppliers, customers, and subcontractors come into play. We have first studied and analyzed the company’s design and industrialisation department. Then we have formalised: a new organisational structure; the processes of development of new products and the management of technical information and of product data.

After this first phase we have focused our work on the study of collaboration and relationships between actors and on the design project coordination [13, 14]. In the next section we introduce this approach and give some results of its implementation.

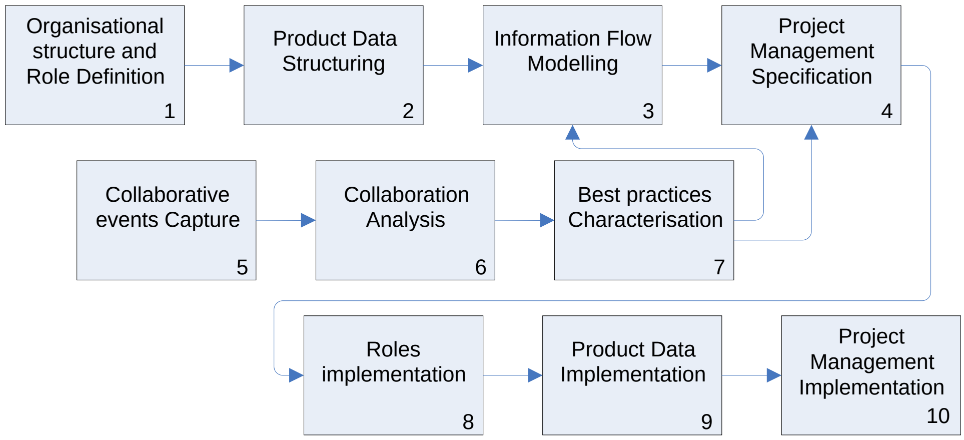
3 From collaboration analysis to design processes characterization

3.1 Collaboration analyses: a method to improve design processes definition

In a previous work of the authors [15] a model and a software tool have been presented to track the collaboration between designers. The model deals with the identification of the main relevant elements for the characterization of the collaborative situations in design. Collaborative situations are defined from a coordination point of view, with scheduling, planning, and the definition of milestones and activities. Alternatively, they are also defined from a human relationships point of view with the persons involved in the collaborative event, their skills, their motivation, and their form of communication. Both points of view are considered to characterize the factors of tracked collaborative events.

To support the traceability of the events, their characterization and the context of the project, we have implemented a software tool named CoCa (an acronym for Collaboration Capture) in order to implement the proposed model and to help managers to analyze collaborative situations occurring in projects. The following method has been proposed to integrate the analysis of collaborative situations into a PDM implementation method, as shown in figure 3. Several steps belong to a generic PDM implementation method, as proposed in [14]: steps from 1 to 4 correspond to a specification phase then steps from 8 to 10 to the configuration and implementation phase.

Figure 3 Method for improving PDM implementation through collaboration analysis



To take into account collaboration analysis, three further steps are now introduced:

- Step 4: Tracking data about collaborative events and their evaluation with CoCa tool.
- Step 5: Analyzing captured data to identify problems or possible improvements, to establish links between events and to define best practices through good tasks' sequences.
- Step 6: Integrating existing process formalization with the identified task sequences.

Step 4 is managed by analysts that are involved in design projects in order to store each collaborative event. In step 5 they have to establish correlations between events in order to identify problems or best practices. One of the expected result is the identification of task sequences corresponding to the resolution of a problem linked to an inadequate process for a given design situation, or to the formalization of an adequate process for another given design situation. That means that in step 6 'good design practices' are formalized for specific design situations. As the 'good design processes' are defined through a deep study of real events occurring during a project, their level of granularity is more accurate than generic processes defined after the interviews of some experts and managers. By this way the added-value of the analyst is then to integrate the adequate 'good design processes' into the generic ones as templates [16]. To do so, he may define nodes of flexibility: at these nodes the future context of the project will allow the user choosing between several possible sequences.

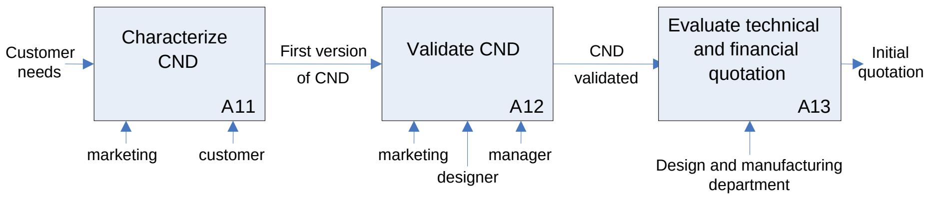
As a consequence, this integrated method allows the establishment of links between the analyses of collaborative practices and the formalization of more complex and flexible workflows. Next section will illustrate this method.

3.2 First experimentation

After four months of tracking projects in our industrial partner, four different projects have been deeply analyzed and more than one hundred collaborative events have been stored. Following example illustrates the consequences of such analyses on the project management: the introduction of flexibility and detailed implementation of design processes. The example is based on the CND (Customer's Need Definition) process which corresponds to the initial financial quotation phase of the design for the customer.

Initially, the CND document was managed by the marketing person who builds the document in collaboration with the customer. Indeed this step defines the specification of the product on the basis of the need expressed by the customer.

Figure 4 First steps of the design process



The first activities of this phase were (figure 4):

- Definition of the CND document by marketing person with the customer (task A11).
- Validation of the document (task A12).
- Notification that the document is complete (between A12 and A13) to the technical department and that a designer has to make the quotation (future tasks A13).

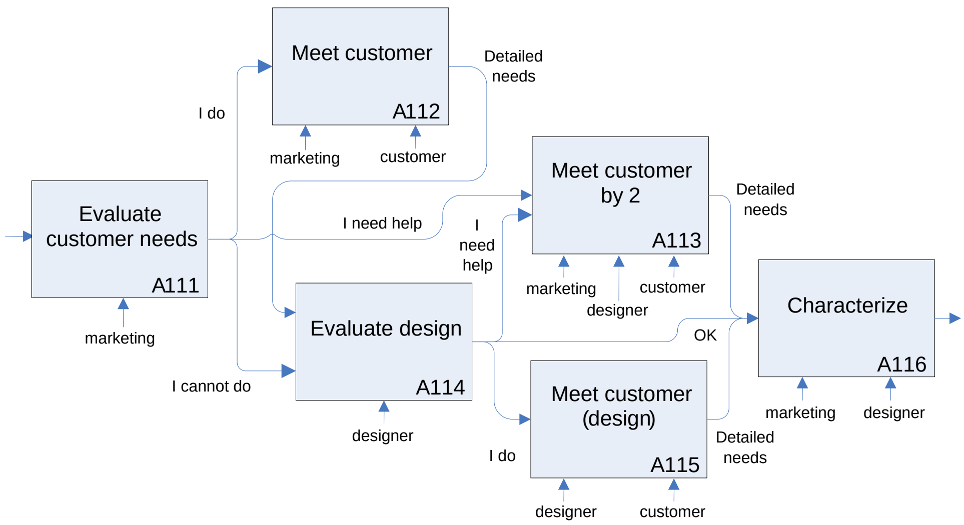
The analysis of this initial collaborative situation through several projects allows identifying that CND process description incorporates neither details on the way to achieve the tasks, nor flexibility. Moreover the marketing person does not always have the necessary technical skills for all customers, and furthermore he does not have enough time to carry out all the CND processes. So problem of customer data management appears between the marketing and technical departments.

With the analysis of the collaboration with the CoCa tool, the analyst can define guidelines and more detailed processes. In this way, the CND process is updated with an increased level of granularity based on the guidelines from the collaboration analysis.

Consequently a new process is proposed: in figure 5 is detailed previous task A11. The marketing person first evaluates the needs of the customer (task A111), then he can:

- reject directly the customer request, if the customer needs are not appropriated for the company (not formalized),
- make a visit to the customer: alone (task A112) before sending the detailed needs to the designer (task A114) or with a designer (task A113),
- or directly send the needs to the designer if they are enough detailed (task A114).

Figure 5 Detailed but flexible process for A11 task



Afterwards when the designer evaluates design (A114), he can meet the customer alone (A115) or with the marketing person (A113), or directly characterize the CND document (A116). At each task marketing person or designer have the possibility to end the process. As a conclusion the project manager has the possibility to automate the design process by implementing a PLM system with this process. The first node of flexibility is the task A11 because the detailed sub-level may not be scheduled for a specific reason. Next nodes of flexibility are associated to tasks A111 and A114 as choices exist for the owner of the task. Next section develops the implementation of such process into a PLM system.

4 A PLM framework for the coordination of design processes

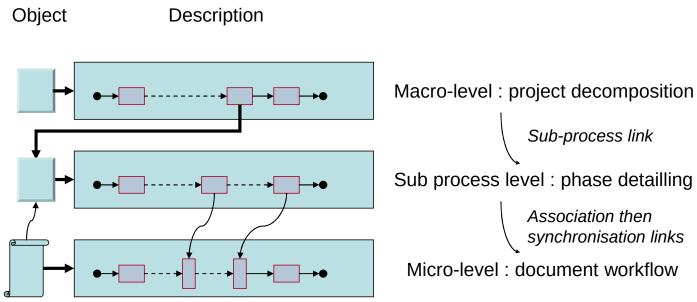
4.1 A framework for multi-level workflow implementation

In the SME context, design process is generally formalized at a macro-level: the process is decomposed into several phases, and main tasks are defined in each phases, as shown in figure 4. As a consequence of the results obtained with the collaboration analysis method, we are able to specify more accurately at least one sub-level: some tasks of macro-level are decomposed into detailed tasks sequences by the identification of collaborative practices that are linked through flexible nodes.

Our first proposal is to characterize the project phases by using a generic workflow: each phase and each milestone of the project are respectively represented by a sub-process and a task. Then each sub-process / phase is defined as a traditional workflow, without document association. Each task of the sub-process / phase must specify to the owner what the documents to be created or modified are. A second level of sub-processes is not possible to control document workflow because document workflows are not "contained" inside a single task of the sub-process / phase, but can be achieved after several tasks of a sub-process / phase, and sometimes after several phases.

Finally at micro-level very basic processes that manage document lifecycles are identified. In this case we need a certain level of correlation between the sub-process / phase workflow and the document in order to synchronize the progress of both processes with the project schedule. This link allows getting information from the document (states, owner …) during the progress of the sub-process workflow.

Figure 6 Multi-level workflow framework for design process management



Such document processes are not always necessary: in most SMEs they reduce the flexibility and they are not implemented. If this is the case, a minimal workflow is still necessary in order to establish the required link. The implementation of such links depends on the functionalities of each PLM system.

Figure 6 illustrates main concepts of the proposed framework for the implementation of the proposed workflows from the macro-level to the micro-level. Vertical boxes at micro-level show the possibility of getting document state from the sub-process level.

4.2 Second experimentation

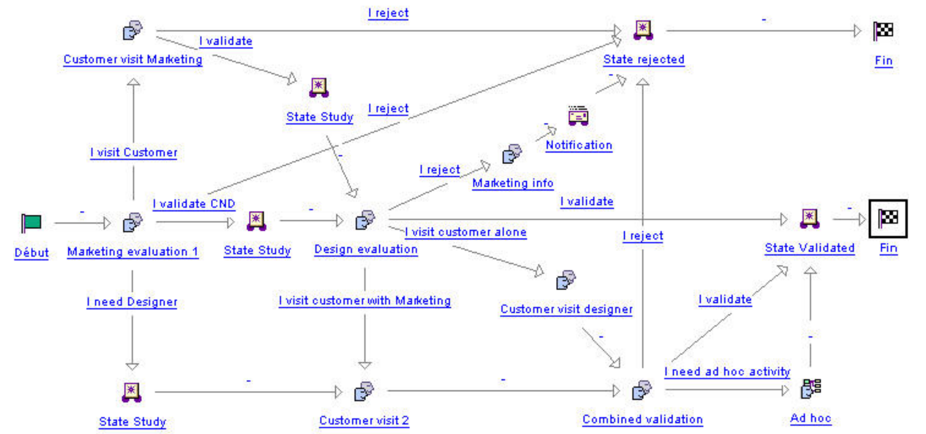
This experimentation is based on Windchill™ (PTC) PLM system. Actually macro-level and sub-process level have been implemented. These two levels can be implemented with traditional workflow configuration.

As an example figure 7 illustrates the workflow defined for managing the CND phase as explained in section 3.2:

- 'State' tasks define the state modification of the CND document.
- All possible ends of the process are also defined as well as the required notifications.

- 'Ad hoc' tasks correspond to the possibility given to a user to create dynamically new required tasks. This allows introducing more flexibility in the design process.

Figure 7 CND phase workflow



The last micro-level is still under development as it requires specific configuration. For example with Windchill the possible mechanisms of synchronization tasks require some Java development.

Such experiment demonstrates that it is possible to implement a framework for multi-level-workflow management. Nevertheless the technical aspects of its implementation depend strongly on the openness of the used PLM system and their possibilities of customization: can document-independent workflow be managed within this PLM system? then can independent workflows be synchronized through their tasks? When validated these requirements imply that the coordination of design projects is possible using this framework. Nevertheless some considerations still remain. The main concerns the acceptability of such multi-level management into SMEs: our industrial partner has a size that requires more formalization while maintaining high level of flexibility. As the framework is not achieved we still do not know if the flexibility and workflows that we propose correspond to this situation with adjustments or not, *a fortiori* for other SMEs.

5 Conclusion

In the worldwide competition among companies, the development of new products has become a challenge where innovation and coordination of design process are two main keys for success.

In SMEs design activity is not completely structured and controlled due to the high level of flexibility of processes. At the same time PLM systems help to rationalize basic design processes and are the main information systems managing the product life cycle in companies. In this paper we have focused on the proposal of a framework for design coordination implemented through a PLM system. First we have proposed an adapted method for implementing PLM systems in order to take into account both more detailed process definition and flexibility by using the analysis of collaborative practices. Second this framework is based on the use of workflow technologies in order to elaborate the structure and the schedule of the project phases and tasks through different and synchronized levels of granularity. First results are enough significant to justify the interest of this framework and future work for implementing all the functionalities of this framework and its experiment in an SME.

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Customer Centric PLM - Integrating customers' feedback into product data and lifecycle processes

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Abstract: To optimize customer satisfaction, an integration of the customers' voice into product development is necessary. For this a methodology was developed, which enables acquiring prospective customer feedback for future (virtual) products and retrospective customer feedback on existing (market launched) products. A web-based feedback assistant was designed and prototypically realised, which allows customers to evaluate product concepts based on customer oriented product test models for extracting feedback. The extracted feedback is mapped on technical product structures using an extended QFD approach and advanced methods for measuring customer satisfaction. The core of the integration concept is the extension of PLM functions, processes and metadata models, whereby technical product data, customer requirements and customer satisfaction indices can be linked context sensitively. The feedback integration approach enables an early product validation before the production/market launch and an analysis of dynamic customer requirements across several product generations.

Keywords: customer integration, customer feedback, customer satisfaction

1 Introduction

Increasingly shorter product lifecycles, increasing cost pressures and the demands for customer orientated products require producing companies to be able to react flexibly towards the changed market conditions. Whilst marketing approaches already pursue a customer orientation to remain competitive, product lifecycle management (PLM) approaches are still product and company orientated. Producing companies are aiming to make their product development processes more efficient. However, effectiveness and regards to current customer requirements today are mostly not part of current PLM strategies and solutions [1]. The results are product flops on the market, because products are either over-engineered or show fundamental deficits [2]. The benefit for customers cannot be increased significantly and unused product parts or functions only take effect as cost drivers. Fundamental rethinking is required to reorientate PLM towards the customers. The customer needs to be seen as a know-how capacity for the product development and no longer solely as a buyer. Whilst product development specific PLM methods mostly are not customer related, marketing orientated solutions generally consider customer satisfaction as a static after market phenomenon [3]. So far, integrating customer feedback to validate products, especially in the early stages of the product lifecycle processes before the market launch, has neither been methodically pursued nor supported by IT. Isolated information technologies as well as heterogeneous marketing instruments are not sufficient for the claim of constant feedback integration. Therefore a concept was compiled, which is based on quality management methods, methods for the customer satisfaction measurement and product lifecycle management approaches. The assigned method components were specifically adapted and ex-tended for the feedback integration [4]. In the capital goods industry customers are already intensively involved in the product development process due to customised products and contract manufacturing. Therefore the developed concept is limited to the range of the consumer goods as well as to market pull innovations and to incremental innovations. Customer integration for radical innovations does not appear beneficial, since the technical experience horizon and the imagination of customers are mostly not sufficient for these innovations. The objectives of the developed concept are the extraction of customer needs, the identification of product components, which have a direct impact on the customer satisfaction, and a systematical retrieval of customer satisfaction indicators for product development. The research results are illustrated using the example of developing a mobile telephone.

2 Overview of customer integration approaches

The existing solutions for the customer's voice integration into the value-added processes differ according to the addressed product lifecycle phase and thus to the point of customer interaction (table 1).

Table 1 customer integration approaches [5]

customer integration system	*interaction point*	*integration approach*
made-to-stock: manufacturing and sale of standardised products to anonymous customers	traditional mass production systems	
match-to-order / locate-to-order: selection of existing (standard) products according to customer requirements	sales, retail	customer relationship management (CRM), communities
bundle-to-order: bundling existing products to customer specific product (based on situation of use)	sales, retail	
assemble-to-order: assembling customised products from standardised, pre-fabricated parts	final assembling	mass customisation
made-to-order: manufacturing customised products including component manufacturing	manufacturing	
development-to-order: customer co-design of product construction, followed by customised made-to-order	design, development	lead user approach, co-designer

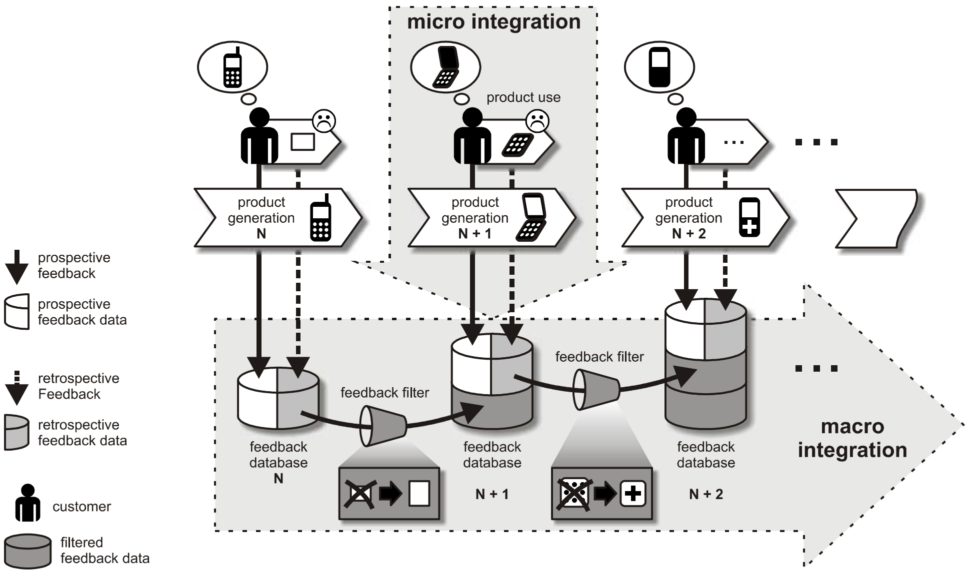
The lead user approach and the co-designer approach are relevant for the product development phase. The lead user approach was developed by Eric von Hippel and is based on extensive investigations, which showed that numerous innovations do not emanate from producing companies, but from customers. Partly the customers even develop innovative products (e.g. mountain bikes). The term of the lead users describes customers, whose momentary product requirements represent an anticipation of future market demands [6]. The term co-designer describes a customer, who is actively involved in product development processes and becomes a temporary co-worker of the company. The customer integration takes place on different integration levels. It can take place on a lower integration level in terms of focus groups or on a high integration level by directly being involved in the product design using specific design tools (tool kits).

Available approaches for integrating the customer's voice are strongly heterogeneous and result from very different points of view. The most important points of view are quality management, marketing oriented approaches and technically aligned methods for requirement analysis. Engineering approaches like product data management (PDM) or product lifecycle management (PLM) still do not include customers as a know-how capacity for product development.

3 Research approach for a Customer Centric PLM

The core of the developed methodology is the extraction of prospective feedback information for future (virtual) and retrospective feedback information for real (market launched) products. The extracted feedback information is mapped onto technical product structures and made accessible for product development by integrating the technical information into a PDM system [7].

Figure 1 Micro and macro feedback integration in the range of several product generations



The information extracted by the retrospective feedback acquisition serves as an input for the development of new product generations. Therefore the concept is not limited to one product generation N (micro integration), but equally addresses the filtering and forwarding of feedback information into the development of the next product generation N+1 (macro integration). In the range of several product generations the developed concept facilitates the systematic accumulation of a knowledge base concerning dynamic customer requirements and the history of changed customer satisfaction with the products (figure 1). The methodology for the integration of customer feedback into the product development is divided into the following steps:

1. differentiation and selection of capable feedback customers,
2. prospective and retrospective acquisition of feedback information,
3. mapping customer feedback onto product structures,
4. extension of PLM meta data models, processes and functions for feedback integration into product development.

3.1 Differentiation and selection of capable feedback customers

The correct selection of feedback customers is essentially important for the success of the feedback integration methodology, since the quality of the feedback information is already specified in this phase. A method for selecting suitable customers was developed, which permits an integrated determination of the customer's market, innovation and pro-active capabilities.

The market capability describes the economical importance of customers for the company. It is determined by the cross-selling potential, the potential loyalty and the commercial stock generated by the customer. The innovation capability addresses the customer's innovation-relevant knowledge. The indicators for the innovation capability are the innovation content of the feedback, the information quality and the customer's willingness to supply feedback. The pro-active capability describes the customer's present relationship to the company and the resulting possibility of acquiring foresighted information for product improvements. For example current customers can only supply information for marginal product improvements, while the competition's customers are capable of supplying high potential information for fundamental product improvements. The determination of these three capabilities is carried out by an integrated scoring/portfolio model. Therefore scorecards are formed for the market capability, innovation capability and pro-active capability from the respective indicators described above. The resulting scores are the basis for the following creation of a three-dimensional customer portfolio.

3.2 Prospective and retrospective acquisition of feedback information

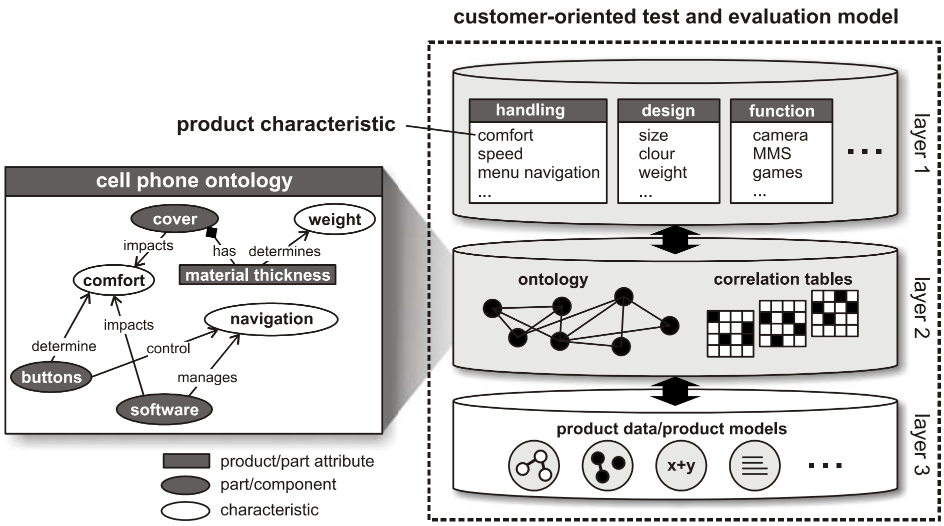
The description of requirements by the customer can be substantially simplified through a customer's consciousness concerning possible problem solution alternatives. In many cases only the existence of solution alternatives leads to new or changed requirements. This conclusion led to the decision to offer digital product models from the product development to the customer in order to evaluate these product models.

3.2.1 T&E model for mapping product data on customer oriented product characteristics

A PDM system, which represents a consistent database within the product development, is required as source for offering product information. The digital product data is filtered and aggregated on the basis of their relevance for the feedback articulation. Since the customer's perspective on a product differs strongly from the product developer's technically oriented perspective, a characteristic-based, customer-oriented product model is generated from the aggregated product data. For this the product data managed in the PDM system is linked with customer-oriented product characteristics by using ontologies (figure 2). The linked product data and characteristics constitute the digital test and evaluation model (T&E model) for the feedback acquisition. On the one hand the T&E model serves as a virtual prototype for the customer to articulate requirements and suggest improvement. On the other hand information from the product utilisation phase is deposited in the T&E model. Equivalent to the PDM system, meta data and physical product data are managed separately. The T&E model consists of three layers:

1. layer 1 (meta data): customer oriented product characteristics,
2. layer 2 (meta data): ontologies and correlation tables for mapping product data onto product characteristics,
3. layer 3 (physical data): relevant product data for the description and simulation of the T&E model.

Figure 2 Customer oriented test and evaluation model (T&E model)



3.2.2 *Prospective feedback acquisition*

The prospective acquisition of customer feedback information takes place during the product development before the start of production (SOP) and thus before the use of the product by the customer. The acquisition of customer requirements and wishes in real time, parallel to product development processes ensures the topicality of customer needs. The aims of the prospective feedback acquisition are the extraction of customer requirements and customer satisfactions, the extraction of the customer's preferred product characteristics (preference configuration), input for improvement and optimisation of product drafts and an early validation of product drafts before the production release.

For this the selected customers are asked to deliver information concerning their buying decision parameters (e.g. product design), confidence parameters (e.g. security, reliability) and product use parameters (e.g. functions). The prospective feedback extraction is carried out in two fundamental steps. In the first step the T&E model is presented to the customer, which he can configure, test, and customise. In the second step the customer evaluates the flexible product characteristics, which result from the configuration and customisation of the T&E model.

3.2.3 Retrospective feedback acquisition

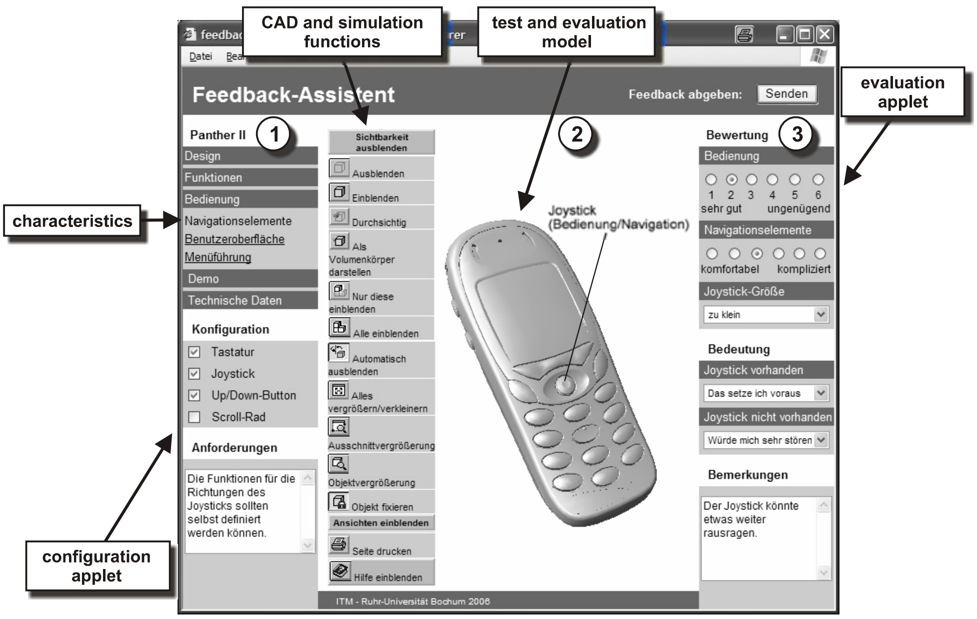
The retrospective acquisition of customer feedback focuses on the extraction of information from the product use under market conditions. On the one hand the customer directly formulates his experiences as well as product advantages and disadvantages during its use. On the other hand user information (e.g. complaints) is extracted indirectly from service and aftersales divisions of the company and led back into the product development. The aims of the retrospective feedback acquisition are the verification of prospective feedback information, due to the market dynamics and changed cus-tomer requirements, the identification of problems during the product use and an analysis of characteristic customer behaviour during the product use.

The retrospectively extracted feedback information can be used to identify room for improvement within the development of the next product generation. In addition, predictions for the future trends of the customers' requests and satisfaction can be derived through the long-term feedback evaluation in context of the macro integration.

3.2.4 Web-based feedback assistant

A web-based feedback assistant was implemented for the collection of feedback information (figure 3).

Figure 3 web-based feedback assistant for feedback collection [7]



This assistant is part of a client/server environment, which is based on a service oriented architecture (SOA). The IT architecture uses web services for the communication between the feedback assistant, the feedback data base application and the PDM system. The graphical user interface of the feedback assistant is arranged into three application areas (figure 3):

- In application area 1 the customers can select preferred product characteristics and configure the digital product by using a configuration applet.
- In application area 2 the T&E model is dynamically generated and visualised from the selected product characteristics and the preferred configuration. In addition, this area contains simplified CAD and simulation functions, in order to offer variation functions to the customer and to simulate product functionalities.
- In the third range the customer has the possibility of evaluating the T&E model and its characteristics by selecting pre-defined evaluation scores, pull down lists and free text input. Addition-ally the importance of the selected product characteristics for the customer is questioned and evaluated by the Kano method.

The collected feedback information is stored, filtered and evaluated in a data warehouse. The result of the evaluation process is formalised feedback data, which is classified by customer requirements, customer satisfaction and product preference.

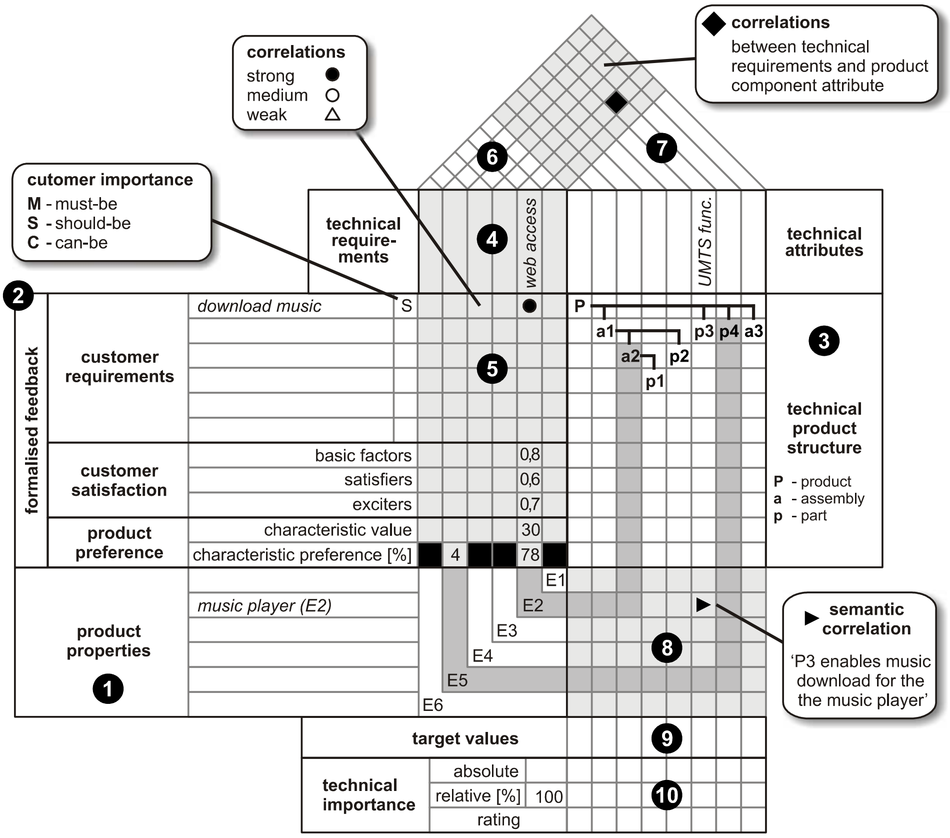
3.3 Mapping the customer feedback onto product structures

The customer-oriented product characteristics and the related feedback have a specific meaning for different product components. Therefore semantic mapping of the feedback on technical product structures is conducted using the house of quality (HoQ) [8]. The product structure represents the basis for product data management. Through the detailed feedback mapping onto product structures a context sensitive accesses to the feedback data within the product development can be reached. Since the com-parison with competitors (used in the traditional HoQ) is not important for semantic feedback map-ping, the appropriate tables were not used. Instead the HoQ was extended using tables for the formal feedback indicators, for the customer-oriented product characteristics and for the technical product structures (figure 4). The following steps are necessary for mapping the feedback onto the product structure:

1. First of all the customer-oriented product characteristics of the T&E model are listed and labeled by an identification number (E1 to En).
2. In the second step the formal feedback is assigned. Therefore the weighted customer requirements, customer satisfaction values and product preferences related to the product characteristics are listed in the feedback table.
3. The third step contains the detailed representation of the technical product structure. In different hierarchy levels the several components of the structure (product, assemblies, parts) are registered.
4. Now the listed customer requirements are translated into significant, technical-oriented requirements.
5. The relations between the customer requirements and technical requirements are registered in the correlation matrix.
6. In the sixth step the mutual relations between the technical requirements are analysed in the conventional roof of the HoQ.

7. In the table above the product structure the concerned attributes of the respective product component are listed. Afterwards the attributes are set in relation with the appropriate technical requirement using an optional symbol in the correlation matrix.
8. In the next step the semantic linkage of the product structure with the feedback data and the product characteristics is set. By allocating the technical requirements to the product structure, the relationship between product components and product characteristics concerned becomes apparent.
9. On the basis of the characteristic values, the technical requirements and the assigned product attributes, an objective target value for each product component is calculated.
10. In order to prioritise improvement and optimisation measures in the product development all product components are weighted regarding their importance.

Figure 4 Extended HoQ for mapping the customer feedback onto technical product structures



The customer satisfaction, extracted by the feedback acquisition, cannot directly be mapped onto the product structure. The satisfaction related to a product assembly or part is composed by different satisfaction values of the respective product characteristics. In order to be able to calculate the satisfaction index for each component of the product structure, a three step multi-attributive model was developed, which is based on the characteristic-oriented procedures for the measurement of customer satisfaction [9]. The computation of the satisfaction indices for several assemblies or parts takes place in the following three stages [7]:

1. Weighting the satisfaction values (according to the Kano classification [10]) and aggregating to a common characteristic-specific satisfaction value:

$$Z_e(E) = \frac{G_{Ba} * Z_{Ba}(E) + G_{Le} * Z_{Le}(E) + G_{Be} * Z_{Be}(E)}{G_{Ba} + G_{Le} + G_{Be}} \quad \text{with: } G_{Ba} > G_{Le} > G_{Be} > 0$$

Z_e = *characteristic-specific satisfaction value*
E = *product characteristic*
G_{Ba} = *weighting of basic factor*
Z_{Ba} = *basic factor*
G_{Le} = *weighting of satisfier factor*
Z_{Le} = *satisfier factor*
G_{Be} = *weighting of exciter factor*
Z_{Be} = *exciter factor*

2. Weighting characteristic-specific satisfaction values related to a product component and aggregation to a product-component-specific satisfaction value:

$$Z_k(K) = \frac{\sum (G_e * Z_e)}{\sum G_e} \quad \text{with: } G_e = \sum_{i=1}^{m} (GA_{ei} * GB_{ei}) \quad \text{and} \quad e = 1 \text{ to } n$$

Z_k = *product component-specific satisfaction value*
K = *product component*
e = *related product characteristic*
G_e = *weighting of characteristic-specific satisfaction value*
Z_e = *characteristic-specific satisfaction value*
GA = *weighting of customer requirement*
GB = *weighting of correlation between customer and technical requirement*
n = *number of related product characteristic*
m = *number of requirements/ correlations per product characteristic*

3. Weighting and aggregating all component-specific satisfaction values, which are subordinated to the referring product component:

$$ZI_K = \frac{G_K * Z_K + \sum (G_k * Z_k)}{G_K + \sum G_k} \quad \text{with: } k = 1 \text{ to } l$$

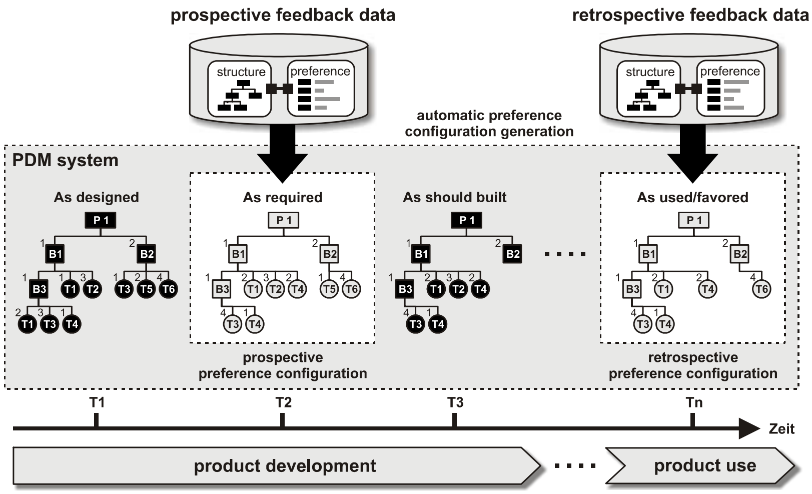
ZI_K = *satisfaction index for product component K*
G_K = *weighting of satisfaction value for product component K*
Z_K = *component-specific satisfaction value for product component K*
G_k = *weighting of satisfaction value for subordinated product component k*
Z_k = *satisfaction value for subordinated product component k*
k = *subordinated product component*
l = *number of subordinated product components*

3.4 Extended PLM for the feedback integration

The information-technical integration of the feedback is carried out using extended meta data models in the PDM system. The meta data model represents the logic linkage of meta data and physical files and is extended by the evaluated feedback information and customer satisfaction indices. In addition to the customer satisfaction indices and technical requirements the customer feedback contains information about the product components preferred by the customer, which resulted from the variation and configuration of the T&E model (preference configuration).

In order to assure access to the preference configuration for the product developer, the configuration management is extended by a prospective and retrospective preference configuration. The prospective preference configuration describes the product configuration demanded by customers (‘as required’), which results from the test functions of the prospective feedback acquisition. The retrospective preference configuration results from the customer’s evaluation of the used product and from the analysis of the product use information ("as used/favored"). On the basis of the part and assembly preferences, the appropriate preference configuration is automatically generated when the feedback data is integrated into the PDM system. Therefore the preference values of the feedback are assigned to the respective components of the product structure, which is managed in the PDM system. Afterwards the resulting preference configuration is automatically generated (figure 5).

Figure 5 Extended configuration management with automatically generated preference configurations [7]

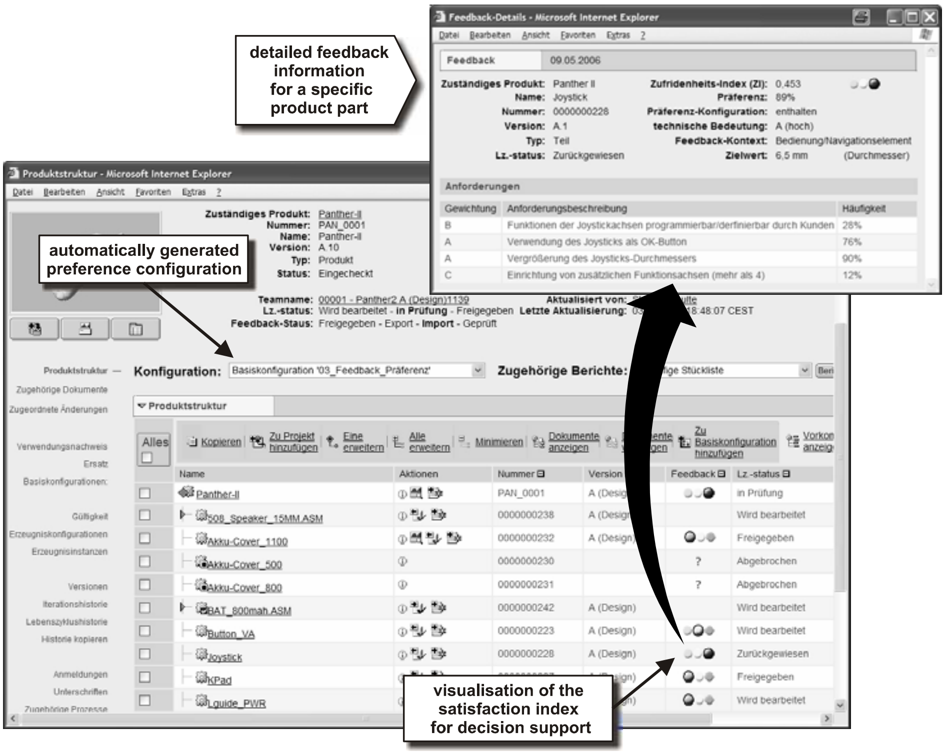


The satisfaction indices of assemblies and parts in the product structure are consolidated and arranged in three signal classes, in order to offer to the product developer direct visualisation of the customer satisfaction status (figure 6):

- Signal green (optimal satisfaction range): The entire product or a product component corresponds as far as possible to the customer requirements and conception, so that further product optimisation is not necessary. The product may be released for production.
- Signal yellow (critical satisfaction range): possibilities for product improvements exist, which are capable of increasing customer satisfaction. A release for production is only conditionally possible.
- Signal red (discontent range): The entire product or a product component does not correspond to the customer requirements. There is compelling need for product improvement and optimisation. A release for production must not take place.

The described signals are linked to the feedback contents stored in the feedback database. In this way the product developer can retrieve directly detailed feedback information for a specific product component using the PDM system (figure 6).

Figure 6 PDM-System with integrated feedback data [7]



4 Conclusions

The extraction of customer satisfaction and requirements only represents the first step of an extensive integration process. Without the purposeful forwarding and application oriented preparation the customer information for the enterprise is worthless. Effective use of customer information is only possible by its systematic, context-oriented integration into the working environment of the product developer. The integration of customers into product development must not be seen as a single project, but as long-term, continuous management task. Customer orientation as part of the enterprise strategy will, in the coming years lead to a transformation of the enterprise organisations from a traditional, monolithic organisation form to a customer-driven organisation form. This organisation form will be characterised on the one hand by an intensive cross-linking of the relevant knowledge carriers for the product development and by the integration of the customer knowledge into the product development processes. On the other hand products will evolve to integrated, customer-oriented total conceptions, which will contain flexible combinations of physical products and services. Regarding the integrated engineering of products and service, as well as the intellectual property rights protection concerning the prospective feedback acquisition, a need for research still exists.

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Linking organizational innovation and product lifecycle management

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Abstract: Innovation is an established factor for competitive success and has been linked traditionally to product and process technology. Research has established clear links between an organisation's innovativeness and technology but reported research in, and links to, process innovation is relatively low. The ability of an organization to innovate in its business processes supported by technology such as PLM is examined in this paper. The literature shows strong links between technology and organizational innovation factors of culture, knowledge management and processes. This paper reviews the enablers for innovation in this context and how the use of PLM systems can influence these organizational innovation factors.

Keyword: organizational innovation, process innovation, culture, technology management, processes

1 Introduction

The general management literature often prescribes that organizations should increase their organizational innovativeness to remain competitive (Porter, 1990). Here organizational innovativeness is defined as an organization's proclivity towards innovation and in turn innovation being defined as the adoption or implementation of 'new' ideas for economic benefit (Salavou, 2004). Through innovation organizations can create new market space through new or improved products, services and processes (Kim and Mauborgne, 1999), leading to new value creation. Despite this, the literature often neglects to address how organizations can impact their innovativeness level.

The key challenge for an organization is to understand how their characteristics affect how innovative they can become. A starting point to examine such characteristics is the typology of innovation that organizations can pursue; radical, incremental, product, process, technical and administrative (Damanpour, 1991).

One innovative development that companies are undertaking is the adoption of the Product Lifecycle Management (PLM) concept. PLM may be defined as …as "a new integrated business model that, using new ICT technologies implements an integrated cooperative and collaborative management of product related data along the product lifecycle" (Garetti, 2004). PLM widens the view of the supply chain from the operational aspects of product transformation to the end-to-end processes and systems as well as collaboration with other enterprises. A subsequent definition is "A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information, supporting the extended enterprise (customers, design and supply partners, etc.) spanning from concept to end of life of a product or plant and integrating people, processes, business systems and information" (Terzi et al., 2005). This broader view with its reference to people, processes, etc. provides a route by which PLM can be examined in the context of organizational innovation.

Whilst PLM could be treated as a technology innovation in its own right this is not the focus of the paper. The paper examines the interrelationships between organizational factors affecting innovation that are related to PLM. In particular how PLM influences and is influenced by culture, knowledge management and processes factors. The paper presents a proposition for each of these three factors and presents early investigation into them. By better understanding the factors of organizational innovativeness the design and operation of PLM systems can be improved to enhance value to the organization or increase competitiveness.

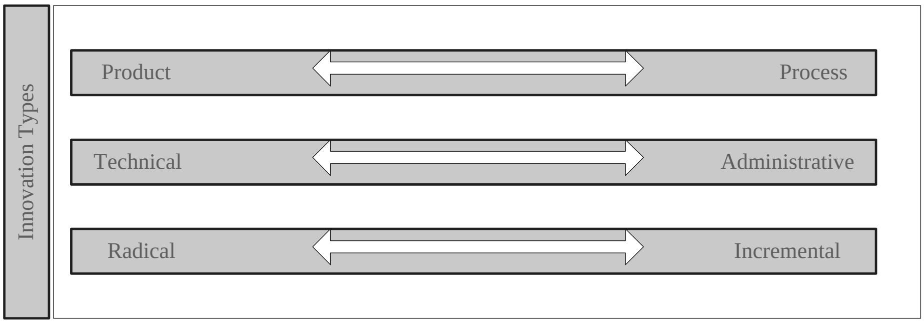
It is important to distinguish between the two levels of PLM. Swink (2006:42) identifies PLM as a "management process aimed at enabling collaboration activities spanning all product value chain elements" whereas a PLM systems is a "collection of hardware and software technologies that support PLM". Both levels of PLM are important for fostering innovation, however, the scope of this paper focuses on PLM systems and the relationship they have with innovation.

2 Innovation

2.1 Types of innovation

Although innovation is often discussed in the literature in general terms it is important to highlight that there are various types of organizational innovation and distinguish between them. One of the main typologies concerned with organizational innovation is put forward by Damanpour (1991). He defines six types of organizational innovation (technical, administrative, product, process, radical and incremental) and argues that they are in tension with each other and exist on a continuum for example a process innovation can be technical or administrative and radical or incremental. These continuums of innovation are shown in figure 1.

Figure 1 Continuums of organizational innovation



Much discussion takes place concerning product, technical and radical innovation due to the relatively high risk and impact they have on both the organization and the consumer whereas administrative, process and incremental innovation receive a more limited examination within the literature perhaps due to the perception that they do not incur great benefit to the organization or the consumer.

One area that lacks debate the most, is that of administrative processes, or as it is referred to in this paper, business process innovation. There has been some discussion on business process innovation in the radical innovation field with the advent of business process reengineering (BPR) (Hammer and Champy, 2001) but incremental business process innovation is often neglected by academic discussion.

Incremental business process innovation is important for organizations to remain competitive as it enables changes in the management and operation of business processes. Business processes are wide ranging across all business functions and small changes across these processes can result in substantial consequential cost benefits. An increase in organizational innovativeness is likely to encourage innovation in business processes. Following a previous structured literature review a number of factors have been identified that influence organizational innovativeness, these include: technology, processes, management, culture, organizational structure, strategy, employees, and knowledge management. The review also identified the main relationships between the factors, identifying the important relationships in driving organizational innovativeness. These factors are considered next.

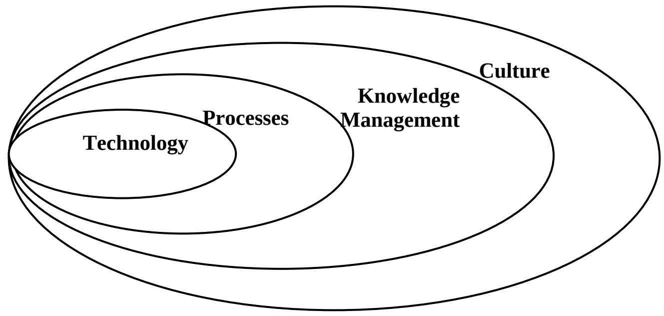
2.2 *Factors of innovativeness*

An area of literature that many scholars have attempted to understand is the factors that impact on an organization’s innovativeness. By understanding these factors both academics and practitioners can identify how innovativeness can be increased. This is a body of literature that is largely fragmented and covers many different subject areas. However, through a structured systematic literature review 12 inductively derived factors were identified, namely: technology, management, processes, strategy, organizational structure, employees, culture, resources, knowledge management, organizational age, organizational size and environment. The literature review also identified the relationships that exist between these factors. One of the main findings from the literature review was that all of the factors were in some way related to each other but some factors had more important interrelationships. Putting this into the context of PLM, by classing PLM systems as “technology”, the factors that impact on PLM’s contribution to organizational innovation can be assessed. Although there are many interrelated factors that influence innovation only three of them are strongly related to technology. The remainder of this paper will focus on the relationships that exist between technology, and therefore PLM, and other factors and how these relationships impact on organizational innovativeness.

2.3 Factors of innovativeness linked to technology

In the classification of the literature, the three of the factors which were most relevant and shown to have most impact on technology (which PLM inherently is) were: culture, knowledge management and processes. These causal links were established both from the number of instances the links were discussed in the each article as well as the discussion itself. The way technology relates to processes, knowledge management and culture is seen in figure 2. This shows that technology is central to the links between the three other factors, with culture being the most encompassing of the factors affecting organizational innovativeness.

Figure 2 Relationship between technology and organizational innovativeness factors



Within the literature on organizational innovativeness, technology supports and enables the other factors and it is the relationships between technology and the other factors that have the largest impact on organizational innovativeness. Each of these relationships will be discussed in detail with regard to how they influence and are influenced by PLM systems.

3 PLM systems and the affect on business process innovation

For companies to become innovative they must focus on the areas that can impact their innovativeness level. Both product and process innovativeness have been identified as major contributors to organizational innovativeness (Wang and Ahmed, 2004), but often the integrated view of both product and processes is not adopted. PLM is an emerging paradigm that can enable businesses to be more innovative as it could support a holistic integrated view of both product and process innovation.

Product lifecycles often span organizational and geographical boundaries and organizational structure is intrinsically linked to organizational boundaries. Structure and how it affects innovativeness is widely discussed in the literature (Damanpour, 1987;

Lemon and Sahota, 2004). Generally the literature is in agreement that flexible, networked companies that collaborate are more innovative. The benefits of networked enterprises are that they are more adaptive and responsive to changes in the external environment (Merx-Chermin and Hijhof, 2005; Loewe and Dominiquini, 2006); also collaboration allows for the free transfer of knowledge and skills to pass within and across organizational boundaries (Pittaway et al., 2004; Miles et al., 2006). However, networked enterprises often have difficulties caused by a number of factors such as geographical distance, conflict with technical or software interfaces and ready access to knowledge and information.

PLM systems technology can overcome the difficulties faced and facilitate the benefits of having an integrated view of the entities involved in product management (Swink, 2006). PLM systems use ICT to integrate all the information relating to a product which results in increased knowledge transfer and visibility. Increased knowledge management and communication results in new ideas being developed which will raise the innovativeness of the organisation. Due to the holistic nature of PLM these new ideas are not restricted to specific areas of the business or to particular products, and can span the whole value chain. Promoting the vision of the whole value chain to employees will have a positive impact on the organization's likelihood at encouraging innovation (Koberg et al., 1996; Hage, 1999; Lewis and Moultrie, 2005).

Having identified the key factors that impact on organizational innovation and which relate most strongly to PLM, the remainder of the paper reviews how PLM impacts upon each of the factors that affect organizational innovativeness, to provide a holistic view of business process innovation.

3.1 Culture

Proposition 1. PLM implementation will encourage organizations to have a more open culture by facilitating communication and networking across organizational boundaries, resulting in increased innovativeness.

Although culture has been discussed widely in general management literature, 'culture' in this research refers to the values and beliefs of the organization and how these impact the innovativeness. It takes also into consideration the organization's approach to collaboration, communication and risk.

Using the tools and software associated with PLM means that collaboration and networking can be supported between the entities involved. For example design and production functions are often separated from each other by physical, geographical and institutional boundaries meaning that both functions have to have an open culture to allow collaboration and communication. Therefore technology is used to nurture the existing culture, but as the changing business environment has resulted in product lifecycles occurring across various boundaries, more organizations are encouraging a culture of collaboration and networking. This flexibility in product lifecycles as well as advances in product development, supply chain management and outsourcing has resulted in networked enterprises becoming commonplace. In order to successfully manage the operations of networked enterprises technology needs to be carefully selected, implemented and controlled. Technology is important for dynamic flow of information between the fractions of the extended enterprise and the enabler of culture and in turn the level of innovation between the players involved.

3.2 Knowledge management

Proposition 2. PLM systems will allow the effective management of knowledge within and beyond the organizational boundaries and more effective knowledge management will result in increased innovativeness.

Knowledge management here refers to the management and utilization of knowledge to impact on innovativeness. This covers all aspects of knowledge, both internal and external to the organization, and also takes organizational learning into consideration as it plays a key role in knowledge management (e.g. Salavou, 2004; Ng, 2004).

The more open the culture the more likely it is that knowledge transfer can occur easily, however this needs to be enabled through effective channels. ICT is commonly used as a facilitator of knowledge transfer (Sorensen and Stuart, 2000; Kandampully, 2002), drawing together fragmented knowledge resources to develop a single knowledge repository (Ettlie, 1980; Damanpour, 1987; Jantunen, 2005). This means that employees can gain access to a wide base of knowledge that is collected throughout and beyond the organisation, and having this information readily available can support employees in the development of new ideas. Successfully using knowledge and learning tools, such as a knowledge repository, to feed into the innovation process results in an integrated approach to new idea development and implementation (Neely et al., 2001; Aranda and Molina-Fernandez, 2002).

In knowledge management, technology is used to enable the capture, storage, management and retrieval of information. As with culture, the role technology plays in influencing knowledge management is one of enablement. In dispersed networks between or within organisation concerned with PLM this role becomes even more important. In today's markets, products have ever shortening lifecycles which result in large amounts of data relating to products which is in turn diffused throughout the extended enterprise. ICT technology solutions can be used to capture knowledge dispersed throughout the network and bring it together into a standard format single point of entry database. This would mean that knowledge relating to the product lifecycle could be shared effectively throughout the whole extended enterprise. Having timely access to relevant information can result in enhanced innovativeness for current and future projects, by building on knowledge generated at each stage of the products lifecycle.

3.3 Processes

Proposition 3. PLM systems can result in business processes being fixed and inflexible to change thus resulting in reduced innovativeness.

The link between technology and business processes can be viewed in two main ways; first as a tool for the routine operation of the processes and second as a facilitator for the re-engineering of the processes. Technology is often used to support the execution of process, such as using enterprise resource planning (ERP) on a daily basis to effectively manage the production process. However, the implementation of this type of technology can also be an opportunity to restructure the business processes of an organization (see Garetti et al., 2005). The technology being implemented might not be innovative in its own right but when used in conjunction with business process re-engineering (Hammer and Champy, 2001) techniques it can result in radical process innovation.

Implementation of a PLM approach (including the necessary technologies) is an opportunity for organizations to carefully analyze and restructure their business processes, thus opening up the opportunity to generate innovative processes. As discussed previously, processes are often neglected with regard to innovation as they are more likely to be incremental in their nature (Damanpour, 1991) but radical innovation can take place within processes, which can result in increased competitiveness and revenue. Being creative in the use of standard 'off-the-shelf' technologies and thinking about the ideal operation of the process can result in increased innovativeness within the organizations processes. However, attention should be taken to the re-structuring of the business processes as this is often more complex and time consuming than implementing new standard technology (Garetti, et al., 2005). It should be also borne in mind that once implemented, PLM systems could act as a restriction to further innovation if they are inflexible.

3.4 Emerging relationships

The previous sections have discussed the links technology and the three factors of processes, knowledge management and culture in the context of organizational innovativeness. This section brings together that discussion and summarizes how the three factors impact positively or negatively on business process innovation.

Table 1 presents the enablers of PLM systems and shows that such systems can provide a number of benefits as well as barriers to organizations wishing to improve their innovativeness.

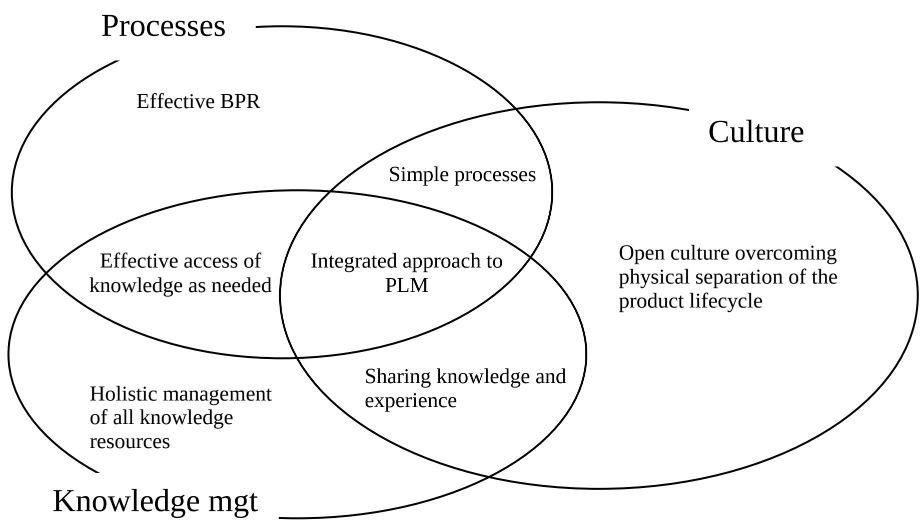
So far only the positive aspects of PLM systems impact on organizational innovativeness factors have been discussed but it is important to note that PLM systems can also have a negative impact on innovativeness. Businesses should be aware that although PLM systems can bring about many positive influences on innovativeness there are also a number of limitations that arise with the implementation. The philosophy of PLM as a management technique is not always endorsed by the adoption of PLM system infrastructure. Cooperation and collaboration between enterprises involved in the product lifecycle will not automatically occur through the implementation of PLM systems, these need to be developed through careful management of an enterprise's culture and its employees. By realizing the PLM philosophy organizational innovativeness can be increased, using the PLM system technology to support the amplification of innovation. Although the factors have been discussed as stand alone elements it should be noted that they will interact with each other through the application of PLM systems. Figure 3 provides an overview of the interactions between the innovativeness factors and the associated benefits of adopting a PLM approach to using technology from the earlier discussion.

The paper presented three propositions; one for each of the three most important factors related to technology and in turn PLM. P1 addressed culture and how sharing across organizational boundaries has potential to increase organizational innovation. P2 focused on the impact of knowledge management and the relationship with the product lifecycle. Finally, P3 looked at the flexibility or otherwise of the business processes that PLM systems support. Figure 3 captures the key outcomes of this analysis in a combined way showing the overlaps between each of the issues examined.

Table 1 PLM for increased innovativeness

Factor	Enablers	Benefits	Barriers
Processes	Effective BPR Simple processes	Improved processes as a result of PLM implementation	PLM infrastructure could result in inflexibility once the process is designed
Knowledge Management	Sharing knowledge and experience Holistic management of all knowledge resources Effective access of knowledge as needed	Culture of enabling knowledge transfer Single knowledge repository Timely access	Differences in PLM interfaces resulting in dissimilar standards Multiple entry of info. Limited quality control over knowledge inputted into the PLM system
Culture	Integrating and sharing the product lifecycle Overcoming physical separation Info. transfer across boundaries Integrated approach to product lifecycle mgt	Open to collaboration Effective communication Acceptance of product lifecycle occurring across organizations	Lack of acceptance of product lifecycle occurring across organizations Physical separation of teams

Figure 3 Interaction of factors of innovativeness in relation to PLM



4 Conclusions

Companies implement PLM as a means to improve the operational management of the overall product lifecycle but the technology associated with PLM systems can have more far reaching benefits for organizations. This paper has shown that PLM systems can be used in a way that will positively impact on innovation.

This paper has shown that PLM systems technology has a direct impact on culture, processes and knowledge management which will in turn drive the innovativeness level of an organization. By using PLM technology to influence these factors, organizations can benefit from improved operational management as well as can also increase the opportunity for business process innovation. The implementation of PLM systems can enable an organization to redesign and configure processes providing the scope for both radical and incremental innovation.

The use of PLM has the ability to support an open and responsive organizational culture, allowing disparate functions, processes and organizations to communicate and collaborate. This type of culture is one that is conducive to increasing innovative organizational behavior. PLM technology has an impact on knowledge management across all functional and organizational boundaries providing effective storage, retrieval and utilization of knowledge. This management of knowledge is synonymous with the communication and collaboration associated with an open, flexible organizational culture. Using PLM to manage knowledge means that knowledge is retained and used throughout the lifecycle of a product. Knowledge is one of the vital seeds of innovative behavior, without which new ideas cannot be developed into business process innovations.

The main learning of this paper is that, if organizations are considering adopting PLM technologies they should also consider how they can be used to influence innovativeness. In order to increase effectiveness of PLM special attention needs to be placed on the main enablers for organizational innovativeness as shown in table 1. These enablers detail the motivations for businesses to improve their innovativeness level while simultaneously adopting a PLM systems approach.

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A framework of PLM practices for multi-partner sourcing organization

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Abstract: Multi Partner sourcing is a reality for most organizations now. The economics of cost and value addition require PLM teams to identify multiple partners and integrate them within the value chain for their product line. This process brings along with it issues like conflict of interests, collaborative knowledge management & ownership & protection of Intellectual Property. This paper presents a framework for Product Lifecycle Management in a Multi Partner Sourcing Organization. It identifies the challenges of Product Lifecycle Management in a Multi Partner Sourcing Organization. The paper defines value configurations for various stages of the Product Lifecycle and proposes a system engineering perspective to the PLM process. In addition, the author presents a structured approach to managing and leading multiple partners who contribute to the various lifecycle stages of a product line.

Keyword: Product Lifecycle Management, Outsourcing, Multiple Partners

1 Introduction

As the availability of skill sets and value spreads across the globe, product lifecycle management becomes a more challenging activity. Sourcing resources from multiple vendors in a globalised scenario entails multiple challenges under any business scenario. Efficient Product Systems require structuring your product management system to optimizing on usage of functional and creative resources. This paper focuses on the challenges specific to the Product Lifecycle Management system.

1.1 Challenges of Multi Partner Sourcing

Multi-Partner sourcing presents challenges at multiple levels of organization and phases of product development. Multi Partner Sourcing Strategies for Product Lifecycle Management require the sourcing organization to view the product lifecycle through a systems perspective. A system's perspective is essential to manage the balance and maintain a collaborative product ecosystem.

Some of the business challenges of having multiple partners in your product system are

- Increased administrative overheads & management costs
- Communication & IT Investments.
- Loss of visibility on the operational expenses in sustaining multi-partner interactions.

- Travel & Shipment costs can end up rising if the logistical pipeline is not maintained with regular replenish cycles.
- Visibility of resource availability
- Conflict of commercial interests
- Information Sharing & Intellectual Property Risks.

Technical challenges in managing multiple product lifecycle partners include

- Loss of control over design changes.
- Data synchronization and translation compliance issues.
- Loss of visibility & reliability in the product delivery process.
- Lack of understanding of design change impact – Occurs because change history is often not adequately documented
- Multiple locations can lead to higher turnaround times on decision making activities.
- The process flow pipeline may end up having multiple hold/wait periods as information and resources move between multiple partners.
- Engineering Change Management
  - o Ensuring the product changes are filtered and structured for maximum benefit
  - o Multiple vendors may end up driving changes independently thus leading to a clogged change pipeline.

Over the next few pages, we will unravel a framework that helps organization's develop multiple partner sourcing systems. This is a five step framework based on value configurations and on systems engineering principles.

2 Step 1 - Visualize your Product Line's Value Chain, its structure, the lifecycle stage and the flow of resources.

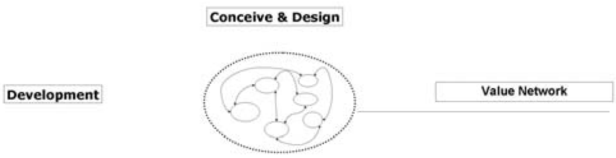
During each stage of the product lifecycle, the 'value' sought is different. From a PLM perspective, there are 4 value creating processes involved in any Product lifecycle: Conceive, Design, Realize, Service. Each product lifecycle stage has some specific configuration requirements for delivering value. Design and issue resolution phases require product managers to bring together expertise within the product system in non-linear ways and hence a value network configuration describes this scenario in a more suitable manner. Production and other product realization processes need repeatability and hence are likely to have a value chain structure where value flows sequentially from one node to another. Customer service on the other hand, needs a more 'shop' like approach with customized interfaces for various types of consumers.

Table 1 Value Configuration characteristics for various product lifecycle stages.

Lifecycle Stage	Development	Introduction	Growth	Maturity	End of Life
Value Configuration	Value Network	Value Network + Value Shop	Value Chain	Value Chain	-

Characteristics of the configuration	Internally directed with structured inputs	Has multiple customer interaction nodes	Process repeatability and reliability are critical	Remains a value chain	Spawns or brings visibility to new value configurati ons - Specifically for new products/so lutions
		Swift feedback mechanism for enhancements and productization	Cost and resource optimization are essential aspects		

Figure 1 Value configurations – Product Development Stage



For product introduction stages, Value network + Value shop configuration enables the provision of quicker turnaround types and also speeds up the movement of valuable information on the user experience from the customer to the design and productization teams. Figures 1 – 5 visualize the various value configurations of a product line at different stages in the product's lifecycle. Through growth and maturity, the focus is on streamlining the value chain & sweating the assets

Figure 2 Value configurations – Product Introduction Stage

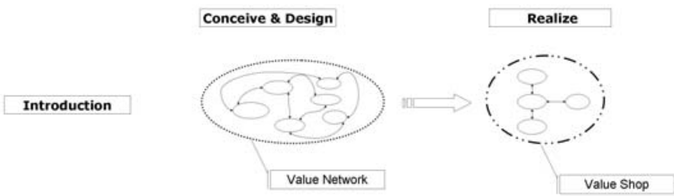


Figure 3 Value configurations – Product Growth Stage

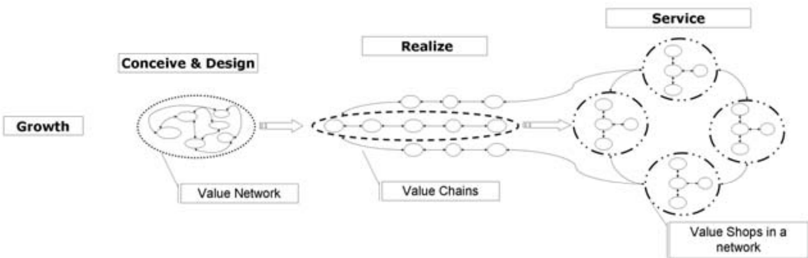


Figure 4 Value configurations – Product Maturity Stage

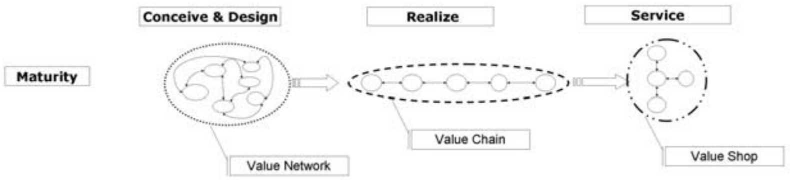
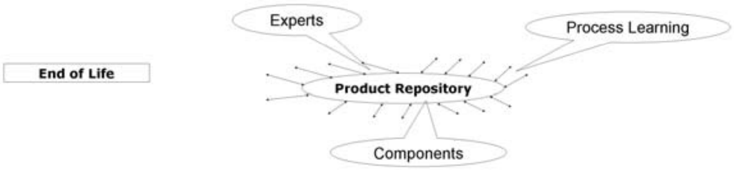


Figure 5 Value configurations – Product End of Life Stage



It is also essential to have a knowledge management structure for product system with some of the following practices

- 'Internal expert – External novice' partnerships during development phases.
- Document the product history, especially the change history.
- Encourage Collaborative learning between partners
- Transitioning practices are critical – Are the key knowledge areas mapped out?
- Do we know
  - Who knows what?
  - Who decides what?
  - Who will need to learn what?

3 Step 2 - Identify the purpose of partnering

Identify the purpose – Why are you partnering? This goes beyond just identifying goals for the activities that the partner is involved in.

- Partnering for ideas/solution/concept
- Partnering for productization of concept
- Partnering for sustaining and enhancing of a product
- Partnering for customer interaction

4 Step 3 - Identify the critical chain – It is essential to understand the cash flow and revenue impact from critical chain elements.

Product sustaining activities often have a critical impact to the cash flow and quarterly revenues of an organization. Operations, Supply Chain and Customer service management typically for the critical chain of activities. Identifying the critical chain will also help in deciding the elements of the value network that need to be co-located.

In the Product Introduction stage, prototyping processes often form the critical chain of activities. Identifying the critical chain will also help you in identifying the right partner for each of the critical chain's activities.

5 Step 4 - Analyze the partner – collaborator structure – 'As Is' & 'Needed'.

Complexity of the value network is dependent on Nodes, Interactions, Cyclic Dependencies. Complex interactions may have a time element of learning. The delivery of effective results may often be delayed for months or even years. In such cases, a slower transition approach between different partners may be needed. In the above value configuration models, it is apparent that multiple partners will end up interacting with different nodes of the value chain and hence a value configuration aggregator may often be required to keep the focus of the multi-partner sourcing product system on the parent organization's priorities. Specific sustaining knowledge or information is often embedded into the product in the productization stage. Hence it is critical to initiate the sustaining related value chain rationalization at the productization stage. Practices like Design for Manufacturability and Design for Testability are essential to the cost effective sustenance of the product line. The benefit of such early involvement of sustaining product groups is a sharing of the logic behind productization decisions and as well as clearly defined transitions. This aggregator may be:

- Another partner who understands the PLM process and the product system.
- An internal program management team

With multiple partners, it is essential that the internal elements of value configurations effectively work together with partners in the co-creation of value. It may also be advisable to rationalize the number of partners at sustaining stage. Product development activities benefit from multiple partners. . Multiple partners are a great idea for development phase when diversity, debate and multiple sources of expertise need to be filtered to create a product. However sustaining activities benefit from consolidation. The cost benefits from sourcing with multiple vendors can be lost in the overheads of managing partners and in terms of the cycle time of many processes. Most sustaining and customer operations have a value chain delivery. However, many of the baseline or background processes related to the Product lifecycle have a value network running through them. For example: Design Collaboration, Customer Operations, System Engineering. It is important to identify the learning processes involved at each stage of the product lifecycle. Problem resolution and related field interactions typically involve a multi-node value configuration based on sharing of knowledge resident in multiple nodes of the value network.

6 Step 5 - Institute a performance management system that sets goals for partners based on their role in the needed value configuration and the risk-reward model for the product lifecycle.

Risk assessment for partner relationships is a multi-tiered exercise [2].The risk reward model should be structured according to the distribution of the value configuration. Value chains have a linear risk structure. Hence at growth stage, it is essential to encourage partners to share the risk. During the initial stages of the product lifecycle, partners may tend to prefer low risk options and hence affect the creative input to the product design or conception process.

Table 2 Risk Reward Models for various product lifecycle stages.

Product Lifecycle Stage	Development	Introduction	Growth	Maturity	End of Life
Risk	Retain	Retain	Share	Share	Retain
Reward	Divergent thinking & collaborative work	Divergent thinking & collaborative work	Streamlining and Margin Improvement Approaches	Streamlining and Margin Improvement Approaches	Knowledge Spin-off and Reuse

Some critical parameters to assess in multi-partner scenarios are:

- Ratio of management overheads to actual work resources – Include both partner resources and internal resources.
- Cost breakdown and margin expectations on products and the product line.
- Work breakdown for each product lifecycle activity & vendor turnaround times for each activity.
- Cycle time for the value creating processes.
- Number of cycles for delivery of results.

Absence of a proper management system in the partner’s structure may often lead to cheaper resourcing. However it can often end up pushing management responsibility for that partner to other partners or the parent organization, thus clogging managerial bandwidth in those organizations. The final and most critical challenge in multi-partner sourcing organization is to get collaboration. Lack of collaboration can often be due to poorly designed partner evaluation practices. One common blind spot - Measuring partners on the basis of goals created just for the activity they are involved in. This type of segregated performance management can lead to value chain issues like non transparent interactions and poor sharing of knowledge.

A performance management system takes a dashboard approach using critical indicators of vendor performance. The institution of such a performance management system built on the value chain aspects discussed earlier in this paper can be effective in guiding and supporting partner activities in a multi-partner sourcing scenario. As part of the assessment processes, you may want to ask a few of the following questions:

- Have you clearly defined interaction points for partners?

- Have you defined the value addition expected from each partner and encouraged them to deliver that.
- Have you clearly defined subject matter experts both internal and those on the partner's teams.
- Have you assessed the need to setup a program management team for managing multiple vendors
- Have you defined the Product Architecture clearly
- Do you ensure that the components of the product system are well defined and documented
- Do your partners have to work with multiple functions in your product management organization?
- Do you have a clear mechanism for defining and prioritizing issues from the critical chain perspective?
- Do you have service level agreements for response time & resolution time for defined issues
- Is your product a long cycle product or a short cycle product?
- Do you intend to run your product family over a long cycle of time?
- Is your product engineering system a concurrent engineering system?
- Does the partner have the adequate level of management overheads?

7 Systems Engineering Approaches

The framework draws from the systems engineering processes and considers the product ecosystem by including various stakeholders and related processes as a single entity. Value configuration modeling is a stakeholder requirements definition process for systems engineering [1]. Step 5 of the framework is a based on systems engineering approaches to define 'Measures of Performance' and 'Measures of Effectiveness'.

8 Summary

Strengths of the framework

- Product Agonistic – Can be applied to any type of product
- Lifecycle stage agnostic – Can be applied at any stage of the lifecycle
- Adaptability – Can be used to build workflow structures for information management.
- Focused on the sourcing organization's capabilities – Hence changes required are within scope of control.
- Can be used to guide both the strategic and tactical aspects of multi-partner sourcing agreements

Weaknesses of the framework

- Application of the framework is dependent on the domain expertise of the implementation group.
- The framework may not be effective in organizations that do not have at least some form of basic lifecycle management processes.

Benefits of the framework for the Sourcing Organization:

- Value focused Product Lifecycle Management – The framework ensures that the product lifecycle management processes are primarily focused on the value addition – This makes the process framework complementary to LEAN implementation strategies.
- Systematic Framework to assess sourcing strategies.
- Better visibility and accountability for associated risks.
- Improved capability to set qualitative and quantitative goals for partners.

Benefits for the Partners:

- Clearer scope and requirements definition
- Better capability to understand and adapt to the value chain.
- Better visibility of the higher levels of value chain in the relationship with the sourcing organization – Leading to a better capability to build a path towards stronger relationship.
- Better visibility and accountability for associated risks.

This paper proposes a five step framework of PLM practices for Multi Partner sourcing organization:

- Visualize your Product Line's Value Chain, its structure, the lifecycle stage and the flow of resources.
- Identify the purpose of partnering
- Identify the critical chain – It is essential to understand the cash flow and revenue impact from critical chain elements.
- Analyze the partner – collaborator structure – 'As Is' & 'Needed'.
- Institute a performance management system that sets goals for partners based on their role in the needed value configuration and the risk-reward model for the product lifecycle.
- Create a vendor and PLM process assessment/appraisal mechanism that regularly asks some of the critical questions identified for your system & evaluate it against the above framework and performance management system.

Multi Partner sourcing is expected to increasingly become the primary mode of operation for organizations around the world. Through this framework, we provide a systems engineering based approach to sourcing strategies for the Product lifecycle management process.

Acknowledgment

The Author would like to acknowledge the support of his colleagues at Wipro Technologies' Product Engineering Services & PLM Practice groups.

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Product life cycle process analysis

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Abstract: In our research, life cycle analysis of a product is viewed as a superset of analysis methods focused on individual life cycle stages. Each of the analyses seeks to qualitatively and quantitatively measure product performance both at the local life cycle stage as well as across the total product life cycle. MP3 player has been identified to highlight the broad application of Product Life Management (PLM) techniques. It is intended to establish product usage modes and manufacturing capabilities of the product markets, and to model them using life cycle simulation. Based on the findings, new life cycle scenarios can be designed improving on the current situation of the markets, with the proposed scenarios being similarly analyzed with PLM tools.

Keyword: Product life cycle, Simulation, Usage mode

1 Introduction

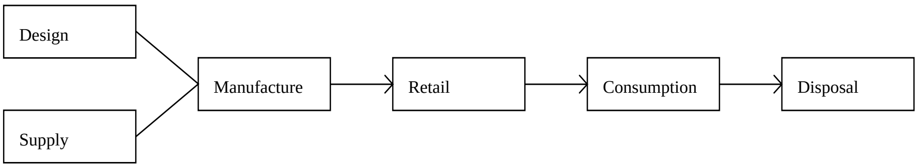
The manufacturing industry is facing a tough test. Many factors are forcing a change in the way products are designed and manufactured, and also the way they and their associated business operations are managed (Suh, 1990). Product life cycle management has been considered for more than a decade as the ideal method to most effectively and efficiently manage a product throughout its life cycle. Despite the growing necessity for such management in all business, the life cycle management concept (Lee & Melkanoff, 1993) has been implemented in very few situations. This is due to the lack of a systematic approach, and limited access to the relevant life cycle management tools and techniques. The expense of implementing such a management concept by an existing business is also a barrier. It is therefore for this research to look at the ways to improve the speed and effectiveness with which life cycle management can be developed and applied to a product life cycle process.

2 Development of Product Life Cycle Management

2.1 The Concept of Product Life Cycle

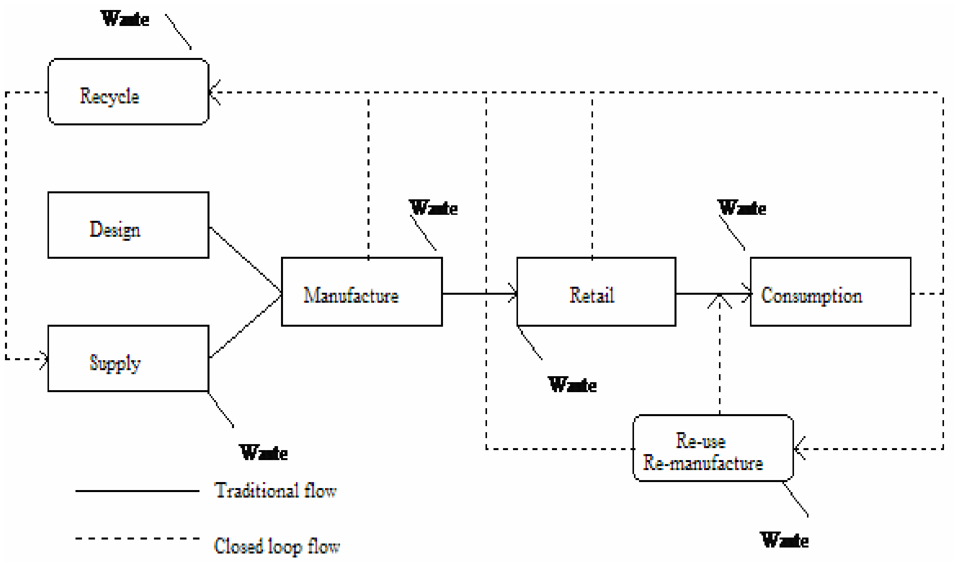
The life cycle of a product starts (Hata et al, 1998) the moment it becomes a concept in a designer’s mind. Traditionally the life cycle of a product as illustrated in Figure 1 is seen as a chain that the product flows through, from raw materials through manufacture to the inevitable disposal of the product at the end of its life span. As well as product flow there is also a flow of resources, energy, materials and finance, as well as a flow of waste out of the chain, not just at the end, but at each stage.

Figure 1 Simply Supply Chain



One concern that PLM addresses is the fact that the traditional life cycle model of a product is not a cycle, but a linear chain. In order to maximize overall life cycle efficiency, and realize environmentally conscious products, PLM identifies the need to make the product life cycle a closed loop as shown in Figure 2. In terms of sustainability, the realization of a closed loop life cycle is vital.

Figure 2 Closed Loop Life Cycle



2.2 *The Important of Product Usage in PLM*

There has been much research into PLM focusing on the importance of the product usage stage of a product life cycle. (Kimura, 2000) Many ideas have been put forward to help improve life cycle management by attempting to take account of product usage. It is a key stage of the life cycle since it is the stage that can be least efficiently managed as, at this stage, control of the product lies with the user and not the producer. For an environmentally conscious product the stages after use are important but are dependent on product usage. To maximize the efficiency of a product's life cycle some control over usage is needed.

In order to make management of a product life cycle easier the concept of a service sector has been put forward (Kimura & Kato, 2002). This idea differs from the current product led markets since the product is no longer what the consumer is purchasing. Instead, the consumer purchases the services the product provides. In this way the product still belongs to the manufacturer, which allows for greater control over the usage of the product during the usage stage of the life cycle.

As has been previously discussed, the manufacturing industry is in transition, but no more than the electrical and electronic goods industry who are under pressure from the EU to adopt a more 'green' attitude with the implementation of the RoHS and WEEE directives (EC Directive on WEEE, 2006). Now, more than ever, realizing a closed loop life cycle for business producing electrical and electronic equipment is essential.

3 MP3 Player

The MP3 player is currently the most popular form of personal music device. Taking over from the Sony walkman in the 1990's, the Apple iPod is the biggest selling product on the market. Since the market is growing and the MP3 player has a relatively short life span, it is important to realize take-back policies at the end of the product's life span with the WEEE directive.

3.1 MP3 Player Questionnaire

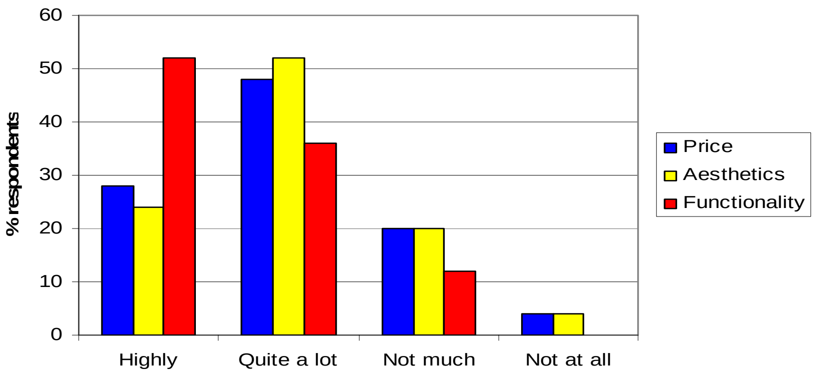
In order to determine feasible life cycle scenarios to be adopted by the MP3 player market, it is first necessary to determine the types of products usage modes present and the manufacturing capabilities of the businesses operating in the current market. Letters and emails were sent to businesses currently operating in the market and a questionnaire was produced and distributed via email to determine the product usage modes.

The questionnaire was designed to determine the main characteristics of a product usage mode. The factors collected are based on the period of usage, the intensity of usage and the main influencing factors of product purchase e.g. functionality, cost, aesthetics etc. Since the MP3 player already exists and this is not a questionnaire for determining potential usage modes for a new product, it was for the questionnaire to determine other factors that influence purchase of a particular product. Also, it was asked whether any maintenance issues arose, since this affects the usage period. Finally, it was asked how consumers' previous products had been dealt with to determine what, if any, policies are currently in use at the end of usage.

The results of the questionnaire showed how dominant the Apple iPod is in the MP3 player market. 72% of respondents owned an Apple music device; 60% of these were iPods. The questionnaire results alluded to an average usage period of 18 months, with the product being used on average for a few hours a day.

The main factor that influenced a consumer's choice of product was functionality, with over 50% claiming it as a highly influencing factor. This was followed by price - 28% claimed this as a highly influencing factor. Aesthetics was deemed the least important factor when it came to product choice. Popularity also played an important part in many consumers' choice of product, with almost 25% of respondents claiming it impacted on their choice of MP3 player; of these respondents, 80% bought an iPod. This can be seen in Figure 3.

Figure 3 Factors Influencing Purchase

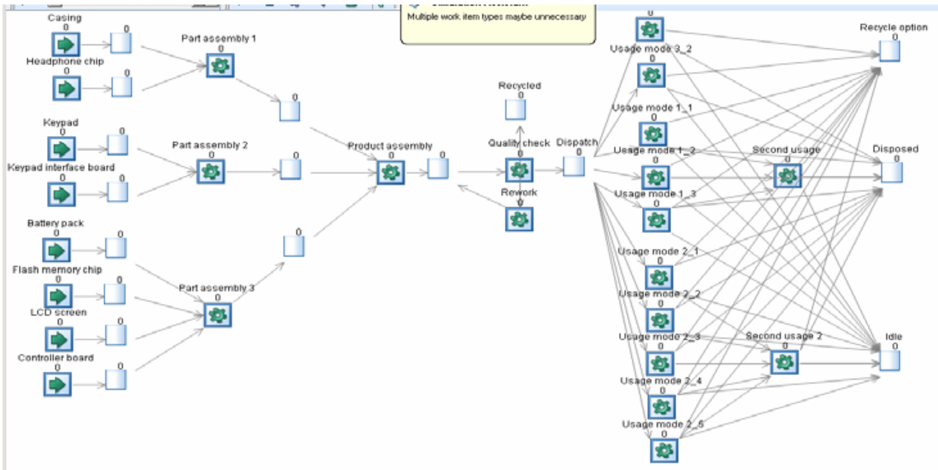


The questionnaire results identify the current MP3 player life cycle scenario as one with a relatively short usage period, after which there are no end-of-life policies to recover the used MP3 players. The growing popularity of MP3 players today coupled with such a short usage period means that there is potentially a large amount of waste generated at the end of the usage stage of the life cycle, with no take-back policies currently in place. The results from the questionnaire also show a product usage mode that involves purchasing a product based mostly on functionality. The product is then used for an average of 18 months, although 28% of products suffer maintenance issues during this time and may need replacing. Another factor to influence the usage period is the fact that around one third of users claimed to be heavily swayed by new product appeal and popularity. With this in mind it can be seen that MP3 player users can be categorized into 3 different product usage modes:

- Usage mode 1 – consumers must have the latest model. Around 30% of consumers follow this usage mode.
- Usage mode 2 – consumers are not swayed by latest model; they replace their product only when they deem that it does not meet their requirements. 50% of consumers follow this usage mode.
- Usage mode 3 – consumers wish to keep their product for as long as possible. Around 20% of consumers act like this.

A simulation of the current life cycle scenario with the 3 different product usage modes was modelled as shown in Figure 4. Life cycle simulation (Hata et al, 2000) is a life cycle management tool that helps design potential life cycles for a product. Simulation also allows for analysis of existing life cycles. There has been research into coupling simulation models with product usage modes in order to develop life cycle scenarios adapted to specific usage modes. Being able to model the usage stage of the life cycle allows for more efficient and effective planning and management of end-of-life stages.

Figure 4 Simulation model of the current MP3 Player Life Cycle



3.2 *Potential MP3 Player Life Cycle Scenarios*

The main areas of concern in the current MP3 player life cycle are the lack of take-back policies. Therefore, the potential scenarios to be developed focus on implementing a recycling/re-use stage.

3.2.1 Recycle Life Cycle Scenario

This is the simplest alteration that can be performed to bring the MP3 player market in line with the WEEE directive. By adding a recycle stage at the end of usage improves resource use since no products are left idle. The concern with recycling (Burke, Beiter & Ishii, 1992) is that it requires a big amount of energy, and the materials that are recycled are degraded so that they can be used for fewer purposes than before. There is also a cost associated with retrieving used products for recycling, especially since the recycle stage will not change the various usage modes in operation in the usage stage. However, the length of the product usage period has no impact on the recycling stage in that goods that are still relatively new can be recycled with goods that are obsolete.

3.2.2 Re-use Life Cycle Scenario

Like the recycle life cycle scenario, a stage is added at the end of usage to take back the used goods. This method however is potentially more cost effective than recycling. Re-using products rather than recycling them can use less energy and cost less; it is still necessary to finance take-back and inspect goods to determine if their quality can be assured for re-use. Re-use is better than recycling since it is a better use of resources and it does not affect the quality of the goods like recycling does.

The concern with re-use is that goods can only be re-used if they are not obsolete. Since implementing a take-back and re-use policy does not affect the product usage period, there is the problem of a lack of products taken back being fit for re-use. One way to improve the amount of goods fit for re-use is to also implement parts re-use. In this way components from products that are not fit for complete re-use can be used in new products, or more feasibly as replacement parts for faulty products still in use. In order to perform parts re-use the product needs to have a modular structure.

3.2.3 Maintenance/upgrade Life Cycle Scenario

This scenario involves implementing a maintenance/upgrade stage for hardware. In order to effectively implement this type of stage into the life cycle some sort of forced recall would be necessary. If there is no control over the usage period there is likely to be little point in maintenance since the products would be obsolete, and there would be little point in upgrading since the majority of components in the product would be highly degraded. With a forced recall, regular maintenance can be performed to ensure product performance is maximized. The problem with a forced recall is that it is a big change from what is currently in use. Consumers are likely to be wary about allowing their product to be taken from them, even for it to be upgraded.

Maintenance and upgrade are best performed on a product that has some level of modularity to its design (Hata, Kato & Kimura, 2001, Gershenson, Prasad & Allamneni, 1999), if the product is assembled in a way that does not allow for easy disassembly then maintenance and upgrade will prove difficult.

3.2.4 Rapid Take-back Re-use/Recycle Life Cycle Scenario

This scenario is a fairly extreme suggestion, incorporating aspects from the previously suggested scenarios. A rapid take-back scheme, much like the forced recall, allows for some control over the usage period. In this way the product usage modes apparent in the current life cycle scenario are eliminated. With rapid take-back, re-use can be maximized. With improved re-use more used products are put back into the usage stage of the life cycle whose life span will still be short; therefore a recycle option is also needed for parts and products that wear out.

4 Results for MP3 Player

The current MP3 player market was modelled as having 3 main types of consumer. The market produces a new product every 12 months with 20% of consumers purchasing the new product. Although this sounds a small amount, this 20% of consumers accounts for almost 44% of MP3 players used over the 5 years simulation. At the end of the simulation almost 60% of the products produced have been used with 20% currently in use, discounting cascade usage. Although this figure is assumed from the simulation, the 20% of products produced that are not used are an inefficient use of resources.

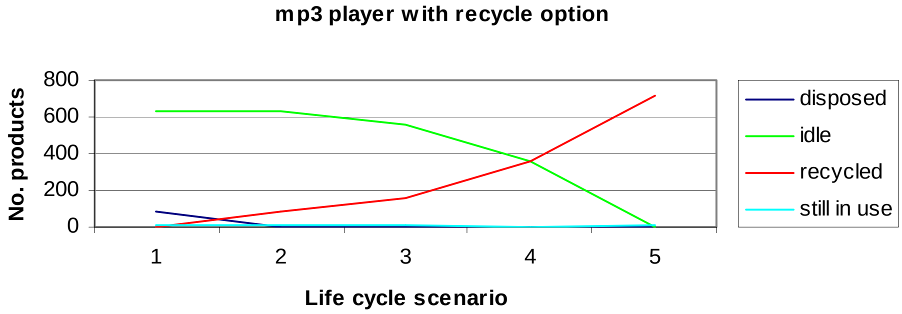
As the results have shown in Table 1, there are a lot of resources that are lying idle in the current MP3 player life cycle; in essence they are wasted. As well as this, there are products that are improperly disposed of which are a hazard to the environment.

Table 1 End-of-life Option Breakdown

	Disposed	Idle	Still in Use	Total
Total	84	628	10	722
Average	3.36	25.12	0.4	28.88
%	11.63	86.98	1.39	100

The idea of a basic recycle policy was put forward to eliminate waste from end-of-life and also attempt to recover the resources that are lying idle and recycle them to improve the efficiency of the life cycle.

Figure 5 Effect of Implementing a Recycle Option at end-of-life



The advantage of a recycle policy is that 100% recycling can eventually be achieved since the age and condition of the products has no bearing on their suitability for recycle. However, as can be seen from Figure 5, although there was 100% recycling in the model, after the 5 year period of simulation there were still products in use due to the fact that there is still no direct control over the usage stage and products are still open to cascade usage.

As an alternative to recycling, a re-use policy was proposed. Re-use is a better use of resources than recycling since recycling degrades the quality of the materials it is recovering. If the quality of products can be assured, re-use allows for fewer components and products to be manufactured to meet the same consumer demand. This reduces energy consumption, waste production and costs, and also reduces the amount of virgin materials used.

Simulations were run with varying levels of take-back for re-use up to 100% take-back. The possibility of parts re-use was added to the simulation to maximise the level of recovered products that could be re-used rather than recycled. In order to do this it was assumed that products had a modular design. Although this is a large assumption, it was seen that the iPod design would allow for such an operation. The other assumption that was made was that there was standardisation between models produced allowing for various components to be re-used in new products.

Although it appears from Figure 6 that product re-use is maximised, the amount of products fit for re-use is dependent on the age and condition they are in when they are taken back.

It can be seen from Figure 7 that although the number of products suitable for re-use is higher with a higher level of take-back, a lower percentage of the total number of products taken back are suitable for re-use. This is mainly due to the fact that, while implementing this type of scheme at the end of the usage stage is an improvement to allowing products to be disposed, there is still a lack of control over when the product becomes available for re-use. Without this control, products can still be used inefficiently, whether they are used for long periods of time, used by another user, or lie idle before eventually ending up back in the control of the manufacturer, by which time products are worn out or have become obsolete.

Figure 6 End-of-life Breakdown for Varying Levels of Re-use

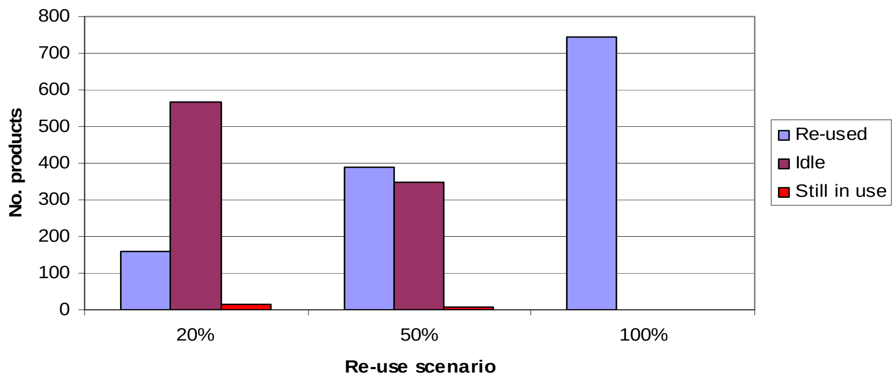
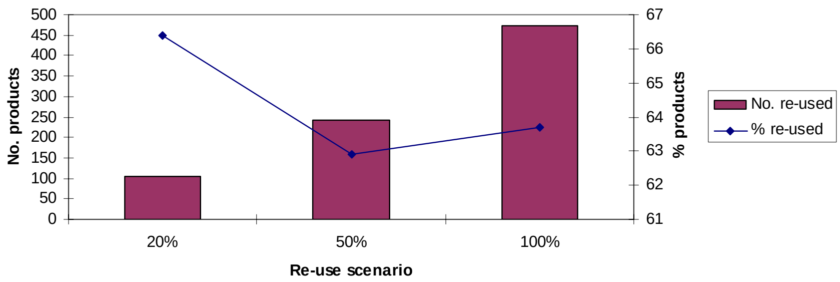


Figure 7 No. of Products Fit for Re-use Vs. % Products Fit for Re-use

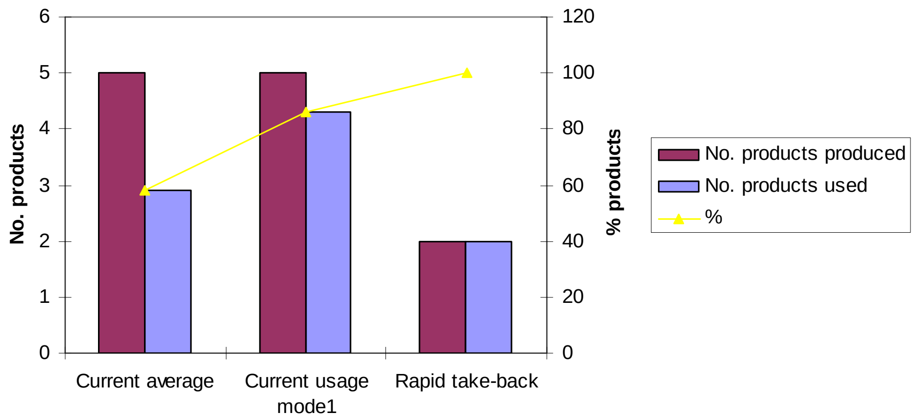


The concept of a rapid take-back life cycle was proposed in order to allow for control over the usage stage. Control of the usage stage allows for better planning and execution of end-of-life policies, maximising efficiency and reducing costs. A rapid take-back maintenance/upgrade scenario was modelled. The forced take-back allows for maintenance to be carried out on products which, along with upgrades, increases the usage period of the product, modelled as 5 years in the simulation. This allows for the volume of products manufactured to be reduced since consumers require new products less frequently. All products produced are also subsequently used.

As Figure 8 shows, the volume of products manufactured in the simulation is reduced while the level of products used is maximised. Even compared to those users in the current MP3 player market who must always own the newest and most popular product, rapid take-back is an improvement since it can be better controlled when products are taken back.

One concern that is still raised even with this increased control of the usage stage is that, even though it is possible for the manufacturer to control when products are recalled it is still not possible to control what the user does with the product. Therefore, the condition of the product when it is recalled for maintenance cannot be assured, and there is always a chance that it will need repairing. Although the cost of such a policy is reduced with forced take-back since it allows for better planning and execution, it is still difficult to factor in the cost of repairs since it is difficult to predict the condition of the recalled goods.

Figure 8 Products Used Vs. Products Produced



5 Conclusions

Products that fall into the EEE category are facing pressures to adopt a more environmentally conscious approach to their business operations. Product life cycle management has been identified as an ideal method for this task. The MP3 player was identified in order to develop a methodology for improving life cycle efficiency with a broad application.

Questionnaires were produced in order to establish what types of consumers operated in the product markets researched. In order to reduce the number of people deterred from answering the questionnaire, some sacrifice of the detail in which the questionnaire analysed the types of consumers of the product was made to keep the questionnaire concise. Fewer responses than expected were collected, however the information gathered was sufficient to identify the usage modes present for the product.

Life cycle simulation models were produced to adapt to the product usage modes found in the product markets. Possible alternative life cycle scenarios were designed and modelled based on the current life cycle models and usage modes. Results from the simulations were compared to those of the current life cycles to highlight the improvements of the proposed life cycle scenarios on the current life cycles.

In order to improve the simulations, more information is needed. A larger response to questionnaires identifying usage modes will improve the understanding of the usage stage and the end-of-life stage of the current life cycles of the MP3 player. Knowledge of manufacturing capabilities gained from industry contact would allow for more accurate modelling of the manufacturing stage, including time to market and the efficiency of the manufacturing process and the individual assembly stage, and also improve the validity of the end-of-life stages proposed.

Acknowledgment

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Chapter 2
Business issues

Knowledge management in flexible supply networks: architecture and major components

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Abstract: New forms of production and collaboration caused by increasing market requirements have led to appearance of complicated and highly flexible supply networks currently recognized as a strategic issue of prime importance. Involving a high number of interacting participants supply networks require intensive knowledge sharing & exchange. The paper presents results of research conducted in this area. It proposes a knowledge management platform for a flexible supply network to support finding available suppliers. In build-to-order supply networks absence of suppliers that could provide required materials/components may require changes in the product structure thus affecting the PLM processes. Special attention is devoted to the ontology-based architecture of the knowledge management platform and competence profiling.

Keyword: knowledge management in flexible supply networks, ontology, competence profile

1 Introduction

Increasing global competition and toughening requirements from customers cause major changes in the world economy. One of the outcomes of these changes is the growing rate of collaboration between manufacturers, their suppliers and customers. This can be explained by the fact that network-like organizations consisting of a large amount of nodes are usually more flexible and robust when compared with hierarchically organized large-scale companies.

The FP6 project "Intelligent Logistics for Innovative Product Technologies" (ILIPT) is devoted to development of new methods and technologies to facilitate the implementation of a new manufacturing paradigm for the European automotive industry [3]. This new paradigm, "the 5-day car" will approach the building of 'cars to order' in a reduced time scale. ILIPT project will address the conceptual and practical aspects of delivering cars to customers only within several days after placing the order, the automotive industry's exciting and radical new business model [4].

One of the tasks of the ILIPT project is development of a common knowledge management platform to support interoperability within the automotive supply network.

This will make it possible to accumulate, share, reuse and process knowledge across the build-to-order (BTO) supply network, which is a good example of flexible supply network. Efficient knowledge distribution and sharing within the flexible supply network can significantly help in increasing the supply network effectiveness & flexibility and in decreasing the lead time and to achieve the goal of 5 days.

In flexible supply networks it is important to derive and process knowledge from various sources including (adapted from [2]):

- customer needs, perceptions, and motivations, etc.;
- expertise within and across the supply network;
- best practices, technology intelligence and forecasting, systemic innovation, etc.;
- products in the marketplace, who is buying them and why, what prices they are selling at;
- what competitors are selling now and what they are planning to sell in the future.

One of the most important problems is coordination of the large amount of independent members of the large network. When dealing with multiple organizations and multiple processes within a complicated supply network, trying to identify and locate a member that has responsibility and/or competence in a particular part of the network can be a laborious, time-consuming process. Developing and maintaining a competence directory of all the relevant parties associated with troubleshooting and solving potential problems can significantly reduce the time. Further, linking this directory to key decision points and frequent problems can further enhance its effectiveness [1].

The knowledge management platform developed within the ILIPT project is aimed to support the design phase of a build-to-order (BTO) supply network in the part of establishing contacts between its potential members, in which manual (human) interactions and negotiations are required. The information provided by the platform thus will help to define feasible product structures and configurations for its BTO production. In accordance with this definition the following functions of the knowledge management platform have been defined:

- accumulation of knowledge required by partners,
- provision of access to this knowledge,
- provision of related documents or links to those documents,
- dynamic knowledge update caused by changes in the BTO network structure.

2 Knowledge Management in Supply Networks

A widely accepted 'working definition' of knowledge management applied in worldwide organizations is available from *WWW Virtual Library on Knowledge Management* [5]:

> "Knowledge Management caters to the critical issues of organizational adaptation, survival, and competence in face of increasingly discontinuous environmental change.... Essentially, it embodies organizational processes that seek synergistic combination of data and information processing capacity of information technologies, and the creative and innovative capacity of human beings."

Knowledge management is defined as a complex set of relations between people, processes and technology bound together with the cultural norms, like mentoring and knowledge sharing. Knowledge management consists of the following major processes: knowledge discovery (knowledge entry, tacit knowledge capturing, etc.), knowledge engineering (knowledge base development, knowledge sharing and reuse, knowledge exchange, etc.), and knowledge mapping (identifying knowledge sources, indexing knowledge, making knowledge accessible, etc.).

Five modes of knowledge generation (innovation) are discussed in [6]:

1. *Acquisition*. In addition to being purchased, outside knowledge can be leased or rented. A common type of leasing is a firm's financial support of university or institutional research in exchange for the right to first commercial use of promising results. But a firm needs to know what it wants in order to have a good chance of getting it. High-level consultants are sometimes surprised at how little clients ask of them in terms of knowledge transfer.
2. *Dedicated resources*. A customary way to generate knowledge in an organization is to establish units or groups specifically for that purpose. But the financial returns on research take time to materialize and may be difficult to measure when they do come. So the premise behind separating R&D from other parts of the firm is to give researchers the freedom to explore ideas without the constraints imposed by a preoccupation with profits and deadlines.
3. *Fusion*. Knowledge generation through fusion purposely introduces complexity and even conflict to create new synergy. It brings together people with different perspectives to work on a problem or project, forcing them to come up with a joint answer. A significant commitment of time and effort is required to give group members enough shared knowledge and shared language to be able to work together. Careful management is also necessary to make sure that the collaboration of different styles and ideas is positive, not merely confrontational. See five knowledge management principles that can help make fusion work effectively in [6].
4. *Adaptation*. A firm's ability to adapt is based on two principal factors: first, having existing internal resources and capabilities that can be utilized in new ways, and second, being open to change. The most important adaptive resources are employees who can acquire new knowledge and skills easily.
5. *Knowledge networking*. Communities brought together by common interests usually talk in person, on the telephone, and via e-mail and groupware to share expertise and solve problems together. When networks of this kind have enough knowledge in common to be able to communicate and collaborate effectively, their ongoing conversation often generates new knowledge within firms. The common denominator for all these efforts is a need for adequate time and space devoted to knowledge creation or acquisition. Space not only means the laboratories and libraries in which discoveries can be made but also the meeting places where knowledge workers can congregate.

Knowledge is commonly believed to be one of the most important, if not the most important strategic resource of an organization. Knowledge management strategies can be distinguished according to the type of knowledge that is focused [6, 7]: (i) core knowledge: the minimum knowledge commonly held by members of an industry, (ii) advanced knowledge: enables an organization to be competitively viable, and (iii) innovative knowledge: enables an organization to lead its industry and to significantly differentiate itself from its competitors.

Generally, the function of the knowledge management in flexible supply networks can be defined as follows: collecting and disseminating all network knowledge concerning the design phase of a supply network and the application of the developed methodologies. The term knowledge here covers:

- supply network structure
- network members' competences
- product structure and technologies
- best practices and business cases
- rules and metrics of choosing models / methods under certain conditions

3 Knowledge Management Platform Architecture

The technological framework of the knowledge management platform involves the following technologies (Figure 1):

- ontology management – efficient application of ontologies in these fields is achieved by means of operations that allow ontology sharing and reuse;
- context management – creation, modification and maintenance of context that is any information that can be used to characterize an entity, where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [8];
- competence profiling – description of supply network members' capabilities, competences and preferences.

Ontology management techniques are used to operate on the extraction of relevant knowledge, its integration into contexts and context consistency checking. In order to enable capturing, monitoring, and analysis of information and its effects the contexts representing problem models and respective decisions made are retained. Object-oriented constraint network mechanism [9] serves for ontology definition.

The conceptual model of the proposed ontology-driven knowledge sharing (Figure 2) is based on the earlier developed idea of knowledge logistics [10]. It correlates with the conceptual integration developed within the Athena project [11] and meets requirements to information systems for flexible supply networks. The common shared ontology describes common entities of the enterprise systems and relationships between them. Knowledge map defines where certain entities of the common ontology and competencies can be found. As a result it is possible to treat all available knowledge and competencies as one distributed knowledge base.

Due to the large amount of information that can be stored in the common ontology and the possibility to have different entities with similar names as well as same entities with different names it is proposed to apply context management. Context defines a narrow domain the customer of the knowledge management platform works with [12].

Since Web-services are currently a de facto standard for inter-system communications, widely supported, and quickly spreading, it is reasonable to use this standard a means of communication. The idea of open services arises from the concept of virtual organization. It can be said that "services are oriented to virtualization of resources" [13]. Services address discovery & invocation of persistent services. Internal implementation of services can be of any nature but their interfaces are standardized [14].

Figure 1 Integrated technological framework of the knowledge management platform

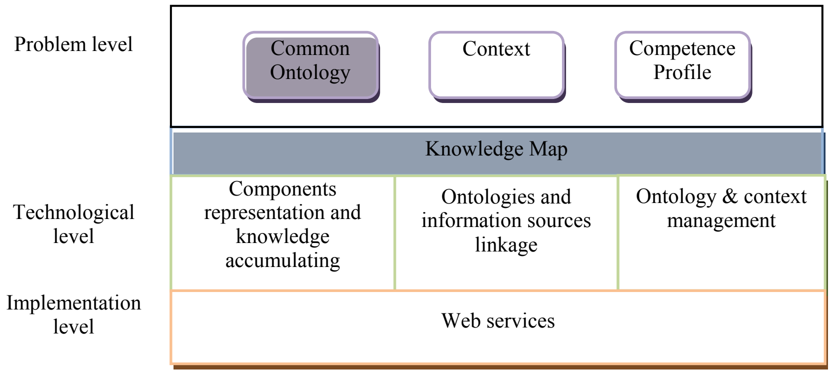
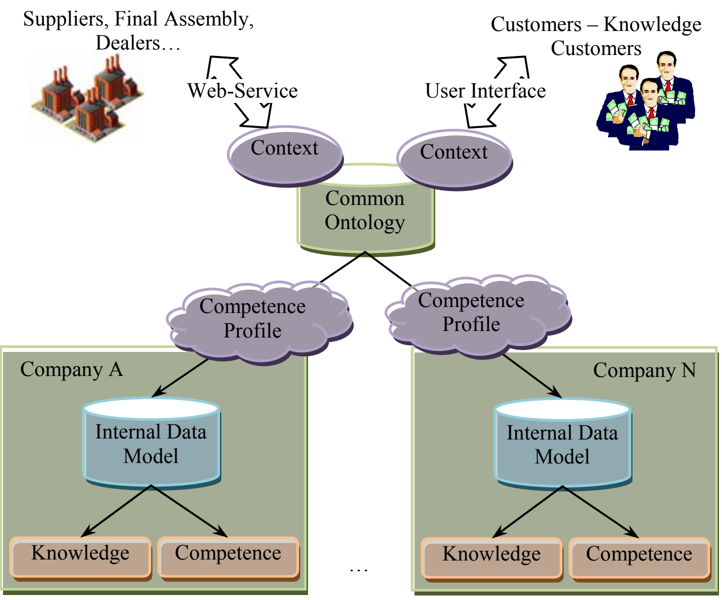


Figure 2 Conceptual model of ontology-driven knowledge sharing



Semantic interoperability is achieved via using the shared ontology providing for common notation and terminology. To provide for semantic interoperability the usage of ontologies as one of the most advanced approaches to knowledge mark-up and description is proposed. Ontologies establish the common terminology between members of a community of interest [15]. This enables organization of semantic interoperability between various subtasks of flexible supply network management. Besides, the ontology model is a means to overcome the problem of semantic heterogeneity. Ontologies provide reusable domain knowledge. Knowledge represented by ontologies is sharable and understandable for both humans and computers.

The concept of the knowledge management platform orients to availability of domain knowledge. The knowledge has to be collected before it can be used. Knowledge collecting includes phases of knowledge representation and integration. Due to the ontology model the heterogeneous knowledge being collected is represented in a uniform way.

4 Common Ontology

According to the developed formalism of object-oriented constraint networks [9], the common ontology is described with a set of *classes*; a set of class *attributes*; a set of attribute *domains*; and a set of *constraints*. The set of constraints comprises (1) *taxonomical* ("is-a") relationships, (2) *hierarchical* ("part-of") relationships, (3) *class cardinality* restriction, (4) *class compatibilities*, (5) *associative* relationships, and (6) *functional* relations.

The tool used for modeling represents the information it contains by means of XML. A file containing such an XML-representation of the enterprise model was used as the source from which the domain ontology was derived [16]. Table 1 shows correspondences between the enterprise model, its representations in XML, and the formalism of object-oriented constraint networks. The built ontology comprises around 500 classes, 2500 class attributes, 400 part-of relationships, and 850 associative relationships. A part of the ontology is presented in Figure 3.

Table 1 Correspondence between Enterprise Model, XML, and OOCN representations

Enterprise Model	XML	Object-Oriented Constraint Networks
Object	Object	Class
Container	Object	Class
Instance	Valueset	A set of attributes
Range	Data type	Domain
Parent-children relationship	Type-of; Child-link	"Is-a" constraint
	Part-link	"Part-of" constraint
Named relationships but "Type-of"/"Of-type"	Relationship	Associative constraint

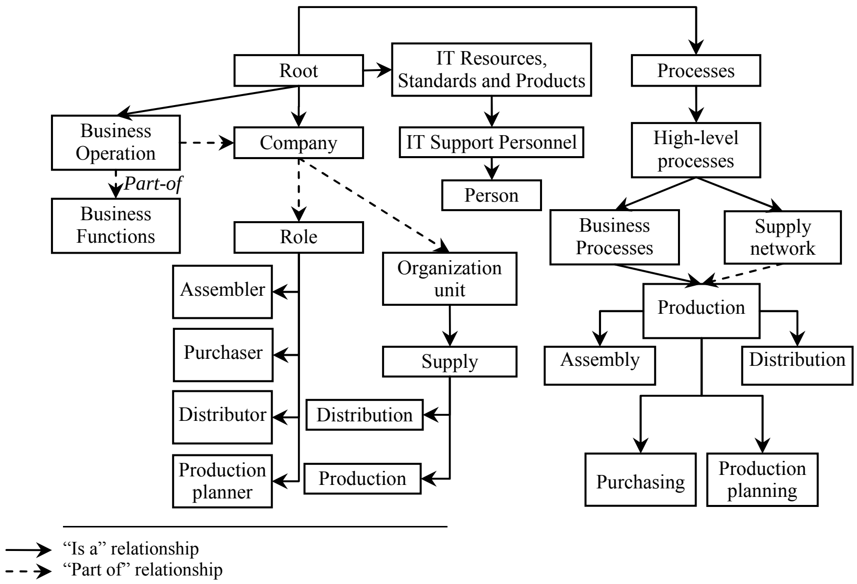
5 Competence Profiles

Based on the analysis of existing profile models the reference model of the competence profile for a supply network member presented in (Figure 4) has been developed.

Competence profile model consists of the following categories:

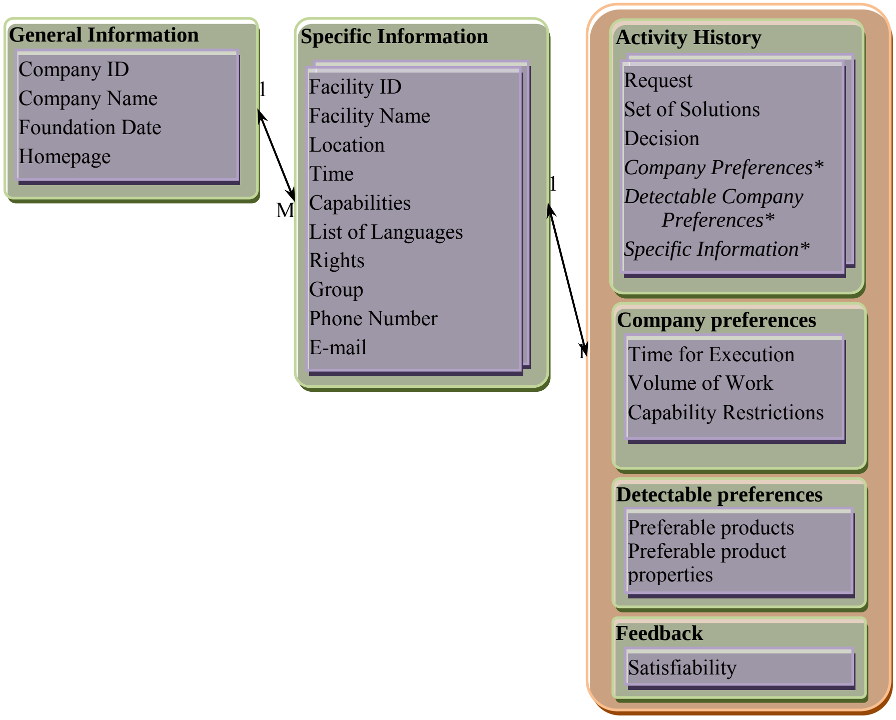
- *General Information* describes general information about company. It contains following properties:
  - Company ID - identifier of the company in the system;
  - *Company Name* - name of the company;
  - *Foundation Date* – date of the company foundation;
  - *Homepage* – URL to the company Web page.

Figure 3 Common ontology (a part): hierarchies view



- *Specific Information* – set of tuples, each tuple describes information about company facilities and contains following properties:
  - *Facility ID* – identifier of the facility in the system;
  - *Facility Name* – name of the facility;
  - *Location* – geographical location of the facility, it can be taken into account for estimating rapidity and quality of order processing in a particular situation;
  - *Time* – time zone of the facility;
  - *Capabilities* – production capabilities of the facility;
  - *List of Languages* – represents languages for contacting with the facility;
  - *Rights* – determine knowledge area which the facility can access, for example facility which produces tires does not need to access information about glass production and cannot access sensible information about its competitors;
  - *Group* – the facility can be a part of a group based on its capabilities;
  - *Phone Number, E-mail* – contact information.
- *Activity History* – set of tuples, each tuple contains following properties:
  - *Request* – request to the company, it can be used for further reuse of sets of solutions for the same or similar requests to the system;
  - *Set of Solutions, Decision* - are used to analyze the company's activities (other companies can see solutions generated in particular situations) and to identify detectable company preferences (via analyzing differences of selected decisions from other offered alternative solutions);
  - *Company Preferences** - stores company preferences at the moment of request initiation. It contains a snapshot of all the properties of the category "Company Preferences";

Figure 4 Reference model of the competence profile



- *Detectable Company Preferences** - stores detectable company preferences at the moment of request initiation. It contains a snapshot of all the properties of the category "Detectable Company Preferences";
- *Specific Information** - stores specific information about the facility at the moment of request initiation. It contains a snapshot of all the properties of the category "Specific Information".

- *Company Preferences* describe company preferences which can be determine manually, this preferences are used to choose this company when set of solutions are generated, it contains the following properties:
  - *Time for Execution* – describes company preference for execution time of work (e.g. short-term or long-term orders);
  - *Volume of Work* - describes company preference for volume of work (e.g. serial production or mass production);
  - *Capability restrictions* - describes company preference for capability restrictions, in this property stored several capabilities and logical restrictions from list of all capabilities for the domain (for example if the company performs operation A, it necessarily performs operation B).
- *Detectable Company Preferences* – describe automatically detectable company preferences, which can be used for choosing a company when generating a set of solutions for a particular order, e.g., products which the company prefers to produce and their properties.

- *Feedback* contains information about quality of the company activity, e.g., satisfy ability that indicates if the company fulfils its orders.

Companies can determine manually which categories of the profile are visible for other companies.

6 Conclusion

The paper describes architecture and major components of knowledge management platform for flexible supply networks. The primary goal of the presented knowledge management platform is a support the design phase of a BTO supply network in the part of establishing contacts between its potential members. In BTO supply networks absence of suppliers that could provide required materials/components may require changes in the product structure thus affecting the PLM processes. A brief review of knowledge management allowed to identify the main functions of knowledge management in supply network including accumulation of knowledge required for partners, providing for access to this knowledge, providing for related documents or links to those documents, and dynamic knowledge update caused by changes in the supply network structure. It is shown that knowledge management platform should be based on such technologies as ontology and context management, profiling, Web-services, etc. The developed ontology and structure of the competence profile are presented.

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PLM design and delivery models: key issues and lessons learned from projects on the field

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Abstract: The paper describes the cultural issues and the fundamental practices required to manage effectively and efficiently PLM projects, as emerged from key lessons learned from projects on the fields and from author's experiences. Major topics presented are: scope definition and monitor, stakeholders' role and involvement, risk and communication management, the role of the project manager, and the overall ability to integrate all the previous aspects into a seamless project body.

A key issue presented is the balance between two emerging design & delivery models: the spec-driven approach, where most of the concept and functional design is obtained through specifications and the pilot/prototype-driven approach, where most of the functional design is obtained thought iterative prototypes. Characteristics, advantages, disadvantages, trends and possible blends of the two models are discusses.

Keywords: PMBOK, Stakeholder, Risk, Communication, Project Management, WBS

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1 Introduction and scenario setting

As PLM is becoming an increasingly complex matter from both theoretical and practical sides – and a paradigm for the 21st century [1] –, lessons from actual implementations have been accumulated in the last ten-fifteen years and can now offer a factual-based help in shaping new initiatives and projects and in discriminating among alternative options.

1.1 Design and delivery: different approaches exist

In the early phase of any PLM initiative a key decision regards the implementation approach. In the last decade different approaches have emerged, each offering different options, advantages as well as different implications.

Particularly the "design and delivery" of the PLM implementation has become a key – and sometime a controversial – issue to address.

Design and delivery, simply stated, are the key decisions about the way, the methods and, ultimately, the activities with whom a PLM set of solutions are conceived, implemented and deployed to users.

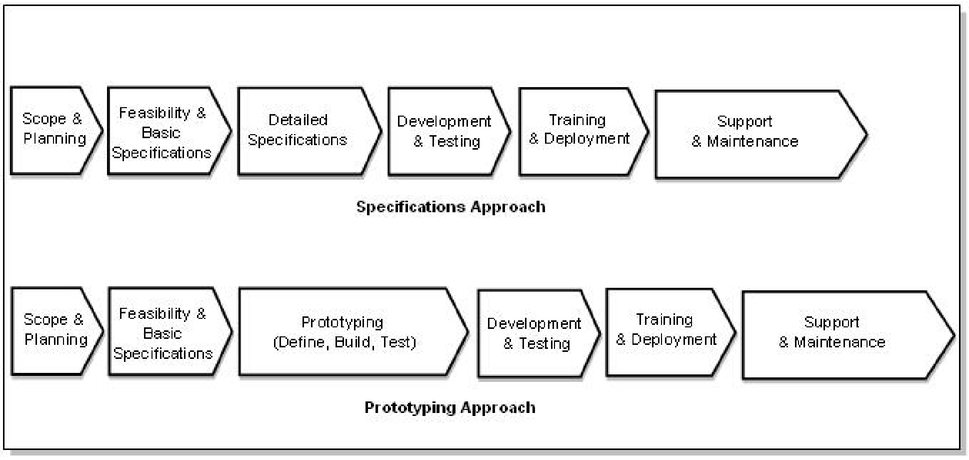
At the extremes two different approaches compete, although often a mixed approach is actually used.

The first approach is based on specifications as mainstream method: they are generated (usually with the help of workshops or interview sessions that bring together subject matter, process and application experts), discussed, revised, validated and approved. From that the PLM system is build, tested (against the specifications) and released in almost a sequential manner.

The second approach is more iterative and relies more on prototypes. They help to build an understanding of the issues and requirements and the solution is based on a iterative prototypes with a growing level of definition and details. In that approach often the final system follows closely the prototypes iterations and in some extreme cases the prototypes themselves evolve towards a final, industrially usable and reliable, solution.

Figure 1 shows the differences.

Figure 1 Different approaches



The two approaches can partially co-exist and collaborate (e.g. a set of initial specs followed by a "requirement assessment prototype"), although is not uncommon that a clear initial cut is done towards one or the other approach. The choice is certainly influenced by various factors such complexity of the PLM issues to be addressed, relationship and trust among the major stakeholders, time and resources available, and whether the implementation is done mostly using organization's internal resources or, alternatively, if a massive support is performed by external suppliers or system integrators.

Anyhow, the two approaches have theirs pro’s & con’s that can be summarized as:

- usually the prototype-approach offer a large degree of confidence in requirements assessment and solution definition as they allow a thorough review and tests before decisions are taken; on the other side this approach it’s likely longer as it requires more time due to coding, the testing sessions and the iterations; this also means, often, more effort and costs
- vice versa, the specs-approach, ideally, is quicker and leaner but also more risky: issues and requirements gathering may lack the details and sense of awareness that prototypes have; and impacts or even feasibility of the final solution can be underestimated; furthermore, with this approach requirements are more subject to *a posteriori* interpretations and often to implicitness (i.e. they are not clearly stated)

1.2 Projects fail

“Most innovations fail”. [2] And the reality is that, in PLM, and more in general in Information Technology, most projects fail. More frequently then expected. And failure may come in different manners, partially or totally.

A well-know organization, the Standish Group [3] – which investigates Information Technology projects success and failures – reports that only 25% to 30% of the projects can be considered successful (out of more then 10000 investigated each year). The remaining projects fail and are canceled at some point of the development cycle or go in production but fail in particular aspects: in time (take longer) or cost (run over budget) or content (scope is reduced). And these percentage are only slowly improving over the years.

Failure in PLM initiatives are particularly high in the early phases of the projects, as soon as the key issues emerge.

1.3 Lessons from the field

This paper is based on the author’s experiences in the field during the last fifteen years of participation and management of initiatives in PLM, Document Management and Knowledge Management with clients of different size and industry, although mostly in the manufacturing and energy industry sectors. If practices for PLM implementation have changed in time this is also due to the feedbacks coming from experiences and lessons learned accumulated, as different issues as been faced.

The paper also benefits from the author’s participation to a recent research project conducted within the Project Management Institute, Northern Italy Chapter in 2005–2006, about “Management and Innovation”. The research aimed at the investigation of practices in managing innovation projects in Northern Italy’s small to medium manufacturing enterprises. The research, among other results, produced an handbook, based on study-cases, aimed to help in addressing the fundamental issues of managing innovation projects [4].

As different countries and different industry sectors may have different issues and practices, the considerations included in this paper should be treated with the limitations imposed from the fields and industries where lessons have been learned, although a large degree of considerations are valid outside the mentioned country and industry boundaries.

2 Key issues and lessons learned

The discussion is based on four knowledge areas (out of nine) presented in the PMI's Project Management Body of Knowledge (PMBOK®) [5]: *Scope, Risk, Communication and Integration*. An additional area of discussion has been introduced, *Stakeholders involvement*, as it seems to be a recurrent aspect across all the knowledge areas and perhaps a key critical success factor of any PLM endeavor.

2.1 Scope definition and monitoring

Scope definition is the first issue to be addressed and it's the foundation of any PLM project initiative. Scope management is a process that doesn't end with its initial definition and requires to be monitored all along the project as scope changes are not uncommon.

Scope itself is a process of discovery and *"is primarily concerned with defining and controlling what is and what is not included in the project"* [5]. Scope is not only about the reasons why the project is carried out. Scope refers either to Project scope – the works that need to done – and Product (or Service) scope – the features and functions that characterize a Product (or Service) –.

Several lessons learned from the field indicated that project scope definition is a task often underestimated and in some cases only partially described or formally approved.

In a process redesign and document management project, which took place in a small-to-medium manufacturing enterprise, team members were unable, during an external project review, to go back to the original decisions and scope statement. The documentation was somehow left incomplete, thus degenerating in features not really requested by the users and later questioned by the management.

Scoping, from the initial scope statement down to the WBS definition, is a collaborative effort that requires contributions from different stakeholders. Rushing to the implementation without sufficient scope definition, discussions and evaluations of the implications has proved to be a major source of misunderstandings, frictions or dissatisfaction with the project outcomes. Ideally an initial "PLM scope and planning phase" or "PLM concept phase" should be considered a phase that precede the actual implementation activities. In the concept phase different tasks are carried on from scope definition to business case preparation and discussion up to the definition of the project WBS. Under this aspect the PMI's WBS Practice Standard [6] are of a great help to build an appropriate and thorough understanding of the "what" on any initiative. This is particularly true for PLM initiatives which offer an high degree of complexity.

2.2 Stakeholders involvement

Stakeholders involvement is perhaps one of the "good practice" less followed in projects and often this is the root cause of others problems ahead. Lessons, learned the hard way, show that neglected stakeholders may generate issues and disruptive effects on the project scope, budget and resources.

The PMBOK® [5] and other sources urge to involve stakeholders (literally *"anyone who as an interest or that can be impacted by the result of the project"* [5]) early in the project and anytime a major step is accomplished. This could be done with an appropriate and thorough stakeholders analysis, aimed to identify and classify stakeholders, understand their expectations and their influence on the projects. The analysis should also define priorities and areas of risks as expectations may be unquantifiable and subjective. Lessons learned from a preliminary assessment in a recent PLM initiative of a medium manufacturing enterprise helped to identify that the same issue, about traceability of product configurations, had different point of view, perception and involvement from different stakeholders of the company, with some of them representing also the point of view of the major suppliers, initially not considered as key source of information. The analysis helped not only in identifying the different needs and wants and the relative importance but also helped to address different communications and reporting needs to be used during the remaining part of the project.

2.3 Risk management

Risk management is an other weak or underestimated area in PLM projects. Uncontrolled risks, e.g. risk that resources are not available at certain project schedule, may have high project impacts and, ultimately, may end up in a unpredictable cost penalty for the project, if not worse.

Although risks are, usually, matter of great initial discussions, it has been observed from the field that "de facto" practice of risk management in PLM projects tends to be reduced to managing technological risks only, or just to address risk identification.

Human resources related or other risks are somehow considered less important.

Risk management offers instead a well-established methodology to capture, identify, classify, address and monitor all kind of risks and their evolution across the project span. The lack of formal risk management work also inhibits the chance to purse opportunities – positive options that may emerge from risks and contingency solutions. In a successful change management project, that included a process and data / document management implementation for an energy sector company, after some initial skepticism, a dedicated set of risks analysis sessions provided benefits to the overall project schedule and resource availability readiness. After risks identification and classification a clear risk response plan was formulated and executed throughout the project. As more understanding of the risks cycle developed in the company, a continuous risks monitor was performed and risks evolution became a constant report section in the monthly project review meeting. The sessions critically examinated scope, boundaries, related assumptions and project constraints, relevant uncertainties and possible negative/positive events that might have had impacts on the projects.

Risk management is a typical collaboration task, which often needs to include contributions from line and general management, even they may not play a direct role in the project. Risk management should definitely be on top of the agenda of the project manager or, for large PLM implementations, even require a dedicated risk manager.

This all end up with the need to define and allocate, since the initial approval of the initiative's budget, of a contingency budget – dedicated to either mitigate, transfer, or accept the risks impacts. This budget should sums up the risks allocations and the beneficial effects of opportunities as they unfold during the project. Although the methodology is well developed and available in many textbook this is a good management practice not fully exploited, yet, in PLM projects.

2.4 Communication management

Communication management is a process aimed to ensure *"appropriate generation, collection, distribution, storage, retrieval and ultimate disposition of project information"* [5].

It's about linking people and information. It's about keeping the focus. It has been observed that failing in communication may generate misunderstanding on specific project items or tasks and – perhaps even more important – may have negative effects on project credibility itself. Lack of, or limited, communication may generate a negative perception about organization's commitment towards the project. Effective communication, instead, is an outstanding proactive mean to anticipate issues and correct unfocused tasks.

Some PLM projects observed in the aerospace industry have defined a project communication plan which included a set of project communication reports issued with predefined frequency, using instead occasional reports for special purposes (e.g. at particular milestones or events). This helped to keep a continuous flow of information towards stakeholders, performing teams and users.

There are three major lessons learned from several PLM projects who managed communication effectively:

- It helps to create more confidence, collaboration and involvement among clients, performing teams and, in general, stakeholders; vice versa projects that poorly communicate have experienced more issues as well a lack of enthusiasm
- There is a better understanding and control of stakeholders' expectations
- Communication management requires a mixed balance among effectiveness and efficiency, as overload of information is perceived as bad as no information; any project plan should include a detailed, specific communication plan
- Change management, *per se* a key aspect of any PLM project, is largely based on a continuous flow of effective communications

Effective and efficient management of information is seen as one of the principal activity for a project manager, sometime taking up to 40% of his or her time. And the task starts with a detailed analysis of the stakeholder (see also the Stakeholder involvement paragraph). PLM initiatives, in general, should be particularly keen to communicate the scope and purposes of the project, the expected impacts, the project progression and the "quick hits" or benefits achieved, as they start to build up.

2.5 Integration management

Integration management is the overall coordination of different processes that overlap and interact (e.g. risk assessment, resources and cost budgeting).

Integration helps in searching for not-so-evident dependencies, in anticipating issues and resolving inconsistencies. Integration is, at its core, about giving the appropriate priorities.

Thus it's a process that require continuous iterations and monitoring. Although very large PLM implementations have an integration manager, whose activities are dedicated to linking someone's else tasks, integration is typically in charge of the project manager and the technical leaders.

PLM, with its far reaching and pervasiveness, is an extraordinary demanding arena for integration, from either the information technologies, the processes, the people and the project activities points of view. Additionally, PLM projects themselves often are, in many ways, one the earliest integration initiatives with whom organizations deal with; this is particularly true for organizations who have always worked in functional, "silos-style", manner.

Interestingly, in a PLM initiative in an large shipbuilding organization, aimed to analyze and change some of the core costs of the products, some key users coming from different design offices recognized that the PLM initiative actually was one of the first chances they had to grasp a better understanding of the work done by other offices, including shipyard design-to-manufacturing processes and issues. This helped to create a better understanding of the integration issues between, e.g. the electrical department office responsible for cable routing and the interior design department responsible for the cabin arrangements. Overall, integration management offers at the same time a top challenge and a great opportunity.

3 Conclusions

Paraphrasing a famous rock & roll song of the 70's: "PLM is here to stay" and several PLM initiatives are in place and others more are on theirs way. Commitment is high and lessons learned from either the conceptual, the delivery and the usage points of view are widely available. Four key conclusions can be drawn.

3.1 PLM requires preparation

Several PLM implementations, either system-driven of process-driven, show that PLM is tough to manage and that it's easy to land in a reduced scope or budget overruns or, more frequently, to delays.

Many PLM implementations were underestimated because, at its core, PLM is fundamentally a revolutionary paradigm which involves integration of different cultures and aspects and often touches the organization's culture, on top of the specific information technologies.

So, PLM initiative requires preparation, planning , some readiness analysis, "think big, act small" attitude, definition of pragmatic objectives to pursue together with short-term returns. Returns are a key for building trust, alongside with a vision of the organization's future, and – overall – a great willing to change.

3.2 Different approaches may coexist

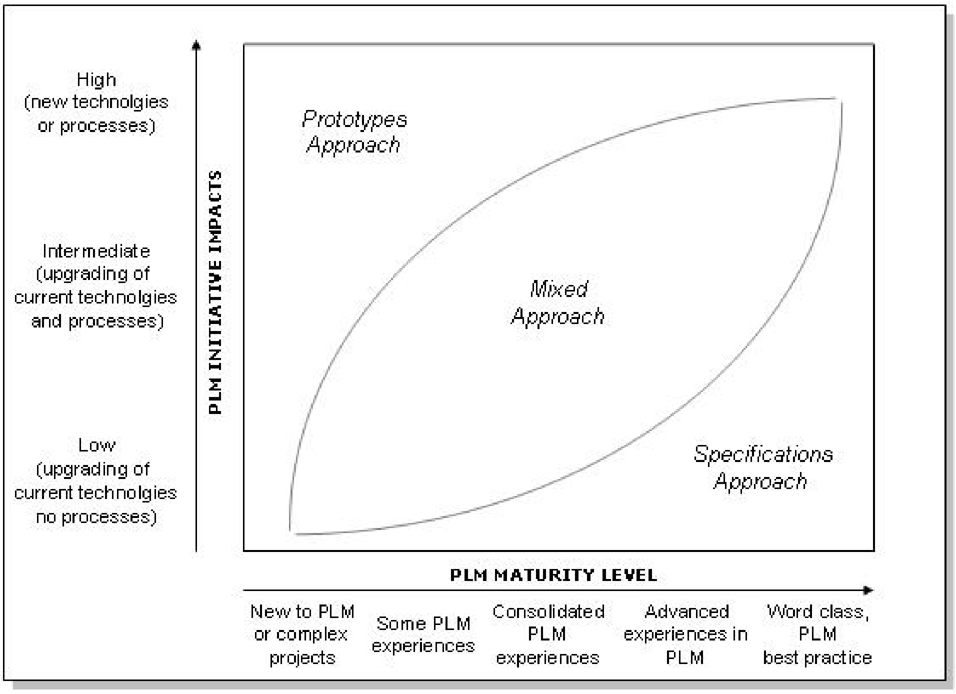
As described before no approach fits all situations and different approaches may even co-exist. The key starting point is the implementing organization's maturity and readiness towards PLM. Unlikely a functional-driven, "send-over-the-wall", organization will be ready to accept and benefit from PLM's extraordinary ability to manage work-in-process information for collaborative development; in this case a push back is more likely if a culture paradigm change has not been established or is not in the scope.

Whether to go with a strict specifications-driven approach or let the prototypes build understanding and insight depends from the organization's maturity and stakeholder's culture, along with the expected impacts of the PLM initiative.

A priori assessment can surely help and should be done early, objectively, and made evident. Lessons learned from projects on the fields can be synthesized in the following figure, although each case should be treated with appropriate considerations.

The Figure 2 correlates the organization's own maturity in dealing with PLM initiatives, somehow a measure of readiness towards complex culture-changing projects, and PLM specific initiatives, objectives and foreseen impacts. Relating these two dimensions can help to build a set of "confidence domains" where different approaches are more appropriates.

Figure 2 Maturity vs. impact assessment



In this model a specification driven approach results more appropriate when settled practices are confronted with initiatives with low or intermediate impacts, as intuitively.

Vice versa a prototypes based approach apply at the other end, when new technologies or limited PLM experiences are in the game.

More interestingly, a mixed approach – with initial high-level specifications followed by few iterative prototypes – is emerging as an appropriate balance between wishes, risks and rewards and awareness. This is possible also thanks to the fact that PLM systems are becoming more advanced and flexible towards changing the data model and processes in a relatively small amount of effort.

3.3 Best project management practices apply

At its core PLM initiatives require that project management best practices are applied solidly. This is particularly true when the PLM initiative has a large number of stakeholders involved (e.g. users, suppliers, teams, departments), when process redesign is in the scope and when cultural change is a key success factor.

Underestimation of the appropriate planning and coordination activities may bring confusion and ultimately questioning the organization’s real commitment towards the PLM initiative. Lessons from the field show that, in complex projects as PLM are, project management activities should lead the effort rather that be a mere registration of facts and numbers. Is has been observed, *a posteriori*, that PLM initiatives can build up to 15% of the overall project effort in planning, integration, communication and reporting: but every single hour spent in those tasks paid off in term of results and users satisfaction. Selecting the appropriate level of coordination is one of the key decisions each PLM initiative’s initiator should address.

3.4 It is a roadmap and an opportunity

Finally, PLM is a roadmap built on a vision. A stepped approach can be applied not only in the scope, or tasks, or the technologies but also on the expected results. Strategic, long-term, changes should be balanced with short-term benefits or even “quick hits”.

Some PLM projects have tried to establish the (informal) “rule of 100 days”: give back a small piece of benefits to the organization each three to four months of project. The rule helped, beside the benefits *per se*, to foster the credibility and correctness of the vision, which requires an high degree of commitment is left alone without short term returns.

This also goes to the point why PLM should be brought to the attention of the top management. As PLM is a strategic business approach, that links different solutions and elements to reach different aspects of the extended organization, the sponsorship and guidance of the top management is a key help in setting the appropriate commitment and to assure resources and budget.

More important, it helps to set the appropriate confidence toward the transition effort, to build a change urgency imperative, and to grow the human capital, the true richness of any organization [7].

Acknowledgments

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Integration of PLM with other concepts for empowering business environments

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Abstract: Innovations for enterprises are essential to survive in this competitive global market. Being an innovative business not only means creating innovative products, but also improving the processes of a company uses to produce its products. It supports its products using innovative approaches to the complete product lifecycle. PLM plays a key role in this and also in today's rapidly changing business environments. It manages the definition lifecycle and the relationships between product–related information and processes. Integration of PLM with other managerial and design concepts, certainly leads to successful business also worthful products for customers. The benefits of integrating PLM will impact many areas of a business, not just engineering, and help companies of all sizes to be more competitive in today's global competitive markets. It includes technology, processes, best practices, and other elements that provide a complete solution to business problems. This paper briefly describes the growth of PLM and also how it suits for empowering business in various modes while integrating with other concepts. The paper concludes with an analysis of PLM in Design concepts and discussion of the business benefits of PLM for automotive and other design enterprises.

Keyword: PLM, Integration, CRM, SCM, ERP, PDM, Design.

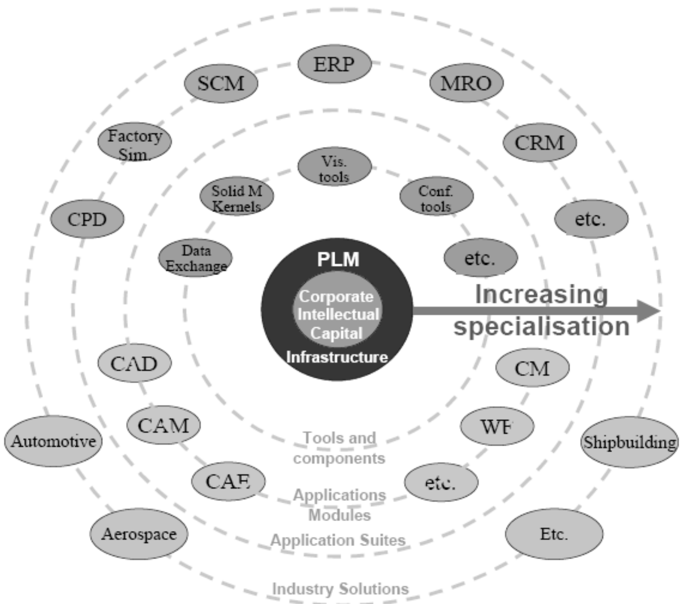
1 Introduction

An enterprise-wide PLM solution consists of a number of system elements that combine together to help an enterprise to deal with increasing product complexity and customization, innovate more quickly, improve quality and lower costs, provide better service to customers, work in virtual teams and provide 24x7 global support, exploit intellectual assets more effectively, insulate itself against the effects of frequent structural changes ranging from full, mergers to temporary partnerships. PLM is a business approach for creation, management, and use of product-associated intellectual capital and information throughout the lifecycle [6]. Thus, there has been a continuous evolution that has expanded the capabilities and lifecycle focus of the enabling technologies, methodologies, and processes [10].

2 History of PLM

PLM has its roots in the design and engineering function Figure [1]. The 1970s saw the introduction of systems to help mange the vast amount of CAD data that was being created to define products [1]. The focus was on the file management and version control, shown by the interchangeable use of terms such as engineering data management EDM and Product data management PDM for these systems. Prior to the 1980's, there was a low level of design automation. PDM had no tools and was using bare hands to manage paper-based information. Early 1980's, design tool usage accelerated with a consequential increase of information to manage [2]. PDM users built their first flint tools and tried to use file systems and naming conventions to solve the problem. Mid 1980's, the first primitive tools started to appear to provide basic vaulting and access control. Wider acceptance of PDM tools was held back in the 1980s by the reluctance of many engineers to get to grips with unfriendly tools. This decade saw better user interfaces, more direct links into CAD systems-the user's primary tool-and better handling of product structures. As the industry evolved, the scope expanded beyond engineering departments. By the early 1990's, industry demanded more sophisticated applications to address issues such as product structure, change control, configuration management, and others [1]. By the 1990s PDM had a strong foothold within the engineering function but other parts of the business were now walking up to the benefits of having access to the product data management solutions that were available. This broader community again demanded improvements, such as better user interfaces, support for platforms other than UNIX and the introduction of visualization software.

Figure 1 The PLM Universe (Datamation Limited, September 2002)



However, in the mid to late 1990's, new acronyms again created confusion in the market as people began to consider the product lifecycle and collaboration— PDM, CPD, CPC, and others [8]. By the late 1990s and into the current decade, the focus was on even closer links with multiple ERP systems, on collaboration with partners and e-business. Vendors have moved from selling packaged, standalone applications to offering systems integration services to pull together a number of complementary solutions. PDM has become PLM providing decision support at an enterprise level as well as continuing to handle traditional PDM functions. The issues for PLM vendors are now whether, with many different kinds of users and with greater cross company collaboration, everyone should have the same PDM system and how they can exploit the power of the intern and the browser web interface. This expansion continues today with PLM solutions touching many different business functions and organizations beyond traditional engineering and design departments. Over the past ten years, visualization and collaboration solutions have emerged. They made number of users able to easily access and use product information previously available only to design engineers who had access to high end design tools. Adoption of Internet based technologies and computing paradigms has made PLM solutions easier to implement and deploy across the globe by integration [3].

3 Integration of PLM

"Innovation is King". "Integration may be Queen."[1] The key takeaway from these statements is that while integration is very important, functionality must be considered a higher priority. For dynamic businesses with frequent product change or for businesses with complex products, this is even more important. The role of Product Lifecycle Management (PLM) is changing. From a set of engineering oriented tools, PLM has evolved into an enterprise-level solution that is at the heart of modern business management. Applications include CAD files management and CAD integrations; product portfolio management; project management; customer needs and feedback management; resource management; strategic sourcing, approved vendors list management; design collaboration; 2D and 3D visualization; change management, quality assurance; and others.

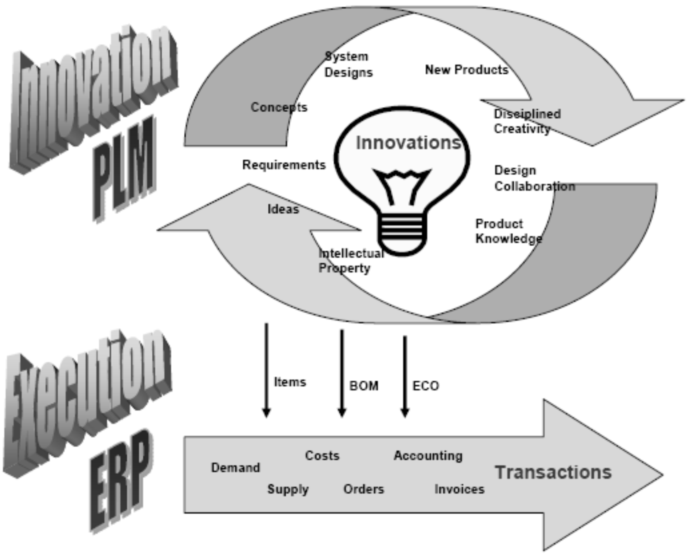
Today, one of the primary drivers is a focus on the product and product innovation, i.e., how to bring an innovative product to market sooner and more efficiently. The pressures of reduced time, improved product quality, and lower costs aren't new, but they are being reaffirmed and folded into programs that focus on the product complexity, not just in terms of a product's physical or mechanical configuration, but complexity in terms of all the electronics and software that are also part of the delivered product or plant. These drivers put increasing pressure on organizations to invest in solutions that include technologies, methodologies, and best practices that can help them improve their ability to focus on product innovation, leverage their business partners, and compete more effectively in the global market place. It causes initiatives and business issues for the last two decades. In 1980's, businesses wanted to achieve cost reduction and cost control, the response was to focus on task automation technologies and methods to improve efficiency and shorten information access times. In the early 1990's the focus shifted to how to improve product quality. One response was concurrent engineering (CE) [18]. In the late 1990's, the primary driver became time-to market; and the response was to focus on creating effective shared environments across diverse organizations. The use of Web-based technologies to facilitate sharing information began to have a significant impact on the integration of new solutions.

3.1 ERP and PLM

In the past decade, many business investments, such as those related to Enterprise Resource Planning (ERP), were made to improve operational efficiency. PLM and ERP are key components of any manufacturer's application strategy, and should be adopted in a way that helps the company achieve their specific business strategy and objectives [15]. PLM provides strong capabilities to encourage and support product innovation, whether that innovation is focused on products that are new to the market or a rapid, competitive response to another company's innovation. PLM also provides capabilities to reduce costs by developing low cost designs and executing product development programs more effectively. ERP, on the other hand, provides strong capabilities to manage the supply and demand for a business, execute plans to meet the demand and provide financial oversight and control. Both PLM and ERP are important, and should be prioritized and selected based on business need and relative product capabilities with the understanding that ERP products are more of a commodity purchase and PLM products are more diverse. PLM and ERP provide value as independent solutions, but can also provide greater value when they play their respective roles in combination to support the business. For best results, the analysis of ERP and PLM should extend beyond the product into the software vendor's capabilities for training, provision of best practice templates, business knowledge and solution implementation. The primary value of ERP comes from integrated business processes. ERP came to prominence at a time when companies were focusing on streamlining the flow of transactions and information across departmental boundaries. Functions that were previously handled with narrowly focused software solutions were incorporated into a broader view of the flow of business. As departmentally-focused decisions and ways of doing business were being re-evaluated—or re engineered—ERP provided a structure to help different areas of the business work more effectively together. The way that ERP helped to break down departmental barriers was to focus on two central themes—managing orders and financial control. ERP is very good at managing the flow of materials. Integrated ERP/PLM offerings may provide part of the solution for simple design environments, although PLM specialists often offer more depth in functionality, flexibility, and domain expertise.

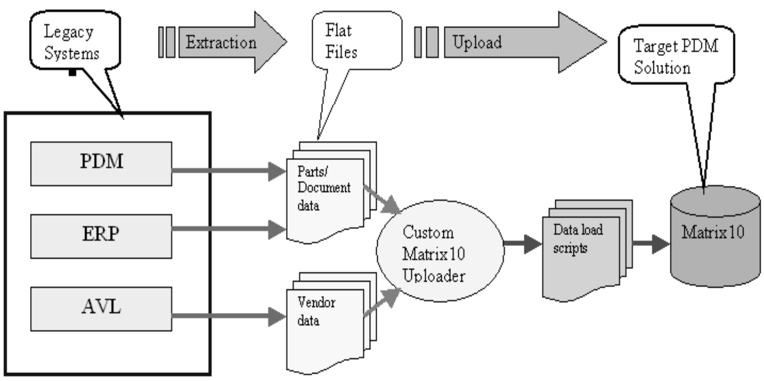
ERP and PLM are both important to manufacturing companies, although the roles that they play may vary Figure[2]. Common integration points between ERP and PLM are new product introduction and the introduction of engineering changes. These are the functions within a business that have the most interaction between innovation and execution. Working with ERP, PLM can play the innovation role for product development and introduction—providing a flexible environment to effectively mange the design and development processes. Working with PLM, ERP can effectively execute and manage the steady-state flow of fulfilling customer orders and managing the operations to ensure that costs are kept in line with plans. ERP and PLM remain very different disciplines. This process is fundamentally different from the transactional flow of business, but should also be connected to achieve maximum benefit.

Figure 2 The Independent and Interrelated Roles of ERP and PLM (Tech-Clarity, Inc. 2004)



The Figure [3] is revealing a case study of a leader in computer server hardware and software products company. The challenge is data migration of legacy data and file content from five different types of systems including Oracle ERP, MfgPro ERP, Metaphase, PDM link, Pro PDM and BEAM. The solution is made by extracting & transforming data from legacy systems into flat files, developing custom utility to upload into Matrix10, implementing complex business rules like normalization, etc in upload, robust back-feed mechanism for error handling and automating validation of migrated data. This integration benefits to bulk loaded 1.5 million parts, supplier, documents data, migrated data, quality and integrity assurance and incremental partial loads done with data verification at each step.

Figure 3 Case study: GSSL



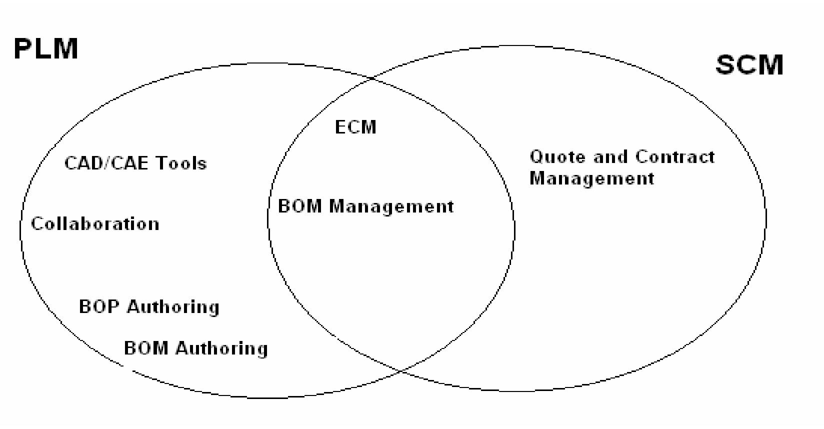
A case study named eManufacturing succeeded with one of the major agriculture equipment manufacturer. The challenge is to increase material utilization in manufacturing processes and leverage efficiencies from sharing and reuse of engineering expertise across the enterprise. The solution is made by integrating multiple heterogeneous design formats and platforms (including several legacy formats) into a simple, browser based design tool, automation of the design processes using GSSL's Nestlib™ technology. The ability to generate nested designs, collaborate and capture engineering knowledge for sheet metal cutting. The newly developed nested designs were stored for re-use on the client's ERP system enabling easy retrieval and order management. The benefits of this integration improved enterprise wide material utilization by over 4%, contributing significantly to the bottom line, slashed design to manufacturing cycle time and reduced manufacturing costs, collaborative enterprise wide re-use of engineering knowledge and Productivity enhancements with the seamless integration of heterogeneous design data sources and legacy formats.

3.2 SCM and PLM

Change is a critical element in any supplier's profit-making strategy. Mastering change requires effectively managing and tracking changes across the operations without inhibiting the innovative processes which are applied in product development and manufacturing. Change management is a PLM-based initiative that enables to manage both formal and informal aspects of change, including processes that range from generating sourcing-related quotes for implementing design changes. The ability to manage and respond to change effectively and quickly directly impacts the strategy for winning future programs and ensuring their financial success. Increased outsourcing makes suppliers more dependent than ever on their supply chains. Rapidly shifting market demands are driving increased change volumes which suppliers must quote in very short time frames. The automotive industry has high expectations and demanding requirements for its suppliers. To be a successful supplier in today's global automotive marketplace, it is essential to Manage more and more programs while making certain that each program launches flawlessly, manage program change to ensure profitability while rapidly and accurately responding to specific changes, integrate other suppliers into your change process Capture, protect and retain your intellectual assets for future re- use. PLM enables to optimize business processes by managing the company's intellectual assets and seamlessly weaving both external and internal innovation practices into the product lifecycle. Today, more than ever before, suppliers are being challenged with shorter lead times, support for multiple CAD formats and competition from global suppliers with expectations of producing a higher quality product. All of this must be done while reducing expenses and increasing Return on investment (ROI). Previous methods of managing information will not support today's more challenging OEM requirements management. After integration it gives Teamcenter suite based solution which is an End to End solution with Teamcenter suite of Products, Manufacturing integration with Technomatix, Multi CAD Integration with Teamcenter and Customization solutions are, SAP Integration using TcIntegrator and Custom Report. Benefits through such integrations are Faster, Reliable and more accurate quoting, Reduced Cycle Time and In-Process waiting time reduced ~ 30%, Improved data consistency, integrity & security and Standardization and Reuse.

Another Case study is Electronic Quotation Management System for Major automotive OEM, the Challenge was Development of a electronic quotation management system as a part of the overall SCM solution. Integration gives solution as Customization of Sourcing central and Team Central, Creation of a Quote Analyzer, Implementation of multi level BOM pricing which involved the pricing of all the parts used, Integration with the legacy system, Implementation of Quick edit feature on the Buyer and Supplier side to reduce the navigation of the end users. Benefits includes, System formed an important component in the selection of vendors on the various user defined criterion and feedbacks from the other systems in the Supply Chain.

Figure 4 Case study: GSSL

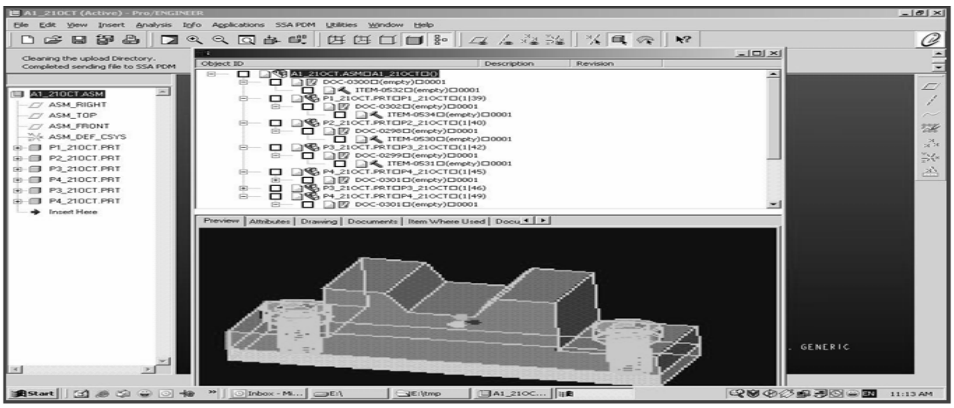


3.3 PDM and PLM

PDM is a foundation for the broader application of PLM [6]. The role of PDM is to manage the essential product information that supports the core customer value. PDM can be thought as a set of applications and capabilities for capturing and maintaining the definition of a product and related data through all phases of a product's life. The four most commonly used PDM applications are Library functions (search and file check-in/check-out), Management of bills of materials (BOMs), Product configuration management (PCM) and Engineering change management (ECM). Today's big business challenges are Product Innovation, Reduced time to market and the most important is Data management i.e., Need to manage increasing volumes of distributed but related data, types of data and systems that create data are continuously changing, Need of constant framework to locate data. In such cases, Product success is determined by meeting customer's unique requirements, providing highest value at lowest cost and delivering continuous innovation. Now a days Organizations are looking to PLM as the path to better and faster product innovation, but essentially all agree that PLM needs to be built on PDM. Product data control and engineering change management are currently the critical business issues across many industries, and the market has acknowledged that paper-based processes don't work and don't scale. So elimination of redundancies and reduction of engineering change cycle times have been priorities for PLM integration. [2] The increased adoption of technologies such as Web services and service-oriented architectures (SOA) are helping companies to bridge the processes and data gaps between individual applications. The combination of managed processes and relationship-driven data management techniques promises to meet the need to integrate and manage PLM processes for today's enterprise. PLM systems, particularly for PDM, serve as repository for CAD files and related product data. PLM suite providers that very tightly link PDM and CAD to manage the complex CAD files that makes up a modern 3D CAD model. Beyond managing the files, these systems also manage the complex relationships between parts and components. This capability, offers the ability to predict and manage how a change to one part impacts other parts and assemblies.[3]. To integrate PDM means to have a secure communications environment among geographically dispersed project teams within and across the extended enterprise, which contains, a dynamic and unified view of product data. Such type of Integration facilitates for rapid iteration, extended data sharing within and across companies. Two aspects important in integration are, making data available throughout the enterprise (This is the major stumbling block to enterprise collaboration) and Visualization i.e., the ability to view the output of any application throughout an enterprise. The research on information integration by Qiao et.al. for PLM calls for a new fundamental information technology to enable adaptive information representation and integration [4]. It focuses on major problems like achievement of a common data format for enabling product visualization and information distribution and enhancing data sharing between PLM software applications; Exploitation of web-based technology in production systems with the crucial ability to manage information access; Management of information of components for reuse purpose and enabling dynamic assembly of customized documents; Development of a mechanism to enable reflecting the disturbance of information change and to create a feedback loop from production to design.[4]. Integration of PDM in PLM will give a smooth flow for data and processes and also a central database management system in Products lifecycle.

Following Case study Figure[5] is related to PDM – CAD Integration in PLM systems for One of the world's largest extended ERP vendors, The challenge was to connect the Enterprise Product Data Management (PDM) system to Pro/Engineer, SolidWorks and Unigraphics. After integration, it became possible to provide a real time transfer of products/part/assembly/drawing data from CAD to client proprietary PDM, Use of Pro/Toolkit, UG/Open and SolidWorks adding, Porting on various flavors of above CAD system. Benefits through these integrations are that the customer can ensure high level information exchange and data integrity between CAD and PDM systems and Elimination of inherent risks and errors associated with data entry from multiple sources.

Figure 5 Case study: GSSL

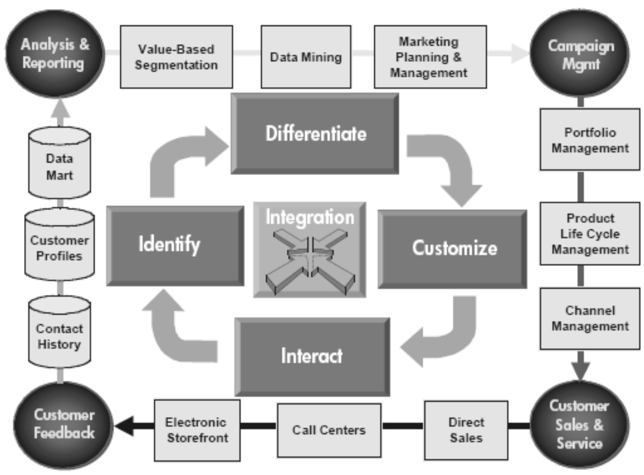


Another Case study is Translators Development – DWX & DWG format to CATIA V5, the Challenge was to develop translators for importing 3D data from DXF & DWG formats (in AutoCAD) to CATIA V5. Integration gives solution as Development of a set of libraries to extract data from DXF and DWG format and / create data in CATIA V5 (It was an API based development on top of CATIA V5 using CAA architecture). The Functionalities of the solution are:Import of DXF or DWG structured documents into CATIA Product Structures or CATIA Structured Parts. Import of 3D wire frame geometry, including points, curves and surfaces. Import of solids across distinguished formats option to save and unload the parts model to limit memory requirements. Benefits of the integration are collaborative work with Cross Product Interoperability and Streamlined conversion of complex CAD data across platforms.

3.4 CRM and PLM

CRM is a customer-centric business strategy that goes beyond increasing transaction volume Figure [6]. Its objectives are to increase profitability, revenue, and customer satisfaction. To achieve CRM, a company wide set of tools, technologies, and procedures promote the relationship with the customer to increase sales. This approach focuses on the long-term relationship with the customers by providing the customer benefits and values from the customer's point of view rather than based on what the company wants to sell. CRM actually represents an enterprise business strategy that involves focusing knowledge, business processes and organizational structures around customers and prospect for the whole organization. Surrounding this business strategy is an information technology infrastructure consisting of data warehouses, decision engines and integrated middleware for touchpoints/channels in order to better understand customer behaviour and respond in a timely and relevant manner. By having customer requirements integrated into development process enables to link documented requirements to constraints that determine whether a product meets its performance, safety, reliability, maintainability and ergonomics metrics – as well as its manufacturability, program cost and delivery schedules [7].

Figure 6 CRM Processes Integrations and Functions (HP White paper)



Prediction of customer behavior and analysis is important, but only deployment will make this useful. In large organizations, specialties of analysis versus execution are likely to become dispersed -- even more so as the level of sophistication in modeling advances. The interface between operational and analytical CRM relies heavily on good meta data for using and reusing data mining model score code. Also, the ability to evaluate and monitor models in a time efficient and error-free manner will lead to improved targeting. CRM allows optimizing the time spent on developing and maintaining successful relationships and maximizing opportunities. CRM enables to capture, manage and track every interaction with customers and suppliers in one place—putting it in front of the sales and customer service people, right when they need it. It provides multiple hierarchical ways to group and sort issues for fast and effective responses.

The last several years saw its objective is to return to the world of personal marketing. In this one-to-one approach, information about a customer (e.g., previous purchases, needs, and wants) is used to frame offers that are more likely to be accepted. This approach is made possible by advances in information technology. CRM involves all of the corporate functions (marketing, manufacturing, customer services, field sales, and field service) required to contact customers directly or indirectly. The term “touch points” is used in CRM to refer to the many ways in which customers and firms interact. Today, the rapid development of network and communication technologies leads each CRM company to move towards new technologies such as data warehousing, knowledge management, and portals on the web. The IT department uses its extensive infrastructure and resources to integrate CRM databases successfully. When properly integrated, CRM technology can provide an infrastructure that enables operational effectiveness. Organizations can leverage the CRM integration to the enhancement of operational effectiveness. As we can see, by linking front office, customer-facing systems (CRM) with back-office systems (ERP, HRM, SCM), organizations can build an infrastructure that enables streamlined business processes, which in turn will lead to operational effectiveness enhancement. Additionally, the tight integration provides a consistent view of customer and back-office information for –theoretically- anybody who needs it, empowering the decision making across the enterprise.

3.5 PLM and Design

In the early days, as discussed previously, CAD file management was the initiator for the development of tools and applications to address the need to manage digital product design data. PLM and PDM before it have demonstrated bottom line value for companies that deploy and utilize PLM solutions. In response to the requirements of their customers, suppliers continue to expand the scope of their product vision, putting much more emphasis on the concepts of collaboration and management of product definition, rather than on just managing product data. PLM’s origin was the need to manage bills of material (BOM) or recipes, manage complex CAD drawings and consolidate product design information in a centralized repository [12]. To extend that capability, PLM adopted collaborative processes to share design information across the enterprise and with supply chain partners. PLM also added tools to help manage the new product introduction process, including project management to better track project progress through stages and portfolio management, to help target the most profitable products mix available. Maintaining relationships between all geometric elements that define products enables engineering and manufacturing teams to create product and tooling at the same time. Since all of the geometry is intelligently connected, updates on either side of engineering/ manufacturing are immediately reflected in each other's definitions. Strategic sourcing is a PLM-based initiative that ties sourcing process with design, engineering and manufacturing processes. By providing a single point of access that all of the stakeholders in supply chain can use to locate sourcing, product and manufacturing information. It Enhances productivity across the entire sourcing process , improves RFI, RFQ and RFP response time while simultaneously ensuring a high level of accuracy and facilitates early supply chain involvement in the sourcing process that helps drive out program cost. Integrating sourcing with other product lifecycle processes provides sourcing teams with immediate access to comprehensive information about products, cost, previous sourcing responses and bid packages. This will significantly improve the ability to deliver accurate responses to all. Real-time collaboration assess the design and manufacturing capabilities of widely distributed subcontractors, distributes a proposed BOM to multiple partners, captures partner-generated design input regardless of the partner's authoring system incorporates partner input into a fully costed BOM that addresses all customer's requirements. Developing the best product for a customer requires an experienced team that can evaluate earlier programs, examine proven designs and create new ideas while making certain to consider the real-world manufacturability of each of these possibilities. Knowledge-driven design and manufacturing is a PLM-enabled initiative that allows you to capture the collective knowledge that people have created and acquired across company's entire history – and incorporate these intellectual assets into new programs for current customer base. Knowledge driven design and manufacturing enables to re-use the knowledge gleaned.

Table 1 Design Case-studies

	Challenge	Solution	Benefits
Routing solution for Pipes, tubes and electrical routes.(Figure.7) for a CAD company	The key challenge was to offer easy to use routing solution to include pipe, tubes and electrical routes in product design. The solution should use the 3D mechanical design environment of the CAD system	Develop a generic Routing solution that brings piping, tubing and electrical harness development under one roof. Support intuitive creation and modification of routed systems	3D parametric modeling of piping, tubing, electrical cable and harness systems. Auto routing to tube, electrical cable and harness segments. Faster time to market. Complete and better design with improved BOM accuracy
3Dimensional Parametric Modeler on SQL database (Figure. 8) for a tool developer industry	Develop a 3D structure modeling system on top of a MCAD system with SQL as back end server	Links CAD Data directly with a database and shares with inline or downstream applications. Collaboration function facilitates import and export from DXF,IGES,STL,STEP. Auto CAD import and export function with free viewer and markup tools. Helps is engineering analysis, customization of product libraries	Cost effective solution with a reduced time to market. Geometric provided expertise in solidworks and software development together to develop a civil engineering application on top of MCAD

Product Enhancement (Figure. 9) for a PLM & ILM Professional Services Company	Enhancements of the quality assurance application	New checks written on the application using the CATIA V5 CAA architecture, Suggested new geometry intensive checks, developed specifications & implemented them. Kernel based development of over 125 checks in 18 Work Packages. Migrated the application from CATIA V5 R11 to R12 & R13 4. Extended the product development for Inventor R95. Worked through Specifications, Design, Development, Unit testing, Integration of complete application	Improve quality and design productivity by reducing time wasted on repetitive tasks. Eliminate inaccurate designs by automating compliance with defined standards. Reduce engineering change orders by significantly reducing design errors
New Product Development for the Apparel Industry (Figure. 10) for embroidery design on apparel and garments	To develop a software product to help design apparels with best embroidery and design layouts	Offshore development for the complete apparel design software. Complete QA responsibilities. 2-tier architecture based on Microsoft technologies. Development in C# 2.0. Solution designed around an existing database structure. Integration with Adobe SVG Viewer for strong XML driven graphics. Workflows built to allow users to create, approve, apply designs and push to production for scheduling. Working on the road map to develop a production scheduler application to take designs from the designer application to manufacturing	Extended our design solution capabilities to the apparel industry. Brought in product architecting expertise to leverage the client's existing business expertise. Futurizied the solution to enable integration in the customer's planned suite of products

Source [GSSL]

Figure 7-10 Design Case-studies

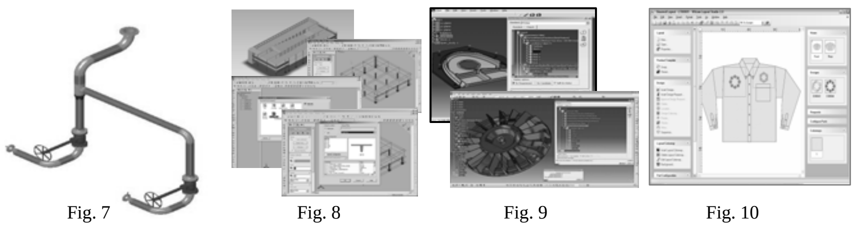


Fig. 7 Fig. 8 Fig. 9 Fig. 10

4 Conclusion

ERP, CRM, PDM, SCM, and design concepts all now integrated within the PLM industry, resulting in a continually growing market for PLM technologies, products, services and more importantly, solutions. While the need for services required to tailor or customize the base products has been reduced, other implementation services (e.g., integration with other business systems, and cultural change and business process engineering consulting) associated with deployment of new capabilities and working paradigms has increased the scope and effectiveness of PLM deployments. By having all product lifecycle information integrated in a single PLM system, product teams are able to understand – and manage – the relationships between all of the requirements, components, products, manufacturing processes and service knowledge that use to support programs. This single source of knowledge provides with a complete picture as to how this information is interrelated, as well as how this information collectively defines the products. These foundations is essential to a commonisation and re-use initiative because it provides the visibility needed for making decisions about re-using specific components in a new program. Interoperable design enables to select, modify or design a component to meet multiple requirements and conditions regardless of the component's originating CAD system. Interoperable design directly facilitates re-use by allowing, to employ existing designs in new assemblies without having to re-author these designs.

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Product lifecycle management opportunities in small medium enterprises

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Abstract: It is widely accepted that PLM represents a competitive edge for manufacturing enterprises. Time-to-market reduction and increased reactivity to market's demand are PLM most known fall-outs. A local survey on PLM penetration in SME demonstrates a substantial lack of interest of SME management regarding PLM opportunities.
Authors deal with the problem analysing reasons and solutions, thus highlighting the need of a simple tool to determine and clarify PLM advantages in the enterprise context. The first step towards the development of such a tool is the enterprise model proposed in the paper.

Keyword: Product Lifecycle Management, Unified Modeling Language, Small and Medium Enterprises

1 The challenge

Today, companies in the aerospace and automotive industry are facing several business challenges: the integration of people, technologies and processes following a company merge; the development of very large product projects that requires heavy resources and a clear organization; a tighter integration between customers, partners and suppliers which requires a simple way to exchange data; and, more than ever, the need to improve operational efficiency while reducing costs.

In particular, it is necessary to:

- ensure the satisfaction of the **Voice Of the Customer** with a clear and shared approach able to support the requirement management phase (definition, validation and control);

- support each phase of the Product Development Process, focusing on feasible solutions able to support the realization of **Product Deliverables**;
- mitigate project development risks improving team collaboration and providing common targets to all the participants involved in the project.

Small Medium Enterprises are tightly integrated in this scenario: they are very well aware of the pressure OEM puts on them, the need to react rapidly, the effort they have to make to achieve innovation in order to capture market attention and remain competitive.

2 How SME tackle the challenge: innovation and PLM

Small Medium Enterprises (SME) are trying to answer in different ways to this challenge, introducing product innovation and anticipating market needs. Some SME are focusing their efforts to reduce product and organization costs moving, for example, the production line in the Far East.

Operational improvements vary according to companies, but manufacturers report that the introduction of **product innovation** leads to significant improvements in the following company key performance metrics:

Table 1 Improved KPI

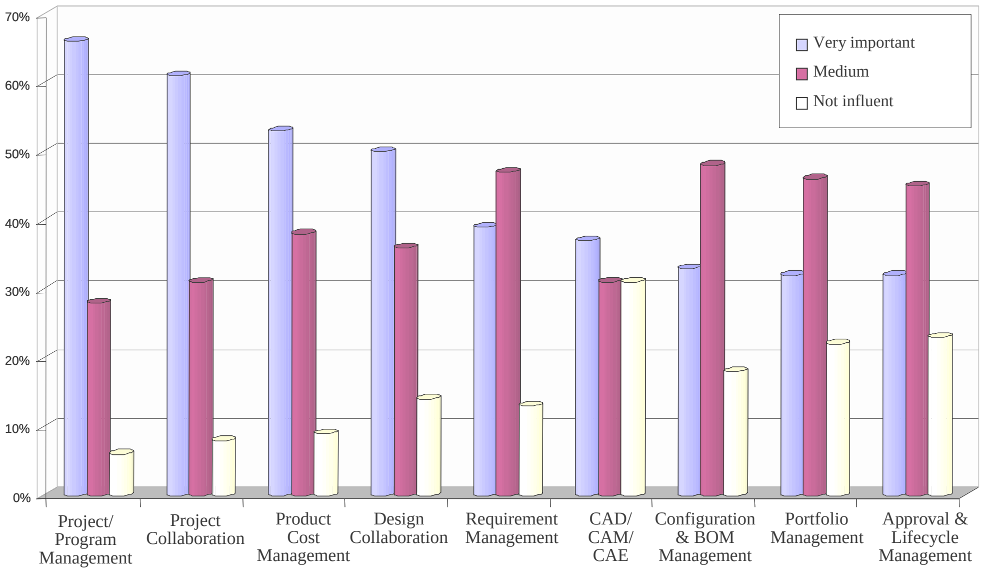
Company Key Performance Indicators improved by Product Innovation introduction	
Time to market	Number of new patents
New product success rate	Percent parts reuse
Percent of revenue from new products	Time to volume production
Process cost reduction	Engineering change cycle time
Total material cost reduction	Warranty claim rate
Number of new products per year	Frequency of regulatory or non-compliance events
Defect rates	Engineering change error rate
Lead time for custom orders	Number of physical prototypes required
Frequency of engineering changes	

A recent survey reports that SME (1) understand the need to introduce tools to foster the product innovation. Information technology tools, like project collaboration environment, collaborative design systems, project management and product data management systems are the right solution to encourage and facilitate the SME capabilities in introducing innovation.

Innovation tools help companies to create a lean organization and are very useful to introduce concepts like: community, cooperation, knowledge and communication. They also support and guide the implementation of these concepts. The graph in Figure 1 shows the importance of the introduction and implementation of innovation tools in SME to achieve this goal.

Unfortunately only 13% of the SME do manage product data with a centralized system. Only 50% of them use information sharing tools and some sort of information systems to automate the company processes. Still, the major tools used in SME are Microsoft Project, Microsoft Office and "ad hoc" systems or information systems developed "in house" (with an expensive cost of ownership effect). Even though all companies agrees on the advantages they would obtain using a product data management system, the PDM and PLM (product lifecycle management) systems have a very small diffusion.

Figure 1 Innovation tools for SME – what SME think about tools



An other way to enhance SME capabilities and gain tangible benefits is to work on the product development process and the other processes related to the product. The following table shows that SME achieve more tangible benefits than OEM improving product related processes.

Table 2 Tangible benefits

Tangible benefits improving processes related to the product	OEM	SME
Increase revenues	19%	19%
Product cost reduction	15%	17%
Product development cost reduction	16%	16%

Product lifecycle management systems help companies to improve, change, manage and control product development process. The SME have more chance to deploy and disseminate in short time a PLM system inside the company. It is easier to introduce changes and new way of working in a SME than in bigger companies, where processes are more static and deeply connected to the organization that, often, is agile like an elephant.

3 A survey of SME positioning in the Italian market

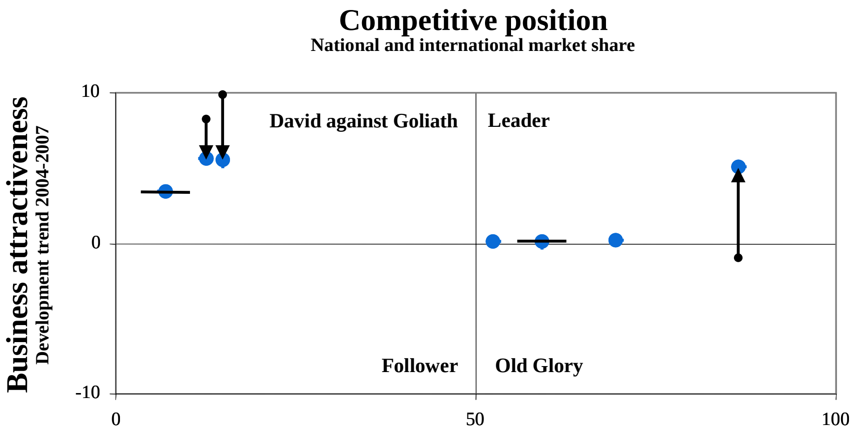
Analyzing the results of the recent survey on the state of the art, the best practice and the positioning of SME in the product development arena (2), we found that SME in Italy (survey was concentrated on the **best SME in the North-West**, 2006) have a good innovation capability as far as the product development process is concerned.

The SME performances have a good positioning, even though there is still a lot of work that can be done to improve their ability to execute. Comparing to the Italian and European average we found in previous survey, they are close to the top of the ranking.

In our analysis it has not been possible to identify a "best in class" on the product development process but some of the SME interviewed cover a specific area where they build up the excellence. Areas of excellence are different for each company: R&D department, production & logistics, organization and team building, cost control, and so on. Information technology is diffused but only for traditional systems like: basic infrastructure (network, hardware and operating systems), ERP, CAD 2D (and sometimes 3D). But companies pay very low attention to process automation and PLM systems.

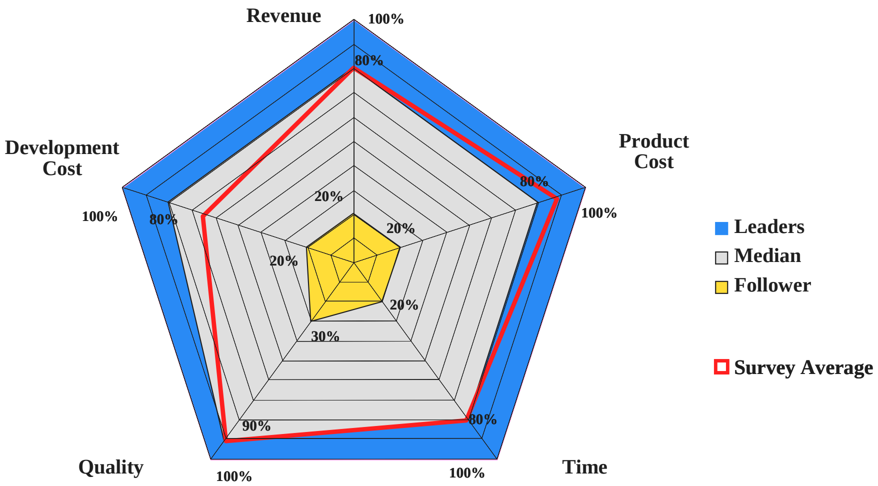
The following charts show SME strategic positioning and the average product innovation process capability.

Figure 2 SME Strategic positioning



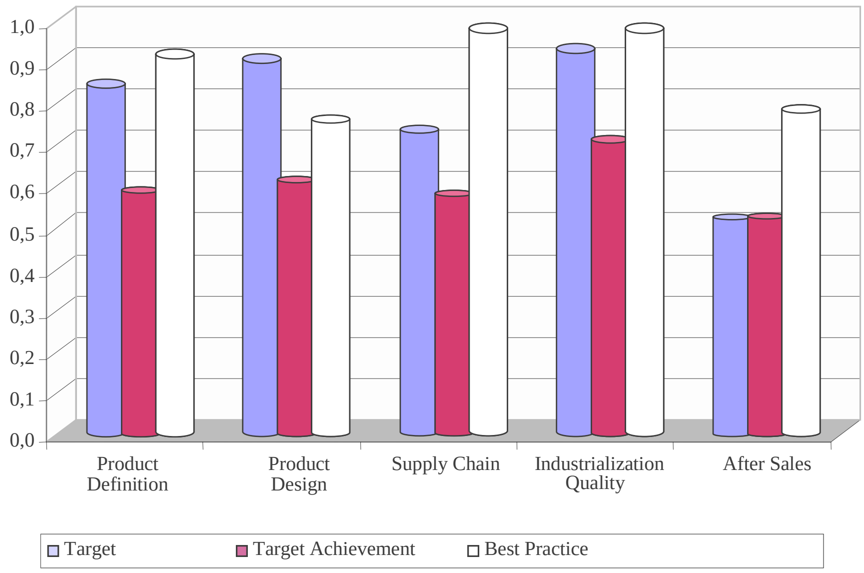
This chart is made using the methodology introduced by the School of Management (3) where the strategic positioning is calculated upon two different variables: the business attractiveness and the competitive positioning. SME which are in the "Leader" quadrant have a very good market positioning due to the great attractiveness of their products. The market share is still growing and the SME in this quadrant are leaders, or they are very close to be the leaders, and there are a small number of potential competitors. SME which are in the "David against Goliath" quadrant have an attractive product, but they have to struggle every day with big competitors, some time against big multinational companies. In the "Old Glory" quadrant there often are SME which have inherited old leadership and good products that were very attractive in the past. Now their business is stable or it has a negative trend. In the last quadrant there are companies with decreasing market share (loss of leadership) or companies with products which have lost their attraction (due to a market contraction).

Figure 3 Product innovation process capability



The chart in Figure 3 shows the SME product innovation process capability, showing the target achievements on revenue, cost, quality and time. Our survey data are compared with international data (1). Both the "Strategic Positioning" and the "Product innovation process capability" show that SME which have contributed to the survey have a good position. During the survey we tried also to assess the company performances on the product development process and compare them with the company targets.

Figure 4 Performance on product development process



The chart in Figure 4 shows that companies interviewed need to improve their performance in the product definition and product design areas, in the supply chain and industrialization / quality units. The after sales area seems less important than others.

In the same chart we reported also the "best practices" identified during the survey. The "best practices" come from different companies but, even though the practices are a good examples of success, in the product design area there is still a lot of work to do, probably because improving the product design phase is not as simple as expected.

4 SME strategies to improve innovation on product development process

"There is no strategy until companies start to spend money", up to now some SME have invested money to achieve better quality in order to remain competitive in the market, others have increased the relationships with universities and academies to amplify the engineering knowledge of specific technologies. Strategies vary by company size and industrial sector, but the survey reports that only 23% of SME pay attention or start activities to manage their actual product portfolio (something more than a simple project selection) to increase revenues and profits, or invest resources and money to find new services and new markets.

New service development is fundamental to achieve company goals and gain more profits. But increased profits can only come from two sources: reduced costs or increased revenues. The cost cutting has already occurred in most companies, and the opportunity to squeeze extra profits from further cost reduction is very small; companies have to operate in a mature market where the revenue growth is limited and it is deeply tied to the companies ability to expand their market. The question is: how? The answer is: developing new products or services designed to increase market share or to attack new markets.

Table 3 SME strategies

Strategies	Percent of occurrence
Improve quality	58%
Increase collaboration with universities	53%
Propose product directly to the final customer (eliminate expensive jump in the value chain)	48%
Acquisition (i.e.: production line in Far East)	37%
Lean Manufacturing	25%
Find new markets and new kind of services	23%
Make only products able to increase revenue	23%

Today, the keyword is not "cost reduction" but "right investment". The survey shows that PLM is one of the most important area of investment to promote innovation and improve company processes, but it is not easy, nor fun, to introduce a new PLM system in a company.

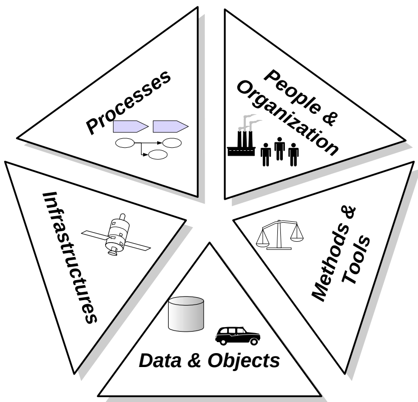
5 PLM in SME: elements to control

It is possible to simplify the Product Development Management System (PDMS) scenario conceiving a conceptual model composed of five elements (see **Figure 5**) : processes, people and organization, infrastructures, methodology and data. The realization and introduction of PDMS impacts on these five elements in different ways and in different moments. During the project each factor must be controlled, and excellence is achieved if all the elements meet their targets.

The **process** usually undergoes continuous improvement, with the difficult target to satisfy company business drivers (cost reduction, better quality, market share extension, …), in a more and more competitive scenario. PDMS objectives must be coherent with the company business strategies, but this is not the main difficulty. The critical factor is the introduction of a system able to support users in the new way of working in accordance with the Business Process Re-engineering.

Company **organization** is often a multi-site, multi-cultural and multidisciplinary environment with an important participation of suppliers and partners. It’s important to follow a “step by step” approach to provide system components which are self-consistent and focalized to support specific geographic locations or specific functionalities by providing a smooth introduction of functional blocks in time, and gradually introducing the new way of working.

Figure 5 Five elements to control



The **infrastructure** (information technology and applications) elements, where innovation and new technologies must coexist with legacy systems and architectural constrains, often require extra effort due to the complexity of integrating PDMS with CAD and PDMS with ERP. Standard integration (out of the box) never meets users’ needs without extra implementation. Logical and physical IT architecture must be planned and designed in order to support the migration plan. New PDM software requires a new way of integration into the existing IT environment. The question is: which processes link the different applications together? The answers are determined by the complexity of the interfaces between the applications. In particular, the PDM – ERP interface is the main interface the whole company is relying on.

Methodology, tools, norms and standards drive the use of specific technologies and applications (CAD, CAT, CAE) in the company, increasing the complexity of the information technology element. Other standard company methodologies, like Six Sigma or the use of military standards, increase the application complexity.

The **data** element objectives are persistence and standard representation. An inadequate compliance with International Standards (i.e. : STEP APs, PDM Schema, PDM Enablers,…) limits the opportunity to integrate and connect the PDMS with heterogeneous systems in order to improve the interface with partners and suppliers. An other aspect is the need to manage business objects, like prototypes, during the product development process. In this case the skill is to manage a particular view of product data together with other technical information. In other words, the capability of managing new types of data aggregation and its standard representation in time.

6 PLM in SME: tools and models

The good results highlighted in the recent survey on SME do not prove that PLM is a solved problem. The biased sampled set (the survey involved voluntary SME), and a careful analysis of collected data (investments, organization, informatics, …) demonstrate that SME need knowledge, technology and support to exploit the potentiality of PLM. According to such scenario, several tasks can be accomplished by academics and professionals to foster PLM in SME.

The most important requisite in the PLM framework is a clear comprehension of enterprise's processes. This fact isn't obvious in SME, where the lean organization reacts to external changes by varying roles, tasks and responsibilities of its personnel.

Business process reengineering is therefore the first fundamental supporting activity. It provides a description of functions, processes and responsibilities which have to be accepted by management and operating people. A simple and efficient method to perform a BPR analysis is the adoption of a data-driven approach: the mere collection of the documents flowing in the enterprise, together with their attributes (sender, receiver, subject, …) and material supports (paper, EDI, …) takes an accurate and exhaustive picture of enterprise. An appropriate reorganization of collected data reveals the company structure, the main processes, the relevant documents and possible gaps in the information flow.

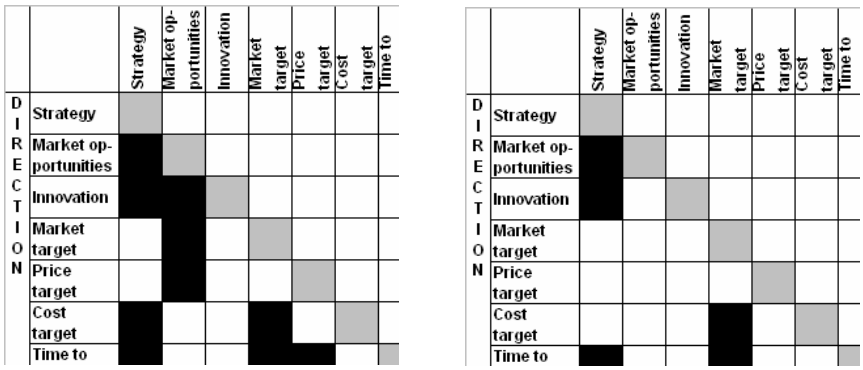
A previous work (4) demonstrates that the investigation on enterprise documents can be used to evaluate the company's performances. A database, composed of simple squared matrices, is created by means of questionnaires filled by employers. The documents are listed in the first row and in the first column of a Data Life-cycle Simulation Matrix (DLSM - Figure 6 left) and are classified according to the company function which is responsible of the document. In the DLSM a filled cell indicates that the document in the row is necessary to create the document in the column, while an empty cell indicates the absence of relationship between the documents.

Analyzing the DLSM with simple functions, commonly available in any spreadsheet tool, it is possible to evaluate the relevance of the documents (thus addressing the need of formalization), the existence of loops (corresponding to concurrent engineering processes), the workflow model (to control product information), and the lack of coordination among company functions.

Similarly, a Data Interchange Simulation Matrix (DISM – Figure 6 right) indicates the role of informatics in supporting the communication within the enterprise. A filled cell in the DISM indicates that the interrelated documents use the same supporting media.

Analyzing the DISM it is possible to identify the mismatching between company functions interfaces. Moreover, focusing on specific media, for example the computer based media, the distance between DISM and DLSM indicates the need of investments in IT sector.

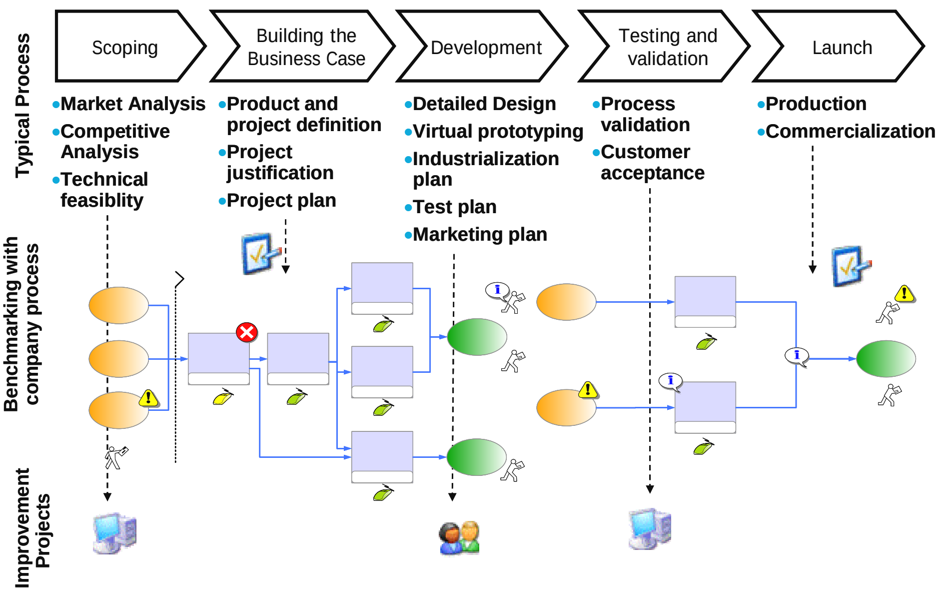
Figure 6 Partial view of the DLSM (left) and DISM (right) matrices



On the basis of DLSM ad DISM it is possible to compare the enterprise performance against the best practices available, for example, in organizational or informational fields. Such information obviously suggests the direction and the amount of future investments in the enterprise structure.

Unfortunately the analysis based on documents and related matrices, only allows a comparison between different situations thus working on a relative scale whilst an absolute scale is desirable to get a more reliable control on enterprise evolution.

Figure 7 Benchmarking



An absolute indicator of enterprise performance can be generated by means of theoretical models, thus suggesting the construction of the conceptual model of SME, to be used as benchmark and illustrated in Figure 7.

The benchmarking model has to satisfy different requirements: uniqueness, completeness and conciseness of enterprise description, generality and understandability of enterprise models. The most appreciable modeling language seems to be SysML, a domain-specific modeling language for systems engineering applications, supporting the specification, analysis, design, verification and validation of a broad range of systems.

By means of SysML it is possible to create several models of the enterprise processes, easily translated in software programs to create a virtual SME where it is possible to simulate and evaluate the enterprise performance. It is noteworthy that the virtual SME plays a fundamental role in communication and training of enterprise people. According to the authors' hope, the didactic role of the model should be as relevant as its benchmarking role of the derived programs.

7 Conclusions

The paper deals with the most important issues in contemporary enterprises: the survival in the global market and the innovation in product development process (probably the most promising solution for surviving). According to international analyses the adoption of holistic PLM approach is the first action to improve SME performances and the recent survey (2), concentrated on a pool of volunteer Italian enterprises, demonstrates their capacity in applying PLM solutions. In spite of the good results of the survey, the authors' experience suggests that Italian SME difficultly control the whole product lifecycle and rarely manage all the elements involved in PLM. In order to provide a soft approach to introduce a new PLM systems in a company, authors suggested a data driven procedure consisting of simple analysis tools applied on a plain collection of enterprises data. An experimental application of the proposed procedure proved its ability in catching the product information flow, but also highlighted the need of a formal model of enterprise processes to gain more knowledge and reliability for PLM Solutions.

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Stakeholders' influence and internal championing of product stewardship in the Italian food packaging industry

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Abstract: Environmental management is becoming a top issue on managers' agendas in several industries. The adoption and implementation of a sound "green" strategy involves following product stewardship practices. Product stewardship is the idea that manufacturers, rather than consumers, governments, or waste companies, ought to take responsibility for the recycling and disposal of their products at the end of their life cycle. This article is aimed at investigating the relationships between the adoption of product stewardship practices and the involvement of different actors in the decision-making process. By means of discriminant analysis, 120 firms have been classified into two different environmental profiles. Results indicate that firms that are more committed to product stewardship differ from less-committed firms in the influence exerted by different stakeholders and in the supportive role played by the management at different hierarchical and functional levels. In general, it appears that top management involvement in the decision-making process is a critical condition for the successful championship of product stewardship. In addition, the effective implementation of product stewardship along the product life-cycle stages is correlated to a strong commitment on the part of chief technical officers and development engineers rather than of manufacturing or marketing managers.

Keyword: corporate environmental management, discriminant analysis, food packaging, organizational championship, product-oriented environmental

1 Introduction

In the last decade, environmental management has come to be an important issue facing companies ([20],[15]). This issue affects all levels of a company's operations ([17]). A vast amount of research has been devoted to investigating and classifying the various environmental management approaches from a strategic perspective, discriminating between reactive and proactive environmental practices. For many firms, the shift to proactive environmental management is driven by pressures from governments, customers , and competitors ([23], [3]), that are identified four environmental management approaches (reactive, proactive, strategic, and crisis-preventive) as a function of endogenous and exogenous environmental risks.

A vast portion of the literature has dealt with product stewardship ([14], [15]), that involves taking responsibility for all the environmental impacts of a product ([10]). There is a common opinion among managers who subscribe to the notion of product stewardship, that operations at every step of the value chain will need to be "internalized" in the future ([8]). Product stewardship strategies are considered to entail integrating external environmental pressures, as reflected by stakeholders' perspectives, into product design and development processes ([2], [12]). [7] have emphasized the role of organizational size and slack, the centralization of decision making, the dominance of the boundary-spanning functions within the organization, and decision-maker flexibility for handling dynamic environmental events.

The study presented here focuses on the corporate approaches to product stewardship and their relationships to the contextual and organizational drivers that mostly influence and support the initiation and implementation of product stewardship practices. There are a number of objectives in this study:

(i) it investigates the extent to which product stewardship practices are integrated into corporate strategy and all the product development stages;

(ii) it tests the hypothesis that firms committed to product stewardship differ from less environmentally committed firms in terms of the influence played by different stakeholders ([13]);

(iii) finally, it explores the differences between firms that are more or less committed to product stewardship in terms of the internal "ownership" and leadership taken by different corporate managers;

Several of the key processes in food packaging industry are common to many manufacturing industries: it faces primarily the same legislative initiatives as those faced by manufacturing industries. The packaging industry appeared to have a number of suitable cross-industry benchmarking candidates. Hence, we believe that the results from this study can be applied to other contexts. The study carries out a statistical analysis of the behaviours of 120 firms operating in the food packaging industry, using discriminant analysis to split firms into proactive or reactive organizations, and it investigates the mentioned issues for each group independently.

The work is organized as follows: first, the concept of product stewardship is briefly introduced. Afterwards, the roles of the different stakeholders and management levels in championing and supporting commitment to product stewardship are discussed. Then, an illustration of the research framework and its methodological foundations is provided, and the results are discussed.

2 Product Stewardship

Over the last few years, public institutions, the market, the financial community, and non-governmental associations have explicitly demanded that firms improve their environmental performance ([3], [11]).

The environment literature stresses three critical groups ([13]): (1) regulatory stakeholders, (2) organizational stakeholders, and (3) community stakeholders.

3 Research Framework and Objectives

The food and beverage packaging industry seems to be quite exposed to the pressures made by different types of stakeholders, both internal and external to the firm, and, thus, represents an appropriate arena for the research objectives that are pursued in this study. The research has been carried out via a postal survey. That industry was selected because it is subject to a significant disposal rate and is often the target of reuse legislation. International standards are currently being developed that would restrict green marketing claims, and this specific industry is facing expanded eco-labelling programs, as well as take-back requirements for products and packaging.

4 Methodology

The research project is articulated in two phases: some preliminary field research (in 18 companies selected and to build the framework of a structured research hypothesis) and a questionnaire survey (carried out using selfadministered questionnaires).

4.1 The Sample

The initial sample was made up of 520 firms in Italy. The target population was obtained from listings provided by the Italian Association of Automatic Packing and Packaging Machinery Manufacturers (UCIMA) and from the CIBUS (an international food exhibition held annually in Parma, Italy) database. These firms were sent a questionnaire in September 1997 and the last response was received in January 1998. The response rate was 19.61% (102 valid questionnaires out of 520). These responses were added to the responses provided by the 18 CEOs in the field research to obtain a final sum of 120 "usable" questionnaires. In order to check that, these 120 respondents are representative of the entire target population, a follow-up telephone survey was carried out on 45 nonrespondents.

Within the sample, we find companies large enough to offer a complete range of products on all world markets, along with smaller firms that are able to fill in the smaller niches in the market, but also in a global frame of reference.

5 Measures and Data Analysis

5.1 Product Stewardship Commitment

Insights into the product stewardship practices followed by the firms of this specific study have been gained both through the field research and through the aggregate statistical analysis. The preliminary discussion with the 18 CEOs pointed out that the advantage derived from a sound product stewardship strategy might be achieved through two primary means. The first is by gaining preferred or even exclusive access to limited resources such as raw materials, productive capacity, or customers. This option has been the basis for the product stewardship strategy of many companies.

Table 1 Profile of the firms in the sample

PRODUCT TYPE[a]				
Bins, drums	Paper and plastic containers	Caps and taps, carton boxes, lids	Bags and pouches (in plastic, for aseptic), carton boxes	Tin plate, TFS, aluminum cans, tin plate cans
35	*28*	*18*	53	*29*
SALES (U.S.$ million)				
<3	*4 to 30*	*30 to 99*	*100 to 499*	*> 500*
17	*43*	*37*	*13*	*10*
EMPLOYEES				
<19	*20 to 99*	*100 to 299*	*300 to 999*	*> 1,000*
38	*41*	*30*	*6*	*5*
PERCENTAGE OF *EXPORT*[b]				
0	*1 to 20*	*21 to 50*	*51 to 80*	*>81*
31	*8*	*26*	*24*	*31*

[a] the sum is not equal to 120 because multiple answers were possible

[b] percentage of total sales on foreign markets

The second means for competitive preemption is by gaining a reputation and environmental leadership that enables the company to establish rules, regulations and standards adopted throughout the industry. The barrier is here represented by standards that are tailored to the firm's specific capabilities and consolidated practices. At the aggregate level, the statistical research started with the concept of product stewardship as the integration of environmental activities along product life cycle. This construct was operationalized and measured by asking the respondents to describe the practices they follow in relation to 18 items. The findings of this initial analysis are reported in table 2. What emerges from the analysis is that environmental effort is still poor, even if an encouraging sign is the relatively important efforts reported in the R&D and design stages. What appears particularly weak is the effort directed toward products designed to accommodate future multiple uses. On the other hand, firms seem to think that environmental efforts are justified as long as they do not result in additional costs.

Table 2 Environmental concern in the product life cycle

ACTIVITIES	**Mean Value**[a]
Research and development stage	3.964
Use more recycled materials	4,66
Reduce the amount of raw materials involved	3,93
Choose raw materials that are less harmful to the environment	4,64
Reduce the amount of energy necessary to use the product	2,9
Increase the product's useful life	3,69
Design stage	3.715
Design the product to accommodate multiple future uses	3,21
Design the product to be easy to repair	2,85
Design the product to be easy to disassemble	3,67
Design the product to be easy to recycle	5,13
Manufacturing stage	3,56
Choose suppliers whose operations pollute less	2,62
Eliminate discharge of pollutants	4,12
Minimize waste	4,05
Reduce the amount of energy required for the manufacturing and assembly of the product	3,32
Find outlets for hazardous waste	3,69
Marketing stage	3,265
Publicize the environmental aspects of the product	2,72
Inform customers of the environmental aspects of the product	3,81
Recycling stage	3,79
Establish recycling procedures	4,1
Ensure that recuperation infrastructure exists	3,48

[a] Based on 7-point Likert scales where *1* = no effort and 7 = considerable effort

To distinguish between proactive and reactive firms, two groups of firms were identified according to their orientation toward product stewardship. The level of product stewardship orientation was measured by an index that was built based on the scores reported in each stage of the life cycle. This index has been computed as the simple algebraic sum of the relative score along each of the 18 activities listed above. The global score ranges from 0 to 126. The median value (76.5) of this aggregate score was considered as the cutoff level for discriminating between firms. The distribution of the scores is reported in figure 2.

The firms in the sample are not homogeneous in terms of the actual level of product stewardship efforts. The distinctive profiles of the two groups of firms are now analyzed. Specifically, differences are established as to the following:

- The benefits derived from product stewardship commitment
- The firm's characteristics that most discriminate between proactive and reactive companies
- The relative importance of stakeholders and managers to the adoption of product stewardship strategies.

6 Results

First, the respondents were asked to rate the relative importance of different benefits resulting from their commitment to product stewardship.

A major outcome is that the more environmentally aware firms seem to derive more beneficial effects from their product related green activities. In firms that are less committed to product stewardship, perceived benefits are weaker with the exception of cost and regulatory benefits. The reduction of environmental liability exposure that is perceived by regulators, may have an impact in terms of providing the company with opportunities for green lobbying and opportunities to join government projects and international scientific committees. Effective communication of environmental friendliness to the customer base may improve their perception of the company's products and operations quality ([22]). Finally, product stewardship may have a beneficial impact on the firm's relationships with its shareholders and other investors ([4], [9]).

Table 3 Benefits of commitment to product stewardship

BENEFITS	*GROUP*	*MEAN*	*Sig. (2-tailed)*
REPUTATION	Less-committed firms	2.64	.000
	More-committed firms	4.36	
ACCESS TO MARKET	Less-committed firms	3.47	.000
	More-committed firms	4.43	
COST	Less-committed firms	3.83	.233
	More-committed firms	3.92	
COMPLIANCE TO REGULATIONS	Less-committed firms	4.07	.340
	More-committed firms	4.00	
EMPLOYEES' MOTIVATION	Less-committed firms	1.76	.000
	More-committed firms	3.18	
COOPERATION BETWEEN EMPLOYEES AND MANAGEMENT	Less-committed firms	2.75	.011
	More-committed firms	2.23	

6.1 Discriminant Analysis

The second set of results concerns the identification of the factors that most discriminate between proactive and reactive firms: discriminant analysis was used to examine these characteristics. It starts with cases in two or more known groups, and then uses a discriminant procedure to identify a linear combination of quantitative predictor variables: the resulting function can be used to classify new cases. Once all the firms are assigned to one of the two groups, the first step is to identify the variables that are thought to have a discriminating power ([16]), shown in table 4. Fisher's linear discriminant functions are used to assign or classify cases into groups: a case is predicted as being a member of the group in which the value of its classification function is largest.

Table 4 Classification function coefficients

	Group		*Structure Matrix*
Variable	*Less committed firms*	*More committed firms*	*Discriminant function*
Number of employees (5)	1.864	0,286	0,852
Sales abroad on total sales (4)	7.379	11.454	0,773
ISO 9000 certification (3)	45.919	38.370	0,581
Type of customer (2)	15.716	16.566	0,249
(Constant)	-65.151	-63.864	

For instance, let us pursue the actual computation of discriminant scores for one of the 120 companies considered in the study. We compute the discriminant scores by taking the original value for a case on each variable and multiplying it by the coefficient for that variable. We then add these products along with the constant term (the adjustment for the means). The discriminant scores are:

DS (group 1) = (1.864 x 5) + (7.379 x 4) + (45.919x1)+(15.716x2)-65.151=35.32;

DS (group 2) = (0.286 x 5) + (11.454 x 4) + (38.370 x 1) + (16.566 x 2) - 63.864 = 38.131.

These results clearly indicate that the considered company belongs to the "More committed firms" group. The classification rate derived from such a multivariate analysis is 95.8% and the discriminant function represents a high degree of retained discriminating characteristics between the two clusters.

The structure matrix reports the pooled correlations between discriminating variables and discriminant functions within the groups. Table 5 provides another way to study the usefulness of each variable in the discriminant function.

This table (that is omitted for brevity) reports the F-statistics and the p values (the "Sig." column in table 5) from a oneway analysis of variance (ANOVA) computed for each variable individually. Wilks' lambda also provides information regarding differences among groups (small values indicate strong group differences). The joint analyses of table 4 and table 5 lead us to the conclusion that the most discriminating features of firms' commitment to product stewardship seem to be, in decreasing order of importance, the level of exported production, the size of the firm, and, finally, the implementation of a total quality program. The type of customer is least important.

The percentage of exported production is the most discriminating characteristic. That may indicate that firms operating in foreign markets must have a higher degree of environmental awareness because they have to comply with compulsory environmental standards that are a prerequisite for trading. The second most discriminating characteristic is the existence of a total quality program.

6.2 Stakeholders' Influence

Stakeholders can directly impact a firm's bottom line if they choose to exert their influence: the first step was to control for differences in respondents' profiles. Our data set included different sources of respondents within the organizations in the sample. To control them, we included dummy variables in our analysis, that identified the following respondents' groupings. The results of this analysis indicate that no significant differences can be ascribed to the typology of respondents. The mean value of the perceived influence exerted by each stakeholder's profile was computed. We used Levene's test for equality of variances and the t-test for equality of means to review the differences among the groups. We conducted this analysis to see if the means were ordered under the two commitment profiles. The results are reported in table 6.

These findings indicate that the driving forces behind proactive product stewardship practices are related to increased competitive pressure and fulfillment of customers' expectations. Proactive firms placed importance on community stakeholders ([5]).

Table 6 Stakeholders' influence

	TOTAL SAMPLE	*LESS-COMMITTED*	*MORE COMMITTED FIRMS*	*F (Levene's test)*	*Sig. (p-value)*	*t (t-test)*	*Sig. (2-tailed)*
Suppliers	*2.95*	*2.34*	*3.54*	*5.651*	*.019*	*-13.426*	*.000*
Shareholders	*2.92*	*2.34*	*3.48*	*6.447*	*.012*	*-12.679*	*.000*
Employees	*2.58*	*1.59*	*3.54*	*2.576*	*.111*	*-19.479*	*.000*
Customers	*4.11*	*3.02*	*5.16*	*66.065*	*.000*	*-23.578*	*.000*
Competitors	*4.07*	*3.05*	*5.05*	*466.273*	*.000*	*-14.039*	*.000*
Government	*4.12*	*3.07*	*5.13*	*221.309*	*.000*	*-10.423*	*.000*
Trade	*3.46*	*3.05*	*3.85*	*6.736*	*.011*	*-11.733*	*.000*
Informal	*2.80*	*1.71*	*3.85*	*112.313*	*.000*	*-17.366*	*.000*
Community	*3.25*	*1.86*	*4.59*	*2.432*	*.122*	*-15.209*	*.000*
Environmental organizations	*2.58*	*1.68*	*3.46*	*101.195*	*.000*	*-12.846*	*.000*
Other lobby	*2.32*	*1.61*	*2.90*	*334.727*	*.000*	*-11.689*	*.000*

6.3 Organizational Championship and Leadership

Table 7 reports the mean values of the scores that respondents have given to the perceived importance of the championship role played by different corporate managers. In less-committed firms, influences are all extremely weak. Production and operations management, otherwise, seems to act as the primary source of the decision-making process. This fact is explained by the cost-cutting nature of environmental activities in such firms.

Table 7 Championship role for proactive and reactive firms

	TOTAL SAMPLE	*LESS COMMITTED FIRMS*	*MORE-COMMITTED FIRMS*	*F (Levene's test)*	*Sig. (p-value)*	*t (t-test)*	*Sig. (2-tailed)*
Top management	4.58	3.68	5.44	1.768	.186	-7.35	.000
R&D managers and/or chief technical officers	3.65	2.73	4.54	.347	.157	-11.31	.000
Production and operations managers	3.00	2.12	3.85	412.127	.000	-12.71	.000
Marketing managers	3.42	2.97	3.85	16.170	.000	-5.47	.000
Shareholders	2.92	2.58	3.25	17.202	**.000**	**-5.33**	**.000**

Research and development directors play an important role because environmental effort is felt to be the base for long-term success, and also because they are assigned, the important function of monitoring the state of the art of technology and regulation. What emerges also is that a key condition for success is to have an R&D director who is not only an effective manager, but also a strategic leader of product-development activities.

Table 8 shows how the leadership of managers at different functional and hierarchical levels is perceived as important in implementing, fostering, and supporting product stewardship initiatives.

This analysis seems to confirm that strong and sound support from top management is required for a program to be actually implemented. Our cluster profiles show that proactive firms, relative to firms with other profiles, appear to have senior management willing to use management systems and/or policies to encourage a corporate environmental ethic through their communications and their environmental practices.

Table 8 Organizational commitment and leadership for proactive and reactive firms

	TOTAL SAMPLE	*LESS-COMMITTED FIRMS*	*MORE COMMITTED FIRMS*	*F*	*Sig.*	*t*	*Sig. (2-tailed)*
Top management	3.97	3.29	4.62	.186	.667	-7.697	.000
R&D managers and/ or chief technical officers	3.96	2.63	5.25	14.766	.000	-14.780	.000
Production and	3.00	2.12	3.85	412.127	.000	-12.711	.000
Marketing managers	3.42	2.97	3.85	16.170	.000	-15.479	.000
Shareholders	2.68	2.58	2.77	2.702	.103	-2.005	.047

A strong discriminating factor between proactive and reactive firms seems to be the dominant role and leadership of R&D directors as opposed to marketing and manufacturing management ([18], [6]). Among the leading edge companies, R&D organizations seek out innovation opportunities in environmentally friendly products, processes, and services and in generating promising project ideas. The necessary organizational competencies and skills are acquired only as a result of appropriate learning mechanisms. In order for involvement to be pervasive, every organizational group has to be committed to learning and be able to follow clear directions and guidelines from top management.

7 Conclusions

One of the major concerns of this article has been to depict organizational profiles of the firms that are more committed to product stewardship. The joint analysis and a successive postal survey have clearly pointed out that a crucial condition for achieving and implementing successful product stewardship practices is a strong strategic alignment between the R&D director (or the chief technical officer) and the company's executive management team. Choosing to be satisfied with an administrative approach to environmental management, impedes the organization to move much beyond the reactive stage. If they decide to promote environmental initiatives, however, the R&D organization will probably find more active ways of pursuing product stewardship.

A second relevant result of this study is that an active product stewardship strategy tends to be established in firms that operate internationally and with internal quality programs. This fact may be explained by the similarities existing between quality management systems (QMS) and environmental management systems (EMS). According to the study of [1], organizations that have developed a quality management system should benefit from this experience when developing EMS because of the many similarities between the two systems.

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PLM in the strategic business management: a product and system co-evolution approach

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Abstract: The design system can be seen as the environment where design projects (product or system design) take place. The aim of this paper is to optimise the synchronisation and the coordination of the development of several design projects in the design system with limited resources and therefore satisfy the strategic performance objectives of the enterprise. With this intention, this paper deals with the role of the PLM in the system evolution management. In a first time, we analyse the PLM concept and we define the impact of the product along the system lifecycle. Then we identify the relations between the product and system co-evolution and the continual improvement process of an enterprise. We focus on the different natures of the product regarding to the decisional level during the strategic business management. Lastly, we present a prototype of software that integrates the PLM concepts and manages design system evolution.

Keyword: Strategic business management, product and system co-evolution, prototype of software

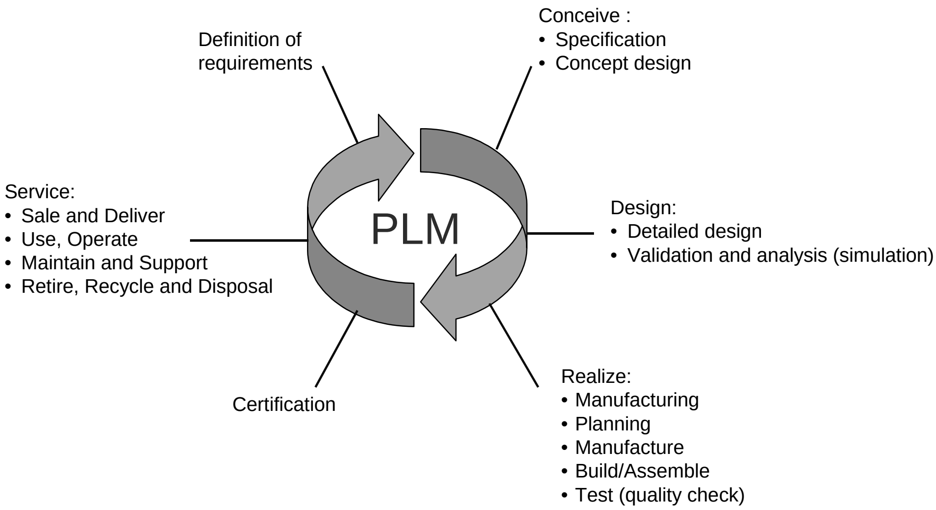
1 Introduction

PLM (Product Lifecycle Management) consists in a strategic approach of information management related to the product, from its definition to the phases of manufacture and recycling. Because PLM systems grew out of product design software, company management tends to delegate the PLM concept to engineering executives, who traditionally have managed their own technology rollouts (1). Firstly, we analyse the PLM concept in order to understand how such a concept allows contributing to the decision-making throughout the product lifecycle, whatever the decisional level of this decision. In a second part, we show how PLM can have a significant role in the management of the system manufacturing the product. Indeed, in response to the evolutions of its environment and its potential internal dysfunctions, a system evolves thanks to actions on its constitution and/or the products manufactured. Hence competitiveness of the system is dependant on a jointly evolution of the products and the system itself, which are carried out according to requirements of the market. To consider the co-evolution of the product and the system we identified and defined three types of activities at each level of the strategic business management. Finally, we present PEGASE, a prototype of software integrating PLM concepts, developed to control design system evolution and design projects progresses.

2 The Product Lifecycle Management concept

PLM (Product Lifecycle Management) consists in a strategic approach of information management related to the product, from its definition to the phases of manufacture and recycling (Figure 1).

Figure 1 Product Lifecycle Management



The Product Lifecycle Management concept holds the promise of seamlessly integrating all the information produced throughout all phases of a product lifecycle to everyone in an organization at every managerial and technical level, along with key suppliers and customers (1). Such considerations allow making concrete improvements in terms of frequency of products launching, stock management and traceability of information flows. Concrete results are, for example: reduced time to market, improved product quality, reduced prototyping costs, savings through the re-use of original data, framework for product optimisation, reduced waste, savings through the complete integration of engineering workflows, etc. Since the PLM takes into account all the activities of the product lifecycle (product conceive, design, manufacture, exploitation, etc.), it leads to assist all the decision-makers implied in these activities. Obviously, it can be question of strategic decisions (what? which product?), tactical decisions (how?) or more operational decisions (which means?).

3 Product and system co-evolution: the role of the PLM in the strategic business management

A company is a complex system which implements human, technical and methodological competencies in order to improve its performances. Along the system lifecycle, in response to the evolutions of its environment and its possible internal dysfunctions, a system evolves thanks to actions on its constitution and/or on the products manufactured.

3.1 An events management procedure to follow-up system evolution

According to Lemoigne (2), complex system analysis refers to three points of view: a *functional* point of view, i.e. the description of system functionality and behaviour, an *ontological* or *organic* point of view, i.e. the description of resources used (human or technical), materials and information, and related control structures, and a *genetic* point of view, which renders system evolutions and development. Two approaches illustrate systems evolutions and development: the Business Process Reengineering and the continuous improvement (Kaizen).

3.1.1 Business Process Reengineering and continuous improvement

Business process reengineering (BPR) is the analysis and redesign of workflows within and between enterprises. BPR promotes the idea that sometimes, radical redesign and reorganization of an enterprise are necessary to lower costs and increase quality of service and that information technology is the key enabler for that radical change (3). Seven principles of reengineering streamline the work process and thereby achieve significant levels of improvement in quality, time management, and cost:

- organize around outcomes, not tasks;
- identify all the processes in an organization and prioritise them in order of redesign urgency;
- integrate information processing work into the real work that produces the information;
- treat geographically dispersed resources as though they were centralized;
- link parallel activities in the workflow instead of just integrating their results;
- put the decision point where the work is performed, and build control into the process;
- capture information once and at the source.

Kaizen is a Japanese word constructed from two ideographs, the first one representing change and the second one goodness or virtue (4). Kaizen is commonly used to indicate the long-term betterment of something or someone (continuous improvement). Such a method involves, at a minimum, the workers who execute a work process, focuses on improving the performance of that work process, seeks to make incremental improvements, and is intended to be repeated over time. Kaizen is also a focused approach that brings critical resources together and empowers participants to not only root cause and determines solutions to implement the change. Time and effort is spent on the shop floor or wherever the value stream problem exists.

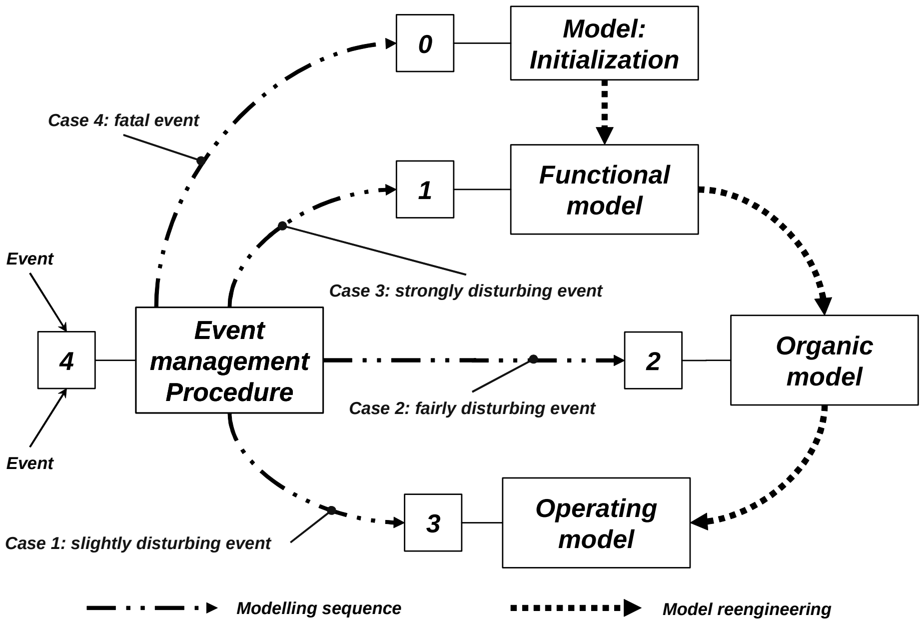
In the following section, we propose to use concepts provided in the two approaches illustrating systems evolutions to develop “an event management procedure” allowing analysing all the events coming from environment of the system (internal or external environment). We show how this procedure allows identifying the different types of system reengineering and we focus on the importance of PLM to manage properly the system evolution.

3.1.2 Events management procedure

To specify systems evolution and development, an analysis of all events coming from system's environment (internal or external environment) liable to trigger the evolution according to enterprise's strategy has to be done. Such events can be planned or unexpected, from external or internal origin, linked to market trends, eruption of new technologies, strategic or capitalistic decisions, etc. An event will be considered as (5):

- Slightly disturbing the current system if it has no impact on its structure. Such an event leads to a operational reengineering (case 1, figure 2);
- Fairly disturbing if it acts upon the organic definition of the system, without modifying its functionality. Such an event leads to an organic reengineering (case 2, figure 2);
- Strongly disturbing if it requires strategic system adjustments impacting its functional characteristics. Such an event leads to a functional reengineering (case 3, figure 2);
- Fatal if it makes the system obsolete and leads to a dismantlement or full reengineering (case 4, figure 2).

Figure 2 System lifecycle modelling and event management procedure [5]



Such a system lifecycle modelling allows identifying the impacts (functional, organic or operational impacts) of the different types of events during the improvement process of a system. Such events can be planned or unexpected, from external or internal origin. For example, a modification on the product constitution could be one of these events. Now, we propose to focus on events concerning the product evolution and we show how it can be preponderant in the strategic management of the system evolution.

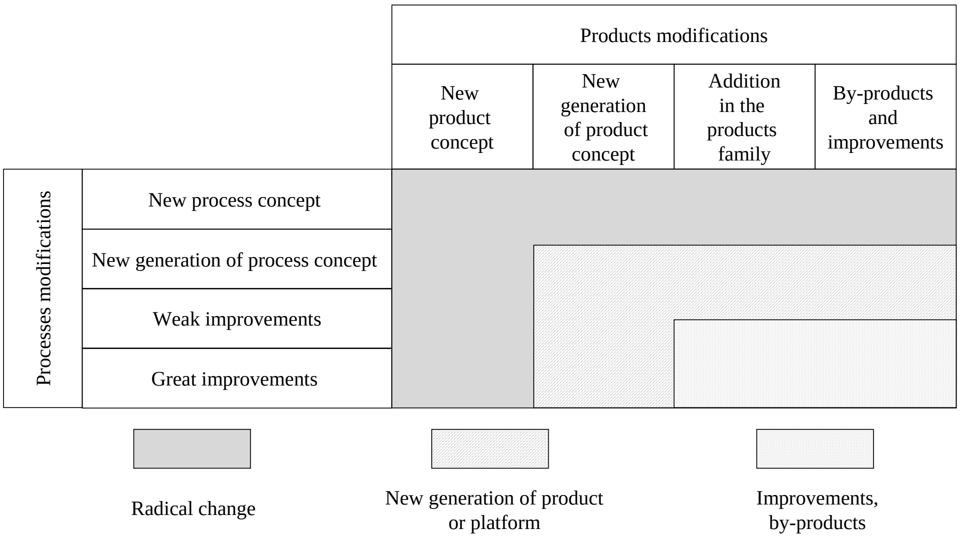
3.2 Value scales of the product

A product can be characterized according to:

- The “service functions”, which are the roles expected of a product or carried out by it, to answer the needs for a given user (6);
- The “technical functions”, which are the relations between the internal components of the product, defined by the designer to ensure the service functions (6);
- The “realization functions”, which are the technological solutions intern with the product and defined by the manufacturer to fulfil the technical functions (7).

The technological variations of these last years and the increasing competition led the companies to modify their design and products development activities. The paradigm of products platforms permits to classify various types of projects of products development (Figure 3). A product platform is a grouping of individual products sharing a common technology. A strategy of products platform allows to reduce the number of pieces and components, the costs relative to the design of buy-products and the investments necessary for new manufacturing processes (8).

Figure 3 Product evolution typologies (9)



Product evolution can be also described by taking into account modifications carried out on the product. This evolution can be classified according to various criteria, according as it is about a modification of an existing product or of a product which is currently in the design process. As product and design process are closely connected, a modification on a product will cause a modification on the design process. Actually, the design process is the set of activities involved to satisfy design objectives in a specific context and these objectives concern product definition. They are constrained by the enterprise organisation (10), by the design phases and are influenced by technologies or human and physical resources (11). Finally, according to the evolution of product in the design process, the design types are different and have specific influences on the system.

3.2.1 Modification of an existing product

When the modification concerns an existing product, it is the calling into question of the functionalities of the product or of its components (following a non–conformity or an improvement of its quality) whereas the production of some specimens already started. In this case, the modification could have only an impact on the succession of activities, which composed the design process, not on the activities themselves. Most of the resolution steps are known (routine design process) and the project is structured according to different activities, which transform the product knowledge. The project manager decomposes the project according to the identified activities and the actors' tasks are very prescriptive. So, the project manager decides on the synchronisation of the human and material resources availability with the activities requirements.

3.2.2 Modification of a product in its design process

When the modification refers to a product which is currently in the design process, it is the calling into question of whole of part of information related to one item (raw material, component, etc.) already validated at various stages of its design. In this case, the modification has an influence on the organisation of the design process but also on the activities of the design process. It's not enough to change design process, it's necessary to identify if new activities have to be created to achieve design objectives. Hence design is not only being considered as a solving problems process but as a creative or innovative design process, and activities don't structure the project. Design must be identifed as a process which support emergence of solutions (9). In this case, the project is organised to favour the collaboration between actors of the process and the project manager searches to create design situations, which facilitate the emergence of solutions. He decides on the adapted organisation to favour collaborative work.

3.3 PLM in the strategic business management

Modifications of an existing product or of a product that is currently designed have different consequences on the strategic business management. At each decisional level, the performance objectives impose to synchronise in time the product and resource availability to perform the activity with the higher level of performance. Thus, there are three basic types of activities: products management, resources management and synchronisation between the product and the resource (planning). These activities have different natures according to the three decisional levels of the strategic business management: the industrial, structural and operational strategies (Table 1). The industrial strategy, the highest level of the lifecycle management, decides on the projects of system and/or product (re)engineering, according to the environmental context. The industrial strategy throws back into question the functional point of view of the enterprise (functional reengineering). The structural strategy consists in implementing the engineering of the design system, and casts doubt over the organic point of view of the enterprise. The design system allows guiding design of new products or redesign of whole or part of the system (organic reengineering). Finally, the operational strategy is in charge of the exploitation of the system (process management and operational reengineering).

Table 1 Nature of the activities at each level of the strategic business management

	Industrial Strategy
Products management	The product management activities are linked with the purpose of the function at the strategic decisional level, which is: to define and make evolve the role of the enterprise in the market. Here, the "product" is therefore this economic role, i.e. the most functional definition of the enterprise.
Resources management	The resource management activities are linked with the human and technical means which make evolve the role of the enterprise: analysts, leaders of the enterprise, external expertises, etc.
Planning	The planning activities realise the synchronisation between the two precedent activities for an adequate industrial strategy of the enterprise. They have to analyse and audit the enterprise (identification of strengths and weaknesses, internal factors) and its environment (identification of opportunities and threats, external factors). Used in a business context, such identifications help the enterprise find a sustainable niche in the market: they uncover opportunities that the enterprise is well placed to take advantage of, and by understanding its weaknesses, it is possible to manage and eliminate threats that would otherwise catch it unawares. It is also the first stage to help managers to focus on key issues and therefore define a new economic role for the enterprise.
	Structural strategy
Products management	The product management activities are linked with the purpose at the structural decisional level, which is: to propose a new structure – organisation, architecture – for the enterprise, then implement it. Here, the "product" is therefore the structure of the whole or part of the enterprise.
Resources management	The resource management activities are linked with the human and technical means which make evolve the reengineering: task forces, tools of project management, etc.
Planning	The planning activities realize the synchronisation between the two precedent activities: a good management allows the structural level to launch reengineering projects taking into account all resources implicated in the projects. Moreover, such activities precise at which phase of the project these resources intervene. Each phase has to be the subject of deliverable, then has to be validated in order to check the conformity of the work carried out with the objective initially envisaged.
	Operational strategy
Products management	The product management activities are linked with the purpose of the function at the operational decisional level, which is: to transform raw materials and components into final products according to objectives, constraints, and criteria (optimisation of some features). We find in product management, the classical functions: to buy, to purchase, to store.
Resources management	The resource management activities are linked with the human and technical means which transform the material flow: operators, machines, tools, etc.
Planning	The planning activities realise the synchronisation between the two precedent activities: a good management allows the operational level to synchronise the available means and the products to be transformed.

By managing each phase of the product lifecycle, the PLM approach helps to decision-makers, at each decisional level, to manage properly the design process but also the system. The definitions of the requirements phase and the early phases of the product lifecycle allow to the industrial strategy to model the system and to plan and optimise the expected evolutions of the system. Concerning the design and realization phases, the PLM helps decision-makers, at a structural decisional level, to create and manage collaborations in the networks of partners. Finally, the PLM permits the exploitation of the system, at the decisional level (operational strategy), by providing information about evolution of the product, the process and the organisation.

According to the PLM concepts, we developed a prototype of software to support design actors during all the product lifecycle. Following section presents this prototype.

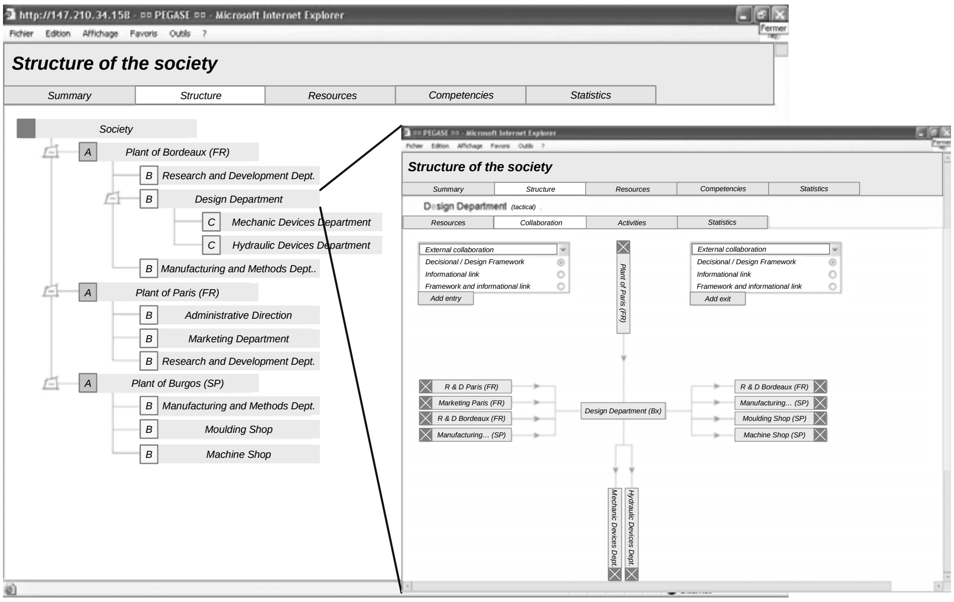
4 Prototype of software to control design projects

According to the PLM concept and the models suggested in the IPPOP project (12) we developed a prototype of software to support actors a design project: PEGASE. The initial objective to which PEGASE must answer is to ensure the connection between the structuring of the organization of the company relating to the design and the control of a design project. The detailed analysis of design processes and of the mechanisms of decision-making throughout the product lifecycle allows identifying elements that have to be managed to control design process (13). Database of PEGASE integrates all these elements. That permits to take into account of the specificity of each activities, at each decisional level of the strategic business management (§3.3). That is to say that each decision-maker and each design actor receive a specific and contexualized set of information to achieive his task according decision-making of the system.

4.1 Structure the decision-making and the project

Within the framework of GRAI R&D approach (14), the modelling of a company makes it possible to formalize its organization (functional decomposition and decisional system) and its technological system (design process). Decision center are identified and their temporal range, their nature and information flows connecting these centers are identified too. The organization is seized within PEGASE and deployed by associating each element of the organization (plant, department, service...) and the corresponding decision centers. Information flows (product data for instance) connecting element of the organisation are specified too (Figure 4). The whole of the resources are also defined: human, material and software. Humans' competencies are managed and are specified according to competencies matrix of the company. Finally, the design process modelled is deployed in the organization by associating each element to sequences of tasks. This process could be the formalization of the quality procedures of the company. When configuration is completed, PEGASE is operational in order to ensure the control of the design. So, the administrator of the system creates and initializes a project by sending the decision frame and associated design frame to the decision centers concerned in the organization.

Figure 4 Functional and decisional structures of the company



4.2 *Structure, plan and follow-up a design project*

When the project is initialized, PEGASE systematically informs the users of the new events which relate to them. So each project manager is informed of his new statute when he is connected. He is able to reach directly the details of the new project and to reach the decision frame that is sent by the upper decisional level. The decision frame enables him to know his context of work: his objectives, his criteria and decision variables, his constraints, his performance indicators and the resources which are allocated to achieve his goals regarding to performance indicators. He creates sub-projects and defines the tasks to be carried out. PEGASE informs each designer affected to specific tasks of their objectives. At the end of their task, designers indicate the value of the design and/or performance indicators that could concern product, process and organization. The project manager is informed of the new values and then could decide to start new activities or to modify some elements of the decision frame.

PEGASE constitutes a specific application of the results from IPPOP project in order to make effective the control of the design projects. The approach suggested is based on an integrated product - process - organization model and on a methodology modelling the design system and structuring, planning and following-up the design projects. Influences of each element of the design context are considered since functional and decisional structures of the design system are identified and external environment is integrated. All the projects of the company could be managed and controlled through the prototype, which provides and capitalizes information on the project and on the resources to follow evolution of the design system. Moreover, the management of the activities only concerns sequential process. The use of workflows technologies such as those existing within the PDM tools should allow a great variety of specification for the managers while providing mechanisms of multilevel synchronization.

5 Conclusion

Competitiveness of a company is dependant on a jointly evolution of products and systems, which are carried out according to requirements of the market. The type of the modification is relative to the environmental context in which the system evolves. We have proposed a characterization of the evolution according to the more or less significant changes that it implies on the system. Then we have focused on the impact of the product on the evolution of the system. We have shown how management of product lifecycle is necessary to control the system evolution and to ensure the achievement of the design process. To synchronize in time the product and resource availability and to perform the activity with the higher level of performance, we have identified and defined three activities at each decisional level of the strategic business management. Finally, we have presented a prototype of software, PEGASE, developed during the IPPOP project and integrating all the concepts provided in the paper.

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Coupling product development and project planning with constraint: a prospective work

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Abstract: This communication is a prospective work trying to gather aiding tools relevant to product development and project planning. For each domain and associated tool, we show how the aiding process can be considered as a constraint satisfaction problem. We then propose to link the two domains in order to permit simultaneously on both problems constraint filtering and optimisation. The paper is organized as follows. After a short introduction, the second section addresses product development, project planning and constraint-based approaches. The presentation of the principle of co-operation is then described. The last section presents two propositions relevant to the cooperation principle between product development and project planning. Several examples illustrate the propositions.

Keyword: Knowledge based system, Project planning, Product development, Constraints satisfaction problem

1 Introduction

In order to allow companies to put on the market competitive products, many scientific works have been achieved on product development and relevant aiding design tool. With the same purpose but in an other domain, some works have also been achieved in project planning and relevant aiding planning tool. For these two domains, significant improvements of quality, cost or efficiency have been provided by aiding tools that rely on knowledge relevant to product development or project planning. But these two domains are most of the time separately studied and as far as we know, see the survey of [1], very few research approaches have tried to gather these two domains in a cooperation framework assembling aiding design tools and aiding planning tools. As on one hand, product development decisions can have strong consequences on project planning, and on the other, project planning decisions can provide hard constraints to product development, it seems necessary to try integrating these two domains.

Therefore, this paper presents some ideas of a prospective work that aims to show how knowledge based assistance tools relevant to product development and project planning can cooperate. We therefore consider the two processes: product development and project planning and we propose to investigate various ways of cooperation. The rest of the paper is organized as follow. In the second section, we will clarify our field of investigations and define: what we mean by product development and project planning, what we mean by knowledge based assistance tools and constraint based assistance tools. The last sub-section will introduce the basic principle of cooperation we intend to study. The third part is concerned by the study of the deployment of the previous cooperation principle. Two situations according to the scope of project planning will be investigated. The first scope considers project planning only at the production or realisation level. The second one considers production and the last steps of product design corresponding with sub-assemblies or component design.

2 Product development and project planning

The purpose of this section is to define and clarify our field of investigation. Product development will be first considered followed by project planning. For each, assistance requirements and aiding tools will be discussed. The last section will introduce cooperation between the two domains.

2.1 Product development

According to [2] and [3] product design can be characterized, with respect to a degree of recurrence, in: creative, innovative and routine design. In order to be able to define aiding tools based on knowledge, we only consider routine design. Furthermore, we assume that the recurrence of the design activity permits us to identify, extract, model and store some product knowledge. This kind of design is very frequent in industry and can be met for example in mechanical engineering (machine tool, crane, …), civil engineering (bridge, buildings…) or automotive industry. It has been shown that product knowledge can be distributed at least in three product views [4]. The first one is a functional or descriptive view that corresponds with the customer need, the product is a set function/sub functions. The second one is a physical view that corresponds in fact with the result of the product design, the product is a set of subassemblies/components. The process view is the last one and describes how the product can be produced, the product is a set of production operations or tasks. We consider that product development is the process gathering the three steps: functional definition, physical definition and production definition as shown in Figure 1. Therefore, the main task of the actor in charge of product development is to define in details the product functions, the product components and the product production process. According with the degree of design recurrence or level of "routine", the share of the available product knowledge between the aiding design system and the actors in charge of product development is as shown in Figure 2.

Figure 1 Product development process

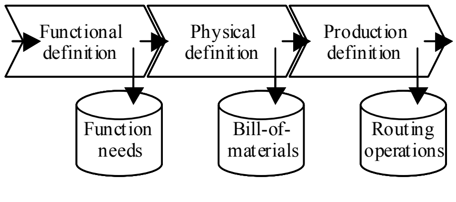
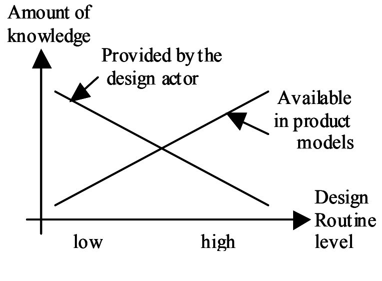


Figure 2 Routine design and knowledge



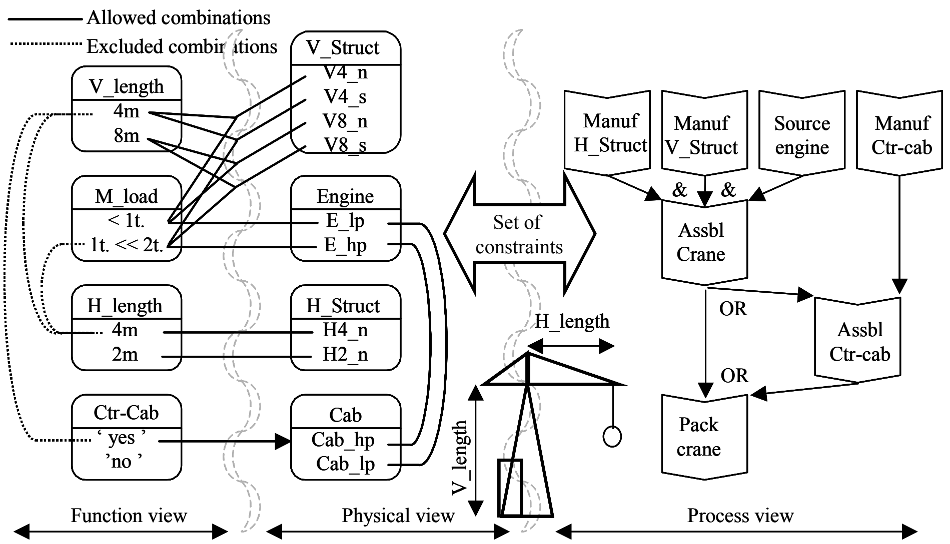
In the case of routine design, many works relevant to the design of: machining operations [5], building and bridges [6], aircraft [7] or heat exchanger [8], have shown that aiding design could be considered as a constraints satisfaction problem (CSP). As the work of [9] has shown how the three previous product model could be described with variables and constraints, we consider the CSP framework for aiding routine design. According to [10], a CSP is as a triplet {X,D,C} where X is a set of variables, D a set of finite domains (one for each variable) and C a set of compatibility constraints (defining the possible or forbidden combinations of variable values). Variable can be either symbolic or numerical and constraints can be either formalized as compatibility tables or mathematical expressions. In product development, the variables represent the product parameters of the three domains (functional, physical and process) and the constraints represent some product knowledge that modulates the combinations of parameter values. Therefore, the corresponding CSP defines or restricts the space of feasible product solutions.

Given the CSP framework, two kinds of assistance can be identified. The first one is interactive and assists the actor at each development decision in order to avoid mistake. Each time the actor inputs a value or a domain restriction on any product parameter, constraint filtering or propagation removes inconsistent values from the domain of definition of the remaining parameters. Therefore the removed values cannot be chosen by the actor and any decision that does not respect the knowledge model cannot be made. This behaviour “value input / constraint filtering” loops until all product parameters are defined. The second assistance corresponds with problem solving. It is of interest when the actor has inputted all his development decisions but leaves some parameters undefined (all decisions have not been made). In this case, CSP optimisation techniques can provide values to undefined parameters while minimizing a criterion.

The example of Figure 3 shows what can be the three views of a very simple product knowledge model corresponding with a configuration or customisation design task. For this customisation situation, the product taken for example is a very simple crane. In its functional or descriptive view (left part of Figure 3), the product can be defined with its height (variable V_length with two possible values 4 and 8 meters), width (variable H_length with two possible values 2 and 4 meters), maximum load (variable M_load with two possible values less than one ton between 1 and 2 tons) and a parameter modulating the existence of a control cabin (variable Ctr-Cab). Three constraints reduce the solution space and exclude combinations of values (doted lines between variable values): a crane can not have same height and width (4 meters), maximum load is not compatible with the larger width and a control cabin can not be present with the lower height. In its physical view (centre part of Figure 3) the knowledge model shows four groups of components: the vertical structure (Variable V_Struct gathering 4 physical components combining different acceptable loads and lengths), the horizontal structure (Variable H_Struct gathering 2 physical components according to its length), the engine (Variable Engine gathering 2 physical components according to its power) and the control cabin (Variable Ctr-Cab gathering 2 physical components according to the engine power). In this physical view, a single constraint associates the possible engine and the control cabin (solid line between variable values). The functional and physical views are linked with constraints that show how the components can fulfil the parameters of the functional view. Three constraints show the following possible combinations (solid lines): (i) the height of the crane (V_length) and the maximum load (M_load) are linked with the vertical structure (V_Struct), (ii) the maximum load (M_load) impacts the engine selection (Engine), and

(iii) the width of the crane (H_length) is associated with the horizontal structure (H_Struct). One activity constraint, with respect to the dynamic extension of CSP [11], is necessary to allow triggering the existence of the variable (Cab) corresponding with the component control cab. It is clearly shown in [9] that a same kind of constraint-based model can be designed for the process view. The process model is a set of generic operations. The generic operations are linked with anteriority constraints. Each generic operation requires at least one resource in a given quantity. Constraints between both functional and physical models and the process model allow to modulate : (i) generic operations and anteriority constraints existence and (ii) resources and quantities of resource used by operations. In order to avoid a heavy model, the right part of Figure 3 just presents the main production operations that are: three manufacturing generic operation (for V_Struct, H_Struct and Cab), one sourcing generic operation (for Engine), two assembly generic operation (for Crane and Ctr-Cab) and a final packing operation. According to the existence of the control cabin and therefore the existence of the assembly operation Ctr-Cab, the routing of the production process changes as shown by the "OR" operator in Figure 3.

Figure 3 Example of the three views of a knowledge model



As a conclusion for this section, we therefore consider that: (i) product knowledge can be distributed in three product views, (ii) each view can be modelled with variables and constraints, (iii) these three views and relevant models are linked by constraints that permit to represent their dependencies and (iv) aiding decision is based on CSP filtering and solving techniques that respectively prevent wrong decision and allow some kinds of optimal decision. For the previous example, if the value '4m' in inputted for variable V_length, filtering will give the value 'no' to variable Ctr-Cab, remove the variable Cab of the physical view and the two operations Manuf Ctr-cab and Assbl Ctr-cab from the process view. This example is however to small and simple in order to illustrate optimisation possibilities.

2.2 Project planning

In this work we just consider the planning aspect of the problem. We therefore assume that we deal with a graph of tasks linked by anteriority constraints. Each task requires at least one resource in a given quantity and is characterized with a duration. In this case, the actor in charge of planning is mainly responsible of choosing the beginning and/or ending dates of each task.

As we deal with routine product design we also consider that the relevant planning part of the project planning is also some kind of a routine job. We therefore consider that some knowledge related to project planning exists, and we assume that this knowledge permits us to establish a knowledge model of what we call a generic graph of tasks. A model of a generic graph defines the planning possibilities of a family of projects. The differences between a graph of tasks and a generic graph of tasks are: (i) the existence and the duration of any task can be modulated, (ii) the anteriority constraints can be associated in "OR" nodes allowing alternative paths, and (iii) the resource and the required quantity of resource can also be modulated. In this case the role of the actor in charge of planning is to define the graph of tasks with respect to a given project (or to instantiate the generic graph of tasks) and to choose beginning and starting dates of each task.

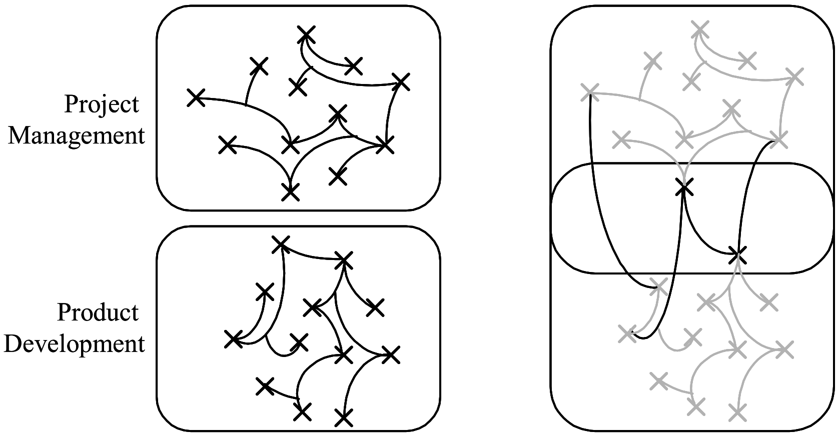
Planning problems or scheduling problems have been investigated for a long time with various constraint based approaches, see for example [12], [13] or [14]. Therefore, as in the previous section, we consider two kinds of assistance. The interactive one assists the actor at each planning decision in order to avoid mistake. Each planning decision, concerning either the definition of the graph or the planning of the tasks, is followed by some constraint filtering that removes inconsistent values from the definition domain of the variables of the model of the generic graph. Therefore the removed values can't be chosen by the actor and any decision that does not respect the knowledge model of the generic graph cannot be made. This behaviour "value input / constraint filtering" loops until the complete definition of the graph and planning of the tasks. When all project planning decisions that interest the actor have been made, leaving some open decisions (all decisions have not been made), the second kind of assistance is optimisation that allows, while minimising some criterion, to complete graph definition and tasks planning.

As a conclusion for this section, we therefore consider that: (i) project knowledge can be gathered in what we call a generic graph of task, (ii) two kinds of decisions exist: graph definition and task planning, (iii) these tow decisions can be considered as a constraint satisfaction problem, and (iv) aiding decision is based on CSP filtering and solving techniques that respectively prevent wrong decision and allow some kinds of optimal decision.

2.3 Principle of cooperation of the two domains.

In the two previous sections, it has been shown that both product development and project planning can be formalized as two constraints satisfaction problems. Given these elements, our cooperation principle is to try to associate this two constraint based problems as show in Figure 4. In this Figure, the X represents the variables and the lines the constraints, in the left part the two problems are clearly separated while in the right part: variables belonging to the two problems have been identified (black X), constraints between variables of the two problems have been modified or added (black lines). Our goals are therefore to be able: (i) to propagate decision consequences of any problem on both problems, (ii) to optimise simultaneously the two problems.

Figure 4 Cooperation principle



Propagating decision from product development to project planning allows to show the consequences of a product development decision (for example, component 'W' has been chosen) on the planning of the project (for example, as the supplier 'W' is overseas project will end two weeks later). In the opposite direction, a project planning decision (for example, terminate the project before 6 months) can reduce product design possibilities (for example, this technical solution can not be used.). In terms of optimisation, the main interest is to allow compromise between the two problems and avoid for example a product with a minimum cost but with an unbearable due date, or on the other side, a very quick delivery cycle of a too expensive product.

3 Two deployments of the cooperation principle.

We will first consider that project planning overlaps only the process definition or realisation level, then the physical definition will be also concerned by overlapping.

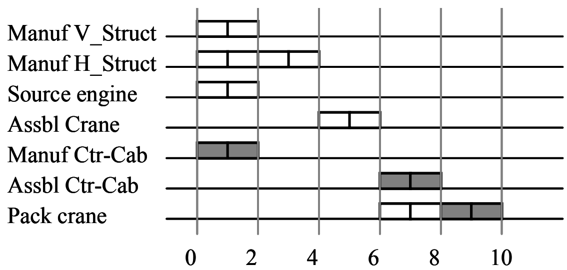
3.1 Overlapping process definition and project planning

In this case, we consider that product management interacts only with the planning of the manufacturing process of the product and therefore decisions relevant to process definition. There is no planning aspect relevant to the functional and physical definitions of the product. We are therefore in the extreme routine design case corresponding with product customisation or configuration and can consider the example of Figure 3.

In order to achieve the overlapping of the models of process definition and project planning, we consider that the model of the process definition is the basis of the generic graph of tasks. The generic operations of the process model correspond with the tasks of the project planning model. Anteriority constraints between generic operations and resources of the process model are also corresponding with the entities of the generic graph of tasks. The missing information for task planning is the duration of each generic operation. But this drawback can be overcome with the definition of a duration attribute attached to each generic operation of the process model of the product development model. Either numerical constraints or compatibility tables can be used to calculate the duration value according to the various development and planning decisions.

In order to illustrate the filtering possibilities, let us consider the example of Figure 3 with the following modifications: (i) all generic operations, except "Manuf H_Struct", have a duration of 2 weeks, (ii) the duration of the generic operation "Manuf H_Struct" is constrained by the component to manufacture "H_struct" according to the following possibilities: (H_struct , Duration) = { (H2_n, 2 weeks) , (H4_n, 4 weeks) } meaning that a small one needs two weeks and the larger one four weeks, (iii) a constraint between variable "Ctr-Cab" and generic operation "Assbl Vtr-cab" permits to modulate the existence of the operation. If we assume only the two following development decisions : 'V_length = 8m', 'H_length = 4m', (i) the filtering of the product development model will identify the component 'H_struct = H4_n' and a duration of 'Manuf H_Struct = 4 weeks', then, (ii) as no decision has been made about the existence of the control cabin, the presence of the operation "Assbl Vtr-cab" in the production process is not decided, therefore (iii) the filtering of the generic graph of tasks , shown in Figure 5 assuming unlimited capacity of resources, permits to compute that the production process duration is between 8 and 10 weeks according to the presence of the control cabin (in grey). Then, if we assume that a maximum value of 9 weeks is inputted for process duration, the filtering of the generic graph of tasks will remove the operation "Assbl Vtr-cab" and the filtering of the product development model will force variable 'VCtr-Cab = no'.

Figure 5 Task planning according to product development decisions



Even if this example is very simple, it shows how the production part of the product development (in this case reduced to a simple configuration or customisation process) can interact with project planning in both ways in order to allow to simultaneously consider the constraints of the two domains.

3.2 Overlapping physical definition and project planning

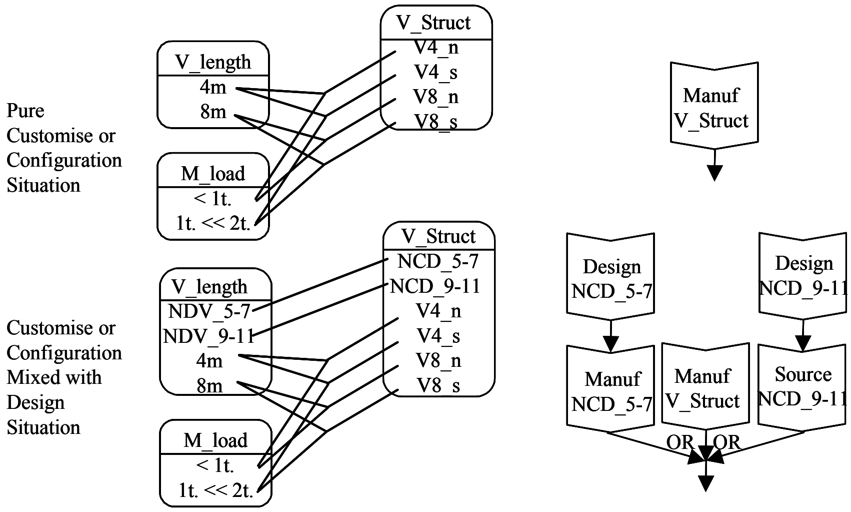
We consider now that the product management interacts with the planning of the manufacturing process as before but also with the planning of some activities relevant to the physical definition of the product. In order to define this situation, we consider the previous customisation or configuration situation but assume that when the solution space (defined in the product development model) can not match the customer requirements, the aiding decision system should be able to support the creation of (i) new product solution and therefore (ii) new activities or tasks corresponding to product design and process design. These new activities or tasks are then added in the model of the production process of the product and subject to planning activities. This globally means that if the detailed design of a given version of the product does not exist some knowledge permit to define and quantify the amount of work necessary to design it and to produce it.

In order to illustrate this situation, we still consider the example of Figure 3 but assume a crane requirement with a height of 10 meters (V_lenght = 10m). It is clear that this value does not belong to the solution space of the model of the product development of Figure 3. If the supplier wants to be able to fulfil this out of range requirement, he needs to create a new solution gathering the design of new components and new operations describing relevant production process.

In order to allow this possibility, the three models relevant to product development must be modified as follow: (i) in the functional definition of the product, in order to enable the actor to input a value that does not exist in the definition domain of a parameter describing the product, a specific symbolic value as for example 'new domain value', is added to its definition domain (ii) the same kind of modification is necessary for the physical definition of the product, a specific value as for example 'new component to design' must be added to the definition domain of the variable corresponding with the component, (iii) the last modification is relevant to the process definition of the product development and consist in adding at least one generic operation (with anteriority constraints) corresponding with the design activity of the new component with its relevant sourcing or manufacturing operations. Therefore the process definition can contain operations relevant to the design of some new component or sub-assemblies of the product.

As an example, we consider the crane of figure 3 (upper part of Figure 6) and assume now that the supplier accepts to design and produce crane with variable V_length between 5 and 7 meters or 9 and 11 meters. Therefore each requirement with a height different from 4 or 8 meters will launch a design process. The product development model is modified as shown in the lower part of Figure 6: (i) the parameter V_length of the functional definition has its definition domain updated with values 'NDV_5-7' and 'NDV_9-11' in order to capture the out of range requirement of new domain value (NDV) between either 5 and 7 meters or 9 and 11, (ii) same kind of addition for the vertical structure of the crane, component variable V-Struct. Two symbolic values corresponding with the new components to design (NCD) 'NCD_5-7' and 'NCD_9-11', are added with respect to the parameter V_length through modification of the constraint linking V_length and V_Struct (it is assumed that the load M_load does not have impact), (iii) as only component 'V_Struct' is impacted by the modification, the process definition modification concerns only the manufacturing operation of this component 'Manuf V_Struct', two new possibilities are now added: (1) for component NCD_5-7, a design operation 'Design NCD_5-7' gathering the detail design of both component and manufacturing process followed by a production operation 'Manuf NCD_5-7' corresponding with the manufacturing operation of this component (2) same general idea for component 'NCD_9-11', a design operation 'Design NCD_9-11' gathering the detail design of the component and the identification of a supplier (because no machine is available for this size of component) followed by a sourcing operation 'Source NCD_9-11'. Each of these generic operations is characterized by a duration attribute and some required resources. These three possibilities are of course linked with de variable V_Struct by constraints that allow selecting the consistent production process. An OR node allows to integrate this process model in the complete process view of the product.

Figure 6 Product development model allowing physical definition overlapping



Constraint filtering allows the kinds of deduction that have been discussed in the end of section 3.1. But the main interest of the added elements is that assembling existing solutions with new designed solutions is now possible, while still taking into account development process planning. An other interesting aspect is related to cost, if we assume that components and resources utilisation can be characterized by some cost values, it is possible to estimate the cost of being specific. For example, it is probable that the development cost of the first crane of 7 meters height, if it includes the specific cost of the design operation, will be larger that the cost of an already designed crane of 8 meters.

4 Conclusion

The goal of this paper was to describe the first results and ideas relevant to the co-operation of aiding tools relevant to product development and project planning. For each of these two fields, aiding decision has been considered as a constraint satisfaction problem. Product development knowledge has been distributed in three product views and project knowledge has been gathered in some kind of generic activity graph. Once the knowledge of two domains was formalised with variables and constraints, two ways to connect them in order to establish co-operation were presented. The fist one just interacts with the production activities of product development, but show however how a planning constraint can be propagated until the customer requirement. The second one is much more promising in the sense that interaction concerns both production and design activities.

As explained in the introduction, this work has begun recently. A first PhD student has already worked on the general background of the problem [1]. A second one is now fully involved on the subject presented in this communication and tries to define, identify, evaluate and select the appropriate knowledge models with relevant constraints formalisms in order to build and implement a mock-up that will allow to evaluate the proposed ideas. At the present time : (i) the three views of the crane model of figure 3 has been defined with a detailed production process, (ii) this model has been set up in a web constraint based environment described in [15] that allows interactive aiding design (that can be interactively tested at : http://iena.enstimac.fr:20000/cgi-bin/vht.pl), (iii) the three views of the model of figure 6 that allows overlapping of design activities are also defined and will be soon set up in the mock-up. We now begin to evaluate various planning issues with constraint and are currently investigating Temporal CSP [12] that assume infinite capacity of resource.

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Cost analysis in mechanical engineering production

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Abstract: This article consists of a cost analysis for the production of a main cinematic chain for a drilling and milling machine (for a production of one piece). For this we followed the steps of the economic value analyze as like: establishing functions for all parts of the assembly, finding out the usage value of each function, by giving marks (0, 1 and 2) from comparing every two functions, calculating the costs of the materials used and the manufacturing process, by the technology used to obtain each part. We considered that all technological processes would be done using numerical control machines. Starting with the necessary costs that are required for the production of the same cinematic chain using classical machines, we are going to compare these costs with the ones we get by using numerical control machines, for the same production unit of one piece.

Keyword: analyses, costs, production, economic value analysis

1 Introduction

Before starting a production of any kind it is advisable to know the production costs involved in the process. These are: the material usage cost, the manufacturing cost witch contains the workers' wages, the costs of the production site maintenance.

In order to get the total production cost we need to sum up all these costs and in this way the beneficiary will know even before the production starts what costs are involved and he will not be surprised by unexpected extra costs. In this way we can also take the best production solution and get the optimum price of production.

The economic value analysis is the best and the fastest way of solving this problem. With its help we can get an optimisation of the technology and even a redesign of some pieces that are not as important as they seemed in our assembly.

Some other pieces can disappear if they turn out to be unnecessary.

This is the kind of analysis that we ran for our assembly.

2 Functional roles of the assembly marks

The first step is to establish the functional role for each part of the assembly. These functional roles are expressed in key words sentences (under "Function"). It is advisable to try and group the functional roles; the goal is not to have to many function sentences, to avoid the analyses of functions doing the same things.

Below is an example for the first 5 assembly marks (Table 1).

Table 1 Functional roles of the assembly marks

Assembly mark number	Assembly mark name	Functional role	Function
01	Main shaft	Ensures the tool carrying away	Gives motion
		Fixes the tool	Fixes marks
		Positions the tool	Marks positioning
02	Cover	Isolates against dust	Makes tightening
03	Spacer	Supports the inner race	Marks positioning
		Prevents the lost of the lubrication medium	Makes tightening
04	Cover	Isolates against dust	Makes tightening
		Positions marks	Marks positioning
05	Main shaft semi casing	Positions marks	Marks positioning
		Fixes marks	Fixes marks

3 Function Nomenclature

After establishing all the functions that are made by the assembly marks, we attributed to each function a symbol for simplifying the next steps (Table 2). The usage value will be calculated in chapter 4.

Table 2 Function Nomenclature

Symbol	Name of function	V_u
A	Gives motion	20.99
B	Fixes marks	16.05
C	Marks positioning	16.05
D	Makes tightening	3.70
E	Allows access	1.23
F	Takes shocks	11.11
G	Makes bearing	7.41
H	Takes loads	7.41
I	Centring marks	16.05

4 Diagram of relations between assembly marks and functions

On this step (Fig. 1) we materialized the relations between the functions and the assembly marks for seeing clearly these relations. Based on these relations we can do a series of charts that indicate which pieces are highly evaluated and which functions need working one.

5 Functions Hierarchy

In order to establish the usage value we compared every two functions and gave mark according to the function's importance in the assembly: 0 – less important; 1 – the same importance; 2 – more important. The producer is the one who sets the importance of each assembly mark. Attributing marks is subjective; there is no strict rule about doing this. The marks are given in concordance with the importance of the functions in that specific assembly. After making the sum of all grades of each function, we calculated the corresponding usage value in percents (Table 3).

Figure 1 Diagram of relations between assembly marks and functions

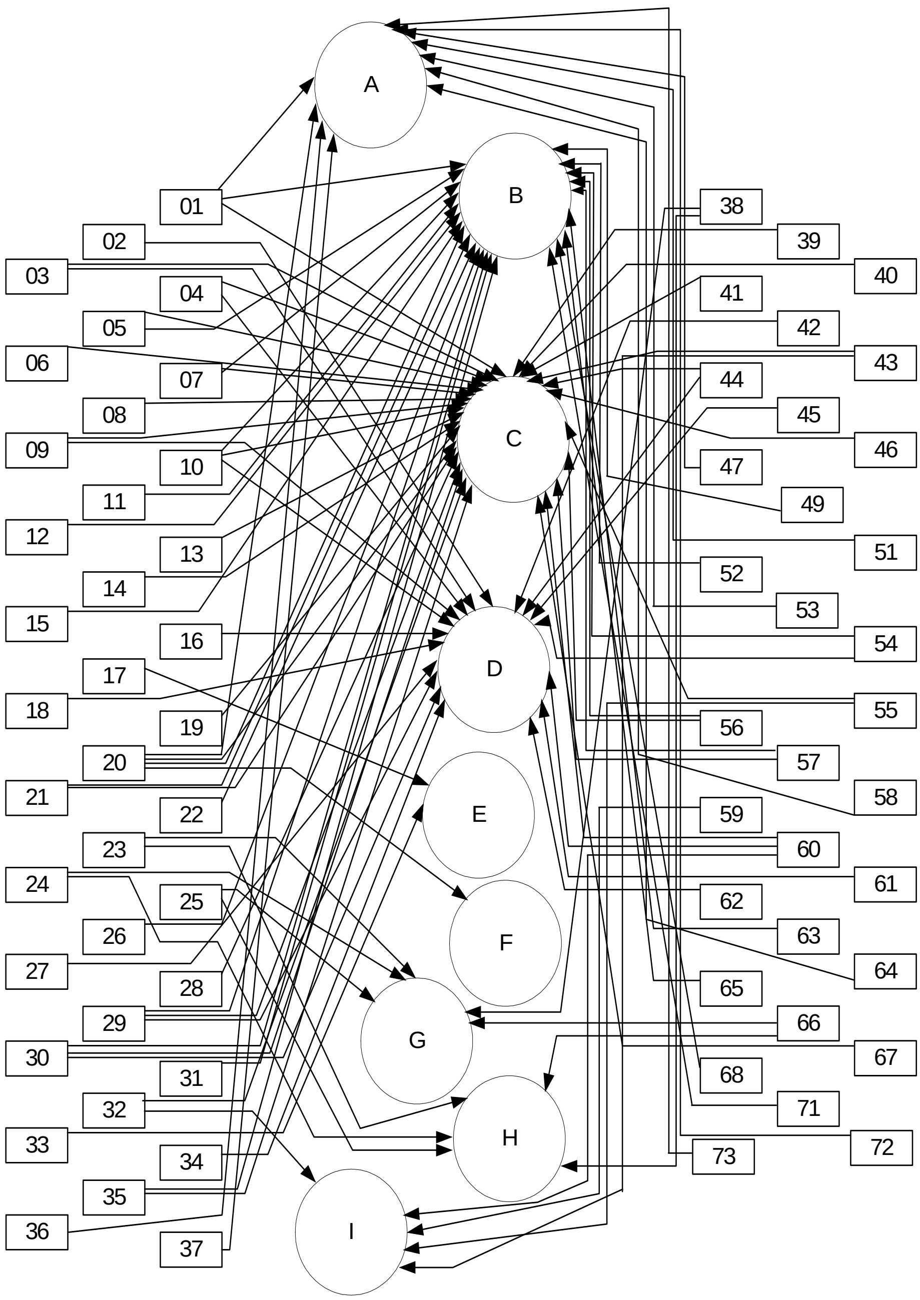


Table 3 Functions Hierarchy

	A	B	C	D	E	F	G	H	I	
A	1	0	0	0	0	0	0	0	0	
B	2	1	1	0	0	0	0	0	1	
C	2	1	1	0	0	0	0	0	1	
D	2	2	2	1	0	2	2	2	2	
E	2	2	2	2	1	2	2	2	2	
F	2	2	2	0	0	1	0	0	2	
G	2	2	2	0	0	2	1	1	2	
H	2	2	2	0	0	2	1	1	2	
I	2	1	1	0	0	0	0	0	1	
Sum	17	13	13	3	1	9	6	6	13	81
V_u (%)	20.99	16.05	16.05	3.70	1.23	11.11	7.41	7.41	16.05	100

6 Economic dimensioning

The first step of the economic dimensioning is to calculate the costs of materials used to obtain the non-standard assembly marks.

An example for this step is shown in Table 4. We exemplified the procedure for the first five assembly marks.

Table 4 Material costs

Assembly mark number	Assembly mark name	STAS / Material	Volume (dm^3)	Unitary cost [RON]	ρ[kg/dm^3]	Price /Material Cost [RON/piece]
01	Main shaft	OLC 45	1,734	2,20	7,85	29,946
02	Cover	OL 37	0,306	2,00	7,85	4,804
03	Spacer	OL 37	0,066	2,00	7,85	1,036
04	Cover	Fc 200	0,306	1,00	7,00	2,142
05	Main shaft semi casing	Fc 200	1,268	1,00	7,00	8,876

In the above table (Table 5) we presented an example of how we calculated the wages that were paid to the workers in order to obtain each piece following the established technology.

Table 5 Wages

Assembly mark number	Machine	Total action time [min]	Total operation time [min]	Wage [RON/month]	Wage costs [RON]
1	Lathe machine with numerical command	171,07	205,3	2.000	12,96
	NC Milling machine	10,45	12,5	2.400	0,95
2	Lathe machine with numerical command	24,55	29,5	2.000	1,86
3	Lathe machine with numerical command	11,03	13,2	2.000	0,84
4	Lathe machine with numerical command	47,85	57,4	2.000	3,63
5	Lathe machine with numerical command	56,91	68,3	2.000	4,31

7 Graphic representations

Before doing the graphic representations we did economic dimensioning, in which we calculated all interfering costs for the not standard assembly marks, like materials usage, the wages paid, etc.

This was possible after we established the operation time needed on each machine for each piece of this assembly. After we found out the necessary times and knowing the wages of the operators for these machines, we have been able to calculate the total cost of the whole manufacturing process.

After doing this we distributed the costs on functions according to their usage values.

In this chapter we use the results from the economic dimensioning. With those results we built a series of bar charts: the bar chart of costs, the Pareto bar charts and the correlation bar chart between the production cost and the usage value.

The purpose is to find out the highest costs, the highly evaluated functions and assembly marks.

7.1 The bar chart of costs on functions

Those bar charts give us important information about the most expensive costs from our production. From both bar charts of costs – in percents (Fig. 2) and RON (Fig. 3), we can easily see that the highest costs are the ones with materials. In this mater the only thing we can do is to use cheaper materials or a different type of blanks for lowering the total costs.

Figure 2 The bar chart of costs on functions – percents

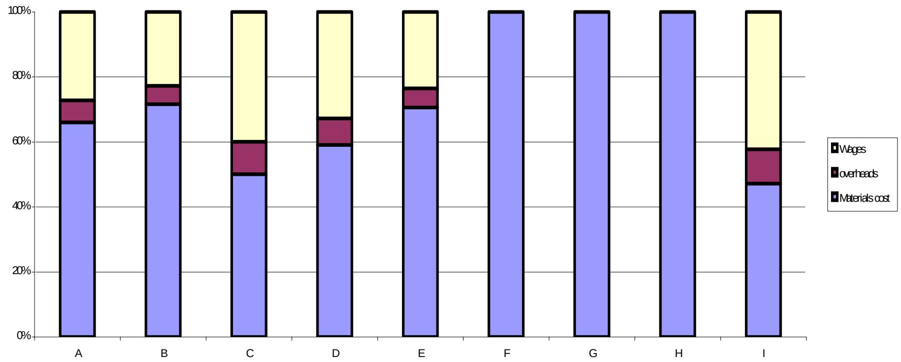
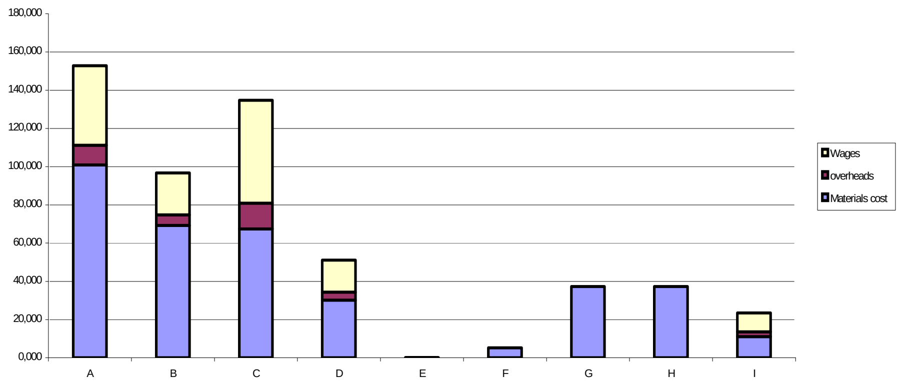


Figure 3 The bar chart of costs on functions – RON



7.2 The Pareto bar chart

The Pareto bar chart on functions (Fig. 4) shows that the important functions of the assembly are A: Gives motion, B: Fixes marks and C: Marks positioning. The important functions are situated as seen under the 70–80% functioning line. The functions were ordered from the most expensive one to the cheapest one, for each second function being built on top of the one before it. In the same way we can determine the important assembly marks (Fig. 5). We find them under the 70–80% line.

After deciding the important functions and assembly marks, we draw the correlation bar chart between the production costs and the usage value (Fig. 6). From this bar chart we can find out the highly evaluated functions of the assembly.

Figure 4 The Pareto bar chart on functions

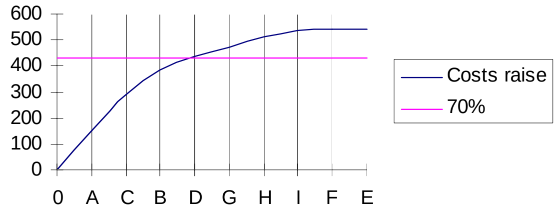


Figure 5 The Pareto bar chart on assembly marks

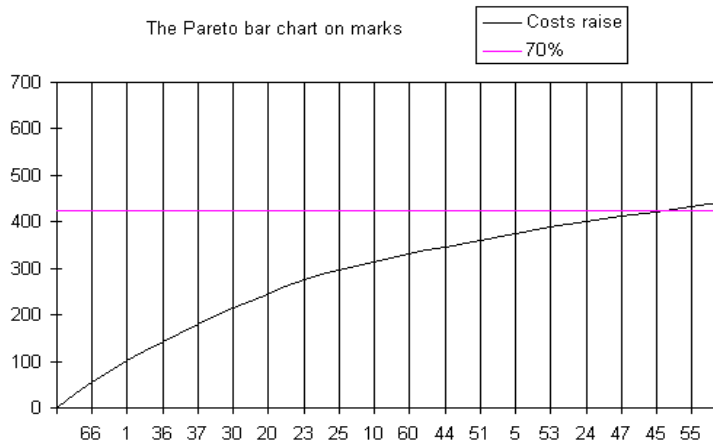
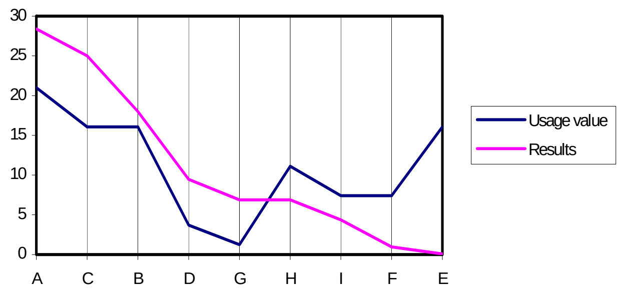


Figure 6 The correlation bar chart between the production costs and the usage value



Looking at the bar chart we can observe the five functions (A, C, B, D and G) that are highly evaluated, this are the functions with the production costs over their usage values. Knowing these functions we also know their corresponding assembly marks and we can take action.

8 The bar charts interpretation

From the bar charts of costs on functions we established that the highest costs are the ones with materials.

The first handy solution for lowering costs is the usage of different blanks.

From Pareto bar charts we established the important functions and assembly marks of the product. These are:

• Functions: A: Gives motion, B: Fixes marks and C: Marks positioning

• Assembly marks:

– A: 1, 20, 36, 37, 47, 51, 53, 58, 64, 72, 73
– B: 1, 5, 7, 10, 11, 12, 15, 20, 21, 22, 26, 29, 30, 31, 35, 49, 52, 54, 56, 57, 63, 65, 68, 71
– C: 1, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 19, 20, 21, 28, 29, 30, 32, 35, 39, 40, 41, 43, 44, 46, 55, 56, 57, 60, 67.

From the correlation bar chart between the production cost and the utilization value we can get the highly evaluated functions: A – Gives motion; C – Marks positioning; B: Fixes marks; D – Makes tightening; G – Makes bearing.

The functions that are highly evaluated, but also important are: A: – Gives motion, B– Fixes marks and C– Marks positioning.

The assembly marks that realize at list one of this functions are: 1, 3, 4, 5, 6, 7, 8, 9, 10,11, 12, 13, 14, 15, 19, 20, 21, 22, 26, 28, 29, 30, 31, 32, 35, 36, 37, 39, 40, 41, 43, 44, 46, 47, 51, 52, 53, 54, 55, 56, 57, 58, 60, 63, 64, 65, 67, 68, 71, 72, 73.

From Pareto bar chart we found out the most important assembly marks: 1, 5, 10, 20, 23, 24, 25, 30, 36, 37, 44, 45, 47, 51, 53, 60 and 66. The assembly marks belonging to both list, are: 1, 5, 10, 20, 30, 36, 37, 44, 47, 51, 53 and 60.

For these assembly marks the production costs are much higher than their usage value and we need to carefully study them in order to determine if there are cheaper ways to obtain them, cheaper materials that can be used. Another possibility is to study if they really are necessary for this assembly.

9 Conclusions

The economical value analysis is probably one of the best ways to an optimum price of production. This should always be done before starting a production of any kind, especially when the beneficiary imposes the maximum allowed price.

From this analyze we can get all kind of important data. We can find out that some pieces that we considered important at the beginning can be disposed at all.

If we find out that too many of the assembly marks are obtain at a cost over their importance in the assembly, we can ask for a review of the whole assembly and even a redesign for it. We can also ask the designer for an easier geometry, if possible, for some pieces that we consider too expensive to obtain and for the once that have a very complex geometrical structure.

An analyze of this kind should be done for any product just after it is designed, in order to discover the best solution before the start of the optimization analyzes for the production site or any other analyze or simulation that will be made in order to have a better productivity.

Authors' contribution is related to adapting economical value analyze to machine tool design, which together with other configuration technique can lead to design optimization in order to obtain the best possible project. Furthermore, we intent to develop new product configuration techniques (e.g. using neural network), based on relevant product history. The final objective is to define a multiple set of design optimization method. So far, the value engineering method could give us a clear idea about the importance of each part of assembly, without considering the design, manufacturing or selling experience.

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Chapter 3

Industrial experiences

Flexible PLM platform implementation for collaborative and simultaneous product development and management in injection moulding's SMEs sector

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Abstract: East Europe enterprises and far east technology supplier's strong competition, forced a lot of Italian SMEs to find innovative product/process solutions to remain in the global market. Developed by five injection moulding's SMEs of Marche industrial district, Co-Mould project primary aim was Collaborative and Simultaneous Product Development platform analysis and creation, focused on product knowledge management and effective sharing. The project led to PLM software platform implementation with a typical "three layers architecture", perfectly tailored to the involved enterprises needs; *server systems connection* "foundation layer" is made up of two secure data storing databases; DS SmarTeam – a technical documentation management software – and MS SharePoint, works on these DBs. SharePoint represent both an essential rate of second *web service implementation* "layer" and of third *user connectivity* "layer". Moreover a workflow management software, called SP Flow, was installed; it links with SmarTeam and with all administrative and managerial enterprise applications. It completely integrate with SharePoint as well, assuring right web visibility to all common clients. In order to complete third "layer" and to allow collaboration and simultaneousness among geographically distributed enterprises, a videoconferencing and desktop sharing system, named One Space.net, was installed. At last, it was expressly developed a quick budget estimation software. The testing process pointed out a time to market cutback in total amount of about 40%, so reducing process development of medium complexity product from 120 days to 75 days.

Keyword: Time to market, collaborative PLM, SME, quick budget estimation, extended enterprise, supply chain, collaborative and simultaneous product development.

1 Introduction

In the last decade, in the injection moulding sector, as well as in more other industrial sectors, both the opening up of new markets caused by globalization and East Europe enterprises and far east technology suppliers strong competition, forced a lot of Italian SMEs to find innovative product/process solutions to remain in the global market.

In fact, thank to lower manufacturing cost, far east enterprises have undercut finished goods up to the tenth part of western enterprises good prices; it has substantially contributed towards Europe economy competitiveness loss, which has been followed by considerable market share decline. Nowadays is therefore essential put products on market aiming to product/process quality and innovation rather than to consumer good prices, because in the latter case western manufacturing system unavoidably would tend towards an unprecedented economic slump. Developed by five injection moulding SMEs of Marche industrial district, Co-Mould project primary aim was Collaborative and Simultaneous Product Development platform analysis and creation, focused on product knowledge management and effective sharing; it has been possible implementing an hardware and software architecture perfectly tailored to involved enterprise needs.

2 Project Purposes

The main project aims were, on the one hand, *effective and efficient synergy promotion* among district enterprises by adopting know how sharing innovative paradigms, on the real agreed workflow basis; on the other hand, *competitive positioning support* of district enterprises in the global market by reducing their Time to Market, production costs and increasing customer satisfaction. In order to achieve these purposes, the project led to innovative platform development, knowledge enabling and its dynamic sharing over the supply chain, i.e. flexible and re-configurable with value chain variables partners-roles as well. Both in this particular industrial sector and in the whole Marche district, project has represented integrated enterprise first example in a geographically distributed environment (extended enterprise) for collaborative product development.
The intervention program was divided in three stages:

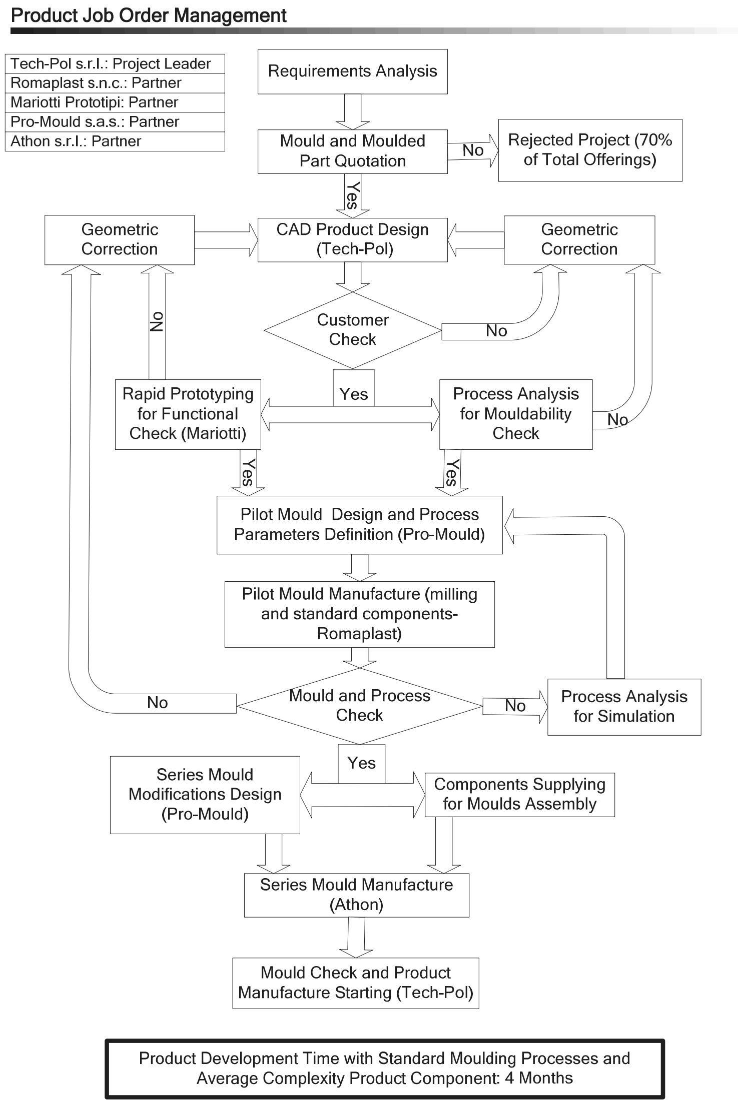
- Stage1: Model definition of product management and development process for injection moulding industrial district;
- Stage2: Realization of prototypal software applications/tools supporting innovative product development and management process;
- Stage3: Project results testing and generalization.

It was completed in 24 months and besides five district SMEs, has involved two excellent research centres, as Politecnico di Milano and Università Politecnica delle Marche, and Marche Science and Technology Park as well.

3 Business Process Analysis and Re-engineering

Before starting project, proposing enterprises – as well as whole district SMEs – had adopted collaborative processes inside themselves only, usually between project and manufacturing department. Implemented technologies supporting product development were CAD-CAM systems only, therefore integration occurred between company technical department and shop floor. Outside communications concerned simple commercial relationships with basic data exchange (e.g. 2D drawing exchange and workmanship requests). Moreover in the whole value chain there were a lot of important problems connected to the following factors: *inside company lack of organization, difficult information retrieval both inside and outside company, communication shortage among partners, global process lack of organization and difficult communication with* *customers*. All these factors were extremely revealing of organizational and technological critical state shown by process; it was very complicated and required more enterprises participation and skills as well. The Figure 1 block scheme highlight all iterations that contribute to waste time in project leader enterprise's product development process. It point out that process was highly sequential and full of information loops; process length evaluation for average complexity product component show its unsatisfactory productivity. For example, technical department staff wasted about 30 hours a week for extra project tasks, such as already used information regeneration, product configurations and old product information retrieve.

Figure 1 Tech-Pol Product Development Process



Moreover, waiting time for a project leader's request to a partner, such as CAD model geometrical modifications, could range from 5 days to 2 weeks, while it should have been sufficient two days at the latest – even for considerable geometrical modifications – in a well organized process.

From Business Process Analysis and Reengineering, carried out in project leader enterprise – cooperating with Marche Science and Technology Park and Università Politecnica delle Marche – came out that spreading information during product development process were composed of dimensioned drafts, 2D technical drawings, 3D CAD models representing components, mould and drift, hand made out bills of materials, machine tool paths, simulation views, materials technical papers, process parameters technical papers. Phone and fax, e-mail, ordinary postage, meetings, ftp, etc., were the only way information moved; they were unable to spread most of the aforesaid information and, in any case, quite unsuited to enabling the real time collaboration among communicating partners. Furthermore, in the 3D CAD model sharing between two enterprises adopting different legacy software, it took often several days to "repair geometries", while the end purpose was maybe only a few dimensions or shapes communication. These evidences only partially indicated whole organizational and technological process critical state; it all caused delays, misunderstandings, project mistakes, subjects sharing problems, that negatively influenced product release time, costs, and therefore, customer satisfaction. Besides, customer did not have any information about job order progress. From BPA emerged that product development participating enterprises were numerous and very small, so that supply chain was strongly geographically distributed. It has determined a strong need of "product development at a distance", that has led to Collaborative Product Development System (CPD System), oriented to effective management/sharing of product information content through a suitable hardware architecture and an optimal software structure. The system support information moving and sharing among geographically distributed enterprises, also allowing workflow control and management of product development process and of the whole product life cycle, as well. Commercial software solutions, named cPLM (collaborative Product Lifecycle Management) were useful to development process but were addressed to all kind of users (big and middle enterprises, all sorts of business); therefore, they were too general and implicated hard customization efforts dedicated to specific environment. The innovative platform has been conceived to support evolution towards total dynamic collaboration, both inside enterprise (among departments and CAD/CAM, CAE, ERP systems, etc.) and outside, e.g. with suppliers (SCM), customers (CRM) and any possible business partner, associate concern and controlled company. System modular structure has allowed dynamic collaboration's "horizontal extensibility" that has also required processes, product data and systems interoperability, supported by high level tools.

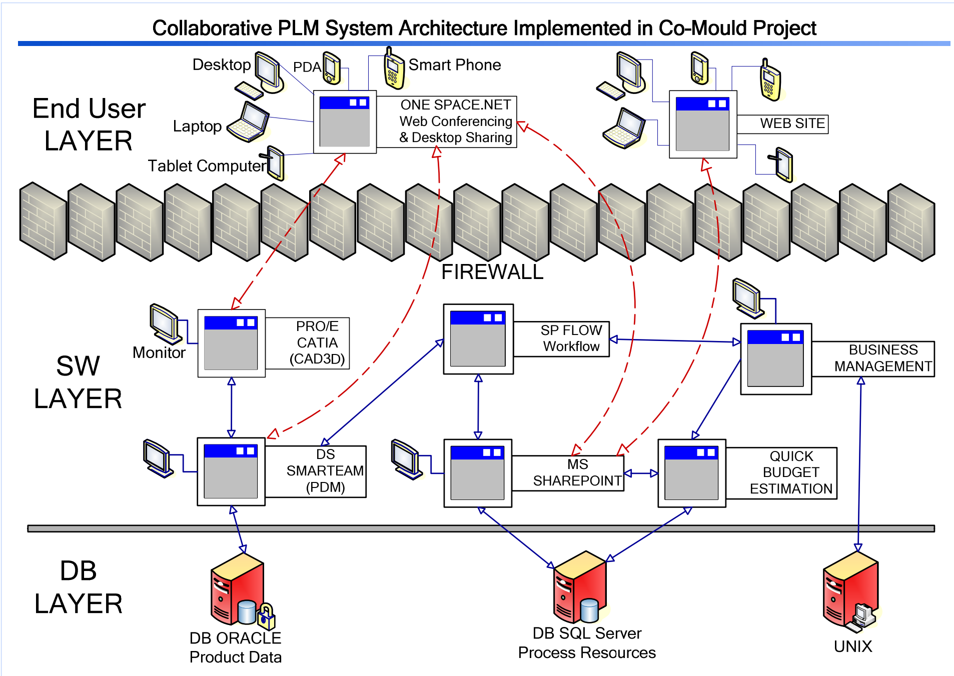
4 Flexible cPLM Platform Implementation

Co-Mould project led to PLM software platform implementation with a typical "three layers architecture", perfectly tailored to the involved enterprise needs. *Server systems connection* "foundation layer" is made up of two secure data storing databases (Oracle 10g and SQL Server); Both DS SmarTeam technical documentation management software, installed in Tech-pol technical office only, and MS SharePoint dynamic web portal software, capable to manage different user types through different access levels, work on these databases. SharePoint represent an essential rate of second *web service implementation* "layer", which comprise every workflow logic, data and activity access and transformation, and of third *user connectivity* "layer", as well. "Foundation Layer" is then completed with Unix operating system, employed as server in Tech-Pol before starting Co-Mould project. Marche Science and Technology Park has installed both Oracle db, on a project leader server, and SmarTeam software on the same db and on five client pc (of which three laptop); it has also executed customization stage complying with specific enterprise needs, and then has carried out technical office staff training phase, in order to quickly and simply teach them first knowledge on the main software facilities (such as project folder generation and management, document management, file loading, links, 2D/3D CAD visualization, BOM, life cycle operations, simple and advanced searching tools).

Besides *web services*, the second "layer" is constituted by new *data transformation mechanism*, as well. Concerning this, SP Flow legacy software was installed; created in .net environment and able to manage whole workflow, it interface with SmarTeam for taking and sending file – complete projects, 3D CAD parts/components, documents, etc. – both to leader project departments and suppliers (designers, prototypers, pilot and standard mould manufacturers). Moreover, it interface with all the administrative and managerial enterprise applications and completely integrate with SharePoint, assuring right web visibility to all common and prospective clients, allowing them to execute full budget estimation procedure. Metisoft company has installed SQL Server database on a Tech-Pol server, SharePoint and its own SP Flow software. Moreover it had been responsible for customization and training of Tech-Pol administrative and technical staffs and of its common suppliers too, as regards technical/commercial workflow running for estimations and job orders management. The "Politecnico di Milano" had expressly developed a quick mould budget estimation software, created in .net environment, based on history data paper archives placed in Tech-Pol and in its four main suppliers. It allow mould budget estimation on the basis of last five years estimations, taking as reference parameters average design costs, component complexity, mould and mould holder type, standard component use, injection and thermostatic systems, moving and closing systems, finishing and foreseen tests. Although it is not shared with customers and suppliers, this automatic tool is fully interfaced with SharePoint, serving as its web part. As regards virtual modelling, 3D CAD CATIA V4/V5 and Pro/Engineer – an integral part of "second layer" – had been installed before project starting and their file are managed by SmarTeam. Within commercial and administrative field, managerial applications supported by Unix operating system and integrated with SP Flow represent history data source that contribute to well operate and improve mould budget estimation software.

In order to complete third "layer" (client side tier) and to allow collaborative and simultaneous process management among geographically distributed enterprises, a videoconferencing and desktop sharing system named OneSpace.net, was installed. This software is also integrated with SharePoint; thanks to its advanced facilities more corresponding to project needs, it has been selected by project leader among several solutions suggested by Design Tools & Methods Group of the Università Politecnica delle Marche. At last, Marche Science and Technology Park, DT&M Group and project leader Tech-Pol have developed a dynamic web site, supported by SharePoint and able to manage various partners (suppliers and customers) in accordance with different access levels. Web site structure is constituted by a public section (open) and a private one; the latter is divided in two sub-sections as well, one of which is customer exclusively dedicated and the other is project partners opened only. In customers reserved area, client enters filling in a form composed by mandatory data field set; then, he send a secure log in (username and password), so that he can enter into the site for getting available information about in progress job order. So doing, customer is integrated in product process development, as he can keep abreast of the order execution in real time, interacting busily with leader enterprise. The cPLM “three layer” system architecture is shown in the figure below.

Figure 2 Co-Mould Architecture



5 Conclusions

Although it had been used standard moulding processes, analyses made on twenty products, developed shortly before starting Co-Mould project, showed that average complexity product component development time – from requirements definition to manufacturing beginning – was about four months (see fig.1). In broad terms, it could be observed that:

- Process loops took up 25% of whole process time, on average;
- Dead times for data lacks (e.g. CNC machines not running for tool paths calculations waiting) were about 15% (at least two weeks).

New process prototypal platform testing highlighted drastic reduction of information loops. Time lags were definitively eliminated because now information are accurately managed and controlled by workflow management system, so assuring full enterprise resources exploitation. The testing process pointed out a time to market cutback in

amount of about 25% (10-15% thanks to process loops cutbacks, 10-15% thanks to dead times elimination) added to another 15% of gained time thanks to many simultaneous phases (such as mould and product design, mould and process parameters optimization, etc.); overall time cut was therefore about 40%, so reducing process development of medium complexity product from 120 days to 75 days.
Thanks to manpower employed cutback, it can be foreseen cost saving of about 15%. Moreover, Co-Mould project has given rise to a considerable cut in after first release ECOs number, customer involvement in the design chain and, consequently, his better satisfaction in terms of:

- Greater agreement between results and expectations (higher product quality);
- Drastic cutback of product release time (quicker deliveries);
- Cost savings of about 15-20%.

At last, other project advantages are budget estimation's writing out time cut, production management optimization, all process parameters control, monitoring improvement and smaller enterprises advanced tools introduction, commonly used in a net system only.

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Introduction to PLM of Hyundai Motor Company

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Abstract: Hyundai Motor Company (HMC) is a leading automobile company in Korea producing more than 2.6 million passenger and commercial vehicles a year. This paper addresses the progress of HMC's PLM (Product Lifecycle Management), focusing on product development process aiming at shortening development period and improving quality.

Keyword: PLM, Product Development Process, Collaborative Environment

1 Introduction

HMC has continuously grown since it was established in 1967 and launched "Pony" which was its first Korean-made automobile exported in 1976. HMC has become a leading automobile company in Korea, producing more than 2.6 million passenger/commercial vehicles in 12 countries and selling vehicles to 193 countries in the world.

However, HMC encounters various challenges. Entering the 21st century, world's automobile market has witnessed continuous increase in demand especially in emerging markets such as BRICs. But, as production capabilities far advance demand because of cut-throat competition in the industry, surplus supply has worsened. Furthermore, automotive companies are burdened with development cost because of varied customer needs, shortened model cycles, high oil prices and hardened environmental rules, so their profitability is falling [1]. To survive in this highly competitive market called 'Red Ocean' and to become a top-notch automobile company in the world, HMC is committed to innovating product development process for high-quality product. This paper is aimed at introducing HMC's PLM, a key part of the innovation process.

2 Establishment of PLM by HMC

2.1 Key Issues in Product Development Process

HMC has developed and run systems to manage product data and to automate unit operations such as BOM, document/drawing management and change management since it introduced CAD for the first time in 1982. However, as the size of company grew and its product lines were expanded, the following problems occurred;

- As varied customer demands need highly complicated product specification management, there were limits in existing BOM structure and legacy system. Also, BOM is organized and managed as separate database per design/manufacturing/AS and there is separate production data managed per plant in the world. Therefore, Man-day to manage these data has increased and compatibility of data is hard to be maintained.
- When designers referred to design progress of other parts related to their own parts, they had to receive related materials directly from the relevant designers or browse relevant model through drawing distribution system only after drawings were released. As a result, there were many problems such as interference in manufacturing process of assembly prototype and function incompatibility, and additional cost and time were needed for design change and die modification. To solve these problems, HMC ran process that sets up cyclical gate during design period, organizes Digital Mock-Up (DMU) based on interim output of design and executes mid-term check. However, this process consumed additional work of designers to create separate DMU data and only very limited number of car models were reviewed because DMU was organized manually by DMU managers.
- As information sharing was not facilitated between design and manufacturing, process planning and resource preparation for manufacturing could start only in the final stages of design.
- As data related to product development was scattered in unit systems, it was difficult to recognize overall project progress and to manage resources efficiently. Additionally, schedules were frequently postponed or budgets were exceeded because risk expectation was difficult.

2.2 Content of PLM System

To solve these problems, HMC sets its top priority on ‘Reduce Time to Develop New Model’ and ‘Secure High Development Quality in Earlier Stage’ by establishing PLM. PLM system is now being developed for the purpose of intensifying information sharing function, providing collaborative working environment and efficient project management.

- Next-generation BOM (Bill of Material) system

First of all, HMC adjusted BOM structure which is the basis of product data. Spec management scheme is reorganized to flexibly respond to varied demands from customers and next-generation BOM system (e-BOM) is also developed to manage and support the spec management in a systematic way. e-BOM is aimed at improving data accuracy and work efficiency by integrating BOM data which were separately managed per division into one system and by making system manage relations between each BOM automatically. Furthermore, accuracy of profitability estimates per product specification is improved by estimating cost data in real-time. The new system has been applied to almost the whole business sections from January 2007.

- Product Data Management (PDM)

HMC has pursued PDM system which is to manage and share design data systematically. The company completed system application to Powertrain R&D division and proceeds pilot project for Vehicle R&D division. After PDM system is completely developed, design results using CAD will be saved in PDM server in real-time and designers will be able to refer to the designs by browsing part models related to their own parts. Also, this system will be connected to e-BOM system and be able to automatically organize DMU in real-time as per product specification. Therefore, unnecessary man-day of designers will be reduced and design quality will be greatly improved as digital verification for various specs will be intensified. In addition, legacy CAD data management system will be integrated and enhanced in PDM and design data will be referred in real-time in stage of design for planning/manufacturing/AS as well as design. So, it will be possible to carry out collaborative work among each division simultaneously.

- Manufacturing Preparation system

So far, manufacturing engineers directly received related data from designers to review manufacturing process. And as there was no system for a systematic review of manufacturing process, process review was not efficient. To address these problems, HMC is developing Digital Manufacturing Engineering System (DMES). DMES is a system related to PDM which is used to gather 3D product design data in real-time, 3D-simulate manufacturing operation and plant layout, integrate and manage manufacturing data. It is forecast that the DMES will enhance design quality and shorten review period of manufacturing engineering by discovering and reflecting expected problems with design in an earlier stage.

- New Product Development System (NPDS)

HMC set up NPDS to manage development schedule, target, resource, achievement and risk of overall development process. Before having the system, managers had to search needed data in each system respectively or collect data directly from designers to recognize product development progress. So, they consumed a lot of time to make materials for strategic decision. However, NDPS provides managers with appropriate data for decision-making by auto-monitoring product development progress as it is related to BOM, PDM and other legacy systems.

3 Benefits of PLM and Major Issues

3.1 Major Benefits from PLM System

At present, most of the main PLM systems are recently built or still being developed. Therefore, there is no statistics about specific benefits of PLM. However, a backbone of PLM is being established and the following benefits are expected if entire system is completely developed and stabilized.

- Collaborative environment and stronger front loading

An ideal environment for collaboration between designers or departments will be provided by developing and connecting BOM/PDM/DMES systems. In the stage of design, a designer can refer to data of other designers for his work. Departments including Planning/Manufacturing/AS can refer to the design work in real-time to expect performance, enhance marketability, and improve assembly and repair convenience. It will make it possible to do tasks of different departments at the same time. Such stronger front loading will reduce product development time by about 25% by the time when the system will be built and stabilized completely. In addition, it will significantly raise product quality by enabling workers to expect post-process problems early in the design stage and prepare for it.

- Efficient project management system to develop a car

A project management environment for the overall car development process will be realized. Centered on NPDS, BOM and PDM will be linked so that users can track down and manage key risk factors such as estimated manufacturing cost. Also, efficient management on project progress, development problem, and resource will be available.

3.2 Major Issues Concerning HMC's PLM Establishment

One of the biggest challenges in establishing PLM is building close relations between systems. To support active collaboration among users, key data of each system should be interrelated. However, data connection in bigger scope cannot but lead to lower performance. The key to successful PLM is, therefore, to make wise trade-off between the two.

And also, HMC's PDM, DMES, NPDS except e-BOM are developed based on commercial package solution. To facilitate connection between the commercial package systems, high performance, stability, open Interface API and data format not biased for any single solution are required. But in reality, interface between commercial solutions is considered as a very complex issue which would involve interests of solution providers. This issue should be addressed by the solution industry in collaboration.

4 Conclusion

This paper briefly looked into PLM establishment in HMC. It is expected that HMC will innovate its product development process through PLM and achieve its goal of 'Reduce Time to Develop New Model' and 'Secure High Development Quality in Earlier Stage'. Its future challenge is to expand PLM scope to the entire enterprise to achieve distinctive competitiveness and maintain the company's growth engine.

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A blended academia-industry learning model for PLM education

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Abstract: This paper describes a university/industry project for the development and operation of a product lifecycle management (PLM) certificate program for Boeing engineers and technologists. This collaborative project between The Boeing Company, Purdue University, Edmonds Community College, and Dassault Systemes is currently being implemented using traditional and distance learning strategies. Boeing employees will learn the strategic importance of PLM coupled with applied PLM laboratory exercises. Employees who enroll in and successfully complete this program receive a PLM certificate from Purdue University The program will be evaluated by an industrial advisory board which will include PLM subject experts, instructional system designers, distance learning experts, and curriculum evaluation experts.

Keyword: Product Lifecycle Management, Engineering, Education, Learning Sciences

1 Introduction

Historically, engineering education has been centered on well-defined solutions; the new global shared risk–shared value business model (e.g., Engineer 2020[1]) is forcing the restructuring of engineering competencies. Real-world problems are rarely the well-bound, defined solutions found in formal engineering education; they typically require leadership skills that manage cultural differences and system engineering, focused on achieving an optimized solution, balancing customer requirements, functional requirements, costs, technology and time constraints. These real-world system level skills often transcend the standard “functional” engineering education.

If you subscribe to Friedman’s “Flat World” [2] perspective, i.e., globalization is forcing a radical change in engineering competencies. Educating the future engineers and technicians will require a restructuring of the engineering core and a new partnership with industry. This academic-industry approach could provide focused research and application opportunities with graduate schools (Gabriele, 2005[3]) and a forge a new engineering educational partnership with academia (Spellings, 2006 [4]). Theses global forces promise to reshape the way we educate our workforce and will ultimately affect a company’s ability to compete economically.

Product Lifecycle Management:

Within the traditional engineering programs, Computer Aided Design, Computer Aided Manufacturing (CAD/CAM) curriculum is considered “an elective”. The focus is placed on the engineering fundamentals, in part to satisfy the academic mission of “teaching how to think”. Within the industry, the mission shifts, and is more experiential, focused on “teaching how to do”. When these two missions integrate problem-based learning, and focused on “theoretical to application” objectives, mastering the required real-world competencies can be accelerated.

The development and application of Product Lifecycle Management (PLM) competencies, specifically, relational processes and methods are critical to the success of the advanced technology Dreamliner™. Compared with historical methods i.e., modeling “dumb” solids and traditional orthographic drawings, the PLM strategy enables the three-dimensional model to become the “authority for manufacturing”. This holistic approach enables digital propagation of design intent within the global partnership environment. Specifically, this strategy enables 1) design collaboration and change propagation at the speed of electrons and 2) The ability to capture and reuse corporate content knowledge and 3) contextual design propagation, i.e., morphing of design intent through contextual geometry relations. When the PLM concepts processes are combined with advanced CAD/CAM measurement systems and methods, they offer tremendous advantages to aircraft designers and manufacturing partners.

2 The Partnership

Addressing the competency shortfalls identified by Boeing in the design and manufacture of the advanced technology Dreamliner™, the Learning, Training, and Development (LTD) group approached Dassault Systems, Purdue University, through the departments of Computer Graphics Technology, and Edmonds Community College to assist in the development of a PLM curriculum that could be delivered within higher education to prospective engineers and technology practitioners. Central to this industry–academic partnership was the development of new coursework to enhance student learning both at the higher education level and at industrial in-service levels. Based on the needs of regional and international manufacturers, and paralleled by the growing need for applying interactivity in the exchange of information data in all manufacturing industries, we have partnered to develop a certificate program that can be used to educate the future engineers and technologists, as well as those who are presently engaged in industry. Boeing's goal in this partnership was to assist in the development of educational materials that could not only be delivered to undergraduate engineering and technology students but also used to create a program for professional development that can be replicated on site within businesses and disseminated throughout institutions of education on a global basis. The intent was to create "theory to practice" opportunities that will (1) attract incumbent employees and (2) develop and attract new engineering students.

The initial focus of the industry – academic team was exploratory. Alternatives and options were explored in relation to solutions content and for how the solutions will be designed, delivered, and operated. During this step, the teams spent a significant portion of their time learning about desired competencies and how they might be leveraged for the benefit of the program. This was accomplished through a mix of local briefings and visits to university and Boeing facilities as appropriate. Likewise, the team explored the strengths and viability of the university, Dassault Systems and Boeing's internal education solutions and approaches under development by the new programs. In parallel with the learning activities, the team began to focus on clearly defining the scope of the effort to be addressed. Educational performance goals, objectives, basic economics and the business model, feasibility of alternatives, stakeholders, interfaces, risks, constraints, strategy, and potential professors and instructors were identified. At the end of this step, the team delivered a set of suggested approaches that included various solution components and alternatives for content providers. At this point in the study, the focus was not to have a final answer but rather to be able to make the technical and business cases for various approaches, highlighting the strengths, weaknesses, costs, and benefits of the business model. Key team members were assigned, and resources were made available to quickly baseline the effort. The scope baselines also included end products, and quality standards, including performance objectives, partnership service levels, critical resources, and assessment-measurement activities. Risks were assessed with mitigation or acceptance recommendations, including Learning Return on Investment (LROI) models. This partnership included University faculty and members of the Boeing Technical Fellowship. An enterprise wide pool of exceptional technical talent focused on meeting Boeing's technical and educational challenges. These scientists, researchers, professors and engineers, who are recognized as industry experts and have networks in the global community, were leveraged for their deep, specialized knowledge and to develop and acquire critical educational material for the certificate program.

3 The Certificate Program and Governance Structure

This state-of-the-art training program combines a lecture-lab approach, through problem-based learning labs, integrating distance learning technology. This industrial-academic certificate program is premised on cooperative learning methods and built on the philosophy that learners learn best through active engagement in meaningful activities. Through this cooperative partnership, Boeing was able to leverage the teaching and theoretical competencies of Purdue University to meet specific business challenges. Purdue was able to leverage the practical application experience of Boeing Subject Matter Experts to make its programs more attractive, interesting, and more immediately relevant. The joint partnership aligned end-user knowledge to fulfill the academic standards and mission of higher education by allowing the curricular materials developed for the PLM certification program to be integrated into existing courses. The use of these materials allows Purdue engineering and technology students to have the advantage of using industry applied and theory curricular materials as part of their educational experiences.

The first of the three courses focuses on the use of PLM in industry and how it is shifting the way companies do business looking forward to the year 2020, coupled with an industry influenced education on how to apply the product design tool CATIA V5 to PLM practices. With globalization forcing radical change in engineering methodologies, the process is more reliant on the individual working in a collaborative environment. Historically the engineering of a new product has rested on a single company and its resources. Today's global marketplace has pushed even the largest companies, such as The Boeing Company, to form strategic risk sharing partnerships to design, build and maintain a product through its entire lifecycle. These real-world problems are rarely the well-bound, defined solutions found in standard engineering education; typically requiring leadership skills that can manage cultural differences and optimize the system solution.

The second course in the series deals with concurrent engineering and relational design using a combination of the design tool CATIA V5 and the product configuration database ENOVIA LCA. The lectures focus on how engineers no longer design their part and add it to the assembly, but design in context with thousands of other engineers around the world at all times. Using a combination of relational design and configuration management, products can be quickly updated by replacing master geometry and updating the links to subordinate geometry creating a whole new product derivative in minutes, saving a company millions of dollars in the process. Applying this concept in the lab, students are grouped into design teams of four to five, each team being assigned a product to collaboratively design using relational design methodologies. They will then store their data in the ENOVIA LCA server hosted on the Purdue campus from across the country to simulate a global infrastructure. Within the teams they must negotiate with each other in order to contribute efficiently to the entire product as a whole. Throughout the design, the instructors will issue change orders to the designs to reinforce the use of relational design. If the products are designed properly, the changes can be made relatively easily with a series of button clicks. If not, they may need to be totally redesigned which requires extra time and effort.

The third and final installment of the certificate program takes the products designed in the previous course and sends them through the manufacturing simulation process to validate the build phase of the lifecycle. The lectures discuss the importance of upstream design and processes to the downstream Manufacturing Bill of Material (MBoM). When a product is not properly designed and does not follow the specified processes upstream, it can cause major cost and build issues downstream. The lab takes the student through usage of the Product, Process and Resource (PPR) in the DELMIA Process Engineer database and DELMIA Digital Process Manufacturing simulation tool and their connectivity to the ENOVIA LCA database to access the design data from CATIA V5. Each group of students is required to build a set of tooling to facilitate the build of their product, develop the process simulation to construct the product and produce a

Manufacturing Bill of Materials (MBoM). Acting as a capstone for the certificate program, this course ends the design and build simulation phase of the product lifecycle.

The three courses detailed below will focus on the theories of PLM through lecture and application using CATIA V5, ENOVIA LCA and DLEMIA V5 as the applied applications. The courses combine interdisciplinary, modular classes and experience-based learning;

1. CATIA for Modern Aircraft Systems. Continual advances in structural analysis and design, computational methods, and fatigue and fracture analysis require that engineers refresh their knowledge of the fundamentals and keep up with new developments.

2. ENOVIA for Modern Aircraft Structures. The application of PLM concepts cross over all major engineering disciplines, including aerospace and material sciences, mechanical engineering, tooling and manufacturing, industrial and product manufacturing, product engineering, maintenance repair. The course seeks to strengthen data management "competency gaps" that have been identified by customers and industrial partners. The course goals were to provide students with a real world experience, in data management and to understand how to navigate the complexities of a Product Data Management system.

3. DELMIA for Modern Aircraft Structures). This course seek to strengthen Boeing's composite focus on several industry-identified "competency gaps" that have been identified by our Boeing Commercial Airplanes customers and industrial partners. The course goals were to provide students with, design integration and simulation - analysis methods, through real-world design case studies.

These courses were designed for engineers who have some working knowledge of CAD/CAM processes and Three-Dimensional modeling but require a detailed or an in-depth understanding of analysis tools and design methodology necessary to design and build aircraft structural hardware. This structured educational approach ensured that educational opportunities were aligned to the product lifecycle. The programs were developed to align with the product lifecycle development strategy and made available just-in-time. We expect to deploy this learning architecture to other subject areas inside of the PLM realm in conjunction with Purdue and other universities, as demand for qualified PLM user's increases across the Boeing enterprise.

This unique methodology fills a gap between the role of the University education system and the needs of The Boeing Company for skilled individuals. The certificate program was divided into three distinct 40-hour courses, each spanning 10 weeks to be delivered consecutively.

Advisory Board

A final and critical aspect of this certificate program was the successful creation of the Industry-Academic Advisory Board. The creation of an advisory board that included senior faculty and experienced professionals proved critical and was one of the most valuable steps in creating a certificate program. This board created the governance processes and scorecard. In general, board members were asked to participate in the following ways:

- Identify and validate the skills and knowledge that current professionals need to gain.
- Review program objectives and course syllabi to ensure high quality and relevance for the target audience.
- Determine the prerequisite education and experience needed by students to succeed in the program.
- Determine the selection and entrance criteria.
- Nominate professors and instructors who have the required technical skills and teaching abilities.
- Assist in the promotion of the program and recruitment of students.
- Assist in the Public Relations and Communication planning
- Governance and scorecard activity
- Export and Intellectual Property issues

4 Program Structure

The applied concepts of design and build will be instructed through a synchronous distance learning format, as well as, a local hands-on lab experience; resulting in a blended learning delivery of the course. Through each of the three 10-week courses students will attend a live one hour lecture delivered by Purdue faculty utilizing an online distance learning application. The weekly one hour lecture will cover the theory behind the concepts of PLM focusing on the business case and how it has been implemented on a global scale to reduce cost and risk. The lecture brings this global concept down to the individual engineer by educating them on how their decisions in the CAD/CAM (CATIA V5) application directly affect each part of the product lifecycle.

Students will then attend a two hour laboratory each week at a community college with Boeing Subject Matter Experts (SMEs) and knowledgeable faculty as instructors to receive hands-on experience in the CAD/CAM tools. During this first delivery of the program, Edmonds Community College in Lynnwood, Washington will be hosting the labs for applied learning. In the future local campuses around the country and throughout the world will be able to benefit from similar partnerships.

To maximize learning in the lab sessions and minimize content maintenance, the certification program will utilize Dassault Systemes world class online training materials for basic applied process methodologies coupled with custom aerospace inspired exercises developed by Boeing SME's and Purdue faculty.

5 Summary

The engineer of 2020 will require new problem solving skills, a multidisciplinary approach, coordination between distant geographical locations and multicultural teams to access and select one of many possible solutions. The challenges before this global aerospace education program in Product Lifecycle Management are great. Assembling meaningful technical information for the global aerospace community will require not only the technical know-how but the judgment as to what is necessary in terms of education for the future workforce. This certificate program provides a convincing and significant model that can be leveraged across industry and higher education. Developing a solid academic, government and industrial business network will enable The Boeing Company, Purdue University, and Edmonds Community College and Dassault Systemes to leverage the enterprise intellect and focus stakeholder resources to build the 21st Century workforce competencies. Through this integration and collaboration, the business transformation is underway and the ability to leverage process knowledge and methodology is within our collective reach. Developing the learning methodologies that seamlessly exchange knowledge across cultural barriers may be ambitious. Cultural ethics and morals are relative and will present a real challenge; furthermore the individual cultural biases can become a real barrier to the exchange of knowledge and processes. However, in spite of these challenges, the power of this educational model promises amazing breakthroughs for the future aerospace industry. The learning design will help entry level and incumbent workers define their learning through contextual, scenario-based and immersive experiences.

Additional Industry-Academic examples include, the Boeing-University of Washington Certificate Program in Aircraft Composite Structural Analysis and Design[6]. This program is progressively tailored, "theory to application" and was recently awarded the Corporate University Xchange[7] "Excellent" award for Industry University partnership, the top award in this class. The wealth of opportunities for generating cases is clear. Partnerships between industry and academic units to generate case-based materials are effective teaching tools. However, the approach is dependent upon a faculty workforce that is skilled in delivery and evaluation of case-based materials, as well as access to a database of case-studies. We are educating the engineers of 2020!

The NAE Engineer of 2020[1] project was an initiative that launched a dialogue about the critical educational changes that are needed to meet the new demands of the engineering profession. In addition, the recommendations from "Preparing Boeing Engineers for Future Learning[8] study revealed a need to explore different approaches to learning, both from the perspective of what is learned, and from the perspective of how learning takes place. A great deal is being discovered about how people learn. Especially important is the need to balance a focus on (a) the core knowledge and skills to be acquired (with understanding rather than only remotely); (b) the strengths and needs of the students in ones courses—including their outside interests; (c) multiple opportunities for formative assessment and opportunities for revision; and (d) the development of a sense of community where everyone feels motivated and empowered to learn from everyone else. Within this balance of features, additional learning and teaching strategies also hold promised

Our curriculum development process followed a design-based research methodology. Specifically, we continually analyzed the learning environment through cycles of design, student engagement, analysis, and redesign. This approach enabled the progressive integration of "usable or application knowledge" and aligned the theoretical and functional knowledge to the industrial environment. Teaching in cooperative or scenario-based environments provided the framework to achieve this type of learning environment. Cooperative-oriented teaching requires far more effort from the instructors, with a new perspective in the application of classroom learning objectives and assessments, but the level of end-use knowledge, problem-solving, and retention on the part of the student is much higher. To obtain this level of learning, a strong focus must be on the psychological needs of the individual student, be he or she Japanese, Italian, Australian, American, etc. No matter how effective the global delivery system of instructional materials, this educational approach will fail if the final product, as delivered to the student, does not meet his or her personal needs and desires. Successfully forging a new partnership, such as the model described above, among academia, public and private entities, and business is strategically critical to achieve educational transformation.

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Shifting lead as PLM introduction strategy

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Abstract: This paper deals with the complexity of providing support for electrical and electronics development in a global product lifecycle management (PLM) system. State-of-practice based on a case study performed in the automotive industry is reported on. A new approach named shifting lead is presented. Applied in IT/IS introduction projects this approach allows user groups or departments with dominating need to take lead in customization and pre-study projects. By balancing disciplinary needs this way a means to obtain process mapping, adapted IT/IS functionality and improved efficiency in the PLM system is obtained. Shifting lead is suggested as a way to create PLM support scalable to a majority of users. The approach is further elaborated to incorporate system integration approaches towards the emerging enterprise PLM system.

Keywords: PLM implementation, mechatronics, information systems, software, complex product development, shifting lead, requirements management, systems engineering

1 Introduction

The automotive industry has encountered a technology shift from developing physical mechanical products to developing systems that include more electronics and software functions. One effect of this shift is the need for integrated product development, in order to increase information exchange between engineering disciplines. In the automotive industry information management systems (IS) have evolved to incorporate multiple organizational functions and different engineering disciplines. The added requirement of working with multi-brand platforms has further increased the need to make information available in globally accessible IS.

PDM implementation projects are more complex than information technology (IT) projects, such as introduction of disciplinary IT support tools and expert tools, and requires reengineering of the product development process to fit both the user needs and the chosen PDM system [1]. Product lifecycle management (PLM) is a business approach and a mindset that spans the entire organisation, integrating people, processes, business systems and information [2]. Garetti et al. [3] state that PLM projects are highly intensive projects from an organisational point of view. The reason is that PLM cuts through all aspects of an organisation from the earliest conceptual design through the life of the product. PLM must serve different stakeholders with interests in different business areas, hence organisational knowledge of how heterogeneous groups work is essential [4]. The PLM scope incorporates IS that deals with product information across the extended enterprise. In the introduction of a PLM system it is required that the operational processes within the organisation are understood, inconsistent terminology is resolved and product views to accommodate consistent data representations are defined. Management commitment and understanding is identified as crucial for this type of introduction projects [3, 5, 6]. Management on different levels needs to create an introduction strategy to guide the introduction that will be the basis for different introduction plans for the selected business areas [7]. The IS users' interest, motivation and willingness to change have to be considered in the introduction process of PLM systems in order to realize high efficiency [8]. IS user perspective and a bottom-up approach when introducing a new PLM system in EE development results in satisfied use [9]. A pure bottom-up approach is however questionable due to limited top management involvement [9].

The performance of pilot studies is encouraged to verify that IS meets the specified requirements [1]. It is important to estimate the IS user maturity as well as IS maturity, adopt the customisation process to individual groups and to find the precision level of the introduction plan in order to prepare for a PLM introduction [10, 11]. Alternative approaches and solutions to accomplish change should be studied. Satisfying results have still not been shown in related research of how to plan for PLM introduction approaches that come to terms with balancing both user needs and business applicability.

2 Research Approach

A case study on introduction processes for PLM systems in complex product development settings has been performed at the electrical and electronics (EE) department of an automotive manufacturer. The case study followed an internal company project that aimed at exploring and analysing prerequisites to obtain a successful introduction strategy of a requirement management (RM) tool. The RM tool is going to manage mechatronic product information in EE development, something that is not possible today at the company.

A participant observation study [12] was conducted by one of the authors who was involved and worked closely for five months with the company. The researcher followed and participated in the project team meetings and was situated on site on average four days a week from August 2006 to January 2007. The field notes that formed the data collection were analyzed and verified through arranged workshops with company employees. As an integrated part of this study 25 semi-structured interviews were conducted to further map the organizational needs. Future users of the RM tool were interviewed, including eleven managers and ten designers from the EE department. Respondents were chosen so that all divisions and levels within the EE organization were represented, spanning from designers to the manager of the EE department down to designers. An additional four interviews, focusing on a recent CAD and PDM introduction project, were performed with designers from the mechanical department.

The four interviews in the mechanical department were made with members from the planning group of the introduction project. The interviewees were selected based on recommendations from contact persons belonging to the company project. The interviews lasted one hour on average and were conducted in August to December 2006.

The RM tool, in this context, will be used as designers' primary IS for retrieving and storing product information and is not intended to be used as an expert tool. The RM tool will contain functionalities such as requirement authoring, system mapping, and verification.

3 Findings

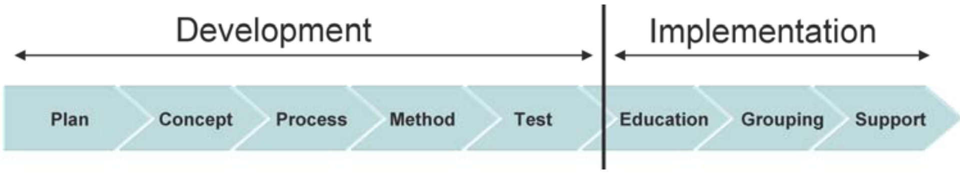
According to the interviewees, introductions of new IT/IS are, to a high degree, driven by technology and partners (brands and IT suppliers) rather than by actual designer (or business) needs. Interviewees experienced that they had to adapt to the introduced technology and very often needed to work with several systems in parallel. There are many differences between the different IS used, *e.g.*, the legacy PDM system and the document management system have similar interfaces but different types of commands to access and search for information. Information management is perceived as confusing and time consuming. One interviewee expressed it as "you have to know the article number and the folder it is stored in, in order to find the information."

3.1 CAD and PDM introduction process

An ongoing combined CAD and PDM introduction project was performed at the mechanical department at the time of the study. The project started a couple of years ago with the purpose to simultaneously introduce a new version of the CAD tool and a PDM system. The project took on a top-down approach where the initiative of a new IT and IS came from upper management. The introduction project was sequentially executed starting with one major development phase that was followed by an implementation phase (Figure1). In order to allow for some adaptation to existing work procedures 80% standardization and 20% customization of system functionality was achieved. This made it possible to allow information exchange cross the extended enterprise, involving other brands and suppliers. According to the interviewees the effect of customisation resided in providing accessible information, similar work procedures and better user interfaces.

Employees with knowledge about different work procedures participated in the project development phase in order to obtain a understanding of the existing needs on different organization levels. Education and long-term commitment towards the new CAD system was considered highly important in the project; hence resources of education specialists in the new system were provided. All end-users attended a training course during a ten-week period, including practical and theoretical exercises. At the end of the training there were group activities and IT support available. During the courses the users worked with their own cases and all courses were adjusted to roles and responsibilities within the organisation. The real need experienced by the designers concerned designing tasks and functionality of the CAD tool, whereas the PDM system introduction was necessary in order to fully use the CAD tool functionality. One designer expressed this as "PDM is something extra that comes along the CAD introduction".

Figure 1 The sequential CAD and PDM introduction process for the mechanical department

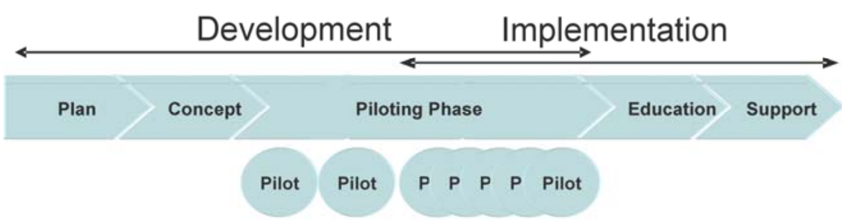


3.2 RM introduction process

The introduction of an RM tool that supports mechatronics development is regarded by management as a partial step towards a global PLM system. The introduction is based on a step-by-step process where the RM tool is introduced and slightly modified according to one user group at a time, resulting in an overlap between development and implementation phases (Figure 2). At the time for the case study the company reached the piloting phase of the introduction process. The selection of the initial pilot group was based on management's belief that this group experienced many diverse needs. Therefore this group would be subject for a pilot to collect requirements that reflected as many different needs as possible. The introduction process was focused around deployment for one development group at a time. This way, each introduction could be seen as a pilot, adapted to a specific group in the organization (Figure 2). The overall integration of each modified instance of the RM tool is coordinated centrally to make sure that the RM tool will work throughout the organisation. The integration of the RM tool to a future PLM system was considered but not of the focus at this stage of the planning phase.

EE designers expressed a need for an RM tool adapted for EE that contains possibilities for model-based development, concurrent simulations and calculations of EE functions and software. According to interviewees the used introduction process effectively gathered user requirements that concurrently could be implemented to user groups by customizing the RM tool, providing the users with an RM system adapted to their development needs. At the same time the RM tool was based on a standardized software solution, similar to the 80/20 customization goal in the step-by-step process. The experienced negative effects of the process was that it was considered costly and time-consuming; there was also a continuous debate over what system and which supplier to use.

Figure 2 The introduction process used at the EE department consisted of an overlapping development and implementation phase that included several pilot projects



4 Analysis

The main business challenge in the studied company seems to be to manage and balance diverse requirements stated by different stakeholders within the organisation. Some conflicting requirements experienced in a field like EE, *e.g.*, different ways of managing versions and configurations, can be traced to diverse traditions within software, electrical and mechanical disciplines, all active in EE development. An example of these differences are concurrent versioning and branch merge functions [13] currently available to software designers and that are incompatible to standard PDM sequential versioning.

A focus on the CAD tool made it more difficult for the designers to understand the need for the PDM system and how it would facilitate development. Since the user is the actual person involved in the design work a focus on the user needs makes it possible to find good integration between processes and tools used in product development. Integration with other disciplines and organizational functions is not within IS user perspective, and sometimes the user does not really know what the best compromise for the business is. All requirements on the RM tool posed by different EE stakeholders are not realistic to achieve but require trade-offs. This is why a combination of user and business needs must be applied, balanced with technical challenges.

4.1 Introduction Process towards PLM

During the interviews the respondents focused on benefits with the introduction of the new CAD tool. Benefits with the CAD system were also evident to most users from the very beginning, but with the new PDM system the benefits are still (after the introduction) difficult for the designer to realise. It is argued that the understanding of what PDM is, and the usability of such a system in order to collaborate and share the product information, is not fully understood in the organisation. The need to integrate additional types of information and connections to the configuration and legacy systems was not part of the process. The large amount of time spent on education and stepwise introduction process is believed to be one reason for this success. Another suggested factor is that CAD by tradition is seen as an essential design tools within automotive industry, and that the CAD introduction therefore was well-planned by management, and well executed in line with the wish of designers.

Considering the planning phase and the intentions of the RM tool introduction process there are other conclusions to be drawn. The intention in the studied company was that when the first groups (the pilots) have been evaluated the remaining groups could be introduced to the new RM tool in a similar way, with the precondition that that introduction was successful. The concept of introducing one group at the time, with small customizations, makes it possible to involve the designers. The shown benefits with IS customisations are for example the possibilities to adapt information presented to a specific role or development group in order to reduce the complexity, and the positive psychological effect of being able to state requirements on the new systems. The RM introduction process makes it possible to speed up the introduction as the tool becomes more mature and bugs are identified. The pilots are similar to a roll-out and can be considered as step-by-step roll-outs. For the last groups only minor customizations are needed and it is expected that they can get started more quickly.

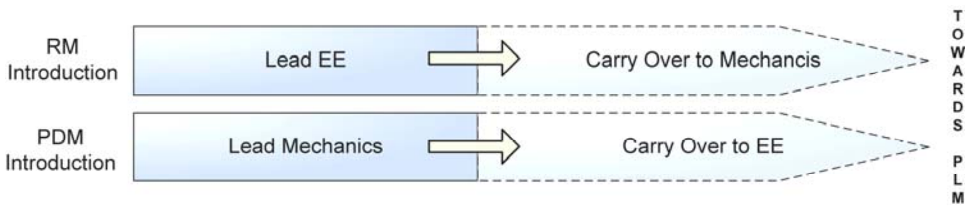
To this point a systematic method for selecting pilot groups has not been used in the studied company. Instead, the selection seems to have been based on personal agendas e.g. where management is supportive, and where money is available to finance such an introduction. This could lead to unnecessary expenditures and heterogeneity, when competing systems are introduced or customisations are done to solve similar needs. Some designers use systems that they are satisfied with and some have other urgencies. If smarter ways are used to identify groups with similar needs by e.g. a questionnaire [14], customisations and introduction could group users based on other properties than organisational belonging e.g. roles, experience, or special needs. If groups could be selected systematically according to needs and willingness to start working with the new RM tool it is believed that the introduction process could be smoother.

5 Shifting Lead

Based on the findings it is suggested that one way to come to terms with the need to balance different requirements and perspectives on an IT/IS solution is to adapt a shifting lead approach. In the studied company, problems with RM are more severe in EE and software development than in mechanical development. In this case it is recommended that EE and software designers should specify the framework for the RM tool. The mechanical branch (that requires less complexity of requirements) can thereafter adopt the RM tool towards their need. The solutions are carried over to the mechanical development in a later stage, but verification and follow-up between the two departments are made continuously.

The same approach can be considered when introducing PDM systems. The use of CAD tools is central to mechanical engineers, and this discipline should take lead when specifying the PDM system since CAD management is central for a PDM system. Once the design is decided a carry over of the PDM system should be made to the EE development. Some modifications to the PDM system for EE development are allowed and might be needed, but made changes must not be conflicting with the overall requirements stated by the mechanical needs. Hence, an increased collaboration and exchange of experiences between different engineering disciplines will help to obtain a mechatronic PLM. The belief is that shifting lead will help different departments to realize diverse needs and the advantages with a transparent IS will become more evident and easier to grasp. An illustration of the shifting lead approach applied to the studied RM and PDM introduction is shown in Figure 3.

Figure 3 Shifting lead and carry over between EE and mechanics.



6 Discussion

Special attention is needed for any department when planning a systems introduction: an introduction of a mechatronic PLM solution faces additional challenges. The commercially off-the-shelf existing IS for EE are less mature and integration concepts towards other systems are less evaluated than for PDM systems for mechanics. The EE department itself is heterogeneous; it includes mainly EE engineers, but also software and mechanical engineers which makes the inter-disciplinary communication problems similar to the problems on an enterprise level. The IS need to support mechanical, electrical and software requirements, and contain the whole span of requirements, solutions, interfaces, and verification objects as well as loose connections towards other systems. The shifting lead approach is believed to support the integration of heterogeneous systems, by, *e.g.*, a service-oriented architecture (SOA) [15]. Shifting lead is applicable in settings where there is a need to share the same information cross-disciplines. It is discussed that a precondition for the shifting lead approach is that there exists similar needs to use the IS throughout the organisation, which is the case with PLM systems.

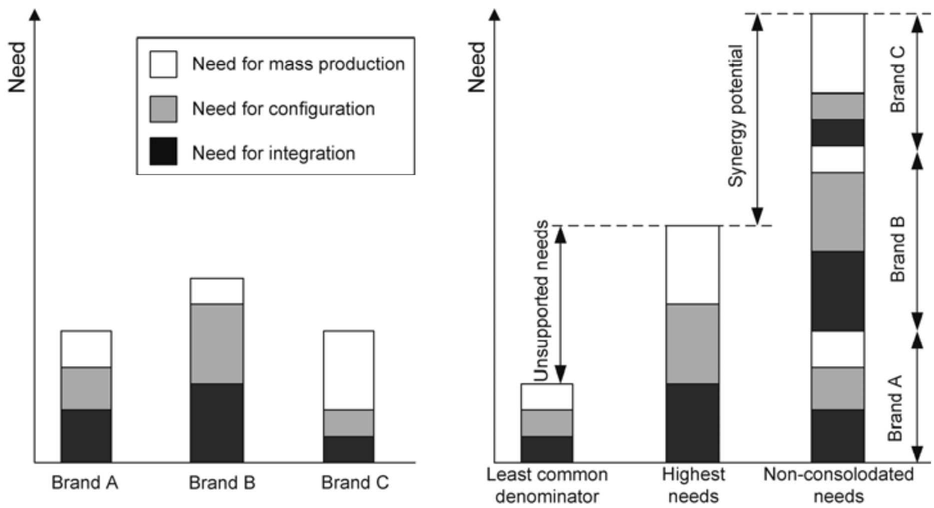
Three main organizational levels are discussed as possible levels for applying the shifting lead approach in a large company. The overall business consists of several business levels; applying this to an automotive company the business level would be the brands that have different, historically separated business units. The second level would be the disciplines within the brand, *e.g.*, mechanical discipline, EE discipline, *etc.* The third level would be the group that share a common need, applied to a car manufacturer; an example could be the development group in charge of the speed control system.

On a business level the approach of shifting lead can be applied on the brands within the group of an automotive manufacturer. The brands have different characteristics and business models for developing cars that could be essential for that brand. There could e.g. be a mass production brand (brand C in Figure 4) and a premium brand (Brand B). Their business models and needs are different which is reflected in their need for IS. In the example, brand B has a higher need for configuration than brand C, but brand C has a higher need for commonality due to its mass production model.

Focusing on the least common denominator (4^{th} column in Figure 4) will lead to a system solution that satisfies the brand with the least complex need. The idea behind this approach would be to start with the least common denominator (needs) and work from there towards more specialised systems for each brand, with a common core. The practice of finding the least common denominator is not believed to work since the group with the least complex need will set the standard. This will make it difficult for the company with the highest need and best practice will not be enabled. Such an approach might lead to IS that does not support brand-specific business models, standardizing development to a level where uniqueness essential for competition advantages is lost.

Another approach could be to develop one system for one brand's need and then use it throughout the organization, meaning, *e.g.*, that brand B's system is used for all brands (which could be considered when one company buys another company and instructs them to use their system). This would be negative for brand C since their business model and hereby their needs are different, which could lead to that their business advantage is lost.

Figure 4 Hypothetical illustration of different needs within an organisation.

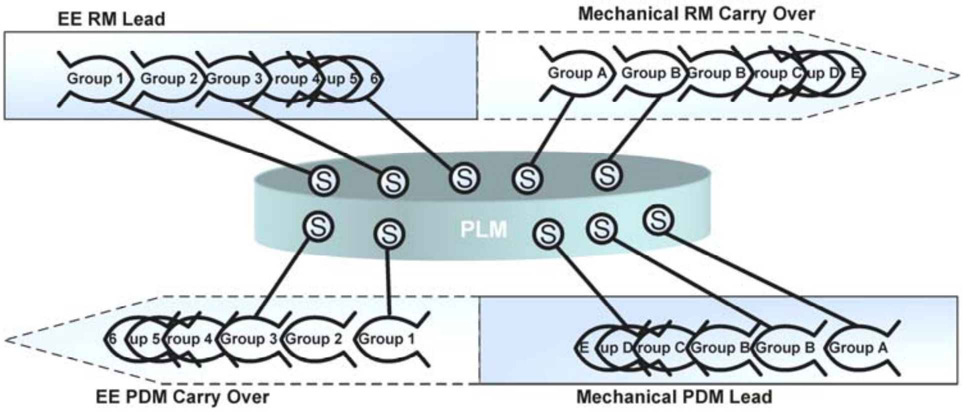


The solution of satisfying all needs (6th column in Figure 4) will also be very difficult to achieve and this solution would most certainly contain overlaps that require extra development costs of the IS without gaining any major advantages. The shifting lead approach suggests that the brand with the highest need must specify the requirements of a common information management system (5th column in Figure 4). This solution will then be possible to scale down for other brands. By identifying IS user needs, the interest group that experiences the most dominating need is allowed to set the IS framework. Responsibility can be distributed in the same way as technology development is distributed across brands to ensure specialization and high quality of technical solutions.

The different needs can be further refined to group development teams. In order to select the group with the highest need, groups could be classified according to Figure 5. The group with the highest need are group number one, and should hence be selected to take lead of that IT system development. However, group two also has major needs regarding that system so it is important that they participate early in the introduction process as well. Group five and six, are content the way things are, and do not need to be rushed into the new IT system. The first groups would be keen on using the system and adapting to it, as well as the last groups are likely to experience the smoothest transition since most mistakes are corrected earlier in the introduction process.

The approach of shifting lead would be similar to a platform strategy common in the automotive business. It is easier to scale down a high end product to a low end product than vice versa. In the case of the mechatronic discipline the higher demands on RM by EE and software development will put that department in charge of stating requirements on the RM system. It is suggested that the IT/IS introduction processes should be coupled with the shifting lead approach, where EE and mechanics shift lead between functionalities in PDM and RM evolved from the introduction projects. The product development process should be the baseline when introducing a new RM tool. Conflicting requirements on whether to choose a standardized RM tool and customize the process after the tool, or customize the tool after the product development process must be balanced. The overall global development process should not be considered to be changed significantly just to fit a local system in one of the local departments. It is also not reasonable to customize a tool to include every delivery and process gate in the development process. The global development process allows flexibility on a user level for standardized tools and systems, a flexibility that can be used in order to customise tools to the work procedures of specific development groups.

Figure 5 A step-by-step introduction process for the exemplified RM project for EE and CAD and PDM project for mechanics addressing the needs in different engineering disciplines. The overall system architecture is exemplified by different PLM services (S) that can be used by any IT/IS, implying an SOA.



7 Conclusions

The question of how to obtain a PLM solution that satisfies IS user and business needs in a way that is technically possible is elaborated in this paper. By applying shifting lead in organisations developing complex products the introduction of PLM is approached according to the needs from different engineering disciplines. It is argued that introduction groups should be chosen according to receptiveness to change and not primarily clustered according to development group, discipline or brand belonging. The approach of shifting lead in introduction projects allows user groups and departments with dominating needs to take lead in the customization and introduction projects, *i.e.*, be the group that states the requirements on the IT/IS. The system solutions can then be adopted for other user groups, expecting reduced rather than increased need for IT/IS functionalities.

It is claimed that EE designers have more demanding needs in the use of RM tools than mechanical designers, and should lead the tool customisation. The same relation goes for the mechanical discipline when comes to CAD and PDM systems. The approach of shifting lead has a strong user focus but must not entirely focus on user needs. Other aspects of PLM introductions also have to be accounted for, *e.g.*, the business needs and the technical challenges, in order to create cost effective solutions with good integration capabilities. It is argued that this process significantly will improve both the quality of IS customizations and the satisfaction of the end users, as well as allowing for IT/IS integration towards a central PLM system.

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Aalborg Industries – Engineer to order PLM

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Abstract: This paper described PLM considerations at Aalborg Industries A/S, a producer of engineer to order heat and steam generating systems, which is currently facing a number of challenges due to globalization, development of organisation structure and high product complexity. The product definition happens over a long period, which also introduces challenges related to managing product information. Aalborg Industries is expecting to meet these challenges by implementing a PLM system; however a number of issues must be addressed to ensure a successful PLM implementation which relate to the current information, product and process structure.

Keywords: Engineer to order, PLM system, product configuration

1 Company Presentation

Aalborg Industries A/S (AI) is a large producer of heat and steam generating systems operating on the global market and dates back to 1912 where it was part of a shipyard based in Aalborg, Denmark before becoming a separate company with steam boilers as core business. In 2005 the turnover was € 222m and average number of employees 1683.

Products are offered for two different application areas; the maritime sector and industrial purposes, where the maritime sector accounts for the majority of the turnover. The typical customers in the maritime sector include shipyards, ship owners and offshore oil production facilities. The main product types are oil fired steam boilers, waste heat recovery boilers, thermal fluid systems, heat exchangers, inert gas systems, burners, control systems and various other system components to form complete heat and steam generating solutions. The systems will usually consist of several of the components mentioned above. Each of these solutions is tailored to meet the individual customers demand, and thus two systems are never identical unless a series of systems are delivered for a series of ships, where the systems will basically be identical with only a few minor differences. The customisation of each product is necessary since the boiler systems need to be integrated with the other systems aboard the ship.

2 Current Situation

This section describes AI's current situation and is intended to describe the motivation for working with product lifecycle management in the future

2.1 Globalisation and business structure

Like many other companies AI has during recent years become more globalized. Due to a number of acquisitions, the organisation is now much more geographically spread compared to 10 years ago. This presents the company with a number of challenges in relation to collaboration between the different business units which have different working procedures, different IT systems and are located in different time zones. Thus a major challenge exists in integrating the business units, to ensure that the competencies are utilised optimally in the market.

New product development projects as well as order execution must take place where the competencies and capacity are available, and projects will be undertaken jointly by different geographical locations. Also sourcing must be optimally utilized on a global scale. AI’s business structure involves that sales and some order execution is carried out in “front end offices” located close to the customers on the various markets. This implies that competencies for sale and order execution must be present in these locations, however due to the product complexity and cost optimality it is considered infeasible to have competencies to carry out all engineering tasks in each office. The front end offices have competencies for the most common tasks, but rely on centralized product centres for advanced engineering tasks. Therefore a number of challenges exist with regard to enabling collaboration globally to ensure that information can be shared effectively between AI’s entities. These challenges must be met in order to optimally utilize the business structure described above.

2.2 Product Definition Process

AI is an engineer to order company which implies that some engineering is necessary during the sales-delivery process. The majority of sold systems are however based on standardized products and components, and do not need a significant engineering effort. AI has implemented a product configuration system including a configurator to use automation to render the sales-delivery process more efficient. In this tool sales people can configure a range of the main products, calculate prices and generate sales documentation such as quotation letter, technical specifications for the main components and a number of CAD drawings and system diagrams may also be generated on basis of the configuration. However, since it is not feasible or cost efficient to implement all products in the system a number of products cannot be fully configured using this system, and the quotation process is less automated. Due to the very high variety, not all product options can be predicted and implemented in the system, so even for configurable products, it is usually necessary to handle a number of customer requirements manually.

During the sales process, the boiler system is basically designed and all main characteristics for components are determined as well as the scope of delivery for the system. When the quoted system is sold and turns into order the approval phase is initiated. During the approval phase, the system is specified more in detail and the specifications with more detailed specifications and CAD drawings are sent to the customer for approval. Usually a number of iterations are required due to change orders from the customer. During this phase, the necessary detailed design of the system and procurement is carried out, class approval and information for manufacturing and assembly of the system is prepared. Once this phase has been finished the system can be manufactured, installed and commissioned. The time span from a sales contract is agreed upon to the delivery of the last system in a series can be several years. Though the systems are in principle sold as being identical, the detailed specifications are seldom constant during this period due to changed customer requirements or AI's product optimisation from one ship in a series to another, and the later systems will not be identical to the earlier systems.

AI provides after sales service for customers, and thus when a system is sold it is necessary to keep track of the configuration of the system, as this is an advantage when selling spare parts and servicing the systems. Since the operation life time for the systems is usually several decades, there is a large amount of information which needs to be managed in order to service customers efficiently.

Since every product is being engineered to order, two main process chains exist, where product information is being generated and maintained. The first process chain involves new product development (NPD) or general maintenance of products not aimed at a particular order. The information generated in these processes is to be used in standard product designs (standard product platform) and are the basis of the systems designed for particular sales orders. The second process chain is related to the sale and delivery of customer orders. Here the products may be slightly or radically modified, without affecting the standard product design. Therefore, the product definition process set-up many challenges in managing product information in the entire product lifecycle.

2.3 Current IT Systems

AI relies on a number of IT systems for daily operation. A CRM system is being used for sales and marketing purposes, and an ERP system is being used for purposes as financial, order execution, etc. 2D and 3D CAD are essential tools in the sales and order execution phases, since they are used both to communicate product specifications to the customers and are being used internally for the order execution as well as manufacturing and installation. CAD files and other technical documentation for the orders must be managed efficiently, hereunder versioning during the entire product lifecycle, which implies a high demand for product data management tools. Due to the complexity and the number of necessary IT systems from various vendors having different or only partly standardized interfaces, integration between the IT systems is an important issue.

2.4 Motivation for PLM

AI is currently in the process of starting a PLM implementation. It is expected that a number of the challenges presented above can be eliminated or reduced significantly by a PLM system. It is expected that a PLM system will greatly reduce the non value adding time induced by e.g. manual handling and versioning of CAD files and documents as well as further increasing documentation quality. By structuring product data in a PLM system, it will be increasingly possible to automate the generation of certain product documentation thereby decreasing the time used in the sales and order execution phase. Also by structuring the product information in a PLM system, more product information and designs can be reused. This is in particular an advantage in engineer to order operation, since some work in each order will be repetition from previous orders and thus reusing this information can save resources. Also a PLM system will support handling of engineering changes, since relations between product information and documentation can be established ensuring consistent information and documentation quality.

A PLM system will furthermore improve collaboration within the company since product information and files can be shared across the organization. This will further enable executing projects with team members from different geographical locations and thereby utilising competencies optimally. Finally, the PLM system is to support the after sales activities by retaining product information for delivered systems and tracking changes. Once after sales service is necessary, product information will be significantly more accessible compared to the current situation improving customer service and rendering the internal business process more efficient.

3 PLM Challenges

Structuring product information in a way that is suitable for implementation in a PLM system is a challenge. To automate parts of the order execution documentation task, there must be a strong relation between product and documentation structure. E.g., information structured document centric needs to be restructured to a product centric structure.

Another PLM challenge is related to the different process chains, product development and order execution. Product information generated in product development will be used for order execution, where it may be altered to meet customer requirements. However customisations in the order execution should be merged into the standardized product portfolio whenever feasible and thereby be reused for following orders. Hence a complex relationship exists between the information in the two process chains which may yield certain challenges in the PLM implementation. Related to this is also the management of product life cycles. In AI's case, two different product life cycles exist; the life cycle of a certain product type or product family in the market (standardized product platform) and the life cycle of a particular instance of a product (as installed and maintained). The information for the two life cycles may be overlapping; however the overlap will vary between orders since the degree of engineering varies between orders. Thus also a complex relationship between the information for these two life cycles exists.

Finally the long time span for a customer order to be executed introduces issues related to PLM. For instance, two products sold as being identical may in practice be different due to customer change orders or standard product design changes. Standard components used in repeated orders may be changed several times during the order time span due to supplier's performance or cost optimization and the relation between standard component designs and their application in products in order needs to be handled.

4 Conclusion

Aalborg Industries (AI) is presently facing a number of challenges related to globalization and a need for integrating different organizational units as well as IT systems. These challenges become even larger due to AI's product and business process complexity. Currently introducing PLM, AI addresses these challenges, but still a number of issues exist that must be addressed to make a successful PLM implementation, including product and information structure, process integration and long order time span. It is however believed that once these issues are addressed AI and the customers can gain significant benefits from a PLM implementation.

Space products lifecycle management: new frontiers for PLM

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Abstract: This paper aims at putting PLM in perspective in a non-traditional field, such as space. Maturing sectors like Aeronautics and Automobile have much in common with the space industry. The article will build upon these similarities to identify differences and provide recommendations based on the experience gained in more traditional sectors. Three steps are used in this process: (1) major areas of a PLM approach are identified; (2) metrics regarding similarities and differences between sectors are described; (3) customization of the PLM approach is detailed for each area according to criteria at hand. Main findings include: (a) low product population imply less configuration management needs; (b) the need for high reliability requires extensive and severe testing and standards enforcement; (c) a strong need exists for enterprise PLM systems scalability, due to a diversification of space programs from space agencies to private companies.

Keyword: space, PLM, processes optimization.

1 PLM in known environments: Aeronautics and Automobile

PLM has been around for several years in sectors like Aeronautics and Automobile. Major areas of PLM are now well identified and data models converge to more standard forms, although there are still consequent differences between customers. Pratt & Whitney Canada delivers thousands of engines for commercial aircrafts each year (1). Bombardier developed 1 new or derivative aircraft per year over the last 16 years (2). Embraer delivered 141 aircrafts in 2005, including 120 commercial aircrafts, 14 for executive, 7 for defense and government. These numbers are stable since 2000 (3). Total number of vehicles sold worldwide by Renault in 2005 (4): 2,533,428. Renault is projecting to develop 26 new models between 2006 and 2009, divided equally between replacement models and expansion models.

PLM can be divided in areas satisfying different needs:

- Computer-Aided Design, Engineering and Manufacturing (e.g. Relational Design, finite-element analyses, manufacturing engineering, plant layout, equipments and packaging design, production tools, process planning)
- Product reviews (e.g. Digital Mock-Up, realistic rendering, Rapid Prototyping, Virtual Reality)
- Documents management (e.g. versioning, lifecycle and propagation management)
- Work management (e.g. linking change orders to product structure modifications)
- Product structure management (e.g. configuration & portfolio management)
- Requirements management (e.g. customer, marketing, and regulatory requirements)
- Knowledge management (e.g. knowledge-based engineering, standards & procedures
- Authorizations management (security model, military regulations enforcement)

Once management topics have been considered, complementary aspects such as system implementation and support need to be investigated: software infrastructure, implementation size (how many users), deployment strategy and scalability, interfaces with other internal information systems (ERPs, CRMs, SCMs) and external systems (e.g. supplier CAD format or PDM system).

2 The Space sector particular context

All sectors are under the same globalization trend. Space is not an exception, with China and India taking a more important place every year (5). Other nations in Asia, Africa and in the Middle East now have concrete space activities, which mean that even high-technology sectors have to face fierce competition from most countries. This trend implies more exchanges between dispersed companies, thus more integrated information systems, with access to information at anytime, from anywhere.

Just like Automobile and Aeronautics, the Space sector faces a very dynamic environment. However, sources of change are specific to the sector (5): shrinking government budgets for defense and scientific space missions, increasing commercial interests for space applications, and technology advancement.

Any of these parameters taken independently calls for more control over products lifecycle. But taken together, they make a PLM approach necessary for companies to keep in control of their products. With fewer workforces to handle more complex products in a shorter time, a clear outlook on the product at any time of its lifecycle is not a nice-to-have, it becomes mandatory.

Between 1998 and 2001, telecommunication satellite operators ordered an average of 27 satellites a year. Between 2002 and 2005, average annual orders have dropped to 15 (5).

Standardization between product models (e.g. communication satellites) is rare, and in any case not comparable to what exists for aircrafts or automobiles. In subsectors such as meteorological or environmental survey, even standardization between production units is almost non-existent, although some efforts have been undertaken to standardize the bus in satellites (the generic part in a satellite, providing for altitude and orientation control for example). The number of parts in a spacecraft varies a lot. At low-end are micro- and nano-satellites which can total less than one thousand parts. On the contrary, bigger satellites or launch vehicles like the Space Shuttle include up to 2.5 million parts (6).

The Space sector is quite different from Aeronautics or Automobile. Indeed, both of these industries were born in the 19th century. Whereas the first satellite to orbit Earth was Sputnik in 1957. That is one of the reasons why much of space activities are still led by governmental programs. There are two sides of the Space sector: whereas more and more private companies develop projects and products, most of the industry is still led by governmental programs. This has a significant impact on budgets, which are less subject to return-on-investment evaluations, and longer delays, due to more layers in the decision-making process.

Mature sub sectors in Space are linked to the Telecommunications industry. This includes geostationary and Low Earth Orbit (LEO) satellites providing for television and intercontinental communications needs. The meteorological and imagery sector is gaining weight (5). Although they look more like science-fiction than industrial ventures for the moment, the following activities may represent an important share of the Space sector in the coming years (7). Future sub-sectors include space mining (extracting resources from asteroids), and space transportation (with such systems as tether space elevators).

3 PLM in Space: specific challenges

From discussions with professionals, it appears that reduction of the time-to-production metric is not as critical as in other sectors. Rather, the pressure comes from respecting project dates once they are set, because launch windows are driven by space mechanics which cannot be negotiated. Launches are critical events that involve not only high technology but also complex relationships between industrials, such as legal agreements and liabilities in case of failure. This is especially true for satellites launched in a “piggyback” configuration, i.e. as secondary payloads on a launch booked for a bigger satellite. To make better use of budgets, it is necessary to look for cost reductions in each of the lifecycle phases of a space product, as well as by analyzing this lifecycle as a whole (8). This calls for both extensive low-level data and powerful analytical tools, which fall under a typical PLM approach.

According to Industry Space Days report (5), the main income source for Space sector around the world is still state budgets. In many cases, it is even the only one. The commercial market is cyclical with a top-level in 2000 and low-level in 2003. The institutional market offers more stability. 50 % of the sector is represented by satellite applications, while the rest mainly consists in launchers production and development, and science & exploration programs. To better adapt to the evolution of space sector towards more private endeavors, it is necessary to reduce development time, and time-to-market in general (6). This requires for changes to be taken into account faster, and for products related decisions to be made with a better knowledge of involved consequences. A PLM approach allows everyone in the company to more accurately estimate the parameters on which decisions need to be made.

Technology is always improving, but also growing in complexity (8). Then for mature technologies, the challenge moves from a development approach to a management approach. As for new technologies, it becomes critical to fully understand how they will integrate with known technical solutions. A PLM approach can be helpful in both regards, because by formalizing rules of use in known technologies, it is easier to assess impacts of design changes, and thus better control the risks, quality, and costs implications of such a change.

Compared to Automobile and Aeronautics, the reliability challenge for space products is far beyond what we already know. For example, the cost of repairs for Hubble in 2008 are immense (900 million US$) (9) and far beyond any ROI justification for a private company. But more than money, it is frequently the feasibility of service missions that is questionable, in particular for geostationary satellites, although some maintenance can be performed on the software through uplink commands. This implies reliable technical choices, including redundancy of systems. The Challenger and Columbia accidents are obvious examples of the huge complexity Space products users are faced with, and how important it is to keep this complexity under control. Any stakeholder must be able to sort out data or contact an expert to find answers to their need, whatever the product lifetime, the location of the request, or the complexity of the analysis. This increased need of reliability requires more testing, more regulations and standards management. The PLM approach can help in linking theory and practice in this matter. PLM systems, by the automation they offer, allow any relationship to be evaluated from both sides. For example, links between requirements on satellites microprocessors and the hardware itself can be audited from the designer and the tester point of view.

A PLM approach allows products developers and users to perform “what-if” scenarios, and then better understand what they are trying to achieve by developing the product. By modeling the products in term of cost, schedule, performance and requirements, it is becomes easier to control what the product should be and to reach the balance between those requirements.

3.1 PLM in Space

A PLM approach helps in formalizing the way products are developed. In a mature PLM implementation, engineering knowledge is embedded directly in the product design, and/or in templates. In either case, such intellectual property (IP) containers will help develop subsequent products faster (because the new product can be smartly derived from the previous one) and better (because past errors and problems can be taken into account). Sharing concept and solutions over missions and products (8) cannot be achieved at reasonable cost without gathering all products data into a single database, or across linked databases. This will allow parts to be reused in different products while keeping a link to the original design to propagate design changes. This does not prevent new designs to be derived, as both capabilities are clearly identified in PLM systems and treated accordingly. Sharing solutions between commercial and military applications is a common need with the Aeronautics sector (8). This requires the products management system to be able to flag military parts and prevent unauthorized actions on them (such as access for example). With a well defined PLM implementation, it is possible to draw an accurate picture of all parts used in a company in almost real time, with regard to their security status and usage. Such an audit would take weeks if not months without a PLM system.

Using commercial and standard equipments is much easier with a PLM system in place: not only is it easier to identify outsourced parts in the system, but it is also possible to integrate suppliers in the approach so that these parts can be audited in real time by any authorized person in the company. The use of standard part or equipment is also a typical aspect of a PLM implementation, and the particular aspects of those components can be fine-tuned to represent the business processes of the company. For example, standard parts can not be edited by designers; they must be managed by a dedicated administrator.

The innovation pace can be enhanced because PLM systems allow for a more dynamic development environment. In a traditional design approach, information is transmitted manually between designers. Using links between informational objects, it is now possible for any designer to evaluate the dependencies of any design item to the rest of the production definition. This is called Relational Design. Again, although this permits a much quicker assessment and realization of any design change, this requires users to properly understand what they are dealing with. Then the downside of this approach is that training needs and learning curve are more demanding than in the past.

Capabilities can be partly embedded in the design itself, using approaches like Knowledge-Based Engineering (KBE). KBE describes the rules used by engineers to make decisions on the design directly in the CAx data. This enables future reuses of models as they can be adapted to new designs, alleviating tasks required for a new program, and then the workforce. On the other hand, this requires more expert users, as users need to be fully aware of the embedded logics in the models to prevent errors in the design process. Assessing and managing risks can be achieved by combining two approaches: developing statistical methods to evaluate risks based on design data, and implementing these relationships into the design, using tools such as KBE. For example, if it has been calculated that the thickness of a part results in fatigue rupture after a million cycles with a 94% probability, it becomes possible to play what-if scenarios and reach a compromise between risks and costs based on hard data rather than rules of thumb.

Prototypes play a very important role in Space product lifecycle: as such products are produced in very limited series, the prototypes represent a significant part of the program costs. It then becomes critical to minimize the number of prototypes used. PLM can help in this regard. Replacing part of testing activities with simulation and analysis is a viable approach if experience has shown that analyses and simulations can be correlated to testing results with a satisfying level of confidence. From a technical point of view, this requires not only extreme levels of precision in the models being simulated, but also very reliable and traceable processes for managing what is being simulated, and under what authority. For example, it is not rare to see huge simulations and analyses being performed on outdated geometry or specifications. Making sure that analysts are testing product data at the right revision, in the proper context, and in collaboration with other disciplines to fully understand how the product will behave, is not an easy task. Only small teams can today rely on personal communication to ensure their approach is complete. For complex products, there is not other choice but to trace modifications using information systems.

Low product volumes do not require extensive configuration management, yet. In the future this PLM area will probably get at least as important as it is today for Aeronautics. Standardization will play a part in the development of the Space sector, not only because parts are so expansive, but also because field usage of parts will be located further than before from shops producing them.

4 Conclusion

This article reviewed similarities and differences between traditional PLM applications such as Automobile and Aeronautics, and new ones such as the Space sector. However, we only presented here the landscape of these new PLM deployments. Further research could analyses in more detail what PLM tools can give the most benefits to Space products lifecycles. In the current context, due to the industrial market orientation towards low cost source countries, PLM applications are facing many challenges in order to support this requirement. For the next years can we predict the same evolution for PLM applications in Space sector, which is considered until to day a protected sector?

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PLM implementation at MAN Diesel A/S: a case study

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Abstract: A leading supplier of large diesel engines for ship propulsion systems, stationary power supply and rail traction, MAN Diesel A/S felt the need for effective management of data and empowerment of their vision for "Lifetime Management of Engines". Prior to PLM implementation, the design and service data of products were being managed by several home grown mainframe-based data management systems. There was a need for a collaborative environment which would improve design re-usability, make spare part identification easier and enable better interaction with engine manufacturers distributed globally. In addition, encapsulation of different rules, processes and standards followed by the various business groups in the organization was to be achieved. This paper would shed light on the implementation of the integrated and collaborative PLM environment at MAN Diesel, Denmark. Attention would also be given to the migration of data from legacy systems to the new environment and interfacing with the ERP system.

Keyword: service, migration, design, ERP, data

1 Introduction

A leading supplier of large diesel engines for ship propulsion systems, stationary power supply and rail traction, MAN Diesel A/S, Denmark felt the need for effective management of data and empowerment of their vision for "Lifetime Management of Engines" (LIME). With over three hundred concurrent users from different functional departments accessing over 2.75 million parts/items and ≈22 million BOM lines, the enormity of the implementation cannot not be overstated.

The Teamcenter Engineering (TcEng) product suite from UGS was identified for managing the product data and processes. As the out-of-the-box (OOTB) product did not satisfy all business requirements, extensive customization was necessary.

2 Why PLM?

Prior to PLM implementation, the design and service data of products were being managed by several home-grown mainframe-based data management systems. The high costs of maintenance of these systems and data integrity were of concern. Besides, various business groups within the organization were working as independent, self sufficient units. MAN Diesel A/S felt the need to consolidate them under one common system to achieve their vision for lifetime management of engine data.

Thus, encapsulation of different rules, processes and standards followed by the various business groups in the organization was to be achieved. There was also a need for a collaborative environment which would improve design re-usability, make spare part identification easier and enable better interaction with engine manufacturers distributed globally. The new system was expected to provide secure and easy accessibility to all technical data describing the engine lifecycle.

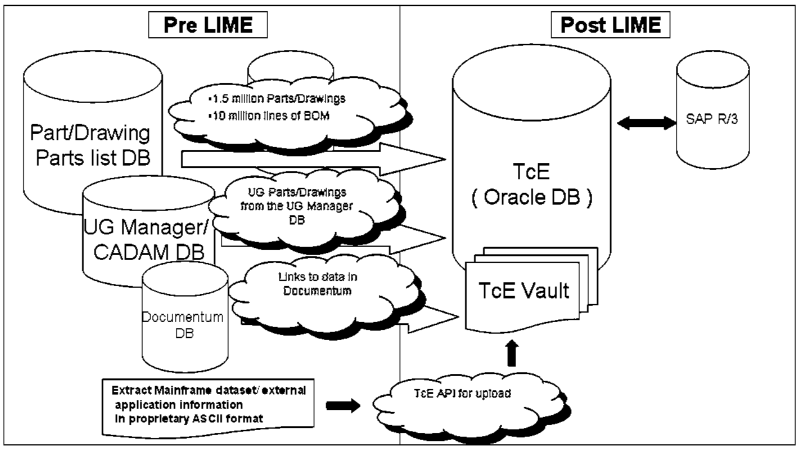
While ERP systems are good for planning and execution during the production phase of the product lifecycle, they were not found to address unique challenges of managing product data from concept through scrap.

3 Migration of Legacy Data to the PLM System

After a detailed study and prototyping, the implementation began with the migration of large volumes of 'live' and 'frozen' data from legacy systems to the PLM system.

Migration of data from legacy enterprise data-systems is one of the important and challenging tasks for most PLM implementations. The challenge lies in handling large volumes of data accumulated over many years. Moreover, the dependency of production activities on data, that is complete and accurate, stresses the importance for error free data migration. Translating data stored in formats as required or limited by legacy systems to conform to the PLM system specifications only adds to the complexity. It is also critical that the migration be completed within the planned timelines due to production schedules and/or inter-dependencies with other systems.

Figure 1 Migration of legacy system data to PLM system

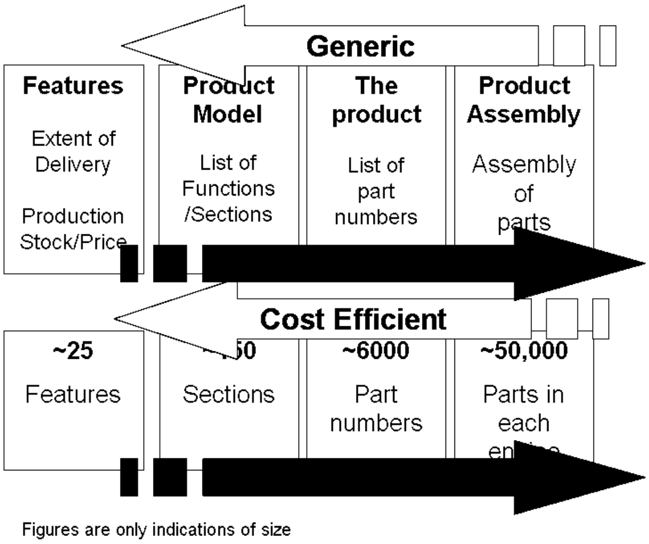


The crucial elements of the migration were to have a clear understanding of business data, processes and rules, identifying pre-requisites and dependencies, performing a detailed analysis of legacy data that would lead to creation of artifacts, carrying out technical evaluations, developing means to monitor and quickly undertake corrective actions and defining the appropriate sequence of data load.

4 Design System Implementation

The design business of MAN Diesel A/S starts with the receipt of an order for a diesel engine from one of its globally distributed licensees or directly from the ship owner, in the form of an “Extent of Delivery” (EOD). The EOD contains detailed engine-related specifications that would form the basis for design. On its creation, experienced design engineers use product configuration to come up with a configured BOM (for the engine type) for the order placed. The idea behind product configuration is reuse of ‘frozen’ design data in creation of new engines. Product Configuration also helps design engineers to identify gaps between available design and the required design for the given EOD. Design Department fills in these gaps by modifying existing design or creating new ones. On completion of design of sub assemblies or entire engine, the data is sent to the licensee for manufacturing the same.

Figure 2 Need for Product configuration



A major challenge in the implementation of the design system was customization of the base product to give users an interface that carried the feel of the home-grown systems that were previously in use. The customization also included business rules and checks to ensure data integrity and creation of data that conforms to the design rules laid down by the organization. Newer challenges are being faced in streamlining the process of product configuration to enable better reuse of already existing design data for similar engine types.

5 Data transfer to Licensees

The design specification, partial or complete, is sent as and when ready, in a standardized format. The information, which is currently transferred on electronic media, contains detailed information on engine structure. This data would act as input to systems at the manufacturer's side and hence, its formatting to suit the licensee's systems is of prime importance. The engine is manufactured based on the design input from MAN Diesel A/S. Modifications, if any, to the design data are usually the result of production constraints in terms of manufacturing equipments or processes. The manufactured engine, after tests for performance and other criteria, is sent to the end customer.

6 Managing Service Data

It has generally been observed that PLM systems are mainly used to manage engineering design data and not considered for service data. MRP/ERP systems are commonly preferred for service requirements. As MAN Diesel's business focus included servicing and supply of spare parts besides core engine design, their TcEng implementation had to cater to both these business areas with equal importance. Since a majority of service data is derived from design data it was advantageous to build and maintain both these data in one common system. The service system essentially manages details related to the engine's operation, maintenance and changes made during its lifetime.

At MAN Diesel, identification of potential spares for a specific engine configuration happens during the design stage itself. This information forms the basis for building the service system. After an engine is put into service, this system would be used for retrieving information to supply spare parts and rectify failed components. Since most engines are built by licensed manufacturers located worldwide, there can be differences between the 'as-designed' and 'as-built' product. This system also helps in capturing such deviations from the original design, during engine servicing. A major challenge faced during the development and implementation was propagation of relevant changes in design data to the service system.

7 Interfacing with ERP Systems

While the Design and Service data are being managed by TcEng, the data pertaining to sales was being managed by an ERP (SAP) system. As the Service system formed the basis for the Sales data, there was a need for updating SAP with data from TcEng regularly. This was accomplished by successful implementing the 'ERP Connect to SAP' package from UGS. One of the major challenges faced during the implementation was synchronization of a large amount of data released in TcEng with the ERP system. This took major proportions, with over 300 concurrent users working with 2.75 million parts and more than 22 million BOM Lines. This meant the interface was expected to handle data transfer load ranging from 450 to 2500 transfers a day, with a peak load of 250 transfers per hour.

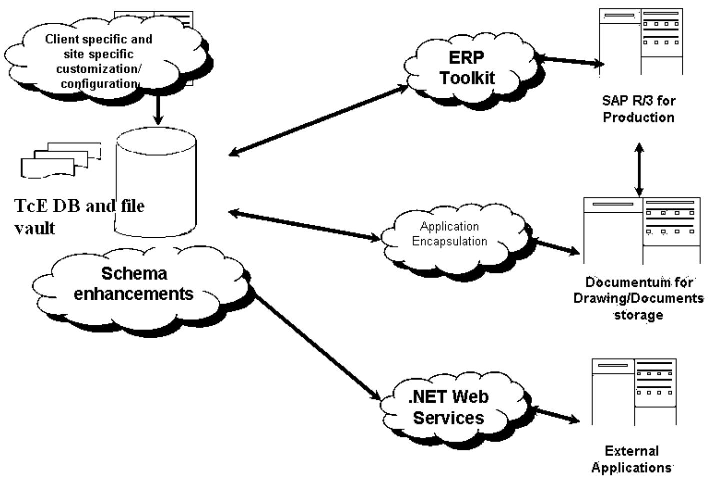
Other challenges faced include managing transfer of data released by multiple users with the use of a single interface license and the transfer of BOMs containing packed lines. All of this had to be done while ensuring integrity of component data transferred by including real time validations. Workarounds implemented to transfer data on non workspace objects and enhancements for centralized troubleshooting and fine tuning had to be addressed.

8 Unique features

The unique aspects of this implementation include:

- Migration of large volumes of data. (approx. 10 million BOMs and 1.5 million items)
- Handling of large volumes of meta-data (approx. 320 Giga-bytes).
- Web service integration with the PLM product for over-the-web retrieval of specific product-related data.
- Advanced product configuration, enabled through customization of the base PLM product.
- CAD integration and customization.
- Online PLM (TcEng) – ERP (SAP) interface with enhanced data validation, reduced manual intervention & data transparency across systems.

Figure 3 Enterprise Information Systems Implementation/Integration

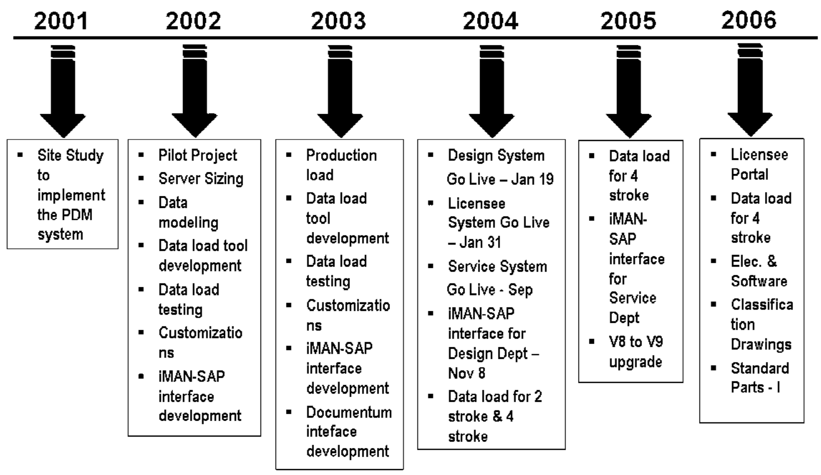


9 Summary

The main reason for the success of this implementation has been the realization of the maxim 'Business is the master; the system is but a slave'. The OOTB functionalities of the PLM product suite were not found to fully address the business requirements and existing process requirements of MAN Diesel A/S. The user community, who were until then, used to the mainframe based interface had to brought into the new system. Thus, maintaining the feel of the PLM predecessor was of also of paramount importance to ensure smooth transition to the new system. This led to extensive customization of the base product.

The implementation incorporated the complex rules of different business groups handling design and service data. Since this data formed the backbone of their business, a smooth transition from legacy systems to the new PLM system was ensured. Beginning with a site study followed by prototyping, the implementation, was successfully rolled out into production with Teamcenter Engineering v8.1.1.1.

Figure 4 Road Map of implementation



Over the past 3 years since roll out, the scope of the implementation has expanded to encompass new requirements, while meeting high expectations from the user community. Currently running on V9.1.3 and with plans to move towards TCE 2005, the system aims at aiding MAN Diesel to move closer to their vision of managing different stages of an engine's lifecycle.

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Chapter 4

Data exchange

Data exchange interface and model for coupling software in nuclear reactor simulations

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Abstract: This paper deals with a structure and organization to handle nuclear reactor models and all the simulations. The phenomena involving in nuclear reactors are complex and often dependant to each other. However, the simulation of these phenomena requires a high precision in order to control the condition of irradiation. Frequently, physicists use different tools with several approximations at each interface. We propose a multi-physics data model describing geometries and materials, called Technological Entity data model. This approach permits a parametric description of a study, independent of the code used to perform the simulation. Technological Entity data model is able to delete, insert and deform only one part of the geometry. Since the model is a parametric one, different releases of the geometry can be stored. An application for an experimental device simulation in an experimental reactor demonstrates the feasibility of the proposed method. It consists in solving a time dependant neutronic/fuel behavior coupling problem on fuel rods.

Keyword: data exchange, model, simulation software coupling, parametric geometry

1 Introduction

This paper deals with a structure and organization to handle nuclear reactor models and all the simulations. Nuclear reactor simulations require a knowledge in several physics fields like neutronics, thermalhydraulics, fuel behaviour. These studies are performed with complex simulation software, generally specialized in one field. Because physical phenomena involved in reactor behaviour are interdependent, physicists assumes simplifications to consider the interdependence of problems within the simulation programs. To avoid these assumptions, a full coupling of simulation is mandatory. Two possibilities exist to couple these software:

- A low level coupling, that implements the coupled problem directly in the solver method of a simulation software;
- A high level coupling, that permits to exchange input and output data between the different software.

The different programs generally require meshes of geometries and a time scheme (a time loop with a time step). A low level coupling implies many constraints. For example, the meshes must be equivalent so that the information are computed at the same points. Moreover the time steps must be compatible.

The second possibility to couple simulation software consists in disconnecting the different application programs and in providing the suitable features permitting to exchange information between a global model and the programs. More precisely, the exchanges are controlled and performed through the interfaces of the programs which are script interfaces. The different treatments of physical phenomena and the data format heterogeneity complicate the development of a high level coupled simulation. To overcome these difficulties, we set-up a parametric and multi-physics data model, called Technological Entity (TE), that permits to define geometries, associate materials and characteristics. This data model describes the geometry of a technological object in a tree-like structure that can be dynamically modified. An interface is proposed for the different physics simulations which does not constrain the physicists to convert their data formats into any other data formats. For each interface a specific function (get result) must be developed. The latter is in charge to return the required value at any point on the geometry so that each program ask to the other interface programs the values it needs at any point. Moreover other functions to supervise calculation steps and time loops of a simulation may be implemented. Then a supervisor program is able to synchronize several simulation programs and exchanges data between them.

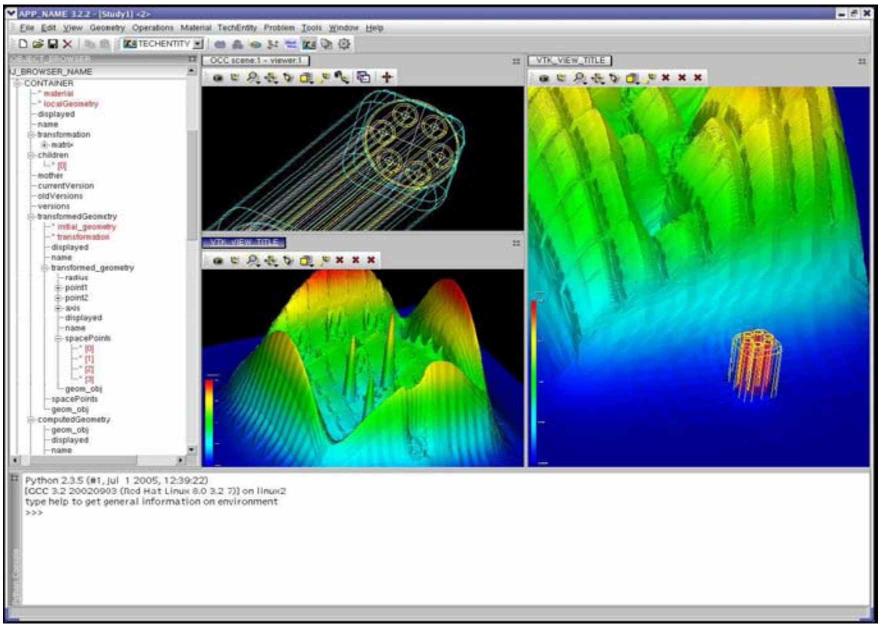
In order to be able to handle such large problems, these developments are integrated in a software component defined in the Open Source SALOME platform[1] dedicated to numerical simulations. Input data for each field are set into the TE data model. All the programs share the same geometry, but can consider different meshes of it. The simulations are adapted in order to be encapsulated in the proposed interfaces, and get their input data in the TE data model. Simulations can append data to the TE data model with their own results.

As the TE data model is integrated in SALOME platform and uses several of its components, we present in section 2 the SALOME platform, dedicated to data-processing and its principal components. Section 3 details the TE data-model developed to define a geometrical domain and how materials are associated. The data exchanges between simulation programs and their interfaces are explained in section 4.

2 Salome Platform

The SALOME platform [1] is an Open Source software developed by many partners, including CEA (Commisariat à l'Energie Atomique) , EDF (Electricité de France) and OpenCascade, based on a CORBA architecture [2]. Several tools dedicated to numeric simulations such as data processing, CAD, meshes and scientific visualizations are integrated in Salome component. Thus GEOM component can be used to define the geometry of an object and SMESH component can be used to mesh this object. After a simulation, VISU component would be used to visualize and process data on a mesh. SALOME and its components can be called either through a graphical interface (Figure 1), or by means of scripts in PYTHON [5] language. Salome is delivered with many components, but we only present in this paper those used within the framework of our developments.

Figure 1 SALOME platform



GEOM component is based on Open Cascade Technology [3]. It provides CAD services to perform geometry computation. In addition, it allows to import and to export geometrical objects in STEP format (ISO10303 AP 203/214), IGES and BREP (internal Open Cascade format).

SMESH component provides mesh computation services with several algorithms. Furthermore external meshes can be interfaced with this component. The computed meshes can be based on GEOM object and exported to MED [4] format presented in the following.

VISU is a scientific visualization component which allows to manipulate and display fields of values on meshes saved in MED format.

The MEDc[4] format was developed with the aim of providing a common data exchange model for physics fields. It is specialized to finite elements and finite differences simulation programs. A MED file, based on HDF5 [6] binary file, can contain large meshes with more than one million nodes. Fortran and C language PLM and LCI libraries are delivered with a MED package. SALOME provides a module, called MEDMEM, which encapsulates the MED C language library in a C++ object data model, wrapped into a PYTHON module.

How the different components are gathered into our simulation platform and how they communicate with our model is developed in the next section.

3 Data Model

It appeared fundamental to organize our simulations around a general model. Each simulation program constructs an adapted view of this model to compute its results. The coupled simulation is based on a multiphysics data model, called Technological Entity

(TE) data model which associates geometry, material and other information on a technological object. An object is described with a tree-like structure where each node is a TE instance.

The Technological Entity data model assures the CAD-CAEd link, as proposed in [7] where the model permits to associate objects of CAD and CAE models. Simulation tools generally need meshed geometries (for example to finite elements calculation and method of characteristics calculation [8]) and in order to couple problems on two domains it is necessary to know domain connectivities. Thus, the Technological Entity needs a true CAD geometry model with shape connectivity information for simulations. To ensure this constraint, TE data model is a Feature oriented model [9]. The advantage of a Feature oriented model is to allow both CSG and B-REPe [10] representations. A CSG model is useful to describe the geometry and B-REP allows to keep connectivity information between shapes. A Technological Entity instance is the smallest element of the tree-like technological entity data model. It is composed of a local geometry and transformations, an associated material, a computation sequences and relations with a mother TE instance and children TE instances. Figure 2 presents how to model the geometry of an object (Modeled object) with a Technological Entity Tree (TET). In this example, the Modeled object is composed by three objects (TE1,TE2 and TE3). Thus, TET is composed by the three corresponding TE, and only their local geometries are entered. Then, TET CAD model (Computed Model) is automatically computed. Figure 3 illustrates with a simplified UML diagram the class organization. Geometric objects of the TE model are specializations of Shape, so all of them implement a getSpacePoints method which returns a list of Point instance. These points are characteristic points for applying geometric transformation to the Shape object. For example, the getSpacePoints method of a Circle instance returns the center point, and space points of the axis which are p0 and p1 (Vector class). The transformed shape of a TE instance, image of the localGeometry shape under the transformationMatrix, is computed and readable. Transformation is applied to each point of Shape spacePoints attribute. Material class is specialized in Solid, Fluid and Gas. A Material can also be a composition of Material instances. Solid Class is specialized in Fuel and Structure, because specific numeric processing would be applied to fuel components.

Figure 2 Technological Entity device modeling

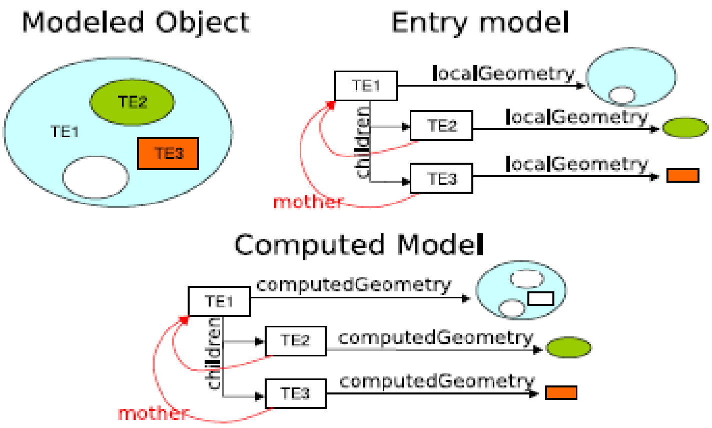
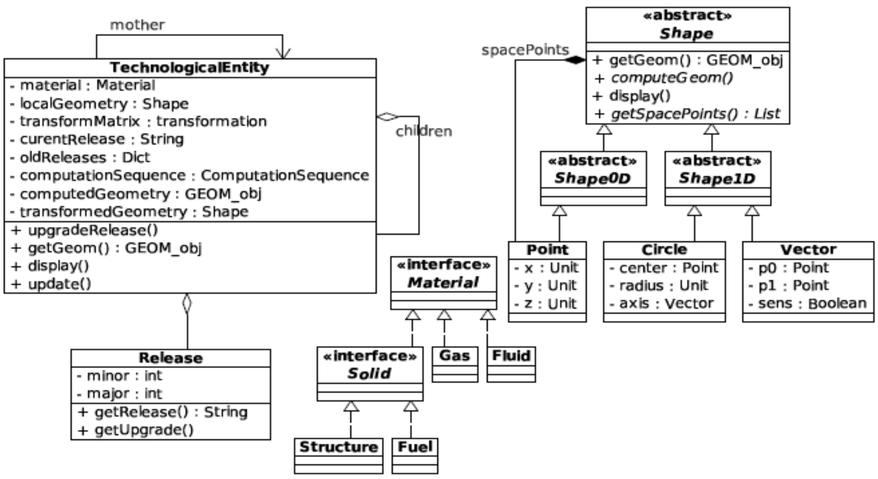


Figure 3 TechnologicalEntity class Diagram



During the design step, only local geometry are given with their associated materials. After that, children are defined for each TE (the mother link is automatically done). In a third step, the representation is computed (by the GEOM Component) and remains resident in memory. For example, following PYTHON Script build a TET composed by two TE. This TET defines an iron tube full of water:

Iron = Structure ( )
Water = Fluid ( )
poo = Point (x=0.0 ,y=0.0 , z=0.0)
pz = Point (x=0.0 ,y=0.0 , z=1.0)
vz = Vector (p0=poo, p1=pz)
c y l i n d e r 1 = Cylinder (poo, vz , radius =3.0 , height =10.0)
c y l i n d e r 2 = Cylinder (poo, vz , radius =2.0 , height =10.0)
te1 = TechnologyEntity (material= Iron, localGeometry=cylinder1)
te2 = TechnologyEntity (material= Water, localGeometry=cylinder 2)
te1 . children = [te2]

The last line permits to append te2 to children list of te1. At this time, a simple new assignment of a localGeometry attribute of an entity, updates the computed geometry. Furthermore, a release identification can be attached to the current tree construction. Modifications between releases are stored in each TE and a mechanism allows the reloading of an older version with a simple assignment of the current release attribute. The coupled simulation scheduling is controlled by the computationSequence attribute of the root object in the TET. In agreement with the scheduling, the different methods are called as presented in the last section.

4 Data Exchange

The package developed in this study is integrated in a SALOME component called TECHENTITY. It is used through the SALOME environment in graphic mode or in a PYTHON [5] batch mode. In the following section, a physics software that provides physics solvers will be named simulation software. Whereas a program which uses a simulation software to perform a simulation of a specific phenomenum will be named a simulation program.

4.1 Organization

To perform a coupled simulation, sequence of simulation programs are manipulated. Moreover, input data of these simulation programs are stored into the same TET. To group them, a ComputationSequence class is defined. An instance of this class is attached to a TE instance of a TET and is composed by instances of classes implementing physics interfaces described in the following. Thus, ComputationSequence permits to launch a coupled simulation and ensures the link between simulation programs and TET. A ComputationSequence instance control its simulation programs through physics interfaces. So simulation programs have to be encapsulated into a physics interface. More precisely, for technical reasons, different levels of interfaces had to be created, as illustrated figures 4 and 5. Physics interfaces have two goals: the first one is to provide simulation results under the same formalism; this is achieved by a CalculationScheme interface (Figure 5); the other goal is to control the simulation program (for example to synchronize it with another). Our physics interfaces are based on the scheme proposed in [11] for coupling simulation software. In this report, a Problem interface is defined (Figure 4) to make easier low level coupling. In our case, physics simulation programs implement one of the specialized Problem interfaces.

Finally, there are four physics interfaces which can be implemented : SteadyProblem, UnSteadyProblem, IterativeSteadyProblem and IterativeUnSteadyProblem. UnSteadyProblem and SteadyProblem interfaces correspond to time dependant and independant simulations. UnSteadyProblem permits to control the time loop of a simulation program. Thereafter, IterativeSteadyProblem or IterativeUnSteadyProblem interfaces permit to control the solvers inner loop (if the simulation software allows it).

To introduce getResults method and the TET in this architecture, Problem interface inherits from CalculationScheme interface (Figure 5). Thus, a simulation program implementing one of the four physics interfaces, reaches the TET data through the association sequence of CalculationScheme. Geometries and materials in the TET can be read or modified by simulation programs.

The getResults method is more specialized to exchange fields of results between simulation programs. Consider two simulation programs with two different meshes of the same geometry. The coupled simulation starts with the first simulation program. The second simulation program needs results obtained by the first simulation program but on a different mesh. It is not generally necessary to convert results on the full mesh but only on a submesh. Thus results computed on the mesh of the first program have to be converted into the mesh (or submesh) of the second program. To convert results, the getResults method returns a value corresponding to a results field on a specified location. For example a finite differences simulation program is running, fields of data are computed on quadrangles. A finite differences simulation program need data on a group of triangles. Then, calls to getResults are done to the finite difference simulation program with triangle shapes. This last simulation program compute physics interpolation of the corresponding data field on these triangles. Implementation of the getResults method is carried out by a physicist because physic interpretations of results are necessary. They are actually specifics to the coupling.

Figure 4 UML diagram of a Problem [11]

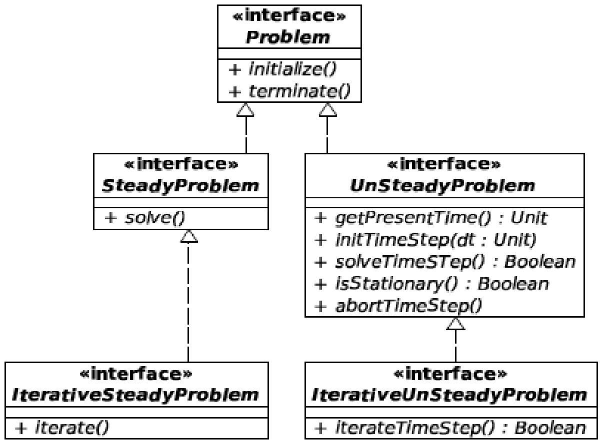
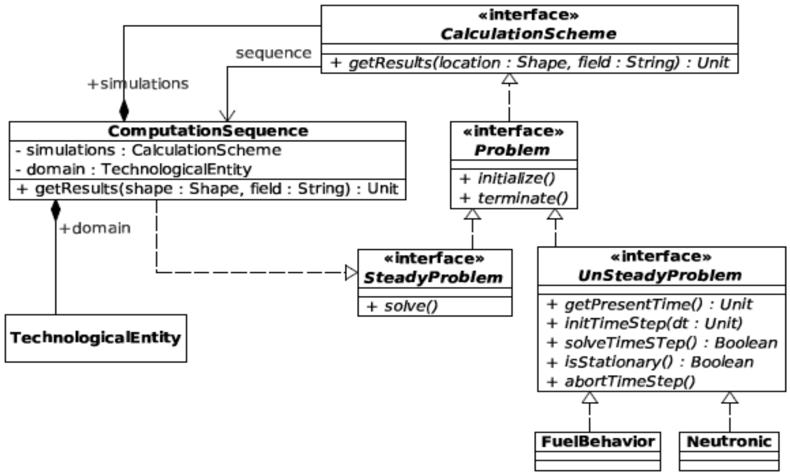


Figure 5 Class diagram of CalculationScheme and ComputationSequence



4.2 Sequence

As illustrated in Figure 5, ComputationSequence class implements SteadyProblem interface, which includes a solve method. Thus the launching of a coupled simulation is performed by the solve method of a ComputationSequence instance.

Let us consider a coupled simulation made up of two simulation programs, one dealing with neutronics, the other dealing with fuel behavior. These simulation programs are encapsulated into UnSteadyProblem interfaces (Figure 5) and appended to the list simulations of a ComputedSequence instance. This last instance is linked to a TET describing the study domain. Figure 6 presents a simple sequence diagram executed by the solve method of the ComputedSequence during two time steps.

First, initialize methods of the two problems are called. These methods initialize simulation programs with their input data and launch simulation software, the execution is blocked before the first calculation step. Then for each calculation step, initTimeStep and solveTimeStep methods are called. The initTimeStep method initialize input data specifics to the current time step, whereas solveTimeStep method performs the physic calculation. At the end of the time loop, terminate methods are called to stop simulation softwares.

Figure 7 presents the same sequence but with a TET model modification. In the initialize method of the FuelBehavior instance, there is a call to getRadius accessor of a Circle instance. The data returned can be an input data for the fuel behavior simulation program. In the same way, the initialize method of the Neutronic instance calls the get-Geom method of a TE instance. The latter returns an instance of the GEOM component which can be exported in other formats (For example STEP format to be meshed). Then initTimeStep and solveTimeSteps methods are called. During a solveTimeStep, fuel behaviour simulation program results lead to a modification of the circle radius. At the end of the computation, FuelBehavior instance sets the new radius of the circle in an upgraded release of the TET.

Second call to initTimeStep method of FuelBehavior instance, presented by figure 7, shows a call to getResults method. Consider that power is an input data of a fuel behaviour simulation and that this power is a time dependant data computed by neutronics simulation program. In the initTimeStep method, there is a call to getResults method of the ComputationSequence instance on the power field. This method exists because ComputationSequence implements SteadyProblem. This field belongs to neutronics, so ComputationSequence calls the getResults method of the Neutronic instance.

Thereafter, if two coupled simulations are in two ComputationSequence instances localized at two different levels of the TET, it is easy to couple them : As the ComputationSequence is a SteadyProblem the two coupled simulations can be directly appended to the simulation list of a third ComputationSequence instance.

Figure 6 Sequence diagram of a coupled simulation (2 time steps)

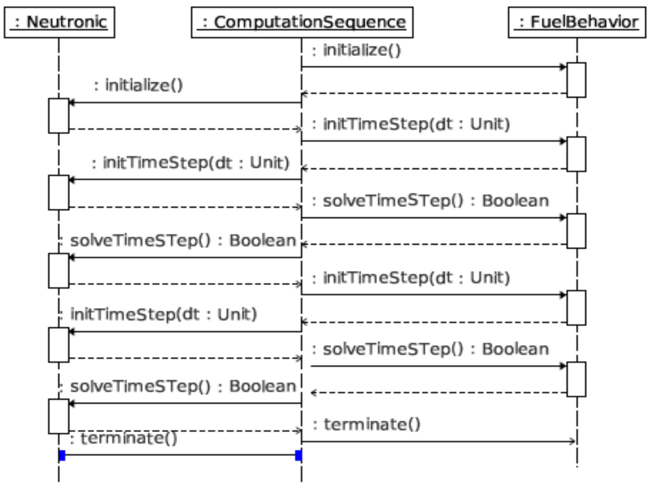
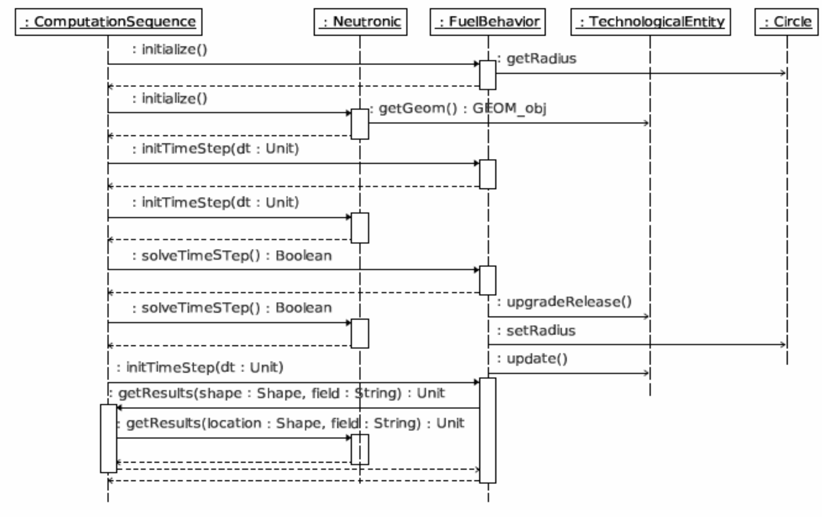


Figure 7 Sequence diagram of a coupled simulation with results exchanges



5 An application

An application of this architecture is applying to simulate an experimental device in a Material Testing Reactor. The device is composed of six fuel rods and is localized in the core periphery (Figure 1). Each rod is studied with a fuel behaviour scheme already developed. This scheme computes 1D thermal variations in a rod and weak deformations. The objective is to replace the simplified neutronic model, used by the fuel behaviour scheme, by a whole core neutronic scheme.

The first neutronic scheme was easily adapted with the UnSteadyProblem interface. It consists in implementing the several methods of this interface applied to the neutronic scheme and identified input and output fields. Then Fuel Behaviour scheme was encapsulated with the same interface. This last scheme deals only with one fuel rods, so six fuel rods calculation schemes will be launched and will exchange data with the same neutronic scheme. The seven treated problems are time dependent (inherits from UnSteadyProblem) and time steps between neutronic and Fuel Behaviour are different. Moreover, irradiation conditions of fuel rods are not the same, and physicists suppose that the irradiation times between rods are different. The data are exchanged between problems at each end of time step calculation. A first advantage of our architecture is to control and synchronize the data exchange between unsteady problems, which could not be done before. To perform a multi-physics simulation, the user creates six fuel behaviour instances applied to each fuel rod of the device, and a neutronic instance. Then he has to create a ComputationSequence instance, and add the seven Problem instances to the simulations attribute. As ComputationSequence inherits from SteadyProblem, simulation is performed by simply calling the three methods initialize, solve and terminate.This new architecture can be easily used to adapt existing calculation scheme to perform multiphysics simulations. It permits calculations which were impossible in the past for technical complexity reasons : so, more accurate results can be reached. The time required to prepare the complete simulation is very short and anyway shorter that the one previously required, to couple two simulation programs only once.

6 Conclusion

Technological Entity data model, developed in the SALOME environment, provides standard CAD models which can be used in other CAD software. In a multi-physics study, it is a common data model for all physics fields simulations. It facilitates data exchanges, allows parametric studies and contributes to the high level coupling of simulation programs. This data model is applied to an irradiation experiment in an experimental nuclear reactor [12]. The aim of this study is to couple a two space dimensions neutronic simulation with a fuel behaviour simulation. These are time dependant problems. The architecture as been developed so as if fuel behaviour simulation computes local weak deformations of the geometry, it would be considered in the neutronic simulation. In the future a three space dimensions thermal-hydraulic simulation will be added to the coupling. Moreover the architecture allows to easily compare results of simulation programs of the same phenomenum on the same domain but with different hypothesis.

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PLM data acquisition to support LCI compilation

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Abstract: Life-Cycle Assessment (LCA) is becoming more and more important as a tool to evaluate the environmental impact of developed products. The role of LCA could be improved if it could be applied during the development process of new products. In order to achieve this target, an important issue to be faced is the data acquisition phase required to compile the Life-Cycle Inventory (LCI).

The objective of our work is the classification of the different types of data required to compile LCIs and the definition of suitable methods to identify and extract the required data from the data bases used by the Product Life-cycle Management (PLM) systems.

To demonstrate, verify, and evaluate the proposed approach, the first results obtained with a prototype system for data acquisition are presented and discussed.

Keyword: data classification, data collection, workflow analysis

1 Introduction

Life-Cycle Assessment (LCA) is the most commonly accepted method to assess the environmental impact of a product, through all the stages of the product life-cycle.

LCA can be seen as a compilation and evaluation of the inputs and outputs and the potential environmental impact of a product system throughout the entire life-cycle, from the extraction and processing of raw materials, to manufacturing, transportation, distribution, maintenance, recycling and eventual reuse [1].

The framework defined by ISO 14040 [2], identifies the following four main steps of LCA: goal definition and scoping; inventory (LCI) analysis; impact assessment (LCIA) and interpretation of results.

The goal definition points out the reason to perform the study and the intended use of the results. The LCI collects all the relevant inputs and outputs for all the processes involved in the LCA: it includes data about energy (electric and thermal) as well as materials (raw materials, semi-fabricated products, supporting and operating materials) consumption. A complete LCI should include data from all the phases of a product life-cycle (raw material acquisition, manufacturing and processing, distribution and transportation, use, reuse and maintenance, recycle and waste management).

The purpose of the LCIA is to consider the LCI results in order to better understand their environmental significance. Finally, the life-cycle interpretation is a procedure to identify, qualify, check and evaluate the information from the results of the LCI and/or LCIA of a product system.

The difficulty with LCA is not the complexity of the methodology, but the complexity of the problem. Each step is very simple and can be understood easily but the thousands of steps required to assemble a complete life-cycle inventory make an accurate LCA extremely difficult and expensive.

Since a full LCA can be time and resource consuming, there is a need for using simplified methods (SLCA) [3, 4, 5].

The role of LCA or SLCA becomes particularly significant if it could be applied during the development process of new products, in order to get feed-backs to drive the identification of environmentally friendly design solutions [6]. In this case, the data acquisition process can be even more complex because during the development stage not all the parameters are completely defined, rather than at the end of the development, when the product information is complete.

As stated in [7], a complete, quantitative LCA has never been accomplished, nor is it likely to be. It could therefore be practical to start with less detailed studies and work towards more detailed studies. Wenzel defines three basic levels of LCA [8]: a matrix LCA (qualitative or semi-quantitative); a screening LCA (quantitative using readily available data or semi quantitative); and a full LCA (quantitative and including new data inventory).

The main goal of our work is to relate product life-cycle management (PLM) and inventory (LCI) analysis in order to identify what data is available, where and when it becomes available during the product life-cycle and how it is possible to retrieve it in order to compile an LCI as soon as possible and then make it available to LCA by means of an appropriate, platform and system independent format.

At the present stage of the work we have approached a screening LCA limited in scope to the production phase. In particular, we use a case-study chosen in the field of production of injection moulded part, which is especially significant in the industrial district of the Marche region.

The paper investigates the diffusion of data required to compile the LCI along the supplier chain (including information about where the data is coming from and which is the degree of availability of the data) with the aim to identify strategies to increase the awareness of Small and Medium sized Enterprises (SME) in respect to LCA, to suggest methodologies to facilitate the collection of sound LCI data and to test available low-cost software tools to support LCI data exchange from the supplier to the main manufacturer using PLM systems to exchange data.

2 PLM and LCI

2.1 PLM and LCI in the Industrial Production Scenario

An important aspect to be considered when reasoning about PLM and LCA from a production perspective is that nowadays the life-cycle of a product is spread among several different companies: the main company is in charge of the product design and assembly, while the production of components and sub-assembly is delegated to external suppliers. In some cases the design of components is performed by the main company, in other cases it is done directly by the supplier according to the main company specifications.

In this scenario, LCA implementation becomes harder due to the fact that often the suppliers refuse to cooperate in LCI data acquisition because they do not want to disclose company critical information.

A possible way for the main company to make the suppliers aware of LCA related activities is to identify eco-design solutions that will minimize the amount of resource which the supplier must allocate for the production and to bring the supplier in on the benefit of the production of an eco-sustainable product.

This aspect is even more critical in a context, like the Italian one, where the external suppliers are mainly represented by SMEs [9]. In this case, the implementation of the LCA methodology is constrained by the need to be inexpensive, rapid in its implementation and reliable. In the concerned scenario, SMEs are mainly manufacturing industries involved in the production phase of the product life-cycle.

2.2 PLM as a tool to support "green" production

In the last decade there has been a large diffusion of Information Technology (IT) systems to support the different phases of the product life-cycle: CAD/CAM/CAE systems to define virtual prototypes and digital mock-up to support design and production; Enterprise Resource Planning (ERP) systems to manage internal resources; Supply Chain Management (SCM) systems to support the communication with the suppliers and Customer Relationship Management (CRM) systems to manage the relationships with the customers.

In this context, PLM systems provide an appropriate environment where to integrate workflows and data coming from the use of all the above-mentioned systems [10]. In the recent years PLM systems have also been considered by many authors and enterprises as a very powerful tools for "*greening*" the product development process. Modern PLM systems have modules to supports business processes such as sustainability reporting, compliant product design, labelling, dangerous goods management, centralized master data management and business-to-business collaboration [11].

Moreover, environmental regulations in Europe (e.g. the EU directives "Waste Electrical and Electronic Equipment" (WEEE) [12] and "Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment" (RHOS)[13]) will force companies to report life-cycle information.

These directives will oblige production companies to provide information about the substances contained in electronic products, to restrict the use of certain substances and to encourage the waste recycling in an environmental conscious way [14].

2.3 PLM supporting LCI

One of the consequences of the use of all the mentioned IT systems, is the creation of a tremendous amount of digital data. This data is organized and stored in suitable formats within the PLM systems, according to the need to preserve the information defined by the data. PLM systems are used to facilitate the management of product and process data and to speed-up the communications among the different departments of a company or between customers and suppliers.

The premise of our approach is that the majority of the information required to compile an LCI is stored in an explicit or implicit way within the data managed by the PLM systems, since the first phases of the product design [15, 16]. Furthermore, the processes workflows defined within the PLM system provide a road-map to identify where and when LCI relevant data will be generated and will become available.

However, in order to be able to efficiently support the collection of the data required to compile the LCI, we need to classify the different types of required data and to define suitable methods to identify and extract the required data from the data base of the Product Life-cycle Management (PLM) systems. At present we classify LCI relevant data as reported in table 1.

Table 1 LCI relevant data classification.

	Global	**Local**
Explicit	- relevant for the processes related to the product as a whole - explicitly stored in the PLM system	- relevant for the processes related to the different components that are part of the product - explicitly stored in the PLM system
Implicit	- relevant for the processes related to the product as a whole - require computation to be extracted from the PLM system	- relevant for the processes related to the different components that are part of the product - require computation to be extracted from the PLM system

Finally, appropriated structures and formats need to be identified in order to make collected LCI data available to LCA. A prototype software tool to support LCI data collection from PLM system is at present under development. The tool is able to semi-automatically collect LCI related data from the PLM data base.

3 The Case Study

In order to validate the proposed approach, a case study has been carried out in the field of automotive injection moulded part manufacturing.

In the first step, the PLM workflow of the processes involved in the injection moulded part production has been analysed. Thanks to the analysis it was possible to relate the processes to the LCI relevant data and to identify at which stage of the workflow the data becomes available. Moreover, it was possible to identify the data location in terms of corporate functions and it was possible to relate the data with the software tools used to manage it.

In the second step, the qualitative and quantitative variables as well as the computation methods for the data have been defined and have been related to the production processes and to the data source.

Finally, the allocation methods for the different types of data have been identified.

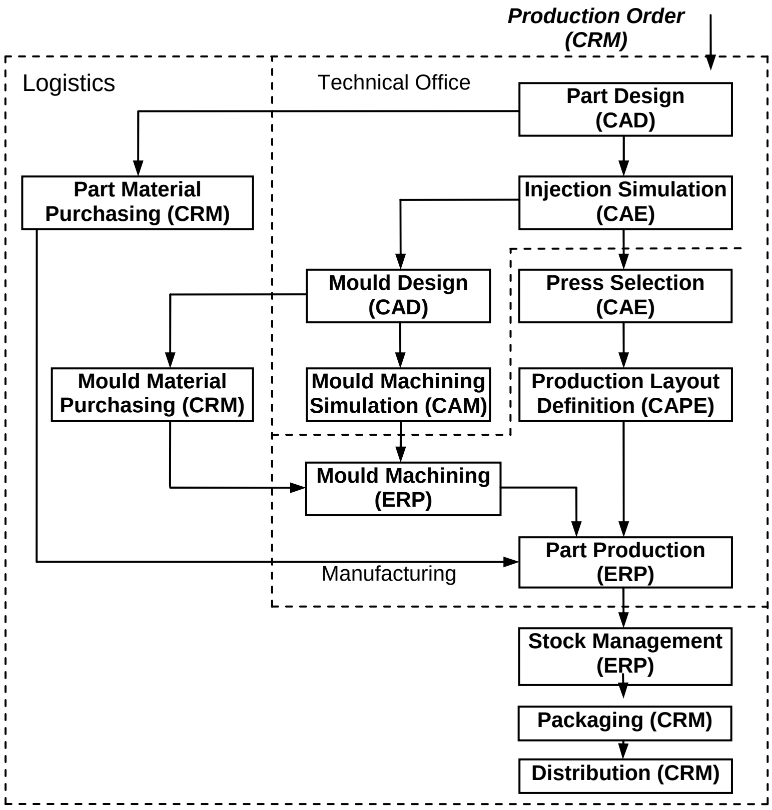
3.1 Injection moulding production workflow

The LCI related data is generated as a consequence of the decisions taken by different experts during the processes workflow. Those experts work in different departments, often even different companies, with the support of different IT tools.

The process starts when the business unit transmits the production order to the technical office. Among the data sent to the technical office there is the CAD model of the part to be produced, together with technical production data such as the part material and the number of requested parts. This information is used to define the amount of polymer requested for production. This data is managed by the customer relationship management (CRM) system.

At this stage, the part design is usually reviewed in order to optimise the part geometry for production (by using the CAD system). The part optimisation is carried out in parallel with the mould design and it is supported by the use of software tools to simulate the injection (CAE) and the mould machining (CAM). The injection simulation is also used to select optimal process parameters as injection points number and location, injection temperature and pressure, etc. Those parameters allow to start the definition of the production layout (supported by the CAPE system), including the press selection.

Figure 1 Injection molding production workflow



In a similar way, the CAM simulation is used to optimise the mould machining process in terms of cutting tools selection, cutting path, cutting speed, etc. Once the mould design and machining has been completed, the parts production can start. The production and stock management data is managed by the enterprise resource planning (ERP) system while the packaging and distribution are managed by the CRM system. Figure 1 summarises the results of the main processes considered in the workflow analysis: the dotted lines indicate the boundary of the different corporate functions; the boxes indicate the different processes and the related supporting software tools, reported within brackets.

3.2 LCI relevant data

In order to identify LCI relevant data, the processes and materials related to the injection moulding production have been grouped by following the traditional LCA subdivision of the input/output flow (i.e. energy consumption, material consumption, waste and transportation). For each considered LCI data, the scope (involved action or product), the qualitative and quantitative variables as well as the computation method have been identified. Moreover the data availability has been defined in terms of the corporate function and workflow process where the data is generated, and the software tool used to manage the data. The corporate function in charge to manage the data and the IT tool where the data is stored have been identified by looking at the process position in the workflow, that also provides hints regarding the stage at which the data become available.

As an example, the amount of polymer required to produce the part has been identified to be an LCI relevant data, belonging to the material consumption flow (see the first row of the material consumption section in table 2). The measurement unit for this data is Kg and the computation method is the multiplication of the part volume for the polymer density. The part volume data is obviously related to the part geometry and it is defined during the part design process. By looking at the workflow chart (see figure 1) we can see that the part design process is accomplished in the technical office by means of using a CAD system.

Table 2 LCI relevant data availability and computation methods.

LCI data		**computation method**	**unit**	**data availability**		
input/output flow	**scope**			**corporate function**	**workflow process**	**tool**
energy consumption	mould machining	CAM simulation working time * machine nominal power * correction factor	Watt	technical office	mould machining simulation	CAM
	internal handling	number of handling * machine power * meter	Watt	logistics	internal handling	ERP
	injection process	press nominal power * injection time	Watt	technical office	injection simulation	CAE
	mould and	(injection temperature	MJ	technical	injection	CAD,

	production material heating	– ambient temperature) * (mould Cp + material Cp)		office	simulation	CAE
material consumption	product material (polymer)	part volume * polymer density	Kg	technical office	part design	CAD
	mould steel	extraction from CAD model properties	Kg	technical office	mould machining simulation	CAM
	auxiliary material (supplies and lubricant)	monthly consumption / monthly part production	Kg, litre	logistics	purchasing	CRM, ERP
	packaging materials	mass of packaging materials	Kg	logistics	packaging	CAD, CRM
waste	steel scraps from the mould machining	mass of row steel block – mould mass from CAD model	Kg	manufactu ring	mould machining simulation	CAD ERP
	production material waste	calculated on press geometry	Kg	manufactu ring	mould design	CAPE
	auxiliary material	monthly disposal / monthly part production	Kg	logistics	part production	CRM, ERP
transportation	from supplier	distance calculation	Km	logistics	purchasing	CRP, ERP
	to the customer	distance calculation	Km	logistics	distribution	CRM, ERP

3.3 LCI data allocation

When the life-cycles of different products are somehow connected, we must take into account the allocation problem. The allocation in LCA refers to the problem, at the inventory stage, of associating the environmental burdens of each single process to the input/output flow. The ISO definition of allocation is: “Partitioning the input or output flows of a unit process to the product system under focus” [18]. In respect to the allocation problem, we have classified the process involved in our case study as:

- *atomic*: related to the production of a single injected part;
- *lot*: related to the production of a lot of parts using the same mould;
- *global*: related to the global production of the company.

An example of *atomic* process flow is the energy consumption for a single injection operation, as the energy consumption to machine the mould is an example of *lot* process flow and the waste of auxiliary materials is related to the *global* production of the company. Once the processes have been classified, appropriated allocation rules have been defined for *lot* and *global* processes (atomic processes do not need allocation rules). Table 3 summarises the identified processes, grouped by input/output flow, classified by type and with the related allocation rule.

Table 3 Data Classification and Allocation Methods.

input/output flow	process	type	allocation rule
energy consumption	mould machining	lot	energy allocated to the estimated amount of products manufactured during mould life
	internal handling	global	energy allocated to the amount of products transported together
	injection process	atomic	none
	mould and production material heating	atomic	none
material consumption	product material (polymer)	atomic	none
	mould steel	lot	mass allocated to the estimated amount of products manufactured during mould life
	auxiliary material (supplies and lubricant)	global	mass allocated to the amount of products for which are consumed by
	packaging materials	global	mass allocated to the amount of products packed together
waste	steel scraps from the mould machining	lot	mass allocated to the estimated amount of products manufactured during mould life
	production material waste	atomic	none
	auxiliary material	global	mass allocated to the amount of products for which are consumed by
transportation	from sub-supplier	global	mass allocated to the amount of material transported together
	to the main manufacturer	global	mass allocated to the amount of material transported together

4 Data Acquisition and Distribution

In the considered case study, the actors playing in the previously described scenario belong to an *extended* and *distributed* enterprise made of four distinct companies: a medium size enterprise, playing as main company, charged for the co-design of the part to be produced and responsible to the customer for the parts production and distribution; a SME charged for the mould design; a SME charged for the mould production and a SME charged for the part production.

The procedures to drive the communications among the experts belonging to the different companies and to support the management of the exchanged data have been implemented by means of using a commercially available PLM system. The system architecture is a traditional client-server architecture. The central database and the server functionality are installed in the main company as the others company are connected to the system through the clients functionality.

From the LCI data retrieval point of view, it is evident that the use of a single database facilitates the data collection. However, several synchronisation issues need to be addressed. As example, it should be taken into account that the data required to calculate flows quantities is generated by engineering processes performed in different enterprises, at different time, by different experts and they are continuously reviewed and updated.

At the present stage of the research work, a prototype system for the semi-automatic acquisition of the LCI relevant data from the PLM central database is under development.

The software system collects and computes the data as summarised in table 2 and 3. The computation is automatically done when the requested data is explicitly represented in the central database or within the models generated by the use of the design/production supporting tools such as CAD, CAM and ERP.

An interaction with the user is requested when the data is implicitly represented and non trivial assumptions are required to acquire the data. In any case, the data availability is communicated to the system through the workflow implemented in the PLM system.

The collected data is then mapped into the ISO\TR 14048 and ECOSPOLD format, in order to make it available for the most common LCA software tools.

The above described procedure simplifies data acquisition and improves data soundness. The possibility to perform fast and sound data acquisition is the fundamental premise to perform qualitative assessment of different design/production solutions and then provide support to the eco-design.

5 Conclusions

The Italian industrial scenario and the issues related to the LCA application were presented, with particular reference to problem of LCI data acquisition. This paper investigates LCI data generation by CAE software during the product life-cycle and its collection among suppliers supported by PLM technology.

The first result of this research was the definition of procedures for the automation of LCI compilation and communication among companies saving time and resource allocation and making this process more reliable for SMEs.

The next step is the development and implementation of the prototype of the data acquisition software in an industrial context.

Hopefully , future collaboration with academic partners, and, even more important, with industrial partners, will lead to improvement of the work presented and thus to a base for improving LCA diffusion in our industrial district.

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Semantic structures in the product data model

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Abstract: The paper presents a conceptual semantic data structure of product model. The proposed data structure aims to capture semantics of product and its components and features but also to provide semantic interpretation of, in such a way, structured data. The key feature of the semantic network is shown in a new data structure of associations between the concepts in the network. This new structure represents the semantics of relations between the concepts and provides analogy-based reasoning. Following the tendency in the knowledge management to model all product properties at a higher level of abstraction in order to capture and reuse product related knowledge, we found that this kind of semantic structure could respond to the most of PLM demands.

Keyword: Product data model, Knowledge management, Semantics, Analogy

1 Introduction

The Internet has made huge quantities of knowledge accessible to everyone looking for it. Information technologies and computer applications in engineering also give fascinating possibilities with respect of products, such as could not have even been imagined until recently. The accessibility of these technologies and the speed of the expansion of knowledge through the World Wide Web open up relentless competition for the target segment of the market. Within the process of developing information technologies, for several decades there has been an effort to create an information data-model, which will be able to store and efficiently (automatically) use large information and knowledge depots, generates through progressive use of IT. One of the results of these attempts is a family of new semantic structures. These models are mainly based on so-called *ontology*-data model [1]. In essence, ontologies are very similar to classical object-oriented data model, but which are web-broaden [2], [3].

Another class of semantic structure that can be even more propulsive in future is certainly semantic data structures, which will be able to use analogies to search and retrieve data in order to capture and reuse explicit and tacit knowledge base. Using analogies is one of the core processes of cognition and may be primary process of all cognition and communication [4], [5], [6]. In practice, in the earliest phase of the product and technology developing and designing some very important or even strategic decisions are made in the conditions of significant indefiniteness. In such cases, assessments and, therefore, decisions themselves, are completely based upon experience-gained knowledge, that is, an analogy analysis of the previous cases for which certain data already exist.

Exactly one line of research in the Laboratory for Intelligent Production Systems is directed towards developing a product model in the form of semantic data structure featured by analogy-based reasoning.

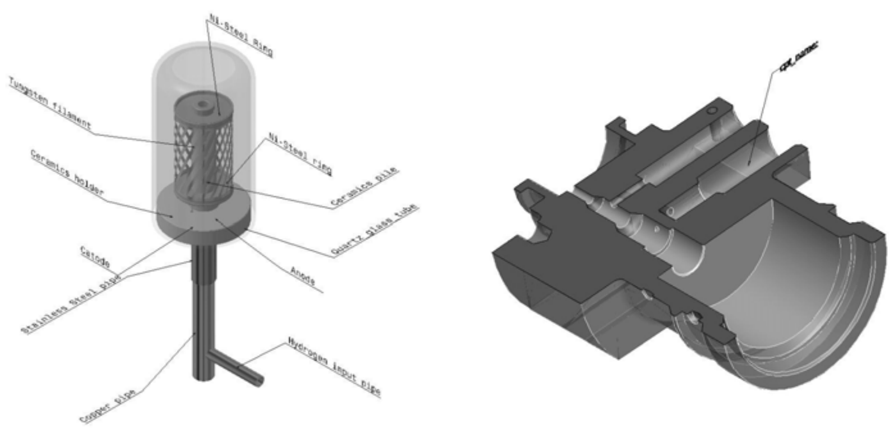
2 Semantic Structure of Product Data

Working in the field of PLM implementation into industry (see acknowledgement: projects 0231 [7], 2092, 6215), that is, with very practical problems, we found that semantic product data structure, which is usually created within UML standards [8] and is embedded in several actual PLM systems, burdens users more then it helps. In addition, it discredits their expectations from the "imposing" concept. Because of that, we have been focusing our research on new forms of semantic data structures in order to find out the one that could be able to provide a highly level abstract formulation of product features at one side, and to be used for computer aided intelligent inference on the other side (making autonomously assessments, decisions, etc.). In brief, we consider that object-oriented data structure should be evolved to, what we call, associations-oriented data structure.

2.1 Concepts of product

Within this kind of organization of product data, each feature or component of product model should be designated by a concept. Data structure of concept consists of just one attribute – *name*. Now, the link between the concept (located in the product model knowledgebase) and the product feature is realized via a parametric note that is native to actual PLM system (Figure1).

Figure 1 Both, the parts in a product assembly and features of the part itself can be designated as concepts. URLs that are indicated by these notes make linkage to the knowledgebase structure in background.



The explicit knowledge (about the product and its components and features) that can be interpreted by strict logical procedure and math expressions, is embedded into, we call it, bodies or records of concepts. The tacit knowledge, which mostly originates from experience (and cannot be interpreted at the same way), is embedded into semantic network of associations and concepts.

2.2 Associations

The role of associations and its data structure is to capture semantics of the product itself and its components and features, but also to provide analogy-based reasoning. The associations associate concepts in the semantic network of knowledgebase and at the same time represent the semantics of relations between the concepts (product components and features– Figure 2.). The data structure of an association is similar to the structure of the record in the relation database model. Each association has nine attributes [9]:

$$A(cpt_i \Leftrightarrow cpt_j)_{ij}: \{cpt_i, r_i, t, h, d, s, c, r_j, cpt_j\} \quad (1)$$

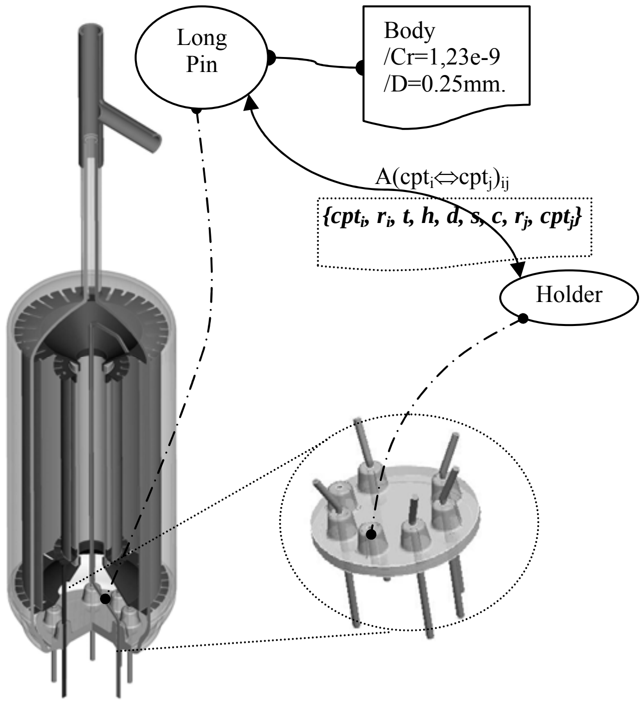
- *Names* of concepts pair it associates - (cpt_i, cpt_j),
- *Role* of each concept within the association (attribute, argument, passive object, subject, activity, etc.) – (r_i, r_j), where $r \in$ R: {R_1, R_2, R_3, …, R_k,},
- *Type* of association (attributive association, synonym assoc., argument assoc., affiliation assoc., functional assoc., etc.), – (t) , where $t \in$ T: {T_1, T_2, T_3, …, T_k,},
- Degree of *Authenticity* of assoc. (0 for maximal arbitrariness, … 1 for maximal authenticity of association) – (h), $h \in [0, 1]$,
- *Direction* (weather both of concepts points out to each other or it is often case that only one of them points out on other or vice versa), – (d), $d \in$ [0, 1, 2], discrete set of values
- *Significance* or weight (0 – without significance, ... 1 – with priority significance), – (s), where $s \in [0, 1]$
- *Character* (positive – one that points out affirmatively, or negative – one that points out non-affirmatively), – (c), where $c \in [0, 1]$

Table 1 A sample of data structure of associations

ID	Name /CPT_i/	R /role/	T /type/	H /auth/	D /dir/	S /sign/	C /char/	R /role/	Name /CPT_j/
A1	Diameter	Attribute	Atr	1	0	1	1	Desc_Obj	Mill
A2	Tool_Holder	Subject	Sub-Obj	1	1	1	1	Object	Cut_Insert
A3	Allot_ number	Action	Func-Arg	1	1	1	1	Argument	Number
…	Action	Child	Affiliation*	1	0	1	1	Parent	F_concept
…	Action	Child	Affiliation	…					Role
…	Role	Attribute	Atr	1	0	1	1	Desc_Obj	Association
…	…	…	…	…	…	…	…	…	…

* *Affiliation = "is kind of"*

Figure 2 Relationships between parts in product assembly designated by associations



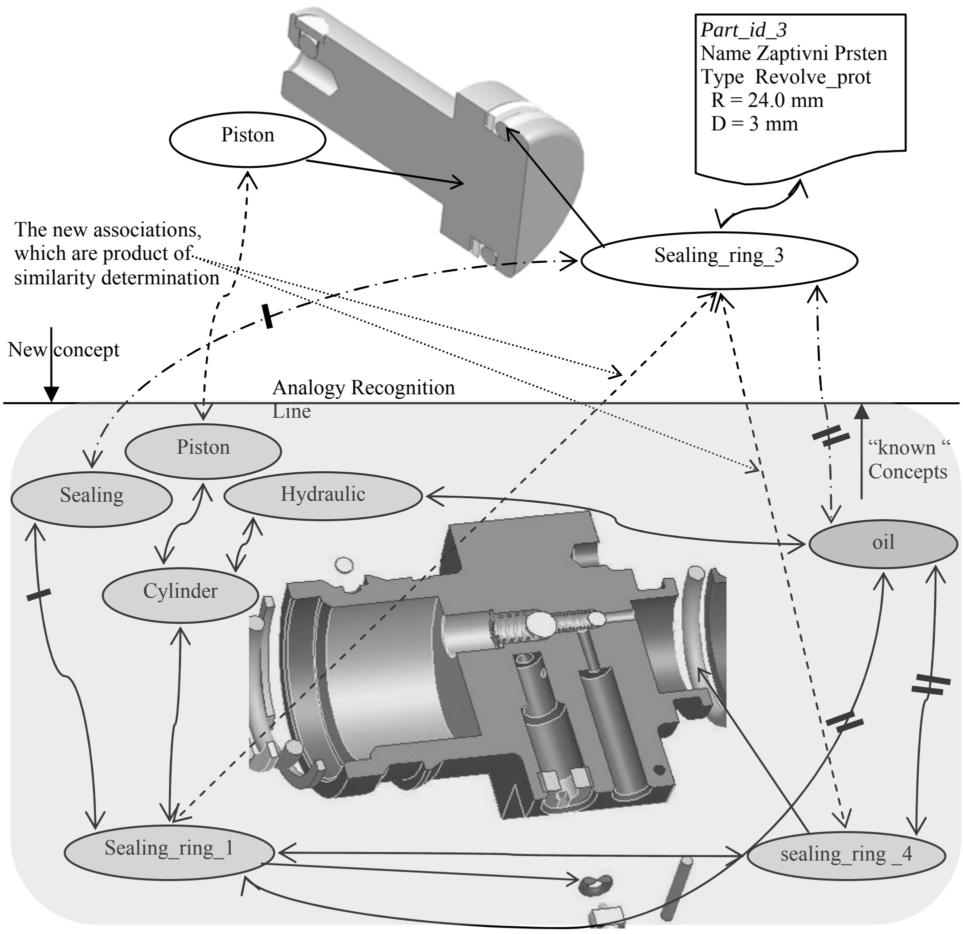
2.3 Bodies of concepts

The bodies of the concepts are third kind of constituent of proposed semantic structure and their role is to store explicit knowledge of concept. This kind of knowledge can be represented by simple symbol or variable, but also bodies can take much more complex data structures such as executive codes of program applications or table-spaces, etc.). In addition, these portions of knowledge are being activated by analogy-based inference engine in the case where all input data for certain also triggered procedure (that is store in a body of concept, too) are presented.

3 Analogy-based inference engine

The analogy-based inferring engine partially automates the semantic interpretation process that is makes knowledge out of otherwise meaningless data [1]. The engine uses associations as road signs in the process of recognition of mutually indicated concepts. This recognition process is in the core of intelligent interpretation of product model (and their components and features) semantics and is performed by determination of degree and class of similarity/difference among associations. The similarity/difference is subsequently transmitted to the determination of the relations among the concepts linked by the given associations.

Figure 3 Simplified schema of similarity determination process



Simplified schema of similarity determination process is shown in Figure 3. It should be noticed that similarity determination process starts with designation of associations between (new) concepts that represent new (to the knowledge base unknown) parts or features and concepts that exists in the semantic network already and represent "known" parts and features. The next step is searching for "known" concepts that have same or similar associations (to the designated "known" concepts) as a new one. In the case where search result brings back one or more "known" concepts, engine does inference autonomously that "new" concept is similar to the retrieved "known" concepts. The inferring is manifested through creation of the appropriate association between new and known concepts by the engine itself. Depending on class and degree of similarity of associations as well as on number of similar associations, the semantics of new concepts is more determined (Figures 4, 5 and 6). Consequently, the semantics of new product and its components and features is more determined, too.

IF A(Sealing_ring3⇔Sealing) ~ A(Sealing_ring1⇔Sealing)

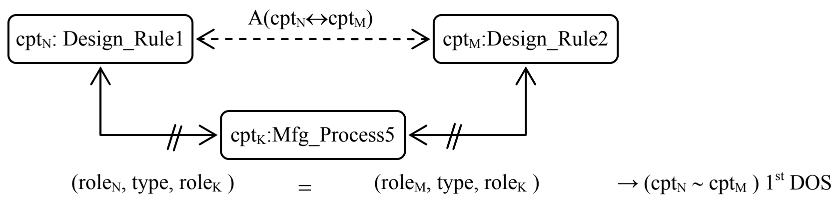
AND A(Sealing_ring3⇔Oil) ~ A(Sealing_ring1⇔Oil)

THEN Sealing_ring3 ~ Sealing_ring1– i.e. *are "probably" similar*

The degree of "probability" is designated by Authenticity attribute of association.

Equality of triplet attributes of associations - roles of concepts and type - $(r_N, t, r_K) = (r_M, t, r_K)$ determines similarity of association's class.

Figure 4 Example from Knowledge Management. Concepts cpt_N and cpt_M are similar (in the 1st degree of similarity: DOS) because they share the same class of association to concept cpt_K, that is they have the same *role* in the association.



The inference engine generates new association that should indicate so-called 1st degree of similarity between the concepts. During the inference event, i.e. association generation user-teacher corrects (affirms/denies) the decisions that are made by the engine autonomously.

Figure 5 Example from Supplier Chain Management. Higher degrees of similarity between two concepts (cpt_N~cpt_M) depend on equality or similarity of other attributes of association to cpt_K.

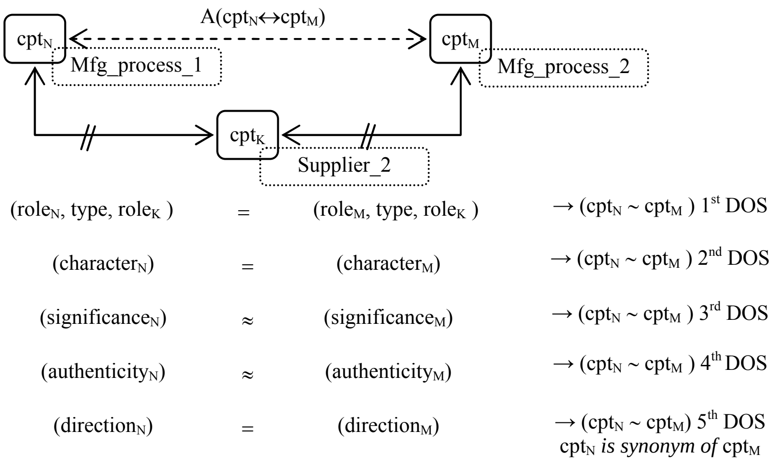
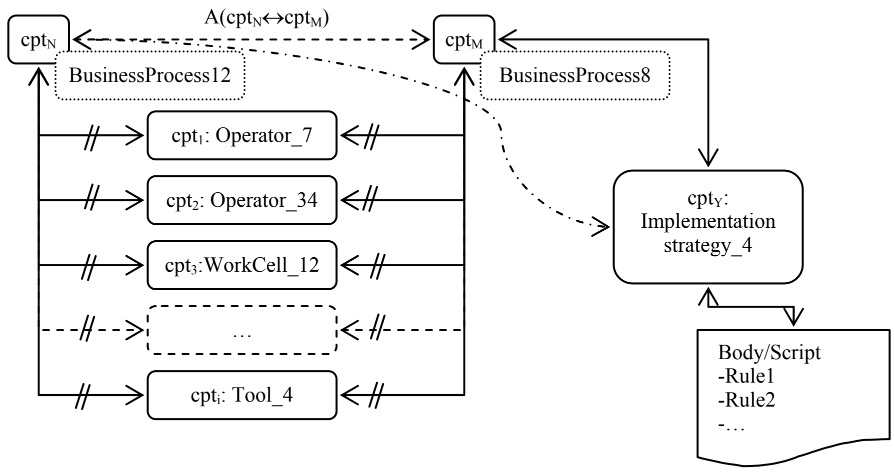


Figure 6 Example form Business Best-Practice management. The bigger number of similar associations to the intermediate concepts indicates higher degree of authenticity of similarity between two concepts (cpt_N~cpt_M).



In the case a high degree of authenticity of similarity between two concepts (cpt_N, cpt_M) has determined, like it is shown in Figure 6, the engine proposes new association to be created between the business process that has to be implemented (represented by "new" concept - cpt_N) and implementation strategy (represented by a concept in the knowledge base - cpt_Y) that has been used for implementation of "known" business process (cpt_M). By this activity, the engine imitates giving of advices "from experience". The proposal can be approved or reject by the user-teacher. The next step for the engine is to call strict logical procedure (e.g. some object-oriented programme code) captured in the *body* of the concept.

If user-teacher rejects proposition of the engine, then it is important to determine the associations and concepts that 'essentially" determine semantic difference between these two concepts (cpt_N, cpt_M) and the reason why the proposed association should not be created. This specific trait of the model additionally completes semantics of the concept cpt_N.

Anyhow, this is the principle how engine autonomously acts, but also at the same time builds semantics (learn and crystallize its knowledge).

4 Conclusion

Paper reports about new conceptual semantic data structure of product model that aims to capture semantics of product itself, its components and features. In the focus of research is proposed associations-oriented data structure in regard to existed object-oriented approaches. In addition, special attention was devoted to design of algorithms for associations similarity determining and analogies that comes from it. This was recognized as a main procedure of analogy-based reasoning as well as semantic interpretation of data.

The ultimate reason for embedding semantic structure in the product data model is the expected breakthrough in data processing that should finally lead to increasing of reliability so as productivity of development department and realizing remarkable savings in product lifecycle management.

A noticed weakness of the model now is poor linkage to the knowledgebase structure. In the next step of the model development we are going to employ web-services that should be capable of allowing the user to model product knowledge into modular and portable semantic structures and link it to the features and parts data structure (to be easier and more intuitive to establish these links).

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Implementation of a product data model to support variant creation process as a part of product lifecycle management

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Abstract: Nowadays the complexity in companies rises rapidly. Enterprises must be able to handle conflictive requirements: On one hand low internal variety in order to achieve low complexity within the company and on the other hand high external variety to cover as much customers as possible is aspired. The key concerning this complexity is to gain control of the variety in the product data to support the variant creation process. Product lifecycle management (PLM) provides the strategy to handle this problem by deploying a product data model. This paper describes a product data model and its implementation in a product data management system (PDMS) to support the variant creation processes as a part of the PLM strategy.

Keyword: variant management, product data model, PLM, PDMS

1 Introduction

The development of the market, demanding an individual product for each customer combined with the requirement of keeping the internal variety of components and assemblies as low as possible, leads to the problem of efficiently enhancing the management of product data. This problem grows according to the product complexity and the number of engineering designers involved as well as the organization-related complexity, which induces department boundaries. An engineering designer is not able to find already existing data/information, relevant for the new order/requirement, in an adequate time. Multiple standardization rules are already defined in internal guidelines. But due to time consuming searching processes, the engineering designer often doesn’t consider this standardization. It is much easier for him to create a new component or new assemblies rather than to use any of the existing ones. In this way the internal complexity will rise rapidly.

Within this product data model a reference product structure will be established, consisting of several reference products with each representing one particular product family. This reference product can be used as a platform in order to keep the necessary standardization of components and assemblies within a certain product group. The reference product structure can support the engineering designer to find the right data to fulfill the new requirements and can additionally be used as a basis for collecting knowledge and building a knowledge pool.

2 PLM

There are a lot of definitions concerning the term Product Lifecycle Management (PLM). Some software vendors define it as a sort of software, but PLM is far more than that. Abramovici et al. defines PLM as the collective term for the integration of various management approaches and IT systems in engineering [1]. Feldhusen et al. emphasizes the knowledge aspect in the definition of PLM, so that PLM is considered as knowledge based company strategy for all processes and its methods concerning the product development from the product idea up to recycling [2].

The purpose of PLM is to integrate, to consistently manage as well as to control data according to the requirements along the whole product life cycle and its variants across departments and sites, thus to control the data complexity [4]. Therefore the implementation of PLM strategies could be considered as a solution to handle the complexity in a company (see Figure 1).

The PLM approach consists of two main aspects [3] (see Figure 2). The first aspect deals with the control of information flows along the whole product life cycle. Thereby not only the flow of information within the company has to be considered but also the collaborative product development with external partners. It means e.g. an exact definition of exchange content has to be clarified and specially comprises the protection of decided company knowledge. The second aspect of PLM deals with the product and its embodiment. Considering the market development in the future the product should be designed in the way that e.g. a variety in function or product extension is possible in later stages without costly redesign. The future market needs will also be considered in the planning, structuring and design of the product, without their whole implementation right in the beginning of the market launch. Thereby the characteristics of the component interfaces are of enormous importance. The standardization of the mechanical, electrical and software-technical parameters is strictly required to enable future replacement of components without problems [3]. The product comprises also provisions on functions and/or properties which can be used on demand.

These days Product Data Management System (PDMS) are in use as a computer aided tool to handle the control of information flows [3]. There are three main focuses to be considered for usage and introduction of the system:

- Product data. It covers all relevant product data and their references. The abstraction of this can be set up in a product data model. A Logical integrated and networked product data model is a central component of a PLM-IT-environment. [1].
- Process. It comprises all processes during product development, including the processes implemented in the system as a workflow. This is described in the process model.
- Organization/Resources. It contains all the resources in the company, which accomplish the process and use/produce the data. In the PDMS-context this resource is considered as an actor and is described in a role model.

Figure 1 External and internal influencing factors of the variety in the company [2].

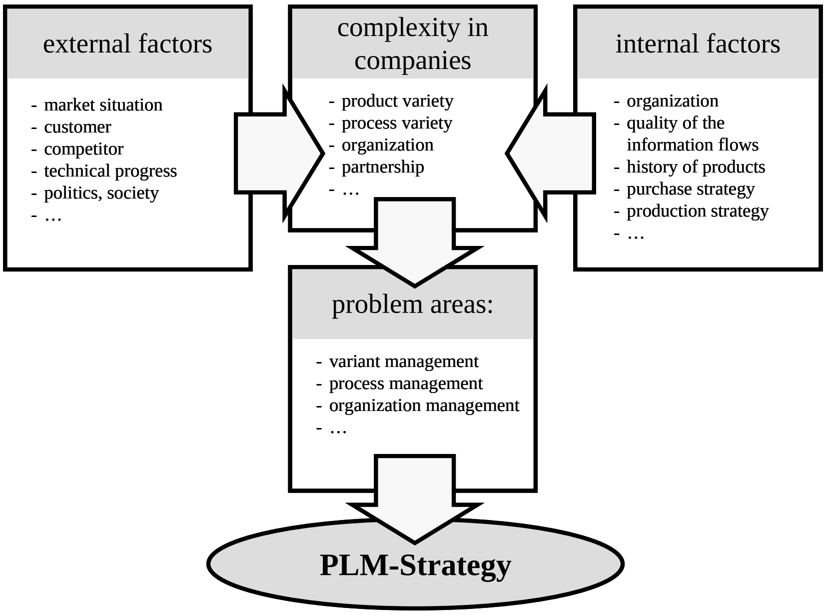
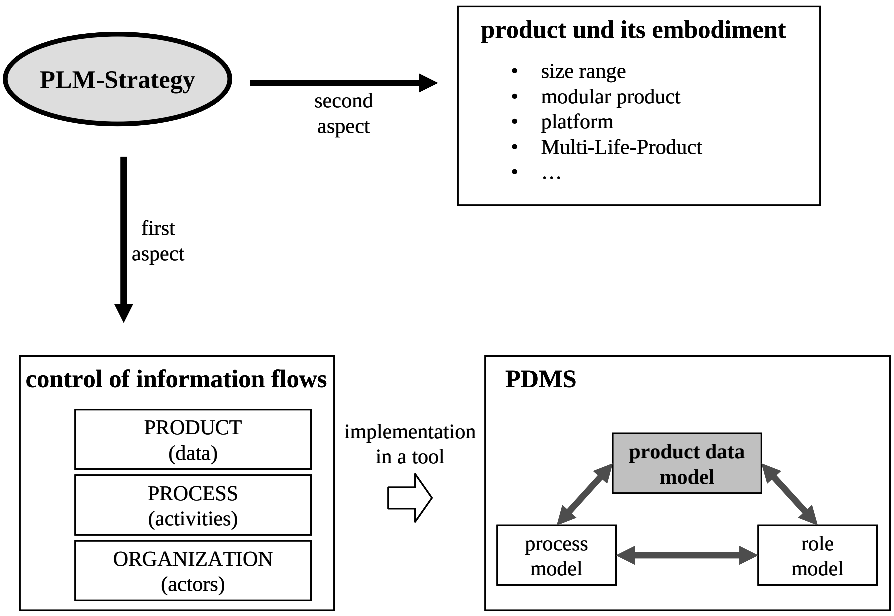


Figure 2 Aspects of PLM



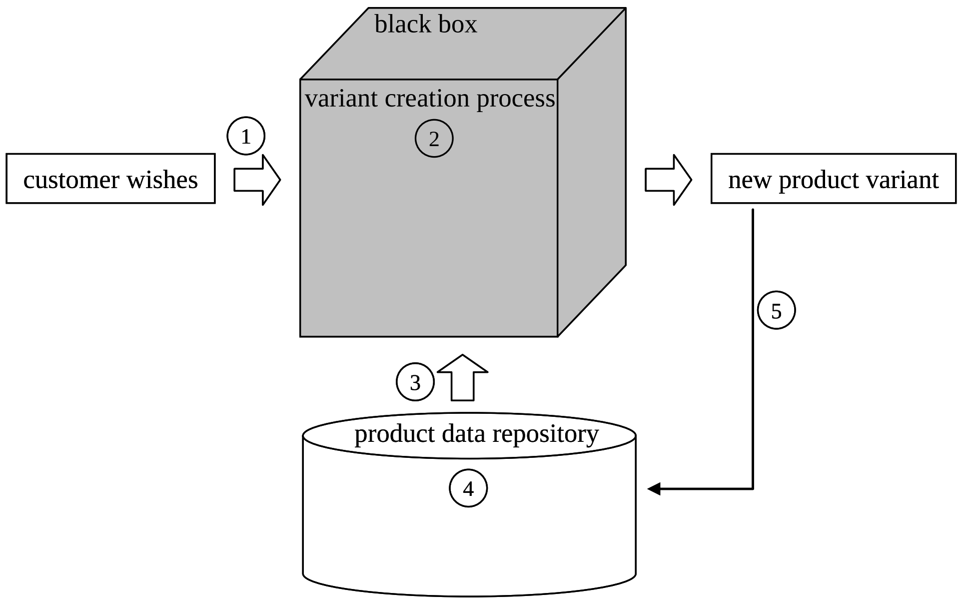
3 Variant Creation Process

In a company with high product variety a new product variant will be generated out of any existing variant, mostly matching the new requirements.

Figure 3 shows a typical procedure to generate new product variants. The variant creation process is schematically illustrated as a black box, because of its high flexibility. This procedure has some deficit characteristics (numbers as shown in Figure 3):

1. The customer wishes are mostly not acquired precisely. This leads to requirements lists, which do not consider existing variants. In many cases there is also a lack of communication between the marketing department and the product development. On the one hand the marketing does not have good overview of the existing product variants and their purposes and on the other hand the requirements coming from the marketing are not subject to be questioned by the engineering designer. The chance to fulfill the customer wishes using the existing variants will be missed.
2. There is no standardized process of variant creation. Every engineering designer has his own procedures. Experiences from other designer or departments will not be utilized or taken into account.
3. The engineering designer randomly chooses any existing variant as a reference product to the new product variant. There is no rule to define the reference product.
4. The Data repository only serves as a collection of product data without any references between each other. The history of a product variant could only be detected with a high effort.
5. New data will just be stored as another data in the repository. The sustainability of product data to support the internal variety to be maintained low is not considered.

Figure 3 Variant creation process as a black box.

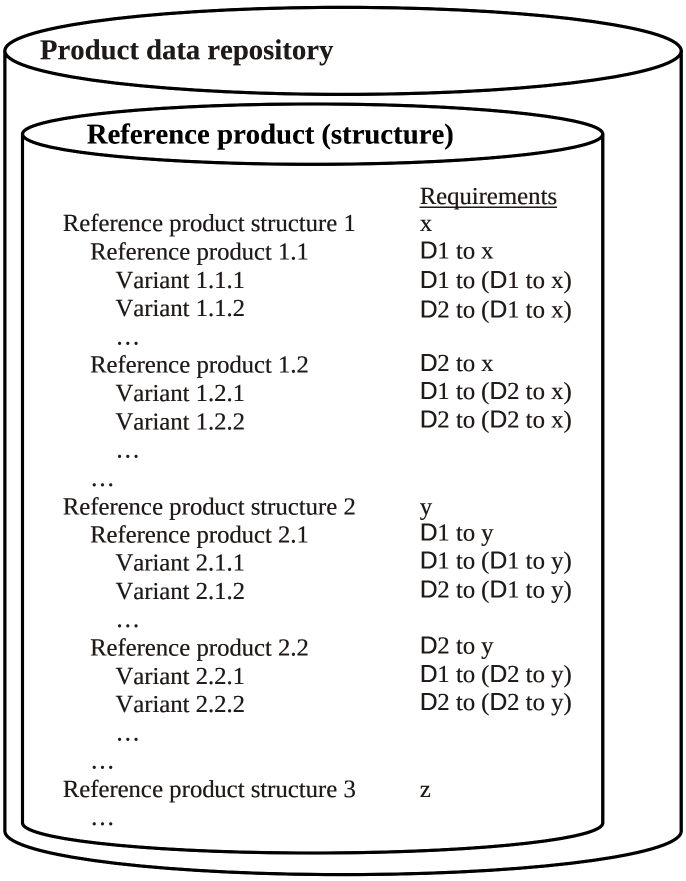


4 Product Data Model

The product data will be stored in a product data repository. The description regarding the content of the data with references between each other will be abstracted in the product data model. This repository does not have to be in a singular databank. It is just a collective term for the storage of all product data. Ideally there is only one reference product structure, which is valid for all product variants existing in the company. But in practice, the variety of products can be very high. It will be very difficult to find the commonality in the structure or a single structure which covers all products will not be practicable for meaningful use.

Product data repository storing the data of product variants is depicted below (see Figure 4). Each product variant has some discrepancies in requirements compared to the reference product, from which the product variant is generated. The reference product has in turn some discrepancies in requirements compared to its reference product structure. The description of the product variants can be conducted through the definition of the requirement discrepancies.

Figure 4 Product data repository



A general product data model is shown in Figure 5. The product itself, an assembly or a part can be considered as an object. Every object will be represented as a node in the product structure. A product data model delivers the description of an object, which can be realized by the definition of documents and object attributes. A document can have either a fundamental content, such as 3D-models, assembly plans etc., or an associative. The last one describes a document which is derived from a basic content.

The document could also be considered as an object (document-object) described by several attributes (document-attribute).

According to its purpose an attribute can be utilized to classify, to realize a rule (e.g. a design rule to describe a combination constraint between the objects) or just to describe a reference to another objects/documents. A certain set of attributes for a certain classification can be defined. The reference attributes also enable the description of relations between the product data model, the process model (e.g. lifecycle status) and the role model (e.g. created by).

Figure 5 General product data model

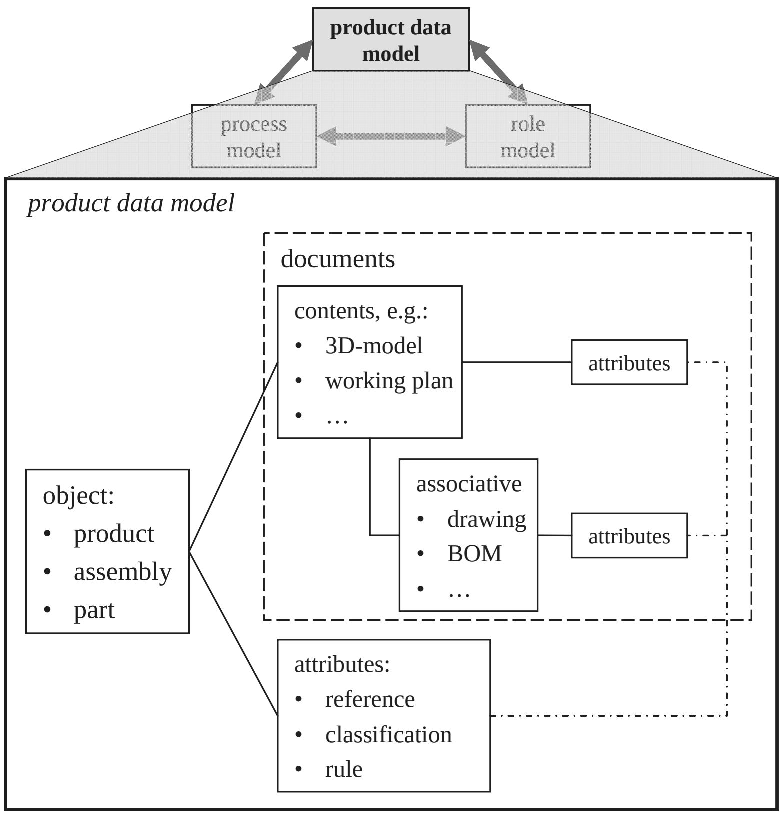
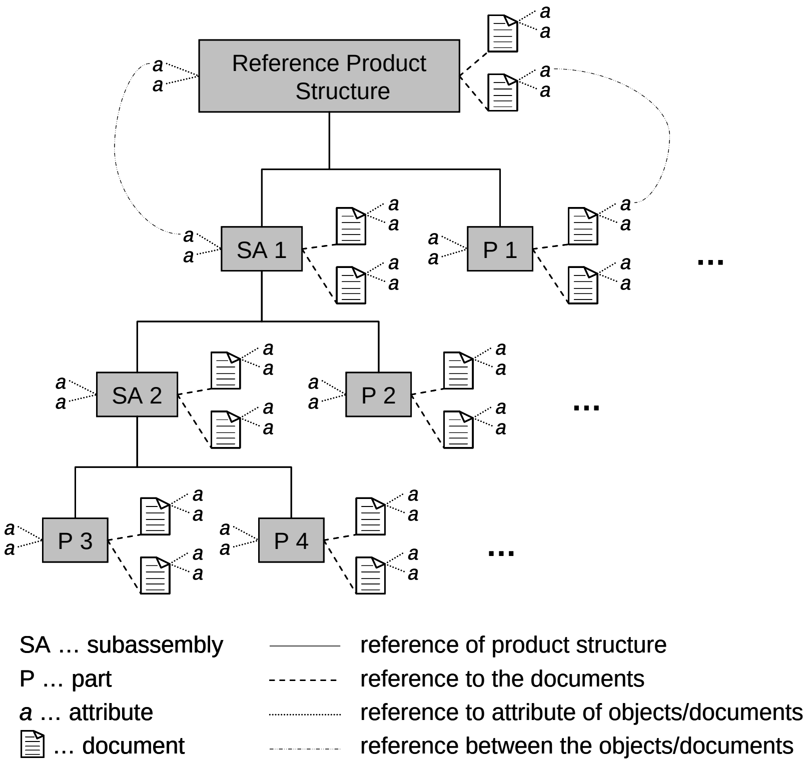


Figure 6 shows a reference product structure derived from the general product data model. Every node in the structure is considered as an object. The structure itself is actually a derivation of the description of the objects (application of reference attributes). This structure will be used as a template to deduce a meaningful reference product, which consists of the existing object instances. The combination of the object instances within a reference product results in a product variant. This procedure allows the engineering designer to create new product variants through a configuration instead of developing a new design. New created objects, which are unavoidable in some cases, should be attached as a further option in the reference product. This assures the sustainability of the entire product data.

The standard procedure to avoid unnecessary creation of new objects should be incorporated in the variant creation process (black box in the **Figure 3**). It can be realized by implementing a strict approval process, which can be realized in PDMS as a workflow.

Figure 6 Reference product structure



5 Summary

The paper emphasizes an aspect of PLM to control the complexity in a company with high product variety. Through an effective arrangement of product data within a product data model the variant creation process can be supported meaningfully. The redundant and dispensable creation of parts/subassemblies can be avoided. Thus the internal complexity can be maintained low. Because of the simplification in the searching process and the low degree of data redundancy, the productive data is of more feasible quality.

The product data model described consists of a reference product structure. Within this structure several reference products can be defined according to the given product attributes. Using the combination of the parts/subassemblies in the reference product a variant can be configured with less effort. At the same time the sustainability of product data can be maintained.

Acknowledgment

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Product data and digital mock-up exchange based on PLM

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Abstract: Nowadays, aeronautics manufacturers work in close partnership to increase competitiveness and to share risks. The digital mock-up aims at providing the same product view to all the partners of the same engine project. It requires intensive data exchange between the partners. But Snecma works on several projects and each project presents a different exchange protocol. Thus Snecma has to develop specific exchange mechanisms for each engine project.

This paper presents Snecma's strategy to exchange data with all the partners of one project and to reduce the development to adapt exchange mechanisms. It consists in the encapsulation of generic functions, reusable applications and adaptable translators. It appears that this solution is adaptable to all engine projects, it offers robustness and a lot of possibilities, but the implementation is difficult.

Keyword: Product Data Exchange, Digital Mock-Up, XML, Extended Enterprise, Standard for Exchange

1 Introduction

Regarding the world wide market, aeronautic manufacturers, in particular engine manufacturers, need to build strong partnership to develop new products. As a consequence collaborative product development approach has to be thought and the intensive use of IT is required to manage business processes and to share product data. Considering the growing of PLM challenges in the enterprise, IT supports are based on PLM, including digital mock-up.

First of all, this paper presents specifications and developments carried out by Snecma (Manufacturer of aircraft and space engine) to manage its product data and exchange them with partners. Section 2 presents the project objectives and associated issues. A survey of the main standards for PLM data exchange is detailed in section 3, considering PDM Schema, PLM Services and PLM XML. Section 4 presents the method chosen by Snecma compared to data exchange standards. This method is illustrated in section 5 by the implementation of a Snecma's engine project.

2 Project context and issues

In order to re-engineer its product development processes, Snecma recently chose to implement a new PLM solution integrating CAD/CAE/CAM processes and providing an efficient support for concurrent engineering and the extended enterprise (Sohlenius, G. (1992)), (Browne, J. et al. (1995)). The aim is to achieve the implementation of a collaborative product development process based on PLM technologies by merging concurrent engineering and extended approaches (Prasad, B. (1996)), (Cullen, P.A. (2000)). Snecma wishes to improve and secure its data exchanges and transfers between the partners of an engine co-development (Pardessus T. (2001)).

This means that the PLM solution manages and stores product data, and then distributes them among the whole design team (Stark, J. (2004)), (Xu, X.W. et al. (2003)). Considering the geometric definition of product, it allows an intensive use of 3D data including form features modeling and interface specifications to describe a skeleton reference as a basis for engine design.

2.1 Snecma's new PLM

The PLM technology used by Snecma is based on ENOVIA VPM (Virtual Product Manager). In order to store and share the product data, Snecma implements three VPM specific workspaces: the working space, the reference space, and the engine space.

The first workspace corresponds to the working space. It is used to store the designers' work in progress.

The second workspace is called reference space. When product data are released, designers transfer their parts and assemblies from the working space to the reference space.

The last workspace is the engine space. It archives the product's Digital Mock-Up (DMU). This workspace contains and integrates product data from the reference space and from partners.

2.2 DMU: the same product reference framework for all partners

The cost and risks of an engine development lead aircraft engine manufacturers to share their skills and knowledge in close partnerships (Shen, W. (2003)).

In order to increase the partnerships efficiency, the main goal of DMU is to integrate the whole engine 3D geometric definition and product structure data based on original CAD files (Huang, C.Q. (2002)). It conducts to the merging of Snecma and partner's product data in the same reference framework.

This system allows Snecma to use the various DMU modules of its CAD system. Designers can analyze the geometric definitions, detect clashes, assess space allocation, and simulate the turboprop disassembling. Based on DMU, they can also evaluate ergonomic and technical constraints during the assembly and maintenance operations.

The mostly used basic modules for DMU management are:

- Clash analysis: this module lists all interferences, contacts or clearances in an assembly.

- Fitting simulation: designers can simulate the disassembling of a part and detect interferences problems or optimize the number of components to be disassembled for maintenance.

These modules aim to reduce numerous problems in the assembly, working and maintenance phases.

2.3 Exchange between heterogeneous PDM/CAx systems

First, regarding industrial IT strategy, each company has its own PDM and CAD systems. In collaborative product development, partners have to exchange their product data with other partners in order to update their DMU.

It represents an effective problem for data exchange because each partner has to translate other partners' data to the format of his own PDM and CAD systems.

To illustrate the numerous IT applications used in such a context, the list of PDM and CAD systems of each partner involved on the engine project SaM146 is detailed below:

- Snecma: ENOVIA VPM (PDM), CATIA V5 (CAD)

- Partner A: CATIA V5 (CAD)

- Partner B: Teamcenter (PDM), UNIGRAPHICS NX (CAD)

- Partner C: Teamcenter (PDM), CATIA V5 (CAD)

- Partner D: UNIGRAPHICS NX (CAD)

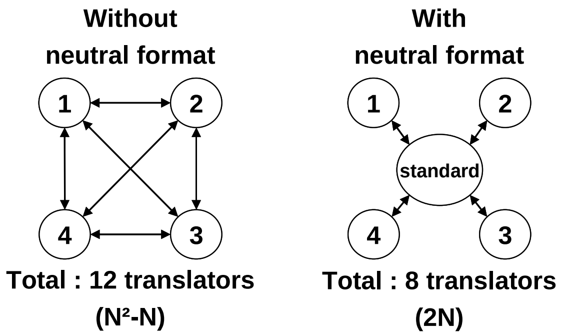
Second, Snecma works on several projects. Each project presents different systems, so that Snecma has to adapt to each project. Snecma's issue is to interface its PDM with all the others PDM of a project and to adapt this interface for each engine project.

3 Survey on existing standards for data exchange

In such a context, each partner still has its own DMU. Regarding DMU's data exchange Snecma needs to replicate the product model from one DMU to another. This requires the definition of a storage format for exchanged data. This format allows the exchange of a static definition of the product.

However, Snecma has to translate partner's data to its own storage format. Because each partner uses different DMU, Snecma has to develop one translator for each of them. As shown on Figure 1, if Snecma and partners use a standard storage format, each of them just has to develop two translators.

Figure 1 The interest of standards in data exchange



Numerous standards have been developed in the last 15 years for different kind of PLM data exchange (Yeh, S.C. et al. (2000)). The following sections will introduce the most operational standards for each kind of exchange.

3.1 PDM Schema

STEP (Standard for Exchange of Product model data) is an international standard developed by ISO (International Standard Organization). Its reference is ISO 10303 (Pratt, M.J. (2005)). This standard offers various means of storage, exchange and archive of product data in a long-term approach.

Based on the entities definition proposed in several STEP parts, the PDM Schema has been specified for exchanging data usually stored by PDM systems (Kindrick J. et al. (2000)), (Machner B. et al. (1998)). This standard is the consistent intersection of entities' definitions and data structures of several STEP application protocols covering numerous fields: mechanical design, product configuration management, electrical design, automotive design (AP203, 212, 214 and 232).

3.2 PLM Services

The PLM Services is a data model based on the PDM Schema and STEP Application Protocol 214 (http://mantis.omg.org/). The PLM Services implement all the entities defined by the PDM Schema and complete the model with additional entities dedicated to the AP214 schema's configuration management. The definition of PLM Services is based on the PDTnet project's issues carried out by ProsSTEP iViP (http://www.prostep.org/file/15730.Fly_allg). The objective of this project was to merge AP214 and XML formats in order to simplify data exchanges between the original equipment manufacturer and its suppliers.

3.3 PLM XML

PLM XML is a format developed by UGS in order to enable interoperability between PLM solutions based on the strength and quality of XML (UGS (2004)). XML, meaning eXtensible Markup Language, is a language structured with tags whose name and organization are not fixed (Burkett, W.C. (2001)). Regarding its tags, the XML structure is derived from SGML and HTML languages and allows users to build their own data structure.

PLM XML offers an efficient and flexible solution for product data exchange via Internet (http://www.plmXML.org). PLM XML is defined as a set of XML schema compliance with the W3C specifications.

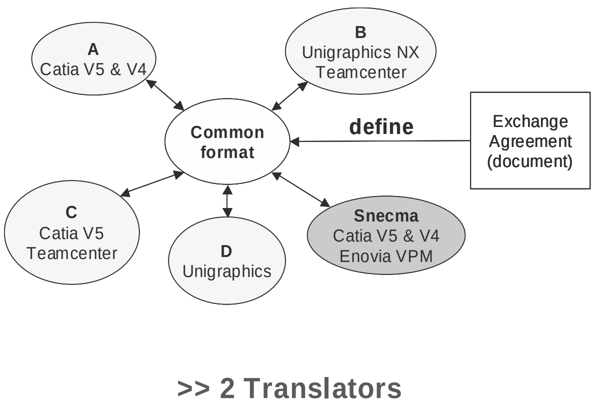
4 Snecma's strategy for data exchange with business partners

4.1 Data translation

4.1.1 Common format

As explained in section 3, the use of standard in data exchange reduces the number of needed translators. Nevertheless, standards are difficult to implement and some partners have leadership position in the project. So they can impose one format for the exchange process. As a consequence, they decided to use a common format, specified in a document called "exchange agreement" (Figure 2). This format can be a legacy one or not.

Figure 2 The common format

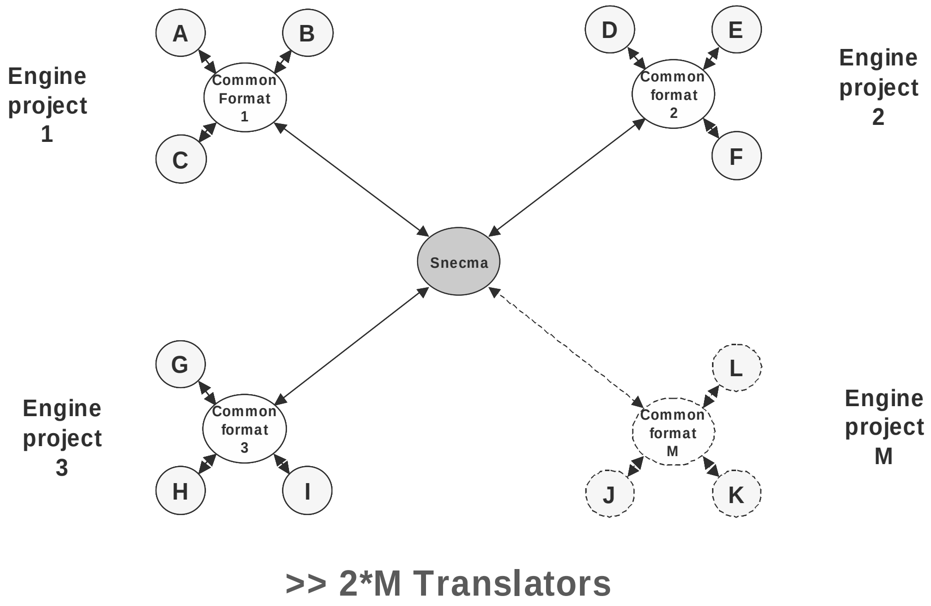


This choice is easier to implement and requires only two translators for Snecma, as in case of the neutral standard use.

4.1.2 Multi-project and multi-partner

Compared to neutral standard, the common format solution presents robustness, low-size files and does not need a lot of time to be implemented. But Snecma works on several engine projects at the same time and each project has a specific common format. So Snecma has to configure its translators for each of them (Figure 3).

Figure 3 Multi-project and multi-partner issue.



For each project, Snecma has to develop two translators. As a consequence, for M projects, it is necessary to develop 2*M translators. The aim is to reduce developments to configure the translators for each engine project.

4.2 Snecma's Exchange mechanism's specification.

4.2.1 Exchange of product structure and geometric data

In the DMU, the product is organized in a tree structure: each node (or PART) contains information such as bill of material or data manager. Links between nodes contain the geometric position of parts and the product structure configuration. Last nodes of product structure are linked to geometrics files. Tree structure's data is called meta-data.

In order to simplify data translation, the "exchange agreement" specifies that meta-data and geometric data are split up in two different files. It implies that Snecma has to develop a translator for meta-data and another for geometric data. This choice is easy to implement because it exists a lot of solutions for geometric data translation. For example, Snecma use a dedicated server (DexCenter - http://www.transcendata.com/dexcenter.htm). So this paper will only consider meta-data's translation mechanisms.

4.2.2 PDM interface

To translate its meta-data into common format and send it to partners, Snecma has specified exchange architecture integrated to its new PDM. Snecma's solution is to use a PDM interface that extracts all DMU's data in a storage files with an internal format (format will be described below). This interface is the same for all engine projects. After extraction, storage files are filtered and translated into project's common format.

The use of a generic PDM interface limits the application customizations for each engine project: instead of extracting data with the translator of each engine project, we have one interface for all projects. Furthermore, data extraction in internal format allows Snecma to run others internals processing on DMU's.

In the other hand, the translation depends on common format so that it can't be the same development for all projects: now, the aim is to reduce developments between the different translation processes.

4.2.3 Internal storage format

Internal storage format is CATIA V5 release 15 legacy for CAD files and an XML file for meta-data. The structure of XML file is based on two main entities:

- PARTS_LIST: it corresponds to the list of objects contained in the product structure.

- PRODUCT_STRUCTURE: it describes the links between objects of the part list.

The objects of PARTS_LIST are linked to the node of PRODUCT_STRUCTURE in order to maintain the consistency between parts' data and their position in the product structure.

Finally, in order to maintain the link between meta-data and CAD files, objects of PARTS_LIST use a pointer on the associated CAD file. This pointer is the name of the CAD file.

The XML file only deals with basic DMU's data because exchange between partners' PDM are technically limited to simple product structure definitions. Its structure inherits from Snecma's PDM architecture and does not aim to match with issues defined in the PLM XML. The structure is simple and flexible because it adapt to any data model from Snecma's DMU. The second advantage of this format is the readability aspect: there is not many information and the XML data schema is close to the modeling of product structure in the Snecma's DMU.

4.2.4 Full exchange mechanisms

Compare to the new exchange mechanism, the former DMU system does not have the same exchange procedure for each engine project. For example on SaM146 project all the data were extracted, translated and filtered by one application. Whereas on TP400 project, all the DMU was extracted and written in an XML file, then an application filtered and translated this XML file.

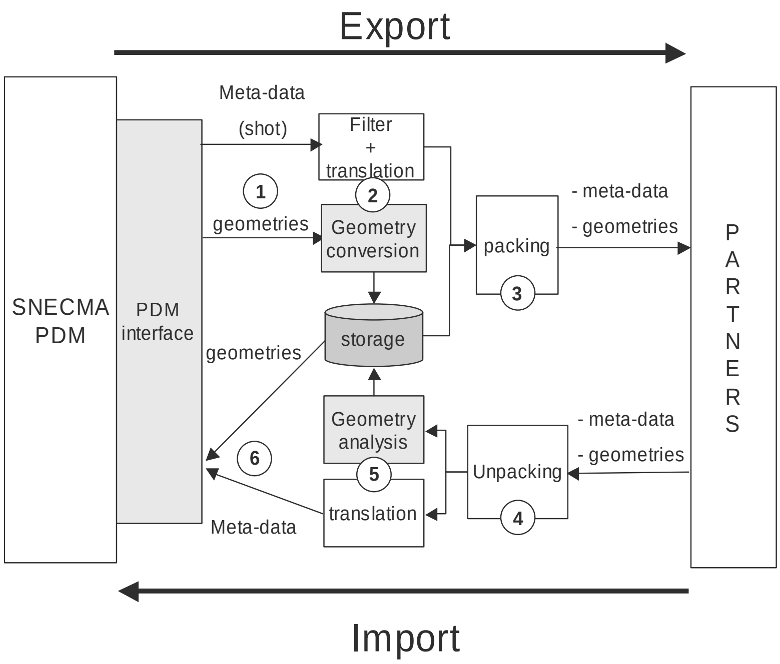
The aim of the new system is to use the same steps for each engine project and to reuse mechanisms between engine projects. Figure 4 shows these different steps.

During an export phase, PDM interface extracts geometric data and the whole product's meta-data (step 1). Geometric data and meta-data are translated to the common format by two different translators (step 2). When all data are translated they are packed and sent to partners (step 3).

During an import phase, partner's data are unpacked (step 4) and meta-data are translated (step 5). PDM interface imports translated meta-data and partners' geometric data (step 6).

Blue boxes are the most generic steps between an engine project to another. Yellow ones are the most specific steps. Packing and unpacking are simple treatment: this step doesn't impact development cost and time. The critic step is the meta-data's translation: it will be described in the following case study.

Figure 4 Exchange mechanisms



5 Case study: SaM146 engine project

SaM146 engine project has been the first to be implemented in the new Snecma's PDM. It is important to make a flexible and robust exchange system because Snecma ensures the leadership on this project: it has the role of engine integrator. This role consists in integrating the 3D data of all partners to the DMU reference framework. Then, the integrator distributes all the updated data to the other partners and guarantees the consistency of the product structure.

5.1 Definition of common format on SaM146

Common format on SaM146 is close to Snecma's internal format. Geometric data use CATIA V5 release R14 legacy format and an XML file implements for meta-data of product structure. The structure of the XML file is the same as Snecma's internal XML, only attributes' names change.

The advantages of XML format for exchange are that the file is easily read. The read of XML format is simplified by the use of parsers. For example, Snecma has developed an application that compares two XML files. It is used to compare its DMU meta-data with meta-data of partner's DMU.

5.2 Meta-data translation : XML tools

In order to translate meta-data file, Snecma has specified several groups of application. Each application has a simple functionality and Snecma encapsulates them to carry out complex processing on XML. These functions are configurable, so they can be reused for others engine projects.

These applications are based on XML parsers: they read the XML file and validate its format. They also respect the aggregation defined in the static definition, for example: if the application deletes a PART from PARTS_LIST, it deletes the corresponding nodes in the product structure.

It's important to notice that XML tools can translate an XML file into another format than XML.

6 Preliminary Results of the implementation of data exchange mechanisms

6.1 Migration onto new PDM

The first use of the exchange mechanisms has been the migration of the former DMU to the new PDM. A specific exchange procedure for migration has been defined and a configured xml tools has been developed to adapt it to the migration.

All data have been exported from former DMU and transferred to the new one while they were or not partners' data. As the exchange mechanisms were not fully automated, this operation allows to prove their flexibility and performance.

6.2 Implementation on engine projects

Encapsulation of xml tools for Sam146 is difficult. Specification of encapsulation is complex because of the number of filters to chain and configure for each partner. The other difficulty is the validation of encapsulation: it was very long because of the size of data and the time that takes the full exchange mechanism.

The second engine project, TP400, wasn't as difficult as SaM146 because we benefited from the experience of the first engine project and the only xml tool use was the translator. But difficulties came from the quality of partners' data: it appeared that some partners' data didn't respect exchange agreement of TP400, so that import was often automatically stopped. This proves the importance of exchange agreement in the automation of exchange between partners.

For the moment exchange mechanisms are operational for two engine projects. Specific development for the third engine project (GP700) is achieved but Snecma and partners have to clarify some aspect of the common format.

7 Conclusion and future works

Snecma and its partners have chosen a solution that reduces the number of data's translation with a shorten implementation time. But the exchange format is specific to one engine project. As a consequence, translations are different between two engine projects. To balance this problem, Snecma's translation strategy aims to be adaptable with only few basic developments.

Second critical aspect: the translation of geometric data is limited to one legacy format. This minimizes the data inconsistency during the translation but it implies a different CAD system has to be customized to fulfill the exchange procedure.

Last, the exchanges are adapted to the geometric data (DMU oriented) but other data may need to be exchanged with partners (FEM, Numerical Simulation, etc.). Thus the next step is to specify the other kind of product data to be integrated and exchanged with partners.

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Assembly modeling approach including assembly process information for mechanical product

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Abstract: Product assembly sequence is directly influenced by API: assembly fixture, assembly tools, assembly operation, and so on. It is important that API is expressed in assembly model in order to achieve good assembly sequence. This paper presents an approach of assembly modeling including API. The basic idea of the approach is to express API in assembly model by building prior relationship and constraint relationship between assembly-cells and API. We analysis and define prior relationship between assembly-cells and API when assembly-cells and API come into and come out from assembly environment. Assembly model including API is built by connected-graph model based on directed graph and undirected graph. Firstly, the directed graph represents the prior relationship between assembly-cells and API when assembly-cells and API come into and come out from assembly environment. Secondly, the undirected graph represents assembly relationship between assembly-cells and API. Thirdly, a connected-graph model is used to integrate the directed graph and the undirected graph. So an assembly model including API appears. The assembly model including API is propitious to express experiences of assembly process and to plan assembly sequence of product. The approach is validated by an example in this paper.

Keyword: Assembly Process Information (API, assembly model, connected-graph model

1 Introduction

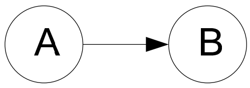
Parts are assembled into product based on assembly fixture which workers deal with according to definite assembly sequence and by adopting appropriate assembly tool and assembly operation to complete the assembly of product. That API such as assembly frock, assembly fixture, assembly tools and assembly operation participates in the assembly is necessary to effectually complete the assembly of product, but the input and output sequence of this API will affect the assembly sequence of product. The gain of assembly sequence roots in the expression of the assembly model evaluate the assembly model by two ways, whether or not directly including CAD model and effectually helping to make logical assembly sequence [1]. Therefore, it is extremely important to input API including assembly frock, assembly fixture, assembly tools, assembly operation to the assembly model for the validity and integrality of the assembly model information. Now, product assembly model involves three types: 1) Conjunction model [2-3]; 2) Hierarchy model [4]; 3) Advanced data structure expression [5-6]. The paper introduces an including API in product assembly model, for importing API to the assembly model and explicating input and output assembly environment of API with assembly cell, this method is good to express assembly experience and plan assembly sequence.

2 Including API in Product Assembly Model

2.1 Priority Relationship Analysis of Assembly Cell and API

Definition 1: Define priority relationship of assembly cell and API participating in the assembly as: *P(A,B)*, where $A, \mathrm{B} \in \{AC, FR, FX, TL, AO\}$: *AC* is assembly cell; *FR* is assembly frock; *FX* is assembly fixture; *TL* is assembly tool; *AO* is assembly operation. $\mathrm{P}(A, B)$ means that *A* is priority to *B*, which is shown by Figure 1.

Figure 1 Direct graph of priority relationship



Assembly process includes two stages: firstly, importing assembly cells and API to assembly environment to complete the assembly; secondly, API must quit assembly environment after completing assembly. To work better, assembly cell and API according to definite priority relationship imports and quits assembly environment. Therefore, $\mathrm{P} = \{PI, PQ\}$, PI means importing priority relationship, PQ means quitting priority relationship.

Definition 2: Input Priority Relationship. While importing assembly cell and API to the assembly environment, define importing priority relationship as $\mathrm{PI}(A, B)$, meaning *A* is priority to *B*.

Definition 3: Output Priority Relationship. Assembly body and API will quit assembly environment after completing it ; Output priority relationship is $\mathrm{PQ}(A, B)$, means *A* is priority to *B*.

Generally, as for a assembly working procedure, input and output of assembly cell, assembly frock, assembly fixture and assembly tool preserve definite priority relationship, shown in Table 1.

For the instance of screw *S* and nut *SC*, *S* is fixed in the fixture *FX*, and then importing nut *SC*, wrest TW fixes nut SC in the appropriate position by using spanner SP and adopting assembly operation. The priority relationships of S, SC, FX, SP, TW importing the assembly environment are $PI(FX, S)$, $PI(S\ ,\ SC)$, $PI(SC\ ,\ SP)$, and $PI(SP\ ,\ TW)$. While assembly is completed, S and SC become an assembly A.

At that time, FX and SP must quit assembly environment. Output priority relationships are $PQ(SP, A)$ and $PQ(A, FX)$. Now assembly of S and SC is finished.

Table 1 Input and output priority relationship table of assembly cell and API in the assembly working procedure

Input priority *PI*		Output priority *PQ*	
Priority relationship	Reason	Priority relationship	Reason
PI (assembly frock, assembly cell) PI (assembly fixture, assembly cell）	Because frock and tool are used to fix assembly body, it is necessary to fix frock and tool first.	PQ（assembly body, assembly frock） PQ（assembly body, assembly fixture）	After completing assembly, Because frock and tool are used to fix assembly body, it is necessary to quit assembly environment first.
PI（assembly cell, assembly tool） PI（assembly tool, assembly operation）	Only that assembly cell enters the appointed position, assembly tool assembles it.	PQ（assembly tool, assembly body） PQ（assembly operation, assembly tool）	While completing assembly, assembly tools work nothing, then assembly tool need to quit assembly environment.

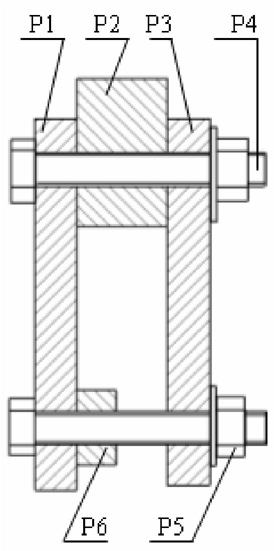
2.2 Including API in Product Assembly Model

In the assembly process, assembly cells are assembled into product according to assembly function by adopting special assembly operation under the support of assembly frock and assembly fixture. Assembly is “set-up” and “cooperation”, where set-up is incorporation and cooperation is the condition of incorporation. [7]

Because of API which includes assembly frock, assembly fixture, assembly tools and assembly operation participating in the assembly, they will affect the assembly sequence. But obtaining logical assembly sequence mainly depends on the expression of product assembly model. Researching API included in product assembly model is extremely valuable for the generation of assembly sequence.

Assembly process including assembly cell, input of API and output of assembly body and API after completing assembly need to be shown in the assembly model. The paper will introduce a conjoint graph model including direct graph and non-direct graph to express product assembly model including API and adopt direct graph $G_1(V, E)$ to show input and output priority relationships of assembly cells and API, where V is a set of nodes and E is a set of priority relationships. Non-direct graph $G_2(P, C)$ is adopted to represent assembly conjoint relationships or assembly constraint relationships among assembly cells, where P is collection of nodes and C is assembly conjoint relationship or assembly constraint relationship. Thus, in the process of set-up in product assembly model including API, input stage including importing priority relationship definition and assembly conjoint relationship or assembly constraint relationship definition, and output stage including quitting priority relationship definition. An example describes assembly model by direct graph and non-direct graph. As is shown in Figure 2, this product is made up of P_1, P_2, P_3, P_4, P_5 and P_6.

Figure 2 An example of assembly body



For the stage inputting assembly cells and API, input priority relationship is defined firstly. To complete the assembly of parts, fixture *FX* fixes two blot parts *P4,* spanner SP screws two nut parts to appropriate position, so we can obtain the priority relationships of assembly cells and API as is shown in the Table2. A Conjoint or constraint relationship among assembly cells is defined secondly. Product assembly model Including API of the product in the input stage is shown by Figure 3(a).

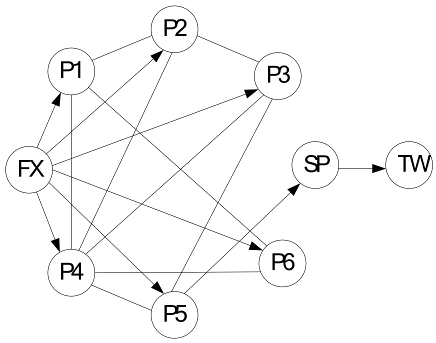
Table 2 Priority relationships between assembly cells and API of the example

Priority relationship	Direct graph of priority relationship
$PI(FX, \{P_1, P_2, P_3, P_4, P_5, P_6\})$	FX → P1, FX → P2, FX → P3, FX → P4, FX → P5, FX → P6
$PI(P_5, SP)$	P5 → SP
$PI(SP, TW)$	SP → TW

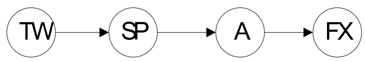
Assembly and API will quit assembly environment after assembly is finished. Product assembly model including API in the output stage of assembly and API is shown by Figure 3(b).

Figure 3 Product assembly model including API

(a) Assembly model in the input stage of assembly cells and API



(b) Assembly model in the output stage of assembly body and API



3 Conclusions

Because the assembly sequence planning mostly depends on the assembly model, and the APIs directly affect assembly sequence, this paper presents product assembly modeling including API. The advantages of the model are as follows:

1) Engineer’ s assembly experience can be translated into the priority relationships of assembly cell and API that importing and quitting assembly environment, conjunction relationship or constraint relationship of assembly cells.

2) The model not only plans assembly cell’s sequence in the assembly process, but also plans API and the sequence of assembly cell that participates in the assembly together. So the assembly modeling is good to assembly sequence planning.

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Chapter 5

Tools

Development of a tool to support the dissemination of information about knowledge in multilingual product development teams

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Abstract: New product development (NPD) represents a significant portion of the product lifecycle. Recent years have seen the adoption of cross-functional stage-gate NPD process models by manufacturers. These models demand the effective sharing of knowledge among individuals with different functional backgrounds and levels of experience. This scenario presents various knowledge sharing challenges. These challenges have been further complicated by the emergence of global product development, in which project teams may be comprised of individuals with no common language. This paper presents a methodology for building a mechanism that allows information about knowledge in the NPD process to be made available in a multilingual environment. The mechanism is a component of an ontology based NPD knowledge sharing developed by the authors. Implementation of the methodology using data from an industrial case study have demonstrated that it can applied successfully in practice, but further development and user feedback from industry is required.

Keyword: metaknowledge ontology, product development, multilingual

1 Introduction

Product development accounts for a significant portion of the product lifecycle, incorporating phases such as product conception, product design and product manufacture. Research has long indicated that many new product development (NPD) projects are considered failures, either because they are not delivered on time or because they do not meet financial targets [1]. Consequently, formal product development process models have been adopted by a growing number of manufacturing companies in order to introduce rigour into product development projects and to support decision-making by project managers [2]. In doing so, the risk of making expensive mistakes that may have to be rectified later on in the product lifecycle is reduced.

A popular formal product development models is the cross-functional stage-gate model. Activities within the process are connected by an exchange of information and knowledge and so effective communication is demanded to manage these activities [3]. However, the stages and review gates of which the model is comprised involve development project team members from different organizational functions, each of whom potentially has a different domain of expertise or level of experience. In recent years, the rise of global product development (GPD) has introduced further complications. GPD team members are typically geographically dispersed, speak different languages and have different cultural backgrounds, an issue identified by Desouza and Evaristo [4].

The knowledge sharing challenges resulting from this situation inspired an investigation of knowledge sharing problems in the NPD process of a major multinational heating systems manufacturer. The manufacturer has three main manufacturing sites based in France, Germany and the United Kingdom. Product development project teams at the company may be comprised of individuals with different specialisations from all three sites, so communication among individuals can take place in any of three languages. New products developed by the company are predominantly variations on existing designs or new product platforms.

An exploratory study at the company identified three knowledge sharing problem categories which have been presented in [5] and [6]. The categories were (a) the lack of an explicit definition of information about knowledge or metaknowledge in the context of the NPD process, (b) the lack of a mechanism to make this metaknowledge accessible to a multidisciplinary, multilingual NPD project team and finally, (c) the lack of a mechanism to disseminate this metaknowledge to team members in different locations. These problems serve to inhibit the achievement of a common or shared understanding of NPD knowledge among NPD project team members.

In order to address these problem categories, a methodology incorporating an ontology-based tool was proposed by which featured a classification of NPD knowledge and a web-based dissemination mechanism. Previous works by the authors have outlined the proposed methodology and demonstrated how the tool could be implemented through an industry based case study [6], and described the development of the NPD process knowledge ontology and web-based dissemination mechanism [5]. This paper compliments this earlier research in two ways. Firstly, the rationale behind the metaknowledge approach, as well as existing approaches to providing multilingual support for ontologies are discussed by reference to the literature. Secondly, and more significantly, the methodology used to develop a multilingual support mechanism intended to address problem category B is presented. Case study data collected at the heating systems manufacturer is used to illustrate the results of applying the methodology in practice.

2 Metaknowledge and Knowledge Sharing

Wright asserted that early knowledge management efforts had focused on capturing knowledge for use as an organisational resource, while largely neglecting the way individuals work with knowledge [7]. Similarly, Keane and Mason proposed that future research on the design of knowledge management systems should focus on how to show information or explicit knowledge, in a fashion that allows users to find and apply it in the required context [8]. One way of achieving this is to provide information about the knowledge, or metaknowledge.

Hendriks referred to metaknowledge in the context of knowledge sharing, describing it as ‘knowledge about the knowledge to be shared’ [9]. Metaknowledge is perceived as taking the form of either information about local information bases, such its location, or information about the owners and users of the knowledge. Examples of knowledge owners are colleagues who might possess the knowledge needed by a knowledge worker. Knowledge users are people who require knowledge already possessed by a knowledge worker. Hendriks viewed metaknowledge as an aid to locating agents that possess or are looking for knowledge.

Latterly, Donnellan and Fitzgerald advocated the exploitation of metaknowledge in their presentation of a knowledge management application to support knowledge dissemination among individuals within the engineering design function of the NPD process [10]. They suggested that metaknowledge should answer questions such as where knowledge about a particular domain could be obtained. This echoes the work of Court, which recommended that information systems used by design engineers should feature the ability to act as a reminder or “memory jogger” of where information may be found [11].

3 Multilingual Support for Ontologies

In recent years, researchers have examined ways to use ontologies to support a multilingual environment. The literature contains two main approaches to the issue, a view supported by Bonino et al. [12].

The first approach is to model the domain concepts in a single language ontology and then to map word keywords from the required languages to the same concept in the ontology. Lauser et al. used this approach to create a prototype biosecurity ontology [13], and Jararr et al. adopted it in their proposal for the construction of an ontology of knowledge in the complaints management domain [14]. Valarkos et al. included it in their proposed methodology for enrichment of a multilingual domain ontology by machine learning [15].

Lauser et al. proposed that a portal may then be constructed to retrieve the same information from the ontology, regardless of the language of the user [13]. This mapping approach is applicable to both the issue of sharing the ontology among users who speak different languages and the issue of semantic differences in vocabularies used by different functions or those with different views of design. Jarrar et al. commented that ontologies represent concepts and not terms, and so they are abstract from natural language [14], or as Bonino et al. stated, an ontology is ‘language independent’ [12]. Jarrar et al further argued an ontology intended is to represent a particular knowledge domain, which is consented to by, and can be shared among its users. Therefore, the lexicalisation of a concept, by which they mean devising a natural language expression to describe that concept, is intended render the ontology more usable.

Guyot et al. defined a multilingual ontology as one that includes a set of dictionaries for each of the languages required by its users [16]. Similarly, Vouros et al. described multilingual ontologies, more simply as ‘multilingual terminological knowledge bases’. Essentially, this is a database of natural language terms each of which lexicalizes a concept in an ontology [17].

In the case of the second approach the alternative perspective on the multilingual ontology described by Jarrar et al. is referred to in [14]. For the case of ontologies used in natural language processing, they suggested, developing a multilingual ontology involves developing an ontology for each language required, along with an alignment layer to map one ontology to another. It is this definition that forms the basis of the second approach, which is suitable for natural language processing applications [14]. Since this is not the application that is of interest here, this approach will not be considered any further. The first approach will be adopted in this study.

4 Method for the development of a multilingual support mechanism

4.1 Background

As outlined in [5], version 3.0 of the frame-based Protégé editor was used to develop the knowledge sharing tool. In the Protégé knowledge model, concepts such as 'knowledge item' or 'NPD process task' are represented by classes. The properties of concepts are represented by slots. Actual data, e.g. a specific knowledge items are manifested as instances of classes. Upon creation of a class and its relevant slots, a form is created that facilitates the acquisition of data about an instance of this class by the tool user. These forms are a key part of the tool user interface [18].

Another important feature of the Protégé knowledge model is its use of metaclasses. Noy et al. described a metaclass as 'a template for classes that are its instances' [18]. That is, it determines the 'own slots' a class will have. Own slots are properties of that class, as opposed to properties of the instances of that class. Classes in Protégé are instances of a metaclass called 'STANDARD CLASS', which contains slots such as the name of the class and documentation for the class. When a class is created the slots of the metaclass become 'own slots' for this class.

In the tool user interface, the name displayed by default for each class is the ':NAME' own slot for that class. Similarly, the display name for slots themselves is assigned to a slot called ':NAME', which is attached to the ':STANDARD-SLOT' metaclass. Protégé provides the facility to create a subclass of a metaclass, to which new slots can be added. These new slots become own slots for classes created as instances of such a subclass. It will be seen that that this is the functionality that will be exploited to build a multilingual support mechanism.

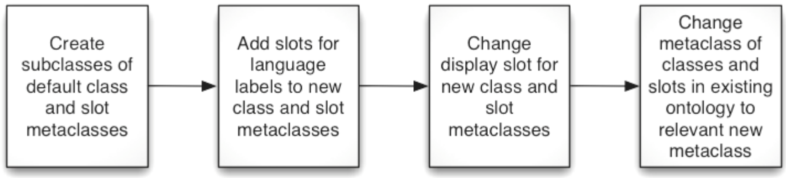
4.2 Approach

It has already been mentioned that one way of adding multilingual support to an ontology is to map word keywords from the desired languages to concepts in an existing single language ontology. There is little literature describing formal methodologies for the development of such ontologies using ontology building software tools. However, Noy proposed informal guidelines for adding natural language labels to concepts in ontologies built using the Protégé ontology editor [19]. It is these guidelines that formed the basis of the method described below.

4.3 Method

The method used to add multilingual support to the tool consisted of four main steps, as shown in Figure 1. There now follows a detailed description of each of these steps, which were arried out using the frame-based version of the Protégé ontology editor.

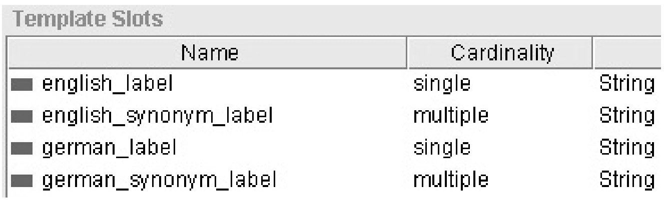
Figure 1 Steps for the addition of multilingual labels to an ontology, based on [19].



Step one involved the creation of a new subclass of the ':STANDARD-CLASS' metaclass and the ':STANDARD-SLOT' metaclass. This new subclass would act as a template to which new slots could be added.

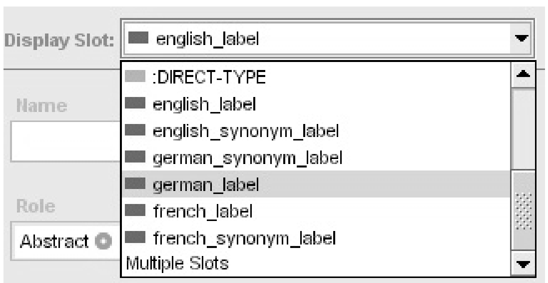
Step two consisted of adding a slot to the new metaclasses for each of the required languages. The slot type was set to 'string', so that the appropriate language label could be added to classes or slots that are instances of their respective metaclass. Each slot was named so as to indicate which language label it should contain, as shown in Figure 2. Slots were also added for synonyms, in order to support potential variations in vocabulary among the different disciplines involved in NPD project teams.

Figure 2 Language slots featured in the for newly created metaclass form.



The aim of step three was to change the text displayed in the tool interface for classes and slots to the desired language. This was achieved by selecting each of the new metaclasses in turn and using the Protégé Form Editor tool to remove the existing 'NAME' slot which is displayed by default. Following this, the required language label slot was selected in the 'Display Slot' list, see Figure 3.

Figure 3 Selection of required language label slot in the Protégé Form Editor.



5 Industrial Case Study

5.1 Background to Industry Case Study

As part of a wider investigation to demonstrate and test the functionality of the tool, the development of which was documented in {Bradfield & Gao 2006 #270}, an industry-based case study was undertaken at the company where the three knowledge sharing problem categories were identified. A detailed description of this industrial study may be found in [5] and [6] and will not be reproduced here. The part of the investigation pertinent to the multilingual support mechanism took place at the German manufacturing site. It focused on the knowledge used and generated in a selection of sub processes in the product conception phase of the new product development business process used by the company. This phase of the process was chosen because of its knowledge intensive nature and the involvement of a broad spectrum of functional disciplines. The languages chosen for the multilingual labels were English and German.

Briefly summarised, the method of investigation for the study consisted of five stages: (1) selection of the three sub-processes reliant of cross-functional involvement; (2) elicitation, mostly from company documentation, of information about the tasks from which the sub process is comprised, (3) elicitation by semi-structured interviews with process experts of information about the knowledge required for and generated by these tasks, (4) capture of this information or metaknowledge in the knowledge sharing tool by manual data entry, and finally, (5) translation of the English language concepts and relationships that form the ontology into German and addition of the multilingual labels according to the method described in the previous section.

5.1.1 Results

Before proceeding any further, it is worth noting that three sub processes selected for the study from the product conception phase were entitled ‘Project Performance’, ‘Generate Product Proposal’ and ‘Product Validation’ The results of implementing the method for the construction of a multilingual mechanism for the case of knowledge used and generated in three selected NPD sub-processes are illustrated in series of screenshots. Three aspects of the multilingual mechanism will be considered here: Note that no claims are made for the accuracy of the German translations and they are featured for illustrative purposes only.

Consider first the forms for classes and slots based on the newly created subclasses of the ‘:STANDARD-CLASS’ and ‘STANDARD-SLOT’ metaclasses. Figure 4 shows a section of the form for the ‘NPD Process Task’ class featuring German and English language label slots, as well as slots for synonyms.

Figure 4 Language label slots on NPD Process Task class form.

Next, consider the resulting tool interface. Figure 5 shows part of the English version of the tool interface. Figure 6, meanwhile shows the same part of the interface but with the default display slot changed to the German language label.

Figure 5 English tool interfaces.

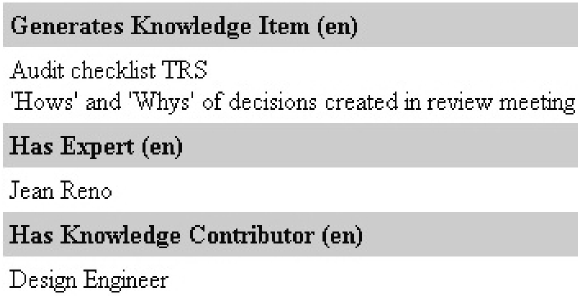
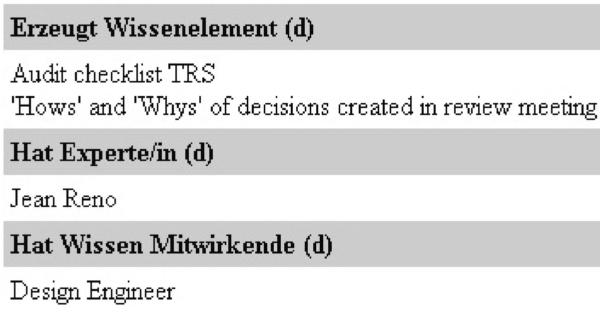
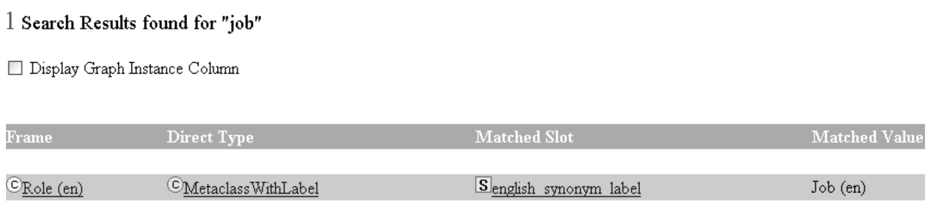


Figure 6 German tool interfaces



Finally, consider the functionality of synonym labels. These labels are not intended to be displayed in the tool interface, but they, or rather their corresponding classes can be found by the search tool in the web-based version of the NPD knowledge-sharing tool. The search tool interface is shown in Fig 7.

Figure 7 Searching for classes in the web interface using synonyms.



5.1.2 Limitations of Method

An industry-based test of the proposed method indicated that it could be successfully implemented to create a mechanism that allows the ontology-based knowledge-sharing tool to support a multilingual environment. However, the method has two important limitations.

Firstly, while new metaclasses featuring slots for language labels can be created using the default class and slot metaclasses, the same approach cannot be applied to instances created from classes. For certain classes in the ontology, such as the ‘Actor’ class, an instance of which might be the name of an individual this issue is unimportant. Other classes though, like the ‘knowledge item’ class, have instances with descriptive phrases that are not language agnostic. One approach to tackling this problem would to be add description slots directly to classes, but this would require the user to manually browse the knowledge items or process tasks. The elicitation of user feedback on this issue is one possible route for further study. Secondly, adding labels to all of the classes and slots is time intensive, although much of this work is a one-off task, since it is not anticipated that the core ontology will be subject to frequent change on a large scale. Any changes that do occur are more likely to minor changes, such as the addition of new instances of knowledge items or process tasks.

It should also be acknowledged that the tool may not support languages that do not use the Latin or Roman alphabet. One final concern is that the user perspective on the usefulness and usability of the multilingual support mechanism component of the knowledge-sharing tool was not assessed.

6 Conclusion

Reference to the literature has highlighted the important role of metaknowledge in the facilitation of knowledge sharing. Nonetheless, in the context of the knowledge sharing problems identified in the NPD process of a multinational heating systems manufacturer, this metaknowledge is of little use, unless it can be conveyed to individuals speaking different languages and performing different functional roles.

To this end a method has been provided to construct a multilingual support mechanism, as part of an ontology-based tool intended to facilitate knowledge sharing. In the NPD process. The method was successfully tested by applying it to an industrial-based case study that focused on three sub-processes in the concept development phase of the new product development process used by the aforementioned manufacturing company. In spite of this, the method has certain weaknesses, namely that it can only be applied to classes and slots in the ontology and not to instances. Effectively, this means that the method is relevant to the tool user interface, but not to the instances of information and data captured by tool users.

Further work then, is required to address the issue of creating language labels for instances, possibly through the use of string-type slots attached to classes. As already alluded to, additional work should also involve an investigation of the usefulness of the tool through interviews with target tool users at the three manufacturing sites.

Acknowledgment

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Machining processes simulation with the use of design and visualization technologies in a virtual environment

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Abstract: The development of PLM systems is closely related to the integration of the design process with the actual manufacturing process and the complete assessment of the operation at an early stage of the program development. Currently a lot of progress has been made on the application of Virtual Reality tools in the various stages of product development. Aim of this work is the integration of virtual environments with production design processes. Most of the existing systems are focused on the study of the machining process kinematics and do not provide information related to the process results. A production processes simulation system was developed for the determination of critical quantitative and qualitative processes parameters. The system provides realistic visualization of the processes in a three dimensional virtual machine shop environment, walk/fly through and interaction capabilities. System user acquires information related to the process simulated in the virtual environment in real time.

Keywords: Virtual Manufacturing, Surface Roughness, machining processes simulation

1 Introduction

The design of the production processes mainly employs two types of systems. Production processes simulation tools, based on CAM systems and quantitative data determination tools, based on arithmetic, analytical and experimental algorithms. CAM systems have limitations such as lack of providing quantitative data and data related to process feasibility [1]. Most of them have trivial visualization capabilities. Quantitative data determination tools also have limitations. Most of them are not integrated with CAM systems and they provide trivial visualization capabilities.

The development of PLM systems is closely related to the integration of the design process with the actual manufacturing process and the complete assessment of the operation at an early stage of the product development. Currently a lot of progress has been made on the application of Virtual Reality tools in the various stages of product development. Most of the existing simulation systems are focused on the study of the machining process kinematics and do not provide information related to the process results. Aim of this work is the integration of virtual environments with production design processes. A production processes simulation system was developed for the determination of critical quantitative and qualitative processes parameters. The system provides realistic visualization of the processes in a three dimensional virtual machine shop environment with walk/fly through and interaction capabilities. System user acquires information related to the process simulated in the virtual environment in real time. The system extends CAM systems' capabilities, by intergrading CAM system functionalities with quantitative data determination models in a three dimensional virtual environment. The system could be used for the verification of machining processes and as an educational tool, because of the realistic graphics environment in which the machining processes are simulated.

2 Literature review

In this section systems similar to the proposed are described, that is systems for machining processes simulation in virtual environments. Iowa University [2] has developed a system for machining processes simulation in a five axes CNC machine. The system aims at the improvement of the workpiece machined surface quality by improving cutter path. Ko et. al. [1] have developed a Virtual Manufacturing system for the determination of optimum feedrate values in 2.5 machining processes that provides the ability to determine cutting forces in order to improve the machined surface quality. Qui et al. [3, 4] have presented a Virtual Reality system for material removal simulation that provides information about the required time for the accomplishment of the machining process and quantitative data like cutting forces, surface roughness, required energy and cutter wear. Bath University [5] has developed a simulation system for several types of machining operations that could be employed for design, modeling and implementation of production plans in the virtual environment, aiming at errors detection in the executed operations. University of Patras, [6] has developed a virtual machining operations environment for operations design and training. Yao, et al. [7] have developed a machining operations virtual simulation environment that provides capabilities for dimension measurement, in order to determine the processed part precision and to measure final surface quality parameters. Peng et al. [8] propose a desktop VR environment to explore the machining process element of CAPP. Spence et al. [9] are developing a multi-axis machining process simulation program with a special sweep representation for Boolean part model updating. Jang et al. [10] develop a voxel-based simulator for multi-axis CNC machining to model efficiently the state of the in-process workpiece, which is generated by successively subtracting tool swept volumes from the workpiece. Lin et al. [11, 12] developed a virtual reality training system to determine the impact of the simulated industrial accident on decision-making performance in a real machining task. Yi et al. [13] presented a computer simulation approach to machining a gear and cam by using a virtual orthogonal 6-rod machine tool. Weinert et al. [14] developed a virtual manufacturing system for the determination of chip thickness throughout the machining process, for quantitative data calculations such as the cutting forces. The outcome of the European research program Virtool [15] is a graphics environment, in which Virtual Reality techniques are employed for training and evaluation of qualitative and quantitative parameters related to the simulated machining process. Montana University [16] has developed a lathe simulation system for training applications. The process parameters are the input to the system and the material removal is being simulated for the part production. Wang et al. [17] developed illumination models in a virtual machining environment for chip simulation. Manufacturing Engineering Laboratory [18] developed a Virtual Reality platform for universities and companies collaboration. In the field of machining the octahedral hexapod machine tool at NIST is being simulated [19] for the implementation of verification tests related to the machine performance, the improvement of the machine control system, etc. Jonsson et al. [20] describe the structure and implementation of a virtual reality concept for real-time simulation and visualization of water jet cutting machine.

3 Virtual Environment for machining processes simulation

Aim of this work is the integration of virtual environments with production design processes. A machining processes' simulation system has been developed for real time visualization, verification and qualitative and quantitative data determination related to the process simulated in the environment. The structure of the system is shown in figure 1. Virtual environment has been developed using commercial software tools. The structure of the virtual environment is shown in figure 2. A complete machine shop has been visualized and the functional characteristics of a three axes CNC milling machine are being simulated.

The virtual environment has the following functional characteristics:

- Objects behavior is as realistic as possible.
- User has the ability to interact with all the objects in the virtual environment.
- User selects cutter from the cutters table and it is installed automatically in the CNC machine spindle.
- User selects workpiece from the workpiece table and it is installed automatically in the CNC machine worktable.
- During machining process simulation, CNC machine axes and cutter animate in a realistic way.

- Workpiece material removal is being visualized in a realistic way during machining process simulation.
- Machining process information like the G code command simulated in the CNC machine, feed, spindle speed and cutter path are visualized in a special table.
- User can pause, stop or restart the machining process.
- When the machining process is finished, quantitative data and graph charts for the process are visualized, according to user preferences.

In figure 3 the virtual environment for machining processes simulation is presented.

Figure 1 Structure of the machining processes simulation system

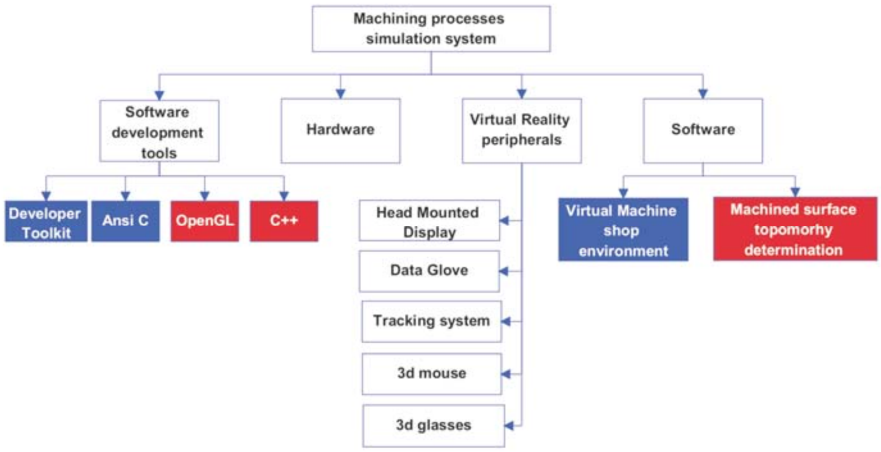
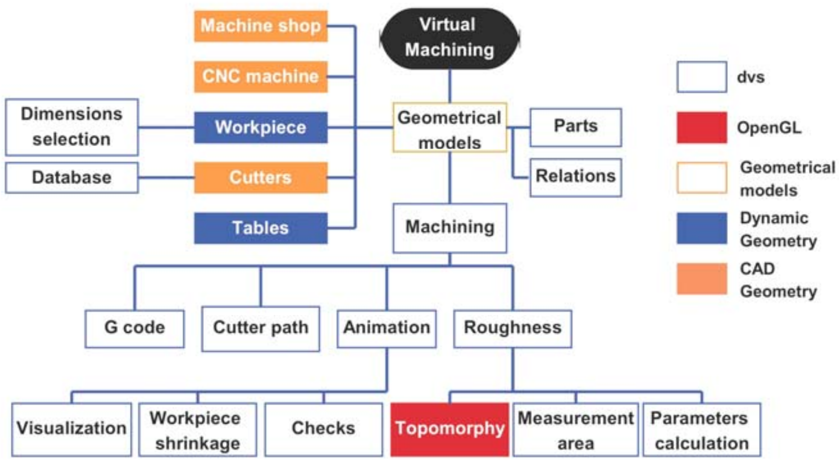


Figure 2 Structure of the virtual environment for machining processes simulation



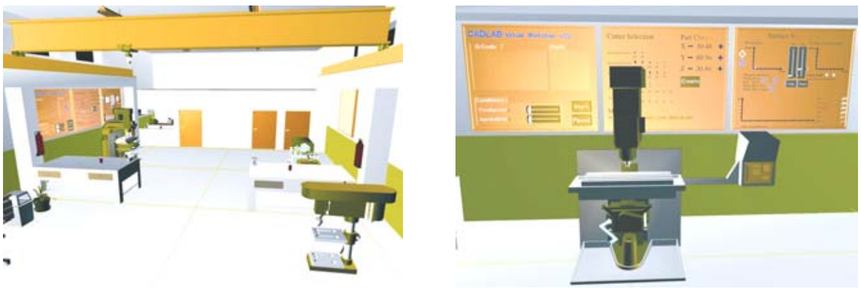
3.1 Virtual environment software modules.

The following modules of the environment have been developed and integrated in the employed Virtual Reality platform for the implementation of a machining processes simulation environment:

- Geometrical models visualization: Models developed in CAD like machine shop building, machines, etc., dynamic geometry models like the workpiece, 3D text, etc., virtual models visualization characteristics, like color and texture.
- Geometry models hierarchy, constraints, interaction attributes.
- CAM system integration.
- Cutter path determination according to the G code program.
- CNC machine axes animation.
- Cutter animation.
- Workpiece material removal visualization during machining processes simulation.
- Quantitative data determination.
- Verification checks during machining processes simulation.

Following, the most critical software parts are being described.

Figure 3 Virtual Environment for machining processes simulation



(a) (b)

3.2 Workpiece definition

Workpiece geometrical model is defined as a polygons mesh with the use of virtual environment dynamic geometry tools that provide the ability to change the shape of the model in real time. The use of dynamic geometry is necessary, in order to visualize the workpiece material removal during machining processes simulation.

In figure 4 the algorithm for the definition of the workpiece polygon mesh is shown. In figure 5 the workpiece is shown in the virtual environment in wireframe and shaded mode.

3.3 CAM system integration.

CAM software tools are used for CNC programming. The produced G code programs are exported by the CAM system in a text format file. In order to integrate the virtual machining processes simulation environment with the CAM system, the G code program is the input to the environment. The software tool integrated in the virtual environment reads the G code file and its data are converted and imported to the environment in a format suitable for further editing.

Figure 4 Algorithm for the definition of the workpiece polygon mesh

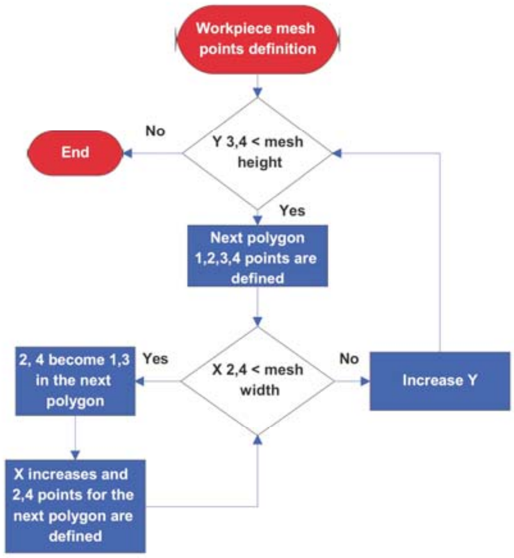
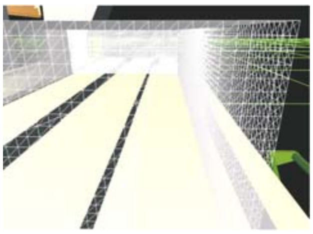
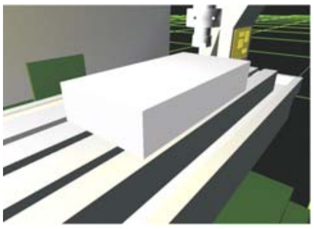


Figure 5



(a) Workpiece in wireframe mode



(b) Workpiece in shaded mode

3.4 Cutter path determination.

Following the G code file import to the system, the path of the cutter is determined. Each G code command define a linear or a curvilinear movement of the cutter in the three dimensional space. A software tool has been developed that converts G code data into geometrical equations for linear and curvilinear trajectories in three dimensions, to define cutter path. These equations are used for the simulation of CNC machine axes movements in the virtual environment. If compensation has been defined in the G code program, offset trajectory is being determined, with the use of appropriate geometrical equations. The intersection point is calculated for each two adjacent trajectories, to determine start point for the next movement. Then, the equations for linear of curvilinear movement are employed.

3.5 Workpiece material removal.

For the simulation of the machining process in the virtual environment, workpiece material removal should be visualized in real time. Cutter removes material when it intersects the workpiece. The material that is removed is the intersection volume between these two objects, at each cutter position. For the visualization of the material removal on the workpiece, the intersection with the cutter has to be determined along the cutter path. Material removal is visualized in the workpiece by altering its polygon mesh vertices coordinates, according to the intersection with the cutter, at each cutter path position.

In the algorithm that was developed:

- The cutter is assumed cylindrical.
- Cutter and workpiece intersection is determined in differentiated path positions.
- Intersection is determined by comparing coordinates between workpiece polygon vertices and lower cutter cross-section.
- Workpiece vertices inside the cutter volume decrease their Z coordinate to the minimum Z coordinate of the cutter.

In figure 6 the visualization of material removal in the virtual environment is shown. In figure 7 the algorithm for workpiece material removal visualization is shown.

3.6 Quantitative data determination.

The virtual environment for machining processes simulation provides quantitative data for the machined surface roughness. Roughness in machining is a parameter related to the geometrical characteristics of the abnormalities produced by the cutter in the machined surface. The size, shape and topomorphy of these abnormalities in the machined surface depend on [21] machining parameters like: cutting speed, feed, cutting depth, etc., geometrical characteristics of the cutter, like cutter nose radius, rake angle, side cutting edge angle and cutting edge geometry, workpiece and tool material combination and their mechanical properties, quality and type of the cutter, jigs, fixtures and lubricant used, vibrations between the cutter and the workpiece.

There are several parameters for surface roughness measurement that provide different information for the measured surface. Surface roughness is measured in areas of the machined surface, selected by user and measurements refer only to the selected area. Thus, in a machined surface, measurements must be made in more than one area. Usually linear or radial measurements are taken. Linear measurements are made in line or vertical to the feed direction for a specific distance. Radial measurements are made around a fixed point for a specific angle.

A model has been developed for the machined surface roughness parameters determination. The model is divided in two parts:

- The determination of machined surface topomorphy.
- The calculation of the surface roughness parameters, according to the surface topomorphy.

In the model, parameters like cutting speed, feed and cutting depth, cutter diameter, height, cutter type, number of teeth and cutting edges geometry that contribute in surface roughness formation are considered. Parameters that contribute in the surface roughness formation, like cutter material, quality and type of the cutter, quality of jigs, fixtures, the use of lubricant, vibrations in the machining process are not considered.

Figure 6 Material removal visualization in the virtual environment

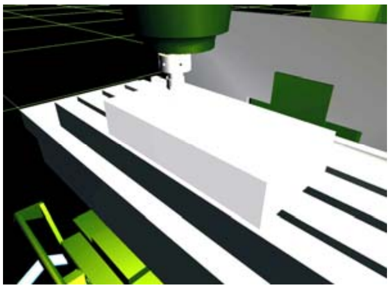
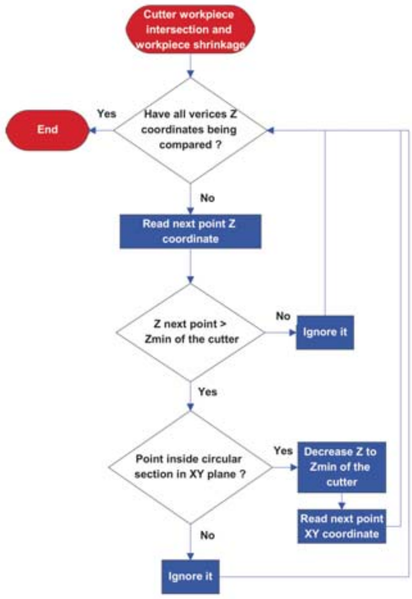


Figure 7 Algorithm for workpiece material removal visualization



3.6.1 Determination of machined surface topomorphy.

The model for the determination of the machined surface topomorphy has been implemented in a three dimensional graphics environment developed in OpenGL (fig. 8). In this environment the motion of the cutter relative to the workpiece is simulated. The motion of the cutter is based on the cutting conditions defined in the G code file. During the motion of the cutter, the sweep surface of its cutting edges is determined. For the determination of cutting edges sweep surface during machining simulation, the cutter is being modeled, according to the shape and number of its cutting edges (fig. 9). Cutting edges shape is defined from the outer edge profile of each cutting edge, which defines the overall cutter profile. Each cutting edge is approximated by equal elementary sections that are straight lines (fig. 10).

The produced sweep surface has overlapping triangles, since part of each cutting edge sweep is being overlapped by the next cutting edge sweep or the next cutter pass sweep. If the cutter sweep surface is projected from its down side, the final machined surface topomorphy is derived, since the overlapped triangles are not visible in this projection, due to the hidden line algorithm, that projects to the user only the geometry visible in each point of view. This final machined surface topomorphy is derived from this projection in the form of cloud of points. The coordinates for the cloud of points are determined. The pixels within workpiece limits visualize the machined surface. These pixels are converted into X and Y coordinates in the graphics environment coordinate system. Z coordinate is derived from the visualization system Z buffer.

The cloud of points coordinates describing the machined surface topomorphy are exported in a text file and used to calculate quantitative parameters for the machined surface roughness in the virtual environment.

3.6.2 Calculation and visualization of surface roughness parameters in a virtual environment.

In real environments surface roughness measurements are carried out in surface regions, selected by user. In the developed system this procedure is being simulated in the virtual environment. A table has been developed for surface roughness quantitative data visualization (fig. 11). On the upper part of the table the measurement region on the workpiece machined surface is defined. On the lower part of the table the selected surface region topomorphy and the respective surface roughness parameters values are being visualized.

For the determination of the measurement region, a handler has been developed (fig. 12). System user defines the position of each handler end. Handler ends define surface roughness measurement area limits. Handler defines a vertical to the machined surface plane, in which topomorphy will be determined and surface roughness parameters will be calculated from this topomorphy.

For surface roughness parameters determination, cloud points near the vertical measurement plane are retrieved from the file. Cloud points used in each calculation are connected with straight lines in the vertical measurement plane to produce surface topomorphy for this region in the virtual environment. In the virtual environment surface roughness parameters and surface topomorphy mean line are calculated. In the quantitative data table, surface topomorphy and mean line are visualized in a specially developed diagram and also surface parameter values are shown. User has the ability to create a machining process report in the form of a text file (fig. 13). In the machining process report file surface roughness data for the measurement region are stored and could be acquired for further use. This process can be repeated in any other region of the machined surface.

Figure 8 OpenGL machining processes simulation environment for machined surface topomorphy determination

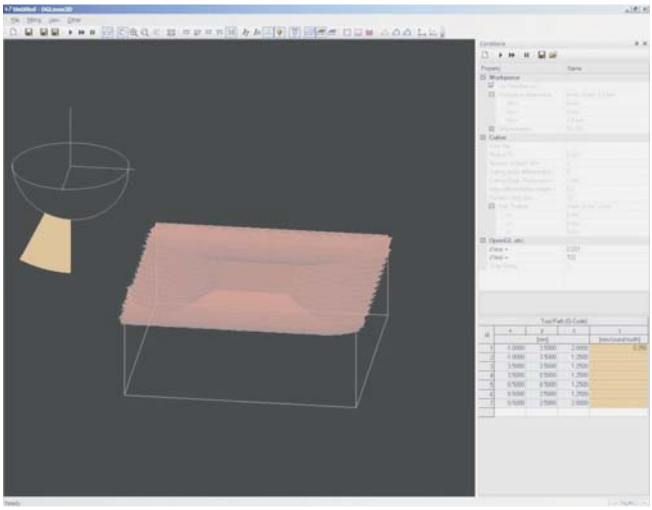
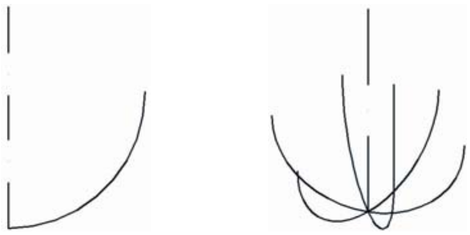


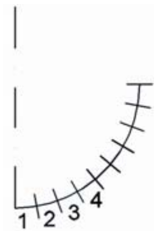
Figure 9 Cutter cutting edges modeling.



(a) Edge on a ball end mill

(b) Ball end mill with six cutting edges

Figure 10 Ball end mill cutting edge modeling.



4 Machining processes simulation pilot case.

In order to acquire results from the system, a user performs the following actions:

- A workpiece has to be created and a cutter has to be selected.
- Cutter path has to be produced in the form of differentiated points in a text file. In the file, differentiated points coordinates are defined in the machine coordinate system.
- Machining process is simulated in the virtual environment.
- The file with the differentiated cutter path points is opened in the OpenGL machined surface topomorphy determination software tool.
- Machining process is simulated in the OpenGL environment.
- Surface topomorphy is exported as a cloud of points in a text file.
- This file is being read in the virtual environment, to visualize surface topomorphy graph and to calculate surface roughness parameter values for the measurement area selected by the user.

User has to select surface measurement area in the virtual environment quantitative data table by setting handler ends positions, either by direct interaction with the geometrical models or by the two sliding handlers in the quantitative data table, defining measurement area. Then, by pressing “Calc” button, surface topomorphy appears in the corresponding graph. In the surface topomorphy graph mean line is shown (a horizontal blue line). Also the system calculates surface roughness parameters for this topomorphy and shows their values in the quantitative data table (fig. 11). User can move the handler (change its position, orientation or length) and take measurements in different areas of the machined surface. This feature is necessary since it is usual in real surface roughness measurements to place the profiler contact element in a position and measure roughness radically from this position at a fixed radius for a specific angle (usually 180^o or 360^o).

The system has a feature for the creation of a machining report in the form of a text file by pressing “Save” on the quantitative data table. The system calculates and stores in this report data related to the G code file used for simulation, the selected cutter, the selected workpiece and surface roughness parameter values for the measurement position are given every 10^o degrees for a full round. In figure 13 an example machining report is given.

5 Conclusions

The main aim of the proposed system is the integration of virtual environments with production design processes. The system extends CAM system capabilities, since it provides higher level visualization functionalities and quantitative data for the production process defined in the CAM system. A new method based in OpenGL programming language is proposed for machined surface topomorphy determination in order to calculate critical quantitative data affecting machined surface roughness. The system could also be used as an education tool since machining processes are realistically executed in the virtual environment. The proposed research contributes in the creation of critical mass contemplations for future research directions. Research evaluation will lead in critical conclusions related with the required production processes simulation systems characteristics and their potential use in real industrial environments. Moreover the proposed system could be further developed to provide additional characteristics and functionalities, could be extended in other machining operations or even other industrial processes.

Currently there is a tendency for Virtual Reality characteristics and production processes models integration. This tendency is leading to the creation of the next generation simulation systems that will provide quantitative data for the process, increased visualization, fly through and interaction capabilities in a virtual environment. The research is this area is showing adequate maturity but the final form of these simulation systems for use in real industrial environments has not yet been delimited, although significant systems have been presented.

Figure 11 Virtual environment quantitative data table

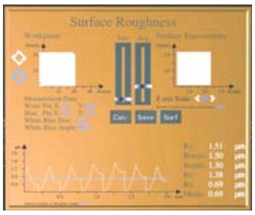


Figure 12 Measurement area determination with the use of the handler

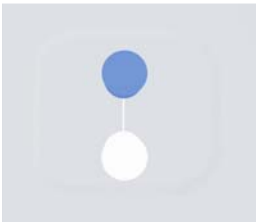
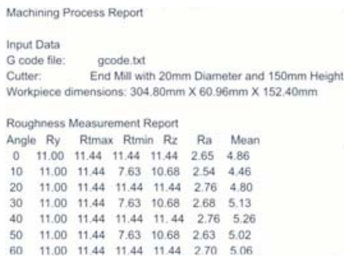


Figure 13 Machining Report example



Machining Process Report

Input Data
G code file: gcode.txt
Cutter: End Mill with 20mm Diameter and 150mm Height
Workpiece dimensions: 304.80mm X 60.96mm X 152.40mm

Roughness Measurement Report

Angle	Ry	Rtmax	Rtmin	Rz	Ra	Mean
0	11.00	11.44	11.44	11.44	2.65	4.86
10	11.00	11.44	7.63	10.68	2.54	4.46
20	11.00	11.44	11.44	11.44	2.76	4.80
30	11.00	11.44	7.63	10.68	2.68	5.13
40	11.00	11.44	11.44	11. 44	2.76	5.26
50	11.00	11.44	7.63	10.68	2.63	5.02
60	11.00	11.44	11.44	11.44	2.70	5.06

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Graphonumerical parameters: collaborative parameters based on scenarios and ontologies

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Abstract: The integration of the notion of extended firm in products development involves the use of knowledge from different skills. Yet, each profession develops its own thesaurus which contains a vocabulary used in a specific context. They are rarely explicit and are difficult to model. Nevertheless, it is essential to define the trade vocabulary in order to parameterize the numerical model, since the first phases of the project. In this way, this vocabulary has to be accompanied with its definition and its use in context. This notion is wide in the area of collaborative work with the setting of a common vocabulary which enables to define the collaborative processes. We suggest a structure, called graphonumerical parameter (GNP), allowing to parameterize a model in a collaborative way.

Keyword: *Ontology*, CAD parameterization, collaborative work, scenario

1 Introduction

80% of the costs of the project are fixed on the first stages of the project. The introduction of knowledge of different domains in these first stages is primordial. Thus, it is necessary to integrate, as soon as possible, all the partners (for example in a prime-manufacturer/subcontractor relation) and all useful information to improve quality, delay and costs. Design is then defined as collaborative and can be optimized by allowing upstream integration of data, resources and knowledge. We believe then in a PLM solution (Product Lifecycle Management) that integrates product, process and resources, and acting as a framework for an efficient collaboration. Actual collaborative design is often reduced to asynchronous data exchanges through PDM, even if some people prefer to speak about "sharing" since the product is a mutual creation. However, collaborative design has to allow collaborative work in the early stages of design. To structure collaborative processes between subcontractors and prime manufacturers, we define the P^4LM methodology which allows the management of Projects, Products, Processes, and Proceeds on a Digital Mock-Up (DMU) [1]. The aim of this methodology is to allow a high semantic knowledge definition of different partners which are involved in a PLM application. A specific CAD architecture has been developed, in DIJA application [2], to integrate knowledge in a synthetic way application [3]. The scope of this paper is to present the knowledge integration in the P^4LM project which is done by a specific representation called graphonumerical parameter (GNP) which comes from graphonumerical expression (GNE). They allow to parameterize in a collaborative way the development of a product by the definition of our ontology and scenarios. They are represented in different semantic definition according to their environment in the DIJA architecture. A state of the art presents *ontology* concept and the different methods to link functional requirement to a CAD model. Then we explain what a GNE is and how to obtain it in a product development. Last, we present an application which illustrates the management of GNP according to the DIJA architecture.

2 CAD parametrization based on ontology

Researches on artificial intelligence in 1970's have postulated assumptions of the knowledge management. A lot of literature has shown the use of Knowledge Based Systems (KBSs) which manage knowledge and support Knowledge Based Engineering (KBE) for the integration of engineering knowledge. A survey can be found in [4]. The majority of commercial CAD software manages KBS to create parameters, trade rules and so on. The relationship with the geometry is based on parameters links and feature-based approach. The parameter approach allows the creation of parameters which are manually linked with a part of the geometry. The designer has to create links during the detailed design. This function-to-form [5] approach is very interesting to propose, in the earlier stages of the design process, *ontology* of the trade parameters which have to be used during the design. The sub-sections present a survey of the *ontology* to form way.

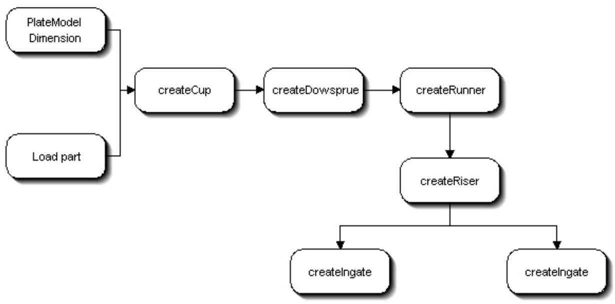
2.1 From ontology to function

The word '*ontology*' comes from the greek 'ontos' for being and 'logos' for word [6]. In the knowledge engineering, "*ontology is frequently viewed as magic panacea*" [7]. Indeed, the variety of use or the variety of the term *ontology* is very large [8]. For [9], *ontology* is a taxonomy of concepts or for [10] a list of constraints and interrelations among the concepts. For [11] "*the main idea is to establish standards models, taxonomies, vocabularies and domain terminologies, and use them to develop appropriate knowledge and reasoning modules*". Some good examples of *ontology* can be found in [12]. The implementation of *ontology* allows a collaborative work inside the firm to establish the common language of its own trade, and outside the firm to establish a common language for the codevelopment of a product. For our team, *ontology* is a vocabulary related to a specific domain. Our objective is to develop a tool which allows the used of *ontology* in PLM and more particularly in CAD software. For instance, a few researches have linked *ontology* to CAD. [13] propose an Assembly Relation Model (ARM) to supervise assembly design. Thus, ARM manages assembly design *ontology* of "*engineering, spatial, assembly and joining relations of assembly*". A very interesting framework is proposed by [14] who defined a model which allows the development of building design objects with "*semantics of interoperable information*" based on *ontology*. A building design object is a CAD object embedded which is a high function representation with reference links to information sources, interdisciplinary object relationships, object constraints … It is an interesting model but the demonstrator is done on a architectural CAD system which is very different to a mechanical CAD system due to internal representation model. Some interesting models have been developed to integrate *ontology* in PLM [15], [16] but there is no links with CAD. When *ontology* has been defined, the aim is to transform them in function to be used in CAD.

2.2 From function to knowledge

In the earlier phase of the development of a product, designers established functions are born from formal vocabularies like *ontology*. The function has to define the 'why' and are linked with a behaviour which defines the 'how'. That's why the function notion is associated to the knowledge notion. A function is the initial data (like a fact) and the knowledge is the process which defines the function. Typically, the knowledge is the actions which permit the application of the function. There are a lot of models to represent knowledge by actions like the frames [17], the semantic networks, the conceptual graphs [18]... [19] work out a mechanism, the scenario, allowing to integrate standard successions of events in the construction of plans. The aim is to restore the implied parts of a situation described in natural language. This concept of scenario belongs to the theory of conceptual dependence which says that each design can be represented by a succession of tasks. Thus an expert who solves a problem sets up (often naturally from where the difficulty of capitalization) a scenario of work which uses explicit or tacit knowledge. This idea concurs the theory of Norman [20] who shows that the user, after having analyzed the problem, the system and the goal to reach, must adopt an action plan. It is an essential stage where the user must mentally set up a succession of actions to be carried out to achieve the fixed goal. Norman posed this thought for the IHM but this method is also adopted by the designers before drawing a part. Many companies have specialized services for the installation of methodology of design. We believe in this representation to define a function (see a trade scenario on figure 1 which represents the function *create a filling system*). However, this procedural representation is not enough to represent knowledge. It's necessary to link declarative aspect to have a less rigid system. Moreover, procedural knowledge is a compilation of declarative knowledge so it's difficult to disassociate. That is why we use KBS based on production rules. Indeed production rules allow a dynamic instantiation of knowledge.

Figure 1 A standard scenario of filling system design



2.3 From knowledge to form

The links between the vocabulary and the geometry is known under design grammar concept [23] and can be represented by formal languages [24] or graphs [25]. The feature-based approach [26] defines features depending on the trade. Some researches used this approach to define a multi-view product [27]. The product is then defined according to the functions of the domain. The most interesting researches link knowledge to geometry according to a multi-level architecture. They define a functional hierarchy with different semantic view depending to abstraction levels. A well-known model is the FBS model [22] which defines an object according to 3 levels: a functional level, a behavior level and a state level. The structure level is also called structure state as the authors write [22] "*we call the state and the structure altogether state*". Every function is associated with a behavior which is a succession of several states. The link between the states and the behaviors is constrained with physical laws. Physical laws are rules which determine the behavior of an entity according to state conditions. The links between the functions and the behaviors are done in a reconnaissance and abstraction process of the human being. These behaviors and states are distinguished according to a view. A test has been done on mechanical design by coupling the FBS SYSFUNG modeler with the MCOES geometric modeler [29]. Many researches [30], [31], [32] have applied a functional hierarchy to define functions in its entirety and then refine them to the geometric level. The different examples are very interesting but there is no really link with the geometry. That's why we develop our own multi-level architecture [3], based on 5 representation environments:

- Geometrical environment contains the information allowing the creation of geometrical models.
- Dialogue environment which is connected, in the DIJA project, with dialogue elements that allow an inexperienced user to conceive a CAD model in a synthesized way and no more in a constructive way.
- Common environment contains common pieces of information to all professions.
- Trade environment contains the know-how of domains involved in the project.
- Application environment defines and analyses in a macroscopic way the collaborative process defining the key stages of the project.

2.4 Conclusion

Ontology allows the set of heterogeneous terms. This term can be used within a firm (to capitalise knowledge) or outside in a collaborative way. They have to be represented by a function. Thus a function is represented by a formal representation. A scenario explains how to set this function. This scenario represents the knowledge. This representation allows an expert to represent his know-how in a top-down approach or bottom-up approach (re-engineering). Thus a design process represents expert know-how. We propose a structure presented below which permits the link between *ontology*, the function, the knowledge and the form.

3 Graphonumerical parameter

3.1 Presentation

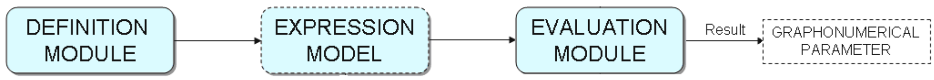
The notion of graphonumerical expression has been defined by [33]. As the author explains, "*during the use of a geometrical modelling software, the operator always has to give values to parameters intervening in the construction of the model*." Whether he knows the exact value and can apply it directly or he would like to calculate the value thanks to external functions connected with the model (as formulas for example). In the second case, the user introduces alphanumerical and geometrical parameters into the CAD system. The author defines the graphonumerical expressions which enable him to identify geometrical elements and to acquire alphanumerical values, thanks to an acquiring function. This method allows the users of the CAD system *Nadrag* to define graphonumerical expressions represented by sentences such as: *create a circle tangent with two straight lines*. It has also been used for the parameterization of geometry in the set up of libraries of portable components and also for the running of techniques of predisplay in CAD thanks to structured dialogues.

This representation, close to the representation of conceptual dependence, enables the acquiring of the knowledge in its context. From a software point of view, the author defines an architecture permitting the running of those parameters (see figure 2):

one unit/module of definition, which allows the construction of the model of the graphonumerical expression: this unit/module is linked to a database containing the vocabulary and to the CAD unit/module for the acquiring and identification phases

one unit/module of evaluation, which allows the evaluation of the graphonumerical expression in order to give a result used in the definition of the CAD model.

Figure 2 Running of the graphonumerical expressions



To sum up, the operator defines graphonumerical expressions which lead in a result, after evaluation, one or several graphonumerical parameters. So, the graphonumerical parameters will structure the CAD model according to the definition's field. The construction of a graphonumerical expression is based on a specific model, presented below.

3.2 Pattern of a graphonumerical expression

A graphonumerical expression permits the running of a profession vocabulary established beforehand and links it with a CAD model. It is defined by a tuple (1).

$$Pge = \langle action \rangle \langle object \rangle \langle constraint\ (s) \rangle \quad (1)$$

An action is an operation by which a modification of the CAD model occurs. An action is characterised by a verb. An object represents the entity which will undergo the action. This entity can be geometrical or alphanumerical. An object is characterised by a noun and its property (as for example triangular_surface). Finally, a constraint is an operation which will run the action under some conditions. These conditions are also defined according to the vocabulary used for the constraint.

There can be only one action but there can be several objects associated with several constraints. One constraint can be directly allocated to an action. This technique permits the characterisation of the functions from a semantic point of view but also from the produced model's point of view.

The link with the geometrical model is done thanks to graphonumerical parameters (GNP) which are created implicitly by the link between the objects and the constraints in the graphonumerical expression. A GNP can have an alphanumerical value (α), geometrical value (β), or an alphanumerical/geometrical one (hence the term graphonumerical) (2).

$$parameter\_value = (\alpha \vee \beta \vee (\alpha \wedge \beta)) \quad (2)$$

It can be linked with a constraint or a rule. It can be defined before the designing process and allocated to a value (for example volume_piece = 500 mm^3) or defined during the design (for example) and allocated to a value. The parameter is the link between the semantic definition of a graphonumerical expression and the CAD model. The next paragraph presents a method to set up a graphonumerical expression.

3.3 Setting up of a graphonumerical expression

Vocabulary classes are different according to the field on which it applies. Vocabulary classes used for the set up of a graphonumerical expression are based on the hierarchical model [3] of the DIJA project [2]. Terms have a different signification according to their belonging environment. For example, an object can be a plunder in the common environment and represented by sides in the geometrical environment. Table 1 presents three classes with some examples of vocabulary for the common and geometric environments.

Table 1 Three classes with some examples of vocabulary on two environments

	Common environment	Geometric environment
actions	*create, modify, consult, delete, apply, transform, add, …*	*create, modify, consult, delete, apply, transform, add, …*
objects	*plunder, hole, conge, bevelled edge, roundness, extrusion, revolution, pocket,…*	*circle, straight line, side, edge, apex…*
constraints	*to the following, depth, angle, nominal diameter, …*	*tangent to, parallel to, perpendicular to, symmetrical to, thanks to, linked with, to be part of, radius, length, …*

So there are different vocabulary classes according to the belonging environment but also according to the applying field. Indeed, within the profession environment vocabulary classes related to ironworks, foundry… cohabit. Or, for example, in the geometric environment, classes related to the BRep model and to the finite element model cohabit. The choice of some class or other is done according to the context.

The setting up of a graphonumerical expression has first to go through the definition of actions' classes and of constraints for the application and trade environments. The other environments have predefined classes. Afterwards, objects' classes are defined and finally the graphonumerical expressions can be built. Each vocabulary is accompanied with a global definition and with a contextual definition.

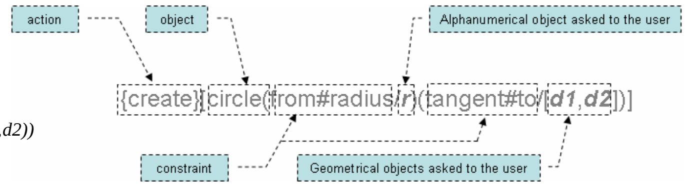
Graphonumerical expressions are represented by a specific semantic detailed hereafter.

3.4 Semantic representation and use of a graphonumerical expression

A graphonumerical expression has to be written as « $\{action\}[object(constraint\,/)]$ ». The character '_' is the separation between the noun and its object's property. An action is controlled by "{}" and an object by "[]". The character '/' enables us to specify the constraints applied to a GNP. The couple constraint/parameter is separated with brackets. When a constraint applies to several parameters, it's necessary to separate the parameters with commas and put them between brackets as for example (constraint/(param1,param2)). When an object is submitted to several constraints, the character '_' has to be oversighted. The character # is used to separate the pronoun from the adjective within a constraint (as tangent#to). When the GNP isn't specified, it has to be defined by the operator. Let's take an example in order to understand better the functioning of the using of a graphonumerical parameter. A user wants to *create a circle* *from a given radius tangent to two secant straight lines*. The concerned environment is the geometrical environment. The graphonumerical expression which corresponds is $\{create\}[circle(\,from\#radius/)(tangent\#to/[2lines])]$ (see figure 3). The algorithm which defines this parameter is detailed on figure 3.

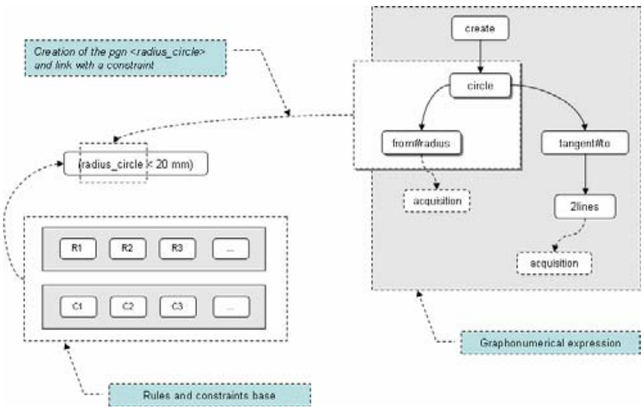
Figure 3 A graphonumerical expression

$d1 \leftarrow acquire\_line()$
$d2 \leftarrow acquire\_line()$
$r \leftarrow acquire\_radius()$
$create\_circle(r)(tangent\_to(d1,d2))$



The graphonumerical expression *create|circle(from#radius/r)(tangent#to/(d1,d2))* is an algorithm which enables us to calculate the possible solutions. It's important to underline the fact that the parameter is defined thanks to the link between an object, a constraint and its parameter. For example, the constraint *from#radius* is linked with the object circle. There is in the model a link between the circle and the radius that has a r value. That's why the parameters used to define the constraints and the profession rules in the knowledge base have to be written according to the syntax <constraint><object> with the corresponding vocabulary classes. In this way, the GNP *radius#circle* is referenced into a constraint *radius#circle < 20mm*, which links knowledge to parameters. A graphonumerical expression can in this manner be represented by a tree whose leaves are actions, objects, parameters and constraints.

Figure 4 Example of a creation of a graphonumerical parameter



The bottom leaves are submitted to the acquiring mechanism acceding to the case to study. This link is done through the semantic of the parameters and the objects (see figure 4). Table 2 presents some GNE examples.

4 Collaboration with graphonumerical parameter

Graphonumerical parameters will also enable us to represent in a geometrical way the collaborative areas. For example, a side which is linked to a graphonumerical parameter defined by a firm A, can be highlightened so that the designers of a firm B can display the collaboration areas. The link with the geometrical model is done in a collaborative way thanks to the possibility of recording knowledge from different fields in a profession environment and the implicit link of this knowledge with the other environments. Indeed, a profession parameter declared by a firm A and a profession parameter declared by a firm B generally speaking don't have the same semantic definition. However, both can have a link with common elements. So, from the common environment, the use of the knowledge is collaborative. This technique allows us to define, in the first stages of the design, the knowledge of the different fields which will intervene in a semantic way. The link with the geometry is done during the detailed design thanks to the stages of the acquiring of the graphonumerical parameters.

Table 2 Example of *ontology*, graphonumerical expressions and graphonumerical parameters

Actor	*Ontology*	Graphonumerical expression	Graphonumerical parameter
Prime manufacturer	distance axis	*{create}[axis(distance/)]*	*axis_distance*
	bore	*{create}[bore(diameter/)]*	*bore_diameter*
	stress	*{respect}[stress(yield#strenght/)]*	*stress_yield#strenght*
Subcontractor	mould joint	*{create}[mould#joint(distance/)]*	*mould#joint_distance*
	clearance	*{create}[clearance(degree/)]*	*clearance_degree*
	salient vertex	*{create}[salient#vertex(fillet/)]*	*salient#vertex_fillet*
	unmaleable shape	*{desactivate}[unmaleable#shape()]*	*unmaleable_shape*
Engineering analysis	fillet	*{desactivate}[fillet()]*	*fillet*
		{desactivate}[fillet(min#radius/)]	*min#radius_fillet*
	part	*{desactivate}[part(symmetry/XYplan)]*	*symmetry_XYplan*

5 Application

An operational application of the P4LM methodology is under development. It integrates GNP management. The system is developed with the API of Catia V5 for parametric design, our portal (www.p4lm.eu) for the knowledge management and annotation software AUTOVUE for the collaboration. The partners connect themselves to the trade portal and give preliminary information for workflow definition (members, workgroups, resources …). They separately give in their KBS (linked to the portal) their trade rules. Then the actors define the different actions of the workflow. Using their proper trade knowledge, they define the different GNE. It can be done using a graphical tool and each manufacturing process is automatically linked to the corresponding GP. After some stages, the last one will be to ensure linking with the geometry (B-Rep) and automated interactive action in Catia.

6 Conclusion

Graphonumerical expressions enable the creation of graphonumerical parameters (before and during the design) which are used in the process of development of a product. The system can in this way react according to the belonging environment of the parameter and to the constraints or rules upon which it is affected. The CAD system will in this manner send back an action regardless of the field from the application of a change in the geometry. For example, if a subcontractor tries to modify a functional surface that is linked to a parameter defined by the orderer in a rule, a collaboration scenario starts in order to solve the problem.
The first workpackage of the project P^4LM was dedicated to the set of the different methodologies which can be used. The structure presented in this article is used for the P^4LM project to define collaborative knowledge. The second workpackage is under development. It consists to find partners (local partners like Forge France, Faurecia, … and national/international partners like EADS, Thalès, …) and to define use cases. When use cases will be approved, ontology and process will be defined in collaboration with partners. Then we pass on the fourth workpackage to develop the tool which supports the P^4LM methodology.

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Multi level configuration of ETO products

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Abstract: The paper introduces and defines central concepts related to multi level configuration and analyzes which challenges an engineer to order company must deal with to be able to realize a multi level configuration system. It is argued that high flexibility can be achieved and focus can be directed in certain business processes if a multi level configuration system is realized.

Keywords: Product configuration, product family modelling, abstraction level, engineer to order.

1 Introduction

Since the introduction of the concept Mass Customization (MC) in the early 1990's [1], this strategy has emerged from being a vision that only a few large companies in the world had partly implemented, to a strategy today widely used by companies in a broad range of industries [2]. The traditional MC companies have formerly been mass producing a low number of variants of products but are changing to a strategy of providing goods that are individually tailored to each customer's requirements thereby achieving a competitive advantage [1]. However, as the strategies and tools of MC have become widely known, they are being utilized in other industries such as engineer to order (ETO). Several ETO companies have found that elements of MC can increase efficiency and profits if applied properly [3,4].

A number of problems related to applying tools and technologies from traditional MC have been identified which often relate to a significantly higher product complexity and variety as well as the complexity of the sales-delivery process [5]. As a consequence of this ETO companies that utilize MC tools usually do this to a limited extent by either limiting the scope to a specific range of products, business processes or both [6-8].

Most MC companies use some form of product configuration process, which is the process of defining a product as a part of a product family usually supported by configuration software. Product configuration has proven to have great potential advantages in many ETO companies including the case company studied in this paper.

1.1 Contributions and Approach

This paper seeks to make the following contributions: 1) Analysis of the potential in using multi level configuration. 2) Definition of key concepts in relation to multi level configuration, in particular abstraction level and degree of detail. 3) identification of key challenges in relation to multi level configuration not addressed by current methods.

The paper is organized as follows: First a case study is presented to identify the areas where traditional configuration systems are not adequate for ETO companies. Subsequently the two concepts abstraction level and degree of detail are defined and illustrated using examples from the case. Finally a number of challenges are described that need to be addressed before a multi level configuration system can be developed. Where applicable, Unified Modelling Language (UML) is used for illustrations.

2 Currently Used ETO Product Configuration Systems

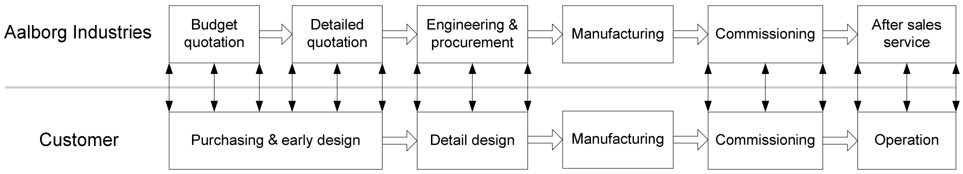
Jørgensen and Petersen [8] proposed the concept of using multiple abstraction levels in both product family modelling and configuration. That paper further suggests that when developing a product family model of an existing product family, the model will start out at a detailed level and over time move towards a more overall focus while becoming less detailed. In this case the low abstraction level and details are not removed but an additional representation is created to supplement detailed level model to present a functional view. The paper also suggests that this could be the case for a product configuration process, such that when configuring a product, the configuration becomes more and more detailed and specific over time. To explore the potential of using multiple abstraction levels in ETO companies, a case will be presented in the following to identify where modelling and configuring on multiple levels can be beneficial.

2.1 Case Study: Product Configuration at AI

The case Company Aalborg Industries A/S (AI) is specialized in steam and heat generating equipment for maritime and industrial applications, with products ranging from small components to complete steam plant systems. In 2005 the turnover was US$ 280 mil and approximately 1680 people were employed. AI is a typical engineer to order company, as the sale and delivery of every major product involves a significant amount of engineering. To render sales-delivery process more efficient AI has implemented a product configuration system while consolidating the product portfolio. After working with product configuration several years AI is now gaining significant benefits, and has learned much about the challenges of implementing product configuration in ETO.

Since the products delivered are very complex, they will typically not be fully specified at the time a quotation is issued. This is due to customer business processes which imply that the customer is not able to specify all requirements in the quotation phase, but more requirements are specified over time as illustrated in figure 1

Figure 1 Interfaces related to the product definition process between AI and customers



A general issue about product configuration in ETO companies including AI is that the configuration process is designed to be carried out in one single step due to the available methods and technologies. This means that all specification of a product is basically determined in one step. This does not mean that a configuration cannot be modified at a later point, but once a configuration has been made, all attributes in the configuration have been assigned values, and the final level of detail has been reached. However, considering the description above of the product definition process at AI, this is not well aligned with the actual business processes.

There are a number of issues related to the current situation where a low level configuration is made every time a quotation is issued. One issue is that the price presented to the customer is based on an assumption that the customer can approve the choices that the sales person has made or the standard values, whereas the true cost of the product is dependent on decisions not yet taken, such as unspecified customer requirements or sourcing decisions. The specification of the product presented to the customer is based on a specific BOM that contains specific components from specific suppliers. This means that if the choice of these components is communicated to the customer, the sales person or engineers do not have the flexibility to substitute these components with other components at a later time to optimize the product with respect to e.g. cost or performance, since contradictory information would be sent to the customer.

Concluding on the description above if configurations could be carried out in multiple stages, this would allow sales people as well as actors in the following processes to remain flexible to optimize the configuration. Also by configuring in multiple stages it can be avoided that options are chosen that the customer does not require thereby designing a too complex or expensive system. Furthermore this would take into account the uncertainties about the configuration when calculating a cost of the product.

3 Concepts of Multiple Level Configuration and Modelling

In relation to product modelling, the distinction between the two concepts product model and product family model is important. The term product model denotes a model representing a specific product, which when discussing product configuration will correspond to the outcome of a configuration process. The product family model will serve as the foundation of the configuration process, as this model generically describes all the products within a product family that can be configured [8].

Since the characteristics of the configuration process will present requirements to how the product family model must be developed, the configuration process will be addressed in the following. Subsequently product family modelling will be addressed since the configuration process will introduce requirements to the product family modelling task. Two modelling dimensions that are highly relevant in this context are the level of abstraction and the degree of detail. The two dimensions are closely related, as a low level of detail usually implies a high level of abstraction. However, the two dimensions are conceptually different, and will thus be described separately.

3.1 Level of Abstraction

The concept of abstraction is described by Daintith [9] as “The principle of ignoring those aspects of a subject that are not relevant to the current purpose in order to concentrate solely on those that are”. Abstraction in the object oriented paradigm is often referred to as generalization and specialization but also the term classification is occasionally used for the same mechanism. The abstraction mechanism is useful for avoiding redundant information and abstracting from information not needed for a specific purpose and is often used in product family modelling but rarely in the configuration process.

Multiple abstraction level product modelling was addressed by Männistö, Peltonen, Soininen and Sulonen [10], however without describing configuration on multiple abstraction levels. Czarnecki, Helsen and Eisenecker [11] proposed an approach for staged configuration using multi level configuration, but was mainly aimed at configuration of software families. Jiao and Tseng [12] described multiple abstraction levels used for modelling different views, functional and technical, on a product family as well as the mapping between the views.

Working with different abstraction levels during a configuration process will imply that in the beginning of the process, the product is configured at a high level of abstraction, which means that only main functionalities are configured. Over time, the configuration will reach a lower level of abstraction, as more specific information is determined about the product.

The abstraction level is a measure of how generic the information about the product and its subcomponents is. At a high level of abstraction, the product information will be general, but when moving to a lower abstraction level the information will be more specific. This transition can be perceived as a selection process, where the configurations or combinations of subcomponents that satisfy the requirements constitute the solution space of the configuration. As the abstraction level becomes lower over time, by describing the configuration more and more specific, the solution space for the configuration decreases also.

3.1.1 Example from Case Study

One example of how multiple abstraction levels could be utilized in the AI case is a configuration made for a budget quotation which describes the product generically, i.e. no or only a few specific components are specified in the quotation, whereas the rest of the components are described functionally and in the following phases of the sales-delivery process, more detailed and more specific information is configured. The different phases of the business processes are shown in a simplified version in table 1, where it is also shown which information is required in each phase for a feed water pump which is a typical system component. The information shown for each phase must be determined in this phase if not already determined. However, to remain flexible to select the optimal components that are included in the product, it is desirable not to determine the information long before it is needed. With current product configurators usually only one specification level exists, implying that all information determined by the configuration system is generated in one process. For the pump example shown in table 1 this includes maker, supplier, specific model, item number and cost even though the configuration is carried out to prepare a quotation, which reduces the flexibility to optimize the configuration.

Table 1 Example of different abstraction levels for a pump in a steam boiler plant with the highest abstraction level in the top and incrementally decreasing.

Phase	Information required
Budget quotation	Delivery scope, cost estimate
Detailed quotation and sales contract	Pump type, capacity
Engineering and approval	Maker, model, maker item no.
Procurement	Supplier, supplier item no.
Installation and commissioning	Calibration, serial no.

After reviewing the concept of abstraction in relation to product configuration the benefits of using multiple abstraction levels can be summarized to greater flexibility, opportunity to optimize and abstraction from unimportant details emphasizing the important information in a given phase of the sales-delivery process.

3.2 Degree of Detail

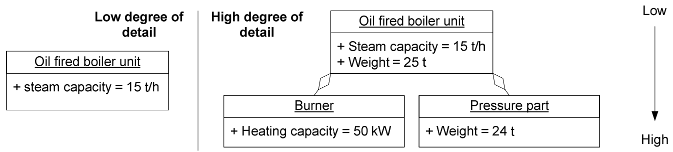
The degree of detail is closely related to the abstraction level although conceptually different. The degree of detail for a configuration is a measure of how much information is determined and to which degree the structure and attributes for the product are known, leading to two different concepts; attribute detail and structure detail.

The attribute detail is a measure of in what detail each component has been described, how many attributes exist or have been assigned values for a component. Structural detail is a measure of how far the configuration has been broken down into components and their subcomponents. When considering a typical sales process in an engineer to order company, the information about the product will tend to go from a low to a high degree of detail, meaning that more and more details about the product will be known over time. This is partly a consequence of the customer gradually specifying the requirements but also due to more details being determined through the engineering process. When relating the concepts abstraction and detail it is evident that as a lower level of abstraction is approached, more and more details are also being determined.

3.2.1 Example from Case

In figure 2 the two different concepts attribute and structural detail are illustrated by a module in two different phases. The right side of the figure illustrates the module at in a later phase in the sales process, as the configuration has been refined to have a higher degree of detail. The increase in the degree of structural detail is illustrated by the “Oil fired boiler unit”, which to the right has been broken down to a “burner” module and a "pressure part" module. The increase in degree of attribute detail is illustrated by the addition of the weight attribute in the "Oil fired boiler unit" object.

Figure 2 Degree of attribute and structure detail illustrated.

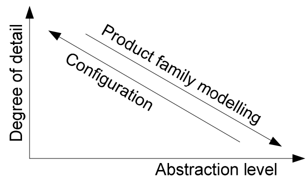


One of the reasons why it is necessary to work with a variable degree of detail over time is that a module in some cases will have a different breakdown structure, as well as different attributes may be relevant, dependent on choices made in the configuration process. One example of this is a configuration option causing a module to be purchased rather than manufactured in-house. In the case of the module being manufactured in-house, a much more detailed breakdown structure of the module is needed later in the configuration process as well as a higher number of attributes, compared to purchasing the module from a supplier.

3.3 Configuring Two Dimensional

As suggested by Jørgensen [8], modelling on multiple abstraction levels will imply that in a configuration process, the abstraction level will move from high to low and the degree of detail will move from low to high as illustrated in figure 3. This is not a general rule which always applies, but to a greater extent a reflection of the focus of different phases in a typical business process in relation to the configuration, sale and manufacturing of a product.

Figure 3 The change in abstraction level and degree of detail in product family modelling and configuration processes.



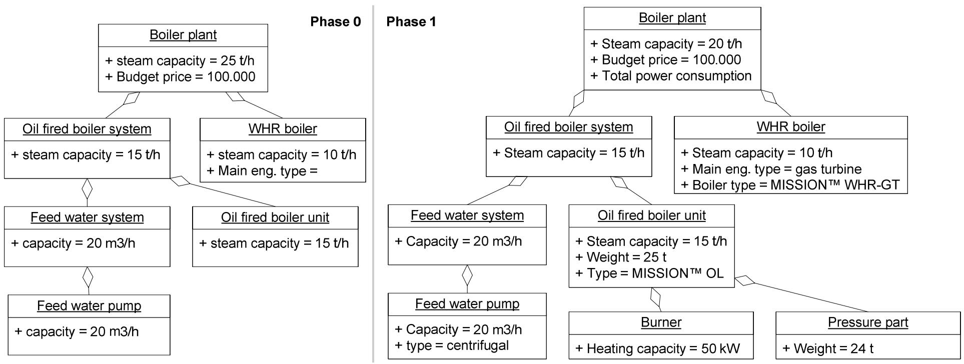
Logically, there is a close relationship between abstraction and detail in a configuration process. Changing a configuration affecting one may very well affect the other as illustrated in the following two examples:

- When a configuration is changed towards a lower abstraction level more specific attributes are added and assigned values. Hence a lower abstraction level will imply a higher degree of detail. A high abstraction level limits the degree of detail, since attributes cannot be assigned values before they are added.
- The more attributes for a given module or component that are assigned values, the fewer actual modules will satisfy these values. Hence, a higher number of attributes assigned values can imply a lower abstraction level.

3.3.1 Example from Case

To illustrate the relationship between the two concepts in one example, a configuration of a steam boiler plant is shown in figure 4 containing a configuration of a steam boiler plant at two different points in time, the right hand being the later point in time. In phase 1, the oil fired boiler is configured to be of the type MISSION™ OL which implies a lower abstraction level of this module, since MISSION™ OL is a more specific description than "Oil fired boiler". The lower abstraction level causes a higher attribute detail e.g. the weight attribute and a higher degree of breakdown detail illustrating the link between abstraction and detail.

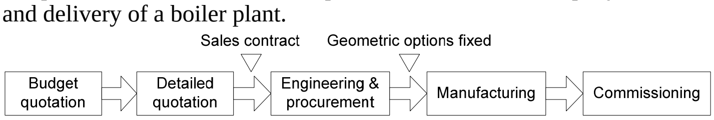
Figure 4 The configuration of a boiler system illustrating abstraction and detail.



The specification the "main engine type" attribute as "gas turbine" is an increase in the degree of detail. However, considering the value of this attribute as a requirement, only one boiler type will satisfy this requirement, and thus the abstraction level is reduced. Hence this relationship illustrates mechanism of an increased degree of detail causing a lower abstraction level.

The degree of detail and abstraction level are closely linked to different phases in the business processes that the configuration system supports. The reason for this is that a number of "gates" exist in business processes, where a given level of abstraction and detail is required. Considering the business processes of AI a number of these gates can be identified to illustrate this. Figure 5 shows a simplified model of the business processes related to the sale and delivery of a steam boiler plant at AI.

Figure 5 Simplified model of the business processes in the case company AI related to the sale and delivery of a boiler plant.



Though the actual number of gates is much higher in the actual business process at AI, the simplified model illustrates the basic principles. Two gates are illustrated in the model:

- At the first gate the configuration must be sufficiently detailed and specific to create a legally binding sales contract requiring a reliable cost estimate and scope of supply, which is achieved at a certain degree of detail and abstraction.

- The second gate is prior to the manufacturing phase. Here the geometric options must be fixed as these influence the manufacturing processes. However they are not significant to the price and do not need to be determined in the sales phase.

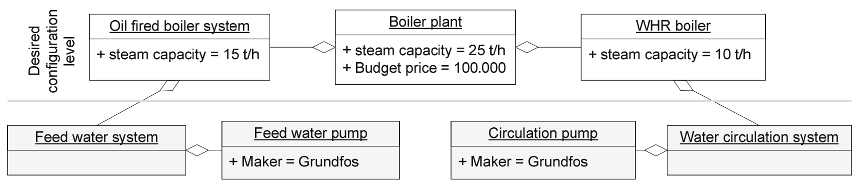
In general, the focus moves from being business oriented working with overall functional specification and few technical specifications towards a more specific technical focus.

4 Challenges in Multi Level configuration

4.1 Configuring on All Levels

In the example of AI's sales process, the customer will in most cases provide a few general requirements. In other cases the customer will also provide very detailed and specific requirements. An example of this is illustrated in figure 6 where some main characteristics have been configured as it is desired in the early sales phases. The boiler plant consists of an oil fired boiler system and a WHR boiler at the configured level. These can be broken down to feed water system and water circulation system, which both contain pump units. However in this example the customer has also specified the maker of all pumps in the system which is below the desired specification level. The problem in this relation is that due to the degree of detail and abstraction level at this point the breakdown structure has not yet been determined. Hence it is not unambiguous what attributes on which module must be assigned a value to satisfy the specific requirement from the customer, which presents a challenge with regard to retaining this requirement.

Figure 6 Illustration of customer requirements configured on different levels in the early phase of a sales process. The grey line represents the configured level of breakdown detail.



One approach to multi level configuration could be to utilize a finite number of levels which involves defining a number of "views" on the product family model, which each have a certain degree of detail and level of abstraction. This approach will allow the company to specify which information must be determined in each phase of a sales and order process. C.f. the description of customer requirements above, this approach may however be somewhat inflexible as attributes not defined for a specific business process cannot be configured if the customer has detailed requirements.

Another approach could be to avoid the predefined levels and thus the products can be configured on a continuously variable level, leading to more flexibility and allowing requirements on any level to be configured if necessary. However this approach will not allow constraining the configuration of certain attributes to certain business processes. Furthermore this approach may be more complex to implement technically than the predefined levels due to constraint complexity as well as the continuous levels may be more difficult to comprehend for the end user.

Since the two approaches may be too rigid or flexible respectively, it could be beneficial to choose an approach that is a combination of the two by defining a number of predefined levels for each component. This would allow the flexibility of configuring on various levels across a configuration while still working with predefined views. Also this would still provide the possibility of controlling on which levels a product is configured since only certain views may be available to a user in a given business process. However, since no experiences are documented in literature about these approaches, it is difficult to draw a final conclusion on which of these approaches is the most appropriate.

4.2 Cost calculation

When configuring a product for a sales quotation it will be necessary to calculate a cost of the product. As described above, the typical approach to calculating cost for configurations by breaking down the product to a detailed BOM does not reflect the actual cost of the product since the product details change after the sales order is taken. Using multi level configuration such BOM cannot be generated since sourcing details and specific components are not specified at the time of sale and thus the cost calculation method above is not applicable. Hence a new cost estimation method needs to be applied to estimate a cost. Preliminary tests with statistical based cost estimation in the case company indicate that a cost can be estimated using significantly fewer parameters and without a BOM than current cost calculation basically without loss of accuracy. Hence this suggests that a solution can be developed to meet this challenge.

4.3 Ensuring Low Level Constraint Satisfaction

When configuring a product in multiple stages a problem arises in relation to constraint satisfaction. If a component is configured at a high abstraction level, the subcomponents may not be known and therefore the constraints that may be related to the subcomponents cannot be taken into account at this time. As the product is configured over time and the information becomes more specific, the constraints on the components may also become more specific. This implies a risk that configuration choices made earlier in the process create conflicts with the more specific constraints These possible conflicts will require attention when modelling the product family to be configured, as they may introduce unsolvable configurations in a multi level configuration system. As mentioned previously no multi level configuration approach has been described comprehensively in literature. Hence the issue of constraint satisfaction on multiple levels has not been described in literature either since it has not been the source of problems in any particular case. Like the issues related to multi level configuration systems presented above, this is also an issue that needs to be addressed before such system can be realized.

5 Conclusion

This paper has presented an analysis of potential challenges that ETO companies may encounter in relation to product configuration methods and tools being designed for use with traditional MC. The analysis was performed by analyzing a case from an ETO company, which has been using product configuration for a longer period of time. The conclusion was that the configuration being defined in one single process reduced the flexibility in the later phases of the sales and order execution processes and in general the configuration systems have a potential for supporting the business processes more efficiently. To improve these issues this paper proposed to use a multi level configuration approach which implies configuring at a high abstraction level and a low degree of detail in the early sales phases and refine the configuration over time. Two key concepts, abstraction and detail, were defined and illustrated by examples from the case. However the multi level approach has a number of issues related to it being: 1) identifying the abstraction levels to configure on; 2) estimating the price of a configuration that cannot be translated to a component specific BOM; and 3) ensuring satisfaction of constraints on lower levels. More research and method development will be necessary to address these issues if a multi level configuration system is to be developed.

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An implementation methodology of SOA based PLM system

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Abstract: The range of IT systems and engineering solutions that fall under the terminology PLM system has been growing with constant introduction of new IT technologies and latest engineering needs. Consequently, a typical PLM system in a large manufacturing company is no longer represented by a single homogeneous IT system but a collection of several commercial packages as well as home grown applications. This paper describes a methodology to implement a PLM system by integrating hybrid legacy IT assets within service-oriented architecture using our best of breed service integration policy.

Keywords: PLM, SOA, Web Service, ESB, BPM, Enterprise Portal

1 Introduction

Large manufacturing companies today have gone through several phases of R&D innovation and advanced their R&D environments and practices significantly from what they used to be in early 1990's when a PDM (Product Data Management) system was first introduced. For example, in 1994 when Samsung Electronics Co. ("SEC", henceforth) embarked on its first corporate PDM system implementation, the focus was on secure on-line management of 2D CAD drawings and related engineering data. Today, however, there is no more 2D CAD drawings managed by the SEC PDM system ("SPDM", henceforth) – they are generated on the fly from a 3D CAD file. In fact, mechanical CAD work itself is becoming relatively minor task of R&D engineers at SEC as the amount of software source codes and corresponding number of software engineers grow at record high rate. The current version of SPDM has not yet caught up with that particular rate of change, and thus much of the software development activities and data at SEC are not fully managed by the SPDM system.

The problem is that there are growing number of other reasons – business wise and IT wise – that require speedy and perpetual change of PDM systems. Business wise, globalization is the number one reason why PDM systems have to change fast. DAMA

(Design Anywhere, Manufacture Anywhere) is no longer a fancy catch phrase of a PLM vendor but a mission critical practice of most large manufacturing companies. The second reason is the digitalization trend of consumer products. Software and SoC (System on Chip) engineering activities account for the major portions of product development time and resources. Legacy PDM systems that are architectured to support 2D drawings or PCB circuit design activities have to change fast to support the new requirements. Then there are several other reasons associated with corporate cultural and organizational change. R&D outsourcing, departmental spin-offs, and M&A (Mergers & Acquisitions) of completely new business are common these days. Consequently, there are constant new requirements for improved business processes as well as infrastructure for better communication, information sharing, and data migration.

IT wise, the reason why a legacy system like SPDM suffers from the lack of usability and performance to end-users is, ironically, the constant increase of the computing power and introduction of new IT technologies. In 2003, SEC had to upgrade its SPDM system to SPDMv6 by replacing its proprietary client/server architecture to a standard web based architecture because web technologies caused end users to demand better user interface and improved usability. Now SPDMv6 needs to be upgraded once again because current State-of-the-art IT technologies can make it a more flexible system that can easily implement fast changing processes and accommodate integration/interface requirements with other enterprise systems like ERP, APS, CRM and SRM.

Faced with above mentioned reasons, SEC is in the course of reviewing several possibilities to migrate current SPDMv6 into a new system. Tentatively we call it a SEC PLM system.

This paper describes our research about the implementation methodology of SOA (Service Oriented Architecture) based PLM system at SEC. We define our definition of a PLM system, describe features of SOA that facilitate implementation of our PLM system, and summarize the result of our initial effort to pilot a SOA based PLM system at SEC.

2 Requirements

In order to define the right PLM system at SEC, we took a survey of 17 business units within SEC and compiled the voice of managers and engineers. Prior to the individual interviews we provided them with a list of questions prompting them about the issues and suggestions regarding our present and future R&D processes and systems. Figure 1 is the summary of responses gathered.

Traditional requirements from managers – quality, cost and delivery efficiency – are still on the top of the list. However, very different kind of requirements prevails from R&D engineers as well as from some managers – *flexibility*. Engineers want flexibility from the legacy PDM system because it takes unacceptably long time for the system to reflect the latest change in their engineer practices. Managers want flexibility because the new rules and regulations they want to enforce are only on some papers or booklets and by the time they are implemented in a system it is typically too late since they are already obsolete.

Additionally, both managers and engineers want to find more global best practices and intellectual properties. Currently each business unit has its own PDM system, and therefore it is not easy to share information even among the business units. Ideally, both local and global best practices and knowledge should be discovered, accumulated and shared corporate-wide.

Figure 1 Voice of Customers

Executives and Directors	R&D Engineers
Maximize R&D productivity and efficiency Make it flexible to adapt to the fast changing customer needs Continually discover innovative product development methodologies Globalize corporate processes and systems Manage and propagate R&D knowledge and best practices	Minimize paper works – including various managerial input to PDM systems Prompt upgrade of applications such as change in regulations and processes are reflected to their systems Extend the coverage of the PDM system so that specialized engineering data and activities can be managed as well Allow engineers to use the tool of their choice Provide more best practices

3 Product Lifecycle Management

SEC began implementation of its first corporate PDM system as early as 1994. By 1996, the first fully functional version of SPDM was deployed at the AV division. Ten years later, SPDM is being used throughout the company both domestically and globally. So, yes SEC has a global PDM system. The difficult question to answer is “does SEC have a PLM system?”

The primary reason is because the definition of PLM is overloaded. Industries, academia, and vendors seem to have different scope and concept of PLM. Pahl and Beitz [1] assert that a lifecycle of a product covered by a PLM may include phases of “Market / Need / Problem”, “Product Planning / Task Setting”, “Design / Development”, “Production / Assembly / Test”, “Marketing / Consulting / Sales”, “Use / Consumption / Maintenance”, “Recycling” and “Disposal.” According to them, a PLM system should cover all those phases of a product lifecycle as well as the data that are traditionally managed by a PDM system. According to Prof. Michael Grieves [2] and PLM Consortium at Michigan University, PLM is “an integrated, information driven approach to all aspects of a product’s life from its design inception, through its manufacture, deployment and maintenance, and culminating in its removal from service and final disposal.” CIMdata [3] defines PLM as “a strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information.” On the other hand, various solution vendors [4, 5, 6] are more down to earth and limit the scope of a PLM system to cover some combination of their PDM system with CAD, CAM, CAE, or digital manufacturing systems. We have reviewed those and several other definitions of PLM and adopted the following to be our working definition – “a solution and a strategic approach to manage human resource, process, business system, information across the product lifecycle from the business planning stage to disposal”

With the agreed upon definition of PLM at SEC, we have scrutinized our legacy SPDM system and concluded that there are four axis of fundamental re-engineering directions needed to transform SPDM into a PLM system – Coverage, Connectivity, Competency, and Flexibility. We believe that the first three can be achieved by adding new best-of-breed engineering solutions available in the market with proper integration with the in-house applications. However, in order to achieve the fourth goal of flexibility, we had to consider new architecture for our new PLM system that can not only accommodate continuous introduction of new best-of-breed applications but also leverage SPDM and tens of other legacy assets already deployed throughout the company.

In the remaining sections of this paper, we describe how we have studied and adopted SOA (Service Oriented Architecture) to satisfy that fourth requirement, the open and flexible architecture for SEC PLM system.

4 Service Oriented Architecture

SOA is an architecture that combines proven advantages of object-oriented modeling and component-based design. Services within a SOA are loosely coupled constituents each of which encapsulate a meaningful business objective or enterprise data and may communicate with each other using some standard protocols. SOA is neither a technology nor commercial solution. Instead it is a form of technology architecture that adheres to the principles of service-orientation and standards of web services [7]. SOA is not a new concept, but we believe it is a right concept at the right time. For many companies that undergo business transformation and find their IT systems too heavy and complex to be promptly transformed, SOA could be regarded as a solution for integrating and simplifying their IT systems [8]. Gartner predicts that by 2008, SOA will provide the basis for 80 percent of development projects [9]. This chapter summarizes aspects of SOA-based system as we understand them – services, ESB (Enterprise Service Bus), BPM (Business Process Management) and EP (Enterprise Portal).

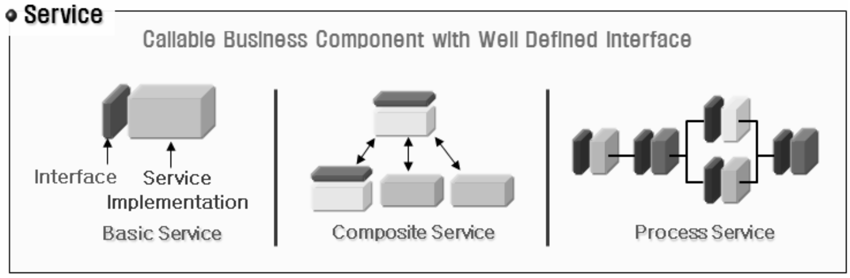
4.1 Services

First, a service within a SOA can be defined as following:

- A service is an implementation independent interface with explicit definition.
- A service is loosely coupled, location-transparent and called by interoperable communication protocol.
- A service encapsulates re-usable business functions

At SEC we differentiate three kinds of services in SOA; basic, composite, and process services. A basic service is an atomic service which can serve some meaningful business function. A composite service consists of combination of one or more basic services. A process service consists of one or more basic services and composite services and forms a business process. Figure 2 illustrates a basic service in SOA which consists of an interface and a service implementation and composite and process services. Although not mandatory, we opted for a standard web service implementation whenever possible.

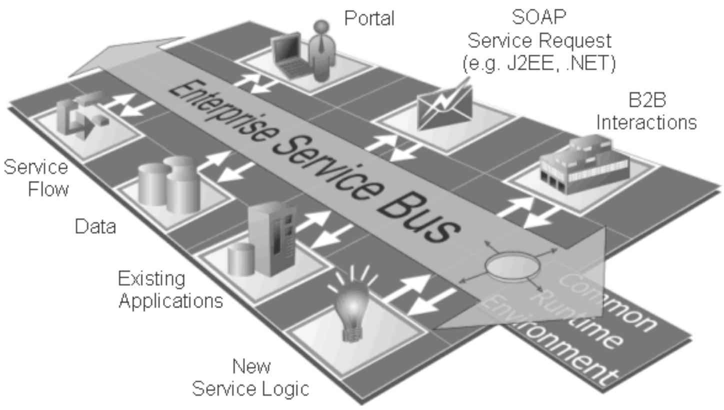
Figure 2 Services in SOA



4.2 Enterprise Service Bus

ESB is a new kind of application integration middleware. Gartner Group defines ESB as "a web-services-capable infrastructure that supports intelligently directed communication and mediated relationships among loosely coupled and decoupled business components." IBM describes ESB as providing a set of infrastructure capabilities, implemented by middleware technology, that enable the integration of services in an SOA. Although, the implementation methodology is different from one vendor to another, the main functionalities of an ESB are the same – a middleware and a bus for communication among services in SOA. Figure 3 is an illustration of an enterprise service bus by IBM [10].

Figure 3 Enterprise Service Bus [10].



4.3 Business Process Management

BPM became a hot IT issue after introduction of BPR (Business Process Re-engineering) in 1990s', and is regarded as business innovation method that supports integration of enterprise processes. BPMS (Business Process Management System) is a management system that optimizes business processes through 'define', 'design', 'execute' and 'analyze' cycles. A business process is choreography of operations executed by the system or human. The definition and design of the process is important in BPM.

The main functions of BPMS are 'process definition', 'process execution', 'process measurement / analysis' and 'process improvement'. The integration of scattered systems throughout the company is a primary purpose of using BPMS. SOA proposes the idea of smooth integration for BPMS because SOA is an architecture that defines business processes as a collection of business services.

4.4 Enterprise Portal

Enterprise Portal is an information gateway to employee, customers and business partners. A portal is in charge of the presentation layer of a SOA system. It integrates system with data and provides single access point to users. When a user interacts with an IT system, s/he only sees the presentation layer. Therefore, portal is often the most important aspect of a web-based IT system and the importance of usability of page layout and content presentation can never be over-emphasized. In our pilot project, we had to update the portal constantly during the various phases of the project.

5 SOA Based PLM System

The mission of our project is to design and implement a pilot system that represents a legitimate fraction of our next generation PLM system that is based on an open and flexible architecture, while satisfying the engineering functional requirements as shown in Figure 4.

Figure 4 Two Facet Requirements for SEC PLM System

Open & Flexible Architecture	Engineering Functionalities
Extensibility & Interoperability	Heterogeneous CAD Data Management
Robustness & Function	PDM Common Service
Process Management	Requirement Management
Technology Platform	Customer & Supplier Management
Easy Development & Maintenance	

5.1 SOA Based PLM System Architecture

Initially, we surveyed the market for a commercial off-the-shelf package solution that would satisfy our requirements. As a result we found the following two schools of solutions:

1. Middleware solutions to implement a SOA based IT systems
2. PLM solutions rooted on a PDM or a drawing management system

No single unified solution was found that could satisfy the two requirements simultaneously. So our next best method was to select the most open and standard middleware solution to implement a basement for our PLM system and then employ a ‘best of breed’ strategy to ‘plug-in’ any number of engineering functionalities from commercial or legacy systems. The resulting SOA based PLM system architecture consists of web services technologies for the application services, ESB technology for message processing of services, BPM technology for business process management, and enterprise portal for UI integration. Figure 5 shows the conceptual architecture of SOA-based PLM system. Each component technology of the referenced SOA is as defined in section 4. It can be noticed in the illustration that SOA based PLM architecture requires services from legacy systems. These services can be accessed through ESB and supplied to the users through integrated UI in portal.

5.2 SOA Based PLM System Implementation

Depending on how to count it, there are more than fifty legacy systems in SEC for the management of R&D processes. In order to minimize the risk while maintaining the meaningful size of the pilot project, we defined the scope of our pilot project to cover twelve systems and sub systems. Our implementation goal was to transform those twelve legacy systems into a SOA based PLM system. For the bases of open and flexible SOA architecture, we installed commercial middleware solutions from a couple of selected vendors. With some customization effort to connect to SEC enterprise SSO (Single Sign On) and LDAP (Lightweight Directory Access Protocol), we managed to establish the basics of presentation, BPM, and ESB layers of our SOA based PLM system. The difficult part was transforming legacy systems into services. There was no right answer when it comes to deciding the size of a basic service. We took the advice from IBM and used the three-fold approach in identifying services; top-down, goal-driven, and bottom-up. Top-down approach is to start from a business process and compile a list of services that are required to run that process. Goal-driven approach is to start from an enterprise KPI (Key Performance Indicator) and derive the business functions needed to achieve the KPI. Bottom-up approach is to analyze existing functions and operations in the legacy system and build up to a meaningful unit of business object. After a number of trials and errors, we identified 20 basic services from the twelve systems. Those are the enterprise services that can be published and shared throughout the company. Using the UDDI (Universal Description, Discovery, and Integration) publication tool from acquired commercial package, we have also registered and published those services within SEC.

In addition to the basic services, we implemented nine composite services and three process services to demonstrate the benefits of the new architecture. In particular, the process services are implemented using the standard BPEL (Business Process Execution Language) and executed on top of the BPM engine that we installed as shown in Figure 6. The flexibility of the process design and the visibility of BPMS, draw positive feedbacks from the process owners and designers alike.

Figure 5 PLM Architecture

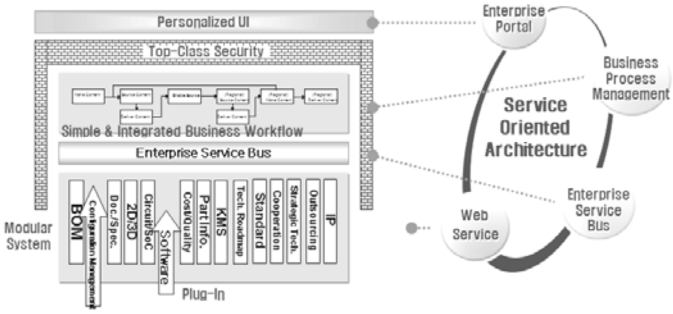
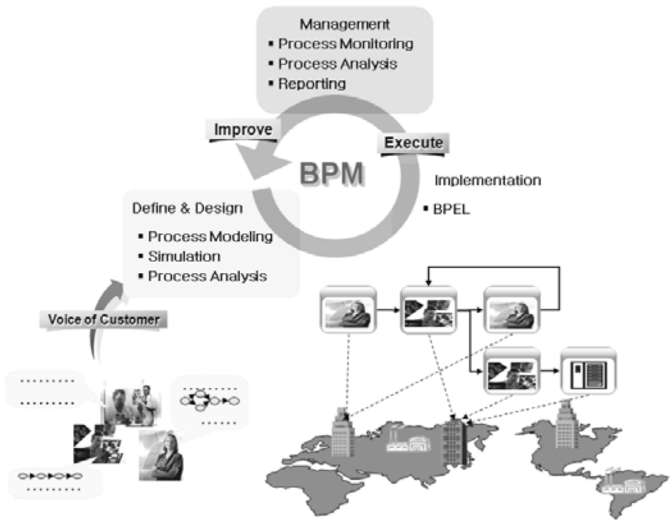


Figure 6 Business process lifecycle for BPMS



6 Conclusion

Although the coverage is limited to a fraction of the work done in R&D systems at SEC, the implementation of the pilot SOA based PLM system introduced in this paper is the first of its kind that attempts to apply complete four layers of SOA to a PLM system – presentation, BPM, ESB, and service layers. So far, the result is promising. We expect to see quick implementation of new business processes which in turn will promote faster change of processes and thus make SEC a more agile company.

Before moving into our next phase of full blown PLM system implementation, however, we still need to solve the granularity issue. Bigger sized services are easier to implement but less modular and thus less useful. Smaller sized services are more difficult to implement and maintain but service re-usability and flexibility will increase.

Also, services in SOA are new IT constructs that require continuous maintenance. Thus we need to define governance rules and assign responsible organization for maintaining services throughout their lifecycle.

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Computer aided consensus searching system for collaborative and distributed design process

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Abstract: This paper proposes an approach for consensus identification during the real interactions in collaborative and distributed design process. For that, from real experiments, the process of collaborative and distributed design is analyzed. Then, based on this analysis, a formal model to represent the consensus is proposed. The analysis of design experiments shows that a design solution is a multiple of consensus solution-nucleus rather than a consensus solution. Based on the concept of consensus and its properties, the actors can be assisted to move towards the consensus improvement or towards the ideal consensus. The concept of consensus is used to evaluate the choice of a solution in terms of consensus and dilemmas; to assist the redesigning of a part or the whole solution according to consensual criteria and to capitalize and share the know-how of the various actors.

Keyword: collaborative and distributed design, design analysis, consensus, intelligent agents.

1 Introduction

The design process is the series of activities by which the information known and recorded about the design product is added to, refined, modified, or made more or less certain. There have been many attempts to draw up models of the design process in systematic steps [6, 16, 18].

In this contex, collaborative and distributed design is an iterative, complex, decision-making engineering process. This complexity results from the conjugation of an important number of heterogeneous data (domains, actors, organization, and methods) interacting between them. The variety of points of view is translated, among others, into the multiple goals to be followed during the design process. It is shown that the interaction is a variable key between actors during collaborative and distributed design [10, 11]. Its importance justifies efforts provided by the scientific community for the analysis of interactions on the one hand [1, 2, 4, 8, 17] and developing tools to support dynamic data sharing in a collaborative design environment on the other [3, 12].

The issued results of interactions must be consensual in order to be accepted. In these conditions, the final solution of the process of design could be only the result of a consensus. Indeed, as new designs are generated, or existing ones modified, there is continuous need to evaluate them. Although the main goal of evaluation is comparing the product design with the engineering requirements, it is important to track changes made in the function of the product [19].

The understanding of the convergence toward a globally acceptable solution requires, on one hand, the modeling of the variables set intervening during interactions between the different actors, and on the other hand, the modeling of the goals and relations that they maintain during the design process. The proposed approach consists in discerning the nucleus of consensus from the real interactions between different actors. Based on this analysis and the associated formalism, we propose an approach for the consensus identification, which could make possible the convergence toward the final solution.

In the second section, the process of cooperative and distributed design is analysed. Based on this analysis, a formal model to represent the consensus is proposed. In the third section, a method for consensus searching during the design process is proposed. The properties related to the consensus are shown. The forth section shows the outlines of an application. In the last section, the conclusion shows some interest of the proposed approach and some perspectives of this approach.

2 Consensus in Collaborative et Distributive Design Process

2.1 Fuzzy Collaborative Design Equations

Design is defined as the mapping process between the functional requirements (FRs) in the functional domain and the design parameters (DPs) in the physical domain [18]. The design process involves choosing the right set of DPs to satisfy the given FRs. It is expressed as:

$$[\mathrm{FR}] = [\mathrm{A}][\mathrm{DP}] \tag{1}$$

where $[\mathrm{FR}]$ is the functional requirement vector, $[\mathrm{A}]$ is the design matrix, and $[\mathrm{DP}]$ is the design parameter vector.

Throughout the cooperative collaborative and distributed design process, the first task of an actor is the proposal of a conjecture. A conjecture represents a candidate solution proposed to a given problem described in functional form [14]. The functional structure of a product is the representation of functional elements of the product [20] and their interrelationships that involve decomposition and/or dependency. Functional modelling has been investigated in the case of single products as well as product families [5, 15,16, 18].

The second task is the evaluation of a conjecture based on the criteria. Let us given the interaction between three actors *i*, *j*, and *k* which represents respectively the design domain, manufacturing domain, and ergonomic domain involved in the study of the function requirement *"separate two cells of a thermal enclosure"*. In the form design components designers exert a great influence on production costs, production times and the quality of the product [16]. Furthermore, collaboration is required to ensure that requirements of appearance, expression and impression still allow the technical functions to be fulfilled within the forms and shapes created. The actor *i* proposes the conjecture: *DP = part with square shape with rounded corners*. It answers to the design problem, since it results from the satisfaction of the functional requirement *"avoid stress concentration"*. The *DP = part with square form with rounded corners* is evaluated *positively*. The two other actors *j* and *k* concerned by this conjecture study this one in comparison respectively with the functional requirements *"easy to machining"* and *"easy to manipulate"*. The actors have to alternatively decide if the conjecture is *"easy to machining"* and *"easy to manipulate"*. They do not always answer either "no" (0) or "yes" (1). A fuzzy set allows having an intermediate membership, which is neither "no" (0) or "yes" (1) in the conventional set theory. For instance, a membership of 1 represents that an element definitively is *"easy to manipulate"*, 0 represents that it is not. A membership of 0.5 shows that it belongs with a half degree in the set *"easy to manipulate"*.

Then, a finer analysis of the interactions between actors during the evaluation of a conjecture results in classifying the functional requirements in two categories:

1. *Shared functional requirements*. These are satisfied by an incomplete physical embodiment. The physical embodiment would have not yet an exact definition. The boundaries of the physical embodiment could be vague. All actors will share these functions.

2. *Domain dependent functional requirements*. These are satisfied by an uncertain physical embodiment. There is some indefiniteness in the physical embodiment. They are particular to each domain.

The conjecture *DP=part with square shape with rounded corners*, proposed by actor i, can be decomposed into two features-conjecture $DP= DP_1 \vee DP_2$, with DP_1 = *part with square shape* and DP_2 = *rounded corners*. Then the proposal of the actor *i* can be represented as:

$$\begin{bmatrix} FR_0 \\ FR_1 \end{bmatrix}_i = \begin{bmatrix} 0.9 & 0 \\ 0 & 0.9 \end{bmatrix}_i \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix}_i \tag{2}$$

where FR_0 = *separate two cells of a thermal enclosure*, and FR_1 = *avoid stress concentration.* The FR_0 is a *shared functional requirement.* The FR_1 is *domain dependent functional requirement*, that is *design dependent functional requirement.*

The reaction of the actor *j* can be represented as:

$$\begin{bmatrix} FR_0 \\ FR_2 \end{bmatrix}_j = \begin{bmatrix} 0.8 & 0 \\ 0 & 0.3 \end{bmatrix}_j \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix}_i \tag{3}$$

where FR_2 = *easy to machine*. The FR_2 is *manufacturing dependent functional requirement.* The matrix of DP is proposed by the actor i.

Finally, the reaction of the actor *k* can be represented as:

$$\begin{bmatrix} FR_0 \\ FR_3 \end{bmatrix}_k = \begin{bmatrix} 0.8 & 0 \\ 0 & 0.8 \end{bmatrix}_k \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix}_i \tag{4}$$

where FR_3 = *easy to manipulate*. The FR_3 is *ergonomic dependent functional requirement*

For a particular domain, we define as a ***design cluster***, the relation of evaluation between a group of functional requirements and a group of conjectures. For example, for the domain *k*, two design clusters can be distinguished: $C_1 = (FR_0, DP_1, 0.8)$; $C_2 = (FR_3, DP_2, 0.8)$. Thus, the design cluster set is a partition of the set of the functional requirements and the set of the conjectures. The concept of the design cluster allows considering a group of functional requirements and related group of the conjectures independently from each other.

2.2 Consensus modeling

We note D_j the domain j, (j=1,…,N) with N the number of domains. The number of the design clusters in the domain j is written $n_j = card(D_j)$. The design clusters for a domain j are noted C_{jp} (j=1,..,N; p=1,..,n_j). is $q = \sum_{j=1}^{N} n_j$. Thus, C_{jp} is the p^{th} design cluster for the domain j. A conjecture DP is decomposed into m features-conjecture DP_i (i=1,…,m). Then, the assignment of the features-conjecture to the design clusters is summarized by the following matrix equation:

$$[DP] = [A][C] \tag{5}$$

where $[DP]$ is features-conjecture vector, $[A]$ is the design matrix, and $[C]$ is the design cluster vector. The features-conjecture vector $[DP]$ contains m rows (i=1,…,m). The design cluster vector $[C]$ contains q rows, where $q = \sum_{j=1}^{N} n_j$ is the number of design clusters. The design matrix $[A]$ maps the features-conjecture to the design clusters. The design matrix A contains m rows and q columns. The entries of the design matrix A represent the evaluation of the features-conjecture in the design clusters.

Consider the case of interactions between three actors i, j and k representing respectively the design domain, manufacturing domain and ergonomic domain. The representation of the relationship between the features-conjectures and design cluster is given by the matrix equation:

$$\begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} = \begin{bmatrix} 0.9 & 0 & 0.8 & 0 & 0.8 & 0 \\ 0 & 0.9 & 0 & 0.3 & 0 & 0.8 \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{12} \\ C_{21} \\ C_{22} \\ C_{31} \\ C_{32} \end{bmatrix} \tag{6}$$

If all the points of view converge towards a conjecture without dilemma, the matrix equation after the permutations of rows of the matrices [DP] and [C] takes a particular aspect. For example, the equation (6), can be transformed into the equation (7) by the permutation of the rows of matrix [C]:

$$\begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} = \begin{bmatrix} 0.9 & 0.8 & 0.8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.9 & 0.8 & 0.3 \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{21} \\ C_{31} \\ C_{12} \\ C_{32} \\ C_{22} \end{bmatrix} \tag{7}$$

One can note that the consensus is complete on the feature-conjecture DP_1, resulting from the total overlapping of design cells C_{11}, C_{21}, C_{31}. Otherwise expressed, the actors i, j, and k representing respectively the *design* domain, *manufacturing* domain and *ergonomics* domain are consensual on the feature-conjecture DP_1, and no consensual on the feature-conjecture DP_2. The equation (7) shows the partition of the set of the feature-conjecture $\{DP_1, DP_2\}$ in two parts $P_1(DP)=\{DP_1\}$ and $P_2(DP)=\{DP_2\}$, and the partition of the set of design clusters $\{C_{11}, C_{12}, C_{21}, C_{22}, C_{31}, C_{32}\}$ in two parts $P_1(C)=\{C_{11}, C_{21}, C_{31}\}$ et $P_2(C)=\{C_{12}, C_{32}, C_{22}\}$, such as every part of features-conjecture P(DP) corresponds to a part of design clusters P(C).

The search of couples (P(DP), P(C)) permits the decomposition of the matrix A in submatrices A(Diagonal) formed of "1" values, and A(Non-Diagonal) formed of "0" values. It is the case of an ideal consensus for proposed features-conjecture. In this case, the set of points of views converges on each feature-conjecture. Here, explicitly, there are not the confrontation and the negotiation between actors. The whole features-conjecture is consensual. Then, the ideal consensus for the previous case can be represented as:

$$\begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{21} \\ C_{31} \\ C_{12} \\ C_{32} \\ C_{22} \end{bmatrix} \tag{8}$$

The consensus would be total on the feature-conjecture DP_1 in the design cells C_{11}, C_{21}, C_{31}, and on the feature-conjecture DP_2 in three corresponding design cells C_{12}, C_{32}, C_{22}. The eqaution (8) represent the form of ideal consensus.

Practically, it is not always the case. During the interaction, the actors needs the confrontation, the negotiation to converge finally towards a consensus and a decision for the considered conjecture.

3 Approach for Consensus Searching

3.1 Fuzzy matrix design decomposition

The classic relationship between the set of features-conjectures DP and the set of design clusters C, characterised by the binary values of the matrix A, $a_{ij} = 1$ and $a_{ij} = 0$, is a particular case of the fuzzy relationship. The decomposition of the binary matrix A in disconnected sub-matrices, corresponds to the ideal consensus searching problem. The problem of the decomposition of a binary matrix A, as the crossing of the set of rows and the set of columns is a correspondence by diagonal blocks, is known as the problem of blocks seriation.

Mathematically, the search for the consensus is transformed into a searching problem for simultaneous partitions of these two sets, features-conjectures and design cells, in correspondences or quasi correspondences: features-conjectures class of partition to design cells class of partition. The basic idea then consists in carrying out permutations of rows and columns of matrix A, such as to bring out the correspondence structure on the crossing of these two sets, features-conjectures and design cells. The methods exploiting this idea are called the blocks seriation methods.

We adopt the formulation of the block seriation problem to treat the case of a fuzzy relationship between the set of features-conjectures and the set of design clusters, represented by the fuzzy design matrix A. Marcotorchino [9] generalized the model of blocks seriation. According to this author, the problem consists in searching the binary matrix Z, with the same dimension as the matrix A, which maximizes the function:

$$F = \alpha \sum_{i=1}^{m} \sum_{j=1}^{q} a_{ij} z_{ij} + \beta \sum_{i=1}^{m} \sum_{j=1}^{q} (1 - a_{ij})(1 - z_{ij}) \tag{9}$$

$$z_{ij} + z_{ij'} + z_{i'j'} - z_{i'j} - 1 \le 1 \quad \forall (i, i'), (j, j') \tag{10}$$

$$z_{i'j'} + z_{i'j} + z_{ij} - z_{ij'} - 1 \le 1 \quad \forall (i, i'), (j, j') \tag{11}$$

$$z_{i'j} + z_{ij} + z_{ij'} - z_{i'j'} - 1 \le 1 \quad \forall (i, i'), (j, j') \tag{12}$$

$$z_{ij'} + z_{i'j'} + z_{i'j} - z_{ij} - 1 \le 1 \quad \forall (i, i'), (j, j') \tag{13}$$

$$\sum_{j=1}^{q} z_{ij} \ge 1 \ \forall i \in I \ ; \ \sum_{i=1}^{m} z_{ij} \ge 1 , \ \forall j \in J \qquad (14), (15)$$

$$z_{ij} \in \{0,1\} \tag{16}$$

$$\alpha + \beta = 1 \tag{17}$$

The constraints (10), (11), (12), (13) represent the conditions of the extended transitivity for the matrix Z. Practically, they ensure that after the permutation of rows and columns of the matrix Z, the diagonal blocks are full of "1" values, and non-diagonal blocks are full of "0" values. The constraints (14) and (15) impose the definition of z_{ij} for all the values of $i \in I$, with I the set rows, and $j \in J$, with J the set of columns. They ensure that each feature-conjecture and each design cell are classified. The constraint (16) imposes a binary matrix. The constraint (17) makes it possible to balance the influence of each term of the function to be maximized, by using weighting. Practically, this constraint permits to simulate the concentration of "1" values on the diagonal blocks.

3.2 Consensus Measuring

In practice, there is a difference between the ideal case and the real case. To evaluate this variation, we propose using the similarity between the ideal matrix [Z] and the real matrix [A]. The first proposed coefficient of similarity between the two matrices is defined as:

$$k_1 = \frac{\sum_{i=1}^{m}\sum_{j=1}^{q} a_{ij} z_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{q} z_{ij}} \tag{18}$$

This coefficient of similarity, $0 \le k_1 \le 1$ compares the number of the positive concordances between A and Z (defined by the term $\sum_{i=1}^{m}\sum_{j=1}^{q} a_{ij} z_{ij}$) with the maximum number of these concordances (defined by the term $\sum_{i=1}^{m}\sum_{j=1}^{q} z_{ij}$). We call it **inter consensus coefficient of design.**

The second proposed coefficient of similarity between the two matrices is defined as:

$$k_2 = \frac{\sum_{i=1}^{m}\sum_{j=1}^{q} (1 - a_{ij})(1 - z_{ij})}{\sum_{i=1}^{m}\sum_{j=1}^{q} (1 - z_{ij})} \tag{19}$$

The second coefficient of similarity, $0 \le k_2 \le 1$ compares the number of the negative concordances between A and Z (it is the term $\sum_{i=1}^{m}\sum_{j=1}^{q} (1 - a_{ij})(1 - z_{ij})$) with the maximum number of these concordances (it is the term $\sum_{i=1}^{m}\sum_{j=1}^{q} (1 - z_{ij})$). We call it **intra consensus coefficient of design.** With these definitions, we can formulate the problem in terms of ***inter consensus*** and ***intra consensus coefficients of design***. The function to be maximized is the following:

$$F = \alpha k_1 + (1 - \alpha) k_2 \tag{20}$$

The maximum of this function is equal to 1. We call it ***global consensus of design***. Then, the global consensus of design, noted k, is defined in terms of inter consensus and intra consensus as:

$$k = \alpha k_1 + (1 - \alpha) k_2 \tag{21}$$

3.3 Consensus Properties

Property 1: Limits of global consensus $0 \le k \le 1$

This property stipulates that the global consensus of design vary between 0 and 1.

If the coefficients inter consensus k_1 and intra consensus k_2 are simultaneously equal to 1 ($k_1 = k_2 = 1$), the global consensus of design is also equal to 1 ($k = 1$). Let us consider $k_1 = k_2 = 1$. Thus, from the equation (21), one can have $k = \alpha 1 + (1-\alpha)1$ and $k = 1$. It is the case of the ***ideal consensus***. In this case matrices A and Z are equal.

If the coefficients inter consensus k_1, and intra consensus k_2, are simultaneously equal to 0 ($k_1 = k_2 = 0$), then the global consensus of design is also equal to 0 ($k = 0$). It is the case of the ***ideal not-consensus***.

If the coefficients inter consensus k_1, $0 \le k_1 \le 1$, and intra consensus k_2, $0 \le k_2 \le 1$, are $k_1 \ge k_2$ (respectively $k_2 \ge k_1$), then the global consensus of design is $k \ge k_1$ (respectively $k \ge k_2$). Let us consider $k_1 \ge k_2$. Thus, from the equation (21), one can have $k \ge \alpha k_1 + (1-\alpha)k_1$ and $k \ge k_1$.

Property 2: Equivalent global consensus and superior global consensus

In practice, the results can be far from the ideal case. The problem is then to choose among all the global consensuses of design the best ones. This makes it possible on the one hand to distinguish the nucleus of the consensus, and on the other hand to seek around the nucleus its improvement or the ideal consensus. It stipulates the conditions of searching the superior global consensus.

This property stipulates that the consensus $k = \alpha k_1 + (1-\alpha)k_2$ is equivalent or superior than the consensus $k' = \alpha k'_1 + (1-\alpha)k'_2$ if $k_1 \ge k'_1$ and $k_2 \ge k'_2$.

Let us given the matrix A and two solution matrices Z and Z'. The equations of the global consensus for the two matrices are respectively:

$$k = \alpha k_1 + (1-\alpha)k_2\,,\ k' = \alpha k'_1 + (1-\alpha)k'_2 \qquad (22)$$

Or:

$$k - k' = \alpha(k_1 - k'_1) + (1-\alpha)(k_2 - k'_2) \qquad (23)$$

If $\begin{cases} k_1 = k'_1 \\ k_2 = k'_2 \end{cases}$ then $k = k'$, therefore the consensus k and k' are equivalent. The solution Z is equivalent to the solution Z'. The actors can choose the nucleus of each consensus to improve them. Otherwise, k is superior to k'. The solution Z is better than Z'. It is the consensus Z, which will be chosen by the actors.

Property 3: Maximum global consensus

This property stipulates that the consensus $k = \alpha k_1 + (1-\alpha)k_2$ and $k' = \alpha k'_1 + (1-\alpha)k'_2$ are maximum if $\begin{cases} k_1 > k'_1 \\ k_2 < k'_2 \end{cases}$ or if $\begin{cases} k_1 < k'_1 \\ k_2 > k'_2 \end{cases}$.

Indeed, solutions Z and Z' are incomparable in terms of an order relationship. Although the consensus $k = \alpha k_1 + (1-\alpha)k_2$ could be superior (respectively inferior) to $k' = \alpha k'_1 + (1-\alpha)k'_2$, $k > k'$ (respectively $k < k'$), the semantics associated to $k > k'$ (respectively $k < k'$) could not be checked. For example, one cannot say that solution Z is better than the solution Z' if its global consensus is superior to Z', its intra consensus is inferior to Z' and its inter consensus and superior to Z'.

4 Application

Based on our proposed approach, here we present an analysis of cooperative collaborative and distributed design process. The following stages are applied in this case:

Stage 1: Design clusters recognition

The work which we undertook was carried out on the filmed cooperative collaborative and distributed design process experiments. The analysis of corpus is done by an actor-observer. The corpus is broken up into discussion. For a given discussion and based on the interaction between actors, the equation representing the relationship between *functional requirements* and *features-conjecture* are built for each domain (the equations (2)-(4)). Based on these relationships, the corresponding *design clusters* are found for each domain.

Stage 2: Consensus Searching

Then, the assignment of the set of *feature-conjectures* to the set of *design cells* is summarized by matrix equation (6). Using the mathematical formulation of consensus, the equations (9)-(21), different values of *global consensus***,** *inter consensus, intra consensus of design* are searched. Based on the properties of the consensus, the maximum ones are retained. The experiment has shown that actors follow one or more proposed movements to improve or to reach the ideal consensus from a retained global maximum consensus.

Stage 3: Consensus Capitalisation

The searched consensuses are capitalized. The set of features-conjecture, the corresponding design cluster, the different values of the global consensus, inter consensus, intra consensus of design are recorded. It make possible to understand the solutions, the consensus and the dilemmas on the various features-conjecture.

5 Conclusion

The interaction between the actors during the collaborative and distributed design shows that this one is a key variable and is the basis of the design logic. From our observation, the results of the interactions during the design process are a set of consensus and dilemmas on features-conjectures. The results obtained by our analysis are a set of nucleus of consensual features-conjectures. For discerning these nucleuses of consensus from the real interaction, a formal approach is proposed. The proposed approach can be used: to analyze the design process; to evaluate the choice of a solution in terms of consensus and dilemmas; to assist the redesigning of a part or the whole solution according to consensual criteria; to capitalize and share the know-how of the various actors. As we continue our research, our aim is the implementation of a multi-agent system as a physically distributed design system using the proposed model of interactions. The fractal approach can help to find multi-level consensus nucleus, from micro-level characterised by strong relationship toward the macro-level characterised less stronger relationship [7, 13].

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A PLM integrator for integrate product information management using commercial PDM systems

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Abstract: PLM(Product Lifecycle Management) is one of innovative manufacturing paradigms which leverages e-business technologies to allow a company's product content to be developed and integrated with all company business process through the extended enterprise. In order to achieve the integrate product information management with many different commercial PDM systems, it is important to define a neutral standard data file format and develop the supporting system. First, we define neutral file refers to the PLM services using XML. This provides a standard to exchange product information such as BOM and Geometry information. Then, we develop the PLM Integrator which supports data exchanges between commercial PDM systems.

Keyword: PLM (Product Lifecycle Management), PDM (Product Data Management), Neutral File, PLM Integrator

1 Introduction

In recent years, manufacturers are under a tremendous pressure to improve their responsiveness and efficiency in the product development, the manufacturing preparation, the production planning and manufacturing with a transparent visibility in production and quality control. And time and cost for the product development and production must be cut shortly to their extreme extent to meet the changing demands of customers in different regions of the world. Therefore most of manufacturing companies need a new production paradigm which can achieve competitive and agile productions. During next

10 years, the manufacturing technology will realize rapid product and process developments using systematic methods, new equipments and processes including simulation, digital virtual manufacturing and so on, and these will be developed and utilized by knowledge-based information management system which has adaptation and sensitiveness, and extended to suppliers globally in the manner of collaboration [1].

PLM (Product Lifecycle Management) is one of innovative manufacturing paradigms which leverages e-business technologies to allow a company's product content to be developed and integrated with all company business processes through the extended enterprise. This provides the ability to make business decisions with full understanding of the product and product portfolio including process, resource and plant [2].

For the success to PLM, the creation, management and coordination of all manufacturing-related information is essential. The exchange of engineering and design data has become a core part of core business processes. But, it is difficult to work and share information efficiently in distributed environment. Typically, CAD (Computer-Aided Design) and PDM (Product Data Management) system is used for many engineering areas of manufacturing industries. CAD is used to create digital models of the products, and PDM systems manage all product-related information through total product lifecycle, such as the bill of materials, drawings, engineering specifications, and etc. But absence of standards between these systems makes it difficult to exchange data.

In order to achieve PLM in distributed environment and many different systems, it is important to define a standard data file format and develop the system which can support it. In this paper, we define a standard data format by using PLM Services which is a one of the standards of PLM data exchange, and develop the PLM Integrator which supports data exchange between different commercial PDM systems and other related systems.

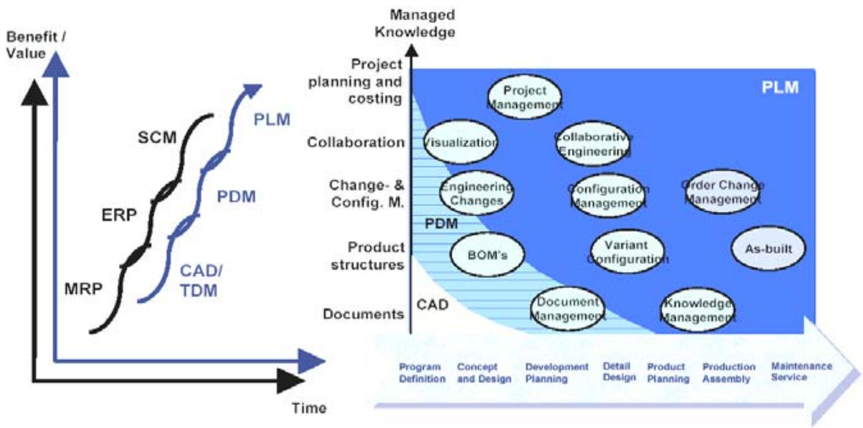
2 Overview of PDM Systems and PLM Services

2.1 PLM (Product Lifecycle Management)

PLM is one of innovative manufacturing paradigms which leverage e-business technologies to allow a company's product content to be developed and integrated with all company business processes (i.e. ERP, CRM, SCM …) through the extended enterprise. All companies need to communicate and manage information with its customers and its suppliers and the resources within the enterprise. In addition, manufacturing engineering companies must also develop, describe, manage and communicate information about their products. This provides the ability to make business decisions with full understanding of the product and product portfolio including process, resource and plant. <Fig. 1> shows concepts of PLM.

PLM extends PPR (product, process and resource) content knowledge into other enterprise processes by coupling e-business technologies with applications focused on product development and manufacturing. Before PLM, applications such as CAD, CAE (Computer-Aided Engineering) and CAM (Computer-Aided Manufacturing) were somewhat independent from the enterprise mainstream. Design and manufacturing engineers could benefit from the rich information associated with a three-dimensional representation of a product, but others in the enterprise did not have easy access to this information [3].

Figure 1 Concept of PLM



(Source : IBM)

Although PLM emerged from tools such as CAD/CAM and PDM, we need to understand it as the integration of these tools with methods, people and the processes through all stages of a product's life. Especially, the core of PLM is in the integrated management of all product data and the technology used to access this information and knowledge. Therefore, we focus to integrate and manage all information related products for successful PLM [4].

2.2 PDM (Product Data Management) systems

PDM systems are one of most important components of a PLM solution. They are the primary system component of PLM. They are systems to manage product data and product workflow. Also, PDM systems are used in the management of the activities in the product lifecycle. These activities start with the specification of a product and include product definition, analysis, manufacturing engineering, shop floor activities and product support. PDM systems provide the rigid support in this complex environment, to the many activities of the lifecycle such as design, sign-off, the sharing of data between multiple users, the tracking of engineering change orders, the management of design alternatives, and the control of product configurations.

In addition to, PDM systems offer the potential for better use of resources, better access to information, better reuse of design information, a reduction in lead times, and improved security of product information. PDM systems help companies to improve their competitive edge. PDM systems improve the way that large numbers of people, co-located or distributed, can work together. As a result, they have a visible effect on parameters such as lead time [5].

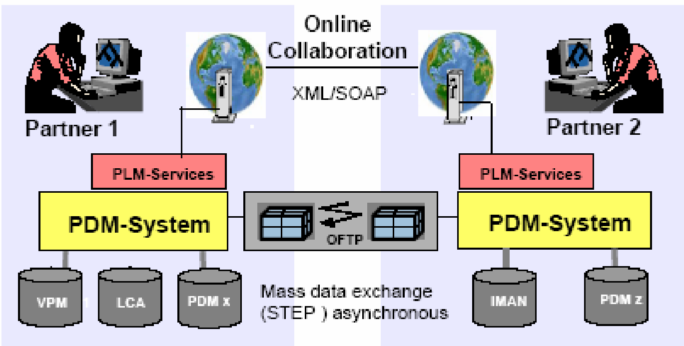
There are several commercial PDM systems support PLM paradigm, such as Teamcenter by UGS PLM Solution and SmarTeam by Dassault systems. For example, Teamcenter integrates perfectly internet and web technology to manage product lifecycle [6].

2.3 PLM Services

PLM Services has been developed by the XPDI (eXtended Product Data Integration) task force of the ProSTEP iViP association. In April 2004, it has been accepted by the OMG (Object Management Group) [7].

The concept of PLM Services includes a server which on the one side maps the system specific structures of PLM solutions, such as ENOVIA, Winchill, Teamcenter, and etc. to the XML PSM. On the other side it exposes endpoints for RPC (Remote Procedure Calls). This standard is completely compliant with STEP AP214 and defines an abstract PIM (Platform Independent Model). For this PIM further transformations can be defined to map it to PSMs (Platform Specific Models) for specific implementation technologies. From this specification, concrete implementations can be derived. It is platform independent, easy to implement, operate, support on-line access and batch operation, and use standards including STEP, XML, UML, SOAP, WSDL. <Fig. 2> shows concepts of the PLM Services [8].

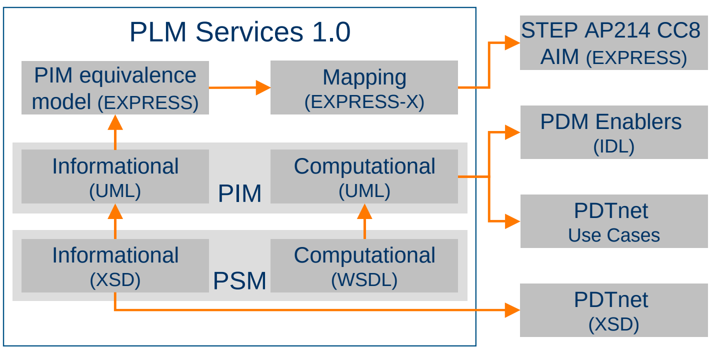
Figure 2 Concepts of PLM Services



(Source : ProSTEP)

<Fig. 3> shows the structure and main sources of PLM Services. PLM Services provides common interface for data exchange. The PLM Services version 1.0 also defines one PSM for the XML and Web Services technology. This gives us to establish a flexible and powerful framework for integration in the context of product creation. In this project, we define neutral file based on the structure and sources of PLM Services.

Figure 3 Structure and Sources of PLM Services 1.0



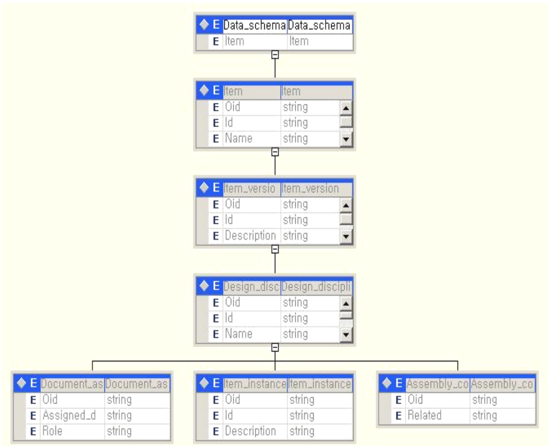
(Source : ProSTEP)

3 Neutral File of Standard for Data Exchanges

The purpose of defining neutral file is to support data exchanges between many different PLM systems. The neutral file should represent all product information such as id, name, version, assembly relation, document and etc., and has to be interoperable in various systems.

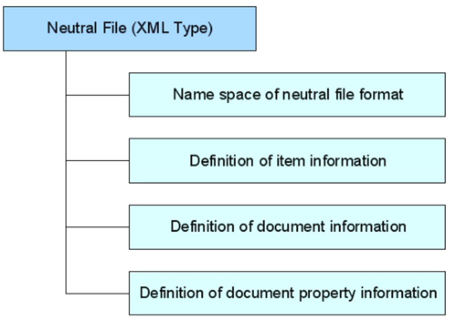
In this paper, we defined the structure and various attributes for expressing product information for exchanges. That's why we use XML to define the neutral file. Basically, the neutral file has the following xml schema as shown in <Fig. 4>. We refer to the PLM Services to design this schema.

Figure 4 XML schema for the neutral file of standard



To represent BOM structure of product, we define neutral files which consist of 4 parts using XML as shown in <Fig. 5>.

Figure 5 Structure of the neutral file



In the first part of XML neutral file, there is 'Name space of neutral file format'. The Second part is '*Definition of item information*' which represents item information such as id, name, and assembly relation of item. And then, the part of '*Definition of document information*' represents information of geometry file such as document id, name, version, size and content. Last part is ‘*Definition of document property information*’ which represents attribute of geometry file such as location, format, size, content, value and unit of geometry file.

The part of ‘*Definition of item information*’ represents id, name, version and assembly relation (BOM) related to item as shown in <Fig. 6>. BOM information is most important information of product data and represented by ‘*Assembly_ component_relationship*’ attribute. If one of items has child item, ‘*Item*’ attribute of the item has ‘*Assembly_component_relationship*’ attribute which defines unique id (oid) of its child item. And <Fig. 7> shows examples of the neutral file.

Figure 6 Structure of ‘*Definition of item information*’

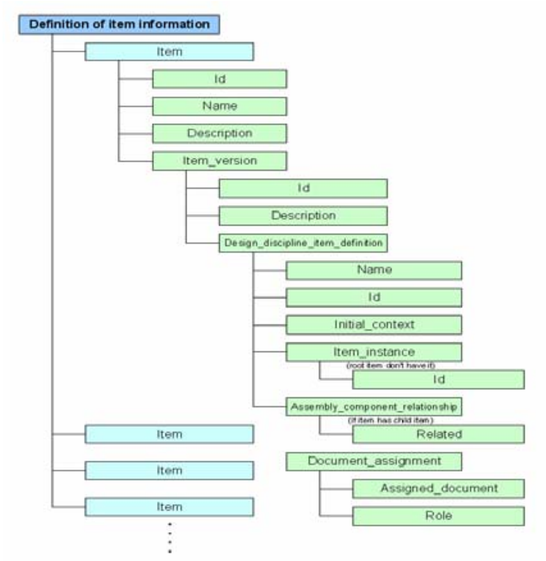


Figure 7 Example of the neutral file

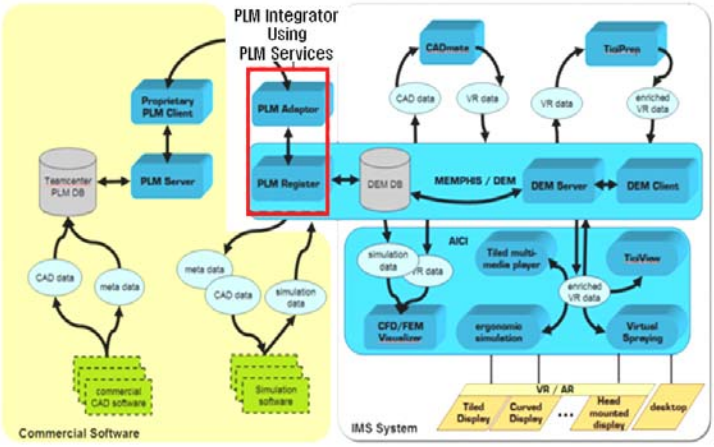

```
  <?xml version="1.0" ?>
- <demn:PLM_Container uid="PLMContainer0"
    xsi:schemaLocation="urn:omg.org/plm20/informational/model InformationModel.Xsd" version_id="1.0"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:demn="urn:omg.org/plm20/informational/model"
    xmlns:dema="urn:omg.org/plm20/informational/model" lang="en">
  - <demn:Item xsi:type="dema:Item" oid="OID:3017816657">
      <demn:Id>assy_engine</demn:Id>
      <demn:Name>assy_engine</demn:Name>
      <demn:Description />
    - <demn:Item_version xsi:type="dema:Item_version" oid="OID:A">
        <demn:Id>A</demn:Id>
        <demn:Description />
      + <demn:Design_discipline_Item_definition xsi:type="dema:Design_discipline_Item_definition"
          oid="OID:3115734791">
      </demn:Item_version>
    </demn:Item>
  - <demn:Item xsi:type="dema:Item" oid="OID:2949879479">
      <demn:Id>joint-carter</demn:Id>
      <demn:Name>joint-carter</demn:Name>
      <demn:Description />
    - <demn:Item_version xsi:type="dema:Item_version" oid="OID:A">
        <demn:Id>A</demn:Id>
        <demn:Description />
      - <demn:Design_discipline_Item_definition xsi:type="dema:Design_discipline_Item_definition"
          oid="OID:1937508989">
          <demn:Name>UG_PART</demn:Name>
          <demn:Id>joint-carter</demn:Id>
        + <demn:Item_instance xsi:type="dema:Single_instance" oid="OID:2949879479">
        - <demn:Document_assignment xsi:type="dema:Document_assignment"
            oid="OID:DOA4227011105">
            <demn:Assigned_document>OID:DOC4227011105</demn:Assigned_document>
            <demn:Role>NULL</demn:Role>
          </demn:Document_assignment>
        </demn:Design_discipline_Item_definition>
      </demn:Item_version>
    </demn:Item>
```

4 PLM Integrator and Implementations

4.1 PLM Integrator

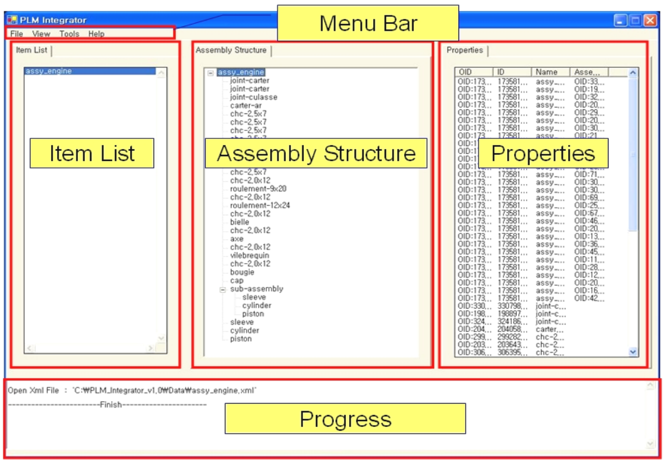
In general, the product information is created by CAD systems and is managed by PDM systems. <Fig. 8> shows that the product data exchanging between PDM system and the MEMPHIS which is the data middleware system [9]. In this paper, standard neutral file is defined to exchange product information between the data middleware and PDM systems, also PLM Integrator is developed for supporting the neutral file.

Figure 8 Architecture of the PLM Integrator



The PLM Integrator must be possible to upload and download CAD files and related metadata between the neutral file and MEMPHIS online. It is able to convert product data in PDM system to neutral file and to upload neutral file made by MEMPHIS to PDM system. To do that, PLM Integrator consists of PLM Register and PLM Adapter. <Fig. 9> shows the user interface of the PLM Integrator developed in this paper.

Figure 9 User interface of the PLM Integrator



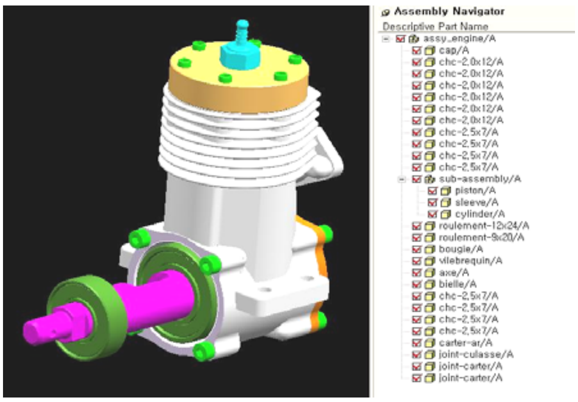
The list-box on the left-side shows the item list and the tree-view on the middle-side shows the assembly structure of selected item. And the list-view on the right-side shows properties of item. In PLM Integrator, we can open neutral file which generated from MEMPHIS or PLM Integrator. Also, PLM Integrator allows users to know items in PDM systems. If a user selects one of these items, the PLM Integrator download BOM information from PDM systems and user can show assembly structure in the tree-view on the middle-side. It generates neutral file automatically that contains all product information such as BOM information at the same time. Furthermore, it supports to download geometry files such as CAD files from PDM systems and upload geometry files to PDM systems.

4.2 Implementations

PLM Integrator and neutral file defined through this paper is applied to “MEMPHIS” which is data middleware system [9], and “Teamcenter” which is PDM systems of UGS PLM Solution. Neutral file was defined as the format, which can include all of data in Teamcenter and MEMPHIS, by referring to data definition format of PLM services. And PLM Integrator was applied to Teamcenter by using API and C++ Language, provided by Teamcenter.

In this paper, it would be implemented the system which give and take the information from MEMPHIS to Teamcenter and from Teamcenter to MEMPHIS by PLM Integrator in including various product data along with the format of the neutral file. For its test, we applied to some industry-like cases. One of these items, “Assy_engine” is engine parts of car and has some sub-assembly part. <Fig. 10> shows 3D CAD data of “Assy_engine”, which include not only basic property like Part ID, Part Name, but also assembly structure.

Figure 10 Geometry files and the BOM information of example case, "Assy_engine"

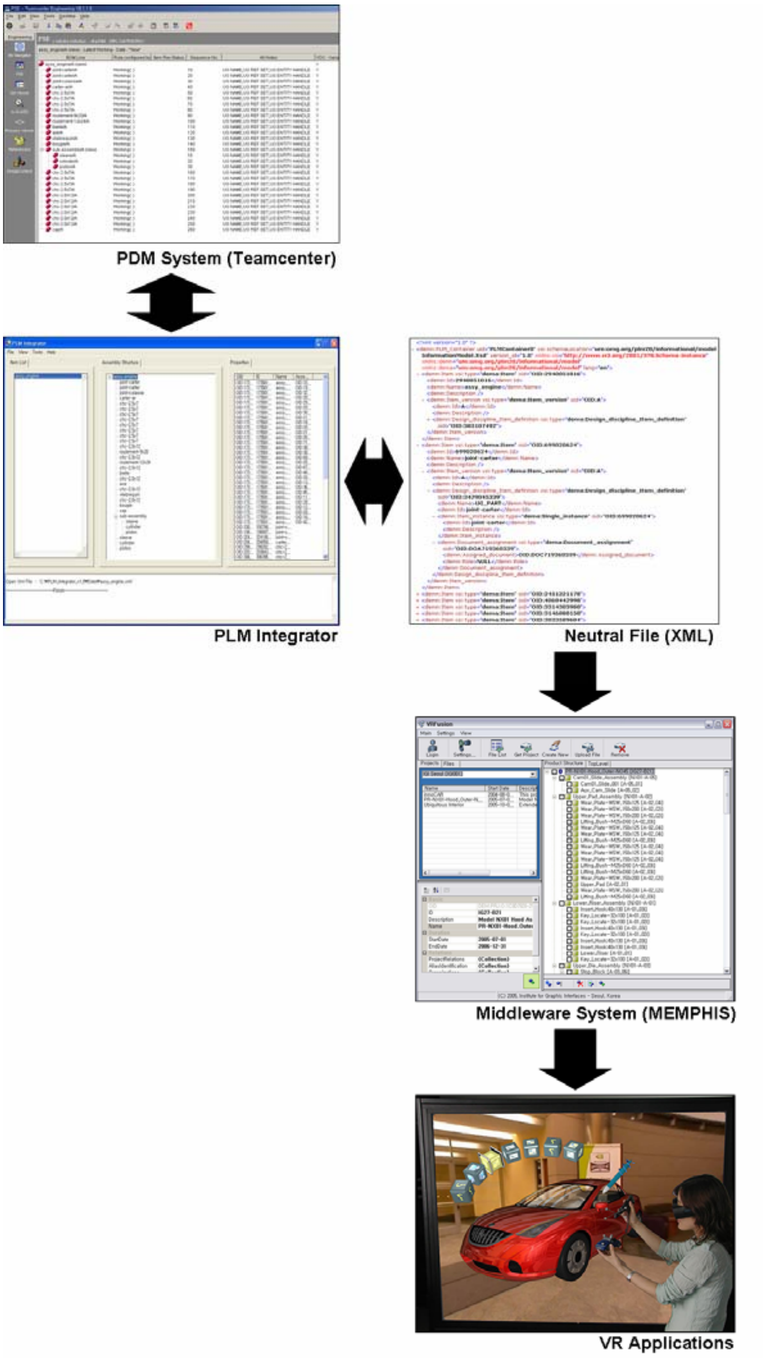


First we opened the neutral file that was generated from MEMPHIS. It contains much information of “Assy_engine” such as ID, Name, and Assembly relation. Next, we uploaded geometry files of “Assy_engine” to Teamcenter.

Also, we tried to download from Teamcenter. First, we downloaded the list of root item from Teamcenter using PLM Integrator. The neutral file was generated automatically and geometry files of “Assy_engine” were downloaded from Teamcenter.

<Fig. 11> shows the work flow implemented in this paper. It includes Teamcenter as commercial PDM, neutral file, PLM Integrator and VR applications via MEMPHIS system.

Figure 11 Implementation of PLM Integrator



5 Conclusions

This paper focuses to achieve the integrate management of necessary information between various different PDM systems, by defining of the standard neutral file and implementations of the supporting system.

The neutral file was defined using XML refer to the data structures of PLM Services, and PLM Integrator was developed for efficient data exchanges between the application middle ware and the PDM system by using the neutral file.

The PLM Integrator developed in this paper provides many functions such as converting date of MEMPHIS, the application middle ware and Teamcenter, the commercial PDM to neutral file. So we can manage all product data which is generated from both Teamcenter and MEMPHIS.

These standard format and system can not only reduce unnecessary efforts for data exchanges between mixed systems but also make the environment which can share information in various systems easily. Finally, we can provide collaborative environment that is able to exchange various information for successful PLM.

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CADFORSIM: methodology and tools to integrate CAD and simulation

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Abstract: Actually design is often done without tacking into account the subsequent steps (simulation, manufacturing …). This implies several iterations to modify the Digital Mock Up. This paper presents a new methodology which allows to take into account the different steps. It introduces different categories of important parameters and tools in order to manage the information. It also manages the different actors which are implied into the development of a product.

Keyword: Methodology, parameters, rules, CAD, CAE

1 Introduction

Very few persons, especially from SME's are well trained to a good use of CAD systems. In fact, many designers don't use the actual power of CAD systems. The design is often done without taking into account the subsequent steps (simulation, manufacturing ...). This implies many iterations to modify the DMU (Digital Mock-Up). So it is very useful to describe rules (best practises ...) and methodologies as design guidelines and to guarantee the quality of the models. Some methods have been developed under the denomination of DFX (Design For X) i.e. (Design For Manufacturing), (Design For Assembly), (Design For Injection Molding) (Design For Recyclability). The goal is to introduce as soon as possible functional and process constraints. Simulation must now be integrated with CAD in the design process. The use of simulation tools brings important advantages: study of alternative solutions, product optimisation, reduction of the number of prototypes, verification of manufacturability, decreasing of delay and cost. If the use of simulation's tools is essential during the design process, the link between the different tools (design, integrated simulation and validation) will not be efficient if there is no methodology [9] to combine these different tools. SME's which will not be able to improve their use of CAD and simulation will probably disappear. This is one of the best ways to improve the products and to optimize them. The impact of the capability to understand best practices and methodologies is very important. You must remember that 80% of the costs are determined in the very first stages of the CAD/CAM process [16]. If you are able to get an adapted CAD model, it becomes possible to optimize the products in some clicks.

2 Background

Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are generally considered as separate domain. More and more research leads to integrate CAD and CAE together. This integration can be realized in several ways:

- adapting CAD results in order to used in CAE
- adapting CAE tools in order to accept CAD input
- integrating in the early stage of the design the constraints which are linked to the CAE and to the inherent trade.

The two first approaches consider separately CAD and CAE and work on communication or exchange between both of them. This is the actual state of the art, in small, but also big firms. The third approach focuses on the synergy between CAD and CAE, for example the integration of CAE constraint in the design stage. This approach seems to us the most promising. A brief survey of literature shows that:

[1] suggest a global view of CAD and FEA separately before integrating and implementing the both together. It supplies some recommendations to realise this integration.

[2] purposes to access to CAD geometry using different techniques in order to repair the model. This intervention takes place at the end of CAD process before the meshing process. It will be better to prevent the designer when some mistakes occur.

[3] based his simplification to different mechanical properties and simulation objectives. Never the simplification will be predict in the early stage of the design. Integration of CAE into design process continues to be awkward.

[4] purpose a better use of Product Data Management tools (PDM) in the CAE environment.

[5] purpose a global view of the process but no refinement with the tools are presented.

[6] developed a simulation-based design component to manage different interaction between CAD and CAE tools.

[7] purpose the use and reused of knowledge using example, instructional case and rule but there is no link with the CAD model to identify which rules is adapted to the case which are studying.

[8] purpose to manipulate a master model which contains information for CAD and CAE in order to idealize the model. The researches are interesting but the examples implemented stay on basic shape. The optimization process is always based on the same model: collect of design variable, cost function to be minimized and constraint that must be satisfied [5]. More often they are collected at the end of the design without thinking if it exist or not in the model and if the modification of the value does not lead to an incompatibility with another parameter or with a downstream stage of the project [4].

All these approaches consist in adding methods or tools in the “CAD CAE” process which become CAD – “linker” – CAE. This approach seems to be a bearing approach facing to the link problem, since the adaptation of the CAD model will lead to numerous iterations. Then, we purpose to deal with this problem in the early stage considering the set of constraint CAD CAE in the product lifecycle.

3 Integrating the simulation parameters in the design process

Our proposal is based on a hierarchical definition of the important parameters. If you consider a prime manufacturer / subcontractor relationship, there will be fours levels:

- functional parameters : they come from the manufacturer choices, even if a collaborative work with subcontractors can be processed ;
- simplification parameters : their role is to facilitate the idealization of the model to prepare meshing ;
- trade parameters : they come from the subcontractor to take into account its knowledge ;
- optimization parameters: they are important to try easily new solution in an iterative process

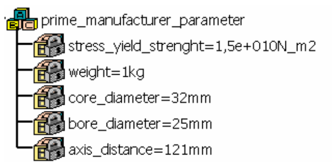
Two important tools are used to manage this hierarchical information:

- in order to link parameters, Graphonumerical parameters are used ;
- in order to apply knowledge, a rule based manager is implemented.

3.1 Functional parameters

At the beginning of the project, the prime manufacturers describe briefly his product using functional specification. The product can be a part from a product or several parts which are assemble. The product must respect some size, some weight. The material or some geometrical constraint like a diameter where an axis is assembling with the part can be imposing by the prime manufacturer. More often the prime manufacturer imposes to the subcontractor that the part respects some rate of constraint, some criterion in fatigue or a limited displacement. All the constraints described in the functional specification must be translating into parameters before starting the design. This is the parameters that the subcontractors must respect to realize the product. If the subcontractor modifies a prime manufacturer parameter to simplify the product, a collaborative scenario is automatically launched. Then the prime manufacturer and the subcontractors validate or not this modification using tools like videoconference, mail or chat… As we can see in the figure 1, the prime manufacturer needs a product which has three dimensional constraints that are two diameters and the axis distance. He imposes a weight that does not exceed 1kg and global stress admissible in the product must be less than 150MPa.

Figure 1 Functional parameters

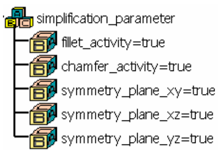


Once the constraints defined by the prime manufacturer are translate into parameter then the expert of simulation can describe his parameter which helps to simplify the part when integrated simulation is needed.

3.2 Simplification's parameters

During the first stage of development of the product, some iteration between CAD and CAE is needed in order to optimize the part or the product. To simplify the simulation's pre processing some details like small chamfers or small fillets can be excluded. These details impose thin meshing in order to have correct result which increases the calculation time. The result in this area is not interesting at this stage of the development. Only the expert of simulation knows which details can be excluded or not. Then he defines some parameters in the form of Boolean expression which can be linked to the different shape of the design. Well when an integrated simulation is needed to validate some choice the designer put the parameter to false before transferring the model to the expert of simulation. At this stage of the development the integrated simulation is only used to help the designer to correctly size the product or to validate some choice of design. At any time it is used to validate the product. Once the simplification parameters take place in the design of the product the subcontractor define his parameters which are needed to manufacture the product.

Figure 2 Ssimplification parameters



As we can see on the figure 2, the expert of simulation predicts to exclude details like the fillet, the chamfer. If the model is realized with different symmetry and if the pre processing permits to simplify the model, some parameters are created to anticipate the simplification.

3.3 Trade's parameters

At this time the subcontractors integrate his trade parameter. These parameters come from his know how or from the literature. For example the blacksmith must relieve some face of the part in order to facilitate his extraction from the tools. The value of the taper is dependant of the machine i.e. crank press hydraulic press or hammer press using to manufacture the product. It can be defined thanks to his knowledge or directly extract from abacus which characterize his trade. All his knowledge can be translated into parameters and linked to the product or part. Then, when a forming simulation is realized and analyzed, the designer can directly modify the parameters which improve the manufacturing process. Then he can optimize the process using to realize the product. If several subcontractors are involved in the project, several sub categories are creating according to the trade. As we can see on the figure 3, the blacksmith introduce in the early stage his trade parameters. The values of these parameters are initially tied and the designer modifies the value when he implements it.

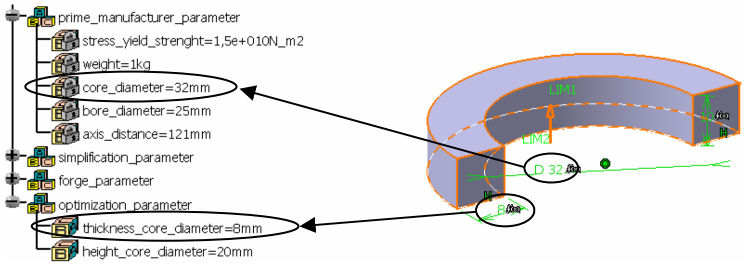
Figure 3 Trade parameter

All the actors which are involved in the project have defined their parameter. Then now the subcontractor can start the design of the product.

3.4 Optimization's parameters

Quite often the subcontractor must supply to the prime manufacturer information to prove that the product realized match to the reality before building any prototype. During the design stage some iteration between CAD and CAE tools are needed. That is why it is important to introduce in the early stage of the design parameters which can be modified in order to optimize the product likes thickness sheet metal for example. Then each shape that is realized by the designer during the global design process must be linked to parameters. These parameters are created during the design stage. This link is ensured by using graphonumerical parameters. Then, using integrated simulation and analyzing result often accordingly to an expert of simulation can lead the designer to modify the value of the different shape if it is necessary. If optimization tools are used the designer can directly get the value of his parameter and modify his model.
As we can see on the figure 4 the design of the model begins. The core diameter is created first. The designer links the core diameter with the different existing parameters. Then the value of the core diameter which is imposed by the prime manufacturer is directly linked to the matching parameter. The thickness and height which are let free by the prime manufacturer to the subcontractor are created and linked to the geometry. These parameters can be modified using integrated simulation in order to optimize the product.

Figure 4 Optimization parameter



All parameters are created in order to guaranty the reusability of the model by the different actors which are involved in the project. The parameters help the designer to simplify the model i.e. for the simulation stage. The quality of the model can be guarantied only if the optimization is global and not local. Then it is important to introduce some rules which can ensure that a modification of a parameter does not lead to generate difficulties to realize the tools for example. The next section presents some rules which can be introduce in the model to guaranty the quality of the model.

4 Rules

A base of trade rules contains all the capitalized rules. These rules are associative what means that each formalized rules must contain at the same time:

- the context of application of the rule
- the condition of processing of the rule [12]

These two items are accompanied by various remarks and diagrams which will make it possible to start the help files. The rules are rules of production [13] representing the constraints and their links. They are expressed in the beginning in natural language and must thus be translated in a specific formalism in the database. A production rule is like:

```
If (Conditions) Then (Conclusions)
```

The part *Conditions* is the process of the rules and the part *Conclusions* describes the actions to be started in the event of release [12].

In order to facilitate the link between CAD and CAE, above all for the integrated simulation, it is important to define some rules which allow the designer to guaranty some coherence in the model and facilitate the simulation pre processing. For example if the model is made up with surface, it makes the meshing process easier that each surface is made up with only four edges and if there is no overlapping between surface. Introducing these rules in the early stage of the development allow the designer to avoid some error which can occur in the downstream stage of the development of the product. The designer is prevented by message and purpose to him one or more scenario to resolve this problem. As we can see on figure 5a the two surfaces are adjacent. To simulate this product the prime manufacturer imposes the use of quad element. The bottom surface has four edges and can be meshed using quad but one side of the surface is thin. Then the meshing process will generate some quad elements that are too much distorted to interpret result on this element as seen on figure 5b. Then the designer is prevented by a message and has the possibility to consult a scenario to resolve the problem. Here the designer must assemble the two surfaces with a distance of confusion which is accepted by the simulation tools (Figure 6). We can see on the figure 7a and 7b the result of the solution.

Figure 5 a) surface with small edge b) distort mesh due to the small edge surface

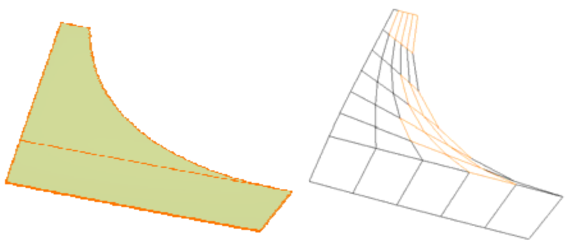


Figure 6 Message to prevent the designer and scenario to resolve the error

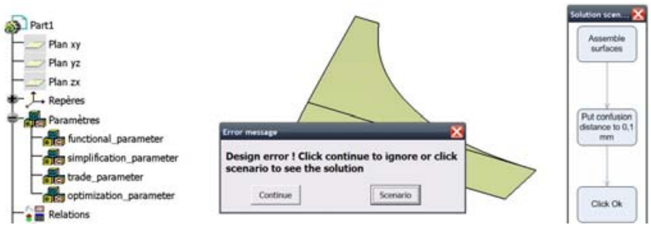
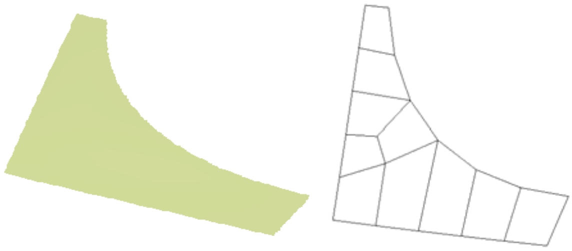
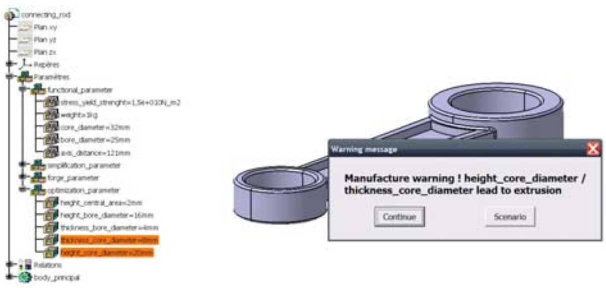


Figure 7 a) surface assemble b) no distorted element



Before beginning the design of a product, it is important to know which manufacturing proceed will be choose to fabricate the product. One or more manufacturing proceed can be chosen in the early stage of the project. A design of a part realized in forging is different for the same design realized in foundry. The values of draw or fillet for example are not the same. The tooling using to realize the product is totally different. During the first stage of the development a lot of iteration between CAD and CAE is needed and amount of modifications are realized according to the results of simulations. These modifications can lead to some shapes that are difficult to manufacture [15]. For example a part realized using rapid prototyping tools, if the ratio thickness / height are too important, the shape can be collapse during the manufacture. Then a modification of the design is needed. To anticipate this problem, some rules providing from manufacturing process, knowledge of expert or from literature is define. They are integrated in the beginning of the design in order to help the designer to take the better decision without generate some difficulties for the next stage of the project. These rules are linked to the different parameters. The designer is prevented in the same way as the design rule. The message gives information about the different parameters which are involved in the problem.

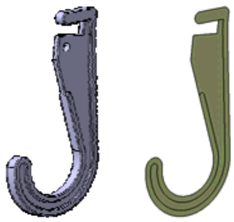
Figure 8 Manufacture problem in forge



A specific class of rules: idealization rules

The model used for the simulation can be different from the model used in the design. In order to reduce the calculation time the model used in simulation can be transformed. These transformations simplify the model, reduce the calculation time, but do not affect the result. These transformations must be integrated in the beginning of the project. Then to help the designer a simulation expert explains which modification can be made in order to idealize the part. For example a part which is wide and the thickness weak can be idealized like a shell [14]. If the ratio length to thickness increases a message must prevent the designer that the idealization could not be used with this design.

Figure 9 3D model idealized to shell for the simulation



All the modifications must be taken into account during the design proceed. All the parameters must be linked to simulation's rule using graphonumerical parameter in the early stage of the project. Then when the part is modified after analyzing result of integrated simulation, the idealize part is modify too. Then the designer does not start the idealization of the part from the scratch.

5 Graphonumerical expression

The notion of graphonumerical expression has been defined by [11]. As the author explains, "during the use of a geometrical modelling software, the operator always has to give values to parameters intervening in the construction of the model." Whether he knows the exact value and can apply it directly or he'd like to calculate the value thanks to external functions connected with the model as formulas for example. In the second case, the user is lead to give alphanumerical and geometrical parameters to the CAO system. The author defines the graphonumerical expressions which enable him to identify geometrical elements and to acquire alphanumerical values, thanks to an acquiring function. This method allows the users of the CAO system Nadrag to define graphonumerical expressions represented by sentences such as: create a circle tangent with two straight lines. It has also been used for the parametering of geometry in the set up of libraries of portable components and also for the running of techniques of predisplay in CAO thanks to structured dialogues.

This representation, close to the representation of conceptual dependence, enables the acquiring of the knowledge in its context. Parametric modelling put constraints on geometric model to design modification or to engineering analysis. Constraints can be geometrical one (at a tangent to) or knowledge one (trade rules, constraints). Our aim is to define collaborative parametric modelling. Thus, we define specific parameters called graphonumerical parameters (GPN). Functional design has to be represented by the vocabulary of the domain. This vocabulary is then used in the definition of trade rules, constraints and scenarios. The particularity of GPN is to link the vocabulary to knowledge and to geometry. Due to our CAD experience, we think that a designer would be able to define sentences like “create a circle, at a tangent to two secant lines”. But in current CAD system, due to the constructive approach of the design, a user has to be well trained to model a part. We propose GPN to constraint the model with knowledge and geometry. A CAD user has to give values to parameters. Either he knows the exact value and he can apply it directly or he wishes to calculate the value with external value which is relative to the CAD model. In the second case, the user has to give alphanumeric and geometric parameters to the CAD system. So the user defined a graphonumerical expression (GPE) which, thanks to an acquisition function, allows to identify geometric entities and to acquire alphanumeric value.

A GPE contains three classes of different terms. These terms are different according to the hierarchical environment. Here are the three classes with some examples of terms:

- action class (create, destroy, modify, consult, remove, apply, to radiate, …)
- object class (part, clearance, hole, rib, face, line, edge, point …)
- constraint class(at a tangent to, parallel to, symmetric to, diameter, mass, length, …)

A GPE is a *tuple* <action><object><constraint><object>… A user can define a GPE like “create_hole(through)(diameter)” which is the translation of “create a through hole with diameter” (a specific syntax has been developed for an intuitive use [10]). When a GPE is applied, the system constructs an implicit parameter which is the link between GPN and trade rules or constraints. For the precedent GPE, an implicit parameter called “diameter_hole” is created.

6 Conclusion

Using simulation is considered as essential during the design process. The use of simulation tools brings important advantages: study of alternative solutions, product optimisation, reduces number of prototype, assessment of manufacturability, decrease of delay and cost. Simulation must now be integrated into the design process. Several ways are realized to introduce it:

- adapting CAD results in order to used in CAE;
- adapting CAE tools in order to accept CAD input;
- integrating in the early stage of the design the constraints which are linked to the CAE and to the inherent trade.

The two first approaches consider separately CAD and CAE and work on communication or exchange between both of them. This is the actual state of the art, in small, but also big firms. The third approach focuses on the synergy between CAD and CAE, for example the integration of CAE constraint in the design stage. This approach seems to us the most promising. We consider a prime manufacturer / subcontractor relationship and we have identified four levels of important parameters: functional parameters, simplification parameters, trade parameters and optimization parameters. Two important tools are used to manage this important information: the graphonumerical expression and a rule based manager. The methodology is implemented and will be tested on industrial case during the P^{4}LM project.

Acknowledgment

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CO-ENV project: collaborative environments and agile product development for modular and configurable products

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Abstract: The extended enterprise concept proposes a new way to approach the product development organization. The methodologies and tools for knowledge sharing and for collaborating in real time along the supply-chain have to be evermore improved and they have to be customized in the specific applicative fields. The CO-ENV research project, that is funded by the Economic Development Italian Minister (2007-2009), moves in this context. The aim is the study of methodologies and the development of dedicated software tools usable in heterogeneous groups of companies to realize the *dynamic collaboration*. The research will be dedicated to modular and configurable products according to the required paradigm of mass customization. The paper will be focused on a deeper description of the project, of its main objectives and of the preliminary studies related to the process model for the dynamic collaboration.

Keyword: Dynamic Collaboration, Collaborative PLM, Modular Products

1 Introduction

The collaboration between companies can be divided in supply-chain collaboration and in design chain collaboration. In the first case, the companies' leader pilots the whole process, exchanging only the strictly necessary information with the partners. In the second case, companies participating in a design chain collaborate by sharing of product and process data and by integrating their engineering applications. Design chain collaboration is a more complex challenge than supply chain collaboration [1]. The product information is very complex as it includes CAD data, design drawings, product structure and configuration data, product and part versions, manufacturing processes, engineering and business processes: all exchanged data is not enough structured and dynamically changes as the design evolves. This information may be changed in a specific manner as product design process may require new activities, new participants and re-routing of information flows. The process integration needs to be flexible, accommodating to new situations and requirements caused by collaborating partners that may be joining or quitting the alliance. The work is deployed in a very heterogeneous computer environment, as collaborating partners normally use different CAD, CAE, PDM/PLM and ERP systems Hence, we can affirm that the dynamic nature of collaboration alliances needs of a wider and efficient integration.

The CO-ENV research project, funded by the Economic Development Italian Minister (budget around 10M€, 2007-2009), moves in this context. The aim is the study of methodologies and the development of dedicated software tools to realize the *dynamic collaboration*. It involves 21 Italian companies (5 big companies and 16 small and medium sized enterprises), including Indesit Company, Biesse Group, Elica Group, Teuco-Guzzini, that belong to three different industrial districts, mechanic, furniture and wellness products, and it is coordinated by the Department of Mechanics of the Polytechnic University of Marche. The project partners are classifiable into three parallel design chains that, instead of the different typologies of manufactured products, have similar product lifecycle development processes: from the ideation and design, to manufacturing and global marketing processes. The homogeneity and complementarities of the research group constitute the right condition for starting-up the research and experimentation of innovative Information Technologies (IT) for implementing concepts such as co-design, agile product development, concurrent engineering, modularity and rapid product variants configuration. The research program, firstly, is focused on the study and definition of theoretical models to organize and concretize the dynamic collaboration, secondly, it will involve the design and development of suitable system architectures for supporting the collaboration and the implementation of dedicated web-based software tools for knowledge sharing, co-designing, technical and marketing product configuring and, finally, workflow managing. The practical experimentation of the prototypal systems will validate the process models and the developed technologies. Various commercial Product Lifecycle/Data Management (PLM/PDM) solutions will constitute the basic platforms to develop the dedicated tools for the specific tasks of the CO-ENV project.

The present paper is focused on a wider description of the project, of its main objectives and of the preliminary studies related to the functionalities required to the process model for the dynamic collaboration.

2 Collaborative design environments and agile product design

The main project research area involves the study of agile methodologies and the development of the related technologies to support the dynamic collaborative design and modular product configuration.

Designing is an activity that typically requires the cooperation of several multidisciplinary design teams, that consists of marketing, engineering, designing and production experts. They use various engineering tools such as CAD/CAE tools, simulation and optimization software, engineering databases, and knowledge-based systems. In this context Concurrent Engineering (CE) approaches aim to reduce project lead times by furthering a closer collaboration between the disciplines involved and facilitating the interaction between the different design tools and software. At any moment, individual members may be working on different versions of a design or viewing the design from various perspectives, at different levels of details [2]. However empirical researches in industrial design teams have shown that CE application has not completely eliminated the above mentioned problems [3]. Even in co-located teams, many critical situations involve clarifying the shared understanding of the task. Communication problems can emerge in the coordination of teams' members with multiple project expertise: the likelihood of misunderstandings tends to increase.

An investigation of distributed teams also revealed that some problems in teamwork can be linked to insufficient overlap in background knowledge and different use of terminology [4].

In order to meet these requirements, it is necessary to have efficient collaborative design environments supported by suitable technologies. These environments should not only automate individual tasks, but also enable individual members to communicate with each other, share information and knowledge, collaborate and coordinate their activities within the context of related design projects. The diverse technologies that support such collaboration are ideally integrated as virtual workspace systems. The collaboration platform is usually set up using and integrating existing underlying workflow and groupware technologies, and additional communication and collaboration tools. The aim of this arrangement is to meet the needs of all collaborators. Such requirements are usually expressed in terms of activities and their attributes, such as people who are executing those activities and components involved in the activities, etc. Our interest for the composition of the collaboration platform is focused on the process-centered view. The process engineering approach [5], assumes that sufficient a priori knowledge about the collaboration process is available to make it possible to model it. The collaboration process is defined in terms of its needs and participants, and this is translated into components of the collaboration platform. To settle the collaboration design problems many research works have been developed, Neale analyses models and frameworks in [6]. A Design Chain Collaboration Framework (DCCF) is proposed by Choi et al. [7]. The DCCF is composed of three reference models capturing the different views of design chain collaboration: design process reference model (DPRM), service component reference model (SCRM), and technology and standard reference model (TSRM). Using the proposed framework, design managers can integrate their design processes from the conceptual phase to the application development phase. Also systems dedicated to specific domains have been studied. For example Kong et al. [8] proposed an Internet-based collaboration system for a press-die design process for automobile manufacturers developed with CORBA, Java, Java3D and a relational database system. A similar system for the injection moulding industry has been proposed by the authors [9]. The system enables users to share design models and it organizes the product design phase on the basis of roles in the process. Furthermore, many commercial PLM systems face the collaborative problems (see www.cimdata.com), but the main open issue remains how to manage the unpredictable process variability and the non-mature data present in the early design phases [10]. Hence, the research efforts have to be dedicated to formalize and manage the non-deterministic processes typical of a dynamic design environment, where partners rapidly change and unexpected situations appear. The emerging *Agile* concept can support the problem solution.

An accurate and comprehensive definition of *Agility* is reported in Preiss et al. [11], it is considered as a new way of thinking the company processes, including design and manufacturing, to give a rapid and flexible response to uncertain and unpredictable changes in the market. It requires collaboration, integration of customers in the product development chain, knowledge reuse and, mainly, the capacity of rapid reconfiguration of products and processes [12]. Our attention is focused on the design processes. The product design activity can be defined as the transformation of explicit and tacit customer requirements in technical solutions. As cited above, when products are complex this transformation needs of multidisciplinary competences. In this case, for maintaining a short time to market, Concurrent Engineering (CE) methods can be applied. But along the product design development many unpredicted events can occur, i.e. the late modification of the customer requirements or the excessive cost of a specific design solution. When the event appears the impact has to be immediately evaluated and the product design process has to be rapidly reconfigured minimising the propagation of the consequences [13]. The concurrent design process can fail when an unexpected change is required; in fact the time penalty is accumulated totally by the affected single team. The difference between agile and concurrent approaches is the responsiveness to the unpredicted changes. The agile design approach implies the definition and classification of the unexpected events, an example is given in Ye [14], for architecting a structure of rules and task management tools able to assign the problem to the right resources without influencing the final time to market. The collaboration design systems cited above have to be integrated with dynamic workflow management systems in order to organise the responsiveness and to monitor the single design teams. On the other hand the approach can be successfully applied if products are redesigned in terms of modularity and configurability. Modular products result in flexible designs, which enable a company to respond to the changing markets and technologies by rapidly and inexpensively creating product variants derived from different combinations of the existing or new modules. The preliminary determination of the product architecture, in this case, facilitates the task assignment and also reduces the number of possible unexpected events. Product modularity has a strong relationship with the modularity of processes and resources [15].

3 CO-ENV project objectives and structure

The CO-ENV research project aims to develop a prototypal hardware and software platform to support the integration and collaboration of the 21 industrial partners in order to create a dynamic design chain. They are divided into three different supply-chains that belong to three different industrial districts: mechanic, furniture and wellness products. The goal of the project is to allow all partners to configure themselves in the market as a single distributed enterprise able to apply agile principles to their design processes. This objective involves the study and development of IT systems for implementation of collaborative designing, for the coordination of all design activities and for the improvement of communication. Despite the diversity of the manufactured products, the CO-ENV partners have similar industrial processes: from conceptual design to engineering design, from manufacturing and to marketing. Furthermore, they are interested into the development of modular and configurable products that helps the realization of the agile principles. These conditions allow the creation of a complete and complementary group to test innovative IT technologies.

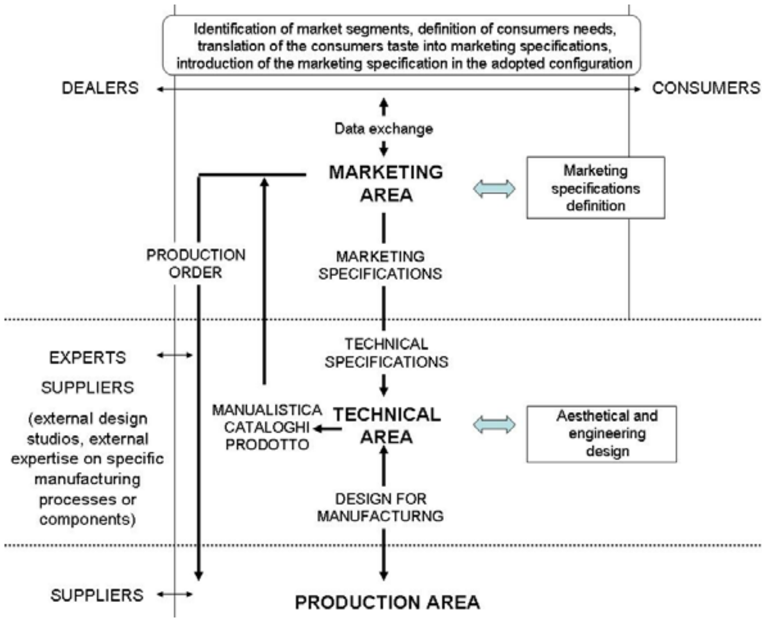
3.1 Industrial context

The design of new products involves the integration of different technological domains: the design chain is branched all over the partners and the management of complexity is imperative.

From a preliminary study of the design processes adopted by each design chain it is worth to notice that all partners have similar models of design development (figure 1): the marketing area collects technical, functional and aesthetic requirements from the analysis of the market needs, translates them first into marketing specifications and then into technical specifications that must be elaborated by the designers and the technical staff in order to realize a new product to completely satisfy them. In this context the normative standards constitute an additional requirement that must be taken into consideration. The design for manufacturing is the main objective of the technical area that strictly collaborates respectively with the engineering, manufacturing areas and the supply-chain in order to completely define and detail the design of the product. Design iterations result from communication problems and from the difficulty to achieve a compromise between form and function, between technical and productive aspects, between costs and product quality, etc. As a consequence of the complexity of the design process, time frame for the development of the product design unpredictably varies and time to market stretches.

Causes of design iterations are related to the difficulties to translate market requirements into an aesthetic shape that can be easily engineered and manufactured, to predict costs and time both in the marketing phase and after, during the supply of services and product components, to manage the interaction between the technical area and the supply-chain, to avoid errors in the fabrication by previously simulating manufacturing and assembly operations, etc.

Figure 1 The current model of design process adopted by each design chain



3.2 Project objectives

The CO-ENV project aims to introduce innovations and improve the processes of conceptual and engineering design, and partly of manufacturing and marketing of new products, by creating an efficient inter-companies (horizontally) and intra-companies (vertically) aggregation. The result consists into the concretisation of a dynamic extended enterprise. In order to be competitive in the global market by rapidly answering to the ever-changing consumers needs, companies should be never again conceived as a scene for individuals interaction but as a system of collective knowledge. Nowadays, new digital technologies play an important role in the formalization and codification of this collective knowledge that is often dispersed into a multitude of individual minds that are involved in the design process.

In this context, the research program plans the study and the implementation of new ICT platforms and related web-based software tools in order:

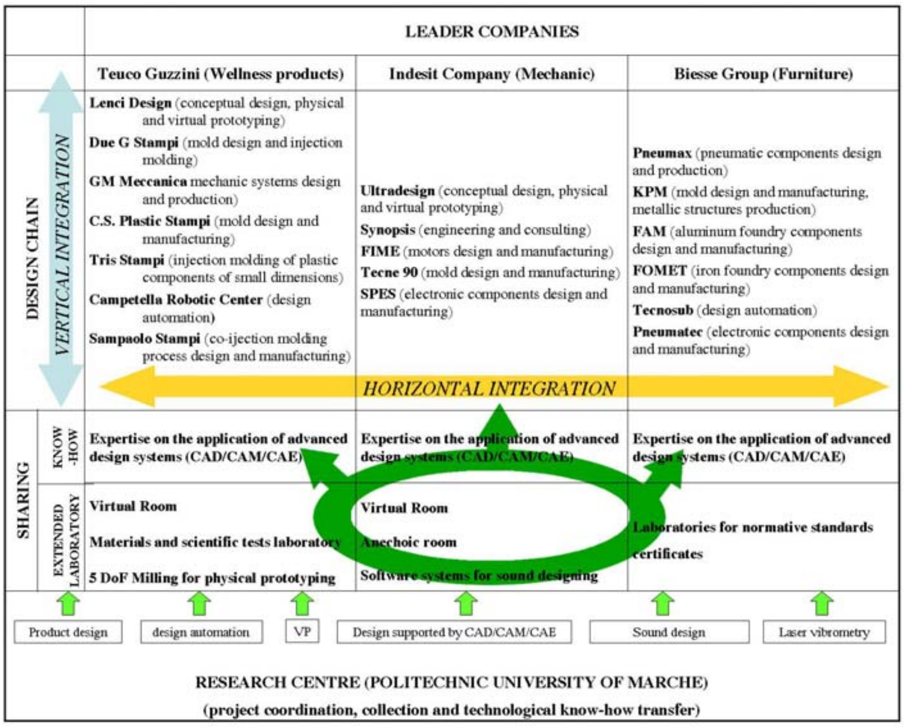
- to dynamically support the collaborative designing of new product by using dedicated systems for data management, data sharing and exchanging among the design chain. As a consequence, the chain will configure itself as the design problem space changes. Furthermore, real time interaction will be provided. The web-based platforms will be integrated by software applications for specific design activities and for the sharing of software tools in remote way (i.e CAE tools).
- to manage both inter-chain and intra-chain processes (ideation, forecasting of the product price, preliminary and detailed design, manufacturing activities, the interaction with the supply-chain, with the consumers, with the dealers, etc.) by adopting *Workflow Management* systems;
- to manage and share the design, the process and the product data across the whole design chain by *Collaborative Product* and *Process Lifecycle Management* systems;
- to improve the interaction between the different actors of the design chain with different insights, tacit knowledge and expertise and to create a dynamic collaboration between all project partners by the CO-ENV web-portal. The sharing of know-how, of expertises, of technical laboratories and of special equipments, the creation of e_learning environments, the remote use of advanced software systems constitute the main functionalities of this web-portal. Furthermore, it will contribute to realize a synergy between all companies in out-sourcing and in marketing logistics;
- to get closed the marketing area and with all company's departments by developing CAD-based tools to rapidly configure product variants as the customers requirements change. These tools will use data and models created in the technical and manufacturing areas. The automatic configuration will be allowed only if modularity concepts will be implemented into the design practice. These systems may constitute a step forward the formalization of the design knowledge. As a consequence interaction time speeds-up.
- to semi-automatically develop and design modular products on the specific customers needs by implementing CAD-based systems for the technical product configuration. The introduction of *mass customisation* principles will help companies to regain a slice of the market that was won by the emergent countries in the last years;
- to support the forecasting of the product price by knowledge-based tools that retrieve data from design documents, preliminary design models, 2D drawings, CAD models, etc.;
- to work in close contact with the suppliers and customers that are not directly involve in the research program by the CO-ENV web-portal;
- to organize and manage e_learning environments for the project partners.

3.3 Project structure and research areas

In order to achieve the above mentioned tasks, particularly those related to process and product management, nowadays, several commercial Product Lifecycle/Data Management (PLM/PDM) solutions are available. They constitute the starting point for our research. Actually, their use into a few industrial partners has highlighted the necessary of an improvement in order to be more efficient in accord with the expressed companies requirements. The implementation of these systems needs of the following: study and re-design of the industrial processes of each design chain, substantial customisation of the basic functionalities and development of additional ones in order to answer to the project partners necessities, integration of new software tools, that will be developed during the three years research program, and finally, definition and implementation of the platforms architectures to benefit of all used and developed software (creation of specific web-portals).

On the basis of these general considerations, the project, that lasts 36 months, will be organized into a preliminary phase where process analysis methodologies will be studied, ideal processes will be modelled in order to better manage the co-design intra and inter-chain, and the outlined models will be applied to the specific process of the project partners, into a second phase where the platforms architectures to support the process management will be conceived and the innovative software tools will be developed, and finally into a third phase where the developed technologies will be experimented and validated. All developed solutions will be organized into two different levels: inter-chain and intra chain levels (figure 2).

Figure 2 Inter-chain and intra-chain structure



The first one aims to achieve both the horizontal integration of the three chains through the creation the CO-ENV web-portal for the *e_collaboration* and the dynamic collaboration of all companies for the development of new products. The second one for the vertical integration of all actors of the design process (from the consumers to the suppliers), will be concretized by the creation of a shared, virtual and collaborative environment that will be web-based.

3.4 Functionalities of the dynamic collaborative model

Processes can be classified as either deterministic or non-deterministic. In a deterministic process, the steps within the process are well defined, thus the process can be modelled with workflow methodologies, and is referred to as a workflow process. In non-deterministic processes, not all steps can be planned ahead. Processes of this type are not well supported by workflow technology, which requires entire processes to be defined in advance. Instead, such collaboration processes need a greater degree of flexibility.

While workflow processes have received much attention in the literature, and are supported by a number of modelling methods, few techniques exist for modelling partially planned collaboration processes. Such processes are common in knowledge-intensive activities such as mechanical and styling product design, and usually follow only general process structures, with details of the process emerging during execution. The rapid negotiation between partners for choosing the better design chain combination is the basic task. The complexity of the design network and the remoteness of individuals participating make it extremely important to be provided with the necessary tools able to manage rapid input and output of discussions. Flexible negotiation protocols are required.

The aim of the CO-ENV project is the development of a web-based environment that will be able both to manage negotiation between conflicting interests in the first phase of workflow design and to manage unpredictable events when they occur in the same workflow when it is in progress. The main problems in the developing dynamic collaboration system are to conceive proper design and negotiation models and to find the way to adapt these models to the specific context of each project partner.

Several functionalities will be implemented within commercial Project Management software that also integrates Workflow Management functionalities in order to achieve the above mentioned tasks.

The first step in the development of the dynamic collaborative model is the definition of functionalities and the conceiving of its architecture:

1) in order to realize a flexible non deterministic workflow, all candidates partners will be invited in the web-based environment by a promoting actor to design a specific workflow for achieving a specific objective.

   The proponent (project leader) selects a predefined workflow (for example the design of a new product or the negotiation process). In order to be customized to the specific task of the project leader, the selected workflow is abstract and generic. Then he/she defines the constraints as time, human resources, costs, etc. in order to manage the negotiation between the invited partners and the qualification of the invited companies and their role in the workflow process. Once identified the type of the process to be performed, the roles of the participants and the constraints, the negotiation can start in order to detail the selected workflow. The system automatically sends an e-mail to the invited partners that answer to the proponent requirements. All partners that answer to the project leader's call, are involved in the negotiation phase: they have to simultaneously design the predefined workflow by choosing the specific activities, by defining their duration, the equipment resources and the number of human resources to perform them, etc. The constraints and rules previously defined by the proponent guarantee the coherence of the decision-making.

Once the workflow has been defined, all partners will carry out the activities in order to achieve the task;

2) a library of unpredictable events that can occur when a specific activity fails has to be defined. A classification of events is imperative. For each event the library contains a set of workflow alternatives.

   Once an activity crashes the system automatically identifies the events that cause it, estimates the state of the process in term of time and costs and retrieves the possible alternative activities to restore the workflow and the necessary resources. The result is a set of alternative variations of the previous defined workflow. For each alternative, the system is able to describe the consequences of the choice. The proponent must rapidly analyse the best solution for his/her objectives and he/she selects the new workflow path. The necessary condition for the generation of the new workflow is the definition of criteria for the damage estimate and for the retrieval of the suitable solutions in accord with the emergent event.

This system can be used both for horizontal collaboration, in order to manage new design processes that can involve partners of different chains and for vertical collaboration, in place of commercial Workflow Management software that can be used only for deterministic processes.

4 Future work

In this paper we described the context and the challenges of the CO-ENV research project. In particular we reported a preliminary study of the functionalities for managing the collaborative dynamic design environments when agile responses, intended as responses to unpredictable changes, are required. Although there has been a great deal of work towards developing collaborative environments, they have to be improved and extended in terms of functionalities especially to provide a more refined model for remote integration, working on communication, collaboration, and coordination. The main research areas that will be subjected to a deep study for the achievement of the results are as follows. First of all a much better and well conceptualized understanding of cooperative work and its complexity is required. In order to be able to provide systems for communicating, monitoring, articulating activities, etc. with respect to the industrial domain we state that understand how the field of work is conceptualized and how the applied models evolve over time and during work, plays a crucial role. A second overall problem has to do with flexibility. Since cooperative work cannot be prescribed to the level of detail that computer-based systems require, we have to establish basic building blocks and platforms. The outstanding problems concern with the determination of which building blocks should be provided, of how to ensure a high degree of flexibility and how to semantically connect building blocks with the cooperation and coordination activities. The third problem is to establish a relation between process and product to map the modularity and the involved actors. The immediate future work will be focused on the more detailed conceptualisation of models and architectures to manage dynamic processes. The long-term results validation will imply the implementation of dedicated frameworks and tools, their experimentation and the empirical evaluation of performances. The deficiency in sound empirical methods for determining outcomes has been one of the leading causes for the lack of collaborative environments success.

Acknowledgments

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Chapter 6

Interoperability

Linking product architecture and network of partners

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Abstract: Conducting locally and globally a network of partners is a hard task for every actor and especially for the company that initiates a product development project which necessitates close collaboration of partners. Some of these difficulties concern the run of the partners' network while others are associated with the run of the project itself and finally others are related to the information asymmetry between various partners (see Arend in [1]). Managers have to cope with them all. But, generally when a difficulty appears it is sourced somewhere else upstream in the process. We focus our study on one of these potential sources which is the product architecture. The idea is to use the product architecture and technical data, even incomplete, to identify the architecture of the network of partners as early as possible during the product development project. It allows clever negotiations and better definition of product & data exchanges protocols between future partners, aiming both at supporting the best the global product development project.

Keyword: Partners network, product architecture, product design.

1 Summary

The product architecture refers mainly to the way that various product functions are associated to its structure. It refers to the layout, configuration of what Ullrich in [2] calls chunk. When the product designers choose the architecture of a product, obviously it should be the *most* relevant one to the goals of the company in terms of innovation and profitability. This relevancy can be expressed by the following idea: the product has to be innovative, feasible, profitable and has to provide a sustainable advantage regarding the competitors. Nevertheless, almost all companies need to co-work with others in order to be able to put on the market that innovative product on time and under good conditions. Although Arend in [1] shows that when there is a control share between partners the efficiency may decrease. This means that to reach a minimum rate of efficiency, the network of partners should become manageable rapidly by consuming as little efforts and money as possible. Jiao underlines that "While seeking technical solutions is the major concern in design, it is at the production stage that product costs are actually committed and product quality and lead times are determined *per se*" [3]. We use this idea arguing that it is possible to control better the costs (time and money) of product's production if the product and the network of partners are designed at the same time and in harmony with their mutual constraints.

Design-for-manufacturing is a known research field (see [2] for instance), which looks for easing the manufacturing of product but less efforts are concentrated on what we call *Design-for-Control*. Talking about *control* refers to two dimensions of management: 1) management of the network of partners which will participate to the design and manufacturing of the product and 2) management of the considered firm. The subject of this paper is to answer one of the arisen questions: how does the product architecture allow the definition of the network architecture and *vice versa*? The network architecture, once simplified by taking into account the coupling between the product's components [2,4], can be used to define performance indicators for collaboration efficiency.

The paper is structured as follows. After a brief state-of-the-art, we propose a formalism, called routed-architecture which allows to define the architecture of the product by focusing on partners' implication. From this routed-architecture, we extract the structure of the network of partners by identifying the junction points and synchronization situations. These formalisms are the first elements that any collaborative project manager may use in order to determine the characteristics of the network of partners they have to set up. Somehow, these formalisms will provide necessary data to determine roughly how the network should be. These ideas are then illustrated through an example taken from the car industry. The results are discussed after and we finish the paper by reviewing the major results and by putting emphasis on what should be improved in the very near future.

2 Related works

Ullrich and Eppinger in [2] define the product architecture as follows: “The architecture of a product is the scheme by which the functional elements of the product are arranged into physical chunks (physical building blocks of a product) and by which the chunks interact.”

The concept of architecture in the literature refers mainly to the modularity even if it may be integral or modular, see Fixson in [4]. However, the study we propose here does not look for the reason why a product (family) architecture is modular or integral. Fixson in his paper classifies the methods which allow to capture the architecture of products into three classes: a) mathematical models which look for solving design described as an optimization problem, b) conceptual model which study the product design from the modularity point of view and the description of the detailed components, and c) engineering models which provide indices to compare product architecture along the dimensions of interest. He defines also a bi-dimensional method to assess the architecture of a product: the function-component allocation scheme and the interface characteristics. Fixson does not consider the way that these assessment dimensions help network designers to improve or to modify the architecture of a product. According to his classification, the approach we defined in this paper is an engineering model because it focuses on the network of design partners.

Jiao et *al*. in [3] gives an intensive survey of methods for product family design. They use a framework defined by Suh in [5] which defines the design domains: customer, functional, physical, process and logistics. In this survey various aspects of these 5 domains are looked. For the logistics, Jiao noticed that mainly the research related to the logistics concerns: supply chain configuration, resource allocation, supplier management and supply contracting. The aspects related to the design of the network studied by our side are not mentioned in this work and seem to be focused rarely in the works reported by Jiao et *al*.

This state-of-the-art does not cover patently all the existing works related to the product architecture, but according to our research, rarely these works focus on the relationships we are working on.

3 Preliminary concepts

In this section, we define a first set of concepts necessary to establish the connection between the product's architecture and that one of the network of partners.

3.1 Collaborative project life cycle

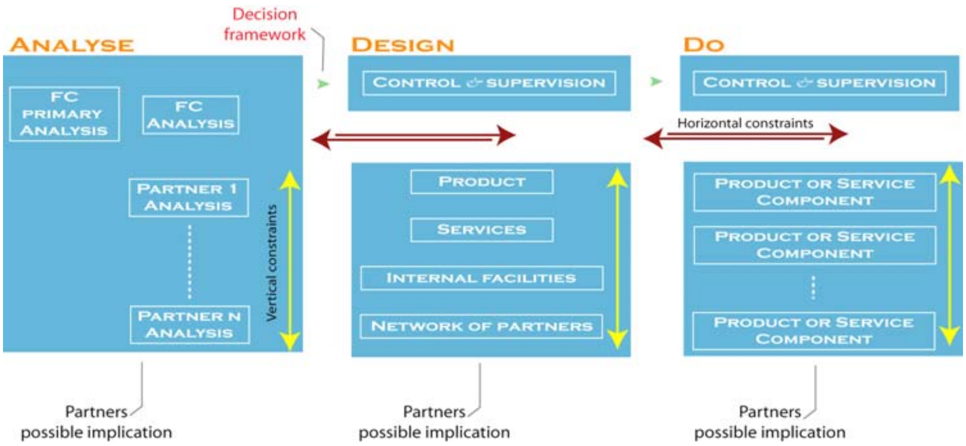
A project performed by a network of partners in collaboration with a target company, let say $\mathfrak{N}$, is called here a collaborative project. This is a collaborative project development project [2]. We subdivide then any collaborative project life cycle into three main phases: *Analysis*, *Design* and *Do*. Figure.1 shows this abstract life cycle. Readers should keep in mind that these phases have complex overlaps during the time, but this point is not discussed hereafter.

During the analysis phase, from the company $\mathfrak{N}$'s point of view, the goal is first to ensure its business objectives by putting on the market a product, radically innovative or not (see [6]). Therefore, the company $\mathfrak{N}$ managers have to answer several questions and especially an important one formulated by *"go/ no go"*. This answer defines future actions of the company. But, this analysis cannot be done without consideration of the business goals and constraints of the partners. Then the question of partners should be posed from the very early steps of the collaboration. In fact, the viability of the collaborative project initiated by $\mathfrak{N}$ depends hardly to the network parameters that can become either powerful trumps or high obstacles. This is the reason why the analysis phase is divided into two steps: *internal* analysis and *trade-off* analysis. The trade-off analysis is performed while several contacts have been established with the most important potential partners of the project *i.e.* the inescapable partners.

The design phase corresponds to four parallel design processes: *S*ervice design, *P*roduct design, *I*nternal facilities and organization design, *N*etwork of partners design. These processes are referred to by the SPIN model. These processes (re-)design all the necessary elements of the collaborative project. Each of them, obviously, has to be controlled by a specific control and supervision sub-system. These latter sub-systems are in charge of the control of the execution of various activities of the SPIN processes and obviously, they work dependently and are coupled together.

Finally, when all these necessary elements are designed or re-designed, the preparation of the product and its associated services can begin. This is the do phase. These manufacturing and preparation are also done by a sub-system, controlled by the manufacturing management sub-system. This latter sub-system is largely studied in the manufacturing management field especially when the production is focused on physical products.

Figure 1 Co-working project simplified life cycle



This global framework allows a clear positioning of previous works: Concurrent engineering which studies the relationship between product and internal facilities and organization, or 3-dimensional concurrent engineering defined by Fine [5] which considers product, processes and network simultaneously.

3.2 Relationships with partners

Two main objectives can be followed when one thinks about the design of the network of partners: the architecture of the network and networking. The architecture of the network is defined by the junction of external actors to the process or to the tree of the engineering and manufacturing BOM, Figure.2. These junction points play an important role not only during the network design but also during the networking (*i.e*. when the network works).

It is possible to associate with every junction point at most two *synchronization situations*. This concept focuses mostly on all those actions necessary to transfer items and associated data to sub-contractors and suppliers or to receive items and associated data from them. Based on the direction of the item/data exchange, two synchronization situation classes are distinguished: emission and reception.

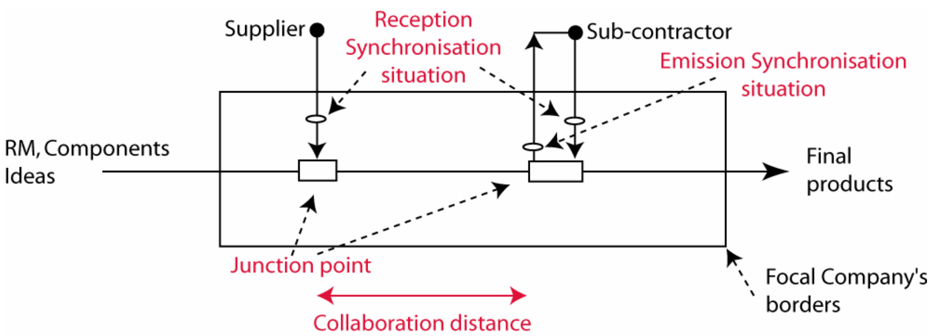
The *emission synchronization situation* consists on preparation of data and/or items in accordance to an implicit or explicit contract, for at least one external actor. For a sub-contractor this preparation means that the items that are to be treated are gathered into transfer batches, an official transfer document is associated with them, their quantity is known, the departure date, the transfer and treatment durations are also known.

The *reception synchronization situation* refers to a similar activity. The focal company has to perform an activity which consists on a preparation of a reception of items and/or data, controlling the quality and quantity of received items, and stocking them is specific areas/support. For physical items reception, it is nothing else than stocking procedures and for data (a CAD file for instance) it may represent a temporary stocking support before its control and integration within a global CAD file.

The identification of synchronization situation allows to determine the necessary co-ordination activities with partners based on the definition of the product. This information is quite interesting during the design phase of any collaborative project. In fact, this information is useful for several activities:

- Analysis phase. As important negotiations should be performed with potential partners in any collaborative project, knowing in advance the future potential complexity push managers to think of preventive actions against any project risks.
- Design phase of the product and the network. Knowing the synchronization situations is useful for control and supervision sub-systems. It allows some kind of "what-if" scenario definition.
- Do phase. The dynamic study of the synchronization situations can help operational effectiveness [6] of actions taken within the firms and especially at their interfaces with the studied company.

Figure 2 Junction points and synchronization situation



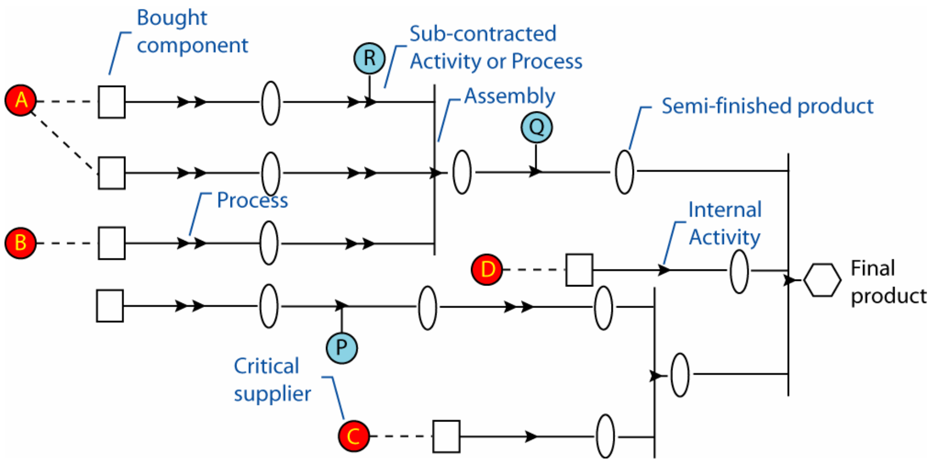
Hereafter, we will show that it is possible to extract a close-to-real network of partners from the architecture of the product.

4 Routed-architecture

First of all, readers must note that the formalism proposed here is focused on physical products. To define the physical structure of a product we use its bill-of-materials, even incomplete. The use of BOM allows users to see the connection between the company $\mathfrak{N}$ and a subset of its suppliers; in other words to determine some of the important junction points and synchronization situations. However, as it mentioned before, in our study we would like to identify the synchronization situations with sub-contractors too in order to determine the rest of the junction points of the co-working project within the firm. This information is available in the macro-routings of the product. Therefore, it is necessary to combine the BOM and the routings of a product. The idea of combining BOM and routings is not new. Jiao in [7] shows that this idea exists from the beginning of 80’s and proposes a generic modeling framework of the combined BOM and routings called BOMO. The formalism we propose here is quite similar to BOMO without the use of “kiting” activity. Anyway, the use of the routed-architecture is not enough to show the way that the suppliers and sub-contractors are connected together. To achieve the final goal of the performance indicators implementation within the network, we have to know the way that components of a product are coupled. This is a known concept and to take account of it we use the Design Matrix. However this point is not developed in this paper.

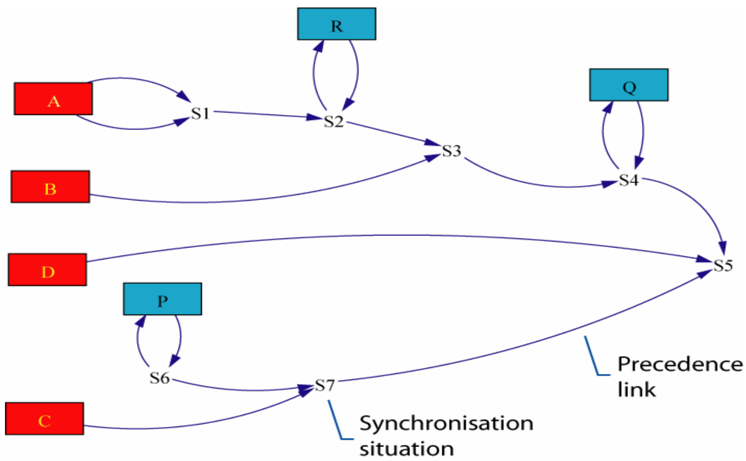
The Figure.3 resumes the proposed simple formalism, called the *routed-architecture*. The idea of the formalism is to represent technical data (routings and BOM) related to a product at the same time from a given point of view. This point of view means that the formalism is used based on a decision level to which the user belongs and the idea of *aggregation* [8] of data and models is present within the modeling approach. It is not necessary to show all the details of these technical data.

Figure 3 Illustration of the formalism to define a product's routed-architecture



This formalism can be used for the design of the network. Once the routed-architecture of a product is defined it is possible to extract from it the architecture of the network by highlighting junction points and associated synchronization situations necessary for the dynamic analysis of the network.

Figure 4 The synchronization graph extracted from the product's routed-architecture



The Figure.4 corresponds to the network of partners that can be extracted from the routed-architecture of the hypothetical product of the Figure.3. To do so, the analyst should analyze systematically the routed-architecture by using the following algorithm:

1. Associate every supplier or sub-contractor with an input node for the network of partners; for example the nodes A or B.

2. For every supplier, a junction point is identified on an activity (mainly assembly). Put an arc between the node representing that supplier and the junction point; for example the arc between the supplier-node B and the junction point S3.
3. For every sub-contractor, a junction point is identified too. Put two arcs between the node representing that sub-contractor and the junction point; for example the arc between the sub-contractor-node R and the junction point for example the node S2.
4. Associate with every junction point connected to a supplier, one reception synchronization situation.
5. Associate with every junction point connected to a sub-contractor, one reception synchronization situation and one emission synchronization situation; ex. R.
6. For all internal operations or activities inside the company, simplify them to one arc which goes from one junction point to another; for example the arc from S1 to S2.

5 Illustration

We should early underline that the example we developed here is taken from a *well-known* process and so the obtained routed-architecture can be as precise as necessary or desired. Our idea is to show the feasibility of the application of the formalism routed-architecture and the way that the network architecture can be extracted from it. Obviously, in the case of a nascent product, the routed-architecture would not be so complete, as complete as our example. Final remark before the example description is that even for an innovative product whose design is in-process and for which all decisions concerning the architecture are not already made, a set of partial technical data (BOM and routings) is available; even though, in real situations, often the product production processes and product architecture are known at least *partly* in advance and the innovation does concern a small percentage of the whole set of components.

Renault™ is one the major car makers in the World and participates to the training of students via dissemination of its industrial practices. The example used here is extracted from the training support documents that Renault™ provides freely to academics. This example shows the car assembly chain including the production of engines, transmission gears and brake discs. As the complete version of the assembly chain is too complex, we decided to simplify it by grouping several operations into one activity, *cf.* Figure.5. Besides, Renault™ does not mention any sub-contractor in this process. So, to illustrate our purposes, we 1) added deliberately two sub-contractors and 2) eliminated several suppliers. In Figure.5, the red boxes correspond to the suppliers.

The application of the algorithm described in §.4 to this routed-architecture provides the network of partners connected to the Renault™, *cf.* Figure.6. The rough architecture of such network is analyzed hereafter for the three phases of the co-working project.

6 Exploitation of the network architecture

To use the architecture of a network as an analysis tool for decision makers, we suppose three scenarios: the network architecture is defined during the analysis phase, design phase or do phase.

1. During the analysis phase. This is mainly the case of a nascent product and many decisions have to be made for the future phases. Studying both product and network

architectures, managers of the company $\mathfrak{N}$ identify the most important components or activities for which they need to look after partners on the market. Important negotiations should be then performed with these potential partners and it might be done based on the constraints coming from the position of the supplied component (from the suppliers) or activity (from the sub-contractors) within the global product and the network. Moreover, these negotiations should take into account the way according to which during the design and do phases partners should collaborate with their company. This means that networking parameters should be estimated before these possible collaborations. If the case concerns known products, modeling the existing technical data helps managers to identify improvements possibilities within the product architecture, functions, components or production process, based on the junction points and especially their associated synchronization situations.

2. During the design phase. In this situation, it might be considered that the preliminary analysis are already done and during this phase, the product, services and internal organization/facilities designers should receive information from the network of partners. Let us take an example. If the architecture shown in Figure.6 corresponds to the first version of the architecture, and if the network designers have enough information from the market to say that *based on the business strategic constraints no potential partner on the market seems to be able to participate to the junction point J7*, the product designers would modify their propositions and the product architecture. This corresponds to what was mentioned in §.3, "what-if" scenarios.
3. During the do phase. At the end of the design phase, when product and network architectures are ready, it is necessary to determine parameters of collaboration between the partners and $\mathfrak{N}$. Two major studies seem to be greatly useful based on the network architecture: i) a dynamic studies. In this case, it is important to define the protocols of exchanges during the synchronization situations, ii) a performance identifiers implementation for the networking. To provide a concrete element necessary for the networking management during the do phase, it is possible to set up conformity indicators within the process according to the existing coupling identified within the network. The concept of conformity indicators is already developed by authors.

7 Conclusions and perspectives

In this paper we presented a formalism which allows analysts to identify the architecture of the network of its partners based on decisions made about the product architecture. The use of this formalism is then illustrated on an industrial case taken from Renault™ car assembly process. The work presented here has been also put into the framework of the co-working projects. The concepts developed for the network of partners are the junction point and synchronization situations. The junction point is a concept useful for the definition of the network while synchronization situations are necessary for networking parameters definition.

In a very close future, two majors research axis will be pursued.

- *Conformity indicators*. One of the main aspects mentioned in this paper but not developed is related to the way that the network architecture and synchronization situations are used to define the conformity indicators. These indicators qualify the collaboration between partners and can be seen as the collaboration sensors that should be used by the control and supervision sub-system to manage the whole collaborative product development project.

- Components *coupling*. The coupling between the building blocks and the interfaces that should be developed between various components of a product influence directly the networking and specially the networking control and supervision strategies. In fact, before implementing any conformity indicators, using the network architecture, analysts have to determine whether yes or not two suppliers and or sub-contractors are directly or indirectly connected together.

Figure 5 The assembly line of Renault™, simplified and slightly modified

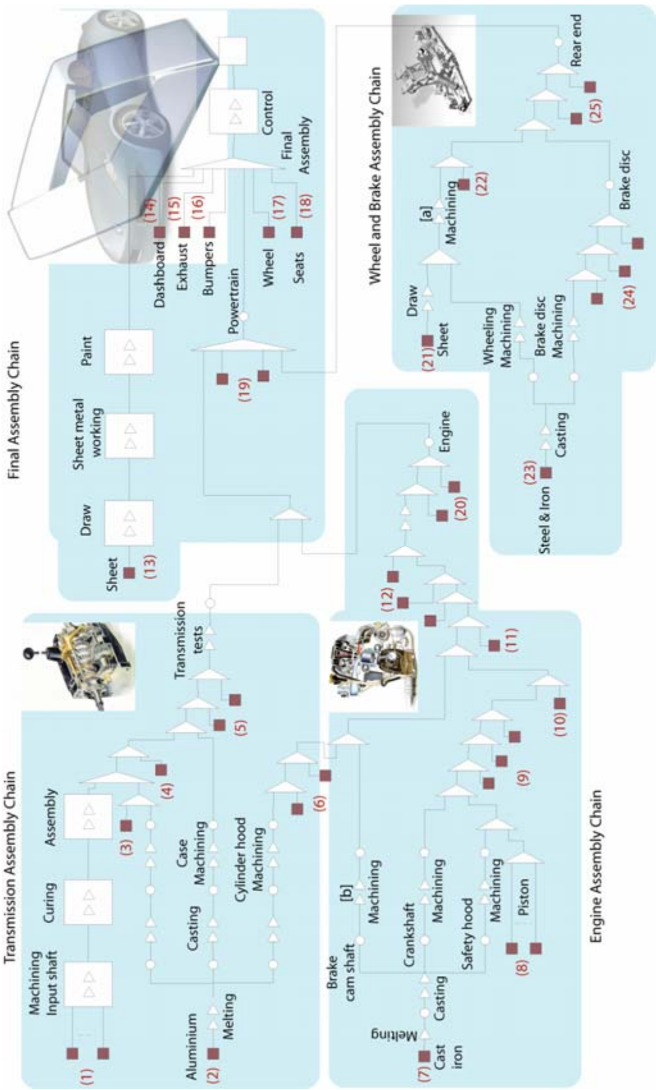
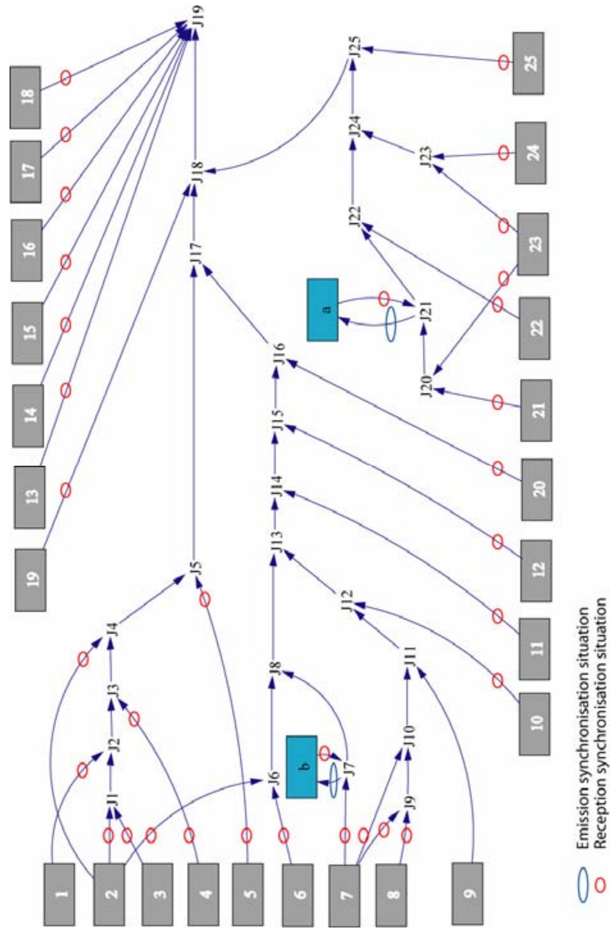


Figure 6 Architecture of the network of suppliers and sub-contractors



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An UML model of the technical information system to enable information handling and recording during the product life cycle

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Abstract: Information management systems play an essential role in the Product Lifecycle Management. Data and documents as well are edited in a digital form and have both to be coherent along the lifecycle. A document must be preserved through time for its use through space. Difficulties observed on various industrial fields in the use of digital documents and more particularly concerning the updating issue conduct us to propose an UML model addressing on one hand the requirements for records keeping and on the other one the needs for easier using and more efficient updating with feedback information captured in operation, maintenance and dismantling activities. This model could be generalized to take into account the various business requirements and needs along the product lifecycle.

Keyword: Maintenance, digital document, UML, information system model.

1 Introduction

Information management systems play an essential role in the Product Lifecycle Management. Information is usually edited in a digital form and there is a need of consistency for product data and documents along the complete lifecycle. Powerful collaborative edition systems are more and more used during design and construction. An efficient integration of operation and maintenance in the Lifecycle is another challenge, which needs new methods and new tools.

We consider this integration from a document point of view and we will propose a definition of the notion of document, which takes into account the digital document and the necessary convergence of data and documents.

Feedback from the field of various industries shows difficulties particularly for the updating and integration of new information during operation and dismantling.

We propose here a conceptual model with an UML representation, which aims at fulfilling the preservation requirements of the recordings and the needs for information handling to support activities of the lifecycle including information updating.

2 Product Lifecycle Management and Technical Information Management

Many authors have underlined the importance of information management in the concept of PLM. We can quote 2 papers of the previous PLM conference in Bangalore:

"… supporting PLM is akin to supporting a composition of information exchanges across time, space and multiple disciplines." [1]

"PLM is an integrated approach for the management of product data along the lifecycle." [2]

Operation, maintenance and dismantling represent the main part (about 80% in time for complex products or process plants) of a complete lifecycle. Integrated information management along the lifecycle has to face the boundaries between the design/construction phase, the operation/maintenance phase and the dismantling phase. The management of information across long periods of time with a reliable preservation and an efficient updating of product information is a real challenge.

Information produced during operation could be better used not only to improve operation and maintenance activities on a given product but also to improve design of new products.

3 Data and document: a unique information system

Many authors, among them B. Schilli et al. [3], make a distinction between structured information (Data) and so-called unstructured information (Documents). XML [4] is often considered as a standard of data exchange although XML is an adaptation of SGML [5] whose purpose was the streamlining of processes for the editing and publishing of documents [6].

Nevertheless, as indicated in [3], documents are often delivered on a paper form at the request of the customer or in a PDF[1] format if delivered in an electronic form.

But data and documents are not independent: data are often consulted within a document form populated by the data for an easier use and document, for instance maintenance procedures, have a mixed content of data on the equipment, the spare parts, the consumables. Corresponding data and documents bases have to be coherent.

Operation and maintenance operators normally have not and don't need to have the same powerful edition systems as in design or re-design phases, but there is a need for a better capturing and sharing of information produced in work situations to enrich or update the initial product digital information. Moreover, we have to take into account that technical information is more and more accessible through web interfaces and n-tier architectures.

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[1] PDF: Portable document format, often called "electronic paper" because it preserves the paper layout of the information. The updating possibilities of a PDF document are however limited.

All this information has to be processed and integrated in the technical information repository shared by the stakeholders.

We claim that the operators of complex products or facilities need more tools enabling the capture of whatever type of information, either geographical, or technical or environmental in order to improve their industrial performance and to fulfill their regulatory requirements thanks to the coherency of their own data and document bases.

This strategy can be profitable also for constructors and engineering companies for the design of new future more sustainable products or plants.

4 What is a digital document?

The difficulty to find a scientific definition of the notion of document has been underlined by many authors [7].

Researchers in the field of documentation or information retrieval can hardly define clear limits of what is a document and what is not a document. We can find information about these difficulties in [8] or [9].

Ranganathan, who had one of the greatest contribution in the field of “Library science” quoted by Buckland in [8], proposed his own definition in [10] of a document as

“ embodied microthought on paper or other material, fit for handling, transport across space and preservation through time.”

Digital documents have the following features:

- Low cumbersomeness,
- Speed of transport trough space,
- Reuse possibilities according to accessible structure level,
- Integration possibilities on the same support of visual and audio information.

Usually, the document is defined as a content on a support. The content is essentially symbolic, that means that it is made of signs belonging to a system ruled by conventions. Auroux, in [12], has shown the processes of normalization and formalization (What he calls a “grammatization” process) with the corresponding technological revolutions (writing, printing and now computing) which aim at enabling the automatic treatment of the symbolical content.

Normalization and formalization of the rules for documents editing precisely aim at computing of the document.

The digital document is not a specific document; he takes profit of new technologies and conventions, which allow a generalization of the concept of document to include new forms of documents like digital mock-ups or other new virtual agents. Before going further we propose our own definition of a document:

“A document is a technical object, result of an intentional inscription process, on a material support with a guarantee of stability through time, of coded representations, produced to be handled, processed and further interpreted by human beings.

This definition insists on 3 features of a document:

- A document is a set of coded representations not to be confused with the content of perceptions of the real technical system,
- A document must be stable through time: as a digital document is the product of many automatic transformations, these transformations have to be precise and stable by design,

- A document has the ability to be easily handled.

We consider the third feature as very important. A traditional book for instance has a format, pages, table of contents, indexes, enabling its external and internal handling. Glossaries, references are also material structures supporting the process of interpretation of a document by the reader.

Strict requirements of conservation have no sense for a digital document [13] because a digital document is always being constructed and reconstructed. But it is also clear that these transformations must allow the complete preservation of the original symbolic logic supported by a document. The CCSDS proposes in [14] a reference model for an Open Archival Information System (OAIS), which addresses these aspects of documents preservation including the preservation of the tools necessary to enable the interpretation of the document. If software or other reference documents like dictionaries are not available, preservation is not useful. These issues are important in technical and business fields which are very dynamical with production of concepts with specific meanings and which grow at the speed of the technical changes.

We will include the UML representation of OAIS in our own model proposed hereafter.

We can now focus on the aspects concerning the handling and the use of the documents and particularly digital documents supporting activities of the Product Lifecycle.

5 Lessons from field experiences

We will here briefly describe lessons drawn from 10 years of personal experience in the field of document engineering in industry and give the main results of recent field research studies on the use of digital documents to support maintenance tasks.

5.1 A double need for preservation and for handling of technical documents

We have carried out the organization of technical archives of 3 shutdown nuclear power plants in France in order to prepare future dismantling operations [15]. This experience has highlighted the importance of the archiving of technical documents. During the dismantling or deconstruction phase, some design and construction documents, which have never been used during the operation, are again needed: for instance it is of great interest to know the type of iron in concrete structures to assess the radioactivity of the elements and thus define the best way to operate the dismantling and to define the disposal of the waste. On the other hand, the experience of dismantling could be integrated for the design of future plants if capture and feedback of information produced on the field is supported by adapted standards and tools.

Experiences in other industrial fields have convinced us that the use of the technological standards like SGML [5], and later XML [4], in the first steps of the Lifecycle can improve the reusability of documents between different projects and give for instance the opportunity to offer Interactive Electronic Technical Publications (IETP) supporting operation/maintenance processes. Article [16] gives an example of intuitive graphical navigation in the documentation of a complex system in the defense industry, based on the use of technological standards for graphical [17] and textual information, thus enabling coherence of documentation with the other product, spare parts and consumables data bases.

5.2 Difficulties in the use of digital documents

In order to get a direct feedback from the field on the use of digital technical documentation, we have carried out studies:

- On military bases equipped with the multirole fighter aircraft Rafale designed and built by Dassault Aviation; the technical publications have been edited according to the rules defined in the international specification S1000D [18]; the use of digital documentation is compulsory before any maintenance operation on the aircraft, (see [19] and [20] for more detailed information on the field studies),
- In a gas storage facility as an example of process plant; all the descriptive documentation of the plant can be retrieved and consulted from a unique digital repository.

We will not insist here on the advantages of a centralized digital repository including the whole documentation, which is updated simultaneously, in comparison with a system with partial paper libraries dispatched at different places and needing manual means for the updating of each library without the guarantee for a technician he has got the last issue for the task he is carrying out.

We will focus here on the main common drawbacks and unsatisfied needs we have perceived through interviews and meetings with about 40 users on our 3 fields of observation.

5.2.1 Which support or tool for complex tasks?

Up to now paper is still the most comfortable support for some complex tasks. For instance paper multifolios electric diagrams for trouble shooting are necessary because that kind of task cannot hardly be realized on a screen.

The alternative to paper is often the design of calculation modules. For instance the flight parameters used to be calculated manually on different curves on sheets of paper. Now data are introduced by the pilot and computed by a module to determine the flight parameters.

For tasks, which cannot be easily formalized for computerization, the use of different sheets of paper, which can be displayed on a desk and annotated is better adapted to support the intellectual work than the discrete consultation of pieces of documents on a screen without efficient means to interact with the content.

5.2.2 How to adapt the support to the working situation?

It is not possible to work with a common computer, even a laptop, in the cockpit of a fighter or in the explosive atmosphere of gas storage. Paper is often the most simple and the cheapest solution. However, Tablet PC can reduce the use of paper for simple procedural tasks in a large number of use cases.

Even with digital reference documentation, printing of content on paper is often necessary to fulfill complex tasks, which cannot simply be expressed in a computable form.

5.2.3 Which method and tool for an efficient updating?

Updating is a longstanding problem for the documentation of industrial facilities. From our various field experiences we propose to draw the following generic lessons:

- The users need to be provided with tools adapted to capture information as far as possible during their main activities,
- A mediation of " Information managers" is necessary to achieve the normalization and formalization for a rapid and efficient information sharing, e.g. through annotations edited with the help of a library of reference templates,
- An instruction process is necessary to validate the content and the maturity of the annotated information and the users have to perceive the progressing status of that annotated information (for instance through a change of color according to each step of the validation process).

We will focus in the next section on the modeling of an information system facing the preservation and use/updating issues.

6 An UML model of the information system

Many international researchers have been recentlty developping information models to support the PLM paradigm using UML:

- Han and Do propose in [21] an object-oriented conceptual model of a collaborative product development management system, which includes sub-models of Product, Participant, Process, Project, Collaboration and Cost (4P2C model);
- Thimm et al. propose in [22] to use PLUML, as unique modeling language and apply it on an example to the various activities of complete Lifecycles;
- Parador and Young [23] suggest the use of IDEF0, IDEF3 and UML as combined methodologies to define the structure of the information model.

Our aim is to integrate this modeling framework to allow reuse of works carried out in other fields and to propose here an UML model of a digital repository focusing on the main features of the domain of data and document management.

Bruno Bachimont proposes in [24] to consider the *network*, the *program* and the *layer* as the new conceptual structures of a computational way of reasoning, respectively compared with the table, the list and the formula described by Jack Goody [25] as conceptual structures of the paper way of reasoning.

A network is a set of connected and interoperable technical objects, which allows the interpretation by human beings of collected information.

A program is a digital process, handling symbols, which can be systematically processed by a machine with discrete states.

Michel Volle has proposed a definition of a model in *layers* in [26]:

A model in *layers* consists in the articulation of several sub-models; each characterized by a specific protocol and linked by interfaces.

The structure in layers supports on one hand the interaction of human beings with a technical system like a digital repository and on the other hand it supports the collaboration of teams.

We consider 3 main types of user in a technical information system: the field user, the information manager and the engineering user. The field user is for instance a maintenance technician who makes a remark or a proposal to change the content of a document. The information manager manages the requests for change, formalizes the content in annotations inside the original content. The engineering user studies the request for change, accepts it or not and, if accepted, includes it in a new version of the document.

The sequence diagram of figure 1 briefly describes the flow of information between the main users.

Figure 1 Sequence diagram of information flows between main users

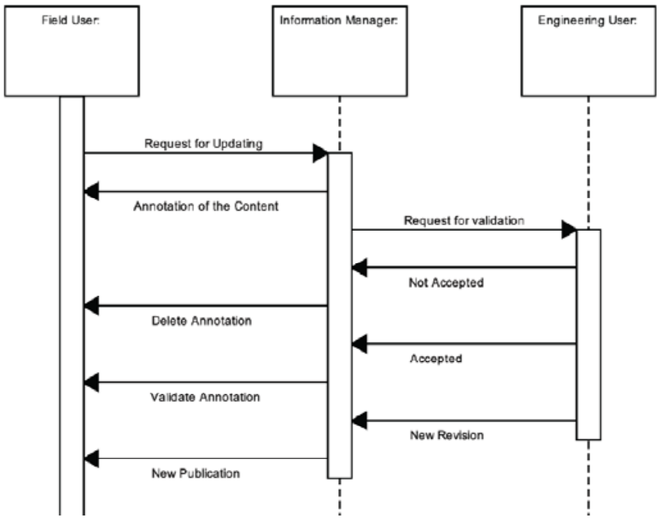


Figure 2 proposes a class diagram of a Digital repository organized in layers. The organization in layers avoids the disorientation of the user and makes it easier for him to handle the information objects. A protocol and a type of information characterize a layer. In order to address the preservation issue of the digital document, it is proposed to connect this model with the Reference Model for an Open Archival Information System [14].

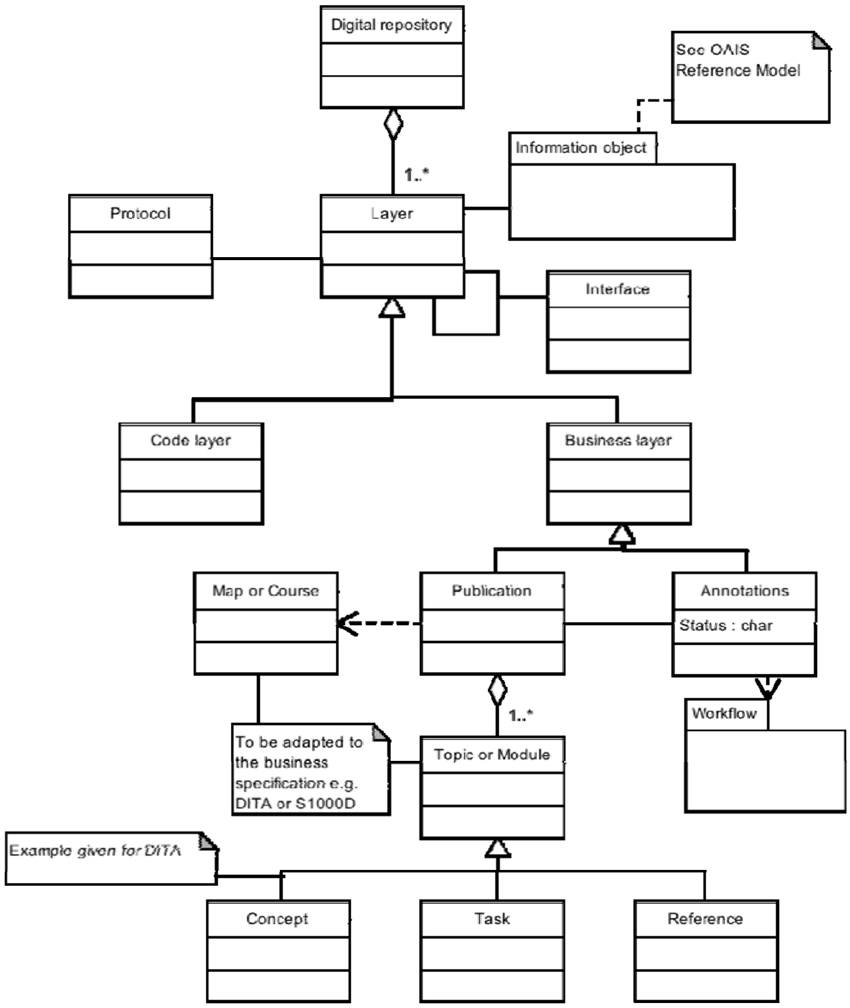
The publication layer is composed of document units which can be defined according to business specifications: S1000D [18], DITA [25] or ISO 15926 [26] (In this last case for the exchange of data along the life cycle of a process plant).

Information on the status of the annotation must be made directly perceptible to the user for instance through a color code according to different steps reached in the updating process (edited, discussed, accepted,..).

We think that integrated tools designed according to this model should enable the capture of information from the network of actors, giving at the same time clear information on the status of the new information. It will thus be helpful to face the main difficulties we have observed during our industrial fields investigations.

We have partly applied these principles with the implementation, in an existing digital repository, of functionalities to convey information for updating and to annotate descriptive drawings of a gas storage plant.

Figure 2 Class diagram of a digital repository in *layers*



7 Perspectives and conclusion

The model we have proposed could be generalized on the whole product or plant Lifecycle taking into account generic use cases (search, retrieve, visualize, print, publish, update, archive), generic events (modification from maintenance, from engineering or from constructor, other event) and various digital document forms. For instance the viability and efficiency of the use of 3D digital mock-ups more and more used in design should be studied in more detail including the analysis of the impact on the operation and maintenance activities.

Digital technology brings many changes and opportunities in the way of managing data and documents for an improved Product Lifecycle Management. Long term preservation and easier handling are the two basic requirements for a technical document system. Business process modeling, use of existing extensible standards and reduction of complexity thanks to the help of a model in layers as proposed in this paper are promising tracks to be deepened in order to achieve a generic framework of the technical document system.

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Proposition of a product information exchange framework: multiple viewpoints approach

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Abstract: In today's competitive world, companies are ever more stressed and subjected to high market requests. Customers are becoming more pretentious in terms of products quality and delivery times, while the product itself is turning to something more complex than just physical good. In this context, companies are considering that constraints are sustained to great product development by integrating the management of its entire lifecycle and its supply-chains. Achieving this goal requires an intense collaboration between multidisciplinary actors. The representation of the actors' viewpoints is the underlying requirement of the collaborative product development. The multiple viewpoints approach was designed to provide an organizational framework following actors' interests in the collaboration, and their relationships. In this paper, a multiple viewpoints representation is presented. Product, process, collaboration, and organization information models are discussed. Based on XML, taking electric connector as an example, an application case, part of product information, is stated.

Keyword : Exchange information, Multidisciplinary collaboration, Product and process information, Product lifecycle management, Multiple viewpoints

1 Introduction

Opening markets and increasing competition have recently led many companies on an international basis to consider the product development as a continuous process. It has raised the product development process concept. Later this concept was extended to cover aspects related to after-sales (as technical maintenance) leasing to the elaboration of the product lifecycle management (PLM) concept. PLM may be defined as "a new integrated business model that, using new ICT technologies, implements an integrated cooperative and collaborative management of product related data along the entire product lifecycle." [1].

The other consequence of global changes in worldwide economy is restructuring/establishing new cooperative relationships between companies. As a result of these changes, new organizational forms such as supply chains (SC) have appeared. The product lifecycle management concept is based on some other achievements from the last decades as Supply Chain Management (SCM). SCM addresses the joint evolution of business strategies and software technologies such as open services. This is a step towards development of new standard-based, loosely coupled and highly dynamic and scalable architectural concepts of Enterprise Application Integration (EAI).

SCM, taking into account product lifecycle factors seems to be one of the industrial challenges of the next years. Where, PLM could provide a shared platform for creation, organization and dissemination of product related knowledge across SC. For this purpose collaborative product development constitutes the core activity of many industrial companies. It includes actually a variety of business processes associated with the activities appearing in the product lifecycle and SC.

However, both systems have not good filter methods for pertinent information extraction, especially to exchange and share information between actors based on their own knowledge. Where several different interpretations of the same information often exist, and many metadata contain information that is related or complementary to other metadata, but these different interpretations are rarely integrated; so that an actor must keep switching back and forth between different applications. In this context, the multiple viewpoints framework is a key element to integrate more than one interpretation approach across a body of information, gaining leverage in retrieval from their diversity and simplifying actor interactions by uniting them under a common interface. Where the multiple viewpoints approach permits to capture/retrieve the adequate information following actors' interests/objectives on the collaboration based on his own experiences/knowledge in PLM or SCM.

The remainder of this paper is organized as follows: section 2 gives an overview of the main viewpoints approach. Section 3 is dedicated to the description of the product, process, collaborative, organization information models integrated in the framework; and the definition of our multiple viewpoints system. In section 4, an example of product is studied and used for instantiating the viewpoints approach. The viewpoint instantiation is then used to show how an effective information extraction is achieved in the PLM/SCM integration system. The paper is ended with some concluding remarks in section 5.

2 Literature Review

We use the term "Viewpoint" to mean a scheme for representing a collection of information objects, along with a mechanism for accessing this information. The term has also been used, with some frequency and great inconsistency, in the areas of information visualization and Human Computer Interfaces (HCI). Researchers such as Teraoka and Maruyama [2] are generally interested in representing a user's interests and purpose. They use "multiple viewpoints" to parameter an information visualization system that indicates how to present information based on a particular interest profile. While a user's interests might serve as the basis for a viewpoint, viewpoints are not limited to different visualizations of the same information relationships; the relationships themselves may differ as well.

Ribière [3] considers “Viewpoint” as a polysemous word, i.e. its definition depends on the context of use. She defines a viewpoint as “*a perspective of interest from which an expert examines the knowledge base*”. It is a general definition that can take several interpretations in different domains of application. She proposes an extension of the conceptual graph formalism to integrate viewpoints in the support and in the building of conceptual graphs. Where the viewpoints allow her to define the context of use and the origin actor of concept types introduced in a graph. The aim of her proposal is to define viewpoints to help knowledge representation with conceptual graphs for multi-expert knowledge acquisition and also to have an accessible and evolutive knowledge base of conceptual graphs through viewpoints.

Powell and French [4] introduce the concept of multiple viewpoints by using both multiple relevance judgments and multiple representations together. Collection selection [5] may also prove an important element in the design of multiple viewpoint algorithms that attempt to gain efficiency by consulting only a subset of the viewpoints in a system.

PLM/SCM integration is a complex phenomenon, where more dimensions and disciplines are giving their contributions. A relevant component of PLM/SCM is the product itself and its information distributed along the whole lifecycle, in other words, the product information exchange between multidisciplinary actors.

In the collaborative development, a lot of studies focusing on knowledge representation and product modelling during collaborative development process have been investigated [6], [7], [8]. However, most of them emphatically address only a part of the entire issue of product modelling. And, up until now, few papers have synthetically investigated product information modelling based on the users’ points of view on a large-system, from the design of product information modelling until there use in different application.

Geryville and al. [9] describe the concept of the multiple viewpoints as a composition of four components: the actor, the viewpoint’s domain, its related objectives (objectives of the actors in the collaboration), and its relationships with the other viewpoints. This definition is characterized by a context, which allows the restitution of the information that the actor wants to use, and a degree of importance of each viewpoint. In this definition, the knowledge dimension of actors, inside the project or the activities, is integrated to perform the interoperability between the actors.

The scope of the presented works mainly deals with the integration of an information visualization interface, where the same information has different meaning following its relationships. However their limitation is that none of them integrate the real interests of the actors within collaborative product development context, such as the extraction/retrieve of adequate information. In multidisciplinary collaboration, the actors need to integrate their viewpoints on the product along its lifecycle stages, where they also need to retrieve important information within different stages according to their interests.

Based on previous studies of collaborative product development process [9],[10], this paper attempts to contribute to give a complete definition for actors’ viewpoints representation; we propose an approach that makes links between the viewpoints and the product, the process, and the organization information for a complete interaction between multidisciplinary actors. To give an appropriate definition of multiple viewpoints actors, we situate the actors under different views (product, process and supply chain organization). In the next section, we define our concepts of multiple viewpoints and its interactions with the product/process information within a collaborative supply chain organization.

3 Proposed Approach

In multidisciplinary collaboration, the framework must be characterized by the following features:

- a base-level information model should contain enough information for various needs of the product collaborators, i.e., the product information model should be based on the entire product lifecycle, to assure that it contains the complete information meeting the various demands of all actors in all product development stages.
- actors' viewpoints should represent the actors' knowledge and interests on the product which permit to help them on their collaboration. In a word, a whole-life-cycle product information model with viewpoint representation is necessary to support collaborative product development.

3.1 Information Model

In previous studies [10], [11], we defined an information model called PPCO (Product–Process–Collaboration–Organization information model) based, especially, on collaboration and project concepts, this study is inspired from Gzara's and al. research [12] where they propose the Product–Process–Organization model (PPO). The PPCO provides a base-level information model that is open, extensible, independent from any product development process; and aiming at capturing the engineering and business context commonly shared in product development.

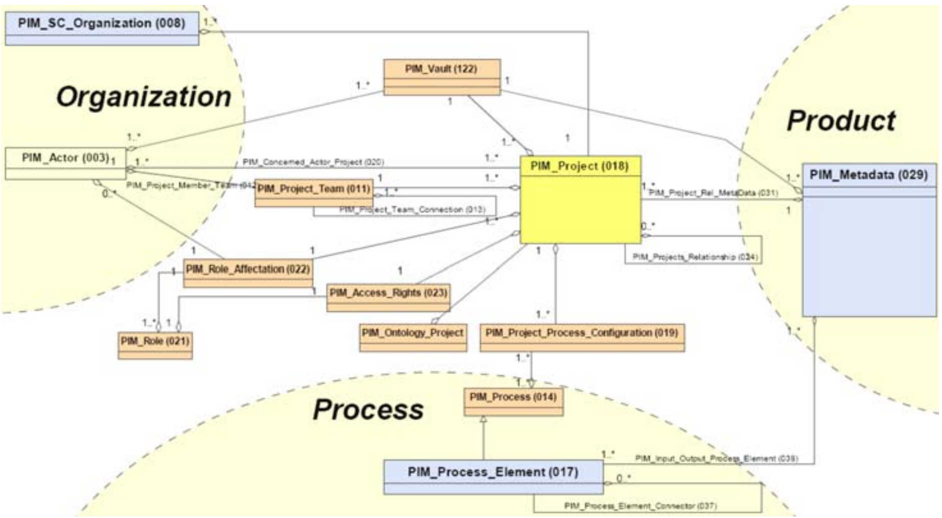
The PPCO model (Fig 1.) is based on the four elements stated previously: product, process, collaboration and organization.

- **Product:** the architecture of the product is defined not only by the decomposition of the final product into components, functions, behaviours, etc, but also by the interactions between all these components. The interactions may include well-specified interfaces and undesired or incidental interactions. The design principles suggest ways to plan architectures with minimal interactions across sub-products, maximizing the density of the interactions. The proposed product metadata model is derived from concepts issued of several existing models, especially the Core Product Model [13].
- **Process:** the product development process is generally a complex procedure involving information exchange across many activities/tasks in order to execute the collaborative work. Various network-based methods have been used to map and study development processes. This model integrates mainly the Integrated Definition of Process Description Capture Method (IDEF3) and the Supply Chain Operations Reference model (SCOR).
- **Organization:** the organization structure determines who works with whom and who reports to whom. However, in supply chains organization we are particularly interested in the study of the communication patterns between the actors conducting the technical development work. This follows from well established methods used to

study communication networks in R&D organization and can be used to assess whether necessary interactions are taking place within the organization.

- **Collaboration:** is an abstract model which we can be found inside the organization, the project and the activities models. This model configures the collaboration's methods between the actors in the same project or activities.

Figure 1 Extraction of the PPCO model



3.2 Multiple Viewpoints Approach

A viewpoint is any structure from which we can elicit an informative result from a collection of information by presenting a query; which is based on some set of relationships among the data. In this section, we define the primary elements of our framework for describing viewpoints and multiple viewpoints approach:

3.2.1 Approach of Multiple Viewpoints

A system of multiple viewpoints consists of : some viewpoints, which represent the knowledge elements of actors' interests on the artefacts (products) ; a set of transition mappings for pairs of viewpoints in the system ; and a merge function that defines how to construct a final result set based on a these viewpoints. An initial consult to the multiple systems might feel some translation and increasing to be usable as a generic use for any viewpoint.

3.2.2 Single Viewpoint

There are myriad methods of representing a single information collection and the relationships among its elements, including information retrieval models, graphs, and hierarchical arrangements. Each viewpoint in a multiple viewpoint system contains a representation of some set of information items, a subset of the universe of information items with which the system is concerned. This is the viewpoint domain. In our case, we consider that the viewpoint domain is related to the PLM phases.

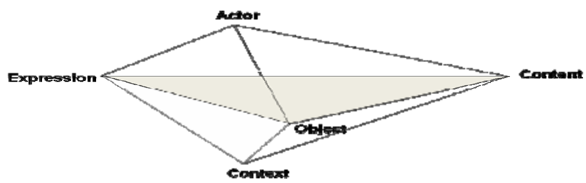
We are less concerned with the representational schema used in a viewpoint but more interested by the meaning of the viewpoint; this is the viewpoint knowledge. Primarily, we need to capture the actor's interests on a given objective, which is related to a collaborative activity, and to represent them as the interaction between the actor knowledge and the product definition (used or created).

So, we consider that a viewpoint implements the condition for an *Actor* to interpret the sense of a collection of information: it is defined by the *Object*, on which the interpretation is performed, the actor performing it, the *Expression* and *Content* of the interpretation of the object by the actor, and the *Context* in which this interpretation is performed.

A viewpoint comprises five poles:

- the **Actor** holds at least one viewpoint, in the context of which he produces an interpretation of the object ;
- the **Object** is interpreted by the actors exerting a viewpoint on it (in our case, the product or artifact is the object) ;
- the **Context** is the condition governing the way which the actor applies his viewpoint (the place from which the viewpoint is applied, the moment in time it is applied, the tool used by the actor to apply his viewpoint…) ;
- the **Expression** is a statement, expressed in a symbolic system, that is attached to the object by the actor within the context of the viewpoint to express his interpretation of the object;
- the **Content** is the meaning given within the context by the actor to the object by means of expression.

Figure 2 Viewpoint definition



3.2.3 Transition Mapping

The transition mapping is at the heart of the concept of multiple viewpoints framework; although the transition mapping does not determine when or to which viewpoint should change, it implicitly describes the relationship between two viewpoints by providing corresponding entrance points for each, and thereby helps us to maintain the context of searching when switching viewpoints.

Let's suppose a simple system with three viewpoints of the same actor. If the system proposes to use one of these, the first which satisfies the requested domain, and the actor is unsatisfied with the result, how should he move to the other viewpoints? The used method is to integrate the appropriate viewpoint which has the same domain as the first one ; so, if we have information about the relationship between both viewpoints, the final result combines each viewpoint result. Else, the system presents the different results.

A transition mapping from one viewpoint to another must transform knowledge's elements of the first viewpoint to the knowledge's elements of the second one. If every knowledge element of each viewpoint's domain is a valid relationship, the system can always perform a transition based on elements in the intersection of both viewpoints' domains; that is, we can move from the representation of certain information in the first viewpoint to the representation of the same information in the second one.

A transition mapping from one element to another may take advantage of known synonyms in two indexing vocabularies, or might make changes based on more complex relations.

In some cases, it will be reasonable to create transition mappings wholly or partly by actors, based on human judgments. In other cases where we have sufficient information about two viewpoint representations, data-mining techniques may be suitable for more automatic discovery of appropriate mappings.

3.2.4 Merging Results

For a system of viewpoints to usually present the results of a series of viewpoint consultations, a well-designed merge method is essential. The merge method must take into account not only any rankings of results from a particular viewpoint, but also any known differences in reliability among viewpoints. The merging algorithm must also handle the case where the same element of the information system appears in two different viewpoint result sets. In many cases, it will be convenient for the system result to appear as a single ranked list, but such formatting must depend on the intended purpose of the system.

4 Example

To illustrate the proposed approach, we present an example of an electrical connector. In the next sections, we introduce product information modelling by given an overview of the product structure, process development, and the development of the supply-chain organization related to the assembly of some part of the electrical connector. After, we present a case of information restitution by using the multiple viewpoints approach.

4.1 Supply Chain Organization Example

The supply chain organization defines the enterprises integrated to develop a new electrical connector project. The organization involves 3 teams; each team has a responsibility for a major component. The given table 1 depicts the principal domains and the competencies of each actor integrated to the development of the product.

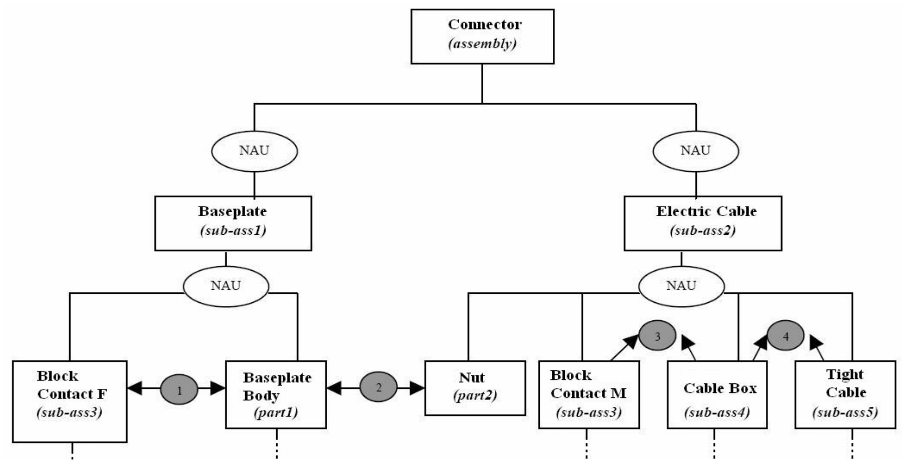
Table 1 Domains and actors' competency

Domains	Competencies	Actors
Electric	Isolation, Polarization, Electricity transportation	M^{r} William Burin (Chief of electric service)
Mechanic	Manipulation, Assembly, Protection	M^{r} Patrick Santorinos (Mechanic responsible)
Signal processing	Covering, Coppering, Abrasion's resistance	M^{rs} Beatrice Mochat (Specialized Engineer)

4.2 Product Structure Example

The complete electrical connector structure is composed of 12 components. In our case, we present only the main part to assembly of the electrical connector. The product architecture and the interactions between some components are documented in this model (Fig. 3).

Figure 3 Assembly model instantiation



4.3 Development Process Example

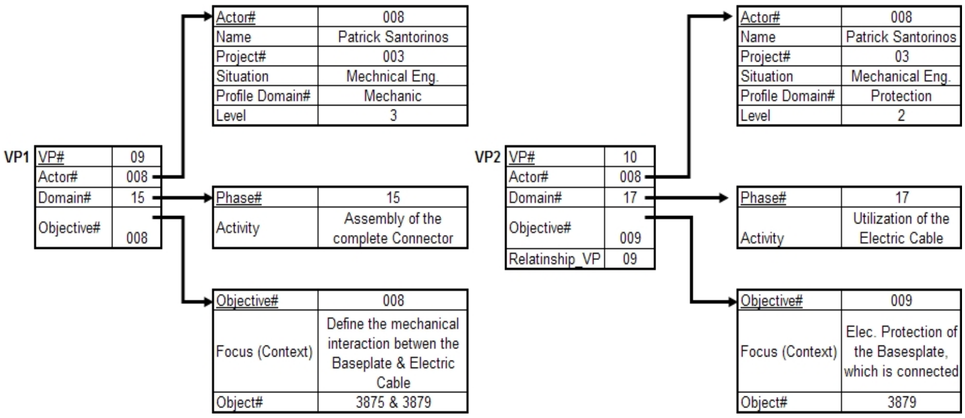
The process development describes manufacturing process to determine the assembly of the final electrical connector following the customer requirements. This is based on a digital model using CAD solid models. Interactions in this type of model represent information flows between the activities (we consider that every process has only one activity). In figure 3, you can see the progress' assembly of the concerned part by following the 4 steps.

4.4 Information Restitution by Viewpoints Approach

Let's take the example of the actor "Patrick Santorinos" integrating the supply chain organization into the team 1 as *an external mechanical expert*. He has two focuses on the product "electrical connector", the first as electric protection, and the second as mechanical design (Fig. 4). The actor's objectives are related respectively to the activity on "utilization" and "mechanic" tasks. To retrieve the adequate information for the actor "Patrick Santorinos", we need to filter and classify the information following his interests. By using the adequate query, the framework compares the information of each viewpoint and gives the sets of adequate information to the actor following his focuses on the product and his activities in the project. Based on the level's batch definition, the system regroups the batches with high-level hierarchy, and retrieves the information which is more adequate to the actor according to his focuses and activities [9].

Firstly, the Multiple Viewpoints system (MV) constructs the viewpoints of the actor following his interests on the product, i.e. for each activity the system try to link the information, needed or generated by the actor, to the profile of the actor. After, the actor can update these viewpoints, because the MV system extract the central actor's knowledge used in the activity. Now, these viewpoints can be used to extract adequate information for this actor. How to use them for the extraction? Really, the MV system tries to make in relationship the viewpoints of the same actors, so be it same information, used or generated, or by the same domain of each viewpoints or by the domain of each activity. By using these relationships, the MV system can retrieve all information needed by the actor, and by using the Merging Results method, the system generates information mappings, which integrate the actor's knowledge elements, the collaboration information, and the information related to the product itself.

Figure 4 Santorinos' Viewpoints



5 Conclusion

PLM-SCM integration is a complex domain, in which all the actors need to exchange and share product and process information. In fact, product information generated by each actor is communicated to all actors in order to integrate them in a shared representation. Knowledge about actors' preferences, methods, etc. and about actors' focuses, constraints, objectives, etc. must be taken into account to manage information extraction.

In multidisciplinary collaboration, the use of viewpoint in the structured collaborative product development shows how the viewpoint notion can provide real help in the extraction, treatment and consulting of adequate product/process information. The proposed viewpoint description and multi-level management approach aim to structure the actor's focuses in multidisciplinary collaboration thanks to a more accurate characterization of the viewpoints, which allows an intelligent indexation of the product/process information.

Actually, the multiple viewpoints framework is implemented on our prototype, designed to the product information exchange, which integrate the PPCO model. We have tested and validated it with first scenario, on the extended supply chain, which implement three examples, automotive piston, industrial cyclone vessel, and the electric connector. Next step, is the integrated of two scenarios on the PLM-SCM integration, which will be tested on the Electric connector.

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Implementing the interoperability between virtual reality technologies and CAD applications

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Abstract: Virtual Reality (VR) technologies are widely used by industries in several phases of the Product Development Process (PDP) and, in particular, in design review and CAE data analysis. Recently, other interesting VR applications are capturing the interest of the industries, but a wider diffusion of these technologies still founds an obstacle in the poor integration with other software employed in the PDP. The present paper starts with an analysis of some new VR applications in the PDP, aiming to define the main CAD-VR interoperability topics. Then the paper shows how the CAD API can be employed to resolve some of the most common interoperability problems, describing the development of three plug-ins for Unigraphics NX3 that allow the user to quickly export meta-data needed for Virtual Assembly applications and multi-body simulations and to post-process data generated in a Virtual Cabling environment.

Keyword: Virtual Reality, CAD, CAE, Virtual prototyping, CAD-VR integration.

1 Introduction

Virtual Reality (VR) technologies are widely used by industries in several phases of the Product Development Process (PDP). Usually, VR is employed for design review and for CAE data analysis, taking advantage from the advanced visualization capabilities offered by immersive visualization and large stereoscopic displays. Recently other interesting VR applications are capturing the interest of the industries: among others virtual assembly, virtual cabling and interactive product simulations have already reached the maturity needed for a routine employment in industries. The new generation of VR applications in the PDP are characterized by a full exploitation of the natural interaction capabilities offered by special VR devices like data gloves and tracking systems. But a wider diffusion of VR technologies still founds an obstacle in the poor integration between VR tools and other software employed in the PDP.

In fact, the lack of integration between VR and other tools employed in the design process, and particularly CAD software, requires a lot of manual work to prepare the virtual environment or to post-process the results obtained in VR.

Many PLM vendors are working on the CAD-VR interoperability because they are currently expanding their offer in IT solutions acquiring or developing the technologies needed to complete their product range with specific VR tools. An effective implementation of a PLM system in a manufacturing industry requires a good interoperability among the various software tools employed in the different phase of the product development process. VR tools like visualization software for DMU or CAE analyses have been included in PLM packages and the integration between CAD software and VR system has been gradually realized thanks to the development of common file format for product data exchange and sharing. UGS [1] and Dassault Systemes [2], two of the foremost companies in the PLM systems market, have released some languages to support interoperability in the PLM system. UGS proposes the JT format that is the one employed for the storage and visualization of DMU geometric data. UGS proposes also the PLM XML format that is defined by a set of XML schemas and includes the representation of both the high-level metadata and the geometric representation of the product. Dassault proposes 3DXML that is an open file format usable in all their software for product development. Both these XML based file formats offer the advantage to be customizable with user defined metadata that can be added to the standard schemas to enhance the model with all the information needed to perform a specific task.

This possibility can be very useful for VR application development. As a matter of fact many specific VR tools, like virtual assembly or virtual cabling, are custom software developed on the basis of the specific needs of each company. So each tool requires different product data and these can be stored using the XML based language. Besides, the availability of a powerful language for data storage does not resolve the problem at all, because it is necessary to develop the software interfaces, in both the CAD and VR applications, able to read and write the specific metadata in the file.

The development of these software interfaces is possible thanks to the CAD Application Programming Interfaces (API) that the user can employ to develop his own plug-in, in order to create the link with the VR tool.

The present paper starts with an analysis of different VR applications into the PDP, aiming to define the main CAD-VR interoperability topics. Then the paper demonstrates how the CAD API can be employed to resolve some of the most common interoperability problems related to the employment of VR applications in the PDP. Finally we focus on the development of three plug-ins for Unigraphics NX3 that allow the user to quickly export meta-data needed for Virtual Assembly applications and multi-body simulations and to post-process data generated in a Virtual Cabling environment.

2 State of the art

A typical problem related to the interoperability between VR applications and CAD is the organization of the Product Data Management (PDM) system. Inside the PDM the components are organized in a typical tree structure that is usually optimized for the development of classic virtual verification like Packaging, CAE, Ergonomics, etc. and not for verification through the use of VR technologies. On this topic Graf et al. [3] present a methodology and software tool to automate the process of data preparation for the purposes of a design review session in VR. The proposed system, named Virtual Design Data Preparation (VDDP), is directly integrated with the PDM and allows the user to navigate through the product structure, select entries for conversion, correct geometric conversion errors and reduce the complexity of the model. On the same topic Jayaram et al. [4] present a method that improves the ability to use the virtual assembly environment to simulate real world assembly sequences in complex models, where there are significant differences between the subassembly and hierarchy representations in the CAD model and the component assembly sequence in the factory floor.

Other typical problems in CAD-VR integration may regard the loss of geometric precision, topological information, assembly structure and semantic data like dimensions, names, constraints, physical properties, etc. [5]. Where the data lost in the conversion process are needed to perform the VR task, it takes a manual reassignment of each property on each object involved in the task. This manual work represents a big inefficiency that is extremely felt in the industrial world, because industries are progressively reducing the product time to market, in order to acquire competitive advantages toward the contenders.

More specific interoperability topics are specifically related to each VR application. One of the most widespread is Virtual Assembly. According to [6], the main goal of a Virtual Assembly application is the assertion that a part or component can be assembled by a human worker, and that it can be disassembled later for service and maintenance. There are other points that need to be analyzed: the ease of assembling/disassembling a part; the time needed by the process; the space necessary for the tools and the stress in terms of ergonomics.

Virtual assembly entails several topics about the integration with CAD systems: most of them are related to the loss of topological and semantic data during the conversion process from CAD to VR.

Jiang-sheng et al. [7] have developed the data decomposition and information translation method (DDITM) able to export geometry, topology and assembly information from the CAD system to a virtual assembly environment.

A different approach to resolve the integration problems for virtual assembly application is presented in [8] where a CAD linked virtual assembly environment is described. It works linking the design dataset in CAD models with the corresponding dataset in the VR application.

The integration approaches described in [7] and [8] consent to transfer all the constraint data from CAD to Virtual Assembly. The difference is that in the first work the CAD writes all the information needed in an exchange file while in the second one a more complex runtime linkage between CAD and virtual assembly is established. In both cases it is not clear if these approaches can be employed with a complex model composed of thousands of parts. In fact in automotive or aerospace industries the DMU is generated as a tessellated model because it is usually impossible to load in a CAD environment the mathematical representations of all models. This limit reduces the advantages offered by these two innovative approaches because the first one requires a manual loading of CAD models to export constraint and mating data, instead the second one requires that all the models are loaded in the CAD environment while the VR application is running.

Also virtual cabling is a promising application of VR in the product development process. Ng et al. [9] present an application in which the user is able to design cable harness using an immersive VR system. Even if the authors present a complete system, they do not discuss about any possible integration with 3D CAD systems. They have proposed only a post-processor to convert the cable data into a two-dimensional layout of the cable harness in AutoCAD DXF format. As we will describe in section 4, the integration between virtual cabling applications and parametric 3D CAD is important because it allows engineers to post-process or modify cables designed in VR that, at the end of the process, becomes an integral part of the product layout.

An innovative application of the VR in the PDP regards the so called Functional Virtual Prototyping (FVP). FVP is the creation of a virtual prototype able to reproduce, as much realistically as possible, the behavior of the product from any point of view. The FVP can be employed in order to reduce the need of building physical prototypes to validate the functionality of complex product in which several components, designed by different teams using different technologies, have to be integrated. As a matter of fact FVP is widely employed in the most advanced industrial fields like aerospace, automotive, robotics, etc., to design both the final product (e.g.: the car) and the most complex parts or systems of the product (e.g.: the Antilock Braking System). As in VP the digital model of the product is called DMU, in FVP it is called Functional DMU (FDMU). At the moment there are not described in literature any research where VR has been employed as an interface to a FDMU. This is probably due to the lack of integration between simulation packages (both CAE and CACE) and VR software.

3 Virtual Assembly

In Virtual Assembly applications the DMU needs a long preparation because the geometry has to be enriched with several types of meta-data like constraints and joints. Motion constraints are important because these facilitate precise object positioning in the virtual environment, especially in some cases where a component is precisely fitted into another, like a gearwheel on a shaft. The second case, in which the user needs some aid to disassembly the components, is related to the presence of screws, bolts and other components coupled with a screw-thread. Since it is very difficult to precisely unscrew a component, the disassembly becomes impossible because the object cannot be moved without going in collision. During the preparation of the virtual environment it is possible to define some disassembly rules that allow the user to overcome this problem. The components with the screw-thread can be preliminary identified so they can be easily disassembled moving them along the constraint axis without considering collisions. The presence of screws and bolts requires also a space reservation analysis to verify that there is enough space to use screwing tools like driver or wrench, for instance. In these analyses the tool’s motion has to be constrained to keep its axis aligned with the screw axis and keeping the tool tip coincident with the head of the screw.

In [10] it is described a virtual maintenance application in which the user can benefit from the geometric constraints that simulate the mechanical behaviour of some elements like doors, hinges, etc. or can help the user to assembly/disassembly particular components like bolts, screws, oil filter, etc.. These constraints were manually defined during the preparation of the virtual environment. As a further development of this previous work, we have investigated the possibility to automate this task because it is one of the critical point in virtual assembly application since it consumes a lot of time.

The approaches present in literature are not appropriate for our purpose because, as discussed in section 2, they do not seem suitable to be employed with large models like the DMUs in the automotive field. Moreover these approaches require the availability of the CAD geometries because these extract topology and mating condition data from the CAD model. In some case this is a limit because, often, the CAD geometries are not available to the VR operators that have only access to tessellated models.

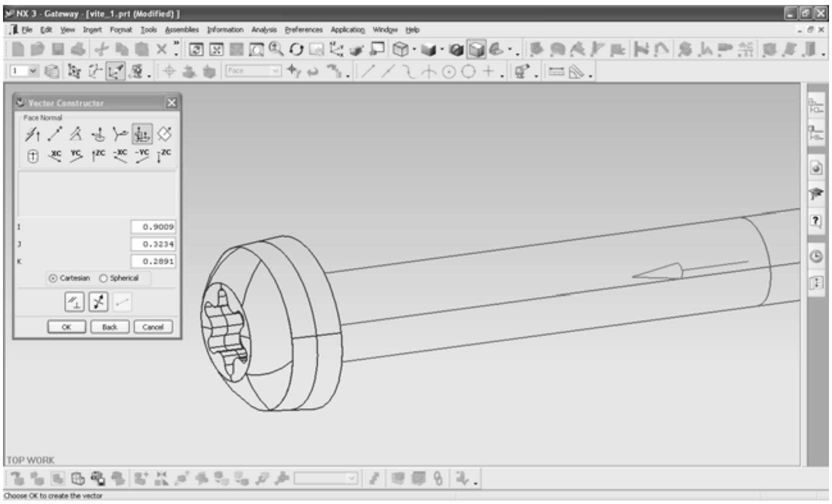
To overcome these problems we have implemented a semi-automatic procedure that allows the VR operator to export from the CAD environment only the constraint data that he/she considers important for the specific task. Considering, for example, the disassembly of a component fixed with four screws: the user select and export only the constraints for the screws and another one to set the initial moving direction of the component to disassembly. All other screws and components present in the assembly will be ignored.

The procedure works both with the geometrical and the tessellated representation of the models. Compared to the approaches presented in section 2 our tool is not completely automated since it does not extract from the CAD model all the possible information about the topology or the mating condition. But with our semi-automatic procedure the operator chooses the constraints needed to perform the analysis and exports only the data relative to these constraints.

We have decided to consider only linear constraints that let the component to move along one direction until it is decoupled from other parts and it can be freely moved by the user. The procedure is supported by a software plug-in for Unigraphics NX3 [1] implemented using the NXOpen API library supplied with Unigraphics. This plug-in allows the operator to load a set of component in the CAD environment and, for each one, to declare the constraint data.

The influence zone of the constraint is defined by a cylinder that the user declares choosing a direction for its axis, by selecting a feature (edge, plane normal, cylinder axis, etc.) and defining a value for the radius and the height. The constraint is active as long as the displacement vector of the moving component (defined as the difference between the current position and the initial position of the object origin) stays inside this cylinder.

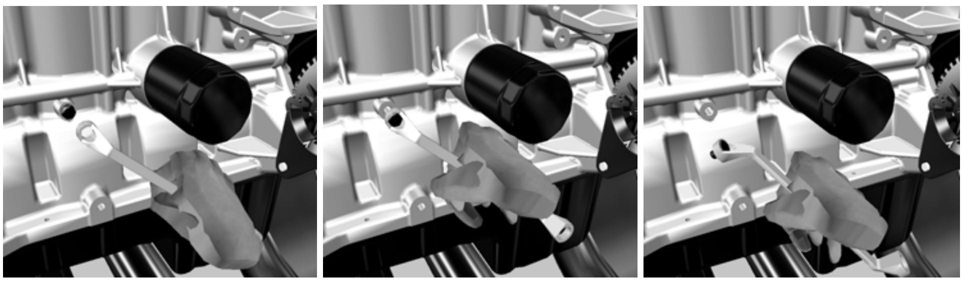
Figure 1 The definition of a constraint for a screw



The plug-in checks also the name of the part on which the constraint has to be applied and search the correspondent part inside the VR file. In our case the VR application has been implemented using dv/Mockup2000i2 by PTC [11] and the supplied C library. All data are directly written inside the .vdi file, which defines the structure of the virtual prototype, using the possibility to declare some user-defined data.

As further development of this interface, we are working on the definition of some standard components libraries that include constrains data. In the case of screws or bolts it is easy to understand that these components are present in several copies in one assembly. So the definition of some components libraries, in which all the data relative to the constraint are included, allows the operator to save a lot of time usually spent to repeat many times the definition of the constraint for each copy of the standard components.

Figure 2 A constraint assists the user while unscrewing a bolt with the aid of a spanner



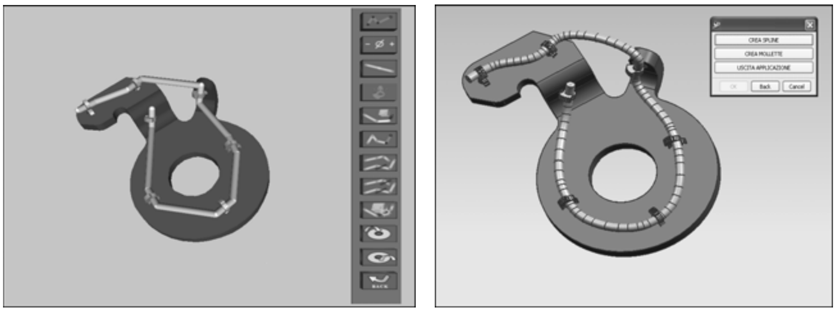
4 Virtual Cabling

In some industrial fields, like automotive or aerospace, cabling design is a critical and time consuming phase. Often, the cables layout sketching requires the visualization of complex models (e.g.: car engine) composed by millions of triangles. Therefore it is convenient to carry out this design phase in a virtual environment where it is possible to visualize and interact with huge DMUs of complex products. In [12] a Virtual Cabling system developed for the automotive industry is described. The goal of this system is to sketch the cabling layout that subsequently will be used like a base from which the designer starts a detailed modelling in CAD environment. All the information generated in VR must be transferred to the CAD system using the PDM like a data repository. In particular a cable is defined by the diameter, by the position of the control points of the spline representing the cable path, and by the position of the cable supports.

The application of Virtual Cabling described in [12] allows one to quickly define the layout of a cable in order to entirely transfer the job from VR environment to the CAD one for further refinements. To do this we have developed a procedure aided by a software tool that elaborates data coming from the virtual environment and reproduces them in CAD environment. Here, the work of the designers can continue, making modifications and defining details with the tools that CAD system place at their disposal.

Also in this case the CAD system employed is Unigraphics NX3 and the software tool is a plug-in developed with the NXOpen API library. In particular, as shown in figure 3, once all the data about the cables and their relative accessories like supports, clamps and clips are exported from the Virtual Cabling environment, the interface automatically acquires this information to exactly reproduce within the CAD environment the same identical situation present in VR. The user can automatically create cables with the diameters specified in VR, or only create spline curves that represent the paths of the cables. The curves can be modified with the CAD and later can be transformed again in cables, using the classical tools for cabling or piping.

Figure 3 Comparison between the results obtained by the plug-in in the CAD (image on the right) and the cable sketched in VR (image on the left).



The interface for data transferring is made up by two parts: the VR part and the CAD part. The first one is responsible of writing the files given in a neutral format which contain two different sets of information: the first set contains the information about the creation of cables that are the number of cables and, for each cable, the coordinates of the vertices and the diameter of the cable. The second set contains the information necessary for the creation of the cable supports, that are the number of supports and for each one position and orientation in the space and a reference to the geometry. This file is loaded by the interface developed for the CAD environment. In particular the plug-in, in first place, visualize the dialogue windows through which the user has the possibility to specify the data files that contain the information relative to the cables and to the supports, and, in second place, ask the user if he/she wants to create only the curves or the whole cables with the specified diameters. After that the file has been loaded and the data are read, the plug-in creates the curves or the cables (according to the choice of the user) using the routines defined in the uf_curve and uf_modl libraries. Finally the supports are created and are positioned inside the assembly. All the geometries created are obviously included in the product structure so the designer can make the modifications that he/she thinks appropriate to obtain the final version of the project. In particular he/she is able to move the control points of the cable or of the spline and to precisely place the supports using feature snap functionality.

5 Physics based simulations

Since VR simulations require a reliable behavior of the objects placed inside the virtual environment, the use of physical simulations is continuously increasing. A lot of VR development platform like Virtools Dev [13], EON Reality [14] and Quest 3D [15] incorporate specific modules for physics based simulation. The technology employed, usually, derives from the videogames world because one of the main requirements is the interactivity or, in other words, the reduction of the latency between the user actions and the physical response of the digital world. There are also some libraries (Havok, ODE, etc.) that allow programmers to include physical behavior to their own code.

The definition of the physical properties in the virtual environment is done by the operator during the preparation of the application. The operator has to define some variables like mass, friction and elasticity for each object involved in the application and, in some cases, he/she has to replicate the presence of link between two or more objects (e.g.: fixed, slider, hinge, ball, etc.). All these properties are, usually, defined in a CAE software for multi-body simulation then the VR operator has to replicate all the work already done by the engineers in the CAE environment. Our idea to achieve a better integration is to make the VR software able to automatically retrieve physics and multi-body data from the CAE environment.

We have developed a software interface to test this idea considering, as a test-case, the realization of a software plug-in for the Mechanism module (Motion Simulation) of Unigraphics NX3 (UG) that is able to retrieve and export all the data relative to the physics properties of the objects involved in the simulation. This plug-in is coupled with a software interface implemented in Virtools Dev 3.0 that reads data exported from UG, associates to each object his physics properties and creates joints and constraints as these were defined in UG.

In the UG environment the user designs and simulates the multi-body structure of the product defining links and joints. A link is a rigid body that consists of UG geometry and it is used to define moveable entities within a mechanism. Instead a joint constrains the motion between two links or between a link and the frame. The plug-in implemented in UG is able to export in a neutral format file all the data relative to the multi-body structure. In order to do that the plug-in starts asking to the user where he/she wants to save the file and then it begins an iterative procedure to retrieve joints data from UG. This procedure asks the UG kernel for any joint present in the current assembly using the UF_OBJ_cycle_objs_in_part that returns all objects of the specified type. The joint data structure includes name, type (slider, cylinder, revolute, screw, universal, spherical, planar and fixed), geometric data (origin and orientation) and the references to the two links associated with the joints. The limits value for each degree of freedom of the joint is not included in the joint data structure, but it can be obtained using the UF_MOTION_ask_joint_limits. For each link the plug-in retrieves the reference to the geometries that make up the link and then, using the UF_MOTION_ask_link_mass_properties function, it retrieves also the physics properties (mass, mass center, moment of inertia) of the rigid body composed by all the geometries included in the link. Only mass and mass center are written in the file while the moment of inertia is not stored because it is automatically computed by Virtools Physics Pack and it is not possible to specify a different one.

All these data are written in the neutral format file that uses a data schema suitable to be easily read from the interface implemented in Virtools. So in future it will be possible to implements other interfaces for several multi-body software using the same file format without the need to re-implement the interface in Virtools. All the constraints in Virtools are defined by twelve values that represent the upper and lower bound for each degree of freedom (DOF) both in translation and in rotation. This compact representation allows us to implement each different type of UG joint except the screw because this requires to establish a relation between rotation and translation. Then for each joint present in the motion scenario the plug-in write in the file the following data:

- Upper and lower bound for each DOF
- The constraint position and orientation
- The names of the geometries that composes the two rigid bodies involved in the constraint
- Mass and mass center of the two rigid bodies.

The interface on the Virtools side has been implemented like a user defined Building Block (BB). A BB is something like a black box with some parameters in input and some in output. Connecting several BBs it is possible to create an interactive application in Virtools. The BB we have implemented to read the file exported from UG/Motion gives in output all the data read from the file and these are immediately usable with the Physics Pack BBs like Physicalize and Set_Physics_Constraint. The first one is used to create the rigid bodies in the simulation with the specified geometries, mass and mass center. The second one is used to create the constraints.

Figure 4 Schema of the interface for transferring physic properties from UG/Motion to Virtools

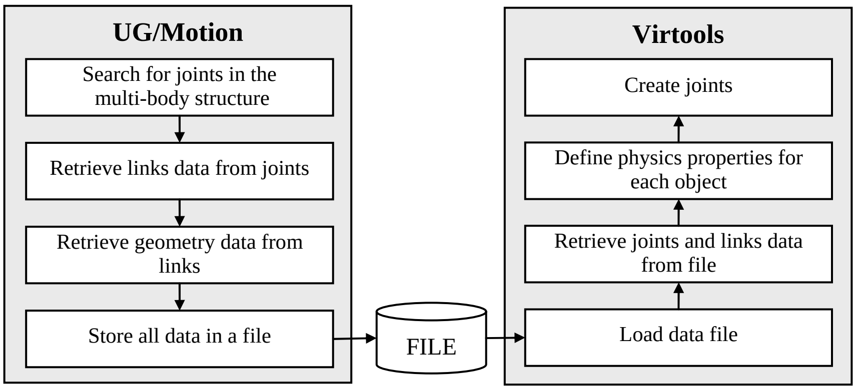
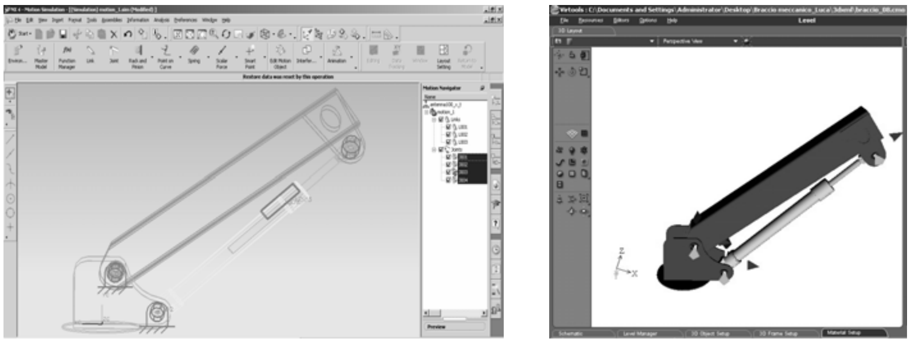


Figure 5 The same multibody file in UG (left image) and Virtools (right image)



6 Conclusions

In this paper we have discussed some problems related to the interoperability between CAx application and VR techniques. The integration of these design tools is a crucial step to achieve an effective employment of the VR technologies in the product development process. Until now the lack of integration between CAx and VR requires that the user does a lot of manual work to prepare the Virtual Environment or to post-process data generated in VR. In our opinion most of this work can be automated developing specific tools able to transfer data among the different CAx and VR software.

We have presented three different cases in which the integration problems have been resolved by developing specific software interfaces able to create an appropriate data exchange link between CAx and VR. The first case regards the classical problem of the generation of constraint data for virtual assembly application. This topic has been approached in an original way implementing a semi-automatic procedure that allows the operator to export only the desired constraint data from the CAD model. The second case analyzes a data flow from VR to CAD and it is relative to a virtual cabling application, in which cables drawn in VR are reproduced inside the CAD environment to continue the design process. The third application allows the operator to export the physical properties of each parts of the product from a multy-body simulator to the physics kernel of the VR application.

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An environment for collaborative design: a new approach to CAD tool interoperability

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Abstract: Computer Aided Design (CAD) are the tools for modelling product design intent. Today's complex design processes require the use of multiple CAD tools that operate in multiple frameworks making management of the complete design process difficult. One way to achieve improvements in efficiency in product design process is through better collaboration of designers working on a common design task and interacting in the design process. In a collaborative design environment, designer interactions are assisted by sharing the common design information through a specific framework. In this paper the Product Process Organisation (PPO) meta-model framework is used to support information sharing. To share information issued from CAD systems is not easy because of the heterogeneity of used tools. To make collaboration efficient, each expert application or design tool should connect and interoperate with the shared framework. This paper illustrates the importance of interoperability as an issue for collaborative design. Then this work describes a meta-modelling architecture to synchronize heterogeneous models. A main step is the extraction of a model from an expert application in a readable format. We use a model driven approach to ease interoperability management. A case study is applied to Esprit^{TM} manufacturing model enabling Esprit^{TM} to interoperate with the PPO collaborative environment.

Keyword: Collaborative design, Interoperability, Models Transformations, Synchronisation, Meta-modelisation, MDA

1 Introduction

To improve the product design process, designers needs to share in real time design related information throughout a platform of collaborative environment. The design of a product involves the collaboration of many team members who are generally geographically distributed and using heterogeneous tools. The heterogeneity of tools implies different file formats and data representation which must be harmonized to ensure the coherence of the design. Complex design processes require the use of multiple CAD tools. The ability to share CAD data is important during product design and manufacturing. Integrating computer aided design (CAD) data tools into the design processes face a number of challenges. One of the most significant challenges is interoperability across the wide range of commercial CAD tools. Although many of these tools support industry data standards and thus claim to be interoperable, the connection between them is not seamless: data exchange through standards induces information lost and redundancy.

This paper presents a case study of tool integration at a collaborative environment. The study examines the enhancement of the product development process resulting from sharing the product model via a platform of collaborative environment. Sharing product model need the extraction, the translation and the synchronization of product data issued from various CAD tools. As a result, the designer will interoperate with the collaborative environment. Sharing and exchanging information from a model to another imposes a translations step. To implement translations between models, the approach suggested in this paper is based on the Model Driven Architecture.

Model Driven Architecture (MDA) [1] appeared after several years of existence of standards of modeling and meta-modeling like UML (Unified Modeling Language)[2] or the MOF (Meta Object Facility)[3]. The MDA offers a unifying framework necessary to the integration of these various activities. The MDA architecture is based on a hierarchy of three levels of abstraction for modeling the systems. The model: a representative of information produced by an expert on a specific project. The meta-model: the class identifying the grammar and dictionary available to create a model. The meta-meta-model: a minimal grammar for meta-model description. In this architecture well known as defined by the OMG, each level maintains a relation of instanciation with the higher level.

Through this meta-modelling architecture, the MDA supports the integration and the handling of heterogeneous models and makes thus possible a total and coherent development. Moreover, the transformation of model, key concept of MDA, authorizes the passage from a modelling field to another which allows, starting from sources models, to obtain models adapted to a particular point of view while keeping a single conceptual framework [4]. We wish to exploit this property in the design of manufacturer products. We are interested on the problem of interoperability in the context of collaborative design: more particularly between the platform of collaborative work and the tools of Computer-Aided Design.

The paper is organized as follows. Section 2 discusses the heterogeneity of CAD tools throughout a collaborative design scenario. We study how to ease interoperability between Esprit™ and the environment of collaborative design PPO via Meta-Modeling. Section 3 discuses main steps for interoperability implementation. An Algorithm to synchronise heterogeneous representations is presented.

2 Heterogeneity of CAD tools

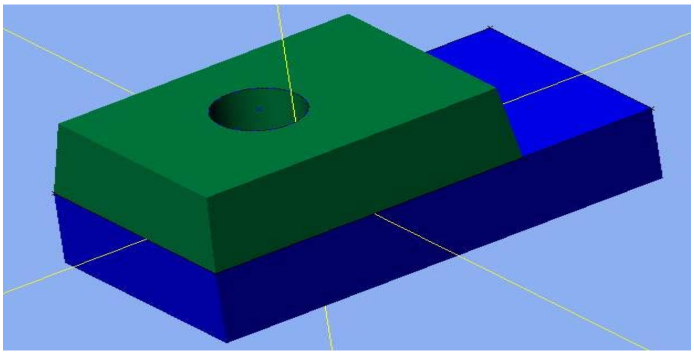
During the product life cycle, different tools are used to achieve the design and the manufacturing of a product. Combining multiple tools in a design process is a natural way to design a complex product. In a collaborative design process, CAD tools are applied concurrently, which means that multiple tools are integrated in one stage of the design flow. Let’s focus on the example of a scenario of collaborative design presented in the section bellow.

2.1 Collaborative design scenario

The design of a product consists of both design and manufacturing step: a designer and a manufacturer are employed at the same time to conceive and manufacture the whole product. A feedback between the two parts is essential. The correct interaction of tools is critical.

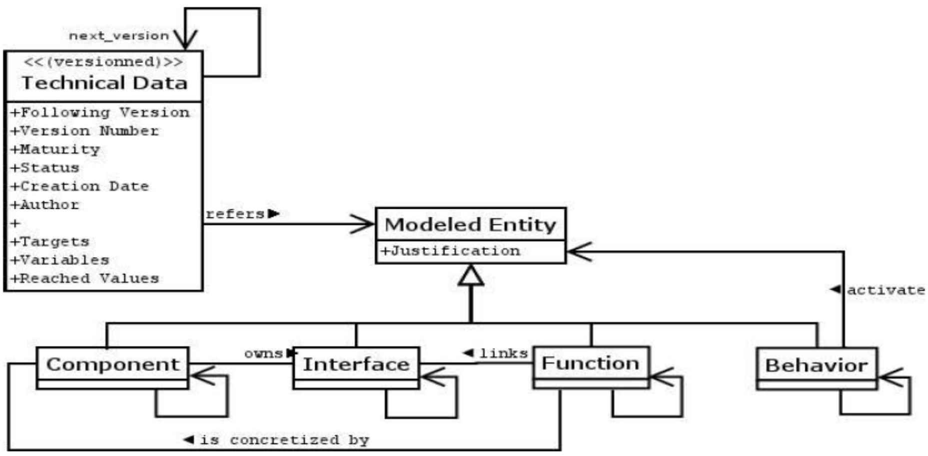
Suppose that the designer and the manufacturer are working on the same product. They use different tools. The manufacturer works for example with the Esprit^{TM} software [5]: he is in charge of the manufacture of the product. The designer is in charge of the representation of the product in a CAD tool. The work to achieve is the design of the assembly of a part A on its support B quickly represented in Figure 1. An assembly project A-B is created. The designer chooses to fix the part A on his support B by drilling. The manufacturer carries out the operation.

Figure 1 CAO Representation of the part A and the support B



Designer defines dimensions associated with each part in order to model drilling by using the CAD software. Manufacturer needs to know these parameters in order to carry out the manufacturing under the Esprit^{TM} software. Designers should share product model through the PPO Meta-Model. PPO (Produced Process Organization) Meta-model [6][7] is the result of integration of three models: a product meta-model, a process meta-model and a organization meta-model. It is a light meta-model (with few concept) and evolutionary. Figure 2 is an UML description of the product meta-model on which we concentrate our study.

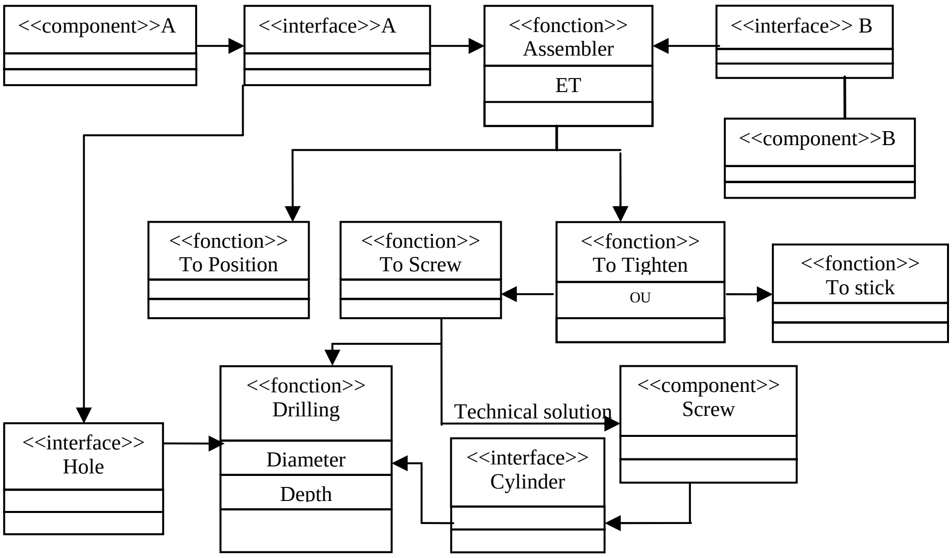
Figure 2 PPO product model



The major concepts of this meta-model are: component, interface, function and behaviour. A product is described by a component which is composed of one or more components. The class component inherits from the class Modeled Entity. With each component we associate interfaces. A function binds one or more interfaces. A behavior is associated to each component.

An instantiation of the product model is represented in Figure 3.

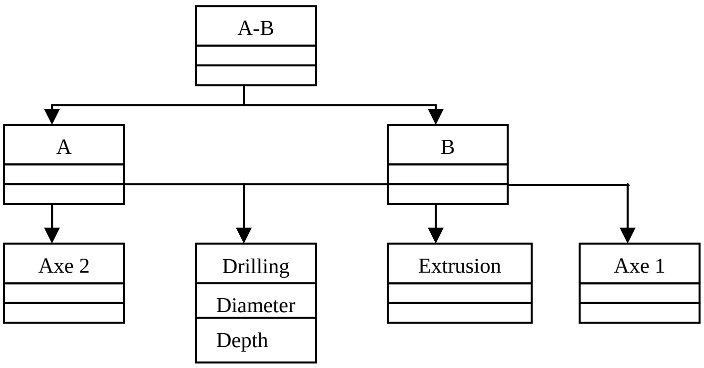
Figure 3 Instantiation of product model: assembly part A-support B



This model contains two components: components A and B. The function "to assemble" link two interfaces of the two components. To carry out the assembly, it is necessary to position and tighten. The expert selects a screwing solution. Screwing is carried out by the function drilling which binds the two interfaces: interface hole of part A and interface cylinder of the component screw.

For the machining operation, manufacturer recovers information from the product model shared via PPO. PPO Model cannot integrate specific rules to the processing of data resulting from Esprit™, else it should be done for any other expertise tool. It is thus chosen to let each expertise define connections rules to PPO.

Figure 4 Esprit™ Product Model

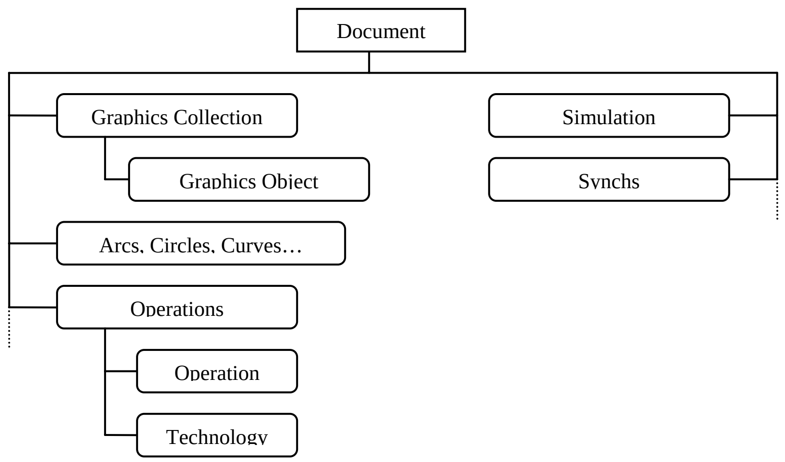


Manufacturer must thus specify the rules of translation between Esprit™ model and PPO model. Figure 4 shows the product model seen by the Esprit™ user. The Esprit™ model is based on a B-Rep model made up of a geometrical tree of characteristic entity. The model describes the structural decomposition of the system. Manufacturer needs primarily to share the data relating to machining operation, such as the depth and the diameter used for the drilling operation. In the paragraph bellow we study how to ease interoperability between Esprit and the environment of collaborative design PPO.

2.2 Meta-Modeling: a key stage of Interoperability

Tools interoperability is studied in terms of collaborative design management. This paper uses design and manufacturing tools as examples to test interoperability enhancement. We use the Esprit™ manufacturing tool in order to realize the machining operation. We suppose we access a collaborative framework dedicated to share design related information. Here we use the PPO framework to define the content shared by the collaborative framework. Generally this model doesn't feet the representation of CAD and manufacturing data. That's why retrieving specialised information is not a simple task. Esprit™ employs a mainly hierarchical model to describe the manufacturing model. In Esprit™ important informations are in a model called "Document". The figure 5 represents an extract of the Esprit™ product model. Importance of information depends on the point of view of each expert analysing the context of work and the objective to be reached. However we can extract from the complete Esprit™ model the information relevant for design collaboration: the machining operations, the tools used to achieve this operation, the information related to a specific face like drilling. Generally Esprit™ works with imported CAD model but until now there is no way to access the CAD Feature tree in the Esprit™ model.

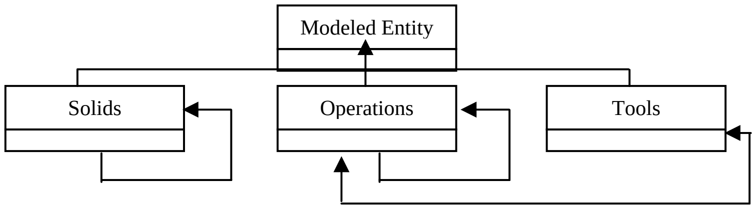
Figure 5 A partial view of Esprit™ model



A first step towards interoperability is the extraction of information from the specific tool. For that, tool developer should write a driver to extract the model that conforms a

Meta-Model. In the case of Esprit™, a Meta-Model simplified to essential information is proposed in the Figure 6.

Figure 6 Esprit™ Meta-Model



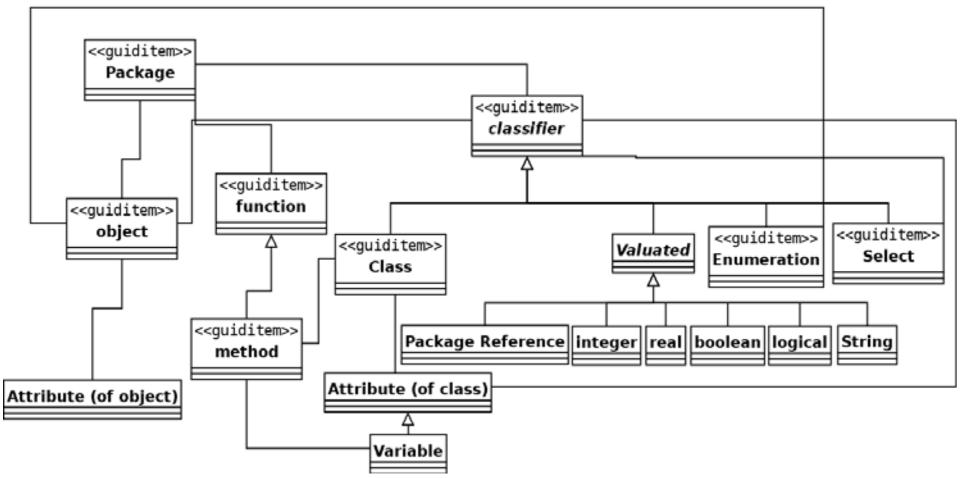
3 Interoperability implementation

Important step towards interoperability is to create Esprit™ and PPO Meta-Models. For that we need a way to express both, Meta-Models and models. We thus expect a meta-meta-model.

3.1 Meta-Meta-Modelisation

We use GAM which is a home made implementation of a meta-meta-model. GAM [8] encodes a language close to the MOF kernel [3]. GAM aims to provide a shared data base which is versioned, and which traces who is responsible of a change. The versioning system is also associated with undo redo functions which are built-in the core data base. Figure 7 represents the GAM Meta-Meta-Model. The instantiation of the GAM meta-meta-model provides either new meta-model description or associated models. Then Esprit™ meta-model and models but also PPO meta-model and models can be modelled with GAM: we can describe the classes used in the meta-model and instantiate these classes with object.

Figure 7 GAM Meta-Model



GAM provides some application protocol interfaces in several computer languages (C, python…) and creates XML files for permanent storage. Figure 8(a) describes a GAM file with the description of a simplified Esprit^{TM} meta-model. The Esprit^{TM} meta-model is composed of a package. The package contains the class Esprit which has some attribute like name. An Esprit class contains one or more solids which can be decomposed in one or more solids. This meta-model may be instantiated as a model in the same framework and provides a storage of relevant information for a specific Esprit^{TM} model. Figure 8(b) presents a sample of the Esprit^{TM} model developed for our example and exported as a GAM model. The object First Solid is an instanciation of the class solids in the Esprit^{TM} meta-model. The interest of this operation is to manage in a formal mode simultaneously the model and its meta-model.

Figure 8 (a)GAM simplified Esprit^{TM} meta-model, (b) GAM simplified Esprit^{TM} model

```
<Package uid="559132"
name="GAM_ESPRIT_Meta_Model">
    <Class uid="559250" name="Esprit" leaf="false"
abstract="true">
      <Specialise/>
    <Attribute name="User Name" classifier="String"
multiplicity="1"/>
          </Class>
<Class uid="559914" name="Solids" leaf="true"
abstract="false"> <Specialise>
<Class ref="559250"/>
</Specialise>
  <Attribute name="Child" classifier="559914"
multiplicity="1..*"/>
   <Attribute name="Part Name" classifier="String"
multiplicity="1"/>
  </Class>
```

(a)

```
    <Package uid="955881"
name="GAM_ESPRIT_Model">
       <Content>
        <Object uid="956313" name="FirstSolid"
classifier="1171374117.163674">
        <Attribute name="child">
         <Object uid="956463" name="SecondSolid"
classifier="163674">
           <Attribute name="child"/>
           <Attribute name="part_name"
value="MySecondSolid"/>
           </Object>
          </Object>
     </Content>
   </Package>
```

(b)

In the same way, this operation can be repeated for the PPO model. Figure 9 (a) (b) show samples of the GAM representation of PPO meta-model and PPO model for the defined example. A PPO meta-model is composed of package. The package contains the class Component, Function, Interface and Behaviour. The Figure 9 (a) represents a part of the description of this meta-model. Figure 9(b) presents a sample of the instanciation of PPO meta-model.

Figure 9 (a)GAM simplified PPO meta-model, (b) GAM simplified PPO model

```
<Package name="ProductModel" visible="true"
uid="9573879">
       <Content>
     <Class name="Component" abstract="false"
leaf="false" uid="9592700">
       <Attribute name="interface"
multiplicity="0..*" mode="mandatory"
unique="false" ordered="false"
classifier="9631250"/>
      <Attribute name="sub_component"
multiplicity="0..*" mode="mandatory"
unique="false" ordered="false"
classifier="9592700"/>
   <Specialise>
```

```
<Class ref="9616649"/>
        </Specialise>
 </Class>
        <Class name="Function" abstract="false"
leaf="false" uid="9578409">
        <Attribute name="working_component"
multiplicity="0..*" mode="mandatory"
unique="false" ordered="false"
classifier="9592700"/>
        <Attribute name="linked_interface"
multiplicity="0..*" mode="mandatory"
unique="false" ordered="false"
classifier="9631250"/>
```

(a)

```
<Object uid="929431" name="Component
A" classifier="9592700">
    <Attribute name="interface">
      <Object uid="929568" name="interface A"
classifier="9631250">
        <Attribute name="sub_interface"/>
        <Attribute name="decomposition_type"/>
      </Object>
      <Object uid="929780" name="interface B"
classifier="9631250">
        <Attribute name="sub_interface"/>
        <Attribute
name="decomposition_type"/>
      </Object>
      <Object uid="929913" name="Assembler"
classifier="9578409">
        <Attribute
name="working_component"/>
        <Attribute name="linked_interface">
        </Attribute>
        </Object>
```

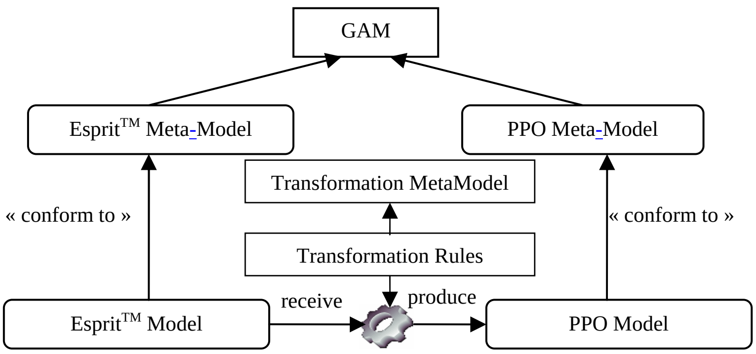
(b)

3.2 MDA approach

Once the Meta-Model and the model are specified, a framework to translate Esprit™ model into PPO is described in Figure10. The designer must define the rules of translations of models.

Our approach for interoperability between tools of design of product is based on the principle of Model Driven Architecture. In this approach, the information described by a tool is a model which conforms to a meta-model. This makes possible the use of transformations of models to convert a model to another.

Figure 10 Interoperability approach



In the MDA approach, specifying the correspondence in the Meta-Model level is a step for the models translations. The table bellows specify the correspondence between Esprit™ and PPO Meta-Model.

Table 1 Meta-Model Correspondence table

Esprit MetaModel	PPO MetaModel
Solids Operations Tools	Component Interface Functions Behaviors

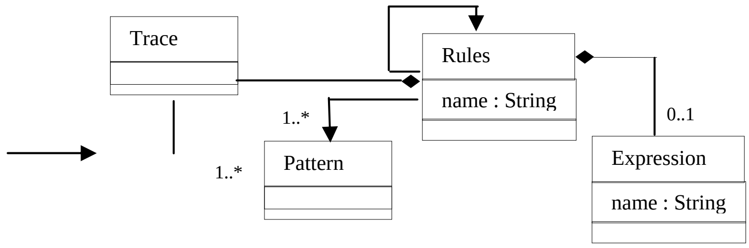
4 Algorithm to synchronise heterogeneous representations

To synchronize the PPO model and the Esprit model implies to create two versions of the PPO and Esprit models but which define the same design artefacts. We want to synchronise the PPO Model and the Esprit Model, for that we should follow some steps:

1. To associate the initial meta-models Esprit and PPO, the table 1 represent a correspondence between the concepts of the two models. The class solids correspond to the component element of the PPO meta-model, Tools are also traduced as component. Operations in the Esprit Meta-model are represented as a function in the PPO meta-model. In this step, we define rules between meta-models.

2. Transformations between meta-models: transformations rules are in the heart of each transformation. Rules are models that conforms a meta-model. The traceability preserves the consistency between two models. The meta-model of rules transformation is presented in Figure 11.

Figure 11 Transformation Meta-Model



This meta-model keep the traceability of the transformations rules since for each rule a trace is associated.

3. Once a modification is done on a model, the new model versions is created. The GAM framework offers a way to get the delta between two versions of the same model. The Figure 12 presents a fragment of the file that is generated automatically for each new modification.

Figure 12 Delta between two model version in GAM framework

<Move-Item uid="1171374150.956313" from-object="" from-device="" from-position="0" to-object="1171374150.955881" to-device="Content" to-position="-1"/>
<Insert-Item uid="1171374150.956313" device="Attribute" name="child" position="-1" sub-item="1171374150.956637"/>
<Set-Property uid="1171374150.956637" device="Attribute" name="part_name" property="value" old-value="" new-value="MyThirdSolid"/>

4. Having the delta between two version of the same model and the tracability of rules transformations, we could generate the new rules (modified rules) to synchronise the new version of the heterogeneous models.

5 Conclusion

The activity of design is a complex task which requires collaboration between designer handling heterogeneous tools via collaborative environments. In this paper PPO environment is proposed for the support of the information exchanges around the product. This paper discusses the interaction of heterogeneous CAD tools in the context of collaborative design environment. By studying the model of a CAD tool, we can know how tools should interact. Integrating multiple CAD tools then becomes the study of the interaction among models. The paper discusses the interaction of Esprit^{TM} manufacturing tool and PPO model. The approach suggested for interoperability is based on the Model Driven Architecture. An approach to structure synchronization of the exchanges is presented. The result shows that a correct interaction is not trivial, and each specific CAD tools should have its interaction. Indeed, MDA seems to be a very generic approach. However we first expect to test this method in real CAD case studies to finally measure how much generic is this method.

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Reference models – A key enabler for multi-life products

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Abstract: Reference models are an approach which is commonly applied to support the design of processes and information systems for business applications. They can be seen as a guideline to develop proper product and process structures. A reference model comprises generic components which can be concretised to represent a certain scenario. In the domain of PLM, reference models have not been commonly applied yet. This paper describes in detail the concept of reference models and current approaches of applying them. Further, aspects concerning the application of reference models to Product Lifecycle Management are discussed. As reference models can be identified to be a key enabler for Multi-Life Products, special focus is put on them within this context. Furthermore, the paper delineates a novel approach based on reference models to support the reengineering of product structures and Product Lifecycle Management processes in order to increase the efficiency of product development.

Keywords: Reference Models, Multi-Life Products, Product Lifecycle Management (PLM)

1 Introduction

Current markets for high technology products are characterised by globalisation and demanding customers. This forces the need for novel technologies, short time-to-market and low market prices. The concepts of PLM (Product Lifecycle Management) are seen to be expedient to cope with these challenges. But in order to get them applied several reengineering activities of products, processes and organisation structures are required. Especially in case of complex products and processes these activities are likewise extensive. Additionally, reengineering activities are often aggravated by a lack of accordant expertise. In particular, SMEs (small and medium enterprises) have a strong focus on their day-to-day business and thus are often overburdened by PLM-related initiatives. Reference models for PLM-scenarios can function as a guideline through the reengineering process. They incorporate common and approved knowledge and make reengineering activities applicable for SMEs. Further, reference models are a key enabler for Multi-Life Products which are characterised by their suitability for multiple market cycles. The concept of reference models as well as their application to PLM and particularly Multi-Life Products will be delineated in this paper.

Chapter 2 gives a short introduction to PLM and Multi-Life Products. In chapter 3 the concept of reference models and current approaches to apply them will be described. Chapter 4 describes the application of reference models for PLM and especially Multi-Life Products. Finally, chapter 5 summarises this contribution.

2 PLM and Multi-Life Products

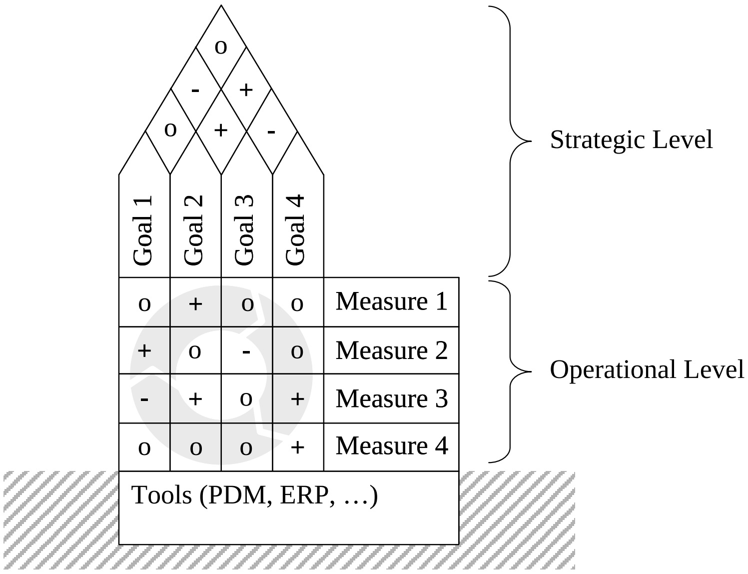
2.1 PLM

During the last years the idea of PLM which emerged in about 2001 [1] has been disseminated in the engineering community. Nowadays, the concepts of PLM are widely perceived and commonly applied in industry. Several definitions of the term "Product Lifecycle Management" exist. These definitions are slightly different but have some aspects in common. PLM is sometimes seen as term for software tools like PDM (Product Data Management) or ERP (Enterprise Resource Planning) [2]. Especially companies which are involved in developing the mentioned software tools propagate this definition. More comprehensive and commonly accepted is the definition of PLM as a strategy [3,4], also called a business concept [5] or an integrated approach [6,7]. A PLM strategy is stated to be knowledge based [4,5,6,7,8]. Hence, PLM focuses not on the lifecycle of a physical product, but on the knowledge describing this lifecycle. The product lifecycle related knowledge can be seen a crucial resource for companies to persist in dynamically changing markets. An aspect which is at least implicitly common through all definitions of PLM is the temporal focus. PLM covers the entire lifecycle of a (virtual) product from the first product idea through development, manufacturing, deployment and maintenance culminating in the product's disposal [3,7]. Even if it is not explicitly mentioned in most cases, the focused object within PLM is not a certain product, but the whole portfolio [1].

The several aspects of PLM which are described above are subsumed by the definition proposed by the authors: *Product Lifecycle Management (PLM) is a knowledge-based enterprise strategy for all processes and methods regarding the development of products from the product idea to recycling* [9].

A definition of PLM as a strategic approach comprises implicitly an operational level as well as PLM-supporting tools. This is depicted by the House of PLM which is shown in Figure 1. The strategic level of PLM is represented by the roof. A strategy is constituted by a bunch of goals (goal 1 … goal 4, Figure 1) which are connected by cause-effect relations [10]. These relations can be of positive or negative character. A positive cause-effect relation between two goals indicates that one goal will be supported by the other one. A goal which interferes with another one is indicated by a negative cause-effect relation. The floors beneath the roof represent the operational level of PLM. Operational measures (measure 1 … measure 4, Figure 1) are applied to reach the strategic goals. Such a measure can contribute to reach a certain goal (indicated by a "+"), but can also counteract that goal (indicated by a "-"). By taking supporting and interfering dependencies between measures and strategic goals into account the House of PLM helps to operationalise a PLM-strategy. The fundament of the house represents the PLM-supporting tools like PDM or ERP systems which are necessary to implement the operational measures efficiently in a commercial environment.

Figure 1 The House of PLM.



2.2 Multi-Life-Products

The definition of PLM mentioned in section 2.1 implies an important issue regarding the product and its design. Variants and/or amendments which are required to fit future market conditions should be realisable without extensive redesign. Changed market conditions determine different market cycles. Products which life cycle can outlast several market cycles are called *Multi-Life Products* [9]. Conventional products which are designed for just a single market cycle are denoted *Single-Life Products*.

To make Multi-Life Products persistent over numerous market cycles, the capability to adapt to changing requirements is required. Therefore, future needs already have to be taken into account when the product is planned. These needs influence the product design, but are not realised at the time of first market launch.

An appropriate product architecture (the functional and the physical structure of a product together with the correlations between these structures [11]) is required to realise Multi-Life Products. Especially the specification of interfaces between the product components is of particular importance. The adaptability towards changing market conditions requires a standardisation of interfaces which encapsulate the mechanical, electrical and software components. This makes the components replaceable. Furthermore, the components can easily be redesigned without side-effects to other components. Common approaches to structure the product architecture accordingly are for example construction kits, modules and platforms [9]. Reference models can be subsidiarily applied to ensure generation-spanning compatibility of components and their constituents from different disciplines (mechanic, electronic, software) and different suppliers.

3 Reference Models

3.1 The Concept of Reference Models

So far, the concept of reference models has been primarily investigated by the German business information systems community. A reference model is a generic information model with a variable application context [12]. Based on a certain reference model multiple application models can be derived. The following major properties characterise reference models [13]:

- **Universal validity**. A reference model features universal validity. This means, that it is applicable for a certain category of application scenarios. Because reference models are applied by deriving a specialised model (as described below), a bunch of application models can be derived from a universally valid reference model. An application model is a specific model which describes a certain application scenario.
- **Reference character**. Reference models can be seen as a guideline for the derived application models. The application models are created based on predefined components of the reference model [14]. These components incorporate valid knowledge and experience. Therefore, a reference model represents a nominal condition [13]. In practice, the reference character of a certain model may be arguable and especially dependent on the experience of the originator regarding the application scenarios [13]. A significant validation of a reference model requires the derivation and evaluation of multiple application models.

Considering the definition and characteristics of reference models delineated above, a reference model can be summarized as an ideal abstract model constituting a reference for a certain category of application models.

The application of reference models is based on the principle of concretion. A model can be concretised by configuration, aggregation, specialisation, instantiation and analogical creation [13,15].

Figure 3 The structure of a reference model.

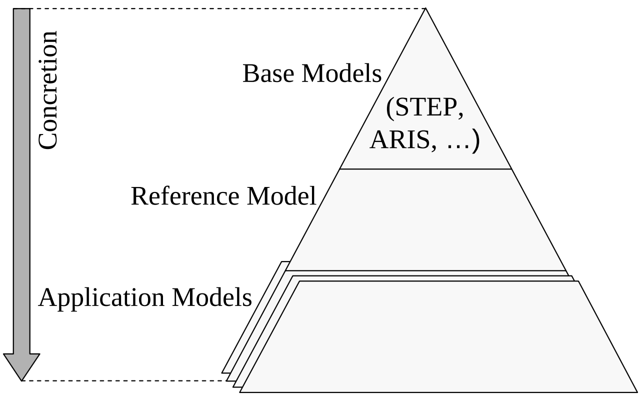


Figure 3 depicts the structure of a reference model. It can be deduced by concretion from existing base models (for example STEP and ARIS in case of PLM, see chapter 4). The reference model comprises model elements describing aspects which are common to all application scenarios. Further concretion of the reference model leads to the application models which describe a certain application scenario in detail. These models include all aspects relevant for this scenario. Irrelevant aspects are discarded in order to structure the application model as generally applicable as possible. The application of reference models within PLM is be described in chapter 4.

Reference models can be applied for several kinds of scenarios (section 3.2). A common intention for the application of reference models is to enhance the efficiency and effectiveness concerning the creation of application models. Because reference models are based on predefined and reusable model components the derived application models will benefit from synergy effects. Due to the reference character described above the quality of application models will increase. Furthermore, reference models store explicit knowledge of the application domain [16] and make it available through the derivation of application models. Therefore, reference models can be considered a medium of knowledge management.

3.2 Current Approaches to Apply Reference Models

Reference models are commonly deployed to develop and maintain commercial information systems, especially ERP-Systems (Enterprise Resource Planning), to utilise the business process knowledge incorporated by the reference models as well as best practises [17]. Generally, these reference models are provided by the software vendors or consultant companies. SAP’s R/3 software documentation for example is a reference model which has been developed largely in accordance with the Event-Driven Process Chain (EPC) method. A very comprehensive reference model for business process and software applications is provided in line with the ARIS-House of Business Engineering (Architecture for Integrated Information Systems) [18]. Further areas in which reference models have been applied are data-warehouse systems [16,19] as well as hospital and public administration systems [20,21]. A commonly used reference model for network applications is the OSI-Model (Open Systems Interconnection Reference Model) [22]. For PLM and PDM reference models have not been widely applied yet.

4 How can Reference Models be expedient for PLM and Multi-Life Products?

The management of product data and processes along the product lifecycle as well as an adequate adaptation of information systems requires a lot of integrative knowledge and skills ranging over the various disciplines of PLM. Additionally, knowledge about product modelling, processes integration and engineering information systems like PDM systems is required. Especially SMEs (Small and Medium Enterprise) often lack these knowledge and skills because employees are strongly engaged in the core business. Their expertise mainly lays in the development of products and appropriate manufacturing resources.

As a result, a couple of problems occur. A missing or incomplete product data model aggravates multiple use of product data. Moreover, the retrieval of product related information and product data will be time consuming and further use of outdated versions takes place. Necessary modifications of components used in multiple assemblies are inhibited because the resulting effects towards the assemblies cannot be retrieved. A version management does not exist, so that iteration states get lost. Missing or incomplete process definitions lead to intransparent processes, especially if several stakeholders are involved. Furthermore, responsibilities are not clearly defined.

Reference models can be commonly applied for PLM to provide knowledge which is required for the management of product data and processes. A reference model representing a certain scenario (a sequence of events with associated entities [23]) incorporates knowledge about this scenario. In case of PLM, a reference model represents valid product, process and organisation models. Therefore, a reference model can on the one hand support the SMEs concerning modelling purposes. On the other hand, consulting companies are enabled to better understand the product and process structures of the SMEs.

Section 4.1 describes an approach to apply reference models to support reengineering activities of arbitrary PLM-scenarios. Reengineering means purposeful modification of such scenarios comprising certain products, processes and organisational units. A specific class of PLM scenarios is constituted by Multi-Life Products as they are associated to a sequence of market changes. The mentioned approach is particularly expedient to support the reengineering of conventional Single-Life Products and associated processes to create Multi-Life Products (section 4.2).

4.1 Reference Models for Product and Process Reengineering

A holistic reengineering approach aims at optimising the product lifecycle concerning time-to-market, costs and quality. Especially in case of complex products and processes according reengineering activities are likewise complex and require much effort to be elaborated. Models describing the reengineered objects help to accomplish that complexity.

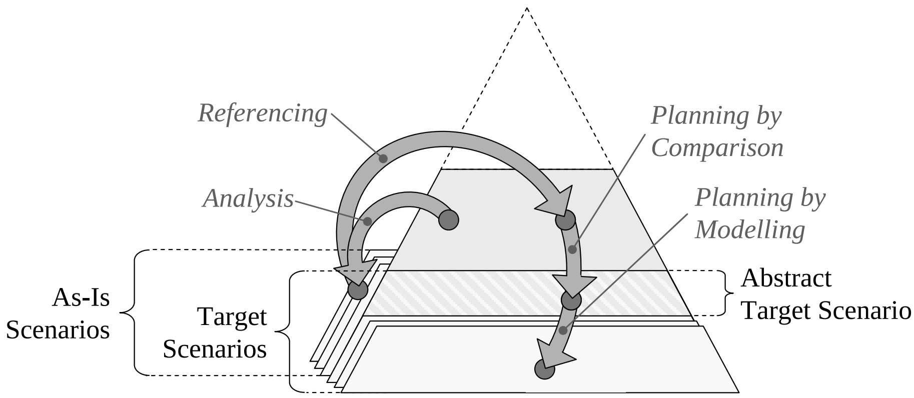
To describe an entire PLM-scenario, a product model, a process model and a role model are required [24]. Whilst reference role models are not known to have been developed so far, several reference models for process and product modelling exist. The common standard for product data exchange STEP can be seen as a reference model for products. ARIS provides a reference model for business processes. To create a reference model for applications in the context of PLM both, STEP and ARIS, can be taken into account as base models (cp. Figure 3). An initial concretion step is required in order to integrate these base models. Further concretion steps will integrate a role model and finally result in a reference model for a PLM-scenario.

Figure 4 depicts an approach to use a reference model as a tool for reengineering (model-driven lifecycle engineering). The reference model will be applied for analysing the current state (as-is scenario[1]). It will be amended by a predefined abstract target scenario as a specific reference model for the target scenarios[2]. Like the application scenarios, the abstract target scenario is derived from the reference model by concretion, but it is more abstract than an application scenario. Similar to the reference model comprising model elements which are common to all application scenarios, the abstract target scenario contains model elements which are common to the target scenarios. Therefore, each target scenario can be deduced from the abstract target scenario by concretion.

[1] An *as-is scenario* is an application scenario. It denotes the original scenario to be reengineered.

[2] A *target scenario* is an application scenario. It describes the desired outcome of the reengineering activities.

Figure 4 Model-driven lifecycle engineering based on a reference model with an abstract target scenario.



As a first step of the reengineering process the current state of the as-is scenario will be analysed and documented (Figure 4). For this purpose, an application model describing the as-is scenario will be derived by concretion of elements from the reference model. On the one hand, that makes the analysis more efficient because precreated and approved model components (from the reference model) are used. On the other hand, it is a prerequisite to perform the subsequent referencing step. In line with the referencing step (Figure 4) the references between the reference model and the model of the as-is scenario which have been established by the prior concretion steps are elaborated. This enables the first of two planning steps (planning by comparison, Figure 4) to be performed based on a comparison between the as-is scenario and the predefined abstract target scenario. As both, the model for the as-is scenario and the model for the abstract target scenario have been derived from the reference model, the references created during the prior step indicate how to reengineer the as-is scenario in order to conform to the abstract target scenario. During this planning by comparison step no modelling activities are performed. Instead, the abstract target scenario is used as a guideline to plan reengineering activities. In line with the second planning step (planning by modelling, Figure 4) the reengineering process will be completed resulting in a target scenario: The model of the abstract target scenario will be completed by concretion yielding a model for the target scenario. This application model can be utilised on the one hand to derive appropriate reengineering activities and on the other hand to control the outcome of these activities.

4.2 Reference Models for Multi-Life Products

A problem which ordinarily occurs, if Multi-Life Products are to be designed, is to anticipate future market cycles. Reference models supplemented by a model for an abstract target scenario evade this problem. Such an approach eases the design of products outlasting several market cycles and thus makes reference models become a key enabler for Multi-Life Products.

If a set of Single-Life Products is interpreted as an as-is scenario and a Multi-Life Product as an abstract target scenario, the approach described in section 4.1 can be applied to design a Multi-Life Product replacing several Single-Life Products. For this purpose, a reference model describing common characteristics of a certain class of products is required. If the reference model is on the one hand more generic, it will be applicable to a wider range of products. A more specific reference model on the other hand will make the modelling as well as the reengineering more efficient. Furthermore, a model for the abstract target scenario has to be created which defines common characteristics making a product suitable for multiple market cycles. Dependencies of product architecture and interface definitions, for example, should be described by that model.

Figure 5 A reference model for Multi-Life Products enables a single product lifecycle spanning several market cycles.

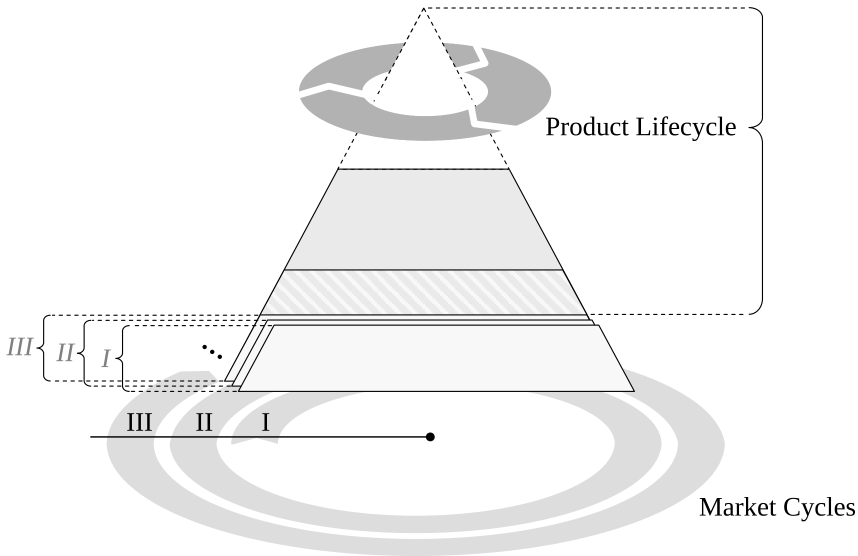


Figure 5 illustrates the application of reference models to design Multi-Life Products. As a Multi-Life Product incorporates characteristics which are commonly appropriate for several market cycles it can be interpreted as an abstract target scenario. Each of the derived target-scenarios describes a well defined product appropriate to be distributed during a distinct market cycle (I-III, Figure 5).

This approach reduces the problem to anticipate market cycles to the problem of defining a product model which covers several market cycles. A distinct product definition appropriate for a certain market cycle (target scenario) can be derived from that model, as soon as the characteristics of the market cycle will be predictable. Furthermore, the reference model supports the reengineering process of Single-Life Products (as-is scenario) resulting in a Multi-Life Product (abstract target scenario) as described in section 4.1.

A Reference product structure [25] is an example for an abstract target scenario representing a Multi-Life Products. Reference product structures describe components of a product structure which are common to multiple market cycles. Further, reference product structures incorporate constraints to model feasible modifications. This makes them easily adaptable to changing market conditions.

5 Summary and Outlook

Reference models are an approach which has been widely applied for several business processes and commercial information systems like ERP systems, data-warehouse systems and hospital as well as public administration systems. The approach has been proven to be expedient to provide knowledge incorporated by common model components and to guide the creation of application models. In this paper a novel approach to apply reference models to PLM and Multi-Life Products which is based on a model for an abstract target scenario is proposed. That approach makes reengineering activities towards a shorter time-to-market, lower costs and a higher quality more efficient and enables SMEs to perform these activities. Additionally, in case of Multi-Life Products reference models are a key enabler because they evade the problem to anticipate future market cycles. Further research will be required to develop reference models for concrete example scenarios in order to fully fathom the potential of reference models for PLM.

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Chapter 7

Knowledge engineering

Knowledge integration and transfer at PLM: a crown gear case study

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Abstract: Product Life Cycle Management (PLM) is a relatively new research concept. PLM integrates the information and knowledge generated during a product's lifecycle to improve it and make the collaborative work easier. A case study is presented to see how knowledge integration using CAD and CAE tools is required for PLM to support a crown gear design at a Swiss metal-working company. CAD tools were implemented to generate a virtual prototype which was used to perform CAE. Finite Element Modeling (FEM) was used to do this engineering analysis. This paper focuses on knowledge integration at collaborative workspace as an issue required at product design stage using a PLM concept. This paper argues that it is required information and knowledge structures along the project life cycle using new methods to obtain product design knowledge integration at PLM.

Keyword: Design knowledge integration, knowledge transfer, Collaborative engineering, PLM

1 Introduction

As companies realize the importance of properly managing their information assets, product lifecycle management (PLM) is being increasingly –but slowly– considered a must. Since its appearance three decades ago, the concept of PLM has been found to be effective and useful hence several PLM tools or solutions are being developed [Rangan, 2005]. Although there are many of these tools in the market, the underlying concept beneath them is the same. Perhaps the most complete definition of PLM is: "A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information, supporting the extended enterprise (customers, design and supply partners, etc.), spanning from concept to end of life of a product or plant and integrating people, processes, business systems, and information" [Terzi, 2005].

Information and data management is one of PLM's main goals, however the authors of this research believe that PLM has also a strong potential for Knowledge Management (KM). The difference between these types of management relies on the difference of some important concept definitions. Data is objective and independent of someone's capability of understanding its meaning; information is data applied into a specific context, which gives meaning to it [Guerra and Young, 2005]; knowledge is the elementary block of experience populating the human mind that makes humans able to interpret new data and process it to transform into new knowledge [Colombo, 2005]. Keeping that difference in mind, KM is a mechanism that facilitates critical organizational processes to support: a) innovation, the generation of new ideas, and the exploitation of the organization's thinking power; b) capturing insight and experience; c) reusing sources of know-how and expertise, d) fostering collaboration, knowledge sharing, continual learning; e) improving the quality of decision making [Levett and Guenov, 2000].

The design knowledge required and generated at the design stage of a product has its own classification. In this research explicit knowledge is considered to be commonly known in the particular field of application – as for example the basic mechanical design theories described in manuals.. Tacit knowledge is considered a personal knowledge coming from the experience that every designer acquires during everyday activity and can be also linked to a subjective condition – in this case an example could be the particular experience obtained from a past project; on the other hand, implicit knowledge could be inferred from an observable behavior [Nickols, 2000]. It is interesting to notice that unlike explicit knowledge,, tacit knowledge is subjective: thus it is difficult to capture and formalize it [Nonaka and Takeuchi, 1995], [Nickols, 2000], [Guerra et al 2005], [Guerra-Zubiaga et al, 2006].

The authors of this research work believe that the understanding and classification of knowledge types are required to obtain knowledge integration at collaborative workspace within the product design stage at PLM environment. A PLM system should be able to provide engineering collaboration and project management tools to help with milestone decisions among geographically dispersed sites [Iyer, 2005].

This paper is structured as follows. In section two the methodology proposed for the knowledge integration and transfer is presented. Section three shows a case study implementing a PLM tool for the design of a crown gear. This case study presents how the understanding and classification of knowledge types are required to obtain knowledge integration at collaborative workspace within the product design stage at PLM environment at this section the generation of design knowledge and its capture is discussed.

2 A PLM Configuration to achieve Knowledge Management

PLM systems are developed to manage all the information/data in the product life-cycle because there are shortcomings for knowledge management. For these reasons, this research intended to explore how a PLM can be configured to be used as a product knowledge management system. The following activities are proposed to accomplish this kind of configuration.

2.1 Define product design parameters to be improved

It is important to identify which product parameters present higher impact to the market value. These parameters are going to be used to evaluate each design developed, consequently selecting which design contributes to the product knowledge. Some activities to obtain these parameters are: (i) identify final customer requirements; (ii) translate customer requirements to technical requirements using methodologies like QFD (Quality Function Deployment)

2.2 Use of the different information/document management tools.

Document management is functionality for managing documents that allows users to store, retrieve, and share them with security and version control [API, 1997]. A document management system consists of several functions to support the document life cycle such as (i) document creation and importing, (ii) data storage, (iii) document editing, (iv) publishing, (v) viewing, (vi) archiving (long-term storage), and (vii) document disposal. [Persson, 2005]

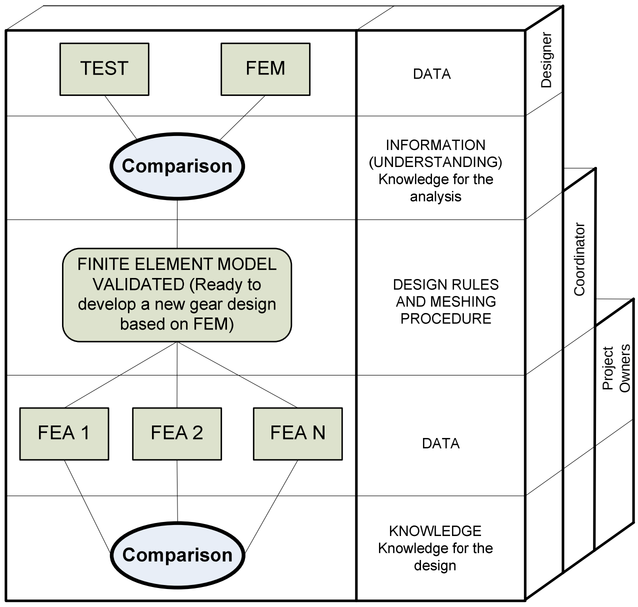
The information in a Product Data Management (PDM) system is structured to follow an object-oriented product information model [Silberschatz, 1997] [Kroenke, 1996]. There are two different types of objects: business items and data items. Business items are objects used for representing parts, assemblies, documents etc. A business item contains metadata and attributes. Metadata describes properties of the product data. An attribute consists of a value and a name, and may be customized.

One manner to organize business or data items is named tree structure; data files are categorized according to general topics or importance. Nowadays, with the computational and technological development reached, this kind of structure has been left behind and new organizational methods for information and Knowledge Management tools such as indexation have been developed.

The actual data is stored in files and is represented in the database as data items. Separating business items and data items provides support for managing heterogeneous data and enables replication of metadata separately. One business item can be related to several data items. Relationships are used between business items and data items. Business items can build a tree structure including several levels of business items. A data item is always related to a business item, and represents a leaf in the tree structure. Attributes can be defined either on objects or relationships. [Persson, 2005]

It is important to identify when data items become information or knowledge. In the Figure 1 is explained how data become knowledge in a typical simulation process. The first step is an experimental analysis and Finite Element Model (FEM) development, at this stage only *data* is generated without any value added to improve the product. After this step, a comparison is made between the physical test and FEM data with the purpose of understanding the data collected and documenting the experiences obtained along the FEM construction. The result of this comparison is *information* because data became related within a context [Guerra and Young 2005] [Guerra et al 2005]. Furthermore, the team's interpretation or understanding of such information is *knowledge* and it can be applied in future design stages. The type of knowledge representation depends on the format used to store it. In the third step, FEM's boundary conditions and meshing procedures are validated using the data obtained from experimental tests. This FEM contains design rules and additionally the meshing procedures are documented. Meshing procedures are explicit type of knowledge. In the fourth step Finite Element Analysis (FEA) are developed and new solutions are obtained. Finally, another comparison is developed and the best solution is selected, obtaining in this process deep product knowledge. The experiences obtained from building FEMs and refining them constitute knowledge; if such experiences are structured in storytelling format they are tacit knowledge [Nonaka and Takeuchi, 1995], [Guerra and Young, 2005].

Figure 1 Constructing Knowledge in a Simulation process.



Information/knowledge is captured and managed by the different project members. For this reason the data/information/knowledge is managed by the PDM software system, and only information relevant for each member is showed.

The objective is to classify the information generated using metadata, document lifecycle (workflows) and technical requirements. The use of workflows is really important to store generated information and knowledge in specific folders according to a tree structure.

2.3 Define a product design process.

Product design processes are defined using workflows, which are a collection of process steps (activities) organized to accomplish some business process [Koksal, 1999]. Using workflows the process design process is developed, which presents the following objectives:

- Improve the coordination between the project team, identifying specific tasks and linking specific documents to each activity.
- Document the process design. Each product design workflow is stored, and can be retrieved to identify how the design team improves specific parameters in the product. That is possible, because in the workflow process is attached the technical requirements identified in the first stage, and each project member can evaluate his design contributions.

2.4 Use of Collaboration Tools

Collaboration tools are used to share the information/knowledge between the different project members (designers, coordinators), supported on web platforms. These tools present the capability to transfer both information and knowledge among all the project members. In this manner project knowledge can be shared and integrated similarly to contributions from each team member.

3 Case study

A project was carried out for a gear company in Switzerland. Following the methodology outlined in section 2 several engineering tasks were done during this project, such as experimental testing (with the use of deformation gauges and other measuring equipment) and the realization of several FEM models. These two main tasks were performed in parallel. The coordination of these tasks was done using PLM and PDM tools. Several computer based information systems were introduced to support integrated product development methodology, which integrates all the activities, methods, information and technologies to conceive the complete Product Life Cycle [Peñaranda et al, 2006]. According to the methodology proposed and described in section 2 this section describes each activity implemented to manage the information and knowledge in this case study.

3.1 Define product design parameters to be improved

The main task of this project was the modification of gear tooth geometry to improve the capabilities of the gear. The customer requirements were provided to the design team during meetings using an informal or a non engineering language. The team also got valuable information from charts, previous results, reports and drawings.

Many of the customer requirements were engineering parameters that had to be taken into consideration when modifying or studying a complex mechanical piece such as gear tooth: load capacity, deformations and stresses, torque transfer and surface geometry.

The project owner used customer requirements tools such QFD to provide the product design parameters mentioned.

3.2 Use of the different information/document management tools

The information and knowledge management refers to all the information concerning the project. This is usually managed by a PLM system under a PDM infrastructure. In this case, the information was managed using TeamCenter ® (a PDM solution by UGS ®). The user allows the client to visualize through a website the data platform implemented in TeamCenter ® and review the project advances. With the use of these tools, the organization of the project's information was successful.

Three methods were used in this project to organize files through TeamCenter®: metadata structuring, linking of files and information organization structure. As for the metadata structuring, each uploaded file required information describing the file contents. This short description would help to find the file with the information provided. Also, this short explanation appeared on the web utility version of TeamCenter ® where the client/project owner could read a short review about each file before accessing them, facilitating and saving time during an assessment. This file description should be concise, short and should describe the file's information from all the perspectives of the product lifecycle.

Some of the files were "linked". Links are often used by software to relate one file with another. It was possible to establish any relation between an uploaded file and another item within the project network. Thus when the user reached a file within the network, a list of related files appeared on the screen. For this project, text documents, CAD and CAE files from various programs were required therefore the use of links among files was key to find correct information and their relation in a suitable time.

This case study required organizing information in structures and a tree structure was selected. The tree structure organization used was an efficient and easy way to organize files by importance or general topics as seen in Table 1. Designers decided to create sub-levels of organization called Working Packages (WP), each WP attended a different area of the project advances.

Table 1 Gear Project knowledge and information categorization. Tree structure.

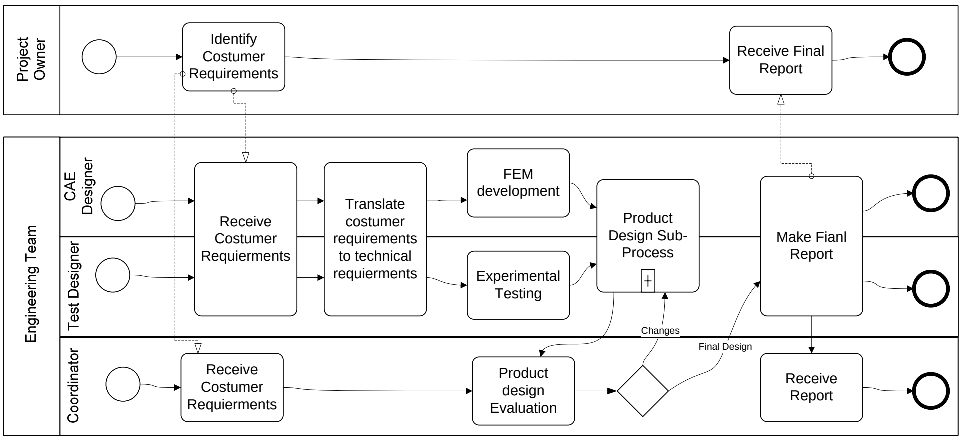
WP01 – CROWN GEAR REVIEW (Data and Information)
- Manufacturing Process for specialized gears.
- Gear Geometrical and Mechanical Design.
- Geometrical parameters
- Materials specification and analysis
- Design Parameters
- Gear Experimental and Computer Aided Testing: Results Analysis
WP02 – GEAR SPECIALIZED AND CAD/CAE SOFTWARE REVIEW (Information and Knowledge)
- Machine element design software
- Specialized software provided by the company
- CAD/CAE Software
WP03 – GEAR SIMULATION ON CAE AND SPECIFIC SOFTWARE (Information and Knowledge)
- Gear Geometry Design
- Machine Element Design and CAE Simulations
WP04 – GEAR EXPERIMENTAL TESTING (Explicit and Tacit Knowledge)
- Reports, photographs and videos
- Organization of output data

WP05 – PROJECT RESULTS (Explicit and Tacit Knowledge)
- CAE validation. Comparison between the experimental testing and Computer simulations
- Final Report: Analysis on results and recommended modifications.

3.3 Define a product design process

Coordination tools comprise all the workflows required to follow the realization of a multidisciplinary project. These tools help to understand the product development stages during its realization and lifecycle. A main workflow was planned according to figure 2 but unfortunately the time span was not enough to use it completely.

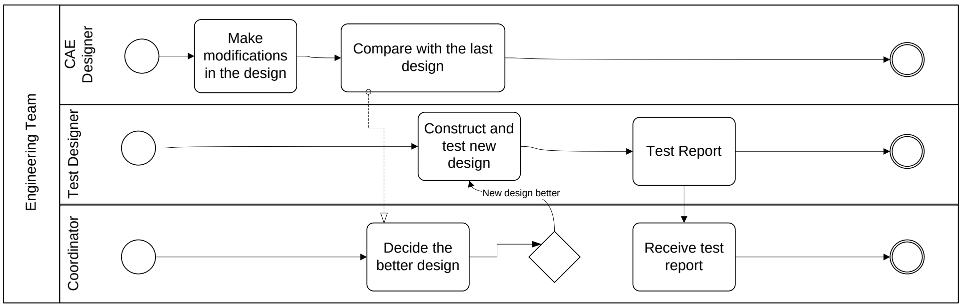
Figure 2 Main Process Workflow



The customer requirements were treated as information and they were not entirely understandable because some of it needed to be transformed into technical requirements. The validation process is the process in which the FEM is compared with the experimental testing data to prove that the results obtained from the CAE software are correct, while the CAD geometry was also verified. These two activities were concurrently performed by two different members of the engineering team. After the two activities were completed and the results were post processed, the comparison between them took place. After validating the information, a technical report was written, including both CAD and CAE results and their specific data provided. The design process (Figure 3) starts by analyzing the project owner requirements. It was required to translate these requirements into an engineering language to have full understanding of the physical phenomena involved. After a careful study of the variables some changes in the previous FEM had to be made. These changes would depend on the case of optimization either involving a change of material, a partial or a complete geometry change. Once data from the FEM were obtained it were compared with the previous models obtained to see if any improvement was accomplished. If no improvement was made, it could be said that the original model was in an optimal state. In case the new FEM results were better than the past ones, a new prototype should be manufactured to perform new experimental tests and validate the FEM model.

This last step could not be achieved during this project since a lack of time, even though the organization for this workflow to work was done. The validation of the last steps was left as further research work.

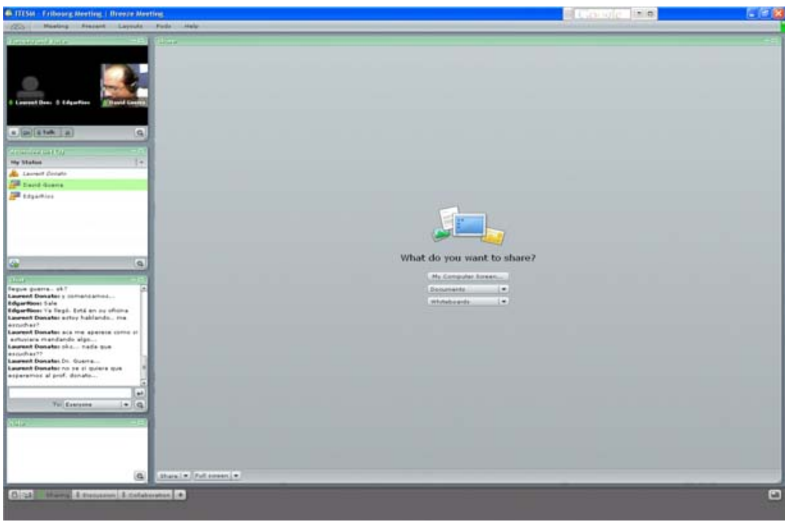
Figure 3 Design Process workflow



3.4 *Use of Collaboration tools*

Collaboration tools are of extreme importance because they enable communication among team members. For the presented case study the software named Breeze ® (shown in figure 5) was used to share information and to make online meetings between team members from University EIA (in Switzerland) and ITESM Campus Monterrey (in Mexico). This kind of collaboration tools allows its users to share information, data and even transfer knowledge. This software played a very important role since it was a bridge and a communication system that allowed important decision making and to keep track of project advances. Through this software video-conferences were made and files, information, pictures, reports and results were transferred.

Figure 4 Collaboration tools (Breeze ®) used to knowledge and information transfer



4 Discussion of results, conclusion and further research

Relevant data, information and knowledge are generated along product development process. The data and information can be capture using proper PDM systems that in this case was TeamCenter. However, there are different formats to capture design knowledge types. Current knowledge can be capture at explicit knowledge representation such as procedures, graphs and tables using a tree structure. Different design knowledge types mainly tacit can be capture using photos and videos using the same tree structure. Tacit design knowledge capture disadvantage is the reduce types of knowledge representation such as video clips. Knowledge types classification within a tree structure can be used through PDM system at PLM. The main advantage of information and knowledge capture through the product lifecycle is that designers can avoid important knowledge lose at the product realization process.

To promote a good habit for the creation, capture and reuse of relevant information and knowledge is required to provide PLM developers (engineering designers) with knowledge types representation as well as methods, techniques and tools (PLM tools) to manage the large amount of information and knowledge generated through the product development process.

Relevant knowledge integration was obtained defining new structures, tools and methods to support product development designers. The engineering team at development process used this approach to manage the large amount of information and knowledge enhancing engineering decisions.

A case study where a PLM configuration to achieve knowledge management was presented in this paper.. The case success was in part, due to the use of Information and knowledge management concepts, in addition to coordination and collaboration tools tools.

Acknowledgments

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A framework for ontology-based manufacturing support systems

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Abstract: Conventionally, design data originally produced in the design department of a company is modified and/or changed by the subsequent departments, such as production, purchase, quality control, and marketing & sales. Each department extracts or saves its necessary information from the product information of a design stage, then, modifies it so as to reflect the characteristics of the department. Many design data are prepared to produce a product, but these data include complicated relationships between parts and processes, which are essential in the design of a production system. However, existing commercial systems do not sufficiently provide functions such as the representation of the relationships and/or features, nor do they support the information required in the subsequent department. Ontology is an information model technology that can be used for many purposes, including enterprise integration, database design, information retrieval and interchange on the Next Generation Web (Semantic Web). This paper addresses a framework for ontology-based manufacturing support systems, which models the relationships among design data, as well as the information in each department. Meta-data implemented through OWL provide inference-based query functions, enhancing the efficiency and usability of the design data. The framework is applied into ontology-based CAPP (Computer-Aided Process Planning) for NC machining processes.

Keyword: Ontology, Semantic Web, OWL, Metadata, CAPP

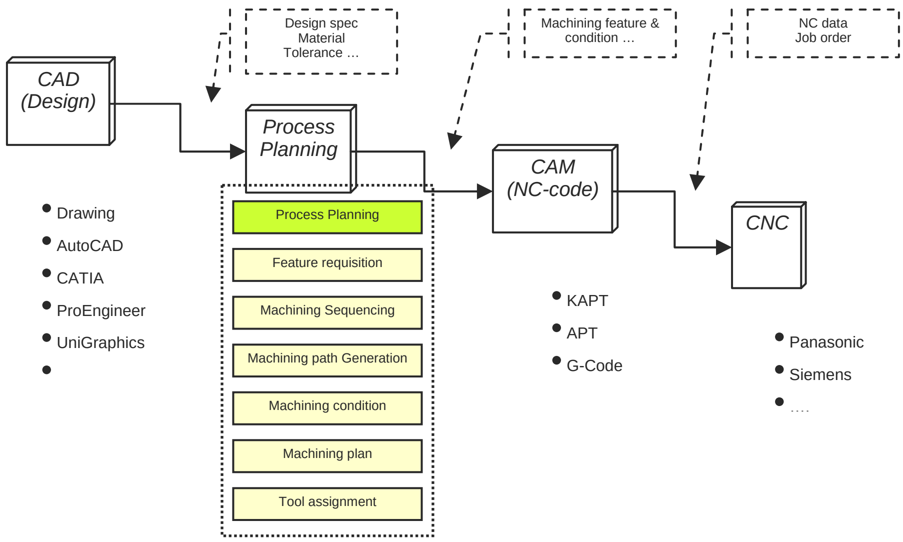
1 Introduction

One of important factors currently affecting the competitiveness of businesses is most probably the effective integration of information for the whole company including cooperative companies. It is necessary to collect, manufacture, and maintain data for the entire operation period of a business and the data and products in a company in order to effectively integrate their information [1]. Studies on business data have been widely conducted in recent years, and many applications have also been reported. However, studies on product data have not been actively performed. Product data including CAD/CAM data should be integrated and managed in a way that addresses the total information for a company by combining it with business data. In addition, the integration of heterogeneous product data with them is required.

CAD data that can be referred to as the origin of product data are usually produced using different CAD systems, such as AutoCAD, CATIA, ProEngineer and UniGraphics, even in a company. In addition, a CNC language that is used to produce certain products consists of different NC (Numerical Control) programming languages, such as APT, FAPT, SAPT and G-code [2]. It is evident that these become an obstacle hindering the sharing of information between various applications in a company. In order to provide data compatibilities between heterogeneous CAD systems, the ISO (International Standards Organization) proposed STEP (Standard for the Exchange of Product Model Data: ISO10303) [3] and STEP-NC (STEP-Compliant Data Interface for Numerical Controls: ISO14649) [4] that is an extended version of the STEP for CNC processing.

Although the STEP proposed at the present time can exchange various types of information, including CAD data by compensating for the demerit of the existing IGES and DXF, there are still lots of limitations in the expression of the meaning of CAD data. Although the drawing expressed by a type of STEP includes the feature information to process certain operations, it is still difficult to account for raw materials, processing conditions, designer's knowledge and purposes. Thus, a method that expresses additional information to provide information sharing between departments except for the simple data included in CAD data is required. For instance, it is necessary to share information between departments, such as a selection of tools according to the processing unit, selection of processing machines, processing methods, and processing materials, in order to process certain products that are just designed from a design process. (See Figure 1) Finally, then, an effective business process can be achieved for this information integration, and an efficient process can be implemented by integrating information between departments and recycling information. This efficiency can be maintained even after machine operators are changed.

Figure 1 The Environment of CAD/CAM based manufacturing companies



In general, each process can be determined according to the experience of certain experts in the production processes. It is necessary to determine optimal machining conditions including an exact understanding of drawings in order to effectively produce products. However, these experts are not enough in the actual field due to the fact that these machining processes are considered to belong to a conventional 3D (difficult, dangerous, dirty) job. In addition, the knowledge accumulated in these machining processes is not properly managed. Thus, it is necessary to reduce the dependency of these experts and increase the reuse of this knowledge by introducing an effective management technique to the machining processes. The reuse of this knowledge will effectively banish the existing errors that occur during the production process since process knowledge can be shared between the designers and operators of the production process.

In recent years, the concept of a semantic web was introduced to accumulate and reuse information in which the semantic web was developed by representing human knowledge according to certain standard formats in order to apply it to both human and machine applications. The objective of the semantic web is to propose a method that standardizes concepts and knowledge, which can be expressed as human languages, and to integrate this standardization in a standard web environment. Ontology is a type of methodology to implement a semantic web, and it can also be recognized as a classification system which divides types and scopes of knowledge in a knowledgebase. In addition, ontology includes additional information in this classification system, such as rules, relationships, constraints, and benefits. Thus, it is a data model that provides certain semantics, which can't be handled by the existing classification system.

This study systematically presents ontology for characteristic features, machining processes, and machines in order to apply it to machining processes, automatically producing CAPP (Computer-Aided Process Planning) using mapping rules and definition functions. In addition, it proposes an ontology based web system framework to apply it to a production department in a machining factory. Ontology is implemented using OWL (Web Ontology Language), which is a standard language of ontology used in the semantic web.

2 Existing Researches

Existing studies on ontology have been accomplished in various fields, such as artificial intelligence, electronic commerce and other industrial fields. In recent years, studies on the sharing of resources using a mapping method for different definitions in the same domain have been actively conducted [5]. Studies on the field of product information sharing using ontology can be summarized as follows:

Courts [6] defines the knowledge that is usually used by an engineer as general knowledge that can be obtained through the experience in an average life and education, domain specialized knowledge that can be obtained through certain studies and experiences in a specific domain, and sequential knowledge that can be obtained through the experience based on the know-how in a specific domain. However, Ferguson [7] suggests this engineering knowledge as a different concept including the experimental data and experiences of an expert.

SHADE [8] proposes an agent based cooperative product design system based on ontology in which each agent has a different level of knowledge to solve problems and uses ontology in order to share a knowledgebase. Although this study presents the relationship between the knowledge used in a problem solving process and the ontology, it has not accounted for the detailed structure of the designed ontology. Jinxin Lin [9] classifies knowledge on the design in order to effectively apply it in businesses, and defines the relationship between knowledge using a specific language.

OntoEdit [10] proposes an ontology based knowledge framework. Also, OntoEdit makes it possible that an engineer can define ontology and rules, and the rule becomes knowledge to solve certain problems. Although this system provides a detailed structure and function of ontology, it failed to present the relationship between knowledge that is used in problem solving.

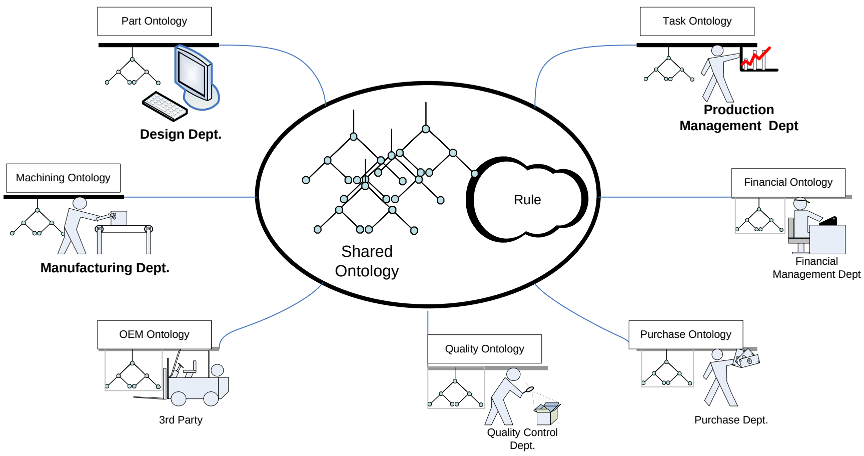
As mentioned so far, existing studies mainly focused on the establishment of ontology and its application using the present thesaurus, semantic maps, and classification systems rather than an actual establishment of ontology itself, and including active studies on the semantic mapping between heterogeneous information systems. This study systematically defines processing features and associated knowledge for machining processes and provides a process planning based on this knowledge. Furthermore, it provides certain techniques that recycle knowledge in developing new products using an ontology database.

3 Semantic web based environment including a CAD system

This study attempts to use a new information expression method known as a semantic web including a CAD system, which is conventionally used to express feature information, in order to implement product data used in a company. As previously mentioned, a semantic web is a type of web that is intended for both human and machine use, and which transfers semantic information using an XML based meta-data. The information produced from various CAD systems used in businesses can be assumed to support a STEP file format and various types of information related to drawings can be implemented using the meta-data of a semantic web. The semantic web environment proposed in this study is illustrated in Figure 2.

Recently, enterprises have introduced various computational systems, such as CIM, ERP, and SCM, in order to apply them as a solution to the integration of various types of information [11]. However, these information systems only mean a syntactical integration of information rather than certain semantic information that includes actual information. For instance, when a certain drawing is prepared which reflects the initial stages of a product being produced by a company, the information of the drawing can be shared and used by several departments. But, it is difficult for engineers to extract the information that is to be actually used in their own works due to the limitation on the understanding of information in CAD drawings. In the case of the purchasing department, it is necessary to extract the materials used in the finished CAD drawing and to estimate the amount of materials used in a production process. This allows for many interventions in an information system used in a company and may disturb automatic flows of information. Thus, the objective of this study is to maximally reduce the participation of workers in the sharing of information between departments in a company using a semantic web including the existing CAD information. The implementation scope of this study is limited to design and machining departments.

Figure 2 Semantic web environment for enterprises

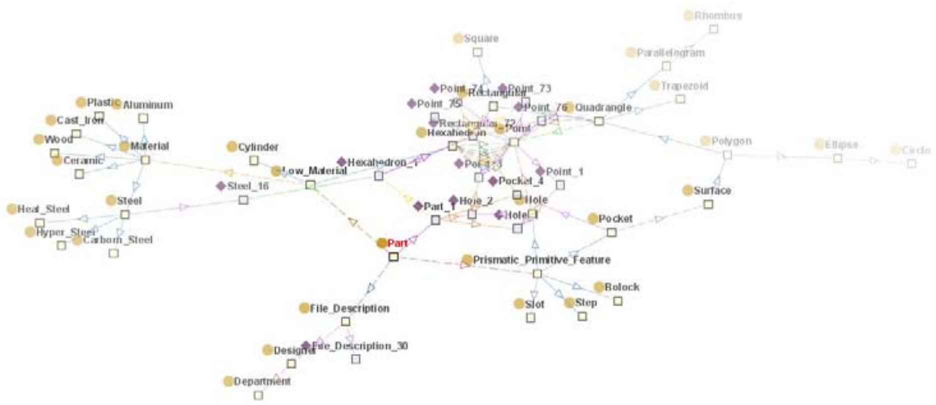


It is necessary to build a hierarchical process in order to implement ontology that shares and reuses a data model, which includes the knowledge and information through an application program, by human and machines [10]. The participation of experts in the process of employing ontology is required as well. The classification of ontology has to first consider in order to systematically implementing ontology. The ontology can be classified based on the product data, such as parts ontology that define feature information and general conditions applied in designs, task ontology that determines machining processes, and machine ontology that assigns machines. Finally, a mapping rule is generated to extract information in order to support CAPP using these Ontologies.

The proposed system access the information related to the characteristic features and machining processes using ontology, which is configured according to three different types of Ontologies, such as parts ontology, task ontology, and machine ontology. Parts ontology is used to define basic information of feature information and drawings. Task ontology is applied to define machining processes. Machine ontology is used to define machines that are used to apply general cutting processes. The parts ontology of these Ontologies is a type of ontology instance that can be generated using a STEP ontology annotator by users during the saving process of the designed data into a database.

Parts ontology that provides basic information regarding the designed data consists of drawings, raw materials, feature geometry, machining information, and material information. Drawings specify designer's ID, name, date, and notice item, which describe short notes to help other users of the drawing. Raw materials that describe materials used in machining processes are determined as cylindrical and hexagonal features in this study. Feature geometry that determines characteristics feature in drawings is designed to define feature geometry as points, which are used to mark coordinates, hole, pocket, slot, and step feature. Machining information defines tolerances in design and machining processes and describes the relationship between machining processes and other processes. Finally, material information describes materials used in the machining processes. Figure 3 presents the structure of parts ontology.

Figure 3 Part ontology graph



Task ontology is applied to define machining processes and can be classified according to various processing units and processing conditions. Processing units define a machine operation step that is used to determine the whole processing order. Processing conditions include allowed tolerances for machining processes and technical information, such as tool information and processing strategies, according to the materials used during the production processes. The major machining process is limited by the operation of tools, such as lathe, drilling, and milling processes. The drilling process is defined as drilling, reaming, boring, counter-boring, counter-sinking, and taping processes, and the milling process is classified into face milling, site milling, and end milling. Also, the machining process used in the milling machine can be classified by tool path patterns such as zigzag and spiral.

Finally, machine ontology defines machines that are applied to machining processes and can be defined according to the characteristics of machines, such as lathe, drilling machine, and milling machine. Drilling and boring processes can be performed in lathe or drilling machines, in which the machine used in a specific process, can be determined according to the feature of parts. The specified machine will propose the optimal processing condition to the process operator including processing conditions based on the applied materials.

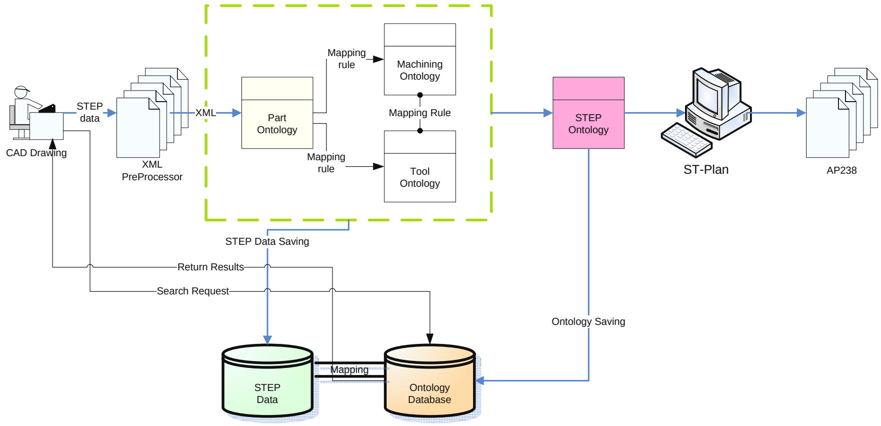
4 OntoCAPP Framework

4.1 System framework

The OntoCAPP (Ontology_based CAPP) system proposed in this study is a type of ontology based web system and defines the characteristic features of machining processes using ontology. In addition, it automatically generates CAPP for machining processes using the predefined process ontology and machine ontology in order to apply it to certain production departments.

This study adds various levels of meta-information in the design process of ontology in order to share the problem occurred in design and machining processes. The accumulated information is considered as resources that will be used in knowledge searching processes. Figure 4 presents the system architecture proposed in this study.

Figure 4 OntoCAPP architecture



When a designer requires a new design according to the requirement of customers, the most similar information in the designed data can be used for a new design process by adding, modifying, and deleting it. Then, the process of searching for the similar characteristic feature in the existing data is the key factor of the new design. Existing database systems, however, do not support the effective searching of similar characteristic features. This study provides a more precise and exact search process for the value applied in features and shape feature categories by defining ontology according to the characteristic feature in the early stage of a design process. The search results obtained in this process will be used in a design process, and the result of the design is applied in the OntoCAPP system. Then, the information of machining processes configured in a specific drawing assigns the proper machines and machining processes for each process according to the designed feature, when the OntoCAPP system orders the generation of a CAPP and proposes a machining sequence for each process. In addition, it provides the material information of tools used in machining process and processing conditions. The information produced in these processes will be provided to the next process and is automatically stored in an ontology database. In this process, the information has a connection ring with STEP data using an URI mapping process in which the desired STEP drawing can easily be shared through an ontology searching process. Because the proposed system is based on a web, it is possible to share the information produced in a company and other partner companies without any temporal or spatial limitations through a simple certification process.

4.2 OntoCAPP modules

The major configuration of the proposed OntoCAPP system consists of *a STEP annotator module* that is able to input the information of designed files, *a process generation module* that is used to generate a machining order according to the feature, *a task generation module* that is applied to machining processes, *a machine assignment module* that is used to assign machines for each process, and *a technology information report module* that is used to assign tools and machining conditions. The generated information using these modules provides STEP-NC information in order to apply it to a CNC machining process in which ST-Plan [13], software of ST-Tools Co., is used to generate this information.

The STEP annotator used in OntoCAPP is a type of module that generates ontology instances automatically for the applied design using the input data of shape features and machining process information. Then, the generated ontology instances can be used to extract specific knowledge for a NC machining process using a mapping rule, being combined with the shared ontology. Because the interface used in this process can be supplied based on a web, every operator who is engaged in this process can access the proper information through a simple certification process.

After defining the volume that is to be removed to achieve the characteristic feature, the process generation module for processing methods and orders according to the objective feature defines and assigns machines for each machining process by considering it as a local goal. Then, the module generates a solution that is used to achieve each specified goal. In addition, the local optimum for this solution can be determined according to the interest of users. These processes will be repeated for all characteristic features that are to be removed. Finally, the whole machining order is reconfigured for the generated local optimum solution in order to provide a final solution.

Finally, it is necessary to assign machining conditions to perform the generated process. The technology information report generation module is used to perform this final process. The major function of this module assigns tools for each machining process by considering materials and feed rates using the generated tool information ontology for each machine.

A Jena2 inference engine [14] is used in this study to define and infer the rules for the production of alternatives in milling process planning. It is a representative engine that can effectively manage the high capacity ontology data using RDF/RDFS and OWL. Jena2 [14] and Wilkinson [3] have version 2.1 currently. Jena2.1 supports RDF/RDFS, DAML+OIL and OWL, providing Persistent Model using a database. Limitations to the inference engine of Jena2 involve that production rules do not support negative representations, supporting only OWL Lite. But, there is no trouble with this, in general, since ontology is implemented conventionally with OWL Lite.

5 Conclusion and Further Research

The advent of semantic web technologies improves the clear recognition of information expression, sharing, and recycling of knowledge. It has extended people’s interest to the concept of knowledge expression, estimation, semantic map, and ontology that has been mainly studied in the field of artificial intelligence. In particular, ontology is taking a solid position as a core technology in semantic web technologies. This study defined characteristic features to support process planning for the countless data produced in production environments using semantic web based ontology, designing machining ontology, as well as parts ontology that can provide basic information for the designed data. The proposed ontology can provide a solution that effectively shares the internal and external product production information in a company under the Internet environment. The advantage of this system is that it can easily reflect changes that occur in the machining environment, such as machine malfunctions and unexpected changes, by modifying the rule or ontology in the system.

Further research would include the development of an effective ontology retrieval algorithm so that established ontology is shared and reused throughout all departments, as well as the actual implementation of the proposed system. In addition, because the semantic web is based on the Internet environment, establishing an accurate and effective web-based based system is required, which uses a VRML, a web based graphic language or XGML technology enhancing the web graphic standard for the next generation. The problem that must be solved in the future is, for a while, an automatic generation of ontology that remains as a bottleneck problem in the ontology field.

Acknowledgement

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Conceptual design knowledge management in a PLM framework

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Abstract: The capability of managing product development is the basis to success the global competition. Successful product development requires improved approaches to organize the development process [1], reducing any kind of waste, and providing goods to meet customer explicit or hidden needs. Lean product development, short time-to-market (TTM) and an effective quality approach are key elements to respond to the competition in our own markets as well as to compete on a global scale. All these aspects must be taken into consideration from the very first steps of the product lifecycle management to gather optimal results. To accomplish this goal methods and tools coming from the systematic innovation field for the management of product knowledge can be adopted.

Keywords: knowledge management, product analysis, product models

1 Introduction

In the present globally-linked economy, product development capabilities and effective management of key processes are the basis to challenge the growing market competitiveness. The strict control of overall time-to-market (TTM), costs and quality is mandatory to respond to competition in our own markets as well as to compete on a global scale. Successful product development requires new and better approaches to organize the development process [1], reducing any kind of waste, and providing goods to meet customer explicit or hidden needs. As the most developed countries are shifting towards services, reducing the rate of GDP coming from the industries, in the same way manufacturing enterprises are widening their interest, formerly addressed almost only to the finished product, to all the product related processes. This requires the enterprises departments to be deeply integrated in order to manage strategic, functional and innovation issues.

Within all the process of the product lifecycle, product development process has the major influence in the competitiveness of companies [2]. Thus, it is decisive to improve its functioning through the integration, both inside traditional design functions and outside, with the other functions of the companies (e.g. marketing, manufacturing) or even with external partners in a concurrent engineering context.

Product development general goals are to better meet customer needs and expectations, to reduce costs while integrating product/process design and to shorten design cycle times. To reach these targets product and process design approach must be linked to the business strategy. Since the dimensions to competition can be identified into cost, quality, TTM and innovativeness, and it is a matter of fact that it is not possible to do extremely well in each of them, the company strategy has to define where to excel and where to accept only a good level of efficiency. A lot of methods, tools and best practices are available to satisfy cost, quality and TTM issues, while innovation has not a long tradition in engineering practices. Strategies to reduce costs have became less and less effective, mainly because west countries have to face the competition of global market where the fast growing economic powers such as China and India are extremely costs aggressive. This implies that, particularly for SMEs, nowadays it may be extremely hard or even impossible to win cost competition. Quality, reliability and safety are essential to keep market share and several broadly validated methods are available to achieve these goals. Quality Function Deployment, Six Sigma and other methods provide tools for controlling and guaranteeing high quality products and production, while FMEA, HAZOP, FTA, Taguchi and other methods teach how to face and manage product risk. Time related issues can be addressed with a good comprehension of market evolution, in order to forecast future needs. Thus, a well-defined development process together with tightly integrated design tools, allows companies to quickly and continuously launch new products into the market. By the way, for the innovation activities less attention has been dedicated trough years to find concrete methodologies and step by step tools to achieve new and better product concepts. As a result the very first phases of product development, such as ideas generation and conceptual design are less developed and have a lower degree of integration with the rest of the product development areas. Actually, methods and tools to support product concept, recently addressed as Computer Aided Innovation (CAI) [3], have been developed for decades but only in the last years they have been meeting enterprises interest and their diffusion is still not wide, especially in SMEs.

The introduction of systematic approaches in the conceptual design step of product development gives the opportunity of filling in the gap existing between data coming from the marketing department and those generated by the design office. The nature of the data managed by marketing people and designers is rather different. Data derived from market analysis or directly retrieved from customers are typically unstructured, sometimes incomplete and hardly matching with engineering requirements. On the other hand when designing a product with traditional CAD/CAE/CAM tools the information used and produced are quantitative, more specific and easily manageable within PDM/PLM framework.

Conceptual design methods provide tools that although being normally used for problem solving activities, can be fruitfully adopted also for mapping product knowledge to gather a fluid flow of information along the early phases of product development.

Success of methods, strategies, tools and techniques for innovation and for product development deeply rely on the knowledge base of the system they deal with. The quality, consistency and structure of technical knowledge are the key point for all the actions taken to manage product and process. In the followings same aspects regarding the way knowledge can be extracted and formalized are discussed and some techniques will be shown.

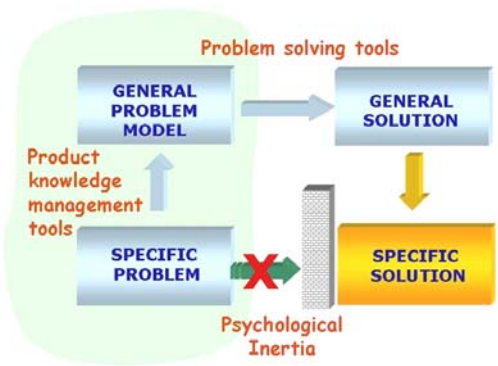
2 Background

The conceptual design phase is normally not supported by structured methods and tools. Even if the matter of managing creativity along the creation of new products is well known since the second half of the last century, most of the approaches available in literature and adopted by industry are mainly based on the idea that, since innovation is a product of the human mind, the process can be improved using psychological techniques. By the way this idea was frequently translated into practical tools relying on a trial and error mechanism. It derives that approaches such as Alex Osborn's Brainstorming, Fritz Zwicky's studies on Morphological Theory or De Bono's Lateral Thinking although represented great innovations and are still practiced nowadays, have the intrinsic limit of being time consuming and low reliable approaches. The suggestions given to remove the so called psychological inertia are well suited for routine or simple inventive problems. In case of complex situations the number of trials increases dramatically, so that it is not possible to forecast time and resources needed to (eventually) find a solution. If this was probably acceptable same decades ago, nowadays it is not tolerable anymore. The uncertainty whether a good solution will ever be found and the impossibility to schedule time and resources needed is one of the major limit of psychological approaches and, on the other hand, the reason why theories for systematic innovation such as TRIZ [4] and GTI [5] are now being highly considered in both academia and industry.

3 Innovation and knowledge management

The systematic approach to solve inventive problems provided by TRIZ is characterized by a set of tools that are not based on psychology issues but on scientific observation of former technical inventions. When dealing with tough problems, TRIZ suggest avoiding the path directly connecting problem to solution because it is likely to be unsuccessful. On the contrary TRIZ propose to apply the solving tools to an abstract model of the real problem. Referring to the Four-Box Scheme for problem solving (Figure 1), the first step is to go 'upward' to the abstract level from user's specific problem to a generalized problem, where the essence of the original problem is extracted after discarding some details or non-essential parts.

Figure 1 Role of knowledge modeling tools in the Four Box Scheme for problem solving



Then the generalized problem can be solved using TRIZ's problem solving tools, to find one or more generalized solutions. Finally, the generalized solution must be translated into a concrete solution for which starting data and specific technical know-how are required.

The first step, from specific to generic problem (highlighted area in Figure 1), is done by means of the modelling tools provided by the methodologies. Modelling tools allow to represent different aspects of the system considering functions performed, identifying causes of malfunctioning or highlighting design intent and constraints.

Modelling activity has two main phase and objectives. The first is to sum up and formalize the main information about the whole system and its close surroundings with the aim of identifying critical areas or ultimate causes of failure, while creating a map of knowledge of the system. The second consist in creating models representing all the relevant details of the recognized area of interest. This normally implies a deeper technical investigation on the system in its working (or failing) condition and the modelling process may require iterative steps to reach the right level of detail.

This phase of the problem solving roadmap is crucial because it influence all the following steps. A well defined model of the system eases the research of the right problem to approach and facilitate its solution. An ill defined model, on the contrary, leads to wrong directions of research, with the result that all the efforts converge to a secondary problem or they turn out to be completely useless.

If a patent is being analysed and modelled, a good work highlight strengths and weakness of the device described, creating a robust base for eventual patent breaking or circumvention. Bad models may bring to wrong evaluations of what is claimed in the patent, with potential severe and expensive legal consequences.

Even if the tools are different for same aspects, they share the same goals. While doing systematic innovation the focus is put on identifying criticalities so that problem solving efforts can converge on the right problem and the solution can be found. On the other hand, the importance of modelling tools for mapping technical information has a greater value since it is adopted for knowledge management in a PLM framework.

The sources of knowledge and its formalization within an enterprise may be various and fragmented into different and unconnected departments and tools capable to collect internal knowledge and to represent it in a readable manner are essential. Moreover modelling tools are extremely efficient not only for internal data, information and expertise but also for other kind of technical documents such as patents.

Actually, innovation methods and TRIZ in particular have a lot to share with patents. Main concepts and the pillars of TRIZ were deducted by patent analysis to create a systematic pattern of invention. Thus, the natural result of applying TRIZ to technical problem is to create new concepts, device or technologies that can be matter for new patents.

The following paragraph is dedicated to the tools, traditional and new, to model the system that has to be innovated, that is malfunctioning or that is described in a patent. The model created contains the knowledge on the system and it must be accurate and complete because it represents the starting point for problem solving tools.

4 Modelling tools and knowledge management

Modelling tools can be divided into two main groups. The first group contains the tools modelling the system on a ‘functional’ level; the second group contains the tools mainly describing the ‘events’ characterizing the system along its working or failing condition. The tools belonging to the first group are Substance Fields (Su-Field) models and Function Tree Diagrams and Functional Models; the tools of the second group analysed for the aim of this work are Root Conflict Analysis (RCA+) models and RelEvent Models.

4.1 Function-based Models

A contemporary of Altshuller, Lawrence D. Miles created the Value Analysis/ Value Engineering (VA/VE) [6]. He conceived of VA in the late 1940s based on the application of function analysis to the components of a product. Components cost reduction was an effective and popular way to improve "value" when direct labour and material cost determined the success of a product. The value analysis technique supported cost reduction activities by relating the cost of components to their function contributions.

Value analysis defines a "basic function" as anything that makes the product work or sell. A function that is defined as "basic" cannot change. Secondary functions, also called "supporting functions", described the manner in which the basic function(s) were implemented. Secondary functions could be modified or eliminated to fulfil the goal of reducing product cost.

When approaching a problem, if we describe in detail what we are trying to accomplish, we tend to describe a solution and miss the opportunity to engage in divergent thinking about other alternatives. When trying to describe problems that affect us, we are limited by personal experience and knowledge, in most cases without realizing it. On the other hand, the more abstractly the functions of what we are trying to accomplish are defined, the more opportunities will be created for divergent thinking and problem solving.

This high level of abstraction can be achieved by describing what is to be accomplished using respectively: a verb for the function performed ("What is to be done?") and a noun for the component that receives the function ("What is it being done to?"). Identifying the function by a verb-noun is not as simple a matter as it appears, but it provides the greatest potential for divergent thinking because it gives the greatest freedom for creatively developing alternatives. A function should be identified as to what is to be accomplished by a solution and not how it is to be accomplished. How the function is identified determines the scope, or range of solutions that can be considered.

The functions designated as "basic" represent the operative function of the item or product and must be maintained and protected. Determining the basic function of single components can be relatively simple. By definition then, functions designated as "basic" will not change, but the way those functions are implemented is open to innovative speculation.

The first step in the VA process is to create a map of the system with particular attention to its scope and to the problems afflicting it. Following actions are aimed at analysing the cost-function relationship of the product to reduce it by eliminating or combining as many secondary functions as possible.

As VA progressed to larger and more complex products and systems, the focus shifted to product development activities where VA can be more effectively applied to a product before it reaches the production phase. However, as products have become more complex and sophisticated, the technique needed to be adapted to a higher level approach. As a result, value analysis evolved into the "Function Analysis System Technique" (FAST).

4.1.1 Function Tree Diagrams and Functional Models

In the same period, while developing TRIZ Altshuller created a modelling tool, known as Substance-Field (Su-Field). Su-Filed models are the representation of the interaction, carried out by means of a generic field, between two substances acting respectively as a tool and as a product.

After defining the Su-Field tool, Altshuller most likely knew and was positively influenced by Miles' work on functions and proposed a method, called Functional Analysis that combines the Su-Field with the pioneering value engineering thinking.

Actually, for both tools the analysis is based on qualitative descriptions of the relationships between the individual components of the overall system. They collect information about the positive and negative aspects of these inter-component relationships in the form: SUBJECT → ACTION → OBJECT.

In each relationship, it is necessary to classify the action in terms of helpful or harmful, insufficient-satisfactory or excessive, directional (one-way, both ways), and time based (continuous, periodic, etc) function. Of primary importance are Function Type and Function Rank descriptions. In TRIZ terms, Function Types are categorised as Basic, Additional, Auxiliary or Harmful. Likewise, Function Ranks can be Insufficient, Satisfactory or Excessive.

As in value engineering functions are the means to increase product value for the company, the market or the final user, in TRIZ functions are mostly associated to the concept of Ideality. The degree of ideality can be measured as the ratio of benefits and harms. Benefits came from useful function the product provides, while harms include negative functions carried out by the product and all the related costs.

Both value analysis and TRIZ use functional models to allow technicians to avoid psychological inertia while approaching a non-routine problem. In other words "…the conditions of the problem should be obligatorily stripped of special terminology, because terms shackle the inventor to old and ingrained concepts about the object"[7]. This is quite clear for all Value Engineers, and it also for every TRIZ expert. Actually the first step in the Four-Box Scheme of figure 1 has the goal of creating an abstract model of the specific system problem, and here the functional approach is fruitfully applied.

In TRIZ there are two types of models based on functional decomposition of a system. The first one is the Function Tree Diagram and the second is the Functional Model. Function Tree Diagrams are directly derived from FAST models of VA and they represent the product through a hierarchical definition of the function it performs. The top element is the Main Useful Function (MUF), i.e. the core function the system is designed for. On the second level there are the function needed to realize the MUF, called auxiliary or secondary. With the same logic further sub-functions are described till the desired level of detail is reached. The way of writing and reading a Function Tree Diagram can be either top down or bottom up, depending on which is the intent of the problem solver. Moving downward is useful to understand *how* a function can be achieved by means of its sub-functions. Moving upward explains the reasons *why* sub-functions are there. This kind of model is normally used in the very first stage of the analysis to understand if there are disconnected areas or useless functions and components. Anyway it collects an easy readable piece of information about the product functional composition.

The second type of system models used in TRIZ are the Functional Models. These are based on a decomposition of the systems into elements of different nature, each performing functions on the others or being the object of the function performed. The underlying subject-action-object logic allows creating a net chart describing the product at a homogeneous level of detail. Hierarchy is no more represented directly into the model and a few models must be drawn to characterise the desired level of complexity. Elements are grouped into:

- Components;
- Supersystem;
- Product.

The Components are devices or parts of the system that are subject and/or object of one or more functions. Normally Components correspond to the real part of the system, but since a single part can fulfil to different goals or vice versa more part can have the same function, Components are not strictly mapped on real product parts.

The Supersystem elements are entities interacting in some way with the system but that are not under the control of the design team. As a consequence Super-systems cannot be modified during the problem solving activity. Typical Supersystems are the environment in which the system operates, or the workers interacting with the system. Super-systems are sometimes used also to define constraints, e.g. when some part of the system must not be changed for some reason.

The Product is the particular component, fundamental for the system that acts as the object of the MUF. Only one component is considered the as the Product and its absence would be enough to invalidate the entire model.

A great difference in respect of the Function Tree Diagrams consist in that the function considered in Functional Models are not only those intended by the technicians when designing the product, but all the real function carried out by the system. So unexpected harmful, insufficient or excessive functions are modelled as well as useful ones.

The rules for composing a Functional Model are simple, but choosing the right verbs for the functions may be tricky. To fulfil the general goal of creating an abstract representation of the system, functions must not be too specific otherwise they would contain information on how to perform the function, and this must be avoided. Moreover the function modelled must be the simplest and as close as possible to the physic of the system (e.g. "air warm up a thermometer" is preferred to "a thermometer measure the temperature of air"). Functions always have to be verbs in active form (e.g. "the wheel pulls the chain" is better than "a chain is pulled by a wheel").

The main differences between TRIZ-based Functional Models and the ones proposed by Value Analysis/Value Engineering are mainly two:

1. TRIZ-based models take into account negative, insufficient or excessive functions that are not considered in Value Analysis/Value Engineering. Harmful functions are always there and must be highlighted to permit the problem solving activities;

2. TRIZ-based models show up the Main Useful Function (MUF), i.e. the most important Subject-Action-Object of the whole system. Normally the object of the MUF is the component marked as "product".

4.1.2 Substance-Field Models

Substance-Field (Su-field) Analysis is a TRIZ analytical tool for modelling problems related to existing technological systems. The system desired function is the output from an object or substance (S1), caused by another object (S2) with the help of some means: a force, energy or field (F).

Substances are objects of any level of complexity. They can be single items or complex systems. The action or means of accomplishing the action is called a field. Su-field Analysis provides a fast, simple model to use for considering different ideas drawn from the knowledge base.

Su-field Analysis was first used to describe the problem and it works the best for well-formulated problems. This analysis is used to zoom in on the zone of interest. However, the analysis can be applied to system as well as component levels of abstraction. This is often at the interface between the two substances. For complex systems there is a Su-field Model for all the zones of interest. Two substances and a field are necessary and sufficient to define a working technical system.

4.2 Event-based Models

4.2.1 Root Conflict Analysis (RCA+)

Valeri Souchkov (ICG Training & Consulting, The Netherlands) developed a cause and effect based tool to deeply analyse a problem system to find out the ultimate source of problems. Souchkov, being one of the most important TRIZ experts, used the cause and effect logic to address the goal of seeking contradiction in order to solve them with TRIZ tools. Actually the acronym RCA+ he introduced do not stand for Root Cause Analysis as one could think, but the term Cause has changed into Conflict to underline the different goal [8].

Although TRIZ provided reliable techniques to solve inventive problems, it always lacked clear and structured way to manage complex problem situations. Without good understanding of underlying causes one risks to invest considerable efforts to solving a wrong problem.

4.2.2 RelEvent Diagrams

RelEvent Diagrams are proposed within Yezersky’s General Theory of Innovation [5] as a product/process/system modelling tool. The underlying philosophy is the cause and effect but several other kinds of information and relation can be put into these diagrams. Both events (positive or negative) and condition (design choices or unchangeable) are connected using cause and effect, and time relations.

The slightly more complex graphic language of RelEvent allows showing in a unique diagram also information about the starting ‘design intent’ or past problems with related solutions. RelEvent is a boosting tool to identify lacks in the as-is system, in a way that makes innovation activity much more accurate and easier.

5 Comparison among modelling tools

When dealing with an innovation issue the efficiency of the approach used is a key factor for reaching quick and bright solutions. The time passing from the manifestation of the problem symptoms to the gathering of inventive solutions must be as short as possible.

Inventive problem often arise in crucial circumstances and late solutions are equal to no solution at all. The choice of the right modelling tool to fit a specific problem situation is important not to lose precious time. By the way in literature no indications on this subject are available.

Function-based approach provide a good product decomposition and the models created represent a clear and well-defined representation of the technical knowledge about the product they are describing. Functional Models are not only the starting point for problem solving tools, they are the final result for the representation of the know-how embedded in the product.

On the other hand event-based approach gives a sharp view of the problem, but they represent only the part of the product strictly related to the malfunctioning or critical area. RCA+ or RelEvent Diagrams are not supposed to be used for mapping the system they are applied to, if not for the specific purpose of problem solving. Event-based models, actually, are developed starting form an evident problematic situation. To find the root-cause or the critical devices, event-based techniques work better if failure or malfunctioning is clearly manifest.

The biggest difference between function-based and event-based approach is in the time domain. Function-based models do not take into account time dimension, while event-based models deeply rely on it. This characteristic is normally not influencing the choice of the modelling tool when dealing with a product. On the contrary, if the problem system realizes a process or its failing condition directly depends on time; event-based techniques are preferable.

Among function-based models some tips may be useful to pick the right tool. Function Tree Diagrams are particularly helpful if we are modelling a complex product (e.g. a car) in which some functional dependencies may be obscure. The tree structure easily shows the hierarchical structure of the product and permits to quickly point out inconsistencies and critical areas. Thus, Function Tree Diagrams are likely to be used alone or before the realization of detailed Functional Models.

The way Functional Models are built does not allow to directly represent hierarchy. If the system is complex more diagrams have to be drawn, each one at a deeper level of detail. Practically, starting from a high level (low detail) diagram, in the followings some parts are focused and expanded while others are neglected, until a diagram describing the system with the proper accuracy is reached. Functional Models that are created only with the purpose of representing technical knowledge have no limitations on the number of element contained into each diagram, except for the ease of reading. On the other hand a good model to be used for problem solving should contain only the components truly involved in the problematic situation. Thus, Functional Models for problem solving should not exceed ten components.

Su-Field models are extremely focused on the pair of conflicting elements and they are not used to represent any complete product or process. Su-Field models are used mainly with the 76 Standards in the context of ARIZ, a structured algorithm for problem solving proposed in TRIZ.

Concerning the event-based models they are preferable for process modelling. Root Conflict Analysis (RCA+) developed by Valeri Souchkov on the base of cause-effect logic has the goal of identifying root problems causing a clear failure in the system. Its strength is due to the quick and easy way it brings from the main negative effect (on the top of the diagram) to all the possible causes. Then the identification of the ultimate cause, or the one that is preferred to be solved is done without much effort. RCA+

models, using a simple notation (+ and – marks), allows also to highlight area where conflicting situations take place.

GTI's RelEvent Diagram is the most complete technique among the ones described so far. While taking advantage of temporal and cause and effect logic RelEvent models also some other feature of the system: the original design intent, choices and unchangeable conditions (marked differently), former problems and their solutions. By the way, the opportunity of describing all these aspects comes with a slightly increased complexity in building the diagrams.

To summarize, none of the presented techniques prevails on the others and the best one to adopt depends on the problem and on the context. The tips presented above are supported by the experience achieved with a few case studies in which Functional Models, RCA+ and RelEvent Diagrams were used for the same system problem and the results were compared.

6 Conclusions

This work describes the way information coming from conceptual design can be exploited to improve knowledge management within the process of product development. Tools derived by Systematic Innovation methodologies (i.e. TRIZ and GTI) have been chosen for this goal because of their capability to formalize the knowledge of pre-design concepts. Anticipating the creation of a robust body of knowledge associated to the product at the very first step of product development is clearly an advantage because it offers the opportunity to early identify criticalities and shorten revision times.Moreover, the use of TRIZ and GTI tools for data modelling encourage the adoption of structured problem solving techniques and speed up innovation of both product and process.

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Towards an ontology for open assembly model

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Abstract: In any industrial scenario, most products are assemblies composed of either parts or subassemblies produced by different companies. Traditionally assembly information model contain information regarding parts, their relationships, and its form. But it is important that the model also represent the function and behavior. This paper addresses the development of an Ontological Assembly Model (OnAM) in the broader context of Product Lifecycle Management (PLM). A model like OnAM can help in achieving various levels of interoperability as required to enable the full potential of PLM. In this paper we first present an Ontology Web Language (OWL) version of the Core Product Model (CPM) [1-2] and subsequently Open Assembly Model (OAM) [3] based on their previous NIST versions in Unified Modelling Language (UML). Besides developing a semantic assembly information model, we further extend this model to incorporate reasoning capabilities. We briefly explore and discuss various tools and methodologies for modeling OnAM with reasoning capabilities. The developed OnAM can be considered an extension to the NIST's OAM with semantic interoperability. This extended OnAM could serve to test the advantages of a semantic approach to represent a product structure evolution i.e., from the design phases and throughout the life of the product. A brief case study is additionally presented to explain the OnAM including rules and reasoning capabilities.

Keyword : Ontological Assembly Model, Core Product Model, Open Assembly Model, Interoperability, Reasoning capabilities

1 Introduction

To achieve an interoperability level that could facilitate the full potential of PLM, it is essential to identify a common data structure to allow information exchange between different stakeholders. Based on new research initiatives in the area of information models based on ontology to support interoperability, it is now possible to share not only information but also support reasoning to extract knowledge. This paper describes an initial effort towards development of an ontology for assembly representation from several considerations including information models for Product Lifecycle Management (PLM) and reasoning. This paper is organized as follows: Section 2 briefly presents the previous and related work at NIST. Section 3 presents ontology for assembly model

(OnAM). Section 4 briefly illustrates a case study based on OnAM with reasoning capabilities. Finally Section 5 summarizes the paper with results and discussions.

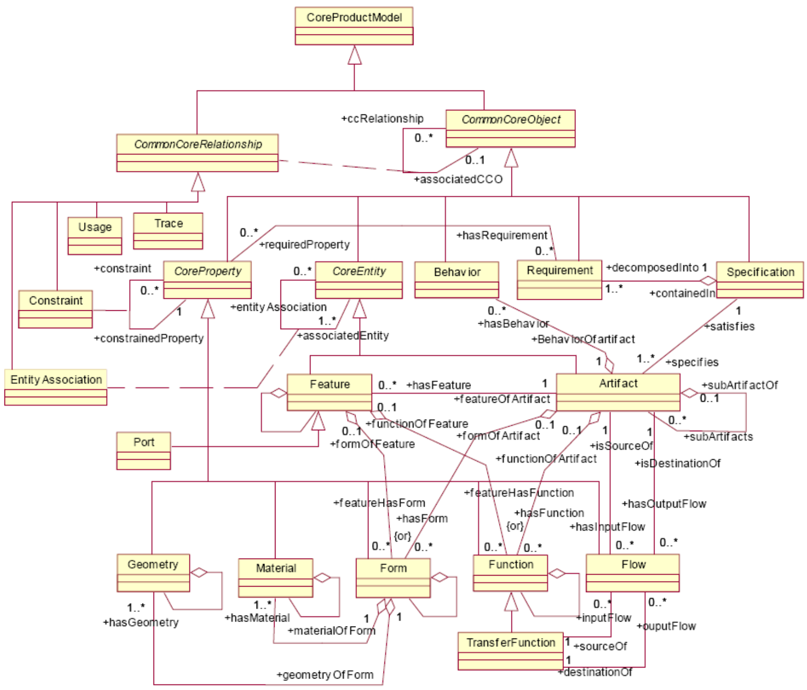
2 Previous Works at NIST

Based on our previous work on Core Product Model (CPM) and Open Assembly Model (OAM) we have developed OnAM. CPM is a product representation model while OAM is the CPM extension for assembly representation. Both CPM and OAM were originally UML models [4]. Following is a brief overview of the UML versions of CPM and OAM.

2.1 Core Product Model (CPM)

The CPM [1] was intended to form a base for representing a product model that could respond to the demands of the next generation CAD systems besides providing improved interoperability among future PLM systems. CPM is composed of four categories of classes: classes that provide supporting information for the objects (abstract classes), physical or conceptual objects classes, classes that describe associations (relationships) among the objects and classes that are commonly used by other classes (see Figure 1). For more information about the classes and relationships please refer [1-2].

Figure 1 Class diagram of the Core Product Model



2.2 Open Assembly Model (OAM)

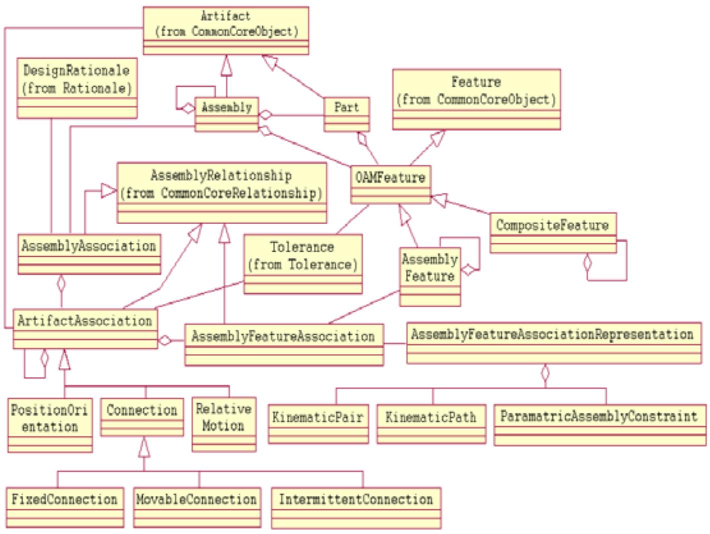
The Open Assembly Model (OAM) [3] extends CPM by providing a standard representation and information exchange for assembly and system level tolerance information. The OAM was developed using UML to be extensible (See Figure 2) to define tolerance representation, representation of kinematics, and engineering analysis at the system level. The assembly information model focuses on the information requirements for part, features and assembly relationships. It defines assembly as a concept and assembly as a data structure. The data structure part of this model is closely aligned with ISO 10303-203 and 10303-214 [5]. Information about assembly relationships and component compositions are incorporated in the model.

3 Ontology for Assembly Representation

The motivations towards an ontology for assembly representation was to explore and extend the current OAM with reasoning capabilities exploiting the ontological representation. We also experimented with various tools for modeling OnAM. Besides defining concepts, the benefits of ontology include:

- Creating abstract models
- Explicating concepts, properties, relations, functions, axioms and constrains
- Creating computer interpretable formulizations so as to infer classes, instances, and in general reasoning through queries.

Figure 2 Overview of the OAM-UML

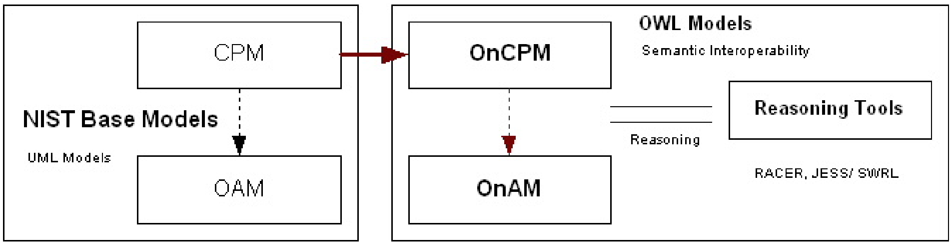


3.1 Methodology

The primary step towards developing OnAM is the translation of the assembly UML model [3] into OWL. We choose a translation based on an incremental approach to model development. Incremental modeling allows us to exploit the experience and knowledge gained from the earlier versions of the model. Although time consuming, this incremental approach enabled testing, subsequently allowing for sharper iteration of the modeling approach. In translating UML to OWL there are several underlying issues. The modeling elements offered by UML are substantially aligned with the needs of object-oriented programming, while OWL was developed to support the semantic web and its core objective is to allow interoperability through semantic data representation. UML and OWL use different modeling paradigms to capture system models [6-12]. Although similar concepts such as classes and relations can be found in UML and OWL, their underlying semantics are quite different. Besides, UML constructs are invariants (static class structure) that restrict the dynamic modification of models while OWL constructs are axioms for performing logic inference. These two languages may look alike on the surface and one can use these two languages to create similar models.

Figure 3 illustrates our approach to model development. We start with the NIST base models in UML and gradually evolve towards the OWL versions to support semantic interoperability and reasoning. In Figure 3, the solid arrow depicts the UML to OWL transformation and the dotted arrows depict the CPM extension to OAM.

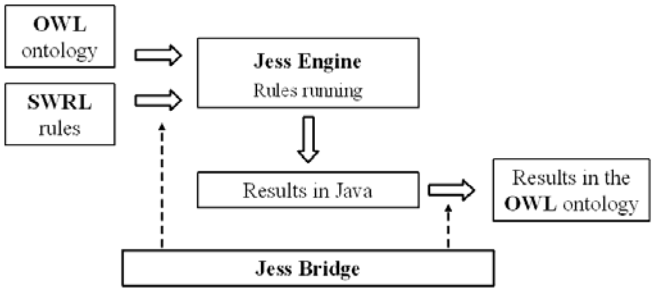
Figure 3 Model Development Approach



3.2 *Tools for Model Development*

The ontology has been modeled using Protégé-OWL [13]. The Protégé-OWL editor is an extension of Protégé that supports OWL. In this experiment we employed two types of reasoning: description logic reasoning and rule-based reasoning. For description logic reasoning, RACER [14], a semantic web information repository with optimized retrieval engine to handle large sets of data descriptions was used. Rules written in Semantic Web Rule Language (SWRL) [15-16] are used to support rule-based reasoning for the assembly models. The Protégé-OWL editor enables users to: load and save OWL and RDF ontologies, edit and visualize classes, properties and SWRL rules, define logical class characteristics as OWL expressions, execute reasoner such as description logic classifiers, edit OWL individuals for semantic web markup. These rules are edited in Protégé-OWL through the SWRLTab, an extension to the editor, and then executed by Jess, a rule engine for the Java platform that supports rule-based programming. We use a Jess Bridge to provide mechanisms for merging SWRL rules and relevant OWL data, to write them to the Jess engine and to return the new inferred information to the ontology (See Figure 4).

Figure 4 SWRL rules, Jess engine and Jess bridge



3.2.1 Ontology for Core Product Model (OnCPM)

As defined in CPM, the classes in OnCPM are grouped into four categories: abstract classes, object classes, relationship classes and utility classes. The abstract classes include: *CoreProductModel*, *CommonCoreObject*, *CommonCoreRelationship*, *CoreProperty* and *CoreEntity*. Object Classes include: *Artifact*, *Feature*, *Port*, *Specification*, *Requirement*, *Function*, *Flow*, *Behavior*, *Form*, *Geometry* and *Material*. Relationship classes include: *Constraint*, *EntityAssociation*, *Usage* and *Trace*. Utility classes include: *Information*, *ProcessInformation* and *Rationale*. The five abstract classes are used as base classes for other OnCPM classes. *CoreProductModel* represents the highest level of generalization; all OnCPM classes are specialized from it according to the class hierarchy (See Figure 1). The common attributes type, name and information for all OnCPM classes are defined in this class. *CommonCoreObject* is the base class for all the object classes. *CommonCoreRelationship* and its specializations, the *EntityAssociation*, *Constraint*, *Usage* and Trace *relationships*, can be applied to instances of classes derived from this class. *CommonCoreRelationship* is the base class from which all association classes are specialized. It also serves as an association to the *CommonCoreObject* class. *CoreEntity* is an abstract class from which the classes *Artifact* and *Feature* are specialized. *EntityAssociation* relationships may be applied to entities in this class. *CoreProperty* is an abstract class from which the classes *Function*, *Flow*, *Form*, *Geometry* and *Material* are specialized. Constraint relationships may be applied to instances of this class.

The key object class in the OnCPM is the *Artifact*. *Artifact* represents a distinct entity, whether that entity is a component, part, subassembly, assembly or the entire product. All the entities can be represented and interrelated through the subArtifacts/subArtifactOf containment hierarchy. Associations and aggregations are other important and fundamental components of the OnCPM.

All object classes, i.e., specializations of the abstract class *CommonCoreObject*, except Flow, have their own independent decomposition hierarchies, also known as ‘part of’ relationships or containment hierarchies. Decomposition hierarchies are represented by attributes such as subArtifacts/subArtifactOf for the *Artifact* class. There are associations between: (a) a *Specification* and the *Artifact* that results from it; (b) a *Flow* and its source and destination Artifacts and its input and output Functions; and (c) an *Artifact* and its Features. Finally, four aggregations are fundamental to the OnCPM: (a) *Function*, *Form* and *Behavior* aggregate into *Artifact*; (b) *Function* and *Form* aggregate into *Feature*; (c) *Geometry* and *Material* aggregate into *Form*; and (d) *Requirement* aggregates into *Specification*. For a detailed description of CPM on with the OnCPM was modeled please refer to [2].

3.2.2 Ontology for Assembly Model (OnAM)

We extend OnCPM to represent assembly information. The classes and properties presented in the previous paragraph are specialized in OnAM to include a standard representation and exchange protocol for assembly, kinematics, and system-level tolerance information. OnAM is extensible and currently provides for tolerance representation and propagation, representation of kinematics, and engineering analysis at the system level [6]. The assembly information model emphasizes the nature and information requirements for part features and assembly relationships.

OnAM incorporates information about assembly relationships and component composition; the representation of the latter is by the class *ArtifactAssociation*, which represents the assembly relationship that generally involves two or more artifacts. Instead of creating another class to aggregate the *ArtifactAssociation* representing the assembly, we choose to directly connect *ArtifactAssociation* to Artifact, thus allowing the possibility to check the assembly relationship involved in the Artifact through the property *ArtifactAssociation2Artifact*.

An Assembly is a composition of its subassemblies and parts. A Part is the lowest level component. Each assembly component (whether a sub-assembly or part) is made up of one or more features, represented in the model by *OAMFeature*. The Assembly and Part classes are sub-classes of the OnCPM Artifact class and *OAMFeature* is a subclass of the OnCPM Feature class. *ArtifactAssociation* is specialized into the following classes: *PositionOrientation*, Relative-Motion and Connection. *OAMFeature* has tolerance information, represented by the class Tolerance, and subclasses *AssemblyFeature* and *CompositeFeature*. *CompositeFeature* represents a composite feature that is decomposable into multiple simple features. *AssemblyFeature*, a sub-class of *OAMFeature*, by definition represents assembly features. Assembly features are a collection of geometric entities of artifacts. They may be partial shape elements of any artifact. The class *AssemblyFeatureAssociation* represents the association between mating assembly features through which relevant artifacts are associated. The class *ArtifactAssociation* is the aggregation of *AssemblyFeatureAssociation*. The class *AssemblyFeatureAssociationRepresentation* represents the assembly relationship between two or more assembly features. This class is an aggregation of parametric assembly constraints, a kinematic pair, and/or a relative motion between assembly features. *KinematicPair* defines the kinematic constraints between two adjacent artifacts (links) at a joint. The kinematic pair represents the geometric aspects of the kinematic constraints of motion between two assembled components. *KinematicPath* represents the relative motion between artifacts.

Tolerancing includes both tolerance analysis and tolerance synthesis. In the context of assembly design, tolerance analysis refers to evaluating the effect of variations of individual part or sub-assembly dimensions on designated dimensions or functions of the resulting assembly. Tolerance synthesis refers to allocation of tolerances to individual parts or sub-assemblies based on tolerance or functional requirements on the assembly. During the design of an assembly, both the assembly structure and the associated tolerance information evolve continuously; we can achieve significant gains by effectively using this information to influence the design of that assembly. Any proactive approach to assembly or tolerance analysis in the early design stages will involve making decisions with incomplete information models. In order to carry out early tolerance synthesis and analysis in the early design stage, we include function, tolerance, and behavior information in the assembly model; this will allow analysis and synthesis of tolerances even with the incomplete data set. In order to achieve this we define a class structure for tolerance specification. *DimensionalTolerance* typically controls the variability of linear dimensions that describe location, size, and angle. *GeometricTolerance* is the general term applied to the category of tolerances used to control shape, position, and runout. The class *GeometricTolerance* is further specialized into *FormTolerance*, *ProfileTolerance*; *RunoutTolerance*; *OrientationTolerance*; and *LocationTolerance*. Datum is a theoretically exact or a simulated piece of geometry, such as a point, line, or plane, which serves as a reference to a tolerance. *DatumFeature* is a physical feature that is applied to establish a datum. *FeatureOfSize* is a feature that is associated with a size dimension, such as the diameter of a spherical or cylindrical surface or the distance between two parallel planes. For detailed information on the classes comprising OnAM refer to [3].

4 Case Study

This section briefly illustrates an example of a planetary gear system (Figure 5) to test OnAM with the reasoning capabilities. The assembly model of a planetary gear system is modeled using a CAD system. The system consists of 4 subassemblies with 30 different parts and each part characterized by its features and tolerances. In the chosen planetary gear system, the connection and pairs between different artifacts are of different types. In this example our aim is to represent scenario of an assembly representation to outline assembly complexity but at the same time not to complicate the example itself. Moreover, the same example had been previously used during the instantiation of the OAM-UML model. For a detailed description of the example refer to [18]. The planetary gear system is modeled using the OnAM using Protégé-OWL [18] based on the methodology discussed previously. Below are a few snapshots of the Protégé OWL OnAM model for illustration purposes. Figure 6 presents a snapshot of OnAM instances browser.

Figure 5 Case study: Planetary Gear System

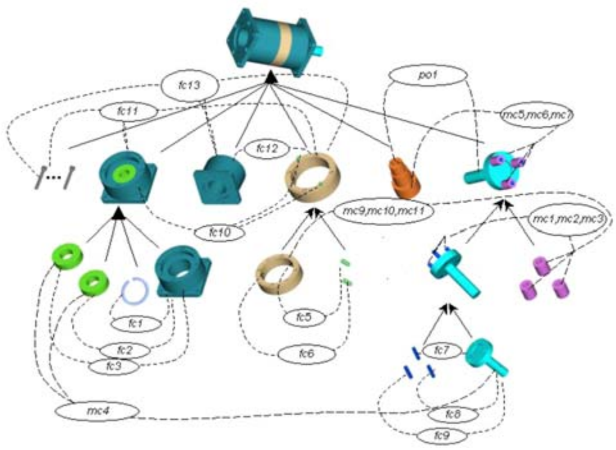
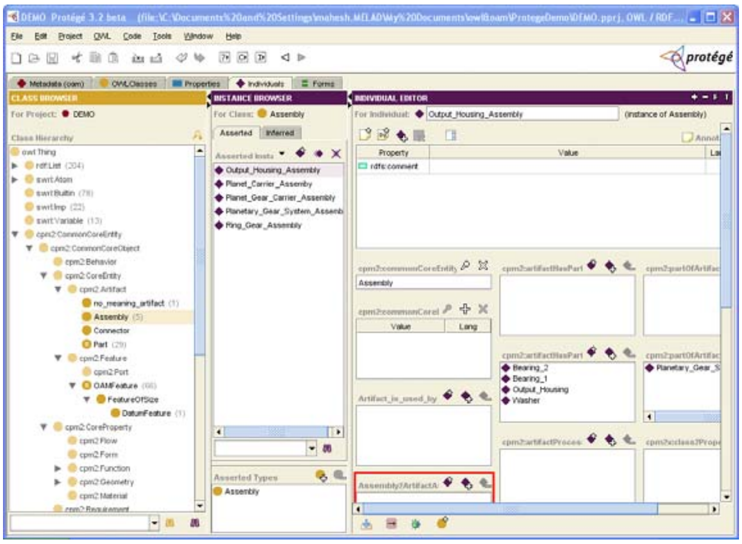


Figure 6 OnAM Class Explorer in Protégé-OWL



4.1 *Reasoning with OnAM*

Classes, properties and restrictions are the conceptual abstractions that OWL offers for the creation of ontology but these are not sufficient to capitalize the real potentials of ontology, i.e., the reasoning capabilities. In OnAM we perform two different kinds of reasoning, the description logic reasoning using RACER [14] and rules based on SWRL [15-16] and reasoner Jess [17].

4.1.1 *Description Logic Reasoning*

Description logic reasoning was carried out using RACER which exploits all the restrictions and the definitions of the classes to infer classes and instances. An example of description logic reasoning from our case study is presented in Table 1. By using the necessary and sufficient conditions on the classes and relationships, RACER can associate an instance to a particular class if it satisfies these conditions. Besides, the role of the reasoner is also to check the consistency of the ontology by verifying the necessary conditions and class hierarchy.

Consider the following example to demonstrate the reasoning based on the description logic used in OnAM. With the UML representations of CPM and OAM, it was possible to state that an assembly has to be composed of at least by two parts (cardinality restriction on the part-of connection between *Assembly* and *Part*, Figure 2), but it was impossible to reason that a general artifact, defined as an instance in the CPM and composed by at least two parts, was indeed an assembly when considered at the OAM level.

But in OnAM we associate the necessary and sufficient condition to the *Part* for which a leaf node has cardinality 0 with the inherited property artifactHasPart_direct (property used to describe the relationship between artifacts and their subassemblies/parts they compose). In this way we define a *Part* like an artifact without subassemblies. Besides the necessary conditions for *Assembly*, there is a constraint of having at least two artifacts connected through the inherited property artifactHasPart_direct. Hence by defining Assembly and Part like partitions of the class *Artifact*, an instance of *Artifact* composed by other artifacts is inferred to be an instance of *Assembly* (See Table 1).

Table 1 Reasoning with RACER

CLASSES	Artifact, Assembly (sub-class of Artifact)
PROPERTIES	cpm2:artifactHasPart_direct (R: Artifact , D: Artifact)
RESTRICTION	on Assembly cpm2:artifactHasPart_direct min 2 (an Artifact is an Assembly only if it is related with at least 2 other Artifacts)
INPUT	an instance of Artifact (*Planet_Carrier_Assembly*) composed through cpm2:artifactHasPart_direct by 4 instances of Part (*Output_Shaft, Planet_Gear_Pin_1, Planet_Gear_Pin_2, Planet_Gear_Pin_3*)
OUTPUT	*Planet_Carrier_Assembly* has been reclassified as an instance of the class Assembly

4.1.2 Rule-based Reasoning

While description logic reasoning is better suited for reasoning about taxonomy classification; rule-based reasoning provides ways to infer implicit information in the model, like reclassifying instances and infer properties between them. We model these rules in SWRL and execute these SWRL rules (See example in Table 2) that interpret the ontology through the Jess Bridge which establish connection between the Protégé-OWL editor and the Jess Engine. There are 4 kinds of rules that are useful both to associate instances to new classes and to create properties between instances.

Property rules: Property rules are used to create new links between instances once some properties are satisfied. They are production rules and they incorporate the meaning into the ontology. Unspecified rules can be inferred with property rules. For example, once we have the structure of an assembly and the *ArtifactAssociation* between its subassembly, the reasoner can easily associate them directly to the assembly. In the example (see Figure 7 and Table 2), once the rules are fired, the ArtifactAssociations existing between the individual subcomponents (Assembly 2, Part 1 and Assembly 3) are associated to the master Assembly 1.

Association rules: We uniquely translate the property classes and the relationships they specify between two elements of the same object class. Figure 8 shows the UML representation of the property class ArtifactAssociation connected to the class Artifact.

Figure 7 Property rule example

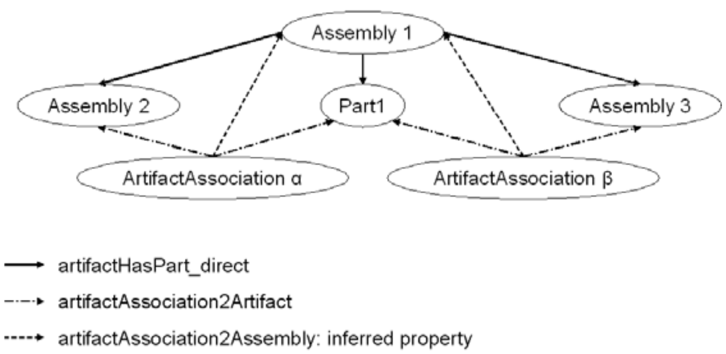


Table 2 Reasoning with JESS/ SWRL

CLASSES	Assembly, Part, ArtifactAssociation
PROPERTIES	artifactAssociation2Assembly (R: ArtifactAssociation , D: Assembly)
AIM	infer the relation between Assembly and ArtifactAssociation
INPUT	an instance of Assembly (*Output_Housing_Assembly*) composed through cpm2:artifactHasPart_direct by both parts and assemblies. These instances of the class Part are connected with instances of the class ArtifactAssociation.
OUTPUT	*Output_Housing_Assembly* has been linked with the corresponding instances of ArtifactAssociation through the ArtifactAssociation2Assembly property.

Figure 8 UML representation of a property class

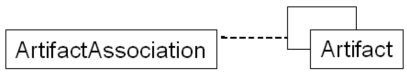
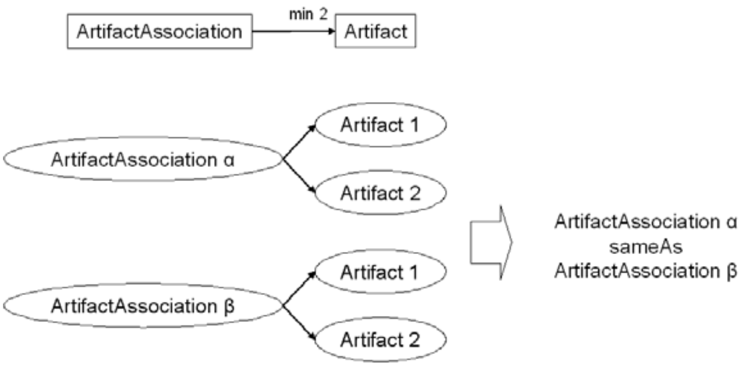


Figure 9 Association rule example

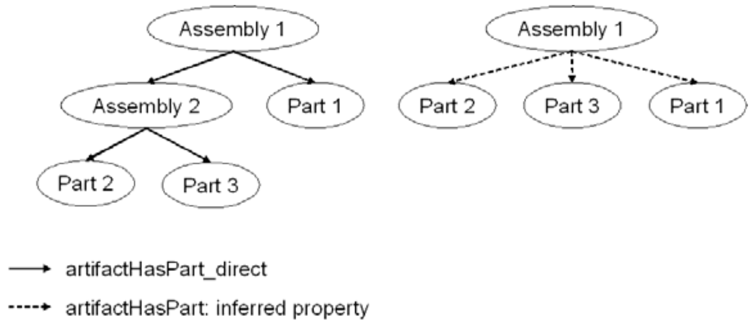


The property class will become a normal class in the ontology and it will be connected to the object class with a binary property. To be binary, we apply a minimum cardinality 2, and then we specify that if two different instances of the property class are connected to the same instances of the object class, then these two instances are the same (see Figure 9). In SWRL it has been translated with the embedded language structure: sameAs. This is allowed since OWL follows the logic axiom paradigm instead of the invariant constructs imposed by UML.

PartOf rules: These rules are needed to create the right structure of assembly to enable the subassemblies distinguish between the direct and indirect properties. We need to use both of them because using only a transitive direct property does not allow us to specify any cardinality on the property. Hence, the indirect property links an assembly with all the parts it composes (example in Figure 10).

Restrict rules: They are useful to populate the classes of the kind not-allowed to restrain user from deleting some properties or instances.

Figure 10 PartOf rule example



5 Results and Discussion

The proposed OnAM aims to address a representation model for interoperability between software platforms with a capability of semantic reasoning. The underlying motivation for the creation of the OWL version of the assembly model is to exploit information model developed using a semantic language and reasoning capabilities. It not only offers the possibility to give a format to the data structure but also a meaning intelligible by a computer. Machines can now easily communicate, since the concepts are formalized and described in the ontology. Moreover, the structure and the semantic nature of the OWL model can be understood and reasoned by suitable reasoning software. In this application, we deployed RACER to check the consistency of the developed ontology, to reclassify classes and to infer the related instances. Further, we have demonstrated the reasoning potentials in OnAM using description logic to rule-based reasoning using Jess/ SWRL. The future scope of research includes more test cases to capture function and behavior into the model and explore the possibility of "annotating" a CAD model using this ontology.

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A feature-based approach to integrate product and process architectures

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Abstract: This contribution describes a feature-based reference model which integrates product and process architectures. A reference model is an abstract, commonly valid model from which an application model describing a certain scenario can be derived. To integrate the product architecture, which comprises the product and the functional structure, and a process architecture, which comprises the process and the organisational structure, a hierarchical feature structure will be applied. This approach aims at making as much product related knowledge reusable as possible. In general, only the data connected to the product structure can be reused as other knowledge is only of implicit character. This knowledge can be turned into explicit using the mentioned feature-based approach. It will be embedded into a reference model to ensure that only common knowledge is incorporated. Product specific knowledge which cannot be reused will be discarded.

Keywords: Reference Model, Product Architecture, Process Architecture, Knowledge Management, Feature Technology

1 Introduction

The development of technical products is increasingly influenced by a global competition. This forces decreasing development times, a strong cost pressure and raising quality requirements. Particularly small and medium-sized enterprises (SME) are coerced to take appropriate measures in order to keep their market position. During the past years, especially Product Lifecycle Management (PLM) has proven to be an adequate strategy.

PLM is defined as a knowledge-based enterprise strategy for all processes and methods regarding the development of products from the product idea to recycling [1]. Knowledge is a major aspect concerning these definitions as PLM is stated to be knowledge based. This implies that PLM focuses not on the lifecycle of a physical product, but on the knowledge describing this lifecycle. All activities within the entire product lifecycle which lead to the product model, the virtual prototype as well as the physical product itself are based on that knowledge. Therefore, product lifecycle related knowledge can be seen a crucial resource for the economical success of a company.

Many product developing companies are organised oriented towards the disciplines involved in the product creation processes. The organisational structure of car manufacturers for example is in most cases a matrix organisation. Distinct cars are developed by project teams, composed of members from different organisational units. Each organisational unit represents a single discipline like car body, engine, gearbox, chassis, electronics or software for example. However, most components of complex products involve several disciplines. An engine as well as an automated gearbox for example is amended by electronic components which in turn comprise software components. This makes responsibilities more unclear. Tasks are related to distinct product components, but the organisational structure cannot unambiguously assign these tasks to the involved employees. Moreover, even knowledge cannot be unambiguously addressed by the organisational structure. The knowledge is primarily bounded to product components, but it originates from different disciplines. Therefore, the knowledge is distributed amongst the organisational structure. On the one hand, this aggravates the exchange of knowledge related to a distinct product component between several organisational units [2,3]. On the other hand, the knowledge can hardly be reused. Due to highly integrated product components with several disciplines involved and the discipline-oriented organisational structure the knowledge is not bounded to the product components. Therefore knowledge might be lost, if a certain component is reused or advanced for new products.

The approach proposed by this paper aims at making multidisciplinary knowledge reusable through various product generations. Hence, a feature-based reference model will be defined. This model integrates the product architecture and the process architecture. To make the knowledge reusable it will be assigned to common features. Similar to a least common denominator these features comprise information common to a certain range of product components.

Chapter 2 will introduce basic principles and technologies which are required for the method delineated in this contribution. This approach is based on a holistic model which describes the product, associated processes and actors in charge. The constituents of this model will be outlined in chapter 3 and chapter 4. Chapter 5 actually describes the mentioned approach. Finally, chapter 6 summarises this contribution.

2 Base Technologies and Related Approaches

2.1 Reference Models

A reference model is a concept similar to a least common denominator. It is defined as a generic information model with a variable application context [4]. Based on a certain reference model multiple application models can be derived. Reference models are characterised by the following major properties [5]:

- **Universal validity**. A reference model features universal validity. This means, that it is applicable for a certain category of application scenarios. Because reference models are applied by deriving a specialised model (as described below), a bunch of application models can be derived from a universally valid reference model. An application model is a specific model describing a certain application scenario.
- **Reference character**. Reference models can be seen as a guideline for derived application models. The application models are created based on predefined

components of the reference model [6]. These components incorporate valid knowledge and experience. Thus, a reference model represents a nominal condition [5]. In practice, the reference character of a certain model may be arguable and especially dependent on the experience of the originator regarding the application scenarios [5]. A significant validation of a reference model requires the derivation and evaluation of multiple application models.

Considering the definition and characteristics of the reference models delineated above, a reference model can be summarized as an ideal abstract model constituting a reference for a certain category of application models. It comprises model elements describing aspects common to all application scenarios.

The application of reference models follows the principle of concretion. A model can be concretised to design a distinct application scenario by configuration, aggregation, specialisation, instantiation and analogical creation [5,7]. Such application models include all aspects relevant for a certain scenario. Irrelevant aspects are discarded in order to structure the application model as generally applicable as possible.

Each reference model can be applied for a bunch of application scenarios. A common intention for the application of reference models is to enhance the efficiency and effectiveness concerning the creation of application models. Because reference models are based on predefined and reusable model components the derived application models will benefit from synergy effects. Due to the reference character described above the quality of application models will increase. Furthermore, reference models store explicit knowledge of the application domain [8] and make it available through the derivation of application models.

2.2 Feature Technology

A commonly accepted definition of a feature originates from the workgroup FEMEX (Feature Modelling Experts) [9]. This definition corresponds to the VDI-directive VDI 2218 [10]. Accordingly, a feature is defined as:

- An IT-based element. It represents aspects of particular (technical) interest of one or more products.
- An aggregation of relevant properties of a product. This aggregation comprises the properties as well as their values, relations and constraints.
- A specific view on the product which can be defined for example by phases within the product lifecycle or technical aspects.

Features were first invented to represent geometric entities which can be manufactured by certain machine tools [11] and to automatically generate NC-software [12]. Common kinds of features are currently design, manufacturing and calculation features. These examples are applied to connect the ideas and intentions of a designer with technical issues [12], e.g. geometric models, manufacturing operations and calculation methods. Existing design, manufacturing or calculation features can be cumulated by aggregating high-order features [13].

2.3 Enterprise Modeling

Current approaches for enterprise modeling originate from the area of business information technologies. These approaches like ARIS [14], for example, strongly focus on enterprise processes. However, a holistic model for development processes additionally requires a comprehensive product data model. Furthermore, an organization model is required to describe the responsibilities for the execution of process steps. Enterprise models for product developing companies therefore comprise a product data model, a process model and an organization model [15]. These three partial models will be described in detail in chapter 3 and chapter 4.

2.4 Engineering Data Exchange Models

Several data models to exchange engineering data have been developed. STEP [16] and IGES [17] are common standards providing a neutral format especially for CAx data. Similarly, the NIST Core Product Model (CPM) has been developed as a base level product model that is not tied to any vendor software. Whilst these models support the exchange of data between different applications, the Product-Process-Organisation model (PPO) [19] shares a common product representation between several disciplines during the development phase of a new product. In contrast, the approach described in this paper aims at sharing product data between subsequent lifecycles. However, exchange models incorporating hierarchical feature structures can be used as a base model.

3 Product Data Model

To define a holistic product data model all data describing certain product aspects have to be taken into account. In practise, a product data model solely implies the product structure and some geometric product data as this is mostly sufficient to plan the manufacturing process. However, to manage the product lifecycle and reuse product information a holistic product data model is required. Therefore, the product data model described in this chapter is amended by a function structure related to the conventional product structure by the product architecture.

3.1 Product Structure

Generally, the product structure describes a hierarchy of physical components [1]. Indivisible components are called parts. An assembly is a component which comprises smaller components and/or parts.

The product structure is not unique. Instead, several kinds of product structures may coexist. The physical structure for example describes the way components are physically connected to each other. The assembly structure is established according to the sequence of assembly. Relations between model components, for example compatibility relations, can be documented by the model-based structure. The function-based structure groups product components according to the functional structure (section 3.2).

Many current products not only comprise physical parts, but also software entities. In case of mechatronic products the software accounts for the functionality of the product. The software has to be managed, versioned, documented and referenced in line with the physical components. Therefore, the product structure will be amended by logical components which represent non-physical constituents of the product. A logical component stands for software in most cases. Even services can be represented by such a component.

To make the classification more intuitive and avoid ambiguity both, the parts and the indivisible logical components will be called items. An assembly which comprises physical as well as logical components is denoted hybrid.

3.2 Functional Structure

The functional structure models the overall function of a product and describes how it is decomposed by partial functions [1]. Each high-order function comprises several partial functions. Indivisible functions are called elementary functions.

Functional structures and product structures cannot be assigned unambiguously to each other. A functional structure is an abstract representation of a certain aspect of a product. Therefore, different products (with different product structures) might share the same functional structure. A product line for example includes products with varying geometries, but a unique functional structure. Likewise, a certain product (or product structure) can have several functional structures. Although all functional structures represent the same overall function, each of them is decomposed by different structures of partial functions.

3.3 Product Architecture

The product architecture denotes a transformation which relates the functional structure to the product structures [20]. Each partial function is assigned a product component which realises that function. According to section 3.1 these product component can be of either physical, logical or hybrid character.

4 Process Model and Organisation Model

The process model describes all activities within a company which process data and material. To perform these activities, resources like employees, machines or finances are required. They can be subsumed by the organisation model. Similar to the product architecture the process architecture connects the process and the organisation model.

4.1 Process Structure

The process structure subdivides a process into partial processes and activities. Each superordinate (partial) process comprises smaller partial processes and/or activities. This leads to a hierarchical structure. Activities are indivisible model elements which are in literature also denoted as process steps.

4.2 Role Structure

Roles are an auxiliary concept which is common amongst the disciplines engineering sciences, business studies and computer science to assign responsibilities for certain tasks to resources. In most cases, these resources are employees, but tasks can also be assigned to machines. A resource performing a task is called an actor.

Roles can be ordered by a hierarchical structure to model more comprehensive superordinate responsibilities. The responsibility for a certain partial process for example is more comprehensive than the responsibility for a task which is part of that partial process. The assigned roles will be superordinate and subordinate respectively.

4.3 Process Architecture

To establish a project, the activities on the on hand and the actors on the other hand have to be related. This is accomplished by the process architecture. Similar to the product architecture which assigns functions to product components, the process architecture assigns activities to actors. Accordingly, it connects the process structure and the organisational structure [21]. An activity which has been assigned to an actor is called a task.

Activities and actors are not assigned directly. Instead, they are connected via the role structure. Each actor is assigned a role and the process structure is mapped on the role structure. This makes the project organisation more flexible because the process structure and the organisational structure are respectively encapsulated by the role structure. A partial process or an activity can be assigned to a role without profound knowledge about the process structure. Similarly, a role can be assigned to an actor without profound knowledge about the organisational structure.

5 A Reference Model to Integrate Product and Process Architecture

The product related knowledge is shared throughout the various models described above. Each model comprises a certain aspect of the explicit knowledge and actually indicates implicit knowledge which is associated with the model by the user. This aggravates the complete reuse of product related knowledge. Generally, the product structure amended by product describing data like CAx-files is exclusively used to describe a product. All knowledge which is not comprised by this model is only implicitly available. However, much of this knowledge could be made explicit by one of the other models. It will presumably get lost, if the product structure is reused in new product lifecycles. Therefore, an integrated product model is required which comprises all product related knowledge.

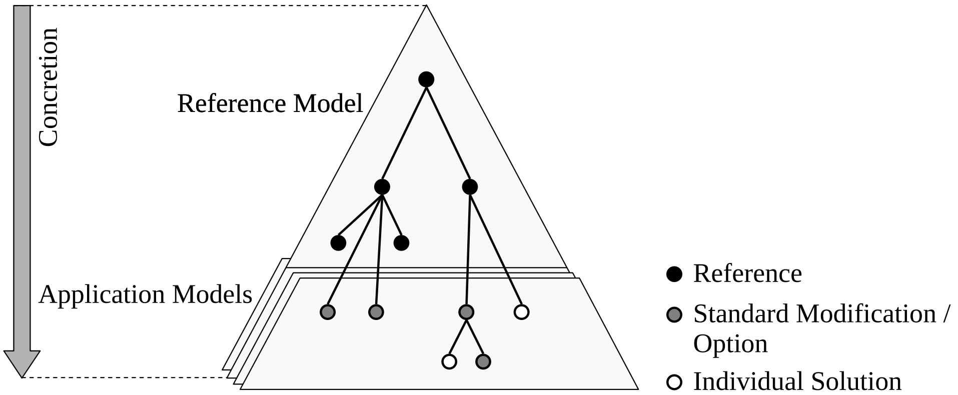
A product model contains knowledge which relates exclusively to a certain instance of a product as well as knowledge which is valid through several product lifecycles. That commonly valid knowledge has to be made reusable in order to avoid mistakes as well as duplication of work and product data. For this purpose a reference model can be applied. The model represents the knowledge which is common to a certain class of products and therefore has to be reused. It comprises a reference product architecture and a reference process architecture. As described in section 5.3, both architectures are integrated by a feature concept.

5.1 Reference Product Architecture

A reference product architecture is a reference model as described in section 2.1. It comprises a reference functional structure and a reference product structure. Both are again reference models and can be concretised resulting in a conventional product structure and a functional structure respectively.

Figure 1 depicts a reference product structure. Reference functional structures are composed similarly. Reference product structures as well as reference functional structures comprise references, standard modifications/options and individual solutions. A reference denotes constantly defined functions or components. Each product or functional structure which is derived from a certain reference structure comprises these references. A standard modification defines a component or function which can be modified, whereas these modifications are constrained. Options are certain kinds of standard modifications. An option represents several components or functions which can be selected alternatively. Individual solutions finally denote unspecific components or functions. An individual solution is not constrained and can be adapted to the individual requirements of a customer without any restrictions.

Figure 1 A reference product structure.



Both, reference product structure and reference functional structure are related to each other by the transformation of the product architecture. This transformation assigns components to functions. Therefore, the reference product structure depends on the reference functional structure. The reference functional structure can hence not only be applied to reuse functional knowledge but also to determine the standard modifications and individual solutions of the product structure. This makes the reference product architecture feasible to predefine certain kinds of product architectures constituted by specific dependencies between the functional structure and the product structure like modular architectures for example (which are constituted by functional and structural independency of certain components, called modules).

5.2 Reference Process Architecture

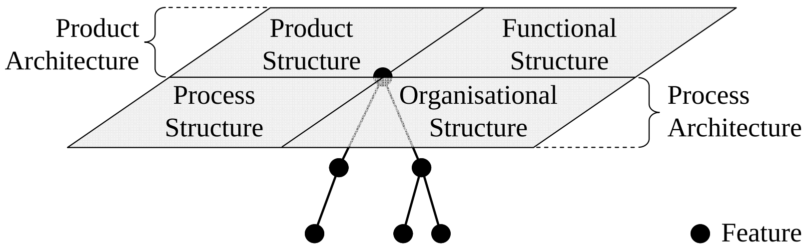
Analogically to reference product architectures described in section 5.1, a reference process architecture is defined as a reference model which comprises a reference process structure and a reference organisational structure. Both are again reference models. A conventional process architecture can be derived from a reference process architecture by concretion of the associated reference process architecture and reference organisational architecture. Similar to a reference product architecture, the reference process architecture is composed of references, standard modifications/options and individual solutions (cp. picture 1).

In order to be compatible with the feature-approach which will be described in section 5.3 the reference process structure cannot be composed arbitrarily. Appropriate approaches are for example process kits [22] or modularised processes [23]. Further, the concept according to Meissner [24], based on three levels of abstraction, can be applied for this purpose.

5.3 Features to Integrate Reference Product and Process Architectures

Currently, product and process knowledge can be assigned on product-level. Each product relates to certain development and manufacturing processes. However, this assignment is either too specific or to general. Specific processes which are tailored to a certain product cannot be reused. In case a product is assigned more general processes which are applicable to several products, the processes can be reused, but a certain amount of procedural knowledge will be lost because procedural commonalities occurring on deeper levels within the product architecture cannot be represented. Features can be applied as an integrating constituent of the product as well as the process architecture to make all procedural knowledge which is common to a certain group of products reusable. Figure 2 illustrates this concept, which will be described in more detail below.

Figure 2 An integrating feature structure.



The elementary constituents of a product structure, the functional structure, the process structure and organizational structure can be described by features: Design features (cp. section 2.2) are commonly applied. They represent the physical and logical aspects of a product. Furthermore, design features can be assembled to parts and therefore be constituents of a product structure.

The concept of design features can easily be extended to integrate functional structures. Therefore, the content of a feature will be amended by functional information. However, there is not a one-to-one assignment between the product structure and the functional structure (which is defined by the product architecture). Instead, on the one hand a single design feature can fulfill several elementary functions according to Koller [25]. On the other hand, several design features may be required to fulfill a single elementary function. Therefore, a flat feature concept is not sufficient. To integrate the product structure and the functional structure, the authors propose a hierarchical feature structure. The top-level feature comprises either a single design feature with several elementary functions or several design features with a single elementary function and will be accounted for reuse. As described below, this concept can be amended by activities and roles to integrate all relevant aspects concerning product creation and manufacturing.

Activities are the most detailed components regarding the process model. An activity defines an explicit instruction for a person in charge and the appropriate inputs and outputs. These aspects can be represented by a feature. Similar to design features and elementary functions, an activity cannot be assigned one-to-one to other aspects describing the product. However, the hierarchical concept described above can be applied for this purpose.

Besides process structures, the process architecture comprises information about responsible actors. To represent all relevant information the hierarchical feature structure described above will therefore be amended by elements from the role structure.

6 Summary

The reference model described above aims at making all product related knowledge reusable. This comprises not only the data which is bound to the product structure, but also the product function, process knowledge and responsibilities concerning the processes. A feature structure has been proposed to transfer implicit into explicit knowledge and integrate it into the reference model. The reference model on the one hand assures the reusability because only common knowledge will be incorporated. The feature concept on the other hand increases the amount of reusable explicit knowledge.

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An artificial intelligence based design environment for complex products

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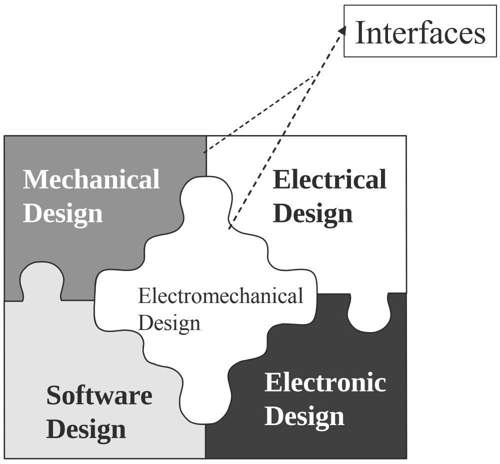
Abstract: Electromechanical products such as electrical toothbrushes and robots carry multi-technological characteristics. Owing to limitations on available expertise, and reach-ability of experts, and engineers and academics, designing these products is a very complicated and time-consuming process. Also, not much research has been carried out developing tools, methods and computer supported systems for dealing with significant issues in electromechanical product design. As a result, a multi-disciplinary design approach is needed to effectively address the above problems. In this research paper, a new object oriented product development approach has been proposed for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products within given requirements. The proposed approach has been implemented in a Delphi based environment integrated with a CAD system. To firmly understand relationships between each component in a complex system some existing products have been examined and modeled in terms of constraints, rules and frames. The system assists designers from different disciplines in evaluating complex systems as far as parts relation, potential effects on each other, costs, weight and physical constraints are concerned in the early stages of the design process. This helps the designers to avoid design iterations leading to longer lead-time, hence increased cost. The system enables to rapidly develop new complex products and add new functions to the existing products within given constraints.

Keyword : Interdisciplinary product design, Object-oriented modeling, Complex product design, Constraints, Conflict management

1 Introduction

Electromechanical products are becoming increasingly sophisticated and significant in advanced high tech products for the commercial and defense markets. These products such as digital cameras and robots have multi-technological characteristics. An electromechanical product consists of electronics, mechanical components, software and other systems. Designing these products is a complex and time-consuming process due to constraints from different view points (fig. 1). In complex product design, early design decisions have significant impacts on product cost, time, and quality. There is lack of people who completely understand the range of discipline-related technologies to be very likely found within electromechanical systems.

Figure 1 Different view points in interdisciplinary product design



Different approaches have been proposed for supporting electromechanical product design. One such approach is that of agent-based systems [1, 2]. As an alternative method of presenting product requirements, constraint networks have been implemented to help the designer to improve product designs by preventing conflicts [3, 4]. A large amount of work has been devoted to the development of physical modeling and simulation environments for electromechanical systems [5, 6, and 7]. Concurrent engineering approach has been successfully implemented in a purely mechanical or purely electronic design domain [8, 9], but little progress has been made towards the use of this approach for electromechanical product design [10, 11]. Various authors have remarkably shown that conflict management, information sharing, integration of CAD tools and collaborative decision-making become critical in advanced electromechanical design [8, 9, 12, 13, 14, and 15].

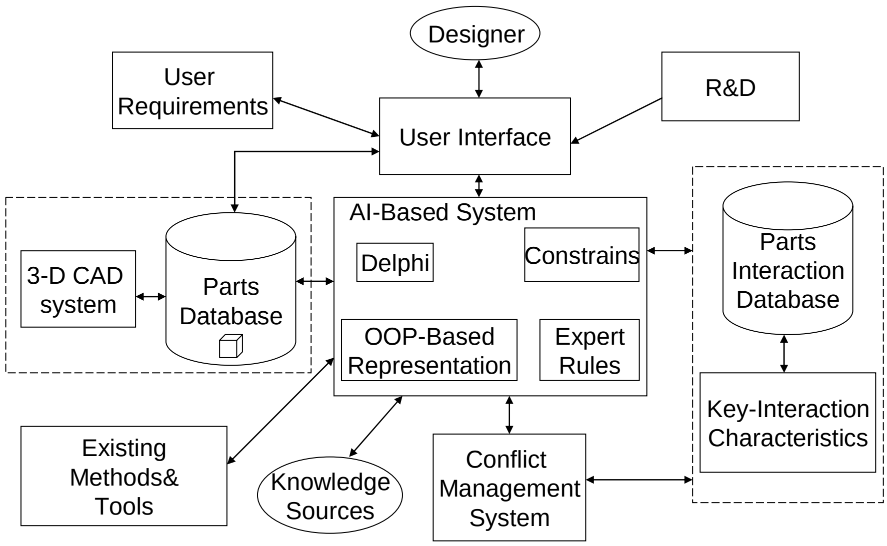
Some researchers in this field have focused on component selection of electronic or mechanical products through internet-based applications [16], however the key topic of interactions between mechanical and electrical/electronic components was not addressed. Object-oriented modeling and bond graphs have also been used to assist in the development of system models [16, 17, 7]. Software systems have been developed to support graphical programming and the intelligent control of complex systems, for example ControlShell, developed by Real-Time Innovation, Inc. [18]. Modelica as an object-oriented language has been also utilized for physical system modeling, visualization and interaction [19].

In spite of a rapid growth and widespread use of mechanical and electronic CAD tools, knowledge gaps still exist between the remote areas of design and manufacture because of the lack of appropriate methods and computer-supported tools which aid the development of electromechanical systems in the early design stages. A cooperative methodology needs to be developed to capture customer requirements, translate them into system requirements, module requirements, and sub-system and component requirements.

2 Proposed Approach to Interdisciplinary Product Design

The proposed approach to address the significant problems of electromechanical proposed design has been shown in Fig. 2. It consists of interacting modules with their own functions. It is an object oriented product development approach for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products subject to given requirements.

Figure 2 A new approach to interdisciplinary product design

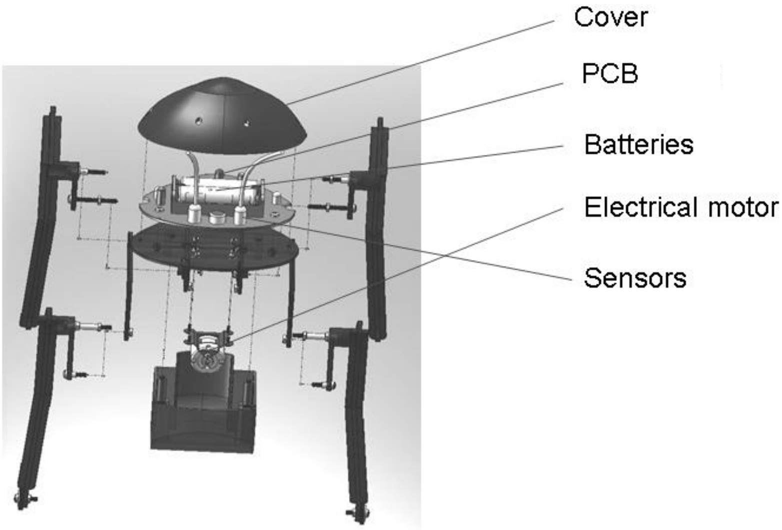


The proposed approach has been implemented in a Delphi based PC environment integrated with a CAD system. To understand relationships between each component in a complex system some existing products such as an electrical toothbrush and a walking robot (Fig. 3) have been examined and relationships between components are modeled based upon constraints, rules and frames. It embodies a CAD module with a part database, requirement definition module, user interface, conflict management system, parts interaction database, AI-based system incorporating constraints, rules of thumb and object-oriented representation of parts with key-interaction characteristics.

2.1 A Working Scenario of the Proposed System

The actual procedure for designing an electromechanical product, via the proposed approach, requires that the designer interacts with the CAD system and parts-database to create the product and its various electronic and mechanical components. Information about the product and its individual components is passed to the knowledge-base system via the user interface. The designer enters requirements, coupled with target cost, weight, speed, dimensions, resources and capabilities, together with other areas of the design process, into the system as a set of constraints. The system conducts various tasks by meeting all the constraints of relevant engineering domains. It begins by concurrently checking the target cost, weight, dimensions and interactions of the proposed system and its sub-systems while they are designed. The system provides the designer with an evaluation of all the decisions associated with the system, its sub-systems and parts. Recommendations are given when the proposed design cannot meet all the requirements. This allows the designer to avoid unexpected consequences leading to longer lead-times, customer dissatisfaction, failures and costs during the product life cycle. Also it allows the effective conflict resolution strategy for design inconsistencies arising from the different areas of the design process.

Figure 3 A 3-D electromechanical walking robot with various interacting parts



2.2 Product Key Characteristics As Constraints

Product key characteristics are generally associated with factors affecting the performance of electromechanical products. These can be modeled in terms of constraints. Electrical/electronic and mechanical systems and components interact one with another when they are designed and worked together. Interactions between individual components can have important impacts on functions, cost, performance and quality. Therefore, these interactions must be taken into account in order to achieve better product designs without conflicts during the design process. The most common key characteristics of electromechanical products are determined as follows; *noise, heat, power, space allocated, vibration, conductivity, velocity, location, gravity, safety, electromagnetism, environment,* and *mass*. In our approach a system design process is divided into subsystems, then components and finally features. Conflicts, which may arise at any level, are resolved at that level subject to the key characteristics set out by the multi-disciplinary design team. The design process consists of four downstream levels; system level, subsystem level, component level and feature level. Similarly, factors affecting electromechanical design are formulated in terms of constraints; *global constraints, local constraints* and *feature constraints* (fig. 4).

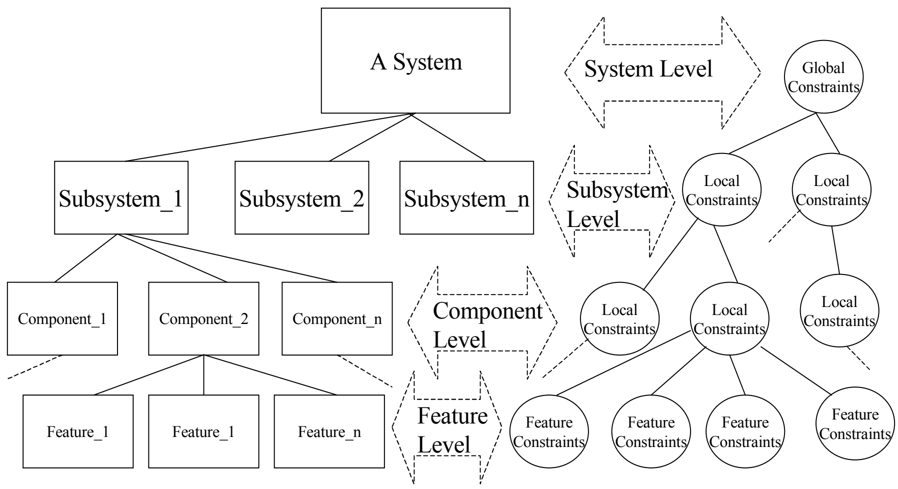
a. *Global constraints* are generally derived from customer requirements. They are associated with the performance a system has to achieve. For instance, "The system (walking robot) must weigh less than 200 g and walk at least 5 second".

b. *Local constraints* are related to individual items of which the actual system is composed, and based on global constraints inherited down the hierarchy. In order to achieve the above performance local constraints can be defined as follows:

- *subsystem_1 (motor) must be no more than 75 g,*
- *subsystem_2 (PCB) must have a length of < 100 mm,*
- *subsystem_n (legs) must carry a load of …..*

c. *Feature constraints* are imposed on feature attributes such as tolerance and process.

Figure 4 Constraints representation



2.3 Conflict Management via Constraint Satisfaction Algorithm (CSA)

Since electromechanical system design is a complicated task, many decision-making problems have to be resolved by the participation of various design engineers with local expertise. A complex system design consists of various activities, which often need to be carried out by different departments or subcontractors, located in remote geographical areas. Co-ordination is therefore considered as the lynch pin of managing interactions and knowledge exchange between these as conflicts often arise due to different views on design parameters. Such co-ordination can be achieved by developing a cooperative constraint-based conflict resolution system that can provide an efficient infrastructure for resolving conflicts by satisfying all the requirements. This problem is then formulated as a constraint satisfaction problem (CSP), that is defined by means of a triple (X, D, C) where X is a set of n variables (i.e. weight, cost, temperature, force), and for each variable $x_i \in X$ there is a corresponding (finite) set $D_i \in D$ that represent its domain (possible values of each variable). The set C is a set of constraints (relationships between parts) that are required to hold between the values of the variables. A value $d^*_i \in D_i$ is assigned to each variable x_i in such a way that all constraints are satisfied, $d^* = (d^*_1, \ldots, d^*_n) \in c_j$ for each $c_j \in C$. The assignment d^* is called a feasible assignment, that meets given requirements. Any constraint that is not satisfied, is called constraint violation, and it is resolved by either a system user or the system itself through negotiations.

2.4 Problems Affecting Electromechanical Product Design Process

Electromechanical systems consist of moving parts, and their size, weight and volume are important. They are also fundamentally 3-dimensional, which increases complexity and number of functions to be carried out. There are strong relationships between 3-D shape and functions, which are difficult to be described. In order to achieve the functions physical prototypes and various analyses should be utilized. Limited space allocated for them needs all items to be designed together in order to avoid side effects on their performance. Electromechanical design requires the combination of functions in complex parts to deal with space, weight and energy/power constraints. Therefore, electromechanical systems design must be considered together with the design of individual components.

2.5 Knowledge Elicitation

Several knowledge sources have been used to capture the knowledge necessary for the development of the system. The necessary expertise has been gathered through meetings and discussions with industry and academe. Expert knowledge has been modeled in terms of constraints, frames, and production rules.

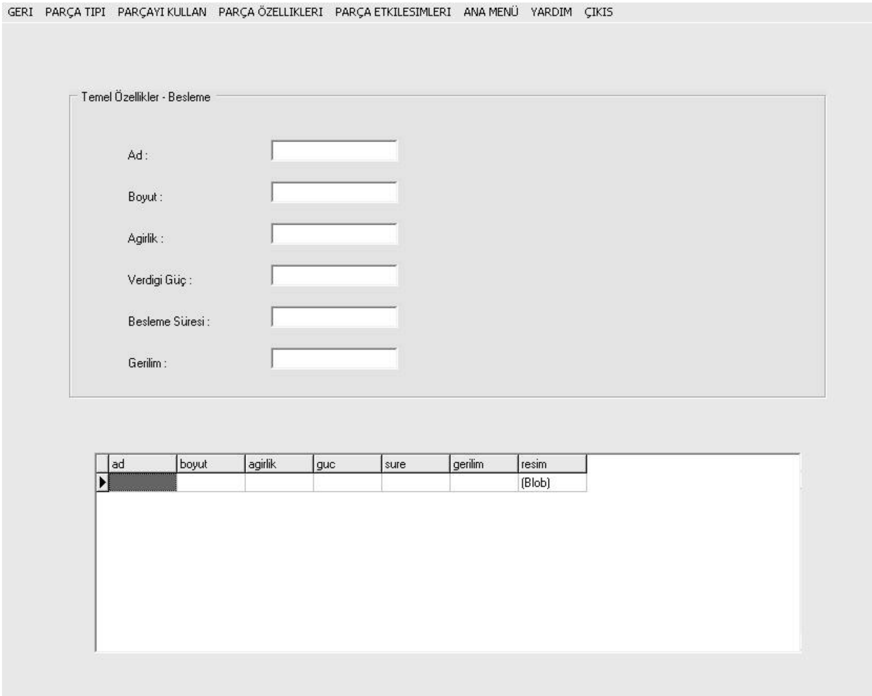
2.6 Knowledge Representation and Dynamic Knowledgebase

The dynamic knowledgebase includes 3D CAD models of mechanical and electrical/electronic components in order to create and configure models of electromechanical systems easily. The knowledge-base consists of separate groups of data: CAD models, key characteristics of the items, attributes, part interactions and constraints imposed on variables. The CAD models represent real electromechanical components such as electric motors and springs. The knowledge-base is dynamic, and multi-functional, allowing the designers to enter newly designed components to the database, and update them whenever necessary (fig. 5). Advanced knowledge representation techniques such as constraints, production rules (if-then), object-oriented programming and frames have been utilized to model the expert knowledge necessary to develop the knowledge-base of the actual system. As an example, object-oriented representation of an electrical motor is shown as follows:

(electrical motor
with
(brand_name :Bosh)
(power :6 W)
(weight: 150 g)
(cost: 3$)

(width: 30 mm)
(length: 50 mm)
(vibration: ………)
(electromagnetism: ………)
(heat_generated:………) (........................))

Figure 5 A database entry for parts



3 2OD-IPD: The Developed Prototype Software

The prototype system with its sub-modules has been still under development and it is shown in Fig. 6. In 2OD-IPD, systems and subsystem concepts are designed together and analyzed within the modeling environment to identify potential failures caused by parts interactions such as overheating, electromagnetism or vibration to increase the quality of the design. It then gives suggestions to the designers to improve the design from different points of view such as electronics. This module which includes a constraint-based conflict resolution system has been still under development. One typical scenario for resolving conflicts could be shown as follows:

2OD-IPD: -- *Vibration may lead to a failure of that sensor. There have been some problems in the past designs. I suggest that you should change the location.*

Designer: -- *Yes. Vibration might be big enough to cause the failure. Further analysis is necessary.*

2OD-IPD: -- *The motor you have selected is increasing the total weight of the system and it violates a weight constraint that should be no more than 250 gr. There are some light weight standard motors. I suggest that you should choose one of them.*

Designer: -- *OK. I think about that. How about dimensions of the printed circuit board (PCB)?*

2OD-IPD: -- *The board dimensions are too big to fit the space allocated. You either make the space bigger or make the board dimensions smaller. But, you should not forget that the total weight of the system might change and it should be no more than 250 gr.*

Designer: -- …

As can be seen from the above scenario, 2OD-IPD promotes product quality through the retention of existing product knowledge, design history and the use of alternative standard components (systems) where appropriate, encouraging communication between interested parties in order to avoid conflicts. This allows designers with a variety of backgrounds to participate in the product development process. The prototype system is a cooperative design environment running under Windows. It has been created with Delphi 6 that is an object-based programming language, enabling the construction of a user-friendly graphic user interface. The '2OD-IPD' prototype software has a capability to create design concepts with simple operations, hence allowing the user to build up a sketch of any system easily to represent the fundamental arrangement of any proposed systems.

Figure 6 The Print-screen of the developed prototype system

4 Conclusions

In this research paper, a new object oriented product development approach has been proposed for integrating mechanical design with electronic design to improve design and manufacture of electromechanical products within given requirements. The proposed approach has been implemented in a Delphi based environment integrated with a CAD system. The integrated prototype design system is composed of various interacting modules, and assists designers from different disciplines in evaluating complex systems as far as parts relation, costs, weight and physical constraints are concerned in the early design process. This helps the designers to avoid design iterations and conflicts leading to longer lead-time, hence increased cost. This system enables to rapidly develop new complex products and add new functions to the existing products within given critical constraints by preventing design conflicts. It has a very good capability for supporting the design of complex products during the conceptual design as it is a co-operative product development tool. Also, it has been developed in a way that the key characteristics affecting the system design have impact on the downstream issues of the design process such as detail design and assembly. It could be used by the designers and manufacturers, who are located in different geographical areas, to create successful product design alternatives by taking the key characteristics into account in the early design stages. Conflicts arising between members of the design team at any level, are resolved by a negotiation based conflict resolution system based upon a key characteristics-driven process. This work is an ongoing research project, which aims to address all crucial issues of electromechanical product design, involving process design, design for X and assembly.

Acknowledgment

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Cad automation and KB user interfaces for an efficient integration of topological optimisation tools in the product development process

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Abstract: This paper presents a methodology that defines the guidelines to obtain an efficient use of topological optimisation in the Product Development Process. This methodology is described referring to a specific case study which concerns the design of a plastic moped wheel.

The possibility of focusing on a specific case-study allows us to demonstrate how the use of SDKs, allowed by the CAx tools employed in the process, improves the efficiency of the methodology. In fact, the paper shows how it can be possible to create custom procedures and interfaces that automate operation sequences, thus fastening the designer's work, according to the typical CAD-Automation approach.

The methodology is supported by a Knowledge Based (KB) user-interface, which allows the user to execute a logical sequence of operations, following the rules defined in the procedures. This helps us to reduce the possibility of error, fastening the process and finding the best solution in order to obtain an optimal design of the product. This work belongs to the research activity of the MUR/PRIN-"Prosit" project.

Keywords: topological optimisation, knowledge based engineering, CAD automation, feature recognition.

1 Introduction

Topology optimisation [1] [2] is an innovative design technique, which aims to generate the optimal shape of a mechanical structure within a pre-defined design space. The method will generate the structural shape thus providing a first idea of an efficient geometry in order to reach the optimisation goal. Therefore, topology optimisation is a much more flexible design tool than classical structural shape optimisation, where only a selected part of the boundary is varied without any chance of generating a lightness hole, for example. Generally, the formulation of a topological optimisation problem allows to define an objective function (typically in terms of volume, mass, uniformity of distribution of the tension or of the energy of deformation) and project constraints (admissible stress and/or strain, constraints, load system, etc.). Topological optimisation tools are put on the market as integrated modules within FEA (Finite Element Analysis) systems like Altair Hyperworks [3], Tosca [4], MSC Nastran [5], which allow engineers to analyse and optimise the product. These tools are widely spreading into different fields of engineering (civil, aeronautics, aerospace, automotive), thanks to their capacity to improve the mechanical properties through a global optimisation of the product in terms of weight, rigidity, resistance and cost.

One of the main limits to a wider diffusion of these tools regards the poor integration with the PLM systems. In order to accomplish an efficient implementation of a PLM system in a manufacturing company, it is necessary to achieve a high interoperability between the various product lifecycle support tools. The most important PLM vendors have developed specific tools to achieve the interoperability between software of different typologies. These tools allow the user to implement the software modules needed to build an efficient communication pipeline between the various PLM components. Generally these Software Development Kits (SDK) are used by the same software house which produces them, in order to implement the interoperability between the several components of its own PLM. In some cases, the SDKs are available to the customers who need to integrate third-part software products, or their own code, on the pipeline.

This paper initially describes the interoperability problems related to the adoption of the modern tools for topological optimisation to support the Product Development Process (PDP) and, then, proposses a methodology to obtain an efficient use of the topological optimisers in the PDP. Our methodology uses the SDK tools of two commercial CAx Systems (SolidWorks and Altair Hyperworks) and takes into consideration three critical problems regarding the interoperability between the topological optimisation and PLM system. The first one is the definition of the problem of submitting to the optimiser, starting from a CAD model which defines maximum dimensions and invariant geometries. The second one concerns the problem of data exchange between CAD and CAE systems. The third one regards the interpretation of the results given by the optimiser, in order to realize the final CAD model, taking into consideration the manufacturability constraints of the product.

The methodology proposed in this paper, defines the guidelines to improve the efficiency in the use of the topological optimisers within the PDP. This methodology is described referring to a specific case study which concerns the design of a plastic moped wheel. The possibility of focusing on a specific case-study allows us to demonstrate how the use of SDKs, allowed by the CAx tools employed in the process, improves the efficiency of the methodology. In fact, the paper shows how it can be possible to create custom procedures and interfaces that automate operation sequences, thus fastening the designer’s work, according to the typical CAD-Automation approach.

The methodology is supported by a Knowledge Based (KB) user-interface, which allows the user to generate the archetype of the product in a completely automatic way, starting from the definition of the parameter’s values through simple dialogue boxes. The generated model is exported in a CAE environment, where the user executes the optimisation of the model. Finally, the KB interface allows the user to interpret the results provided by the optimiser and to define the optimal parameters of the final model. This helps us to reduce the possibility of error, fastening the process and finding the best solution to obtain an optimal design of the product.

This work belongs to the research activity of the "MUR/PRIN-Prosit" project (www.kaemart.it/prosit) and its purpose is to study and prove the possibility of integrating innovative tools, like Product Lifecycle Management and Knowledge Based Engineering systems, with CAI (Computer Aided Innovation) tools and with topological optimisers, in order to offer formalized and validated routines, which allow a systematic adoption and an integrated utilisation of such tools in the PDP [6].

2 KBE system and topological optimisation integration

Nowadays the PDP includes many critical aspects, which depend on increasing requirements of the market pushed by the global competition. To improve their competitiveness, the companies are continuously researching on product innovation, supporting this complex process with the introduction of new manufacturing technologies and the most recent collaborative design environments. A very critical issue in current PDP is related to the management of design knowledge. The reasons and logic of the decisional process for the design of a certain product are known to the expert designer who has created the product, but they are not often explicitly formalized, expressed and stored. It follows that in the design stage of new products, designers may have access to the results of existing product designs (CAD models), but not to the reasons of their design choices.

Therefore, there is a need, clearly expressed by manufacturing companies, for methods and tools capable of acquiring the design knowledge, in order to make it formalized and available in subsequent stages of the PDP and in future projects.

There have been some commercial KBE (Knowledge Based Engineering) Systems for over 15 years, like SeaShell, KTI - The ICAD System, Behavioral Modeling-PTC, RuleStream, etc. These softwares support the formalization of knowledge by incorporating the design choices (design intent), the engineering and manufacturing rules and the best practices, in order to make such knowledge available for a rapid development of new products. These systems usually work on high-level product representation schemes [7], which enclose both the geometry of the component, described in terms of features, and other attributes and rules that implement the knowledge base associated to that component [8].

An effective introduction of new design techniques, like topological optimisation, requires the adoption of methodologies and tools able to formalize, store and make the knowledge and the experience acquired by engineers involved in the PDP available to other designers.

In the specific case of topological optimisers, one of the main problems regards the loss of all features data in the optimisation process. The output of topological optimisers, i.e.: the optimised model is a voxel model, so it takes into account neither functional and technological features, nor rules and attributes associated to the various parts of the product. In practice, the geometry can be useless because the optimised model:

1) may not be manufacturable or its manufacturing costs may be very high;
2) violates design constraints, standard norms or functional aspects;
3) turns out to be very complex to rebuild in terms of functional and technological features.

In all these cases, the designer has to model the geometry again interpreting the results obtained by the optimisation process, and considering norms and manufacturing constraints [9].

During the phase of feature based redesign, the modules of feature recognition are the only tools offered by PLM systems as a support for the user. At present, only few PLM systems are able to offer the advantages of feature recognition tools; among others the most widespread are *feature recognition 1* of Catia, *Holemaking* of UG/NX, *Feature Recognizer* of SolidEdge and *Feature Works* of Solid Works. On the other hand, in literature, the present researches recommend the use of genetic algorithms and neural networks, in order to expand and improve the feature libraries [10-11]. But these researches deal with few features to recognize and with 2D or $2D^{1/2}$ shapes (obtained by a projection of a 2d shape into 3rd dimension) and never with complex geometry [12-14].

In literature, various researchers have faced the optimisation problem through, either classic approaches of shape recognition [15], or design by feature. Others have tried to introduce the optimisation into the phase of conceptual design with the adoption of hybrid CAD/FEM systems. In the above mentioned researches, structural characteristics, calculated a priori, are assigned to each component [16]. Till now, these isolated attempts have not lead to consolidated solutions. In conclusion, feature recognition techniques are not able, at the moment, to support the post-processing of optimiser results. This means that it is necessary to develop specific design methodologies that describe some formalized procedures, needed to implement a systematic introduction of topological optimisation tools in PDP.

3 The proposed approach

As stated in the previous section, the interoperability between PLM systems and optimisation tools is a critical point that has not been analyzed either in the commercial systems or in the solutions proposed in literature. A solution to this problem could be found by implementing the interoperability of the various tools employed (i.e.: CAD and topological optimiser) and defining a better practice to integrate the topological optimisation tools with modern PLM system. In particular, as regards the interoperability between different systems, we propose the implementation of a KB custom user interface, in order to automate, support and simplify the geometric model redesign. Moreover, we have tried to define some guidelines that lead the engineer during the translation of topological optimisation results into a technological feature based geometry. From this point of view the methodology aims to capture the designer's knowledge regarding to the optimisation process, in order to make it usable in future projects.

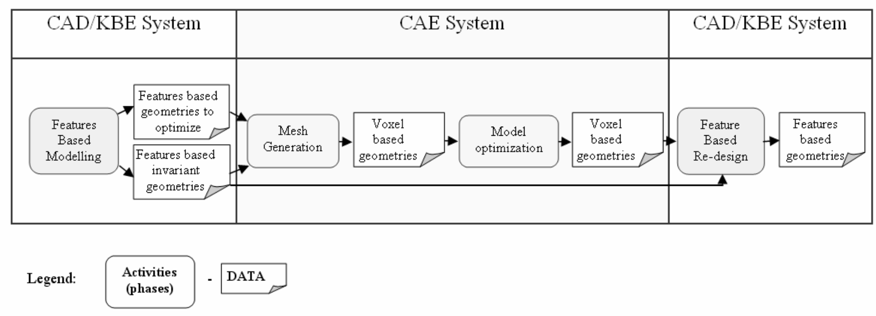
3.1 The methodology

The experience of the PROSIT project, in which different research units are working on various case studies, allows us to acquire the knowledge needed to define the above-mentioned guidelines. In particular, two considerations have arisen from this experience:

1. depending on the type of product and project statements, it is always possible to subdivide the geometric model into a set of “characteristic” volumes that can be considered invariant volumes or volumes to be optimised;
2. the invariant geometries cannot be modified during the optimisation process. Maintaining the knowledge of these geometries across the optimisation process simplifies the designer’s job in the redesigning phase.

On the basis of the considerations above, the guidelines of the proposed methodology have been identified. The methodology is supported by a custom user interface, in a CAD environment, that aids the designer in definition, storage and management of geometries, both invariant and not, of the model.

Figure 1 Scheme of the methodology



The methodology consists in the following steps (figure 1):

- *Feature Based Modelling*. The designer models the component in question starting from a pre-existent sketch conveniently parameterized. The custom user interface manages the examined part like a set of distinct volumes which may be considered, depending on the cases, invariant or to be optimised. Each volume is formed by a set of parameters to allow a wide modelling flexibility. At the end of this phase, the interface allows the automatic rescue of the model to optimise, in which the file with invariant volumes is different from the file with volumes to optimise.
- *Mesh Generation and Model Optimisation.* In the optimisation phase, the designer has to most of all, define the collectors, that is the declaration of physic properties of the model and of the boundary conditions. It is possible to create a collector to specify the type of material, another one for loads and constraints, others to define variant and/or invariant volumes. Once the topological optimisation phase is completed, it is possible to export results in CAD environment.
- *Feature Based Re-Design.* The interface allows the overlap of the initial model as well as the optimised model. In this way, the automatic feature recognition of invariant volumes, allows the user to redesign the model in a simple and fast way. So the redesigning phase is reduced to sketch contours or sections of optimised

geometry that successively will be transformed into solids through sweep, loft or extrusion features.

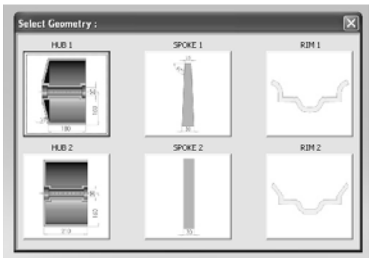
The various phases of the methodology will be described in detail in section 5 making use of a test case.

3.2 The implemented tool

SolidWorks API [17] are used to implement KB custom user interfaces and operations of CAD automation. The implementation of the knowledge consists especially in:

1. identification, within the component in question, of volumes that can be considered "homogeneous" as regards to an optimisation problem;
2. creation of DB structure concerning the component. Such DB must be structured so that it may reflect the above-mentioned subdivision into volumes (figure 2);
3. DB population, that is the modelling of single volumes, conveniently parametrized, to allow the widest geometric covering for this particular kind of component, during the modelling phase.

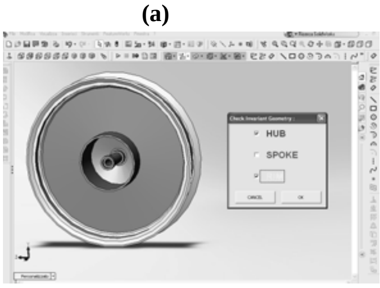
Figure 2 Example of DB for a moped wheel.



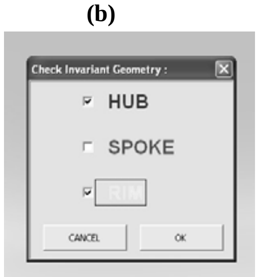
The CAD automation operations, that have been implemented, deal especially with the import/export of CAD geometry to the optimisation system. These operations have been implemented, in order to assure both the utmost operative usability and the full compatibility between models (format, unit of measure, reference frame, etc.). Moreover, the interface allows to save all possible combinations of characterical volumes in two distinct files ("invariant geometries" and "geometries to optimise") (figure 3).

Figure 3 (a) Moped wheel and custom user interface for invariant geometries checking; (b) zoom on the user interface in which hub and rim geometries are checked by user.

(a)



(b)



4 Test case

A specific case study which concerns the design of a plastic moped wheel is used to test and validate the efficacy of the methodology. The implementation of the knowledge, in the procedure proposed as a test case, consists especially in:

1. identification of the parts of the moped wheel that can be considered "homogeneous" with reference to an optimisation problem; in the case study the rim, the hub and the spoke are identified;
2. creation of a geometrical model DB for each of the three parts;
3. feature based modelling of the three parts.

4.1 Geometries modelling

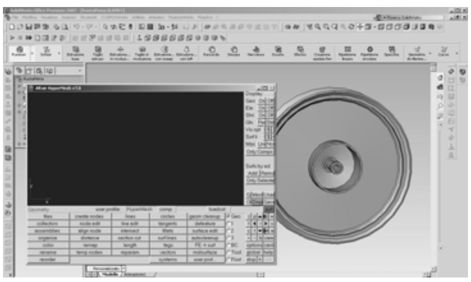
The KB interface, implemented like a SolidWorks plug-in, supports, in an automatic manner, the generation of the three above-mentioned volumes, through a dialogue window. At the moment, we have developed only one DB related to the plastic moped wheel.

By the activation of sketch functionality, the user can select the rim, the hub and the spoke from three different windows. All geometries in the DB are parametric. So, it is possible to modify the dimensions, according to the specific needs (figure 4).

Figure 4 Customization of a moped wheel by using geometrical models DB.

By means of CAD automation it is possible to make an efficient data management. In fact, both the file of invariant volumes and the one in which the volume to optimise is automatically stored in different files. In the file of invariant volumes it is also possible to include the main reference planes and other custom planes to assist the redesign phase.

Figure 5 Direct launch execution of Hypermesh inside SolidWorks.

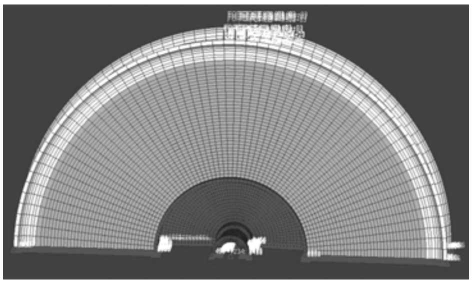


The KB interface is able to support the user in the exportation of a geometry model into the CAE environment, by means of a direct call to the optimisation software (Altair HyperMesh). This functionality is implemented through the Visual Basic 6 routines, and it is able to execute the HyperMesh module directly in SolidWorks. By means of Tcl/Tk script it is possible to automatically import the wheel geometries (figure 5).

4.2 Mesh generation and model optimisation

At the moment, we are developing a KB interface in Altair, which is able to support the designer in the definition of collectors. This functionality will be implemented through Tcl/Tk script, and it will be developed in Process Studio and Process Manager, that are the Altair Hyperworks developing environments. According to the test case, the optimisation analysis of spoke contours is carried out with a concentrated force applied on the wheel as hypothesis (impact wheel simulation) and the mass minimisation is the objective function. The hub and the rim have been considered invariant volumes. The simulation has been completed considering only half a wheel (figure 6).

Figure 6 Geometry, constraint and force collectors in Optistruct.

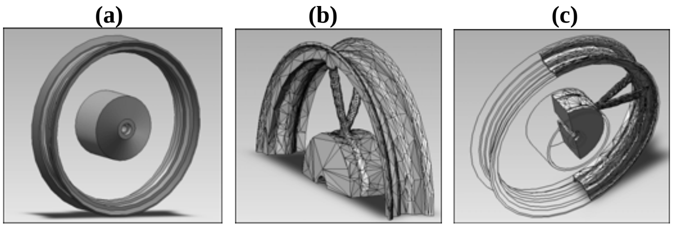


At the end of optimisation process it is necessary to execute the OssMooth module present in Hyper Works. The purpose of this functionality is to provide an iso-density surface based on the volumetric density information of a topology optimisation, which is conducted by using OptiStruct. In other words, OssMooth is able to translate the topological optimisation results into an IGES format file.

4.3 Overlapping geometries

Once the topological optimisation phase is completed, it is possible to import results into CAD environment. At first, the KB interface loads the invariant geometry of the model, that have been defined in the previous steps, and, after that, it automatically loads the optimised model. In the case study the hub and the rim are loaded as invariant volumes and the spoke as an optimised volume, generated by Altair. The designer handles these models, in order to assure the perfect overlapping of reference frames. In figure 7 the overlapping between the optimised model of the wheel with the initial hub and rim is shown.

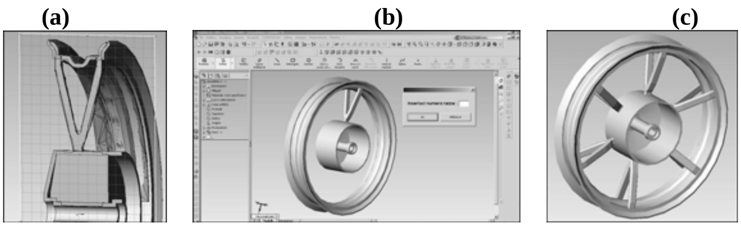
Figure 7 (a) Loading of invariant geometries checked by user in previous phase; (b) optimised geometry ; (c) overlap of the invariant geometries and the optimised geometry.



4.4 Feature based Re-Design

The last step of the methodology requires the re-designing of the optimised volumes, in order to obtain a feature based manufacturable product model. Both the invariant volumes and the data planes simplify this operation. The KB interface allows an aided modelling in this phase, in order to allow the user to position temporary planes in a dynamic manner. On these planes it is possible to sketch contours, spoke sections and/or guidelines to use in sweep, loft or extrusion features (figure 8). The sketch of the contours is realised following the shape of the spoke generated by the topological optimiser. At the end of the sketch phase, through the interface, it is possible to introduce the number of the spokes in order to automatically generate the circle pattern feature (figure 8).

Figure 8 Aided modelling with custom user interface: (a) reference plane for spoke contour sketching; (b) user interface in which introduce the number of spokes; (c) final model.



Once the recognition phase is ended, the user has a feature based model that can be used in various CAE analysis. The latter can be implemented directly in SolidWorks environment through the CosmosWorks module.

5 Conclusions

In this work a methodology which defines the guidelines to implement an efficient use of topological optimisation tools in PDP has been described. The target of our methodology is to define the best practice, in order to integrate the optimisation tools in the PLM systems. In CAD environment, these guidelines are translated into a knowledge based user interface that is able to support and simplify the designer’s job during the redesigning model phase. Through this interface the user works iteratively both in CAD and CAE environment, in order to identify the best solution to obtain the optimal design of the product. Actually, the interface has been implemented in SolidWorks in order to allow an efficient interoperability between CAD systems and topological optimisation modules OptiStruct of Altair HyperWorks. At present, the methodology has been tested with the plastic moped wheel case study only.

As scheduled in the PROSIT project, the methodology will be developed and improved by testing new case studies. KB interface functionalities will be extended to CAD environments to provide a further automation of the procedure and a second user interface will be implemented to simplify optimisation settings in Altair Hyperworks. Finally, we aim to fully test the efficacy of the proposed methodology comparing it with the traditional approach.

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Chapter 8

Concurrent development and engineering

Aligning supply chain management and new product development: a general framework

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Abstract: Competition in the global marketplace, evolving technologies, the need to satisfy more and more sophisticated customers and the shortening of product life cycles are some of the fundamental challenges that firms are facing. To remain competitive, firms should generate new products, while maintaining high supply chain performances. Therefore they should align the objectives of the processes of New Product Development (NPD) and Supply Chain Management (SCM). An analysis of the literature shows that the "commonality-variety" trade-off is one of the main issue when addressing this topic, as it has strong impacts on supply chain, while being one of the most important decision taken during NPD. In this article we propose a framework for studying the possibility to align NPD process and SCM process by aligning the level of variety that is created during NPD and the variety that is/can be transported, in order to improve supply chain performances. To sustain and obtain alignment new PLM solutions should be proposed.

Keyword: Variety; Alignment; Supply Chain; New Product Development

1 Introduction

In 1980's managers began to realize the benefits they would have obtained by considering manufacturing and assembly constrains early in the design process. The paradigm of concurrent design of product and production process, that generally is named "concurrent engineering" (Swink, 1998; Boothroyd et al., 1994), was born.

Recently a similar transformation has begun in the area of Supply Chain Management (SCM). As a matter of fact in the last 20 years of SCM studies, models and methods for designing supply chain and manage operations have been developed assuming that product design decisions were already made (Simchi-Levi et al., 2003). However fierce competition in today's global market, rapid evolving technologies, the need to satisfy more and more sophisticated customers and the shortening of product life cycles force firms to generate new and more attractive products, in the form of not only variants to existing products, but also completely new and radically innovative products (Cooper, 1993). Consequently, supply chain managers will find more and more complex to follow the rate of new products introduction while plan material requirements, schedule production and estimate lead times and costs (Kohdate and Suzue, 1990), and generally efficiently "integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements" (Simchi-Levi et al., 2003). Moreover, Lee and Sasses (1995) state: "Any attempt to redesign for supply chain management is severely limited by the basic design of the product, which can seldom be altered significantly once it has entered the marketplace."

As far as Product Lifecycle Management (PLM) is concerned, Ming et al.(2005) affirm that the actual manufacturing application systems, such as, product data management (PDM), SCM or demand chain management (DCM), are not adequately designed to satisfy the new business need for collaborative tools and capabilities throughout the product lifecycle. They outline the main gaps between the industrial companies demand for technological solutions and tools available on the market, and they conclude that the main solutions provided in the market are addressing the issue of design for manufacturing while firms are demanding for design for supply chain and lifecycle efficiency solutions. Some researchers have begun to study these issues form a theoretical point of view. In particular they focused on how to design concurrently product, process and capabilities (Fine, 1995) and to generate the optimal configuration of the product, manufacturing process and supply sources in order to form an efficient and effective supply chain in a simultaneous and integrated manner (Huang et al., 2005). These are approaches that resemble concurrent engineering, and indeed Fine (1995) called it: "3-Dimensions Concurrent Engineering". Generally in 3-D concurrent engineering approach, New Product Development (NPD) managers, taking supply chain concerns into account in product and process design phase, are designing the supply chain with the product and the product is designed for that supply chain. For this reason coordination and integration between NPD and SCM processes are strongly advised and in operations literature there has been an increasing emphasis on coordinating supply chain management decisions and new product development decisions (Rungtusanatham and Forza, 2005). Yet, despite one part of the problem is undeniably the ability to coordinate decisions across the two processes, a model that can be used by managers to align the different objectives, thus the decisions, and consequently all the processes underneath, to a common goal in order to gain advantages, is missing. Some attempts to investigate this alignment has been done for example by Danese and Romano (2004) that propose a first model for aligning sales, production planning and engineering in high-variety versatile manufacturing environment, and by Tellarini (2005) who states that, even if Supply Chain managers feel the launch of a new product as a "friendly fire" against them, the right management approach would be to redesign the supply chain to support the new product launch and the commercial strategy. In this sense best practice initiatives carried out by companies as Dell, Hp and Zara (Magretta, 1998; Feitzer and Lee, 1997; Ghemawat and Nuevo, 2003) have been studied in recent years. These firms have demonstrated that the effort to redesign one firm's products to increase supply chain performances, or vice versa, to redesign a supply chain for a new product, can be the source of a sustainable competitive advantage.

These examples show that the issue of aligning the NPD and SCM processes is definitely relevant for both operational level managers but also for top managers that have a broader point of view on firm's processes and on firm strategic direction. Moreover a deeper knowledge about alignment of NPD and SCM may represent the basis for developing technological solutions for PLM in the extended enterprise.

Therefore in this paper we want to address this main question: "*What is Supply Chain Management – New Product Development alignment? What main issues should be taken into consideration when analyzing alignment?*". Therefore, the objective of this paper is to review the literature on this issue and propose a framework for studying the problem of aligning SCM and NPD.

This framework might be the starting point for further researches: specifically, it may be the basis for addressing other research questions such as: "how the alignment of the two processes of NPD and SCM to the common objective of satisfying client needs can improve firm performances? And, how can alignment be obtained"

The paper is organized as follow. In sections 2 we set out a theoretical review of studies that deals with decisions in SCM and NPD and the interactions between them. In particular in section 2 we describe the two main approaches to the problem, and then we focus on the analysis of the literature about two themes: modularity and variety. In section 3 we present the results of the literature analysis that lead to the operational definition of alignment. This definition is the starting point for the framework definition. We will discuss the framework in section 4. Finally in section 5, we point out some main conclusions and directions for future research.

2 Literature state-of-the-art

Literature concerning NPD, SCM and NPD-SCM interaction have been analyzed. Analyzing NPD and SCM literature, we identify the two main approaches to the problem, while by the literature concerning NPD and SCM interaction, we found out that there are two main themes of our interest: modularity and product architecture and variety management

2.1 NPD and SCM related literature

NPD is the process that transforms a market opportunity and a set of assumptions about product technology into a marketable product (Krishnan and Ulrich, 2001; Weelwright and Clark, 1992; Cooper, 1993), or a product that "fits with market". Final client needs should be assessed and considered since the very beginning of this process (Hauser and Clausing, 1988; Ulrich and Eppinger, 2000). NPD driven literature is mainly based on the "constraints' anticipation" concept, which underlies both concurrent engineering (CE) and project management (Bartezzaghi et al., 1999).

SCM is the approach to designing, organizing, and executing all the activities from planning to distribution focusing on actions along the entire value chain (Childerhouse et al., 2002). SCM Oriented literature provides management rules and guidelines to design and manage supply chains. Recently, researchers started investigating the factors needed to design effective supply chains (Childerhouse et al., 2002; Olhager, 2003) and to evaluate supply chain performances (Fahmy Salama et al., 2006; Caridi et al., 2002). Demand driven supply chain design has the main goal to design the "right" supply chain for that product, that is for that market (Fisher, 1997; Christopher and Towill, 2000; Mason-Jones et al., 2000; Aitken at al., 2003). Cost, quality, lead time and service level depend on supply chain structure and management, and originally on supply chain design.

2.2 Modularity and product architecture

Product structure is initially created by product design and then referenced by most of the enterprise business processes throughout the entire product lifecycle. Product structure information is needed for generating a manufacturing plan and schedule, and also for creating a packing plan for shipment (He et al. 2006). As a matter of fact, product structure is one of the most important aspects of PLM. To define product structure, some models that take into account supply chain constraints since the earlier phases of NPD have been proposed. Basically, some researchers developed general models based on the idea to express supply chain costs as a function of some product characteristics, or based on product representation (i.e. Bill of Material (Bom), General-Bom, Planning Bill). The objective was to choose the best product structure that minimizes the total cost of the supply chain (Lee and Sasser, 1995; Huang et al. 2005; Blackhurts et al., 2005).

The most used representation of product structure is product architecture. Product architecture is ”the scheme by which the function of the product is allocated to physical components” (Ulrich, 1995). Krishnan and Ulrich (2001) in their review analyze the decisions of product, process and supply chain design and conclude that the trade-offs between them are better addressed by considering the intermediate decision of the product architecture. This is the driver which will impact the most supply chain decisions and management. For this reason these connections have been investigated and tools for designers to “anticipate” the impacts on supply chains have been developed, (Fixson, 2005; Fixson and Clark, 2002; Mikkola and Gassmann, 2003) Some of the links have been studied, in particular with a focus on sourcing (Novak and Eppinger, 1998; Hsuan, 1999), part commonality strategy (Fixson and Clark, 2002) and postponement strategy and implementation decisions (Lee and Tang, 1998; Feitzinger and Lee, 1997; Van Hoeck, 2001).

The concept of modularity and architecture has been also extended to production process and supply chains. Fine (1995) claims that firm should be able to design concurrently a product, its production process and its supply chain by matching product, process and supply chain architectures. Some validation of this concept have been proposed by Fine at al. (2005), and by Voordijk et al. (2006).

The empirical research by Salvador et al. (2002) is one of the few attempts to study product architecture and modularity from a SCM Oriented point of view. Studying the relationships between modularity and operational performances, they develop insight on the implications of type of product modularity on operational performances-product variety trade-off and supply chain performances.

2.3 Variety Management

Variety is a multi-dimensional concept. It has been defined in both a static (Pine II, 1993; Ulrich, 1995), and dynamic way (Fisher and Ittner, 1999). Martin and Ishii (2002) define variety as both the variety within the current product and variety across future generations of the products. Variety can be defined: functional, i.e. related to customer satisfaction, or technical, i.e related to manufacturability and costs (Du et al.,2001; Jiao et al, 2006b).

Variety is mainly addressed in NPD oriented literature in the main trade-off “variety – commonality”, i.e. the architecture definition phase (Ulrich and Eppinger, 2000; Erens and Verhulst 1997), or in the platform definition one (Robertson and Ulrich, 1998; Huang et al., 2005; Krishnan and Gupta, 2001; Martin and Ishii, 2002; Farrell and Simpson, 2003; Jiao et al., 2006a). Product architecture decision affects the commercial variety that can be proposed in the marketplace. Ulrich (1995) states that “with a modular product architecture, product variety can be achieved with or without flexible component production equipment”.

Variety, and so commonality, is connected to operational performances and costs: as product variety increases higher direct manufacturing costs, manufacturing overhead, delivery times and inventory levels increase (Fisher at al 1999; Miller and Vollman 1985; Fisher and Ittner 1999; MacDuffie et al., 1996; Ramdas and Sawney, 2001). Fisher and Ittner (1999) advocate the importance to distinguish between “variable” and “fixed” costs of variety. Variable costs are those that vary day-to-day depending on the variety level of each day schedule, while fixed cost include flexible automated systems that can deal with greater variety (Akturk and Yayla, 2006). Prasad (1998) propose a rough index to measure of cost of variety connected to manufacturing costs and plant layout or supplier changes. Underestimating the costs of product variety leads companies to offer product variety that is greater than the optimal (Thonemann and Bradley, 2002), but, on the other hand, increasing too much the component commonality can lead to overdesign effects and costs (Krishnan and Gupta, 2001). Brun et al. (2006) introduce and define the concept of behavioural costs as “those costs which arise because of the reaction of people to “excessive” variety”.

Conceptually the impacts of variety on a firm depends on its inherent flexibility (Ramdas, 2003; Berry and Cooper, 1999). De Silveira (1998) develops a framework for the choice of the proper flexibility strategy to deal with high product variety in manufacturing environment. Some empirical and conceptual researches extended this concept to some aspects of SCM (Randall and Ulrich, 2001; Salvador et al., 2002).

One of the best-known models for variety management is Variety Reduction Program (VRP) by Koudate and Suzue (1990).The aim is to reduce variety impacts on production. More recent works propose qualitative models to define the right level of variety considering both revenues and costs at firm level (Olavson et al., 2006). Gottfredson and Aspinall (2005) suggest to choose the level of variety (named the “innovation fulcrum”) by balancing complexity and innovation.

In this context it’s remarkable the statement by Ramdas (2003): “how firm choose to *create* variety and how a firm’s supply chain is managed to *implement* variety are key determinants of the success of a strategy of variety increasing”.

3 Operational definition of alignment

The term “alignment of” two processes has been used to indicate that the process owners at all levels share a common objective. In the case of alignment of the processes of NPD and SCM, the process owners share the common objective of satisfying client needs and a common view on what the “client needs” are (Lee, 2004; Danese and Romano, 2004). In this sense alignment is a “scalable” concept, meaning that in a case it is referring to the alignment of NPD and the design and management of the internal supply chain, while in another case it is referring to the alignment of NPD and the design and management of the supply chain in which the company acts.

On the basis of the above mentioned state-of-the-art review, it can be stated that variety management is one point of interest when studying alignment. As already stated above, starting from Ramdas (2003), variety related decisions can be grouped in: “variety creation” decisions and “variety transportation” decisions. In the first group the decisions concerning how, when, which mix variety/innovation to create, given that the market needs and the target market have been defined, will be included and in the latter the supply chain design and management decisions that affect the ability of the supply chain to actually transport the variety to the market.

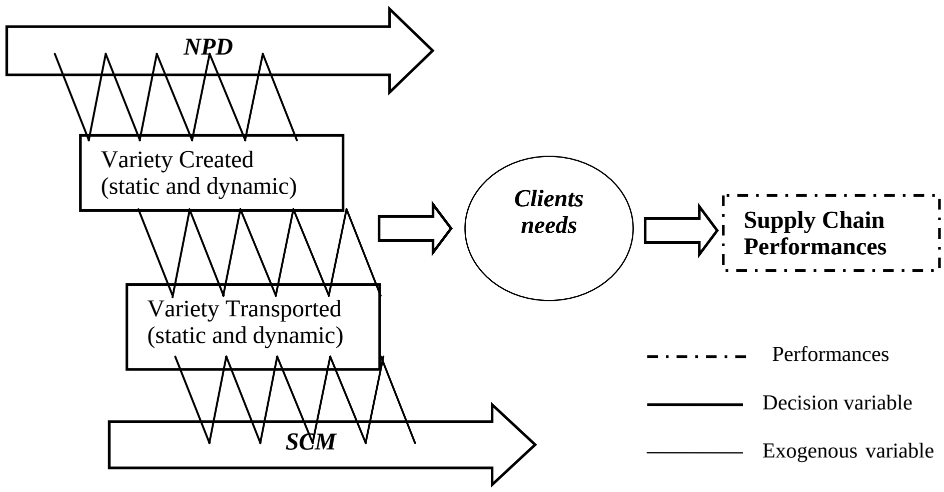
Given this distinction between variety creation and variety transportation decisions, the following operational definition of variety alignment may be proposed:

Variety alignment to clients needs means that the variety created is equal to the variety transported and the variety requested by clients.

4 Proposed Framework

Coherently with the operational definition of alignment given in the last section, we propose a framework (Fig. 1) to support the analysis of alignment and of the creation and transportation of variety in NPD process and SCM.

Figure 1 Framework



The issue can be declined at different levels. At a higher level, when creating variety in NPD process, main issues are the level of customization required by the market and the timing of new products introduction. These decisions impact on, for example, the decision of which type and which level of modularity embed in the new product.

From a Supply Chain Management point of view, when developing the supply chain strategy the level of variety that a certain supply chain can “transport” over time should be assessed. This means, for example, to define the supply chain structure and the position of the Order Penetration Point (Olnagher, 2003), and to assess the costs of the variety that is transported and the “limit” of the variety that can be transported by the supply chain. At operational level, this means to define integration systems and planning systems to be used and to assess their capability to deal with increasing variety.

5 Conclusions

Erens at al (1997) state that the “product density” , that is the number of product variants that are introduced over the life-cycle of the product family, is increasing. To remain competitive firms should be able to sustain innovation by integrating and coordinating the two processes of NPD and SCM. According to us, it could be interesting to study more specifically the issue of aligning these two processes, i.e to study the problem of aligning the process owners objectives to the common goal of client needs satisfaction.

In this paper we present an analysis of the literature on this topic. On the basis of this analysis we develop a general framework for addressing this problem. We analyzed the literature and we found out that two approaches are clearly visible: the first one is a NPD Oriented approach, i.e. to design a product taking into account the costs and the possible effects on the supply chain, the latter is a SCM Oriented approach, i.e. to provide management rules and guidelines to design and manage a supply chain capable to follow and sustain innovation. Moreover, two are the main topics of our interest: modularity and product architecture definition, and variety management. In these areas, there are some un-answered questions, among the others how to design variety taking into account supply chain issues and how to design the supply chain in order to increase the variety that can be transported. Then, we develop the framework. Basically, the idea underlying the framework is that the problem of aligning the two processes is strictly connected to the alignment of the level of variety created and the variety that a supply chain can manage and “transport” to the marketplace. Variety is created during NPD process while Supply Chain Design and Management can affect the ability of a supply chain to transport such variety to the marketplace. The framework outlines these relationships. Moreover it outlines the third relationship: supply chain performances may be impacted by the alignment of variety created, transported and required by final customers.

At the moment, the empirical validation of the framework is underway, as we are developing the analysis of a case study in an Italian firm that produces household and industrial electronic appliances.

Analyzing the relationship between variety alignment and performances could be the starting point for developing new managerial and organizational approaches for “designing concurrently” new products and supply chains and for aligning innovation management process and operations management processes. Further research can be framework refinement, that implies to define unambiguously the concept of variety created and transported, and the identification of the relevant measures and indicators that case-by-case are needed to evaluate alignment. This can help to develop a methodology to support NPD and SCM alignment and can pave the way to the definition of new managerial approaches, new models and new PLM solutions to obtain alignment.

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Logistics and product life cycle: towards a design for logistics approach

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Abstract: The value of information exchanged among several actors involved in the Supply Chain (SC) can be exploited for gaining relevant advantages in operations efficiency and effectiveness but also for implementing the delivery of new or re-engineered added-value services associated with products. Logistic processes sustain many phases of Product Life-Cycle (PLC), from product design to dismissal and recycling. The paper provides an approach which identifies the main logistic processes performed throughout PLC. Process life-cycle and manufacturing sectors are introduced as further dimensions. Design for logistics is introduced as a systemic approach for the design of products and logistic processes as well. The objective is to lead to the integration of key logistic processes. The proposed approach distinguishes between two enabling factors: methodologies deriving from management and industrial engineering and technologies coming from computers science, telecommunication and electronic engineering. Process and organizational innovations, enabling information and communication technologies are recognized as essential conditions.

Keywords: Product Life Cycle, Process Life Cycle, Logistics

1 Introduction

Supply Chain Management (SCM) encompasses methodologies and tools that aim at providing efficiency and effectiveness in operations management, co-ordination in complex business networks, high service levels for customers. The value of information exchanged among suppliers, manufacturers, logistic operators, distributors, and after sales technical support can be also exploited for implementing the delivery of added-value services associated with products. For this purpose, systemic approaches have to be developed in order to identify, place, and integrate the key logistic processes throughout the PLC. Logistics sustains all the phases of PLC, from design to product dismissal and recycling: for this reason it can be considered as an entry point for an integrated management of products, life-cycle-oriented.

Current industrial scenario highlights in several manufacturing sectors a shortening PLC. A similar trend is also observed for the life-cycle of technologies or processes that underpin each phase of PLC. Manufacturers, suppliers, logistic operators cope with a relevant increase in the competitive pressure mainly deriving from: (*i)* globalization, which is leading to a new world distribution of production and markets [1], (*ii*) demand constraints from the standpoints of cost, time, quality, customization [2, 3]. Especially in mature sectors the European manufacturers are facing the severe pressure generated by new emerging countries while in high-tech sectors by advanced countries [1]. For these reasons new approaches are needed in order to cope with competitiveness issues by shifting "from designing and selling physical products to supplying systems of product and services" [3].

The paper provides an approach which identifies the main logistic processes performed in each phase of PLC. Moreover, process life-cycle and manufacturing sectors are introduced as further dimensions. Process and organizational innovations, enabling Information and Communication Technologies (ICT) have been recognized as essential conditions. The objective is to lead to the integration of logistic processes in manufacturing scenarios characterized by delocalized production, markets distribution, distributed decision-making, demands' uncertainty. The proposed approach distinguishes between two enabling factors: (*i*) methodologies deriving from management and industrial engineering and (*ii*) technologies coming from computers science, telecommunication and electronic engineering. From a synergy perspective, the latter factors can implement the former while converging on common objectives such as process optimization and integration, widespread product information, traceability, and new high added-value services throughout PLC associated with products.

The remainder of this paper is organized as follows: in Section 2 actors and supporting tools in logistic scenarios are presented. The proposed approach is presented through the *Logistic Matrix* in Section 3 and in the following sub-sections. Section 4 reports the links between Product Life-cycle Management (PLM) and logistics. In Section 5 the relevance of Decision Support Systems (DSS) based on simulation and optimization is described. Conclusions follow.

2 Logistic scenario: actors and supporting tools

Logistics systems consist of facilities connected by transportation services. Materials are manufactured, stored, sorted, sold or consumed in the facilities (e.g., manufacturing and assembly centers, warehouses, distribution centers, transportation and trans-shipment terminals, retail points, etc.). Transportation services perform the movement and handling of materials among the facilities by means of vehicles and equipments [4]. The main actors involved in logistic scenarios are suppliers, manufacturers, Logistics Service Providers (LSPs), retailers, users. Logistic activities are often carried out within logistics systems by outsourcing policies in the value chain. Accordingly, different types of LSPs are in charge for the execution of specific processes with different positions in the chain: 1^{st} party LSPs, 2^{nd} party LSPs, 3^{rd} party LSPs, and 4^{th} party LSPs. 1^{st} party LSPs are in charge for the execution of physical tasks (e.g., transportation), 2^{nd} party LSPs manage a logistic task often by outsourcing it to 1^{st} party LSPs. Generally, 3^{rd} party LSPs manage and orchestrate complete logistic processes while optimizing the SC performance (e.g., costs, lead-times, etc.) and possibly subcontracting tasks to 1^{st} and 2^{nd} party LSPs. 4^{th}

party LSPs participate in SC configuration and re-design in order to improve customer service level, minimize costs, delivery added-value services, develop knowledge-intensive logistics and marketing competencies for their customers (i.e., suppliers, manufacturers). 4^{th} party LSPs usually exploit outsourcing to 3^{rd} party LSPs. In Panayides and So (2005) LSP-client relationships issues are presented.

Many ICT solutions for production, logistics, and customer interface are available in the market: for instance global systems (e.g., Enterprise Resource Planning, SCM, Customer Relationship Management, Product Life Cycle Management systems) or dedicated systems (e.g., Warehouse Management Systems, Manufacturing Execution Systems, Transportation Management Systems, Fleet Management Systems). Other systems assist product identification and traceability (e.g., Radio Frequency Identification technologies (RFID), barcode).

PLC is steadily becoming more and more relevant due to the increasing importance and awareness of social, environmental, and regulatory issues (see for instance [6] concerning electrical and electronic equipments); moreover, due to the fundamental aspects concerning efficiency of production and logistic processes, effectiveness in terms of customization, shortening PLC and process life cycle, changes in products' usage modalities. Therefore, future developments of ICT tools seem to consider co-operative solutions for PLM, Customer Relationship Management, and SCM.

3 PLC and process life-cycle: the Logistic Matrix

The PLC consists of the following main phases: design, production, distribution, use & maintenance, dismissal and recycling.

Several processes sustain the mentioned PLC phases. All the processes performed are characterized by a life-cycle (i.e., process life cycle or technology life-cycle). The process life-cycle can be decomposed into the following phases: R&D, design, implementation, process use, "recycling of knowledge" / process re-engineering / re-configuration.

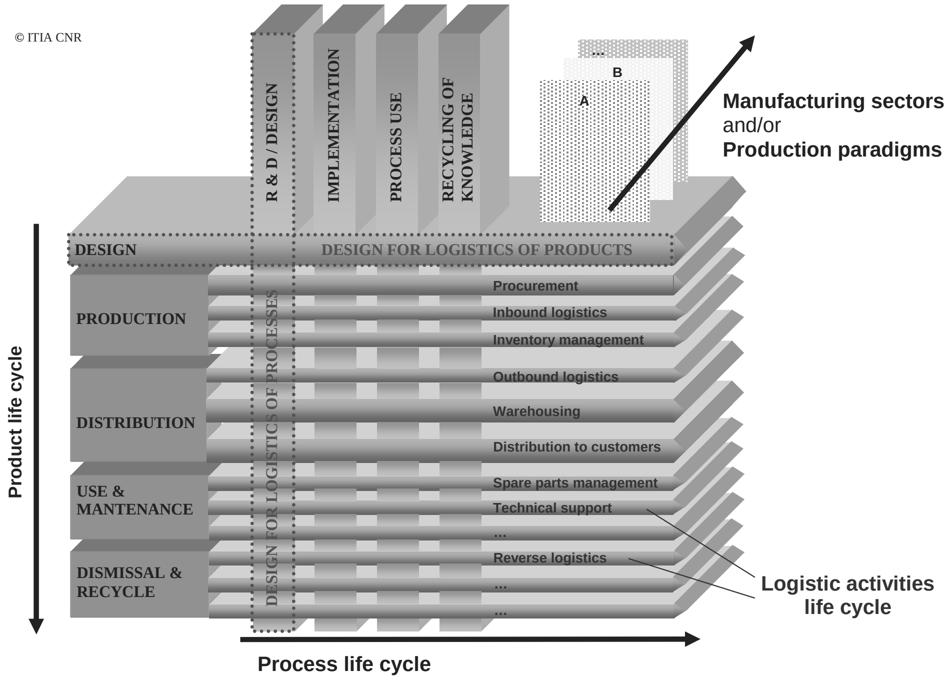
The proposed approach aims at identifying among the sustaining processes those related to logistics, while defining a set of logistic macro-processes. Therefore, the following logistic macro-processes can be identified by focusing on logistics throughout PLC (see the Logistic Matrix in Figure 1):

- design for logistics (product design phase),
- procurement, inventory management, inbound logistics (production),
- outbound logistics, warehousing, transportation (product distribution),
- spare parts management, after sales technical support (product use & maintenance),
- reverse logistics (product dismissal, recovery, re-manufacturing/recycling).

Indeed, the *design for logistics* processes have a wider impact on PLC because they have to be carried out also in the design phases of all the processes that underpin PLC, as introduced in Figure 1 with the dotted lines hereinafter presented and detailed.

Reverse logistics is related to the activities triggered by used products no longer required by end-users to "products" again usable in the market [7]. Reverse logistics processes embrace reverse distribution, inventory and production issues (e.g., recycling or re-manufacturing).

Figure 1 The Logistic Matrix



The Logistic Matrix can be also observed from the following standpoints: strategic, tactical, operational decision levels. Strategic decisions usually concern design issues, process flows, automation levels, selection of physical equipments (functional and technical specifications) and facilities. Tactical decisions are related to organization, sizing of facilities, and planning activities. Operational decisions concern planning and operational control. However, according to the Logistic Matrix reference model, strategic, tactical, and operational levels can be identified along the process life cycle phases of the PLC.

Integrated approaches for design, planning, and control of logistic processes are the basis for achieving high performance levels. In particular, optimal planning and control are effective if a suitable process integration (i.e., both managerial and operational) is enabled and deployed. However, integration of logistic processes is a very complex issue [8]. Process integration is a key activity herein intended as a systematic identification, rightsizing, effective connection, coordination, and automation of interdependent processes (at organizational and inter-organizational level) through proper interfaces (in terms of data structures, information and material flows required, ICT) to achieve a transversal minimization of lead times and costs while meeting the customer service requirements in different production areas and markets.

The main limitations that arise in facing SCM problems in distributed (i.e., networked) production are, for instance, the dynamic character of scenarios, the uncertainty, the huge number of actors involved (e.g., suppliers, manufacturers, LSPs), the high number of interdependencies, conflicting objectives that can lead to suboptimal solutions, lack of coordination in decision-making, difficult technology integration.

3.1 Design for Logistics

Design for logistics concepts usually involve consideration of material procurement and distribution costs during the product design phase. In particular product packaging and transportation requirements are considered during the design process [9]. Nevertheless our approach includes in the Design for Logistics concepts also the design phase of all the logistic processes identified throughout PLC. So doing the design of warehousing or transportation processes, for instance, is referred to Design for Logistics concepts. This is justified by the necessary minimization of the whole logistic costs that impact on total product's cost by starting from the design phase of the identified logistic processes. This aspect suggests that through this approach the design of logistic processes and optimization strategies can be coordinated and harmonized in order to achieve effective process integration and optimization at operational level while meeting customer requirements.

In the United Nations Environment Program (UNEP) studies it is underlined the importance of orientation to life-cycle management concepts starting from the design of both product and sustaining processes of PLC (see for instance [10-11]).

Kimura and Kato [12] propose a methodology for designing and managing PLC that aims at providing information sharing between manufacturers and users while considering, respectively, PLC and usage modalities.

Hatch and Badinelli [13] argue that if logistics issues are not addressed during the product design and the production and logistics system design as well, operation (i.e., use) & maintenance phase entails extremely high support costs for the customer. Operations & maintenance is in fact the longest phase of PLC and very relevant costs can be generated. The same authors develop for this purpose a *concurrent optimization* approach by using dynamic programming and relationships among variables, parameters, and performance measures of the different life-cycle phases. The approach provides a model and an optimization scheme that take concurrently into account decisions concerning product design, manufacturing and logistics system design (*manugistics system design*), production and field operation control. The solution is provided by exploiting a multi-criteria function that considers the minimization of life-cycle costs and the maximization of operational availability subjected to product design requirements.

Hence, the design phase of PLC logistic processes should address costs minimization issues also for procurement, handling, warehousing, transportation, technical support, after sales maintenance, and disposal processes by means of integrated design approaches.

3.2 Process & organizational innovations, and ICT

Process integration has been introduced as a key activity for achieving full connection and coordination of logistic processes, cost and time minimization, customer satisfaction. From the standpoint of the Logistic Matrix (Figure 1) before presented, this concept turns into innovation of processes, organization, technology [14].

Process innovation follows two directions along the Logistic Matrix: (*i*) a vertical one which entails a global integration and connection of logistic macro-processes identified throughout the PLC; (*ii*) an horizontal one dealing with the definition of standard sets of requirements and operations that can be turned into advanced added-value logistic services in order to serve different manufacturing sectors while exploiting possible economies of scale or scope.

Innovation in organizational structures aims at defining new roles and responsibilities for the orchestration and transversal management of logistic processes within an organization but also beyond its boundaries. In fact Extended and Virtual Enterprises, for instance, constitute inter-organizational relationships in networked scenarios that successfully encourage collaborative approaches. New business models that consider the collaboration and competence issues and concurrently the concept of service associated with goods need to be effectively managed and regulated in those scenarios.

Innovation in technology (i.e., ICT) entails the deployment of tools and solutions for supporting both management and execution of logistic processes. Currently, many effective solutions support the management of specific processes (e.g., Warehouse Management Systems, Manufacturing Execution Systems, Transportation Management Systems, etc.) or they assist global management (e.g., ERP systems, SCM systems). From the perspective of life cycle-based logistics, it is necessary to design and develop new flexible solutions in order to fully support the responsiveness capability of decision makers and process owners in the event of unpredicted changes in logistic networks or modifications in the objectives (e.g., performance measures). Innovations will have to enable the integration of different technologies for decision support, information and material flow traceability (e.g., RFID), remote monitoring and control. For this purpose these technologies will have to be transectoral in order to enable also the process innovation towards the above mentioned horizontal direction (i.e., serving different manufacturing sectors) and organization as well by fostering new concepts in the delivery of advanced and high added-value logistic services through their integration with Decision Support Systems (DSS) dedicated to logistic operations management.

Moreover, in order to effectively achieve an actual integration, the design of processes and optimization techniques should be carried out in a manner that may facilitate their successive integration in the implementation phase. In fact, Bernand and Perry [15] indicate that product, technology, and process modeling represent fundamental basis for achieving informational integration during PLM when the activities are computer-aided.

3.3 Role of methodologies and technologies

In order to meet customer requirements and gain competitive levels of efficiency, the combination of enabling methodologies and technologies is an essential factor. Methodologies and technologies are intended as elements for fostering the introduction of innovations and added-value creation. Generally, the enabling methodologies derive from Management and Industrial Engineering for solving problems related to manufacturing or service systems while the enabling technologies derive from Electronic and Telecommunication Engineering or Computer Science.

The enabling methodologies refer to *enabling managerial factors* such as management and execution strategies or methods (e.g., for production, procurement, distribution, maintenance) or changes in some elements of the organization. The enabling managerial factors are often (not necessarily) codified, and implemented into advanced ICT-based solutions (e.g., ERP, SCM systems, CRM systems, etc.). In that case the ICT systems contain the enabling methodologies.

The enabling technologies are those factors represented by computers and related equipments, telecommunication devices, electronic components, audio-video devices, office-machinery, software, specific technologies for supporting material flow management (e.g., traceability) such as RFID or barcode.

It is important to point out that those enabling factors (i.e., methodologies and technologies) have different characters (sources) under the logical and intellectual viewpoints. Nevertheless, they may converge on common objectives in a synergetic manner (e.g., systems' performance optimization, process integration, innovation, widespread product information, traceability, high added-value services throughout PLC, etc.) [16]. Moreover the integration of the mentioned methodologies and technologies supported by new business models may constitute transectoral enabling factors [14].

4 PLM and Logistics

In the literature there are several definitions for describing the PLM concept. Among these, Terzi [17] provides a very exhaustive definition[1] reported in the footnote. Moreover, literature highlights other interpretations or focalizations about PLM definition depending on the industrial or research context (e.g., environmental focus, distribution and reverse logistics focus, ICT focus). Nevertheless, it seems to be recognized that SCM and related techniques represent an entry gate for deploying PLM-oriented policies [18].

Kimura and Kato [12] introduce the concept of physical products as a "media for conveying required services".

The concept of service associated with products is encompassed in the most recent guidelines for developing new business models in EU manufacturing. The leading idea is to shift the business towards the delivery of systems of products and services (i.e., product/services or extended products) for jointly fulfilling users' demand, minimizing total life-cycle costs, and environmental impacts [3]. Awareness of sustainability in the value chain is then identified as an essential direction to be addresses. Sustainability and efficiency aspects in design, production, utilization, and recovery of products have been recognized in the regulatory climate for many products (see for instance[6]).

Services and service engineering associated with products hence embrace logistics under two main standpoints: (*i*) on the *back-office* side regarding the activities that allow the production and distribution of goods in sub-networks consisting of suppliers, manufacturers, LSPs; (*ii*) on the *front-office* side (i.e., customer interface) concerning the activities that assist and support the use & maintenance and dismissal phases of PLC [16]. In fact Takata et al. [19] face the changing role of maintenance in life-cycle management while pointing out the strong relationships with other phases of PLC (i.e., design, production, end-of-life) and the importance of integrating technologies (new or existing) and information for effectively performing maintenance operations. The same authors also argue that by focusing on new maintenance roles it may be fostered the shift of business models from product providers towards service providers with maintenance as a major service.

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[1] "PLM is an integrated, ICT supported, approach to the cooperative management of all product related data along the various phases of the product lifecycle. As such PLM involves: (1) a strategic management point of view, where the "product" is the only enterprise value creator, (2) the application of a collaborative approach for the empowerment of all the enterprise core-competences distributed along different actors, and (3) the adoption of a large number of IT solutions and tools in order to practically establish a coordinated, integrated and access-safe product information management environments." Terzi, S. (2005) Elements of Product Lifecycle Management: Definitions, Open Issues and Reference Models, *Doctoral dissertation*, U.F.R. Sciences & Techniques Mathématiques, Informatique, Automatique Ecole Doctorale IAEM Lorraine, Département de Formation Doctorale Automatique, Nancy, France - Scuola di Dottorato di Ricerca in Ingegneria Gestionale Politecnico di Milano, Italy, chp 4.

Moreover, in the selection of maintenance services to be delivered, it seems to be appropriate to distinguish among product types, product complexity, reference markets, length of PLC [16]. In fact Kimura and Kato [12] underline that, depending on products and customer satisfaction, life-cycle management options may entail a long-life maintenance-centered or short-life maintenance-free management.

Therefore, logistics and related processes should be considered as important elements to be well-fitted throughout PLC and in its management strategies.

5 DSS based on optimization and simulation

Literature concerning SCM highlights many solution approaches devoted to logistics systems modeling, simulation, performance prediction, process integration and optimization.

Thomas and Griffin [2] present coordination problems in SC concerning strategic and operational planning at various stages and faced by Operations Research methods. Among others, important conclusions are: the relevance of knowledge of all added-value activities in the SC and the great improvement opportunities it may create. Moreover the importance of added-value logistics and reverse logistics is envisaged.

Lin and Shaw [8] propose a modeling approach based on Multi Agent Systems (MAS) for re-engineering the order fulfillment process, from production to distribution, in order to integrate the SC networks. The length of PLC is one of the features useful for defining the different types of networks.

Jung et al. [20] present a simulation-based optimization approach for facing customer satisfaction level and safety stock problems under demand uncertainty in complex SCs. An interesting character of their work is the extended use of simulation and optimization by adopting *Simulation Optimization* and Simulation with Embedded Optimization approaches.

Terzi and Cavalieri [21] describe the very relevant role of simulation techniques (i.e., parallel/distributed discrete event simulation) in SCM. In their survey it is described the evolving scenario of logistic networks towards collaborative paradigms supported by co-operative ICT-based solutions at organizational and inter-organizational levels. This trend has changed also the traditional simulation paradigms. The authors highlight, among other aspects, requirements and hurdles for logistics networks integrability and argue that the adoption of distributed collaborative IT solutions is strongly needed.

This conclusion confirms that in networked environments, characterized by distributed decision-making, autonomy, data privacy needs, information sharing, there is a strong need of flexible, robust, interoperable, and efficient ICT-based solutions in order to deploy management strategies PLC-oriented in logistics. From the PLC standpoint, the responsiveness capability of decision makers and process owners have to be strengthened when unpredictable events occur and the objective functions change in strongly dynamic and networked scenarios at tactical and operational decision levels. Hence simulation-based solutions that embed optimization modules have to be addressed by industrial research. Nevertheless, also strategic decisions in design phases can be supported by following these research directions. For all these purposes, modular and suitable DSS that cover several phases of PLC for logistic process design and management have to be developed. MAS paradigm is suitable to represent networked scenarios before mentioned. The adoption of different optimization techniques (also for the same decision making problem) may give great flexibility to users when boundary conditions, objective functions, and networks' characteristics change [16]. Hence, the effective connection and integration between (*i*) solving algorithms for decision-making problems in logistics and (*ii*) simulation reproducing networked environments constitute promising trends of development.

6 Conclusions

PLC is steadily becoming more and more relevant due to the increasing importance and awareness of social, environmental, and regulatory issues. Other elements that confirm PLC relevance are: efficiency of production and logistic processes, effectiveness in terms of customization, shortening PLC and process life cycle, changes in products' usage modalities. Those elements significantly affect competitiveness especially for many European manufacturing sectors. The information exchanged among suppliers, manufacturers, logistic operators, distributors, and after sales technical support in the SC can be exploited for both gaining relevant efficiency and effectiveness levels and implementing the delivery of added-value services associated with products throughout PLC. SCM and related techniques may then represent an entry gate for deploying PLM-oriented policies. The paper focuses on the definition of a Logistic Matrix reference model by which key logistic macro-processes are identified throughout PLC. Design for Logistics has been introduced as an approach for designing products and logistic processes. The objective is to lead to the integration of logistic processes in manufacturing scenarios characterized by delocalized production, markets distribution, distributed decision-making, demands' uncertainty. This challenge can be faced by integration among SC actors in order to achieve full connection and coordination of logistic processes, cost and time minimization, customer satisfaction. This concept entails innovation in processes, organization, technology. Managerial methodologies and technologies (supported by proper business models) are essential transectoral enabling factors for designing and deploying DSS and ICT-based solutions in order to achieve systems' performance prediction and optimization, process integration, innovation, widespread product information, traceability, and delivery of high added-value services throughout PLC. Main future research tasks will cover the application to industrial test cases and the definition of key performance indicators related to the Logistics Matrix.

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Application of kansai engineering to product development

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Abstract: Extracting emotions and translating them to product development is crucial to balance the product's design and performance attributes. Kansei Engineering (KE) can aid in the development of the complete product from its physical appearance to its required performance. The study conducted aimed to determine the effect of changes in the design parameters on the key emotions or adjectives commonly used to describe the product. A domain for an existing product was developed using several KE methods followed by a database comprised of appropriate semantic terms and product properties. The results show clear differences between the High type of users and Medium type of users. The factor analysis determined the four significant factors that are important when the clusters were combined. Regression analysis was carried out both on the Kansei-words and different factors from different clusters. The database was successfully validated at an Australian based company AB.

Keyword: Kansai Engineering, Product Development, Clustering Regression Analysis

1 Introduction

Many consumer goods manufacturers encounter the predicament that some of the new products they introduce to the market are not well received by potential customers as they had anticipated. One possible attribute may be that the products simply did not capture the customer's emotions. This lack of customer feel may result in low sales volume and loss in investments. The importance of emotions in developing a product design relates to KE since the word Kansei depicts the emotion of the user. The same emotion or 'kansei' is the information that is gathered from users to build into product specifications. This topic emphasizes the need to understand the consumers' emotion and how it affects the market appreciation of the product, through psychological triggering of emotions. Nagamachi described KE as emotional technology [1,2]. The applications of KE covers several automotive companies such as Mazda and Nissan, apparel companies, electronic home product companies such as Sanyo and Sharp, office machine companies such as Epson, Fuji and Canon, cosmetics companies such as Shiseido, and other product sectors. Norman argues how emotions are inseparable from cognition. Emotions are a necessary part of cognition, since everything we do and everything we think is tinged with emotion [3]. Some objects evoke strong, positive emotions such as love, attachment and happiness, which invoke a change in perception. An example of this is the review of

New York Times on BMW's new MINI Cooper car. New York Times quotes "Whatever one may think of the MINI Cooper's dynamic attributes, which range from very good to marginal, it is fair to say that almost no new vehicle in recent memory has provoked more smiles". The writer notes that the car is so much fun to look at and drive, that the reviewer suggest that you over look the car's faults [4]. Tractinsky (1997) researched whether aesthetic preferences are culturally dependent and carried out a detailed research similar to one carried out in Japan, in Israel where people are mainly action oriented [5]. He translated the Japanese keys to Hebrew and designed the experiment with rigorous methodological controls. In summary, not only did he find that his results replicated that of the Japanese findings but also, contrary to his belief that usability and aesthetics were not related. The results that were gathered showed a stronger correlation in Israel than in Japan. Thus further enforcing how emotions can tend to control both behavioural and reflective analysis. According to Norman (2004), there are three aspects in product design: visceral, behavioural and reflective design. These levels are mapped into product characteristics by attributing which aspect of the product triggers the level. The findings showed that the visceral design is more commonly concerned with the appearance of the product. Behavioural design is measured by the pleasure and effectiveness of use. While reflective design is targeted using the self-image, personal satisfaction and memories of the users. For example, Microsoft's advertisement of their new game console called XBOX appeals to teenagers and young adults, who seek fast and exciting games with a high level of visceral arousal. These people can be contrasted with those who prefer the commonly accepted norm like sunsets and fresh air, which they find as emotionally satisfying. The advertisement pits the reflective emotions of being outside and sitting quietly while enjoying the sunset against the continuous visceral and behavioural thrill of the fast moving and engaging video game. In summary, products can have personality and emotion built into them. However this does not mean that the performance must be compromised, since trying to attract the customer is not enough to maintain a consistent market appreciation. Performance can also be enhanced using the same principle of capturing the emotion of what satisfies the user when using the product. Asahi's detailed and structured approach to product development is instrumental in its success [6]. Childs (2002) detailed how Seiko Epson Corporation (SEC) of Japan has integrated Kansei Engineering techniques to its product life cycle[7]. Mazda Motor Corporation led to designs with ergonomic beauty and subjective feelings or Kansei beauty. Different priorities from different markets have lead to different design actions. The prioritised elements and the tree of such elements becomes the target for KCCS (Kansei Category Classification System) translations. Emotions experienced through drivers' hands and feet were gathered as well as feelings of touch or tactile feel as important aspects of the instrument panel.

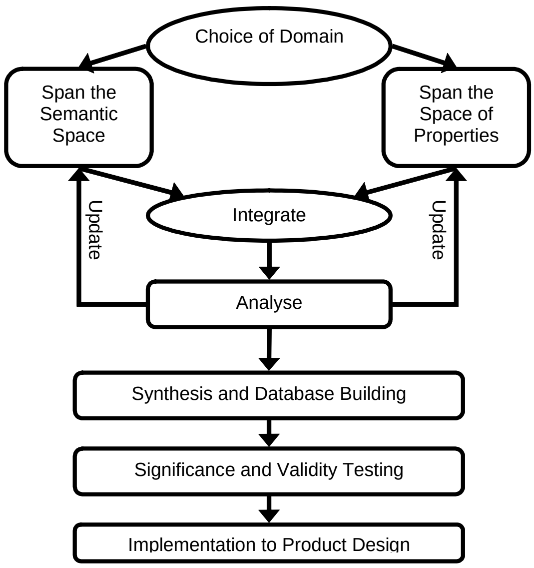
The extensive application opportunities and advances in technology, have led to the evolution of different types of Kansei Engineering. The first type of Kansei Engineering is called Category Classification. A central notion of this method is the so-called zero level concept. Zero level is the abstract concept chosen as target for the development process of the selected product in question. A tree structure starting from the zero level concept is broken down into sub-concepts, which in turn are further broken down into lower levels and so on. The last level of sub-concepts is the actual physical traits at a very detailed level. Kansei Engineering System, KES, is the second type of KE and also based on the general methodology described above. This system was created to manage a complex computerised system of databases, which holds all the information about a particular product. The system may suggest a model of the product that fits the customer's wishes [1]. Further developments have led to the creation of the two most recent types of KE, Virtual Kansei Engineering and Internet Kansei Design System. Internet Kansei Design System integrates the vast communication and networking possibilities that the internet has to offer to the development of the Kansei Engineering technology [2].

This paper aims to summarize the results of a study which determined the effect of changes in the design parameters on the key emotions or adjectives commonly used to describe a product. Eight different samples of mobile phones were used and a semantic space comprised of a total of 188 words describing a phone was prepared to select the set of potential Kansei words. The data and results of the study were given to the designers of company AB which aimed to utilize these results to suggest a new conceptual mobile phone design. Overwhelmingly, positive feedback was received from the designers on the Kansei database developed.

2 Methodology

The model used in this research is a modified version of a flowchart proposed by Lindberg [8]. The case study on a mobile hand phone design was used to illustrate the performance of the proposed approach [9]. The methodology is initiated by the selection of a domain. The domain determines the appropriate data that needs to be gathered, which are the parallel procedures of selecting appropriate semantic terms and product properties. The data gathered was analyzed using regression methods and tested for validity. Eventually, a model is built for the integration of Kansei words to product properties (Figure 1). The model created can also be used as a database of design parameters that can be used as a tool or guideline when designing or redesigning a product.

Figure 1 Methodology of the research



2.1 Selection of the Domain

In this research, the domain product that was selected is a mobile phone where manufacturers need to consider the sheer competitiveness and growing demand in global markets. The rapid rate of replacement makes this product ideal to study for product life cycle management as well as in terms of profitability and to quickly respond to consumers' preferences with regards to design and performance. The selected target market was the youth market of university students. The evaluation approach for the model-based analysis was initiated by decomposing the wide spectrum of user satisfaction into specific 'dimensions'. These 'dimensions' constitute various aspects of the perceived image, and impression felt by users. Information about the 'dimensions' were gathered from a survey that was conducted to examine how people express their feelings, images, or impressions about products.

2.2 User Information Data Collection

Basic personal information as well as information regarding their background and experience on mobile phones were collected. The users' background and experience with mobile phones determines their field knowledge and their contribution to the database.

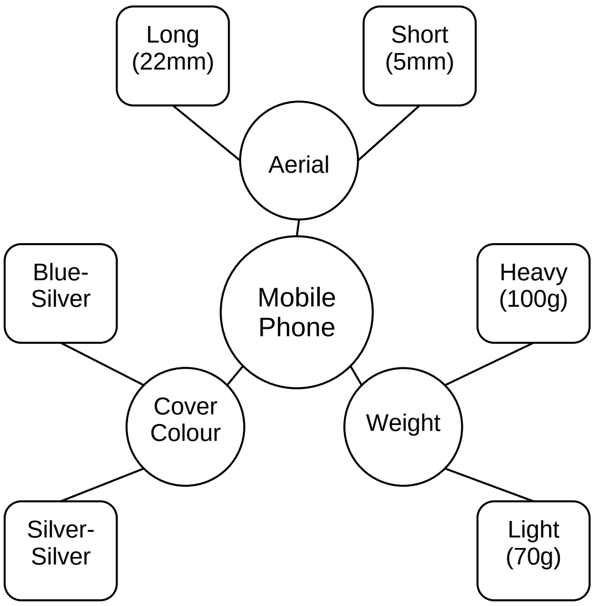
2.3 The Semantic Space

A total of 188 words for the semantic space were gathered from various mobile phone brochures and websites. The respondents were asked about words that they would 'commonly and normally' use to describe a phone. After all the respondents have completed marking their preferred Kansei words, the data was sorted to finalize the top twenty words. The word ADVANCE was voted as the most commonly used description when selecting a phone, according to the focus group. Next set of words were QUALITY, COMFORTABLE, COMPACT and CREATIVE scoring equal votes followed by VERSATILE and LIGHT which were ranked third. EFFICIENT, CLEAN, CHEAP, CONVENIENT and ATTRACTIVE are all fourth in ranking followed by DURABLE, SMALL, BALANCED, BASIC, STYLISH, LATEST, MODERN and INNOVATIVE. Determining the Zero-Level was conducted for three predetermined headings. The headings displayed were "EXCITING AND ENTERTAINING", "EYE CATCHING AND APPEALING" and "EASY AND HASSLE-FREE". The respondents ranked which of these headings would be most required in their selection of a mobile phone from 1 to 3, 1 being the highest and 3 being the least likely. It was found that "EASY AND HASSLE-FREE" has scored the highest rank from all 3 clusters that were analyzed. In the combined cluster "EXCITING AND ENTERTAINING" and "EYE CATCHING AND APPEALING" had equal ranks according to preferences. While in the high user cluster, "EYE CATCHING AND APPEALING" was slightly more preferred than "EXCITING AND ENTERTAINING", which was already anticipated since this group had more attachments to the aesthetics of the phone. The medium users cluster however preferred "EXCITING AND ENTERTAINING" in comparison to "EYE CATCHING AND APPEALING". These clusters mentioned here were further elaborated in the cluster analysis. Then under each heading, all twenty Kansei words were listed and the respondents were asked to rate the relation of the Kansei words to the headings above. The rating scores were from the range of -3 to 3, where -3 meant that there is a negative relation between the adjective and the heading, while 3 is the highest rating on the positive side which suggests that the adjective highly complements the heading. This information was used to determine the factor name, by selecting the highest rating Kansei word among the factor group.

2.4 Span the Space of Properties

The span of the properties that can be tested in the experiment was limited by the variations that can be done with the given samples. The samples selected were the actual dummy versions of the phone. An illustration of the design parameters was tested and the categories under each parameter are shown in Figure 2.

Figure 2 Illustration of Product Properties for Evaluation



2.5 Arrangement of Samples

Each respondent was shown the same samples under the same sample number. The advantage of performing a full factorial experiment in this case is the capability of testing the effect of a single design element as well as the effect of altering all the elements at the same time. Table 1 illustrates how SAMPLE 1 and SAMPLE 2 vary only in WEIGHT, while maintaining aerial and colour the same. This same comparison can be done with SAMPLE 3 and 4, SAMPLE 5 and 6, SAMPLE 7 and 8. An example of testing the effect of two parameters at the same time is the comparison between SAMPLE 1 and 4, where the WEIGHT and AERIAL are different while maintaining the same COLOUR. And lastly testing the effect of changing all the parameters at the same time can be seen by comparing SAMPLE 1 with SAMPLE 8.

2.6 Clustering of Users

The clustering method was applied in this study to investigate the effect of the respondent's knowledge and experience on mobiles phone, on their choice of words and design preferences. Clustering was conducted based on a set of qualitative questions that measure the experience and knowledge of respondents on the product. A weighting was applied to each corresponding answer to a question. All these weightings added up to the total score of the specific respondent. Then the mean score from all the respondents was calculated. The mean score determined the cut-off line between the HIGH USER and the MEDIUM USER. Factor Analysis was conducted to group Kansei key words that had similar score and trend behaviours with the changes in the design parameter. Amongst all factors, this project was "EASY AND HASSLE-FREE" factor was ranked of highest importance.

Table 1 The Sample Arrangement for the Experiment.

	WEIGHT	AERIAL	COLOUR
SAMPLE 1	100g	Long	Silver
SAMPLE 2	70g	Long	Silver
SAMPLE 3	100g	Short	Silver
SAMPLE 4	70g	Short	Silver
SAMPLE 5	100g	Long	Blue
SAMPLE 6	70g	Long	Blue
SAMPLE 7	100g	Short	Blue
SAMPLE 8	70g	Short	Blue

3 Analysis and Results

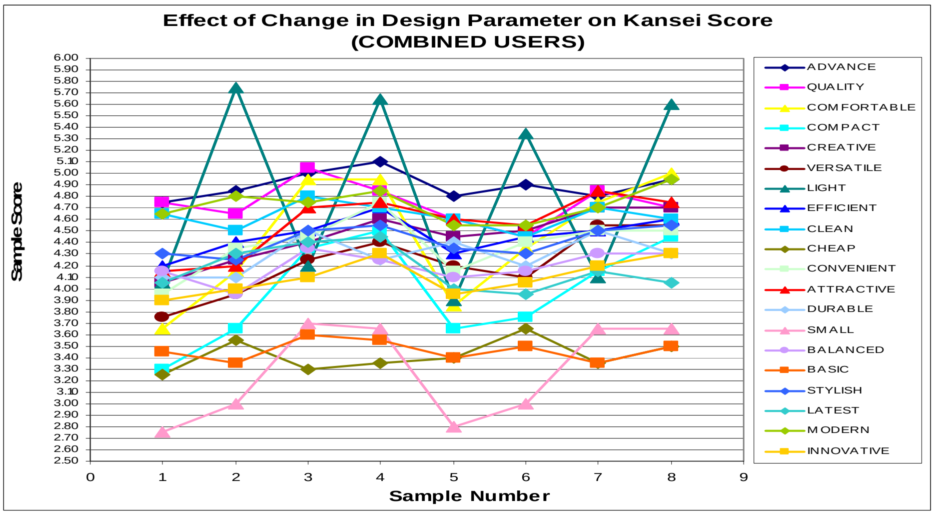
The gathered data was further analysed regarding the effects of changes in product characteristics in order to observe the apparent trends and behaviours of current and potential users. The data was analysed based on two clusters combined and two clusters set individually. A significance test was also conducted to identify the significance of the data to the analysis. The combined user data is composed of all the responses gathered. Kansei words were grouped in factors according to their response to the changes in the design parameters (Figure 3). Kansei words with visually similar magnitude and trend were grouped together as one factor. Significance tests were conducted for each factor to determine if it was necessary to be included in the database as well as to determine product characteristics that required close attention during design.

In addition, multiple linear regression analyses was carried out for each of the 20 selected Kansei words. Table 2 below shows the results of the analysis for one of the Kansei word – "Quality". High values of MCC^2 indicate that the data from all the clusters are valid. For the HIGH users, a silver phone with short aerials and has a lighter weight, exudes a feeling of higher Quality. MEDIUM users are not sensitive to colour when defining Quality. On the other hand, medium users prefer a heavier phone with long aerials. Generally from combining both sources together, a silver phone with short aerials and 100 grams of weight would be viewed as a high Quality mobile phone.

4 Validations

The KE database developed in this study was successfully validated at an Australian based company AB, which offers services that range from providing print designs to electronic presentations. The designers were given three weeks of development time to create a concept phone based on the database developed and the dummy phones provided. A common suggestion that was gathered from the designers was that the database could be further reduced to less numbers of Kansei words that directly target the Zero-Level. Therefore factorisation was conducted to group the words that had that same trend effect with changes in design parameters.

Figure 3 Graph of the sample numbers versus sample scores for Combined Users



5 Conclusions

The results of this study showed that, HIGH type of users, those that have a wide experience and knowledge about phones are more sensitive to the aesthetic effects of the phone. The results from the factor analysis confirm that in all cases the colour-combination was a significant attribute in defining a certain emotion. On the other hand, MEDIUM type users are more concerned on the convenience and ease of use of the mobile phone unit. The aerial length and weight have a significant effect on each factor. An extension of this study would be a development of a Kansei Engineering Expert System for different individual products or groups of products throughout their life cycle.

Acknowledgment

Authors would like to acknowledge the contributions of Mr Victor Solis to the contents of this paper.

Table 2 Regression analysis for Kansei Word – "Quality"

Kansei word	Cluster	Mcc^2	Product characteristics	Pcc	Category	Cs
Quality	High	0.934	Colour-combination	-0.966	Blue-silver	-0.961
					Plain silver	0.961
			Weight	0.277	70 grams	0.074
					100 grams	-0.074
			Aerial	0.277	Short	0.074
					Long	-0.074
	Medium	0.975	Colour-combination	0.000	Blue-silver	0.000
					Plain silver	0.000
			Weight	-0.961	70 grams	-0.548
					100 grams	0.548
			Aerial	0.982	Short	0.822
					Long	-0.822
	Combined	0.989	Colour-combination	-0.980	Blue-silver	-0.512
					Plain silver	0.512
			Weight	-0.973	70 grams	-0.439
					100 grams	0.439
			Aerial	0.990	Short	0.731
					Long	-0.731

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Propagating engineering changes to manufacturing process planning: does PLM meet the need?

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Abstract: Manufacturing process planning is mainly based on information coming from engineering, on manufacturing data, and on the know-how of the process planner. When an engineering change is brought to the part, the process planner has to propagate its impact to the manufacturing work instructions (MWI). In spite of the increasing interest in the PLM (Product Lifecycle Management) approach and tools, propagation of engineering changes to the MWI has received very limited support from existing applications.

The research presented in this paper builds on a case study conducted within the process planning department of a manufacturing company operating in the aerospace sector. First, the detailed investigation conducted to document the change propagation process from engineering to the MWI is described. Next, an activities model (IDEF0) of the MWI development process is presented. The IDEF0 model contains 201 activities and 120 «informational object-information repository» couples. Lastly, an overview of an information management tool required to support MWI development process is presented. The number of informational objects without any information system as repository and the proposed Dashboard solution confirm the long road ahead for PLM systems in order to meet the real-world needs of propagating engineering changes to the manufacturing process planning.

Keywords: information management, manufacturing process planning, product development, process modeling, dashboard, IDEF0, PLM, engineering change, informational object.

1 Introduction

PLM is often presented by CIMdata Inc. as "a business approach to solving the problem of managing the complete set of product and plant definition information and the processes through which it passes. The PLM process includes creating and changing that information, managing it through its life and disseminating and using it throughout the lifecycle of the product". From such a definition, we could expect PLM tools to efficiently support the work of propagating a change from an element of information that defines a product, to other elements of information that define the Manufacturing Work Instruction (MWI) of this product.

Ideally, the process planner would want the following to be true: «Greatly improved knowledge management occurs because all types of product definition information become associatively linked to the manufacturing processes and tooling designs when Digital Manufacturing is used within a broad-based PLM initiative. This preserves, in fact increases, the value of data. The result is that, as the product design changes, process and resource plans can be more quickly and accurately updated». [CIMdata Inc.]

However, what is observed in practice differs from this ideal. Managing and propagating an engineering change from the design definition to the process plan remains basically a manual operation. Here, we distinguish Change Management and Change Propagation.

«**Engineering Change Management** (ECM) is an important component of PLM. ECM modules in current PLM solutions conform to the industry-standard CMII closed-loop change model. They provide customised forms and pre-defined work-flows for creating and processing change requests, change orders, etc. » [1]. **Engineering Change Propagation** differs from ECM. It consists of the action of integrating an engineering change into the impacted pieces of information. Propagating changes between geometrical data are managed and facilitated, to some extent, by CAD systems through constraints previously established between elements of the involved models.

In industrial practice, when an engineering change is brought to a part, for example to a tolerance, managing and propagating its impact through the different organizations involved in the product development to the relevant portion of the process plan, tooling, inspection document, etc., is highly complex and basically reliant on human expertise. This paper examines some issues involved in propagating engineering change to the process plan and identifies limitations of current PLM solutions involved in the engineering change propagation process.

An in-depth study of the challenge related to engineering change propagation to the manufacturing process plan is presented first. Some results of a case study are described; an IDEF0 model for a manufacturing process planning department is presented, as well as an overview of a proposed dashboard solution.

2 Challenge and approach

2.1 Challenge

During the development of complex products such as those found in aeronautics, the Manufacturing Work Instruction (MWI) development constitutes a complex process that uses a significant number of stakeholders, documents, and applications. The task of the manufacturing process planners is initiated from engineering drawings to lead to the MWI. A large portion of this work is based on the process planner's know-how. The development process of the MWI could be schematized as shown in figure 1, where F_i F'_i and O_i are defined as follows.

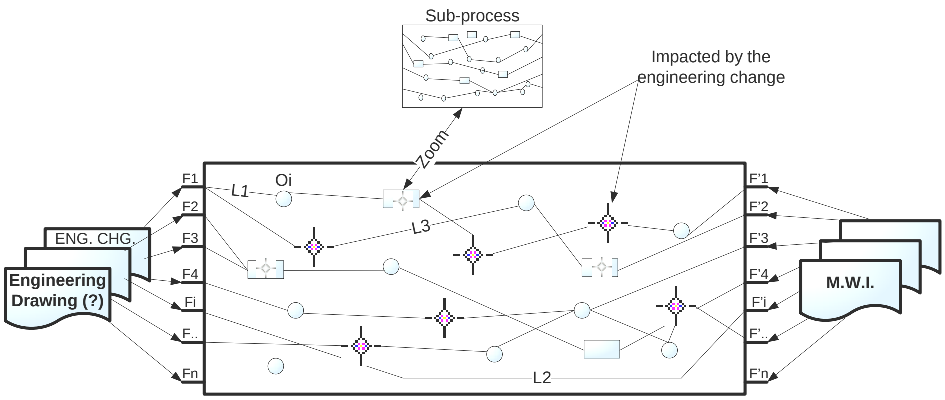
F_i: Feature of the engineering drawing: it can be a dimension, a surface quality, a tolerance, a special treatment, etc.

F'_i: Feature of the MWI: it can be a dimension, a tolerance, an adjustment, a tooling, etc.

O_i: Informational object: it can be a piece of data, a unit of information, a formal or abstract knowledge, a document, a set of documents, an electronic file, etc.

By analogy, using Maurino's [2] description of a technical object, the concept of informational object was introduced within this work to have a common representation of all the product information.

Figure 1 Engineering change impact on the MWI development process



As figure 1 illustrates, our basic MWI development process model relies on the assumption that the features defined by the Engineering drawings are transformed into MWI features via links that involve some process planning knowledge. One of our global scientific objectives is to identify the various links that exist between the informational objects, understanding their types and formalizing them. The identification of these various links offers a potential for connecting engineering drawings features and MWI features. Conceptually, this model is similar to the situation observed today between the CAD model objects that define the product (as is done, for example, with Catia V5), but expands it to a much wider application domain. If this model was to work, it would offer a means to quickly identify the informational objects impacted by the change when an engineering change impact study is required.

This goal is not easy to reach since a great number of these links are based on human know-how. Moreover, the identification of the informational objects involved in the MWI development process requires a great effort since several of them are non-formal.

In the case of complex product development**,** the MWI development process involves a great volume of information and actors, and it is difficult for manufacturing process planners to determine the informational objects impacted by a change. Engineering change impact study is still a difficult task based essentially on experience and knowledge.

The case study conducted, in the context of this research work, within the process planning department of a manufacturing company operating in the aerospace sector, confirms that even in the presence of CAD, PDM, MES, ERP and other applications, it

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remains very difficult for the manufacturing process planner to quickly identify which informational objects of complex MWI documents are impacted by an engineering change and in which way.

The lack of an information structure to support the propagation of an engineering change seems to be the principal reason for this problem. This structure of information is composed by informational objects and their links. However, if the granularity of the considered informational objects is established at the feature level, the multiple links that relate an engineering feature to a MWI feature are from being completely documented and formalized.

2.2 Approach

An interesting approach to solve the engineering change propagation problem consists in managing the various links between technical objects (Maurino [2]) involved in the MWI development process. Giguère [3] successfully used this approach to propagate changes within geometric models belonging to the engineering domain. Michaud [4] used it to cross the Engineering domain boundary, and propagated changes up to the tooling but considered only the geometrical aspects. In both cases, the approach was used to solve some well circumscribed and formalized problems (a limited number of less complex links were controlled and formalized[1]), but was not generalized.

In a general context involving multiple domains, where the level of abstraction is high and the process is more complex, it is difficult to identify all the informational objects involved and their links, as is the case with the MWI development process. In order to help solve this problem, taking as a starting point the principal ideas of the approach based on links management (Michaud [4] and Giguère [3]) and that proposed by Eversheim [5], an approach with two components was proposed within the context of this work.

Component A) Documentation of the MWI development processes: This component aims at studying in great detail the MWI development processes and the Engineering-to-MWI change propagation process. This component's objective is to identify the principal informational objects involved and their links. The links between the informational objects are based on the activities model and methods model co-ordinately with the reference model suggested by Eversheim [5]. The IDEF (Integrated DEFinition) was used to apply this approach, mainly IDEF0 (activities model). Before building the IDEF0 model, two business maps describing the MWI development and the MWI modification processes were elaborated.

Component B) Gathering and analysis of business requirements for change impact analysis: This component aims at identifying the business requirements of the manufacturing process planners related to the study of the engineering change impact. Based on interviews, this component also aims at proposing the ideal solution that facilitates the engineering change impact study and its integration.

The approach described above was applied and validated with the manufacturing process planning department of an aeronautic company. The results are presented below.

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[1] The informational objects are known and the task-specific knowledge conveyed by each link is formalized.

3 Case Study

3.1 Manufacturing Process Planning Business Map

The MPP map documented in this study describes the work performed by the manufacturing process planning department, or MPP department, and is described with more details in reference [6]. This department's main task is to prepare and coordinate the development of the process plan folder, named MWI, in accordance with the requirements of the engineering department. The MWI is a folder composed of several operations sheets. This case study focuses on new parts being developed. New parts are developed simultaneously by Engineering and MPP departments in order to allow early detection of potential manufacturing problems and to accelerate the development cycle. These parts are subjected to a great number of changes while being developed, and these changes do impact the MWI [6].

Starting with an engineering drawing in preliminary release, the MPP engineers study, prepare and coordinate the realization of all the documentation required to manufacture a part and to pilot the prototype manufacturing process. Manufacturing process planners also study and manage the integration of the engineering changes to the MWI during the product development cycle. MPP team leaders manage and follow the MWI projects developed by MPP engineers; they contribute their expertise when needed and ensure that established deadlines are respected. The MPP department interacts with representatives of multiple departments involved in the development of the MWI [6].

Two main processes were identified and targeted in this research project. The **reference process** is used to develop the MWI for a new part. It is the development process used to create an initial version of the MWI; this reference process does not involve any engineering change integration. Due to the important number of tasks and disciplines involved (80 tasks and 14 disciplines), it is clear that even though we conducted an in-depth documentation and analysis, details are omitted here for concision and confidentiality reasons [6].

The **engineering change propagation** process is used to integrate a change to a MWI being developed. This process describes a change which affects the MWI. There are several types of changes. Engineering changes are the only changes considered here. In a majority of cases, engineering changes are communicated through modifications on the engineering drawings (or, in certain cases, are communicated verbally). It should be noted that the process described applies to new parts development; hence the level of formalism observed differs from the one that would have been observed for production parts [6].

3.2 Activity model (IDEF0) for manufacturing process planning

Based on the abstraction level offered by the two business processes introduced above, it was decided to conduct a more detailed study of the MWI development process in order to build a deeper understanding of the process planners' information needs. Thus we chose to use IDEF modeling techniques to build an activity (IDEF0) model that would offer a thorough documentation of the manufacturing process planning activity. The model IDEF0 developed describes in a hierarchical way all the tasks done by the

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manufacturing process planner during the MWI development process (the reference process and the change propagation process).

The model begins on the level "A0" (Develop the MWI of a part), which is the principal activity (figure 2). Then, this activity is broken up into three activities (figure 3): A1) Elaborate the MWI folder (equivalent to the reference process of the MWI development); A2) Modify the MWI folder (equivalent to the change propagation process of the MWI development); A3) Validate the MWI (to start part production).

Due to the IDEF0 model size (201 activities) the activity "A21" describing the engineering change impact study was selected to be described below. This activity was decomposed into two levels and three diagrams are shown below (figures 4, 5 and 6).

The IDEF0 model shows that the manufacturing process planner has to take many decisions to propagate engineering change on the MWI. These decisions could be to cancel a request for tooling, which involves notifying a specific stakeholder involved in the MWI development process. Actually, the PLM and workflow solutions offer many capabilities to easily send information, to follow up deliverables and to notify stakeholders but they can't help manufacturing process planners to take decision in case of propagating engineering change. The lack is essentially due to the fact that a great part of the knowledge and information involved in the MWI development process is still non-captured by PLM systems.

3.3 Analysis

Analysis of the business maps reveals that the MPP, which leads to the development of an MWI folder, is a very complex process that heavily relies on the process planner's expertise, who needs to act on multiple pieces of information provided by various sources. This complexity, coupled with the vast amount of engineering and manufacturing features involved in MWI development, leads us to consider that capturing the links that associate these features was not within our reach. However, understanding the organization of the activities involved in MWI development, as per the IDEF model, also leads to another important conclusion: due to this complexity, the process planners must have a clear vision of all the ongoing and coming tasks performed by all the actors involved in order to better carry out the change's impact study. Thus, even without being able to capture and manipulate the links that exist between the involved pieces of information, there is still a need for a solution that offers a centralized vision of all the process planning tasks and deliverables. This target appears as a viable alternative that would still bring improvements to the change impact study and integration to the MWI. The various actors involved in the process have validated this conclusion.

A quantitative analysis of the 'informational objects' contained in the IDEF0 model demonstrates that a significant part of the informational objects of the MPP is contained on paper (mark-ups on the drawings, check-lists of deliverables, approval sheets, etc.), which leads to conclude that an important portion of the MWI development process is still not covered by a software application. An analysis of the information included on the IDEF0 model revealed that at least 35 % of the 'informational objects' manipulated by the manufacturing process planners are not located in PLM software [6]. Hence, the importance of paper, the significant number of software tools, the large number of tasks and actors involved in the MWI development process, are multiple factors that confirm the process planners' needs towards a solution enabling visibility into the process. The proposed Dashboard is a solution that offers a centralized location for the process planner to retrieve all data relevant to his work [6].

3.4 Requirements for an information management tool to support manufacturing process planning: Dashboard

The business maps as well as the IDEF0 model provided us with an adequate understanding of the process planning process. To further refine our comprehension of the process planners' needs, and to define the dashboard solution profile, questionnaires and interviews were used to obtain information from all participants of the MWI development process, including the process planners. The anticipated users of the dashboard solution are manufacturing process planners, their team leaders, the engineering department and the actors participating in the MWI development process. On top of the needs expressed by the users, and after documenting the manufacturing process planning work as well as its software environment, we added other requirements to the dashboard specifications regarding the traceability of a MWI development project.

Generally, a dashboard solution is defined as a user interface that filters, organizes and presents information in a way that is easy to read. It can be considered too, as a small, defined set of key metrics used to provide a quick evaluation of a project or process status. In our case, the dashboard solution is exceeds this basic definition. In addition of capturing and centralizing information coming from different systems (CAD, ERP, MES…), it allows manufacturing process planners to access those systems from a unique interface. The main interface of the dashboard solution is divided in five areas:

- Project identification: it includes basic information about the project and the list of resources involved in the MWI development process.

Figure 2 A-0 diagram: Develop the MWI of a part (context)

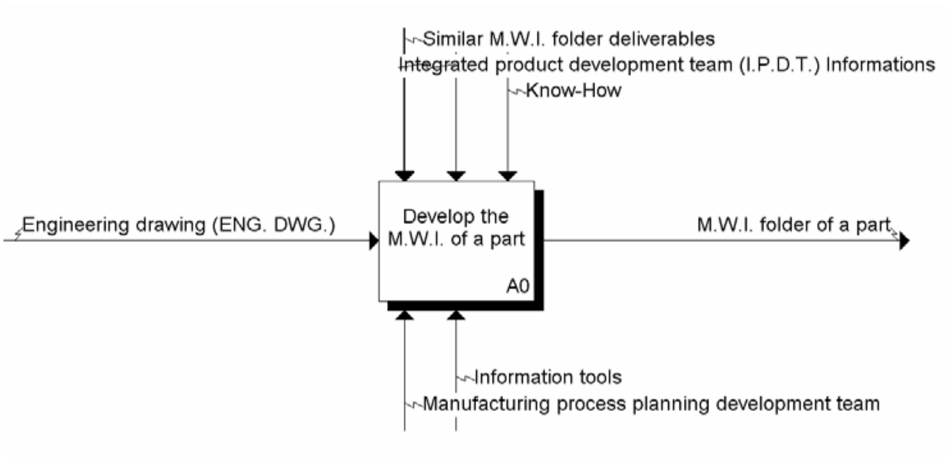

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Figure 3 A-0 diagram: Develop the MWI of a part

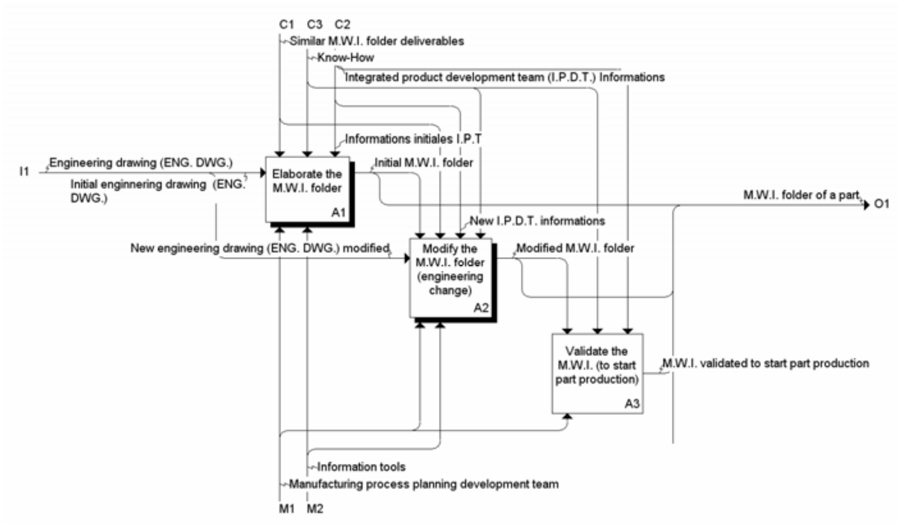


Figure 4 A21 Diagram: Study the engineering change impact and notify stakeholders (context)

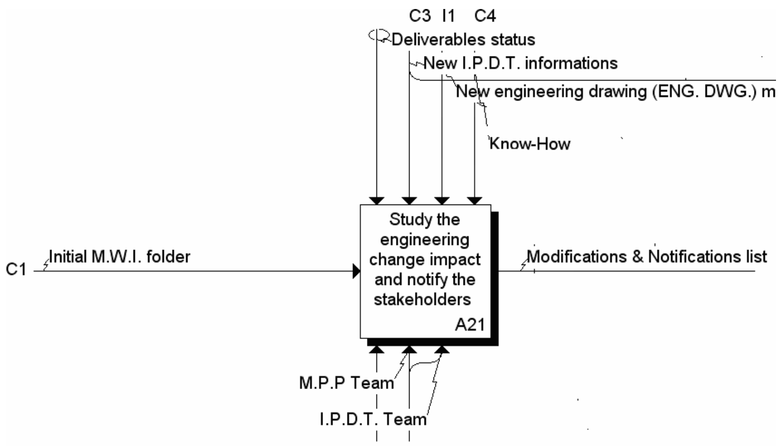


Figure 5 A21 Diagram: Study the engineering change impact and notify the stakeholders

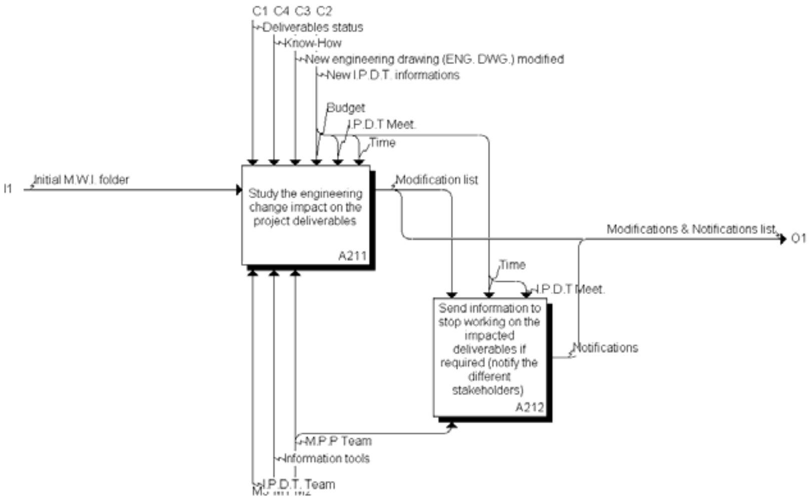
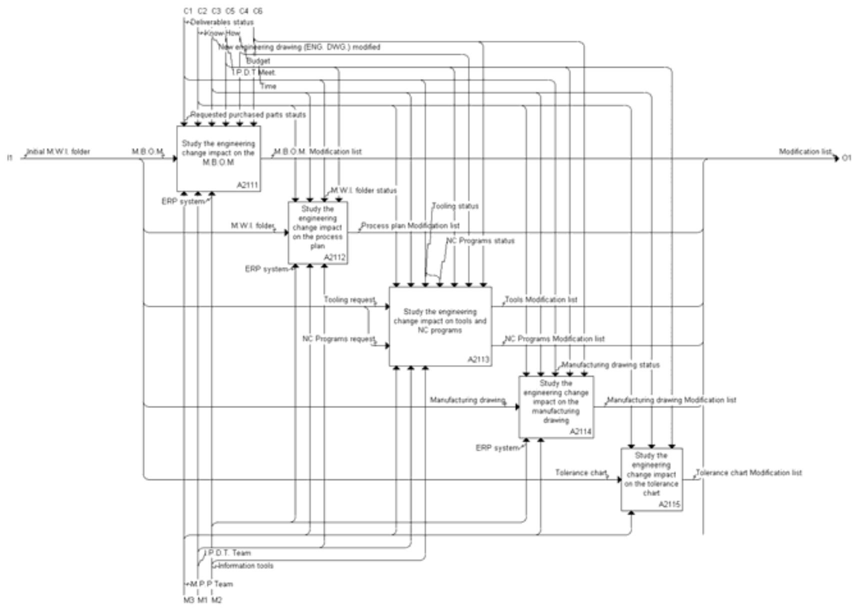


Figure 6 A211 Diagram: Study the engineering change impact on the project deliverables



- Manufacturing process planner's deliverables list and status.
- Manufacturing process planner's tasks list: it contains a list of the main tasks to be performed by the process planner and is linked to the status of the deliverables. When a deliverable is released, the associated task is displayed as completed.
- Project deliverables overview: For each actor involved in the MWI development process, it gives an overview of his deliverables status. It also allows the

manufacturing process planners to dig through them using direct links to others systems (CAD, ERP, MES, …).

- Communication window: it allows the manufacturing process planners to chat with the different actors involved in a project. Moreover, it captures all the communications related to a specific project.

The dashboard solution requirements are illustrated in [6], it provides a global idea of the proposed interface and functionalities. It will be used as a guide for a future development of the solution or for the acquisition of an off-the shelf solution.

4 Conclusion

From a scientific point of view, the maps and the IDEF0 model enabled us to make an inventory of the informational objects involved in the MWI development process. This allows us to progress towards the control of change propagation, by the identification of these informational objects as well as some associations between them. The maps and the IDEF0 model also made it possible to document, in detail, the activities of manufacturing process planning to improve the understanding of the study of a change impact; such a study often relies on the process planners' expertise.

Although many editors of PLM software promise to offer a global canvas of the product development domain, a long journey remains ahead by the PLM systems. The study presented in this paper confirms that there is a major area of the product development process that requires more attention in order to achieve the PLM goals; it is the manufacturing process planning for complex products.

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Innovative product development in a concurrent engineering environment through the extended enterprise

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Abstract: This document compiles and presents the results from several years of research within Dr. Sorli's Engineering Design Research Group in the lines of Product Development in the extended enterprise including some research projects within the frame of the European Commission Framework Programmes. The main business aim is to produce a leap forward in industrial design performance in manufacturing Companies.
The paper will present a model describing a new paradigm for the development process of new products and their manufacturing processes combining the concepts of Innovation, Knowledge Management and integrating tools and techniques from Total Quality Management (TQM), Concurrent Engineering (CE) and Information Technologies (IT) within a real working framework shifting towards the required cultural changes. The model is partially based on the Ph.D.'s thesis developed by Dr. Sorli.

Keyword: Product/process, Innovation, Knowledge Management, Concurrent Engineering, Extended Enterprise

1 Introduction

Lead Time or *Time to market* has been generally admitted to be one of the most important keys for success in manufacturing companies. Combination of factors such as ever changing market needs and expectations, rough competition and emerging technologies among others, challenges industrial companies to continuously increase the rate of new products to the market to fulfil all these requirements.

On the other side, "new products" is a broad expression that may cover from minor lifting to a radical new version. As a matter of fact, nowadays there are quite few really "new products" (we may call them "inventions") since new developments are mostly based on existing ones. Most of the inventions (patents) are new solutions to old problems in same old products. Generally speaking, this approach may be valid for manufactured goods but even in the field of information technologies after the explosion of the *World Wide Web*, most of the innovations or new products actually follow the same schema.

Real level of change varies depending on several factors and, the most important, is driven by customer perception: *if the customer feels that the product is really new, then it is new,* whatever technical changes there would actually be inside it.

2 Product development

Decision on launching a new product into the market is always a rough one but surely enough it is a "must" and if successful, it pays back very well. As a mater of fact, successful stories tell us that 80% of revenues come from products developed in the last 5 years.

Decision on initiation a new product development process has to be sound based on:

- Strategic analysis of the company's situation in order to prioritize these product families giving the Company the better revenue expectations.
- Market knowledge to develop a product aiming to a specific target and well fitting whit this group's needs and requirements.
- Foreseeable future trends of the market needs.

A good knowledge of these factors is ineludibly to develop a new product with the highest success probabilities.

Besides these factors, there are still some others that the entrepreneur has to be quite aware of:

- **Need and timing**. Introducing in the market a new invention is usually a matter of timing, the product has to show up just in the real moment when the need is starting to arouse, and the market needs time to adopt it and get adapted to it. History of technology is full of examples of good products/inventions that have failed just for being advanced to their time.
- **Marketing Strategy.** It can surely help rise and strengthen a hidden need, it may only be true if there is a real need to fulfil. Poor strategies: aiming to the wrong target or choosing the wrong need will surely finish in product failures.
- **Capital investment**. Even brilliant ideas can't survive shortsightedness of potential investors. In the current market, an idea should not only be unique but it has to reach the market within the buying power of the target user.
- **Luck.** Finally there is an intangible factor what is nevertheless really unavoidable. There is a real need of some doses of good luck but being aware that luck is not as unmanageable as seems to be but it is a combination of aspects as good sense, deep conviction and persistence.

Within this frame, the new model we are describing next postulates a brand new approach covering the above mentioned points.

3 New paradigm

The Model we are putting forward brings together techniques drawn from:

- Concurrent engineering
- Total quality management
- Extended enterprise (suppliers and users integration)
- Support from Information and Communication Technologies (ICTs).

The Model puts forward a framework comprising methodology, guides for action, and tools based on the integration of above mentioned factors, all underpinned by an information-management system. Thus the new Model put forward will help companies to optimise the joint application of these methodologies and their computer tools: Integrated Engineering as the merging of Concurrent Engineering (CE) plus the concept and tools of Total Quality Management (TQM), while also adding the concept of "extended enterprise" or supplier integration, and drawing on the resources of information tools (ICTs).

4 Benefits

We will now analyse the main benefits that can be expected of the new ways of working**.** In this, we have based our research on gathering data and studies setting out the benefits of the Japanese model based on concurrent engineering and on the use of certain tools and methodologies – such as QFD.

4.1 Shortening the time scales

The new process may take as little as half the time of the traditional process. Shorter lead times in product development come not from reducing the number of tasks but from making them concurrent and optimising them.

Table 1 sets out comparative data on the distribution of effort in percentage terms in the development stages for a British company and a Japanese one using CE techniques. Data are taken from a 1990 study by B. Prasard. Table 1 shows us how these efforts are reflected in a considerable reduction in time.

Table 1 Effort percentages by stages

	Stages of the process		
Company	Definition	Design	Redesign
British	17%	33%	50%
Japanese	66%	24%	10%

This difference in effort deployment brings better product definition, significantly reducing the need for redesigning. Most cases of redesign stem from a product definition that failed to take account of the potential future problems of other departments in the development process. Redesign increases cost, effort and it always means lengthening the time span.

4.2 Reducing Costs

Reducing total costs for development

Recent studies show that the use of Simultaneous Engineering techniques brings savings of 20% in the total cost of a new product. These objectives will be achieved more easily by integrating the two techniques plus incorporating the use of TRIZ and QFD (which will be outlined later), as proposed in this New Model for the development process.

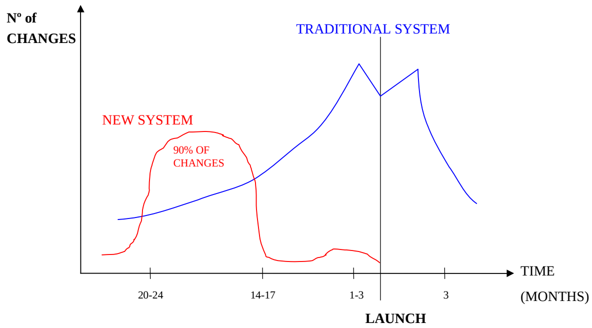
Specifically, the use of this new model by companies will enable them to achieve these estimated goals:

Reducing development costs by the range of 20% at least, breaking down in:

- Lead time reduction, reduction on development hours and reduction on other costs.
- Reducing quality costs by 30% - in terms of the following quality costs among others: Warranties, repairs, repercussions of poor quality on the company's image in the market (Brand) and better pay-off (return on investment)

As mentioned above, these reductions are achieved thanks to bringing all departments involved into the design and development process, particularly the manufacturing department and the external suppliers in the product's value chain. The objective must be to concentrate changes in the preliminary Design stages, in such a way that the product is mature by the time it reaches manufacturing stage – in which changes bring heavy costs – and reaches the market in virtually "untouchable" form. Figure 1 shows the differences between a traditional process and the new process as regards the amount of changes and timing of occurrence of Engineering Changes.

Figure 1 Engineering Changes



This diagram, which was popularised by Toyota when it began to apply QFD in the 1970s, uses real data to show how Engineering Changes in the Traditional Process are accumulated mostly in stages very close to the launching date. However, in the new process, teamwork and the use of QFD along with other Concurrent Engineering techniques manage to concentrate the changes in very preliminary stages. In addition, the overall volume of changes is reduced by nearly 70%.

5 General stages in the new product-design model

5.1 General introduction

Currently, the challenge facing manufacturers is to reduce product-development time as far as possible. The Model proposed here consists of getting *all the departments* involved in product design and development to work closely together from the initial stages bearing constantly in mind the objectives of optimising the added value and reducing the number of changes. Within this new approach, *all departments* mean internal and external teams: "Extended Enterprise".

Good results can be achieved by using Simultaneous Engineering, Total Quality or Extended Enterprise separately, but optimum results cannot be achieved without integration. In the product design and development process, our Model is based on integrating all these techniques, plus software and information tools to make it work.

In short, it can be said that the main characteristics of this new design and development process are based on three fundamental aspects on superimposed levels, namely:

✓ **Gearing company culture towards Total Quality**

This entails a number of changes which, to summarise from several sources, are framed in these *ten commandments:* Customer orientation, Management leadership, Decisions based on analysing the facts and the data, Management by processes, Involvement of all the staff, Quality assurance for the product, Association with suppliers ("Extended Enterprise"), Looking for results not only in the short but in the medium and long term, Continuous improvement and Contributions to society.

✓ **Changes in operations and in organisation structure**

- **Teamwork**

Work teams showing the usual features of present-day teams – interdepartmental and multifunctional – and then adding the new feature of also being inter-company, i.e. they also achieve the effective integration of functional areas of cooperating companies: "extended Enterprise" (what has until now being called "outsourcing").

- **Concurrent Engineering**

Concurrent Engineering is based on making the process stages overlap and concur, using the team structure mentioned above in conjunction with advanced tools and methodologies: QFD, TRIZ, DoE, FMEA, Taguchi, 7 M´s, Simulation, etc., all backed by an Information and Communication Management System (ICT).

✓ **Information Management**

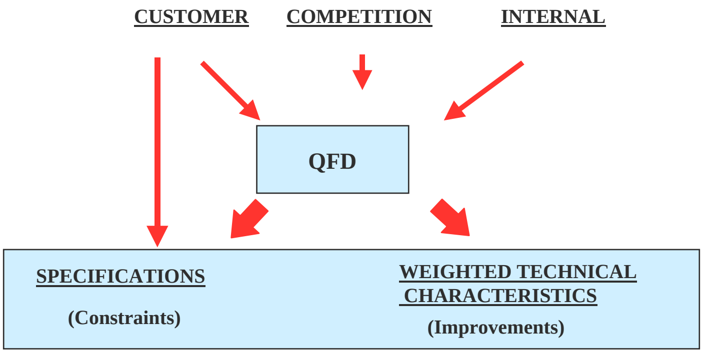
The new Information Management System requires certain fundamental elements:

- **The use of systems** of the kind known as *shareware* and *groupware*; drawing on a common database, these facilitate a number of aspects such as sharing information, working simultaneously with the same data, off-site working etc.
- **Management by projects:** As previously pointed out, the new decentralised approach entails a significant loss of control. Control must be focused exclusively on the Project, this is what is known as Management by Projects. Of great interest in this aspect are the contributions of Goldratt in his books "The Goal" and "Critical Chain".
- **The existence of interfaces**. Although the structure of the teams and the increase in their autonomy usually facilitates communication, it is very important to establish the appropriate communication channels very clearly, and to be very aware of possible human problems.

5.2 Defining the Specifications

In this stage, the characteristics of the new desired product and the way how it is to be manufactured are mapped out.

Figure 2 Defining the Specifications



The key tool at this stage is QFD which helps us interpret and organise the various groups of requirements, the output being the set of product specifications. The inputs for the QFD process come from three main sources: the customer (the most important source); internal needs or policies; and the situation of the competition. The specifications termed 'basic' or 'restrictions' are mainly directly imposed by the customer, who sets down a number of minimum requirements in his tender specifications. The "would-be improved" specifications are those that enable us to identify the main points which, if improved, will bring a significant increase in satisfaction in the market. Naturally, "over-exciting" specifications drive that satisfaction level up exponentially.

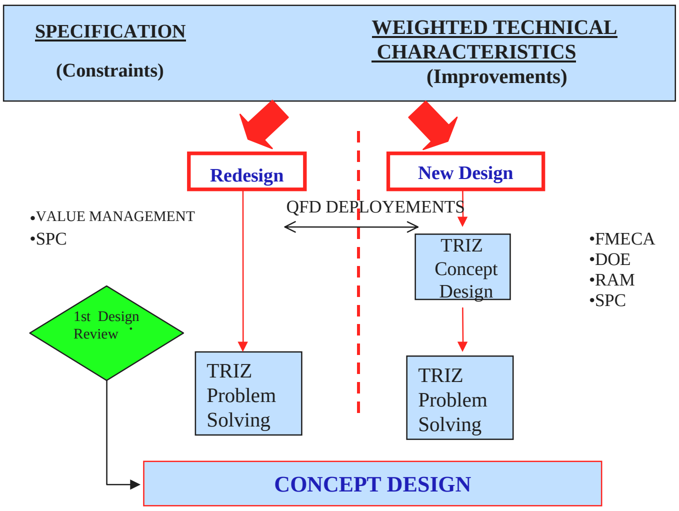
5.3 Conceptual Design

By **Conceptual Design** we mean designing a product in general terms, covering aspects such as the architecture and modularity of the system, its main and secondary functions, volumes, interfaces with other elements around it, etc. One or more possible conceptual solutions are analysed and selected in this Conceptual Design, for subsequent validation.

However, it is highly advisable to define as little as possible at this stage as regards technological and functional solutions, materials to be used, processes etc., since if such aspects are demarcated too tightly at this very early stage, limits are set on the range of possibilities, and creativity is blocked, the result being routine, repetitive solutions – in a word, bad solutions.

Starting from the set of specifications, two distinct paths can be traced for reaching the Conceptual Design of the product: Product Improvement (Redesign) or New Design. The distinction between Redesign and New Design is difficult to pin down generically. We can say that the level of changes introduced is what makes the difference. As said before, the real point is customer perception: *if the customer feels that the product is really new, then it is new*. We thus view "**Product Improvement**" (Redesign) as developing a "new product" based on the current one through introducing a number of relatively small improvements whereas "**New Design**" implies developing and designing a significant new product with a clear and tangible difference from the old one.

Figure 3 Conceptual Design



5.4 Detail Design

A variable and interactive set of stages runs between Conceptual Design and Detail Design, we having broken these down into:

- **Simulation**: The use of tools, essentially computer tools, to ‘fill in’ the Conceptual Design with technology and constructive solutions. Simulation and computation are used to validate the conceptual solutions, the most promising one being chosen.
- **Improving the solution:** using conceptual tools to improve and optimise the chosen solution as far as possible.
- **Prototyping:** developing real or virtual prototypes for evaluating the product’s performance in the real world as realistically as possible: structural representation, fatigue tests and trials, strength, matters of appearance, interferences with the surrounding context, ergonomics etc.

As we have said, this process may go through all the interactions deemed necessary until a suitable solution is reached, within the time limits set by the overall framework of the development process.

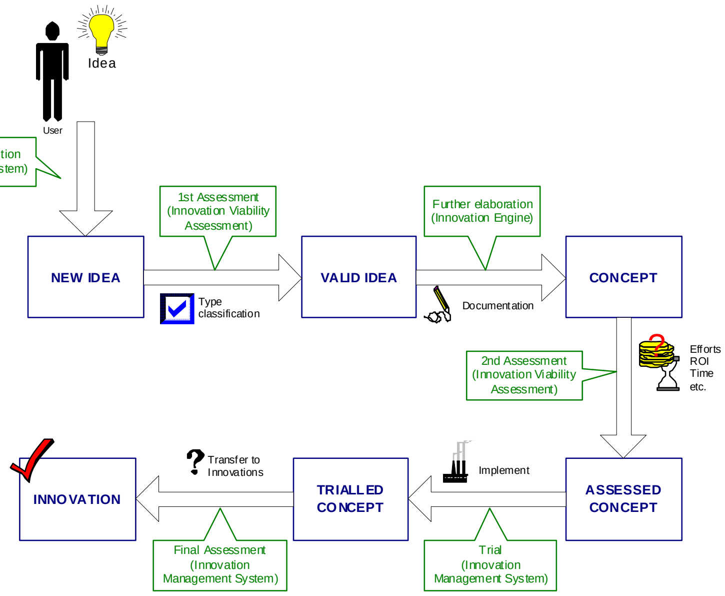
5.5 Innovation

In current Global Markets, innovation is generally one of the most critical factors for success in industrial firms. Former advantages based on aspects as costs reduction, natural resources, geographical situation and so on are no more valuable since globalization is flattening these issues and furthermore, needed natural resources are usually coming from outside. Nowadays motto should be “Innovate or lose”. This new situation needs to introduce relevant changes in the way the companies are working. One of these changes has to be accomplished in the field of new products development that is the basis of the success of manufacturing companies.

Within this frame we may say some words about a research project recently ended under the 6th Framework in the European research field: AIM Project (Acceleration of Innovative Ideas into the Market, *IST-2001-52222*).

The AIM system is thought as a process of innovation, which means that an Idea will undergo a complete cycle, in order to be collected, documented, classified and used in the AIM system. Ultimately, Ideas turn into Innovations, which is one main objective of the system. This section provides a rough overview of the life cycle of an idea. Figure 4 shows the complete path that an idea undergoes in the system. This life cycle is the basis of the innovation process, containing the activities to be realised to achieve innovations in the concurrent enterprise.

Figure 4 AIM Innovation Life cycle



Though the whole "AIM Innovation life-cycle" (see figure 4) is following TRIZ theory, basically the "Innovation Engine" (2nd Step) is based roughly in Altshuller's Innovation Algorithm (ARIZ) by means of proposing key questions that the analyser has to think about combined with other innovation techniques and tools in order to foster the generation of innovative ideas that have to finally result in a valid concept.

The life cycle starts with data acquisition, where ideas are collected using an appropriate graphical user interface, accompanied by knowledge acquisition methods. The users of the extended enterprise will use remotely the system to document their thoughts and viewpoints concerning the products and services of a company.

The AIM system followed a component-based development, enabling an easy extensibility, robustness and customisation, and supporting the activities identified in the idea life cycle. The main features of the AIM System are:

- AIM enables users along the extended enterprise to introduce ideas and report problems.
- AIM enables the complete modelling of the extended enterprise in order to support an appropriate and efficient structure and classification of ideas and problems.
- AIM provides functionality to validate the ideas, classifying them by type.
- AIM includes an extensive search system for ideas in order to support definition, elaboration and combination of ideas and development of innovative concepts.
- AIM supports users in the technical development of ideas, following a TRIZ-based methodology, for in-depth analysis of technical contradictions.

- AIM supports users, following a TRIZ-based methodology, in depth-analysis and solving of problems and failure situations.
- AIM supports the assessment of the ideas developed in terms of technical viability, resources, costs, benefits etc.

AIM system includes methods and tools (modules) for collecting innovative ideas and knowledge on products/processes. The system also contemplates another important source of innovative knowledge coming from problems and potential improvements. The system also supports assessment on these innovative ideas and helps manage them in order to provide the best way of using them for innovative product and process designs. These ideas and knowledge will later be developed into a means of fostering industrial innovations. It will enable organizational learning by providing means to collect, store and use/develop innovative ideas over the extended enterprise.

6 Information and communication technologies (ICT)

It is obvious that only last years' rapid evolution of the Technologies of Information and Communications management (ICT) has actually allowed this new working paradigm, thus making possible a real collaboration among different teams geographically dispersed.

With globalisation, enterprises are strategically distributing their design and manufacturing activities in different regions to remain competitive. Therefore, there is the need for platforms to facilitate the product development and manufacturing requiring collaboration among disparate parties in different geographic locations to cost effectively win customers in a short time. Collaboration is particularly vital from the extended enterprise perspective, and in particular for product design since this upstream activity in the product life cycle has a decisive impact on the success of the particular product.

Big automotive manufacturers are since some time ago launching many experiments on "Virtual product development" by means of using new Internet based technologies in connecting remote locations in cooperative work on the same project. Moreover, passing the work packages over through the "*Wide Word Web (www)"* and using common workspaces and databases, allows remote teams to jump from continent to continent linking the project on a continuous mode, from USA to India, Europe, Japan, etc. In this way design engineers may literally work around the clock. These "e-business" strategies also contribute to lead-time reduction.

Some examples of this new ways of working can be collected from Honda claiming that his all new 2001 Honda Civic model, first model to use the new strategy, has achieved a process reduction of 15%. Also Daimler-Chrysler, on a supply-chain pilot, claims a reduction of 92% coming down from previous 14 days to just one, on the specific issue of sending production program information to suppliers.

ICT give design people a sound base to build on it. Nevertheless, it is not to forget that tools of this kind are *just tools.* In summary, they need people working on them using methodologies and other conceptual tools of the kind that have been mentioned in the previous points and are described in the following ones.

7 Conclusions

Authors believe that the new Model for Product Design & Development Process that has been outlined along this paper offers the industrial designer a comprehensive methodology integrating the latest technologies and tools. There are some innovations being put forward in this New Model that make it unique, highlighted as follows:

- Integrating a novel Innovation Methodology – TRIZ– into the Product Development Process.
- Employing QFD (Quality Function Deployment) as the guiding thread for the entire process.
- Viewing Integrated Engineering as the integration of Concurrent/Simultaneous Engineering (CSE) and Total Quality Management (TQM) at Management level; these two methodologies will work together to give better quality (meeting customer requirements) and shorter development lead time.
- Developing a methodology, guidelines and tools within a multifunctional and multi-company context: “Extended Enterprise”.
- Making use of the potential and ability of the new ICTs which allows quick and reliable exchange of information working in parallel frequently at remote locations.

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Exploring the relationship between after-sales service strategies and design for X methodologies

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Abstract: Modern industrial companies cannot consider their business role ending up with the transactional undertaking of product sale. They must indeed focus their efforts in ensuring a long-lasting and stable relationship with the final customer through the overall product life-cycle by providing a customized and value-added portfolio of connected services. In the western mature economies, the evolution of cultural and sociological models, along with the continuous breakthrough of the technological edges, are driving consumers to put more emphasis on the functional properties of a product. The transition from a product manufacturer into a service provider constitutes a major managerial challenge. Services require organizational principles, structures and processes new to the product manufacturers, which encompass the whole product life-cycle, from its conceptual phase to its dismissal point. The purpose of this paper is to evaluate how Design for X methodologies and practices can consistently enable the achievement of the objectives of specific after-sales strategic profiles, by encompassing those distinctive features which can at best fulfil the customer's requirements and expectations throughout his product life-cycle usage. A model is proposed relating after-sales strategies with "Design for X" methodologies.

Keyword: product life-cycle; after-sales strategy; design for X

1 Introduction

In the western mature economies, consumers put more emphasis on the functional properties of a product, than on the joy of purchasing and owning a physical product. In particular, after-sales activities are a relevant source of revenue, profit and competitive advantage in most manufacturing industries. The after-sales service market amounts up to four or five times the market for new products and, during the product life-cycle, it can generate more than three times the turnover related to the product purchase [1, 3]. Goffin [2], resorting to previous literature, stresses the role of after-sales as: (i) a source of revenue, (ii) a lever for customer satisfaction, (iii) a potential source of competitive advantage, and (iv) a lever for increasing the success rate of new products. Moreover, accepting the claim that returning customers are the most profitable ones, as they require less marketing effort and relationship building, after-sales service plays a critical role as a way to achieve customer satisfaction and retention [4]. Finally, after-sales activities may act as a lever to increase the success rate when introducing new products thanks for instance to the data retrieval and information feedback gathered during product usage [2, 5]. From the offer standpoint, manufacturing companies are forced to shift their traditional product-centric business perspective to a more profitable and sustainable customer-oriented strategy. This strategy is mainly pursued by endowing a product with tangible and intangible elements of differentiation, which make it perceived as unique, not easily replaceable and qualified for setting premium prices. These premises may explain the change in the role of the after-sales function, traditionally seen only as a cost generator and a “necessary evil” [6]. The change is in favour of a view that considers after-sales as a source of competitive advantage and business opportunity. The transition from a product manufacturer into a service provider constitutes a major managerial challenge. Services require organizational principles, structures and processes new to product manufacturers, which encompass the whole product life-cycle, from its conceptual phase to its dismissal point [7]. The increasing importance of intangible factors is changing the concept of the product which, traditionally seen as a tangible entity, tends at de-materializing and becoming a component of a more complex platform [9]. Studies on Design for Serviceability [10], for Supportability [5], for Maintainability [11], and for Life-Cycle [12] are all evidences of the need to establish a thorough relationship between customer support requirements and new product development. Purpose of the paper is to evaluate how Design for X methodologies and practices may enable the achievement of the benefits related to a specific after-sales strategic profile, by encompassing, since the earlier steps of the product design and development, the distinctive features which can at best fulfil the customer’s requirements and expectations throughout the product life-cycle usage. The paper is structured as follows. Section two is devoted to a literature review on the strategic role of the after-sales service in industrial companies, with a specific reference to the durable consumer goods. Section three deals with “Design for X” methodologies, in particular those oriented to the product usage phase, after its production and sale. In section four a conceptual model will be proposed, providing a relation between after-sales strategies and the degree of adoption of specific “Design for X” methodologies and practices. The final section draws some concluding remarks and addresses the managerial implications and further developments of the research.

2 After-sales strategies

Service strategy emerges as a relevant issue for manufacturing firms [13] [17]. The reasons for such an integration are normally put forth along three lines: i.) services can be a source of interesting and stable revenues and profit margins; ii.) customers require more services, and iii.) from a competitive perspective, services are much more difficult to imitate, thus becoming a sustainable source of competitive advantage [7]. Most manufacturing firms provide services to sell and support their products. However, these services are often designed as an afterthought, progressively added and integrated with the underlying physical product as a way to increase or revitalize product sales. As a contrast, firms may identify, since the early product concept and design phases, the opportunities coming out from the service arena and set up the structures and processes to exploit it, shifting towards a service-oriented organization. A critical success factor for this transition may be the creation of a separate organization to handle the service offering. In this case the product becomes part of the offering as opposed to being the centre of the value proposition [7]. Moving from these preliminary considerations, a classification of after-sales strategies for manufacturing firms has been developed [20] that points out four strategic profiles, shown in Table 1.

Table 1 Strategic profiles of after-sales service

After Sales strategy	Business Strategy	Relevance of After Sales	Economical Responsibility	Product-Service Portfolio	Time Horizon
Product Support	Cost Leader	Necessary Evil	Cost Centre	Relevance of tangible properties	Short-term
Cash Generator	Cost Leader Technological Pioneer	Ancillary Role Source of profitability	Profit Centre	Relevance of tangible properties	Short-term
Business Generator	Technological Pioneer Differentiator	Generator of new business opportunities and profitability	Business Unit	Relevance of intangible properties	Medium -term
Brand Fostering	Best in all	Supporting company's image and customer loyalty	Cost/Investment Centre	Relevance of intangible properties	Long-term

Product Support – this is the traditional role of After-sales Service seen as a "necessary evil" [6] and a cost centre mainly deputed to manage warranty issues or early defiance of the product. This is the typical strategy for low cost items, e.g. small domestic appliances. Therefore, the after-sales service offer is simple, mainly based on reparation and sales of spare parts and components. However, attention may be devoted to the design of an information feedback system to gather data from the field, to assess the product performance and to support their improvement over time. The financial responsibility assigned to the after-sales unit in this case is cost reduction and control, pursued through a high level of efficiency and high volumes.

Cash generator – in this case After-sales Service represents a good source of revenues by selling spare parts and accessories (i.e. tangible items related to the product); companies belonging to this strategic approach try to regain the profitability lost in product sale during the after-sales phase; this is the typical behaviour for non commoditized products, as in the premium segments of the motorbike industry or in the consumer electronics.

Business generator - In this case the after-sales service is considered as a business unit, operating and managed like an autonomous entity. The link with the product is less intense and the main objective of the after-sales unit is to develop a comprehensive package of services. Service may be independent from the goods: a customer may experience the service offered without consuming the underlying company's goods. Through its service offer, the firm looks for differentiation from competitors and for new business opportunities. A market-focused vision leads, then, to the consideration of after-sales services as an important competitive weapon. The financial responsibility of the after-sales unit is, in this case, that of a profit centre, but the evaluation of the overall performance is also centred on other performance factors, such as customer satisfaction and the innovation rate of services.

Brand fostering - From a managerial perspective, the after-sales has similar characteristics as in the previous case: a complex offer, with high managerial autonomy. However, in this profile, the mission of after-sales shifts from the achievement of profit margins striving for customer loyalty and brand image. The after-sales service, through customer loyalty, has a positive impact on the future sales of products. After-sales service, then, is considered as an investment centre, which contributes to sustain the brand image and increase in the long term the product sales.

3 "Design for X" methodologies

The differentiation of the approaches adopted for the design and the development of new products can be undoubtedly interpreted as the answer of the industrial systems to the expectations and needs of the modern markets, such as customers' awareness of the role of services, as well as of products eco-compatibility and environmental concerns. Companies have therefore changed their design attitude from a functional-oriented configuration [22] to a Concurrent Engineering vision, a managerial "systematic approach to the integrated concurrent design and their related processes, including manufacture and support [23] … where product development emphasizes the response to customer expectations [24] … and the product design considers all elements of the product life cycle from conception through disposal… [25]".

Along with the traditional design rules for optimization of assembly [26] and manufacturing [27], a wide range of new methodologies, generally defined as "Design for X" (DFX) have been generated as effective tools for the Concurrent Engineering philosophy [29]. DFX approaches suggest that the design of a product may be continually reviewed in order to find ways to improve company's effectiveness and efficiency, linking in some way customer requirements to quality criteria like robustness, serviceability, reliability and environmental impacts.

Benefits arising from the implementation of DFX techniques may be classified in three classes [32]: i.) competitive advantage in terms of quality level, cost reduction, increased flexibility, improved productivity; ii.) rationalisation of decision making processes for the extended product development; iii) high efficiency in using the resources for the design of products and services. Literature concerning DFX proposes a plethora of DFX specifications dedicated to specific markets and/or to particular types of products. A brief description of the DFX specifications which may have a relationship and/or a direct impact on the management of after-sales processes is provided in the following sub-sections.

3.1 Design for Maintenance/Maintainability

Maintainability is an important aspect of life-cycle design, and it plays a significant role during the service period of the product. It represents the design attribute of a system which facilitates the performance of various maintenance activities, as inspection, repair,replacement and diagnosis. Ivory *et al.* [35] identify two different streams of literature related to this topic: the first one refers to what is requested for effective maintenance activities [42], while the second deals with issues of design as related to reliability and maintainability [45], and includes design guidelines. They lead the correct identification of design specifications to impart intrinsic maintainability features in the system for ease of maintenance [46], allowing a company to minimize the utilization of personnel and tools for maintenance activities as well as to reduce the product costs during its utilization. As identified by [12], effective Design for Maintenance rules have to: i) facilitate the identification of product and components failures; ii) make the accessibility to components easier during the maintenance activities; this is fundamental to reduce the time needed to identify and disassembly a broken part; iii) advise the utilisation of light components in order to make easier the disassembly and the extraction of a failed piece; iv) ban the use of components characterised by large dimensions and complex shapes, in order to avoid the breaking of adjacent parts during the extraction of a failed one; v) reduce the number and type of special tools and equipment; vi) provide procedures for assembly and testing in order to verify the installation accuracy in real time.

3.2 Design for Reliability

The reliability of a system can be considered a measure of its performance. As systems have grown more complex, the consequences of their unreliable behaviour have become severe in terms of costs, efforts and lives [36]. As a consequence, the responsibility of design engineers to develop products which meet not only objectives in terms of functionality, manufacturability and quality, but also in reliability [47], have become more and more important for companies. As identified by [48], effective Design for Reliability rules should lead to create simple products, to provide the redundancy of crucial components in order to allow the product reliability even in case of failure, to adopt parts and components duly tested before their installation and to identify and avoid all processes and products which have already caused a failure. Several techniques, methodologies and tools based on linear and non-linear programming [50], Genetic Algorithms [36], Fuzzy Logic [52], Expert Systems [47] and statistical approaches have been proposed by researchers in the past few decades to allow engineers at designing reliable systems within a given period with minimum costs.

3.3 Design for Serviceability

The key role played by services during a product life emphasizes the necessity to consider their usage since its concept. Conversely, product serviceability tends to be an after-thought in the design of many products. Personnel responsible for maintenance and service need to be involved early to share their concerns and requirements. The design of the support processes needs to be developed in parallel with the design of the product. This can lead to lower the overall life cycle costs and a product design that is optimized to its support processes. Four different approaches to Design for Serviceability can be considered:

- to modularize, or to create products from subcomponents that are easily manufactured and assembled; this approach makes it simpler to identify, access, test, repair and replace critical subassemblies, which reduces the cost and duration of after-sale service and enables customers to address certain problems directly;
- to standardize components and parts across a range of brands and products; this allows the optimization of manufacturers' costs through the service operations standardization as well as repair centers staff and resources sharing;
- to develop remote diagnostics or self-diagnostics able to identify a problem and to alert immediately both the customer and the technical assistance centre through wireless communication devices; the results are greater customer satisfaction and lower service costs through early and accurate problem diagnosis.

3.4 Design for life-cycle

In dynamic business environments, companies are seeking new ways of providing additional value to customers and gain a competitive edge over their competitors. Product design and a clear focus on managing the entire product lifecycle have emerged as critical areas for investment [54]. Design for Life-cycle approaches address the identification of design issues to optimise the product management performances during its life from the concept to the disposal, through product and process design, production, marketing and sales, distribution and use [57]. Performances can be measured in terms of manufacturing impact, time to market, quality and costs. "Total system cost is often not visible, particularly those costs associated with system operation and support" [58]. Life-Cycle costing is the management philosophy that emphasizes the selection and design of a system based on minimizing life-cycle cost, using parametric replacement [59] or analytic models [60]. The existing engineering literature proposes numerous methodologies for incorporating life-cycle modelling into product design differing: i) in the motivation for modelling, depending on time, economic or environmental needs [63]; ii) in the scope of the life cycle analyzed, considering either the product life-cycle as a whole or a single phase [64]; iii) in the adopted approach, e.g. analytic [65], parametric [66], and knowledge-based [63]; iv) in the phase(s) of design they support, including conceptual, embodiment and detailed phases [67]; v) in the treatment of uncertainty [70].

4 A conceptual model for relating after-sales strategies with "Design for X" methodologies

According to Lele [6, 71], the critical factor that influences the strategy formulation is the amount of costs, either fixed (i.e. not depending on the downtime) or variable (i.e. depending on the downtime) incurred by the customer in case of product failure. His proposed approach distinguishes between three possible strategies that allow reaching cost effective configurations of the after-sales service on the basis of different customers needs and product specifications, influencing product design strategies (figure 1).

Figure 1 Support system strategies [6, 71]

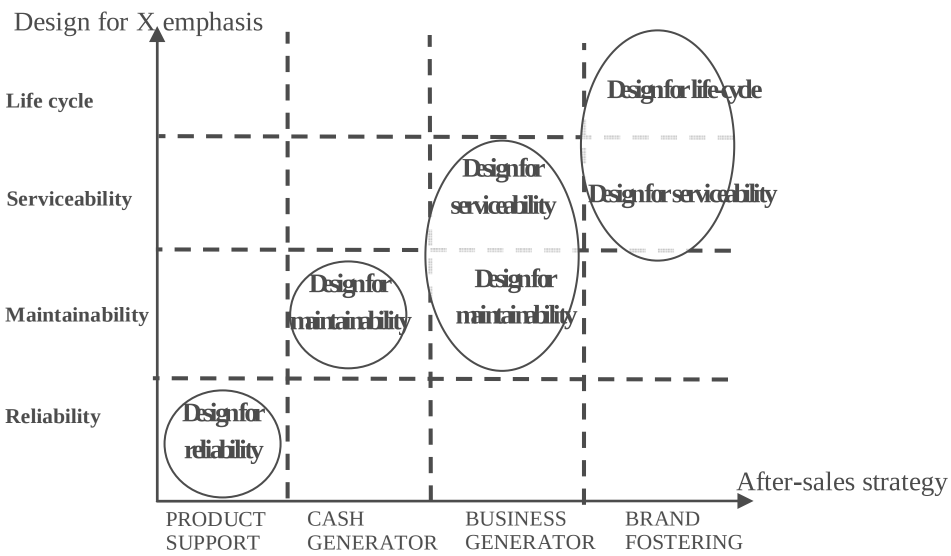
Fixed costs		Variable costs: Low	Variable costs: High
	High	*Repairable*	*Never fail*
	Low	*Disposable*	*Rapid responses*

- A *disposable* product support strategy is advised for those products characterized by low fixed and variable downtime costs, such as small domestic appliances; the product is designed to be reliable, but no attention is devoted to reparability or maintainability since, when the product fails, it is discarded.
- When product presents high fixed and low variable downtime costs, such as large household appliances, the best strategy, according to Lele, leads to *reparability*, i.e. a product service system design that minimizes repair costs.
- If the dominant costs are related to variable (and thus to the downtime duration) *rapid response* is the suggested strategy; service systems should minimize total downtime when a breakdown occurs, both through after-sales organization (e.g. availability of spare part inventories) and through product design (e.g. component standardization).
- Finally, products taking to both high fixed and variable failure costs are simply advised not to fail: a *never fail* design and service strategy is suggested, through, for example, component redundancy or continuous monitoring.

[5] highlight how "many aspects of support are strongly influenced by the product design and so customer support requirements should be evaluated during product development". However, the need to consider customer support during new product development has

been largely ignored by both companies and researchers [41]. A pioneer in "Design for X" practices related to customer support strategy has been Rank-Xerox [72], recognizing goals of product design such as ease-of-use, ease-of-cleaning, easier maintenance and ease-of-repair. Other empirical examples are provided by [10] and [41]. Apart from these contributions, there is still a scarce attention on the understanding of which design methodologies to select in accordance and consistency with an explicit after-sales strategy pursued by a company. Taking as a reference point the classification provided in section 2, the following conceptual model tries to fill this gap, by providing an attempt of correspondence between supportive DFX methodologies and a specific after-sales strategy. This model neglects any DFX techniques oriented to the production process, such as design for assembly or design for manufacturing: these are practices functional for manufacturing costs and time-to-market reduction, but are not supportive to the after-sales strategy adopted. As depicted in figure 2, according to the model the following prescriptions can be highlighted:

Figure 2 The AS_DFX (After-Sales Design-for-X) model



- A *product support* after-sales strategy is better associated to a *design for reliability* methodology: in this strategic profile, in fact, after-sales support is considered a cost that needs to be avoided or minimized, while no emphasis is put on the offer of value-added and intangible services; the strategy is particularly suited to low-value products (e.g. small appliances), or to products subject to technological obsolescence and/or at early stages in their lifecycle (e.g. consumer electronics products), for which a product failure leads to substitution rather than to repair; as result, no particular requirements arise on product design, except to achieve a satisfactory level of reliability without increasing product costs, in order to be competitive on the market.

- In the case of a *cash generator* strategy, instead, after-sales support is seen as a source of revenue, through the sale of physical services (repair, spare parts, accessories): the highest the efficiency in product maintenance activities, the highest the profit achievable through the provision of these services. Emphasis in product design is thus on the methodologies that facilitate the *maintainability* of the product itself, for instance through easy identification of parts, ease of disassembly, and so forth.
- *Business generators* also see after-sales as a significant source of revenue, but they are oriented to offer a wide range of services, including new, intangible and value added ones. *Design for maintainability* can be a methodology adopted in product design also in this case, in order to increase the efficiency of physical support. Along with it, nonetheless, particular relevance is on *design for serviceability* practices, for instance through the development of easily-upgradeable products, the development of remote diagnosis or self diagnostic tools.
- Finally, companies with a *brand fostering* after-sales mission will emphasize *design for serviceability* practices, too, in order to develop the offer of intangible and value added services. Moreover, *design for life-cycle* methodologies are consistent with this after-sales strategic profile, since the focus is on the satisfaction of a returning customer: therefore, cost minimization is pursued with a product lifecycle perspective, from the manufacturing/assembly stage, through its usage at the end customer, to its disposal, aiming at the reuse and recycling of parts.

5 Conclusions and managerial implications

The paper explores the relationship between the definition of an after-sales strategy and the product design methodologies adopted by manufacturing companies of durable goods. The classification of after-sales strategies provided focuses on the service offer (tangible vs. intangible and traditional vs. innovative, value added services) and on the economic horizon (cost reduction, short term vs. long term profitability). The model shows, how the strategic after-sales orientation is consistent with a “Design for X” approach in the product design and development phases. Some considerations can be drawn from the previous sections. First of all, this paper points out the importance of considering after-sales support as a relevant input when designing a new product: costs related to after-sales services should be minimized from the design phase, and business opportunities enabled. Nonetheless very few managerial research exists relating the two aspects [5]. But which costs have to be considered? Our model suggests to adopt the design methodologies that allow to minimize the after-sales costs related to a service offer consistent with the after-sales strategy. A design for reliability, for instance, would reduce costs related to product maintenance. Secondly, our model provides guidelines for after-sales and product development managers. Comparing the behaviour of their company to the model suggestions, they may verify the consistency of the after-sales strategy with the design practices adopted.

An empirical evaluation of the model proposed in this paper should follow as a future research activity. We suggest both a case studies and a survey research methodology. The first one would allow to further point out the relationships between after-sales and product design, also through a longitudinal analysis. An extensive research over a broad sample of companies, instead, would allow to validate the model (on a statistical basis), by an empirical assessment of the after-sales strategy and Design for X practices adopted by the companies.

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Proposal of integration of some methods to develop industrial products

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Abstract: A wide variety of design methods (brain storming, morphological matrix, heuristic methods, TRIZ …) are available to the engineer, who wants to develop innovative industrial products. The aim of the proposed paper is an attempt to make a step toward the integration of all these methods. In order to include also the modern appreciable tendency to accomplish a more and more strict integration and interaction between product and communication in all phases of the life cycle, it is possible to consider the corresponding communication too, introducing, in analogy to the *Design for X* (*DfX*) concept, the *Communication for X* (*CfX*) concept. In this paper, a general schema of the above summarized integrated design process will be proposed and deeply analyzed. Starting from this schema, some considerations will be drawn and a practical sample application will be illustrated.

Keyword: design methods; communication; integration

1 Introduction

The engineering design can be defined as the activity necessary to individuate, adequately elaborate and well organize all the information needed both for the development and the production of an industrial product.

After the formalization of the product function, the first step consists in the identification of all the principles suitable for accomplishing the function. The individuation of all the suitable principle could be a possible help in overcoming the psychological inertia. This approach, in fact, obliges the designer to consider not only the usual solutions, but also the solutions that, at a first glance, could appear `strange', but, after a more detailed analysis could reveal unsuspected advantages. The subsequent step consists in a deep analysis of all the solutions, in order to choose the `best' one, that is the solution that best fulfills all the requirement that a product’s *Life Cycle Analysis* (*LCA*) could highlight.

A wide variety of design methods (brainstorming, morphological matrix, heuristic methods, TRIZ …) are nowadays available to the engineer, who wants to develop innovative industrial products. An approach useful for the engineers could be an integration between two important chapters of the Design Theories:

In the design methodology, it is possible to distinguish two fundamental chapters:

- *Theory of Technical Systems* (*TTS*), which fundamental aim is to develop principles and constructive solutions to perform a given function;

- *Design for X* (*DfX*), which fundamental aim is to orient the optimization of the product in the *X*-phase of its life-cycle. Starting from the evolution of the behavior, it is possible to choose the `best' product, among a given set, in relation to the design requirements, and to orient the designer in upgrading the a given product's behavior in the phase (*X*) of its life cycle.

In the following, an integration between these two approaches will be presented and discussed.

2 Objective

The objective of our research is to conceive a general design procedure, starting from the two above mentioned design theories. In the following some fundamental steps, that could be useful guidelines for the designer, will be highlighted; furthermore, some problem and step that would require particular attention will be pointed out.

This approach will be then applied to a sample case-study.

3 Method

After an analysis of the lay-out of several design procedures, a simple logical schema has been conceived. This schema could be usefully adopted both in design education, tanks to its simplicity, and in the industrial world, since, in spite of its simplicity, it could be a valid help in the first design phase, to abandon the usual ways of thinking.

The proposed approach consists then in the following steps, that achieve also an integration of *TTS* and *DfX* approaches:

1. Identify the general function to be performed by the product; in this first step, the fundamental goal of the designer is defined;
2. Choose the general principle to perform the function (e.g. mechanical, electrical, biological, ...); this principle could be chosen from an archive of principle, taking into account not only the general function, but also the whole life cycle of the product, even if, at this level, only generic phases could be considered;
3. Determine the general architecture of the product and analyze the general function, in order to find out the component functions;
4. Draw the skeleton of the morphological matrix, whose rows correspond to the component functions and each cell contains the corresponding principle;
5. Identify the points of the morphological matrix: this can be accomplished drawing on many sources, e.g.:
   - *state of the art*: it comprehends the normal construction practice [1];
   - *historical heritage*: it includes the solutions of the past, that, in some cases and after a critical revision, could become a source of `new' ideas [2];
   - *innovative solutions*: we include in this category all the solutions coming from heuristic methods, TRIZ, observation of natural phenomena, as well as the solutions conceived starting from pre-competitive research results [3], [4];
   - *designer's personal creativity*: even if the previous approaches could comprehend all the knowledge, it would be an error to neglect the

astonishing possibilities of the un-conscious reasoning that is behind intuition and creativity.

On the basis of authors' experience, some problems commonly arose when a designers follows this kind of approach. In the following list, they are summarized as well as some hints about hoe to overcome these difficulties.

1. *state of the art*: the realization of catalogues of parts and components could be a very complex and time consuming work, but they are essential for a clever and innovative design. These catalogues could indeed allow to choose the `best' components, following one or more of the following approaches.
   - personal experience of the designer;
   - evaluation of the behavior of the components in every phase of the life cycle that are significant for the specific product;
   - by means of an expert system.

   In order to simplify the application of this approach, it would be useful to systematically sort the components in the catalogues, putting each component in relation with its behavior. A smart and universally applicable method to realize this kind of catalogue is still missing and it could be an interesting research subject.
2. *historical heritage*: the following list summarizes the problems that could arise using this source and some hints about how to overcome them:
   - realization of archives, based on collections of historical constructive solutions, that perform a given function. The basic structure of these archives should include:
     - at least a picture of the solution;
     - data-base, with all information interesting for the choice;
     - linkage between image and data-base.
   - the use of these archives could be made easier following one of these criteria:
     - *generalization*: on the basis of an historical investigation, it would be possible to find out the more commonly adopted general principles, in order to evaluate possibility to apply these general principle to the specific problem;
     - *evaluation*: on the basis of the evaluation of the behaviour of each historical solution in the life cycle, it would be possible to point out the `best' one, even if, it will be necessary to modify it to fulfill the modern requirements.
3. *innovative solutions*: heuristic methods are the methods that can be more easily integrated in our approach. The main drawbacks of their use are
   - their diffusion is limited (especially in Italy);
   - the integration of the older methods (brainstorming, morphological matrix, heuristic methods) with the more recent ones (TRIZ, …) and the critical observation of natural phenomena (another interesting source of new ideas);

   A possible way to overcome these difficulties could be the identification of physical and technical contradictions, followed by the individuation of innovative principles, thanks to the TRIZ-matrix.

Figure 1 shows the general schema of the design process based on these considerations.

In this way, the points of the morphological matrix can be filled with a high number of principles for each function.

Performing a congruent synthesis of the principles for each component function organized in the morphological matrix, it is then possible to identify one or even more general principles to perform the general function.

Applying the *DfX* concepts, as to say considering how all principles behaves in relation to the phases of the life cycle taking into account all the requirements of the specific design, the more promising principle can then be identified.

The chosen principle can then be upgraded considering the `design rules' that can be derived from the life cycle phases, applying *DfX* concept once again.

In order to consider also nowadays appreciable tendency to accomplish a more and more strict integration and interaction between product and communication in all phases of the life cycle, it is possible to consider the corresponding communication too, introducing, in analogy to the *DfX* concept, the `*Communication for X'* (*CfX*) concept.

4 Results

A very simple application of the above briefly described design procedure has been develop in order to illustrate the method. The aim of the simplicity of the chosen sample function (rotation of 90° of the line of action of a force) is to draw more attention to the method itself, even if it could not allow to highlight enough in detail all the problem that a designer has to face developing a new product.

As an example, the general above described schema was applied to a simple case, that is explained step by step in the present section.

1. *general function*: rotation of 90° of the line of action of a force.
2. *general principle*: as stated in the previous section, the general principle should be chosen among an archive of principles. Figure 2 shows a sample archives of principles; in particular it is worth noting that a multi-layer structure of these archives would allow to refine the design up to the desired detail level. In order to develop this example, the developed archive was integrated with the Creax web resources [5]. Considering the design requirements, the principle `mechanical with a square lever' has been chosen.
3. *schema and component functions*: after the choice of the general principle, it is possible to draw a schema of the mechanism and to highlight the component functions (Figure 3). The individuated component functions are:

   F1 = application of input force P1

   F2 = application of output force P2

   F3 = linkage to the frame

   F4 = connection between the part that accomplish the functions (physical continuity)

Figure 1 General schema of the design process

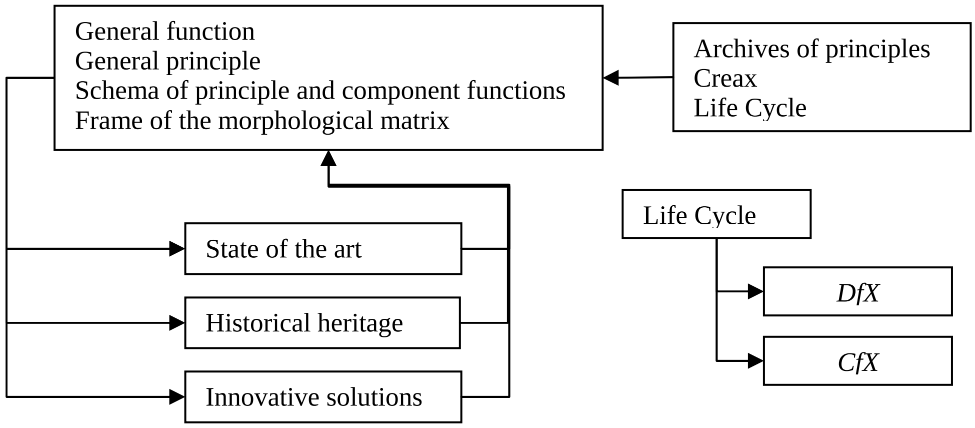


Figure 2 Archives of principles

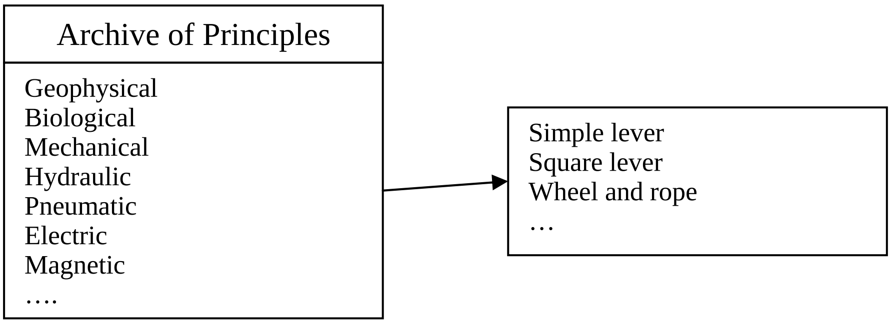


Figure 3 Schema of the mechanical principle with square lever

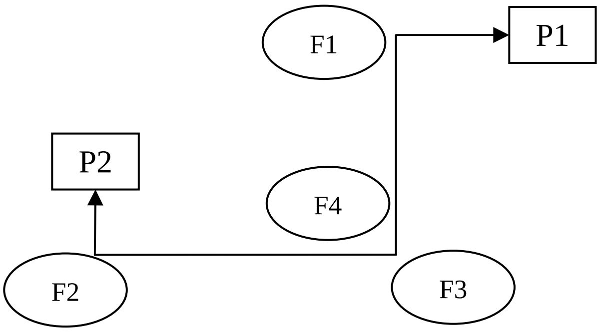
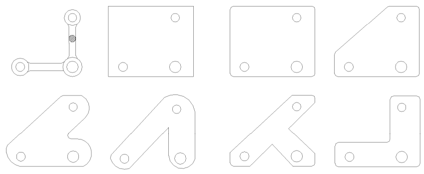


Figure 4 Frame and approach to the morphological matrix

F1	F2	F3	F4
Pin	Pin	Pin	
Hole	Hole	Hole	
Hinge	Hinge	Notch	
………	……….	……..	…………

4. *morphological matrix*:
   (a) *state of the art*: Figure 4 shows a sample morphological matrix with some principles of the component functions derived analyzing the state of the art.
   (b) *historical heritage*: no significant constructive examples was found. Actually, the considered case study is so simple that the state of the art can be dated back to an `historical era'.
   (c) *innovation*: The first way to introduce an innovation could rely on the investigation of using other possible physical phenomena, geometry, kinematics or force generation method. The TRIZ could help in finding out innovative principles. For example, the following principles could be proposed for functions F1 and F2: hydraulic or pneumatic connection (with pressure), hydraulic or pneumatic connection (with depression), magnetic connection, adhesive connection.
   An other way for the innovation is the use TRIZ to identify technical and physical contradiction. A physical contradiction happens when an element or a characteristic must be present (to fulfill some requirements) and also not present (for other requirements). In the considered case-study, the linkage pin (F3) must be present (to realize the rotation) but it would be better if it would be absent (to save space, so that the force line of action could actually rotate around the center of the pin). The innovation could then be based on one of the following principles: separation in space, separation in time, separation in structure.
   In our opinion the more promising solutions could come from an application of the third principle, substituting the pin with a flexural spring.
5. *congruent synthesis*: the points of the morphological matrix are filled with `all' the principles found for each component function. A congruent synthesis of the principles relative to the component functions allows to find general principles for the general function (Figures 5).

Figure 5 Sample solutions

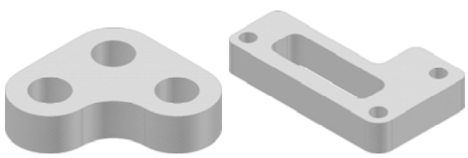
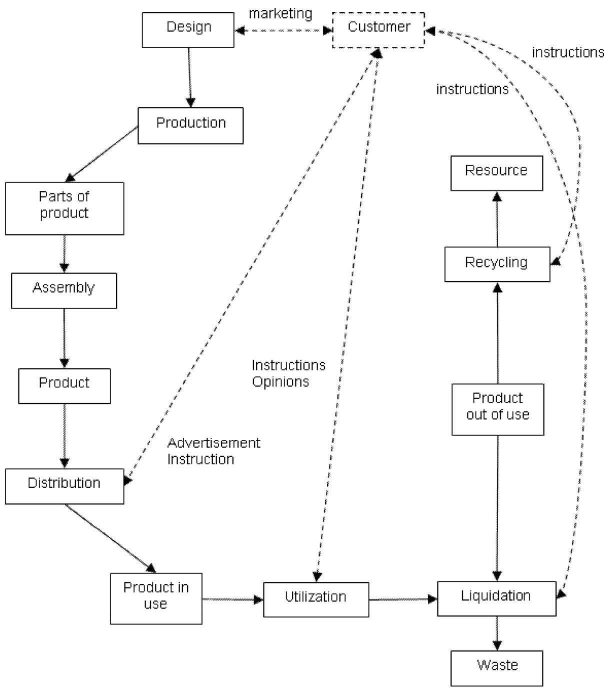


Figure 6 Life Cycle of a product



6. *choice of the `best' principle*: with respect to the specific design requirements, the best principle could be chosen considering principles' behavior in each phases of the life cycle of the product (Figure 6). The general phases can be analyzed to highlight the specific phases (Table 1). Refining the process of analysis for each specific phases, paying particular attention to the specific phases from the points of view of the fundamental requirements (as simplicity, efficiency, safety, sustainability and cost), it is possible to find out the aspects that characterize the behavior of the product in the life cycle. As an example, if we consider the specific phase `packaging' and the requirement `sustainability', the following aspects could be highlighted: no needs of packaging, limited packaging, package reusable as a package, package reusable as a product, package with low energy consumption, package reusable as material, package with elimination with low environmental impact.
7. *communication for X*: the strict connection between communication and product have not to be neglected. Therefore, in parallel to the *DfX* concept, it is useful to consider the `*Communication for X* (*CfX*)' concept, that means the realization of all types of communication necessary to the phase `*X*' of the product. In the specific case, the phase *X* could be one of the following:
   (a) assembly
   (b) installation
   (c) maintenance, i.e. periodic verifying and lubrication of the pin.

Figure 7 Examples of graphical communication

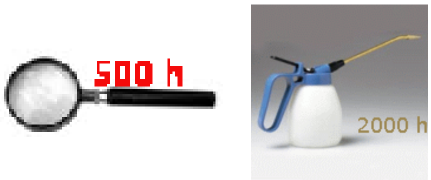


Table 1 Specific phases

General phase	Specific phase
Distribution	Packaging, Charging, Transportation , Discharging
Utilization	Behavior, Maintenance, Ergonomics, Safety, Reliability, Aesthetics
Liquidation	Reuse, Recycling, Elimination

The instruction for use and maintenance could be expressed in form of schematic drawings (or pictograms) instead in terms of texts. Figure 7 shows an example, that indicates that inspection is required every *500 h* and maintenance (lubrication) every *2000 h*.

5 Conclusions

The authors have applied systematically this procedure in the Design Education and, particularly, in the course `Design Methods'. During this course, small groups of students chose a function and, by applying the above described procedure, develop principles and constructive solutions to perform the chosen function. The first results (the course started in the Academic Year 2004/2005) seem to be encouraging: the students work with interest and enthusiasm and have developed many interesting and innovative solutions. It is worth noting that many students, during the same year, chose also to attend the course `History of Mechanical Engineering': this is an opportunity to analyze the integration between the two courses and how it is possible to find innovative solution also by means of critical analyses and revisions of historical solutions.

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Next generation PLM - an integrated approach to product development in the service industry

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Abstract: Consistent definition, categorization and operationalization of products delivered to global markets and customized for different buyer segments are some of the major challenges for the Product Lifecycle Management in the service industry. It can be argued that process supporting technologies/solutions e.g. WFMS exist nowadays for the creation of a seamless environment for accessing, altering and reasoning about product information that is being produced in fragmented and distributed environment. A holistic approach that is suitable for aligning the PLM business requirements to the potentials of new technology driven concepts in the information management such as SOA is nevertheless still missing. The authors give reasons why the holistic view on the Product Lifecycle Management as well as the link between an inter-company wide information management is critical for an efficient PLM and present an integrated approach taking these aspects into account. In this paper four building blocks of Next Generation PLM in the service industry are introduced. The paper closes with the presentation of a short case study.

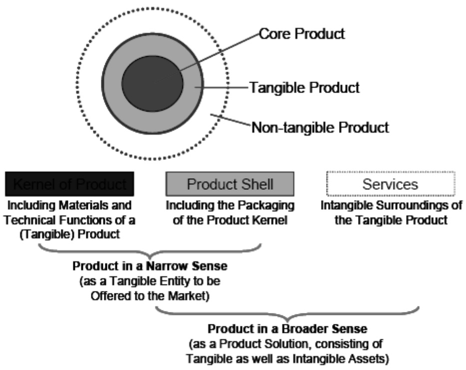
1 Motivation

As Shark (2004) postulates, Product Lifecycle Management (PLM) is the activity of managing a company's products across the complete lifecycle, from the early stages of conception to the final disposal or recycling of a product. From this definition, a strong interrelation between the value creation process and the PLM of the company can be deduced. Taking the current globally changing business environment into account the PLM can be considered as a strategic weapon for enabling the company to provide an additional value to customers and thereby gain a competitive advantage over their competitors. Especially in the telecommunication industry, which experienced a significant change in its environment during the last five years, PLM is considered to be essential for facing ever shorter innovation cycles (Wöhler-Moorhoff et al., 2004). In the following two sections, we introduce the main business drivers, which currently have the most impact on a company's business model and are expected to do so in future. For each business driver specific PLM-relevant challenges can be derived. These challenges will be pointed out in detail in the last section of this chapter and will serve as motivation for our integrated PLM-approach in chapter 2. The validation of this approach is the goal of chapter 3 by introducing a case study.

1.1 Business Drivers

The dichotomy between tangible goods and immaterial services is subject to change according to Saaksvuori (2004). In the service industry as well as in the traditional industries like manufacturing this development towards a hybrid or extended product can be observed. (Figure 1) Following the argumentation of Mateika (2005) a critical success factor in the manufacturing industry is the ability to provide more profitable services in addition to the tangible good. But this combination of tangible and intangible attributes in terms of the extended product increases the complexity in managing the Product Lifecycle (Saaksvuori, 2004). Especially in the service sector (eg. telecommunication) products typically consist of several modules that in sum create the customer benefit (e.g. Multi-Play products). Each module embodies its own lifecycle, which implies an additional product complexity in terms of module design, module management and module removal from the product.

Figure 1 Extended Product according to Thoben et al., 2001



Global and deregulated markets result in global competition that every company is confronted with. For the service industries this results into the shift from the suppliers' market to a buyers' market, where the customer is the focal point. Because by their very nature services are easy to copy, companies in the service industry actually face more pressure to innovate and develop new products than manufacturers. This business driver forces companies to follow either a cost-leadership strategy or a differentiation strategy on a global scale according to Porter (1985). In order to perform in the cost-leadership role, companies have to implement efficient processes regarding the development of complex products and to handle the order management process. Simultaneously companies have to cooperate with numerous business partners, which results in a high effort for coordination. A product/service differentiation strategy implies processes that ensure short time-to-market on one hand and an effective degree of freedom in the process definition for staying innovative on the other hand.

Increasing regulations such as safety, environmental and product reliability will influence company's PLM-process. Especially the resulting effort for ensuring traceability will have an impact. Traceability has two dimensions in the PLM-context. First of all it is related to the PLM process itself. Effective measures have to be in place in order to ensure the flow of transactions to identify where material misstatements due to error or fraud could occur (Sarbanes Oxley Act). Further, traceability in the order-delivery process is about tracking of an individual product units or even components. Legal frameworks like TREAD Act for the automotive industry in the USA or REACH for the chemical industry in EU can be subsumed under this dimension. Companies that need to respond to this kind of regulation must ensure that the implementation and the integration in the existing processes happen to be simple and at the least possible lifecycle costs.

1.2 Challenges

Based on the outlined business drivers, challenges for companies can be derived on the strategy, process and IT layer. An overview of these challenges is given in the following table.

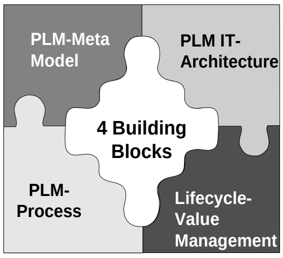
Table 1 PLM-relevant challenges

	Strategy Impact	**Impact on Processes**	**Impact on IT**
Business Driver 1: *Managementof Extended Product*	Less vertical integration, more horizontal integration of the value chain Focusing on product modularization and utilisation of product and service platforms to enable the re-use of components	Collaborative PLM-process with defined interfaces Process readiness for the management of complex products and services	Data exchange standards IT-representation of complex products Appropriate fulfilment of the information need
Business Driver 2: *Globali-zation*	Commitment to either a product individualisation or product standardisation strategy Focus on innovations	Improvement in the process automatisation Inter-company wide process standards	Enterprise Application Integration with external business partner Support of the process execution by providing appropriate IT-functionality
Business Driver 3: *Legal Frame-works*	Comply to regulations e.g. Sarbanes Oxley Act, TREAD Act	Support for traceability of products by standardised and well documented processes Support for traceability of processes	Management of product related information during the whole lifecycle

2 Integrated PLM- Approach

The integrated PLM- Approach consists of four components depicted in figure 2. In the following paragraphs the different components are described further.

Figure 2 Four components constituting the integrated PLM-approach



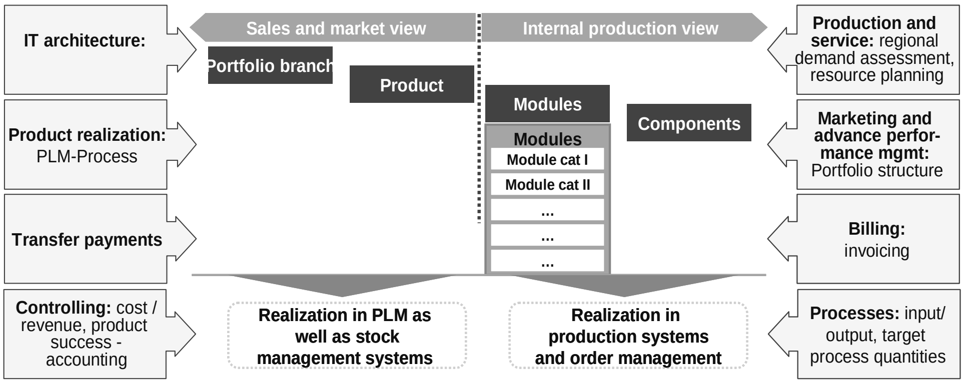
2.1 PLM Meta-Model

Many present quality deficiencies in the product development (esp. in the service industry) originate from a diffuse definition of products as well as from the inconsistent view on the object “product“. The studies show that 80% of the total cost structure over a product’s lifecycle is pre-determined during the concept and design phase. Especially in the service industry, the product (or service) should be clearly and precisely defined to be developed, commercialized and to be understood from the customer.

The product as the main subject of the process needs to be defined and this definition of product should be taken from the customers´ perspective. A product is an entity the customer perceives in its entirety and is characterized by being offered to a market place. Only with such definition of their products the service companies can stay ahead of their competitors and make their product and services clearly identifiable to consumers. From internal point of view, there should be a constant product definition with the overall product lifecycle and for all business process. The product of the service company, in the eyes of end-users, is becoming an unified “experience” that is based on the delivery of multi-dimensional packages (such as in the telco industry: voice, video, and data as an integrated package across mobile and fixed infrastructure which, deconstructed reveals multiple layers of hardware, software applications, and services). The precise definitions of the complete product range and their categorization still remain a problem especially in the service industry (eg. Telecommunication, energy, financial services industry etc.). For example, in the telecommunication industry essentially four categories of products can be differentiated: market product (service), standard solution, customized (individual solution) and bundle. All offered products and services can be assigned to one of the mentioned categories. Product definition is not simply a reflection of the engineering design. It also includes the entire set of information that defines how the product is designed, manufactured, operated and managed on the market and finally withdrawed from the market. This product definition is continually updated throughout the entire lifecycle from idea generation until withdrawal from the market and it is the same for all business processes. This view allows considering the product as a core information object (CIO).

Product definition should be furthermore detailed by the company-wide specific PLM Meta-Model to decrease complexity costs in the service industry. Such Meta-Model defines the product (service) on an even more detailed level for the optimization of time to market and decreasing of resembling components. PLM Meta-Model is the basis for standardization and modularization of products (services). Modular product data structure as core element of PLM Meta-Model ensures linking the sales perspective to the internal (production) perspective in relation to the offered products and services. The main aim of introducing a modular product structure is the optimization of the product development in the service company. The unique PLM Meta-Model and the corresponding processes should be implemented by considering the existing processes, company structures, and cultures. Requirements from the affected functional areas flow into the definition of the product data structure (see fig.3). One master product data management fits all needs of the main processes and its interfaces.

Figure 3 Definition and requirements on product data structure



Using PLM Meta-Model leads to simplification and cost optimisation of “product and service engineering” through the re-use of the production and service modules, shorten “time-to-market”, avoiding overlaps in development and reduce technical variance, availability of the product modules range of all service lines (factories) for all division of the service company.

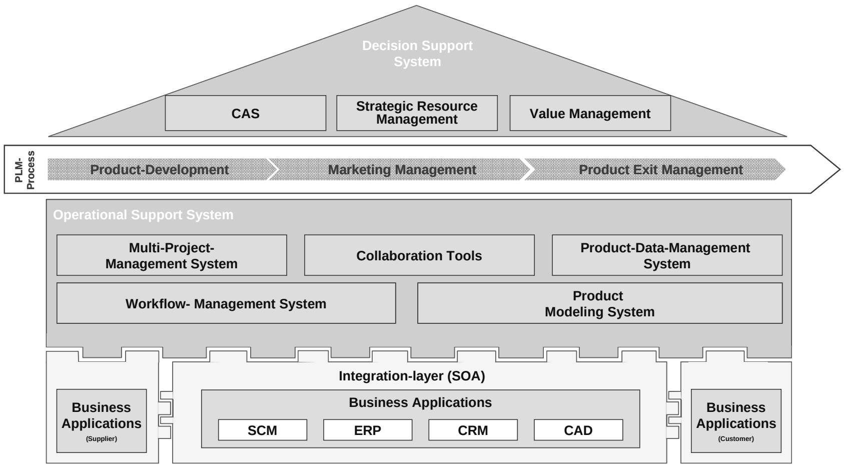
2.2 PLM IT-Architecture

The foundation for moving a product through its complete lifecycle beginning with the product idea and ending with the product removal from the market is a solid PLM IT-Architecture, that is customized for the company-specific PLM- requirements. In our perspective, such a PLM IT- Architecture must support the PLM- process in the dimensions: (1) Decision support, (2) Operational support and (3) integration of supplemental business applications. A standardized off-the-shelf PLM-System is therefore not the tool of choice as Ausura and Deck (2007) point out. Instead we suggest to rely on a PLM IT- Architecture that re-uses, respectively customizes existing IT-components as far as possible. In the next paragraphs a description of the essential IT-components is given that build up the PLM IT- Architecture.

The main purpose of a decision Support System (DSS) is to gather and consolidate data from operative systems in order to provide the senior management with aggregated information regarding the product lifecycle. The Computer Aided Selling (CAS) module provides functionality for the product configuration[1] and product pricing. The component Strategic Resource Management focuses on the long-term resource capacity planning on a strategic level. Product portfolio management aspects are covered with the last Value Management component.

On the operational level the PLM- process execution is supported by the Operational Support System (OSS). The Workflow Management Systems (WFMS) enables a higher degree of process automatisation. Especially in the context of distributing and releasing unstructured content like a product specification in cross-functional teams, the WFMS plays an essential role through a strong link to the Product Data Management System (PDM). The Product Modeling System and the PDM are closely coupled. The former defines the product structure, in which types of modules the product is decomposed into[2]. In the database context this functionality is similar to the schema definition. The PDM-systems stores all product relevant data according to this definition and provides different views for each stakeholder e.g. marketing and engineering. The Multi-Project Management System as well as the Collaboration Tools are instruments for managing the product in different phases in a collaborative environment.

Figure 4 PLM IT- Architecture building the IT-foundation of the PLM -approach



A PLM IT- Architecture is supposed to hold the promise of seamlessly integrating and presenting all information produced throughout all phases of a product's life cycle to everyone in an organization, along with external business partners. For ensuring this functionality, an EAI-approach has to be implemented. According to recent research activities a Service Oriented Architecture (SOA) is most suitable to integrate the business applications from external partner e.g. suppliers as well as integrating the own business

[1] The CAS module is also essential in the operative context for the order management. In our understanding CAS goes beyond the operative support and helps to steer the variant management in order to cope with the increasing product complexity nowadays.

[2] .For example hierarchies of assembly groups can be defined. Additionally constraints and rules can be modeled constricting the combination of specific modules.

applications like ERP, CRM etc. in order to fulfil the promise of seamless integration for becoming a real-time enterprise (Abramovici, 2002).

2.3 PLM-Process

Companies in the service industry should take a disciplined, analytical approach to developing new products (services), relying on targeted customer input just as companies outside the service sector do. The main design goals of this approach is to facilitate the execution of this collaborative process (efficiency goal) and equally important to align the activities with the strategic goals of the company (effectiveness goal).

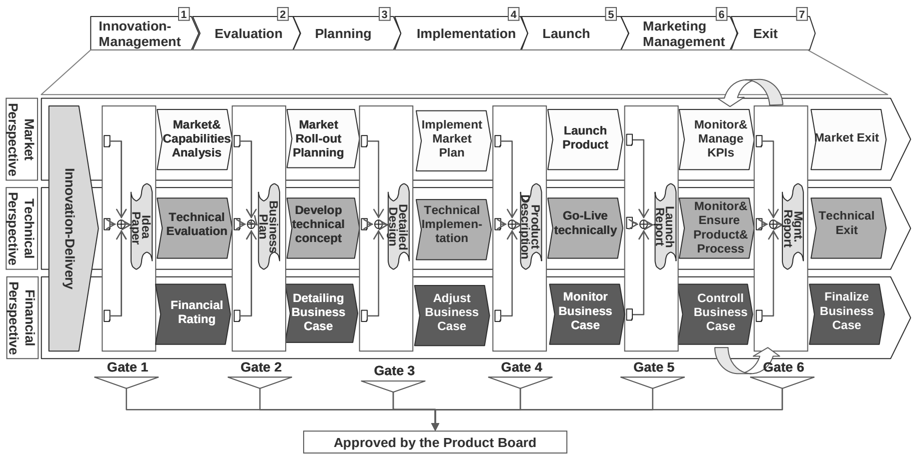
Our PLM-Process approach is based on three principles: Stage Gate Approach, Multi-Perspective, Metrics based Management. These principles are subject for further explanation in the following paragraphs.

Principle One: Stage-Gate Approach. The Stage-Gate Approach is both a conceptual and an operational model for the development, marketing and removal of a product during its life cycle. The PLM- Process consists of seven stages. This structure is oriented on the life cycle of the product and has been validated in several projects by Detecon Inc. primarily in the Telco-Industry. Every stage consists of a distinct number of activities (organized in perspectives, refer to the next section), which have to be accomplished by specific process stakeholders at the given phase. The entrance to each stage is a gate; these gates control the process much like quality control checkpoints. Each gate is characterized by a set of deliverables as input, a set of exit criteria and an output. Gates are manned by senior managers that form the so-called Product Board. The Product Board acts as a gate-keeper that evaluates the results from one stage by a given set of criteria. Based on this evaluation, the product board can either decide whether the product idea proceeds to the next stage, re-starts at the previous stage or is archived.

Principle Two: Multi- Perspective. Product Lifecycle Management has always to cope with the conflict of objectives between the product marketing and the technical side. Several case studies have documented that this conflict often results in product failure in the market. Either because the product specification is too much technical driven and therefore far from the market demand or the product marketing has defined product specifications without collaborating with the technical department about technical feasibility beforehand. For solving that conflict of objectives three perspectives on the process have to be taken into account in order to ensure an efficient coordination and collaboration of the relevant departments or business partners. In the market perspective all activities are assigned to that relate to the product marketing. Referring to the service industry, typical tasks like the definition of product specifications and the management of the product on the market-place belong into this category. By contrast the technical perspective subsumes all technical or production- oriented activities. Additionally the financial implications of moving the product through the life cycle are grouped in the financial perspective.

Principle Three: Metrics based Management. In addition to the process definition the organisational component must not be neglected. Since products, and consequently the PLM-process, become more complex and involves internal as well as external partners along the value chain, there is a greater need to balance top- management control with the empowerment of self-managed, cross functional teams. As a prerequisite for achieving this balance, the company has to implement a metrics-based management approach in which teams are measured on strategic performance indicators such as development cost, time to market and customer satisfaction. The definition and selection of the indicators is critical for the successful implementation of the PLM-concept. By setting the weights properly the teams will self-steer to the greatest short- and long-term profit, which results in less coordination effort and efficiency gains especially in the context of for cross-departmental teams.

Figure 5 PLM-Process based on three principles



2.4 Lifecycle Value Management

Life cycle oriented product planning is a necessity for companies on the competitive market and requires a robust and systematic process combined with the right organizational environment. Enterprises use Lifecycle Value Management to support the management of the product after launch through the growth, maturity, and decline stages of the product life cycle. In the overall value chain, Lifecycle Value Management ensures that the products and services which are developed and implemented fulfill the market requirements and reflect the market demand. Lifecycle Value Management requires permanent attendance for analysing and planning for ensuring the customer benefits and the alignment to all company functions. There are three different but supplementary building blocks of Lifecycle Value Management.

Value oriented portfolio management (incl. IT-supported portfolio database. Increased complexity of product marketing in the service company without an appropriate and efficient data foundation results in a lack of business transparency and low synergies in the value network. The modular structure of the portfolio promotes the use of common parts in the production processes, increasing the ratio mass production to overall production. Strategic alignment and value based product portfolio management enable an effective product lifecycle management. Focusing on clearly defined products makes a significant contribution to effective portfolio management. The products can be positioned without overlaps and in accordance with market demand. Value oriented portfolio management helps to prioritize product investments. Sales and marketing departments benefit from the increased transparency of the product range and the improved comprehensibility for the customers.

Customer Needs Management. Customer Needs Management incl. Requirement Management builds interface between PLM and Customer Relationship Management (CRM) and gives input for the collaborative product design. The effective Customer Need Management ensures that product content matches customer requirements and allows delivering more personalized products by facilitating mass customization.

Reporting and controlling process regarding the product lifecycle management process. The referencing of different divisions (sales, resources and production planning; cost/profit accounting, etc.) to a standard product definition lays the foundation for the application of important controlling instruments (e.g. product success accounting). The unambiguous correlation of the basic data to business management indicators along the lines of a standard product structure provides staff and management with precise and timely information about all of the critical success factors that help staff and management to make the right decisions at the right time.

Implementation of these three building blocks combined with a modular product data structure ensures the "state-of-the art" Lifecycle Value Management:

- Individual product performance information available at real-time.
- Product Manager retains product accountability throughout life cycle.
- Strategy for product growth, maturity, and withdrawal stages is defined up front.
- Product and service replacement strategy also considered.
- Systematic (e.g. annual) review and clean-up/optimization of product portfolio.

3 Case Study

A renowned company in the telecommunications industry carried out an extensive restructuring program which would enable it to maintain its position in a deregulated market environment. The objective was on the one hand to convert the previously technical driven approach for the product design (i.e., their orientation towards technical performance features) to an approach focusing on the customers' needs and requirements. On the other hand, the aim was to develop and implement the integrated management approach, Next Generation PLM. In the initial situation the PLM and the platform was not "state-of-the-art" (eg. no withdrawal phase, missing of decisi-on gates, long "time-to-market" etc). A portfolio management process was not designed and implemented. The current portfolio structure was oriented on the organizational or technical structure and not organized from the customer's point of view. The product portfolio was characterized by a large number of product variants and features. All these products needed to be handled individually from an IT management perspective. This broad variety of products needed to be realized and implemented within all operative processes, IT-applications and –systems as well as sales information tools. This led to an enormous complexity that impedes the maintenance of IT-landscape and the management and optimization of the processes. No integrated IT-solutions were available at company and at its affiliates. During the project the integrated PLM approach valid for the company and its affiliates was developed. Implementation of Next Generation PLM at this company showed the valuable benefits for solid product development, marketing and strategy:

PLM Meta-Model:

- Easier know how exchange and using of the "same language" during product development as well as fast and efficient communication between international partner

- Introduction of the harmonized product definition and product portfolio for all national and international affiliate companies
- The product portfolios across all of the company were to be reduced by 50% and integrated into a modular structure.
- Adoption of the product data platform at all international subsidiaries

PLM Process and Structures

- Acceleration time-to-market up to 25% by several product groups
- Efficient cost savings along the PLM process by using standard support system and re-using of modules and components (process costs saving up to 170 m USD/year in the product realization phase)
- Effective and similar procedure of innovation and market management projects execution

PLM IT-Architecture

- An implemented shared platform for document and project management.
- One physical server is used to support separate product lifecycle management processes in all divisions and subsidiaries

Lifecycle Value Management

- Sound marketing strategy due to the early recognition of market needs and standardized information
- More detailed input for controlling for exactly allocation of revenue and costs to products
- Simpler allocation at cost centres and cost unit
- Introduction of the harmonized product portfolio for all national and international affiliate companies

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Chapter 9

Middle and end of life issues

An investigation into the early and retirement life-cycle stages: tools, requirements

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Abstract: This publication discusses the integration of the conceptual design and the end-of-life stages in the management of a product. This is done by pointing out the influences of the end-of-life of a product on the cost of a product and investigating links between these two stages. Then, both stages and their interrelations are examined for possible needs in terms of their management. This knowledge is then used to evaluate the status quo of product life-cycle management. In particular, the gap between the "as-is" and "should be" functionality of PLM solutions with respect to these two stages is examined for two most popular PLM solutions.

Keyword: conceptual design, end-of-life, PLM, product life-cycle management

1 Introduction

Product life-cycle management (PLM) - as considered in this publication - is a holistic approach concerned with product data, the associated business processes governing it, as well as people involved in the various stages of the life of the product as defined in [1]. PLM by this definition can be looked upon as being the sum of three aspects:

Product data, which comprises all data related to the product: CAD/CAM models, bills of material, and so on, including documents such as governmental regulations and costumer feed back.

Extended enterprise consists of strategic partners of a company and other product stake holders (for example, materials suppliers, sub-contractors, and customers). Thus, the extended enterprise possibly includes multi-national companies and may extend beyond geographical and company boundaries.

People, processes, information and business systems comprises everybody and everything that is part of the workflow. Processes include program and project management processes as well as processes required to manufacture the product or plant, the processes to distribute, operate, dispose, or decommission the product at the end of its useful life. Business systems encompass, among others, CRM, SCM, and ERP systems. Although alternative definitions of PLM exist, the authors feel that this definition is closest to their understanding of PLM and because it is independent of any organisation (in particular their strategic interest) or PLM implementation.

1.1 Motivation

The primary reason for the industry using PLM systems is the need for improving the management of PLM in order to provide sustainable products at lowest cost and to capture the market the soonest possible due to an improved management of the three aspects of PLM [2]. The improvement in communication within a company and the extended enterprise is perhaps the most important single benefit from a functional product lifecycle management system [3]. Currently, PLM solutions and their actual implementation in companies are most prevalent for the detailed design and manufacturing stages, but are rather scarce if not absent in other stages. It can be expected that if PLM is extended to other stages in a product's life-cycle, a company's competitiveness can be further improved. This publication therefore focuses on the needs of other life-cycle stages, in particular on the conceptual design and product end-of-life for reasons further discussed in the following. The conceptual design stage is rather crucial in determining the overall direction of the product development process [4, 5]. A good product concept can reduce the number of design iterations and therefore benefit the timeliness of the product launch. When a new product is launched, the first two companies control about 80% of market share within that particular product category [6]. Furthermore, compared with the later stages of product development, product conceptualization commits more than 70% of total cost incurred during the entire product life cycle. In other words, even the highest quality of manufacturing and production cannot compensate for a poor design concept released from the product conceptualization stage. Decisions made at the conceptual design stage have significant influence on factors such as costs, performance, reliability, safety and environmental impact of a product [7]. It is estimated that around 60% of the resources needed to manufacture a product are committed once the conceptual design is completed [8]. As the conceptual design itself accounts for a relatively small percentage of the total development cost, investing in this stage has pivotal effects with respect to product costs [9]. At the same time, the influence of a product's end-of-life on (conceptual) design becomes stronger for several reasons:

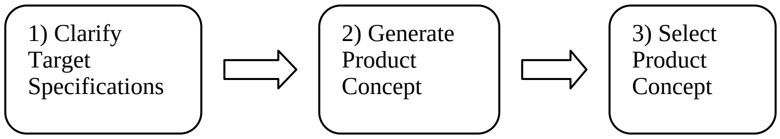
- The consumer is the dominant stake holder in the end-of-life of a product and has growing demands in terms of ecological impact, customisability, functionality, energy consumption, and so on.
- Ecological constraints on products become stricter: standards and regulations constrain the use of materials and the way they are disposed or recycled, enforce systematic collection of products for recycling, or disallow the use of certain substances [10, 11].

This strengthening of influences of constraints originating from a product's end-of-life on design implies that one should not be considered without the other. It is not inconceivable that in the near future a design will only be successful if it complies with constraints imposed by its end-of-life. In consequence of this observation and to better understand how today's PLM solutions support these two life-cycle stages in terms of data, processes and benefits to stakeholders, this paper discusses the characteristics of these two stages, it tries to identify the needs of these two stages, and it examines dominant PLM solutions – those offered by UGS and Autodesk – with respect to their proposed management of the two stages in question. It is *not* the intention of the authors to compare the solutions on the basis of their efficiency, usability, and so on.

2 Conceptual design

During this stage, the company's strategic partners and customers align their needs and requirements. Then, the company's product designers develop a design concept, which is subsequently developed in the embodiment design stage. Although many highly detailed methodologies for the conceptual design exist (see for example [12-15]), this paper is based on the simplified model presented in figure 1, which captures the essence of all these more elaborate models while highlighting the essential activities.

Figure 1 Essential steps of the conceptual design stage



Clarify target specifications: the engineering design specification embodies information on customer and company requirements, which fall into three groups:

- Functional performance: motion/kinematics, forces/torque, energy conversion/usage, control.
- Operating environment: air temperature, pressure, humidity, contaminants, shock, and vibration.
- Product factors safety: economic, geometric limitation, maintenance, repair, retirement, reliability, robustness, pollution, human factors, and appearance.

The customer requirements and the preliminary product specifications are inputs to this stage, although often this information is still refined after the concept generation is initiated. The three main outcomes are: (i) an activity analysis list, (ii) a function decomposition diagram, (iii) a technical specification list, (iv) a product modular decomposition diagram.

Generate product concepts: the design team determines the approximate description of the technology, the working principles, the form of the product, as well as many ideas and concepts as possible so to ensure that the design space is thoroughly explored [9]. A concept is usually expressed as a set of sketches or rough three-dimensional models accompanied by brief textual descriptions. Designers critically examine its feasibility and possibilities for further improvement. Idea generation requires creativity and imagination as well as logic and reasoning to analyze and ascertain the feasibility of the concepts and ideas. Though the proficiency of designing and idea generation may seem to depend highly on individual skill and expertise, the process can also be improved through the use of rational and systematic design methods. There are many steps in the concept generation stage and they serve different functions. The steps and tools used are summarized in table 1.

Table 1 Steps in concept generation

Step		Tools
Search Externally	Aimed at finding existing solutions to satisfy the specifications identified in the previous stage. The external search is essentially an information gathering process.	1. Interviews 2. Consult experts 3. Search patents 4. Search published literature 5. Benchmarking

Search Internally	Internal search uses personal and team knowledge and creativity to generate solution concepts.	1.Individual discussion 2.Group discussion 3.Review of relevant past cases
Explore	A systematic exploration alternative solutions results in a synthesis of solutions fragments.	1. Classification tree 2. Morphological chart 3. Concept combination table

2.1 Current practices of conceptual design

Each team member usually maintains a project notebook containing information such as product ideas and sketches that may be used for patent disclosures as well as trademark and/or copyright registrations [16, 17]. The team establishes a central repository. Sketching is preferred as compared to CAD as they can quickly communicate form and function. Design review meeting minutes are maintained to record the team's findings as well as its reasoning. Subsequent design teams may tighten the design process arising from the minutes to avoid past mistakes [18]. During activities related to the concept design stage, a host of information and documents is produced and processed:

Photocopies of archival matter	Printouts from the internet
Vendor catalogues and data sheets	Preliminary test results
Approximate calculations	Patent abstracts
Minutes of meetings	Concept sketches
Concept screening sheets	Concept evaluation matrices
Expert interview notes	Standards, laws, etc.

2.2 The needs of the concept design

In the past, concept design activities relied on documents written on paper distributed and passed on according to a business process defined by a company. An absence or presence of a document triggered an action. In a digital environment, digital documents replace paper documents, yet the same or similar business processes are adopted.

To improve the product development process, new products are created by combining or modifying existing designs [19]. It is well-known that the reuse of existing design information is much more cost effective and time saving as compared to designing a product from scratch [20]. Thus, the ease of retrieving this data, determines to a considerable extent the efficiency of the design process. A globalisation of design, marketing, manufacturing and support is a major factor for companies to remain competitive [2]. Consequently, there is a need for the concept design team to communicate efficiently over large distances. Product conceptualization must also take into account the marketing perspective [21]. Based on this understanding, an integration of the three perspectives, namely functional, commercial and marketing, becomes imperative in product conceptualization. Criteria based on these factors can help the designer to select the best concept more comprehensively and appropriately. Overall, the conceptual as well as other design stages hinge very much on an efficient collaboration and communication, possibly over large distances. This suggests the use of a virtual PLM room in which the team can work and exchange information. In this room, visualization tools and access to the same data as used in a conventional design process are very important. Table 2 shows some of the activities that the authors feel a virtual PLM room should accommodate.

Table 2 Design activities and tools

Activities	Tools/methods
Search	Data vault (past designs and related information) Design pattern recognition and analysis Online catalogue Web-browser
Write	Word processor
Sketch and Design	Sketching tools, CAD Recalled existing design patterns and modules with modification tools
Analyze	Spreadsheets Flow charts Quality function deployment (QFD) tables Engineering design specification tools
Discussion, Decision making, and review	Voice and video recording and playback Minutes Digital whiteboard Vote scoring matrices Progress charts Presentation tools

3 Product end-of-life

Most considerations made with respect to a product's end-of-life concern directly or indirectly its environmental impact. However, companies do not directly judge the environmental impact of a design, including those from manufacturing, use and retirement, but base their judgment on governmental or international regulations or directives, industrial standards, and possibly recommendations from various sources or self-imposed rules (in the following, these documents are referred to as regulations). These considerations fall into two groups:

- The first group is most relevant to the conceptual or detailed design stage. Considerations in this group are implemented as a compliance of the product to regulations.
- The second group of considerations is related to use and retirement of the product (for example: detailed product information or contacts of re-manufacturers).

Some of the information pertinent to a product can not be completely managed by a system installed in a company or in a group of companies, as an explicit (contractual) agreement or an explicit communication channel between their respective PLM systems is inconceivable. Examples for such situations are:

- The unavailability of a (comprehensive) PLM system due to technological or economical constraints.
- An end-user can not be expected to own or even access such a system (including, say, an online WWW interface to a PLM system).

- Numerous companies are potential partners for the collection, transport, repair, maintenance, recycling, treatment (including hazardous materials), or disposal of products. However, their number prevents the manufacturer from establishing individual agreements on end-of-life management all of them.

3.1 Current practices of end-of-life management

It is worth noting that a considerable amount of PLM is implicit in what may be called "best practices". For example, the industry standardizes materials, parts, labels, and so on, which considerably reduces the need for the exchange of product specifications and requirements. In other words, the bodies issuing industrial standards implicitly manage the life-cycle of a product or ease issues related to their management.

Designers and manufacturers check relevant regulations as comprehensively as possible and integrate them into product design and manufacturing processes, and so on. This practice excludes

- the compliance of manufacturing processes and related business activities,
- the generation of related reports or manuals and their distribution to concerned stakeholders, and
- the management of new or changes to existing regulations.

Stakeholders most concerned with these documents (though the relevance of these documents depends on the individual stakeholder) are designers (conceptual and detail), end-users, regulating bodies, as well as companies taking care of collection, remanufacturing, disposal, recycling, and so on of used products. The large number of stakeholders and types of documents implies that a workflow or a peer-to-peer communication is impossible and some sort of mass-communication is more suitable (WWW pages, mass-emailing, and similar). With respect to remanufacturing and recycling, the manufacturer has to provide fairly detailed specifications of the product (or even give instructions for remanufacturing or recycling procedures). On the other hand, information on the ease of remanufacturing or recycling a certain product (possibly with suggestions for changes to the product) can help to improve the products and increase the competitiveness of the product. As re-manufacturers, recyclers, and end-users are not necessarily in close contact (bound by an explicit contract or agreement), their integration in a PLM process requires communication channels that are accessible to everybody. Similar arguments apply to repair and maintenance of consumer products and low-cost products. The disposal of the product is rather different in this aspect: direct communication between the manufacturer, the end-user, and the company disposing of the product is likely not necessary.

3.2 The needs of end-of-life

With respect to the compliance of a product, its production, and its end-of-life treatment with regulations, a PLM system should provide tools to support the activities related to supervising its compliance. This tool is likely data driven (that is a process checking a product's compliance is triggered by a change to regulations or product data) and knowledge based (the regulations will have to be "translated" into a knowledge base which checks the compliance). Effective communication between the designer or manufacturer and many end-of-life stakeholders is difficult to achieve within a dedicated

PLM system. Therefore, a PLM system must support alternative information channels. These information channels could be:

- WWW pages with product information for end-users, recyclers, and so on.
- An electronic mail system alerting end-of-life stakeholders of product changes or other urgent issues.
- An integration of an analysis of costumer feedback obtained through email or a feedback WWW page.
- An online forum where companies announce their capabilities to handle a certain product.

Consequently, a PLM system should support these or interface with them.

4 Conceptual design and end-of-life

The link between conceptual design and end-of-life originates mostly from considerations of environmental aspects. Designers are required to reduce and avoid pollution caused by a product over the whole life-cycle. Some of these activities include choosing the materials for construction and auxiliary purposes, production processes and the disposal of waste materials. Table 1 summarizes important environmental factors a design team should consider.

Table 3 Environmental factors linked concept design

Material and part selection	The material or by-products of an (improper) disposal may pollute the environment or change the cost of product retirement.
Mechanical equipments and processes	Thermal pollution occurs when the ambient temperature increases at the work area. Apart from contributing waste energy, this effect causes discomfort and health problems. Noise pollution due to emission of sound from operating equipment or processes. Vibration of machines weakens structures and might result in failures and can be harmful for humans. Pollution by by-products of the manufacturing process.
Energy	Some of the energy used in machines can be recovered and reused (e.g. heat from combustion or air conditioning) or energy losses reduced (e.g. those from friction in bearings).

It is worth noting that the factors in table 1 often pertain to regulations. This means they are not handled differently compared to those concerned with safety issues or industrial standards. End-of-life management requires (in particular remanufacturing, recycling, and disposal) information on the product that are not necessarily contained in a design. In conclusion, the conceptual design stage raises the following challenges with respect to PLM:

- PLM has to establish links between multidisciplinary knowledge sources, possibly overlapping or conflicting with one another. This includes in particular parallel and periodically coordinated work by specialists with different backgrounds at geographically distant locations.
- This stage requires a systematic selection process of the best concepts based on factors like functionality and marketability, as well as the end-of-life.
- The reuse of design information in both semantics and implementation levels.
- An understanding and thorough documentation of customer needs, with an emphasis on end-of-life requirements, and linking them to technical specifications.

5 PLM solutions for conceptual design and end-of-life

5.1 Conceptual design

Autodesk [22] Alias Studio[1] and NX[2] by UGS [23] provide both industrial design and styling tools to support the concept design stage. Both solutions allow designers to sketch 2D or 3D models in a digital environment in various ways. Both systems claim to improve communications within the development team (attributed by the respective solution providers to the graphical representation of design concepts and the ease of creating them). Neither of the solutions integrates business processes or the extended enterprise applications as a PLM systems should.

Alias Studio entirely delegates PLM-related functionality other than rudimentary product data management to other solutions, *e.g.* Autodesk Data Management. Compared to this, NX provides similar functionalities as Alias Studio but implicitly integrates some PLM functionality as it includes CAD, CAM, and other modules. Whether this difference is significant is open to debate: Autodesk offers other solutions, which in sum provide similar functionality. NX requires an additional PLM solution - Teamcenter or UGS Velocity - in order to cover the three aspects of PLM mentioned in the introduction. UGS's solution provides the following functionality relevant to conceptual design and end-of-life:

- Teamcenter Community, which can be configured to define a workflow and therefore communication channels with the extended enterprise (which seems to exclude the end-users and companies with no explicit alliance with the manufacturing company).
- Environmental and regulatory compliance management to address overall compliance objectives while enabling producers to comply with specific directives, as well manage and report on environmental compliance and material content [10, 11].

Both solutions support most of the identified needs of the conceptual design stage, but neglect the integration of functional, commercial and marketing concerns during product concept development beyond a simple inclusion of the respective stakeholders into the workflow. Neither tool provides an integration of something close to the suggested virtual PLM room.

5.2 End-of-life and links to conceptual design

Neither Autodesk nor UGS provide explicit end-of-life management modules concerned with regulation compliance. Little support is given to the communication with end-of-life stakeholders without a close relation to the company. For example, if a redefinition of the workflow (integrating end-of-life stakeholders in the business processes at the end-of-life of a product or into designing a product for end-of-life) in the respective PLM solution (Teamcenter community and Autodesk Data Management) is acceptable, the integration of a re-manufacturer is possible. Information concerned with the end-of-life of a product is not explicitly handled during conceptual or detailed design in either solution; at least,

[1] Autodesk Alias Studio, Autodesk Streamline, Autodesk Data Management are trademarks by Autodesk Inc.
[2] NX, Teamcenter, UGS Velocity, Teamcenter Community, NX Check-Mate, and NX Quick Check are trademarks by UGS Corp.

no explicit access to it is given. It is not clear whether the Teamcenter compliance solution can be used for purposes other than evaluating a product's design with respect to a given set of regulations; in particular, whether it could be used to ensure that a certain recycling or disposal process is adopted. Furthermore, UGS offers two modules called NX Check-Mate and NX Quick Check; both modules are in principle capable of supporting a design analysis with respect to arbitrary criteria. This could be used for an evaluation of end-of-life processes, yet an appropriate knowledgebase is not provided. Another issue concerns the communication channels offered by the PLM systems. Particular to the end-of-life are two types of communication:

- Communication between close (commercial) partners (typically two companies with an explicit agreement) with dedicated PLM systems and the possibility of establishing a dedicated communication channel through which data is transferred reliably in both ways.
- The other type of communication is rather loose, short in time, often unidirectional (typically between a company and an end-user), and does not follow a particular protocol (*i.e.* through emails or WWW pages). This also includes the communication between companies concerned with recycling or disposal and the manufacturer, with whom they often do not have a close relationship.

The latter type of communication is somewhat addressed by Autodesk Streamline, yet the solution seems short on collecting or analysing feedback from clients. Consequently, industry uses *ad hoc* methods to communicate with end-users, recyclers, and similar stakeholders. On a general note, both PLM solutions often have overlapping functions which are relevant to the conceptual design and end-of-life stages of a product. For example, UGS offers three modules concerned with design validation, Autodesk attributes conceptual design facilities to AutoCAD and Alias Studio.

6 Concluding remarks

This publication examines links between conceptual design and end-of-life of a product and enumerates the most important relationships between stakeholders, business processes, and associated data. Some of these relationships are compared with industrial practice. For example, conceptual designs are evaluated for compliance with laws, regulations and standards, but much less with respect to aspects like the cost of maintenance, remanufacturing, disposal, etc. Overall, considerations of end-of-life processes enjoy little attention by PLM systems during the conceptual design stage. No explicit support for the integration of the numerous end-of-life stakeholders, business processes, and so on concerned with the ultimate retirement of the product is given by either of the evaluated PLM systems. A closer examination of end-of-life and conceptualisation with respect to their special needs resulted in a set of requirements. These were then used to evaluate the abilities of two major PLM solutions. Overall, it can be stated that PLM solutions cater rather well to the conceptual design stage with respect of the product functionality expected by the authors. However, the solutions of the two major PLM solution providers have little to offer for the end-of-life management. The only contributions come from the generic communication framework of both solutions with two exceptions: UGS proposes support for managing products' compliance with regulations and standards, thus addressing implicitly environmental issues, while

Autodesk proposes a solution that manages information given to stakeholders outside the range of close business partners.

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An innovative framework for information flows collection in PLM environment

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Abstract: The globalization of competition has entailed that organizations of developed countries have to face new forms of competitor with low labour cost and often advantageous exchange rate (and then favourable export selling prices). In such a scenario, innovation and organizational flexibility is becoming fundamental levers to enable enterprises to increase their competitiveness.

In this paper we propose an innovative framework with the purpose of promoting innovation in three main aspects: technological innovation, business models innovation and product innovation. The framework is based on the Product Lifecycle Management (PLM) methodology; in particular we are going to discuss the possibility of integrating innovative technologies like RFId (Radio Frequency Identification) and XML (eXtensible Markup Language and derivation). The first is an enabled technology for PLM representing an informative support on the product for both producers and customers. The latter, on the other hand, is an essential component to obtain shared information on product between producers and customers throughout the different phases of the product lifecycle. By considering holistic property the proposed system achieves not only a valid and innovative framework for product innovation support, but also a framework that allows customer participation in the supply chain. The paper is supported by a case study of an Umbrian company which tested the proposed framework.

Keyword: Product Lifecycle Management, RFId, XML, Innovation

1 Introduction

In the current global economic context, the following radical changes which have shifted the competitive advantage’s resources, the new essential source for creating value is progress and the strategic use of methodologies, models and tools to optimize value creation. Such a scenario determined the diffusion of models for management product optimization from “the cradle till the grave” [1]. A first consideration regards the fact that the competition has become global and that in the less developed economies it is possible to lever the monetary exchange and the labour costs. This factor has given the developed countries SMEs (small and medium enterprises) just one road to follow, that is the technical, product and process innovation way, and also organisational flexibility. A second consideration regards the fact that the market of the developed countries is composed mainly by a knitted network of SMEs that have more difficulty in this new global scenario because of various problems such as the pruned investment capacity, the shrunk contractual power with the suppliers, the cultural opposition of the entrepreneurs to change. Related to the moderate capacity of investment is that undertaking an informational project (introduction of ERP, SCM,CRM, MRP tools) implies risks for the SMEs [2]. Connected to cultural opposition of the entrepreneurs is the engineering process's issue (BPR, Business Process Reengineering) seen as "deep rethink and radical reshape of the enterprise processes, settled to accomplish great improvements for the critical parameters of performance such as costs, quality, service and utility" [3]. If we focus on large consumer goods industry (food, drinks, home products, cosmetics, toys, etc.), for example, the following assessments can be made; recent researches reveal that a six month delay for a new product launch can reduce a third of the potential pay-off in the first five years of life, and just one out of 3000 becomes a commercial success that remains on the market for long term[4]; the fundamental innovation is seen more and more as the only possibility of success for the new product, in spite of renewals and simple extension of the existent production lines that represent the norm and not the innovation, make up, on average, up till 70% of the activities; moreover, for the consumers and environment protection, new norms and laws which oblige the enterprise to outline and control everything it " touches" each product is continuously introduced; new initiatives as Global Data Synchronization (GDS), held by the most potential international chains of distribution, are seen by the large consumption products industry as additional costs without any additional value [5]. In this more and more complex scenario, no company can consider itself all-content; consequently attention must be shifted from the cost control's initiatives put in practice during the last years to the initiatives which have as purpose the pay-off increase. Having this goal in mind the article aims to define a system that allows the SMEs to realize the technological, process and product innovation. As a matter of fact, the architecture of the system turns out to be the following: PLM+RFId+XLM. In the following paragraph the philosophy referred in the article will be discussed, the Product Lifecycle Management (PLM). It regards an innovative model for the management of product lifecycle. The PLM is carried out by managing and, therefore, trying to optimize all the product lifecycle stages, seeking a major control on it in order to prevent a malfunctioning or danger for people and goods. Having a major control on their own products allows the company to understand the informative flows which will allow it to comprehend in which direction to go with the product improvement research [6, 7, 8, 9, 10, 11, 12, 13]. Afterwards the RFId technology will be argued, i.e. the informative support for the product that will allow the PLM to be enabled. RFId stands for Radio Frequency Identification and it is a new innovative technology that allows to automatically identify persons, animals and things. This technology will play the role of informative support for the product during all the stages of its lifecycle in order to seize the informative fluxes. Moreover we will discuss about XML technology necessary to achieve interoperation between the different systems of the different actors who intervene during the different stages of the product lifecycle. XML stands for Extensible Markup language. XLM is a meta-mark-up language [14]. The XML will allow all the actors that intervene during the product lifecycle to gain to the information that will be memorized on the product tag, therefore sharing the information about a resource. In the third paragraph the meta-holistic approach that characterize the system will be proposed. In the fourth paragraph a case study for the validation of the proposed meta-holistic system will be illustrated. In the fifth paragraph the achieved results will be discussed. In this way the necessary information for the product's production chain optimization will be obtained. In addition, it will be possible to have the control of the product which will allows to obtain information from which the necessary knowledge may be attained to improve the product.

2 PLM, RFId, XML

2.1 PLM Concept: Origin & Evolution

PLM acronym was originally introduced in environment compatibility studies for industrial products – ages ’70 – to suggest that a physical asset must be designed and realized for environment sustainability, by considering product life-cycle phase, including mainly disposal and recycling. Life-cycle can be thought as the different phase of product life: conception, design, production, distribution, sales, disposal and/or recycling. At the end of ’90 PLM-mean started to evolve on entire system product management and traceability, during the different life-phases, changing in this way the mean of the acronym [15].

Following the definition proposed by Daratech [16],Qad[17], ARC Advisor Group News [18], CimData [19] and others [20, 21, 22, 23, 24], Garetti [15] define PLM as an integrated business approach that, with information technology aid, realize an integrated, cooperative and collaborative information product management during all the life-cycle. For this reason, it can be argued that PLM includes: a strategic orientation for value creation “on” and “across” the product; a collaborative approach application for core-competences exploitation of different actors; an important utilization of IT solutions to realize an integrated, coordinated, safe information management for value creation. PLM is complex and full-comprehensive, a new integration phenomenon that actually runs in industrial context and that joins organizational dimensions (processes), economical dimensions (costs and proceeds), technical dimensions (IT systems).
Now we show which are the most important areas that PLM involves.

2.2 RFId Definition

Radio Frequency Identification allows the automatic identification of people and things with the use of radio wave. Through technologies and instruments development, that allow micro-systems distributed memory realization able to answer wire-less interrogation, information flows management manners and information systems structure can be entirely changed. RFId technologies allow to install, at low costs, on a product or bin, one tag (chip + memory) that can memorize all information necessary to identify plus other information that can be modified during operative processes. [25, 26, 27, 28] This ‘mobile memory’ not only can keep track of product history, but also it doesn’t need maintenance or charge. This utilization facility and low costs allow these new technologies to expand itself in industrial and commercial sectors. New features are added to basic functions: measurement of physical metrics, actuators command, etc. The increasing utilization of these new technologies places the bases for an “Ubiquitous Society that will change a lot of existing paradigms” [29, 30, 31, 32, 33].

2.3 XML Definition & Derivation

XML stands for Extensible Markup Language (often written as eXtensibleMarkup Language to justify the acronym). XML is a set of rules to define semantic tags that split a document into parts and identify the different parts of the document. It is a meta-markup language that defines a syntax used to define other domain-specific, semantic, structured markup languages [14, 34, 35, 36].

XML, as meta-markup language, allows to define structural rules for a given type of document, so that organizations and groups can use a common language for a given topic. For example, Boston M.I.T. has developed Physical Markup Language, a language designed for physical object standardization and description and usable by both, human and machine. Primary objective for PML is served as common base for software applications, data storage and instruments for commerce and industry [37].

3 Meta-Holistic Approach

3.1 The Information central role

In organization's life information plays a primary role: in fact information allows to reduce waste, obtain competitive advantage compared to the other organizations in the market, reduce manufacturing and inventory costs, reduce lead time, etc.. The Product Lifecycle Management and Information relationship is very strong and very important too; in fact from information analysis and from increasing control on product, it's possible to understand how to optimize product production, how to make product lifecycle management efficient and effective, how to innovate products, etc.[1]. RFId technology and information relationship is very important too: in fact RFId is the instruments on which it is possible to store information about one product, and this information can be modified along the different product lifecycle phases, memorizing, from time to time, significant and useful information. Finally, Physical Markup Language and information relationship is very strong too: in fact PML allows, through the property of being understandable both, human and machine, to obtain interoperability between different information systems of different actors that attend in the different lifecycle phases; PML allows share information between the constituting supply chain actors.

3.2 Extended Supply Chain Information Flows

A typical supply chain is defined by suppliers, partners, producers, carriers and product sellers networks. [38, 39, 40, 41, 42]. Hence Supply Chain Management (SCM) implies product management until its retail. One of the problems in the apply PLM approach is the lack of product feedback information, that come from users. So we try to define product lifecycle by management information on product instruments during the different phases of product lifecycle. In so far as we imagine a lifecycle split in two fundamental parts, one from conception to product distribution/retail, that we could argue be cover by supply chain management applications, and the other one, from distribution/retail to product disposal. So the extended supply chain is defined by all the phases before retail, with in addition, use and disposal/recycle phases[43, 44]. Figure 1 illustrates the abovementioned.

Figure 1 Information flows in extended supply chain

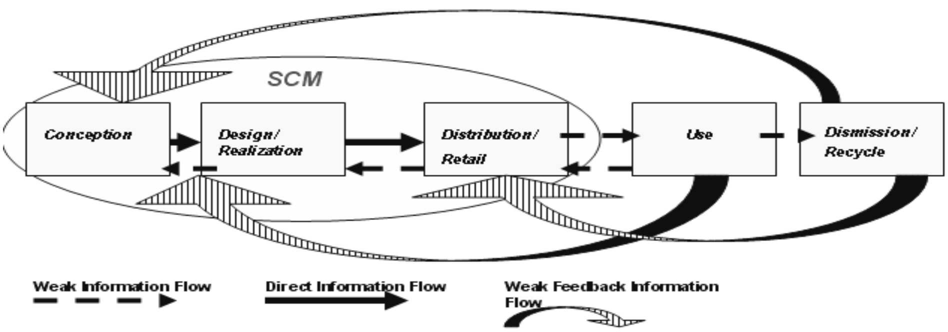


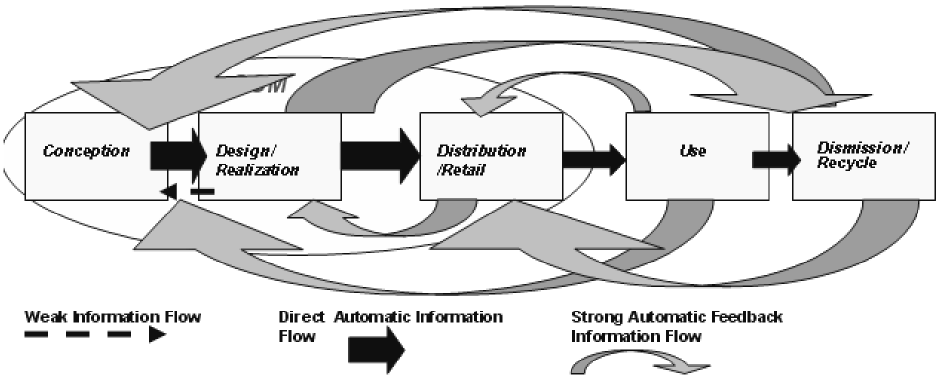
Figure 1 shows primaries information flows concerning product life, from conception to disposal, that propose distribution/retail phase like the central divider. Weak information flows are in dot-black; they are from the design/realization phase to conception (as an example during given product realization you can image a different version of the product), from the distribution/retail phase to design/realization (as an example distributors needs can change product realization phase), from utilization phase to distribution/retail phase (as an example a costumer can explain needs that change product distribution, and going back in the different phases in design/realization, conception phases too). These information flows are defined weak because their capacity to have a positive impact on product improvement processes is very low, given the difficulty to be received and intercepted. Possible causes can be the lack of communication between different partners of collaborative product development, the difficulty of receive information from costumer without adequate technology, etc.[1,10]. Bold information flow represents instead the classic information flow through product lifecycle; such a flow goes forth from the conception product phase throw design/realization phase, until the distribution/retail one. As it can be seen from the figure, the information flow from conception phase to distribution/retail phase (that is what we have defined SC) is well structured, while information flow from distribution/retail phase to disposal/recycling phase is still very weak because, generally, available information after product sale decreasing in considerable way and even more after its utilization, in disposal/recycling phase [1]. Traditionally, information flow direct to costumers could be defined like “static” because once given (as an example with tag or with handbook) this information flow doesn’t change, i.e. it couldn’t be adapted to the different lifecycle phases. These features determine that, sold product, producers have no control in product life and there is a risk that users don’t have adequate support for the correct use/functioning of the product and consequentially they perceive negligence from producers to themselves.

Figure 2 After sale product information flows

Moreover it must be considered a feedback flows that can’t be realized without a right technology support. Feedback flows (as an example information in product disposal, or products with reduced life due to design or manufacturing errors) are very important for improvement product processes. Actually, by information obtained by feedback flows, it is possible to think, design, obtain improvements for the products (for example Design for disassemblies). Now we try to demonstrate what we mean with “feedback flows are not determining for improvement product processes without a right support technology” expression; collecting feedback information is very difficult due to its nature; indeed the primary feature we must considered is that information is “distributed”, i.e. it is linked to every single customer who buys and uses the product. Another important feature we have to consider is that information is rarely formally recorded, so in many cases it could be very expensive to gather (for example some customer relationship management methodologies are based on phone interview). Considering these features, is easily understood the importance of having a common data storage and a central repository allowing the memorization of the different point of view of the different actors attending along the product lifecycle. In the next lines we discuss the information flows collecting problem by RFId and PML technology support in PLM environment. Hence figure 3 shows information flows in extended enterprise with proposed system implemented. By observing figure 3, it can be seen the primary importance that automatic identification technologies (RFId) and interoperability technologies (PML) can cover all product lifecycle. As first, you can notice an increasing direct information flows manageable. In fact on an RFId tag, where it can be memorized for example an EPC code (Electronic

Product Code, an unique identifier for product)[45], it is possible to memorize any other useful information during the various phase of life In this way, the first part of the problem, that is the centralization of information could be solved: the product itself (the RFID within it) is the repository of data. Hence it is simple to understand how the most part of information needs could be satisfied when the product "lives from the cradle to the grave". As an example you can memorize information for customer use of the product, you can memorize information to suggest disposals on how to manage the different parts of the product in recycling phase, etc.

Figure 3 Flows information with technological and methodological support



Moreover, since it is possible to modify tag information, this allows "dynamic information flows", i.e. information flows can change respect to the different phases of product lifecycle, and it is possible update the information, about the product, in the central repository by passing the tag near the reader. Afterwards it will be possible store in a file the information that maintain the history of the product life, in order to achieve traceability. In this scenario, allowed by RFId technologies, insert itself the integration role of PML technologies (in this specific case) or XML become fundamental, indeed, one of the problems related to the effective integration of the different actors participating in extended SC is the lack of an integrable information/data management system [46]. Since those information flows are "dynamics" it will be possible to customize not only the physical object but the object information flows too. By using this proposed system it will be possible to have an information system shared and integrated among all actors in product lifecycle or at least from the conception phase to retail/distribution phase; in this integrated database/repository it will be possible to realize a knowledge merge of the different actors, that is, for example, whoever designs products can know, and so consequently behave, the problems that occur in retail/distribution phase[15]. It is important to note that the most significant advantage is to recover information, in this system is performed automatically by RFId and PML technologies use. If we use automated identification technologies (RFId) and interoperability enabling technologies (PML) it is important to note that feedback information flows is more significant than the feedback flows without this technological support; in fact considering the phases from the conception to retail, information flow is automatic given that it is memorized on smart tag and moreover because PML enables system interoperability for the different actors that participate in the extend supply chain. For example if we recognize that a product in the manufacturing phase is not reliable, this important information immediately comes back to whoever designs products and therefore they start to try to correct the error; or if the product sales are beyond expectation integrated information system alert product manufacturers that it is necessary to produce more products to satisfy market (better demand plan reducing bull-whip effect) [47]. More important is that it could happen in real time. If we look at figure 3 we can note that still external extended supply chain phases have important advantages from feedback flows. In fact information that can be read from users and disposals of the product can allow them to communicate their comments, their questions, their opinions to whoever produces and manages products by different services that can performed and built to support product utilization and disposal exploiting RFId and PML technologies. As an example, considering that a famous mobile telephone organization starts producing a mobile telephone with integrated RFId reader [48], we can think to built an application that allows users that read information memorized in product tag to send their opinions, advice, claims, inquiries directly to product producers.

4 Solution Application

In this brief section we argue a possible implementation of the proposed system. We try to apply this system in an Italian product characterizing sector, wine sector. When we talk about wine, we must consider that wine product is highly related with customer opinions and sensations. The aim of this system is to make customer participant to weaving factory. The objective of the product is to provoke in customer emotions, experience that are not limited in entertain customer, but that can train, involve and delight customer exploiting every contact moment: before, during and after sales, through product, service, organization staff and clearly communication [49]. For this reason it is performed installing RFId chip inside wine bottle cork. The cork can contain, in addition to wine information like for example when the wine has been bottled or when the grape was gathered.., information about organoleptic features, barriques passage, wine grape, soil, bin etc. In the same way, it can contain information like, for example, wine food matching, wine colours table matching, tale from wine production region or music from wine production region for allow customers, for example, an Australian one, to feel, for some minutes, absorbed in the typical context where wine come from, in this case Italy. To obtain integration a new markup language was designed, Wine Markup Language,as shown in figure 4.

Figure 4 Wine Markup Language

```
<wine>
    <name> Sagrantino </name>
    <year> 2001 </year>
    <date> 2345546443 </date>
    <general-features>
                <fermentation bin > acciaio inox n°42 </fermentation bin>
                <fermentation days> 23 </fermentation days>
                <barriques passage> 45532456267</barriques passage>
                <barriques typology > 26Tonnellerie Saury MT,2
                Tonnellerie Boutes TM+ 1°  </barriques typology>
                <wine grape> Sangiovese 100%  </wine grape>
                <alcohol> 14,45  </alcohol>
                <ph> 3.4 </ph>
    </general-features>
    <organoleptic features>
          <colour> rubino molto carico con tenui riflessi aranciati; </colour>
          <aroma> ampio con sensazioni molto intense di frutti di bosco,
          confettura e di spezie unitamente a delicati aromi vanigliati; </aroma>
          <flavour> pieno, di grande corpo, persistente e ben equilibrato; </flavour>
    </organoleptic features>
</wine>
```

Another important justification that has contributed to make interesting this work is that wine product is strongly linked to customer feedback, because if it is a positive feedback then customers will be faithful to the product and to the organization-brand that make product, if instead it is a negative feedback, more than in other product sector, organization must change immediately to avoid losing customers. In fact if wine takes on a bad reputation it will be very hard and difficult that customers will taste the product again in the future, hence it will become necessary to start a large advertising campaign to promote product, and this action could be not sufficient to destroy customers diffidence Feedback information will concern polls submit to product users or concerning to product preferences for customer, or also to obtain a customer judgement on the product. That is why an application is been designed that by means of WML technologies allows interoperability and communication between producers system information and customer mobile telephone.

5 Conclusions & Discussion

In this economic context principal organizational features must be flexibility, adaptability, rapidly alignment in new competitive scenarios. The old organization models are characterized by different critical aspects, like rigid structures that do not comply market requirements. A new methodology for extended enterprise management was studied, PLM (Product Lifecycle Management), that could represent an efficient and effective model to take out SMEs from crisis situation and to reinforce their market position in global market, obtaining improvements in competitiveness. Others advantages that originate from PLM implementation are: a better control on products for producers, a better informative action for customers, a more efficient and effective extended supply chain management, a more incisive environment sustainability action, a support effort for continuous innovation inside organization, a considerable resources saving in terms of staff cost and time [50]. In order to enable in the most efficient and effective way PLM methodology, RFId technologies (Radio Frequency Identification), as physical framework for information memorization that allow automatic identification of product, cans, pallets on which RFId tag is applied, have been implemented. Next step was to identify a technology that could allow integration and interoperability between the different applications that have to use RFId tag memorized data. This technology is called XML (eXtensible Markup Language), and in particular a derivation, PML (Physical Markup Language); PML allows integration of the different actors participating in product life, "from the cradle to the grave", moreover it is simple to understand by both human and machine. Finally we presented a particular application of this framework in the wine industry, where we defined a markup language (WineML) that could allow wine data interchange between different actors in extended supply chain.

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RFID technology in the life cycle of complex machinery and plants

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Abstract: Radio frequency identification (RFID) technology is entering ever more domains of logistics and engineering. RFID components are for example used in the manufacture of complex machinery and equipment and in their delivery to customers and commissioning as well as in the subsequent phase of maintenance by plant operators. Awareness is increasingly growing in companies that such holistic and cross-company process chains require new approaches to and methods for the integrated utilization of RFID components. This begins in the design engineering of components, which are outfitted with RFID components either permanently or only to support selected process steps, and ends with the removal of the transponder or the deletion of the data stored on a component's transponder. An issue parallel to the physical handling of RFID components is the use of RFID to support cross-company information exchange.

Keywords: Life Cycle, Complex Machinery, RFID, Industrial Maintenance, Telematics, Mobile Computing

1 Material Internet: Radio Technologies Are Conquering Logistics Assets

Information on the identity, current position and status of goods and loading equipment of transportation as well as this data's real-time availability in expediting systems is assuming a pivotal role in logistics. The trend toward miniaturizing equipment as costs are falling is opening a new market for autonomous logistic assets equipped with sensor technology and communication modules to optimize operational and logistics processes. At present, coupling RFID systems for asset identification with telematic modules is generating new products that fall under the "secure chain of goods". This is giving technical logistics systems entirely new properties. Thus, goods are enabled to communicate with a system on the lowest level as possible, which will in turn make it possible to decentralize the IT and control architecture. Ideally, the logistic asset itself will decide which path it should take based on its communication with the system. Consequently, a complete system will be able to react more quickly to changes and it will be possible to delegate decisions close to the operative level.

The concepts of “pervasive computing” and “ubiquitous computing” [1-2] surrounding RF technologies represent new developments in information and communication technologies. In the course of this development, everyday objects will be equipped with microelectronics in the future. The thusly created “intelligent” objects, also called “smart objects” or “smart devices” will affect nearly all areas of daily life and naturally industrial processes too.

Concepts such as the “material Internet” [3] describe a paradigm change from hierarchical control mechanisms to autonomous, intercommunicating object structures that integrate functionalities for identification, localization and cross-company data exchange.

2 Basic Principles of RF Systems

RFID is frequently employed as a generic term for the complete technical infrastructure. A radio frequency (RF) or radio frequency identification (RFID) system includes:

- A transponder (a word made up from transmit and respond; also called an RFID tag or label),
- A transceiver unit (reader with integrated antenna) and
- Integration with servers and service and enterprise resource planning systems.

The transponder has a chip connected with an antenna. The chip receives its operating power either through the RF field emitted by the reader (passive transponder) or has a self-contained power supply (active transponder). The memory capacity of passive transponders varies from 128 bytes to 4,000-6,000 bytes, depending on the design. Active transponders frequently have a memory capacity of up to 256 bytes, yet can be upgraded with separate memory chips. Readers are either available as stationary units (gate or tunnels systems) or integrated in mobile terminals such as PDA or industrial handhelds.

The table below is an overview of existing RF technologies. Systems based on 13.56 MHz (worldwide), 868 MHz (Europe) and 2.45 GHz are particularly interesting for use in manufacturing, delivery processes in conjunction with plant engineering processes and subsequent maintenance by a plant operator or manufacturer.

Table 1 Characteristics of RF systems

Frequency Range	**Wavelength**	**Operating Mode**	**Key Functions for Logistics Applications**
< 135 kHz	low frequency (LF)	passive	Identification, communication (0.5 m)
13.56 MHz	high frequency (HF)	passive	Identification, communication (0 - 0.6 m)
433 MHz	ultra high frequency (UHF)	passive	Identification, communication (6 - 8 m)

868 MHz	ultra high frequency (UHF)	passive, active	Identification, communication (2 - 4 m)
2.45 GHz	microwave	active	Identification, localization, communication (50 - 200 m)
5.8 GHz	microwave	active	Identification, localization, communication (50 - 200 m)

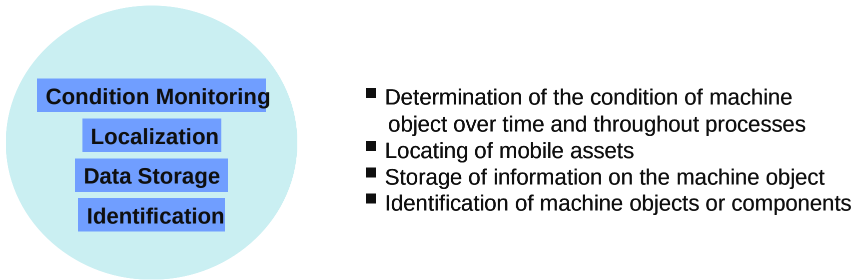
Source [4, p. 30].

Databases can be used to visualize identification, position and status data and integrate it in company IT systems.

3 Basic Application Scenarios of RF Technology in the Life Cycle of Complex Industrial Assets

RF technologies provide the functionalities presented in Figure 1 upon which application scenarios can be built.

Figure 1 Characterization of potential uses of RFID



The functionalities mentioned can be employed in different stages of technical development in the

- industrial manufacturing,
- delivery and construction processes,
- maintenance and
- dismantling / disposal

of complex machinery and plants. Along with the actual machine components, other types of assets such as tools (for manufacturing, maintenance, etc.), vehicles (for internal transportation, deliveries to customers, etc.) or personnel (internal, subcontracted) also provide reasons for installing RFID systems. However the observations below only apply to machine components and related aspects and potential benefits in the life cycle for component and plant manufacturers, general contractors and service providers in the plant engineering sector and plant operators. Thus, applications in the range of 13.56 MHz and 868 MHz are primarily described.

3.1 RFID in Manufacturing

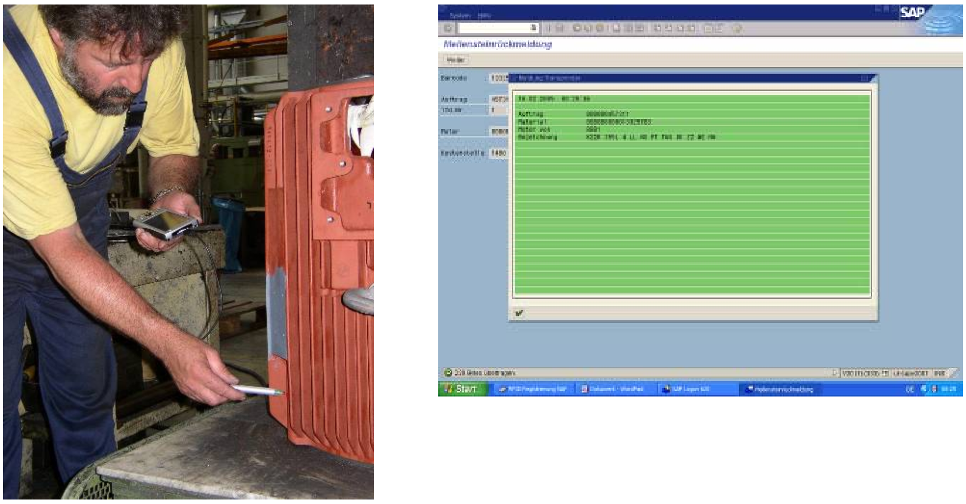
RF technologies based on 125 kHz have long proven themselves in automation of manufacturing processes. This technology is used to internally control mobile ground conveyors or for tool changing systems in automatic machining centers.

More recently, approaches to using active transponders to track semifinished or finished products in manufacturing can be observed. Such projects are primarily found in the automotive sector to track autobodies and the skids carrying them.

Other manufacturers are also discovering the advantages RF technology though and other frequency ranges are also being used, e.g. 13.56 MHz. In Germany for instance, first pilot projects have been carried out in small and medium-sized enterprises. A medium-sized manufacturer of electric motors has mounted 13.56 MHz transponders on its motors within a dual strategy [5]:

1. Monitoring production flows and controlling the progress of manufacturing.
2. Electronic nameplate and maintenance history file for motor maintenance by after sales service.

Figure 2 Usage of RFID tags for mile stone monitoring in manufacturing of electric motors



In conjunction with this dual strategy, the manufacturer successfully dealt with the following issues:

- What ambient conditions exist in industrial manufacturing and later in day-to-day operation at a client's facilities? How sturdy do transponders have to be to function properly in both ambient conditions?
- What mechanical machining, assembly/disassembly and handling processes (in the sense of deliver / transport) are the components and thus the RFID transponders subjected to in manufacturing and maintenance?

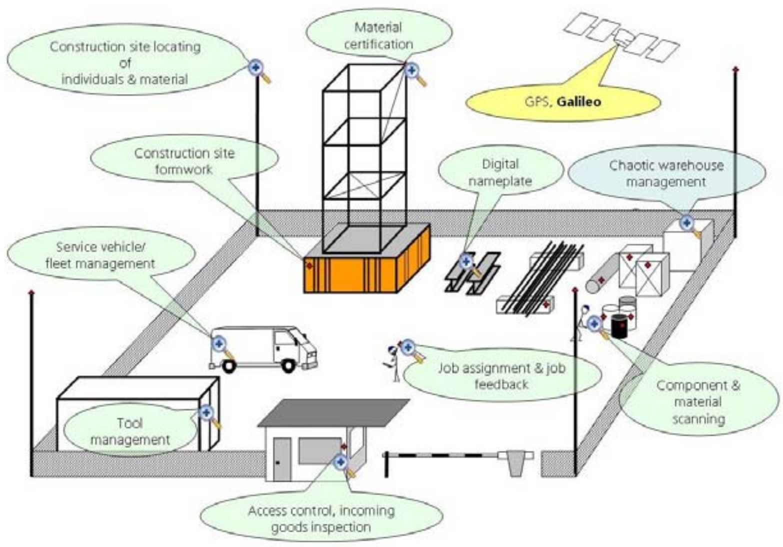
- Is it necessary to remove a transponder when production concludes and replace it with another transponder (type) for after sales service?
- What manufacturing data and what maintenance data should be stored on the transponder?
- Etc.

These questions about transponder design, place of attachment, memory capacity and service life could be answered with great certainty for an individual company. This task immediately becomes more complex though when the maintenance departments of customers from different industries (chemical industry, wind power generating industry, etc.) who are the later motor operators are involved in selecting the RFID systems and specifying the necessary data. Section 3.3 addresses this in more detail in.

3.2 RFID and Telematics in Industrial Plant Construction

In industrial plant construction the physical processes on a construction site are fields of application that, both from the perspective of logistics and construction, provide great potential for improving productivity by using RFID and telematics (Fig. 3).

Figure 3 Application of RF based methods in construction site logistics



Source [6, p. 25].

The increasing complexity of technical installation and the requirements of reliable and cost effective plant operation are generating increasing demand for information in logistics and construction. Engineering effective and efficient logistics and assembly processes necessitates being able to store and retrieve assured and up-to-date information about configuration, state changes and past measures as well as requisite documents on components, assemblies and equipment in real-time directly on site. In addition, international flows of goods have general requirements ranging from product identity to traceability, packaging and product liability up through safety.

From the standpoint of logistics, beneficial aspects of RF technologies are [7, p.152]:

- *Status detection* of logistic assets (e.g. construction material and humidity) and related jobs (manufactured – packaged - shipped – received at the construction site – stored – used),
- Representation of the *secure* supply chain beyond company and territorial borders (components, transport unit, spare parts, tools, etc.),
- Precise *identifiability* of logistic assets (units of goods, personnel, tools, etc.) in the company/at the construction site,
- Precise *localizability* of logistic assets (units of goods, personnel, tools, etc.) in the company/at the construction site.

Studies completed by the Fraunhofer IFF [8-9] have demonstrated that the operating conditions (e.g. dirt, dust, extreme climate, abrasive material, metallic environment) equipment can be subjected to as well as the logistic conditions (e.g. large proportion of third party suppliers, international transport chains, the specificity of maintenance measures for construction sites) generate a wide variety of requirements on formulating a technical concept for the use of RF technologies (cf. Tab. 2).

Table 2 Ambient conditions in construction site logistics

Technical Ambient Conditions	**Organizational Ambient Conditions**
Rough Environment Metal / dirt / dust Weather / climate / temperature Type of maintenance / cycle	Approx. 5% material losses (Reason: Deliveries cannot be found) [8]
Global Export Local third party service providers Customs / transport delays Missing I&C / different standards	Approx. 30-50% productive hours of work (Reason: Searching for, identifying, transporting, transferring material) [10]
Large Share of Purchased Parts High logistics expenses	RF technologies can save approx. 25% of the hours of work in building construction spent on inspecting deliveries and entering data in material management systems [11, p. 51]

The mobility of the resources (material, equipment, personnel) in job site assembly substantially increases the variety of production processes in terms of space, time and complexity. Insufficient material supply at a construction site, which can cause productivity to drop up to 50%, is frequently considered to be a primary cause of failures (cf. [12]). Hence, information and document management for industrial plant construction projects to reliably supply information about decisions has been gaining importance in recent years ([12-13]). RFID transponders, RFID location systems and mobile terminals/devices are increasingly being used as information carriers ([14], [15], [16]).

Large deliveries of material and equipment have to be managed whenever plants are built, modernized or shut down. The secure transfer of goods between supplier and customer or between supplier, carrier(s) and customer is growing ever more important in international supply chains. The advantages of RFID and telematics are above all in the monitoring of delivery and assembly processes and in the prevention of

- Information media breaks between the different IT systems of those involved and
- Errors caused by manually transferring data into these IT systems.

Generally, different operations are accelerated (e.g. receipt of incoming goods, assembly) and unproductive labor time moving about searching for delivered components are reduced.

Here too, a fundamental problem is bundling the requirements of manufacturers, transportation service providers, plant construction firms and later operators to select the RFID systems, reference processes and data exchange standards to be used and transferring them to practicable and economically expedient technical solutions from the perspective of the overall plant engineering supply chain.

3.3 RFID in Maintenance

The first pilot projects in Germany on the utilization of passive transponders in maintenance were already underway in the mid 1990s. One of the first to adopt such an approach and technology, AIRBUS Hamburg started its first project to track aircraft tools in 1999. The objective of the project was to globally track tools for aircraft maintenance, which AIRBUS lends to airlines and must be recalibrated after every use.

AIRBUS continued this project in 2003 with another project to identify spare parts with the stated objective [17] "to simplify component repair management, where the repair and flight history of the component will be available electronically. The passive transponder assures the availability and accuracy of vital information and documentation and also allows a comprehensive tracking system. The airlines will further benefit by time saved on trouble shooting, parts inspection, repairs administration and on the whole logistics cycle".

Another outstanding RFID project in maintenance involves the mounting of transponders on maintenance assets at Frankfurt Airport. Aware that the quality of its facility management processes is crucial to guaranteeing smooth operations, maximum security, and convenience for travelers, the airport's operating company FRAPORT AG decided to test the benefits of RFID in this area and initiated a pilot project in 2003 [18]. The facility managers are particularly interested in applying RFID to problems such as easy identification, distributed data storage, fraud prevention, structured documentation, and paperless information management by using mobile applications for maintenance processes. In the past, the inspection of 22,000 fire shutters generated 88,000 pages of paper documentation that had to be archived for several years. The RFID based mobile solution has eliminated this work completely. The company is now extending this solution to other applications such as fire doors, smoke detectors or conveyor flaps.

Small and medium-sized enterprises are increasingly discovering the advantages of RFID for themselves. Virtually every industry is represented here, for example:

- Manufacturer of electric motors; 2004 (see Section 3.1).
- Paper manufacturer, 2006. This company is using RFID technology in conjunction with mobile terminals for paperless order management and real-time order feedback.
- Aluminum rolling mill, 2006. This company is also using mobile terminals and RFID technology to track reparable components that are installed in different places during their service life.
- Other RFID pilot projects in maintenance in Germany currently come from the automotive industry, energy industry and hospital management.

The chief advantages of using RFID in maintenance processes are the precise identification of maintenance assets when required maintenance work is being done, the storage of data relevant for maintenance (e.g. servicing and inspection data) directly on a particular object, the elimination of previously necessary paper documents (cf. FRAPORT AG) and the acceleration of information flows [19, p. 25].

Manufacturer and operator groups have a vested interest in utilizing operation information in a maintenance history file:

- Manufacturers are interested in improving their products when they can draw knowledge relevant for design engineering and manufacturing from the operation of components and
- Plant operators are interested in improving their maintenance processes through better monitoring and controlling for instance.

4 Conclusion

RF technologies are on the threshold of entering the mass market. Various sectors such as commerce and parcel service are making great efforts to create a stable, standardized environment for the introduction of RFID technology in the overall value added chain. To this end, users are forming strategic partnerships in order to establish a close relationship between the developers and users of hardware and software. Both sectors are endeavoring to standardize both RFID based applications and technologies and products to make it easier for companies to start using the new technology and to clearly communicate its advantages.

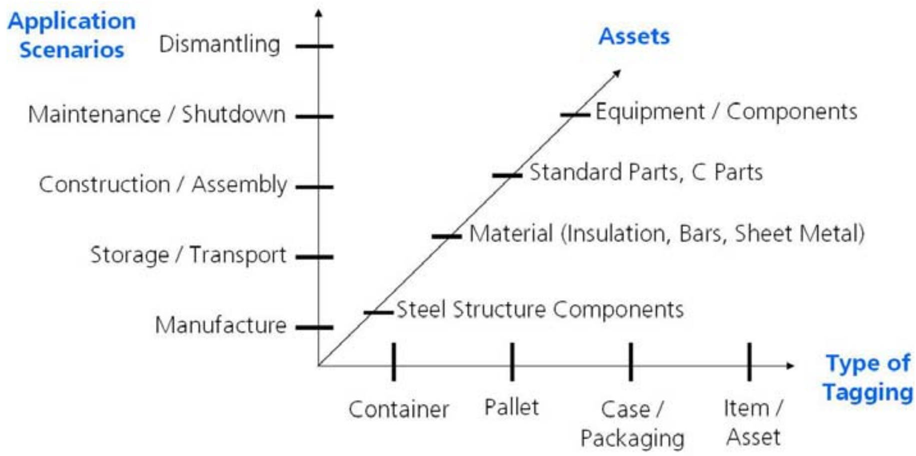
Current activities in these fields are having and will have an impact on other sectors such as mechanical and plant engineering or the maintenance industry. So far, pilot projects have characteristically been undertaken by individual plant operators independently planning and carrying out the implementation of RFID with the goal of improving the effectiveness and efficiency of their maintenance processes. On the other hand, certain manufacturers of complex machinery have already also integrated transponders in their products and are selling these to customers. Since there are no mandatory technical or IT standards at present for cross-company use of RFID technology in production or maintenance, interest groups are forming around this issue. The continued use of tags already installed by suppliers (cf. [5]) for various processes (e.g. warehouse management, assembly and disassembly, maintenance, shutdown) is giving the plant construction and maintenance sector as well as manufacturers a competitive edge too.

The multitude of different logistics processes in a plant's life cycle that involve third party service providers is making it difficult to apply a standardized approach to integrate RF based technologies. A classification based on the field of application, the asset being analyzed and its packaging unit can provide a foundation for making RF based processes standardizable and certifiable in the future (Fig. 4).

Cross-company working groups are forming around life cycle-based process analyses to work on the standardization and certification of RFID systems for the processes addressed above in Sections 3.1 through 3.3. Both manufactures of complex components and equipment and later users such as plant operators, subcontracted maintenance firms or transportation service providers have recognized the benefits of RFID. Among other things, their collective efforts are aimed at:

- Establishing guidelines for the placement of transponders (initially) on components, e.g. engines, transmissions.
- Specifying reference processes in manufacturing, plant construction and maintenance that RFID can support.
- In conjunction with the reference processes, formulating recommendations on the selection of RFID technology as well as useable, commercially available products (RFID transponders, readers, mobile terminals/handhelds).
- Defining the respective data models and interfaces to company-based IT systems such as ERP or CMMS for the reference processes.
- Addressing other issues such as data security and integrity and process reliability with RFID.

Figure 4 Classification of RF based scenarios as the basis of standardization and certification



Future developments will go beyond single company applications to standardized cross-company applications. The results of this collaborative work are continuously being published. This is intended to raise awareness in the whole industry of potentials for improvement with RFID and to disseminate the requisite technological know-how.

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Architecture for life cycle management of product and services

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Abstract: Companies that are expanding their product offering to cover also lifecycle services in the customers' facilities are facing the increasing complexity to manage the information. The problem arises when the company is looking for growth by taking bigger role of the customers' process by providing the value added services on site.

The business critical information is described with items that are usually mastered in the ERP or PLM systems. Sharing the same information enables global operations and optimization.

This article focuses on methodology how to manage product and product related information during lifecycles of the product. The article introduces product management architecture, which consists of harmonized and standardized business semantics, classified functional structures and interface definition. Using these elements any product or service, in the recognized class, can be semantically described and communicated through interface definition.

Keyword: Business Co- evolution, Life Cycle Engineering, PLM Implementation, Life Cycle Management Architecture

1 Introduction

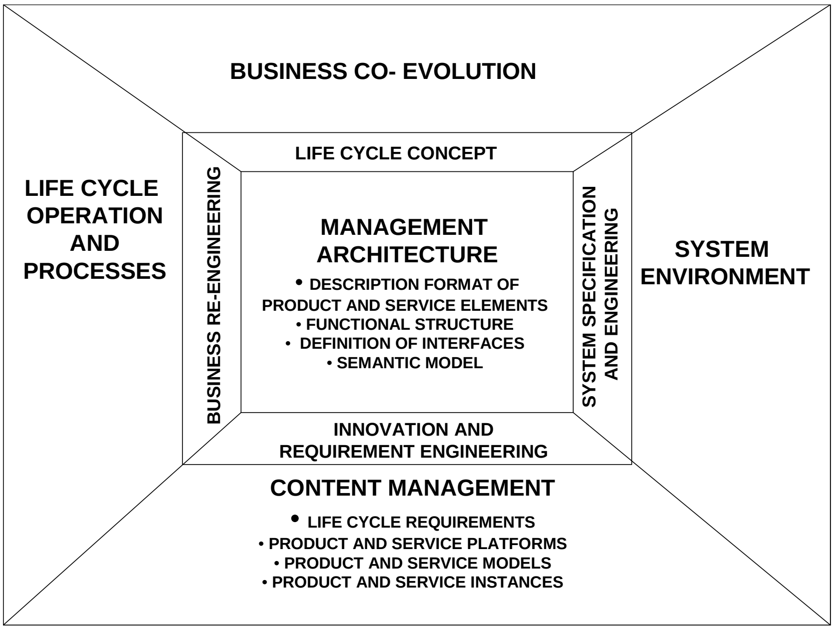
Industrial services, B-to-B services, are expected to have high potential for companies especially in traditional industries, such as manufacturing or real estate business. Enterprises need to develop new business models and innovation concepts especially in those businesses where product life cycles are long. Manufacturing companies entering into life cycle business undergo a significant value transition.

When companies are expanding their product offering to cover also lifecycle services they are facing the increasing complexity to manage the product and service information. Typically the manufacturing companies IT systems and mindset are tuned for transaction based capital business - new product sales and delivery process.

The problem arises when the company is looking for growth by taking bigger role of the customers' process by providing the value added services on site. The company must understand the customers' process and also orchestrate service and maintenance actions of the partner network. The customers' success is depending on the capability of the network, which is an emerging property of collaboration. In the life cycle business the focus is in the customers' process and the business critical information is life cycle knowledge of the process, products and their performance.

The differences between capital and lifecycle business has led to two different business models. The companies that are running both businesses can make a substantial progress by integrating the information management together. The goal is to achieve not only better information management but also enhance dynamic interrelation between products and services enabling innovations based on customer value. The problem is that the business critical information and the business focus are different. There is a need for a management architecture that harmonizes the product modeling and provides a platform to transmit the lifecycle knowledge in network environment (Figure 1). This article introduces how management architecture coordinates the re-engineering of operations and processes and engineering of systems and system environment. It also guides and systematizes continuous platform content development, product modeling and instance management for lifecycle services.

Figure 1 Management architecture for Product Life Cycle Business Management



The product management architecture is based on underlying elements that are harmonized and standardized business semantics, functional structures and interface definition. Using these elements any product or service, in the recognized class, can be semantically described and communicated through interface definition. The content is described as modules that can refer to the physical items, processes or information. Modules are re-usable elements that have internal semantic description. Modules have three management layers: platforms, product model and product instance that form three different views to the module system.

At the platform level capability, technology and customer requirements are mapped against modules in order to optimize the module space against the business. On the product model level modules are attached to the functional structure and semantic description by using external rules. Product models define current offering. Finally the product instance is created through product model using requirement definition and it is carrying the full semantic description “specification” as well as item structure. The version history of the product instance describe the physical product in different stages of the product life cycle (as designed, as manufactured, as delivered, as maintained). Product instance can be used also to gather and cluster the life cycle information of itself and the process. This article introduces management architecture for product management as a solution to integrate together product lifecycle information and lifecycle knowledge.

2 Theoretical Frame work

In the following is introduced the theoretical framework of product management architecture for life cycle management. The existing theoretical approach of product architecture is based on modularity and complexity (Baldwin and Clark, 1997). The idea is captured by three terms: abstraction, information hiding, and interface (Baldwin and Clark, 2000). Product architecture and functional structures are following the ideas of (Ulrich, 1997). Product architecture consists of elements of the mechanical structure to manage modularity. A complex system can be managed by dividing it up into smaller pieces and looking at each one separately. When the complexity of one of the elements crosses a certain threshold, that complexity can be isolated by defining a separate abstraction that has a simple interface. The abstraction hides the complexity of the element; the interface indicates how the element interacts with the larger system. Modularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them (Baldwin & Clark 2000). Modularization should support also life cycle management (Barnes and MacKay , 2000). This demands that modular system is dynamic over the life cycle (Riitahuhta and Andreasen, 1999). Product platform approach is adopted for strategic level product management. Platform structures can be used in managing variations and decreasing complexity (Meyer and Lehnerd, 1997). Service can be managed also by platform structures (Meyer and DeTore, 1999). Companies need platform strategy to be able to benefit re-use of platforms and modules with well-defined interfaces. Product and service platforms are the foundation of derivative products/services. Both the product and service need to be defined before they can be effectively used in configuration according customer and functional requirements (Salminen & Pillai, 2003). The goal is to reach up to a rationalized and optimized product and service platform with configured interfaces by interactions understood and determined. The literature defines solution architecture for the management of life cycle business. It consists of customer and functional requirements over the life cycle, product and service features, life cycle functions and operations, modules and components and interfaces (Salminen and Pillai, 2005). All Principles of mass customization of products and services (Pine, 1993) need to be applied in the adaptation of customers’ needs in life cycle business. Interoperation is supported by infrastructure model, which includes common semantics and semantics infrastructure (Pallot et all, 2004). Unlike in traditional capital business in the life cycle business the innovation is very much front-end process. Working closely with the customers and their processes create deep understanding of the customers' value. This life-cycle knowledge is critical success factor for innovating new solutions and enables punctual innovation (Tammela and Salminen, 2006). In this article is introduced enlargement to the known theories and concentrated on product management architecture as fundamental structure to support business co-evolution.

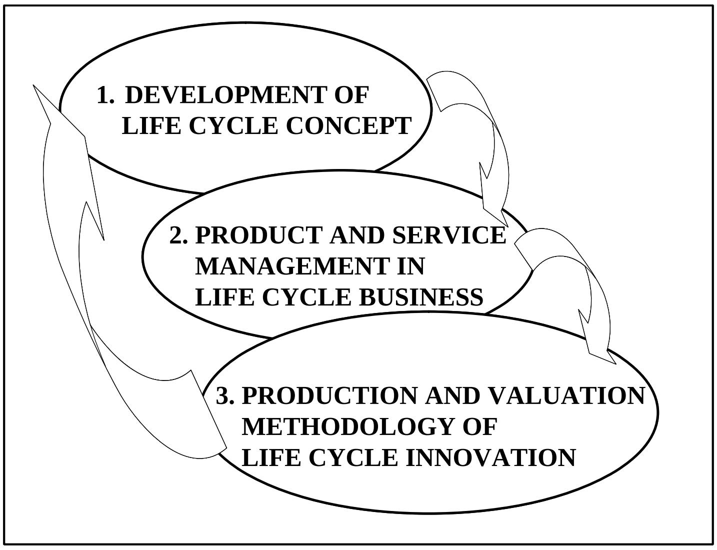
3 Life Cycle Business and Product Life Cycle Management

Life cycle business is understood as an involvement to customer's business process in a long term relationship. Depending on the grade of the involvement the business model is different. The dominating factor is the customer value. When taking bigger role in the customer's business process the focus and the role of the company is changing. Typical path for manufacturing companies to enter in life cycle business is to provide spare parts and product based maintenance services. When the share of the services is increasing company's role is turning to solution partner. The availability services become possible when the services are taking place at customer's facilities. Relationship can develop to role of performance partner where focus is in efficiency of the customer process (OEE).

It is very much a strategic decision for the company in which role it is operating. However the changes in customer's business may open an opportunity expand the role to a service provider or performance partner. For manufacturing companies this opportunity is taking place when customer is outsourcing in-house operations and re-organizing the value network.

Life cycle business in the company point of view can be understood as management of the three elements: Life Cycle Concept, Offering Management and Life Cycle Innovation. (Figure 2.)

Figure 2 The continuous change of the Life Cycle Business



Stepping to a new role in the customer's business is a question of the business transition for the company. The company must adapt new value and operating model. In order to succeed there must be a *Life Cycle Concept* to guide the process. The concept is a strategic plan to implement the new business model.

It is typical in large companies that there are multiple business lines. Each business has own inherent dynamics and maturity. Some customers are ready to move faster and providing new business opportunities than the others. The *Life Cycle Concept* is management tool to control and lead the business transition.

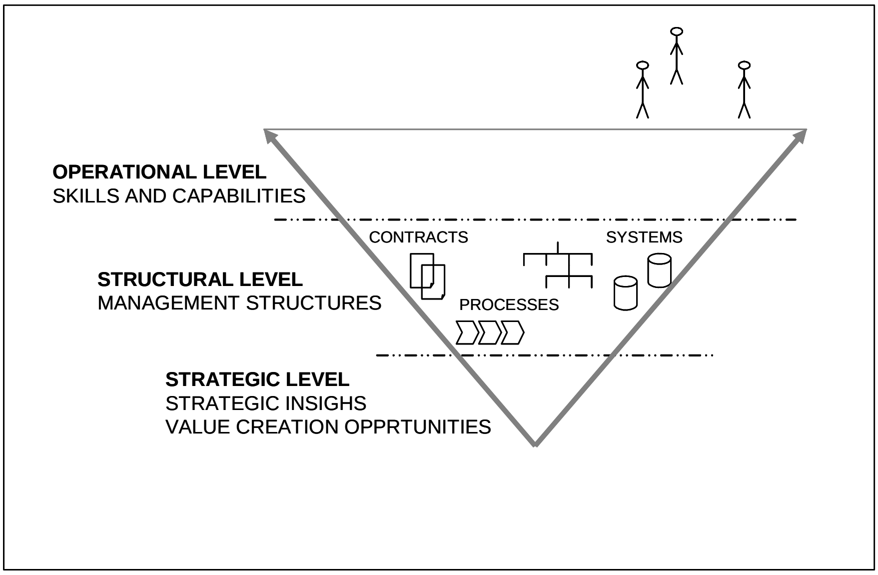
The *Offering Management* covers the products and services for succeeding in the business. When climbing up from the role of machine supplier towards to performance partner the portion of the services increase in the offering. For solution providers the delivery covers the products and the services. There is a point where services cannot anymore handle as an extension of the product. Services need own management structure

Product Lifecycle Management provides the framework to manage the product related data and information providing the platform to develop industrial services. Services can have identity that is not attached to the product individuals; however it can be attached to the customer value. There is a dynamic interrelation with industrial services and the products. The service management needs to take in the same systematic level as a product management.

Life Cycle Innovation is the mechanism that continuously renews the offering. The scope of the innovation is also expanding when climbing up from the role of machine supplier towards to performance and value partner. The product and services are in the scope of the solution provider, but by the services the whole business processes can be innovated. Unlike in traditional capital business in the life cycle business the innovation is very much front-end process. Working closely with the customers and their processes create deep understanding of the customers' value. This life-cycle knowledge is critical success factor for innovating new solutions and enables punctual innovation (Tammela, Salminen).

Manufacturing companies entering into service business undergo a stepwise transition process from equipment-based to more customer-oriented. Methods and structures supporting the business need to be adapted to a new situation. A company, willing to run profitable business in industrial context, needs to master its business transition at three levels: 1) the strategic level and strategic insights, 2) structural level and 3) operational level. Three levels of management are illustrated in (Figure 3).

Figure 3 Three level of management in Life Cycle Business

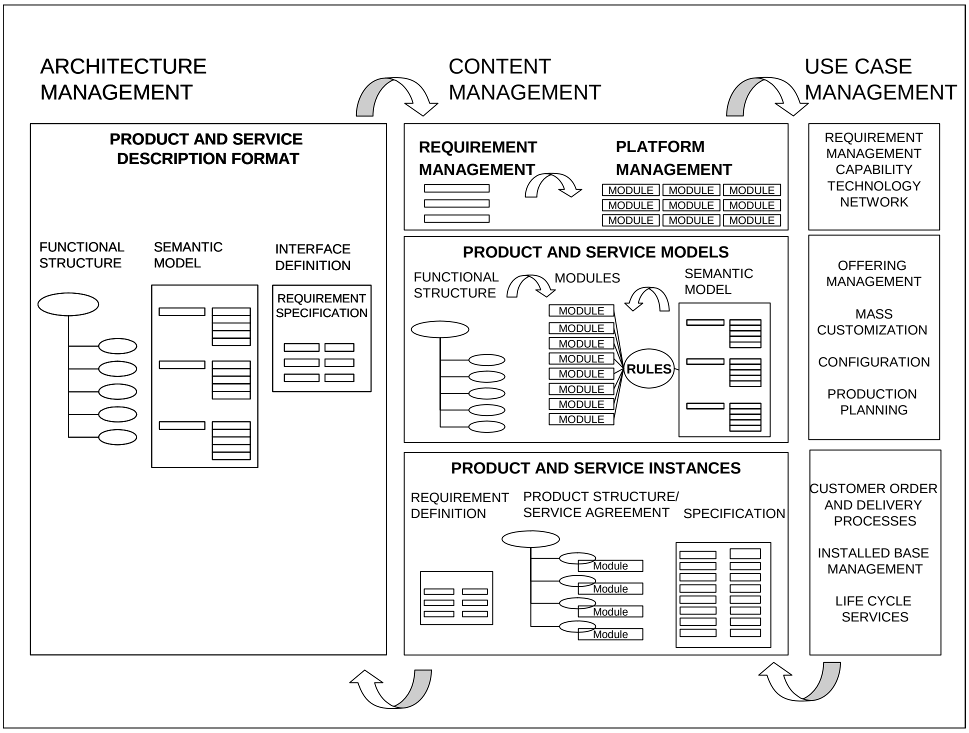


When amount of product and services are increasing, the offering management and the relation between the products and services become more complex. In order to reduce complexity the main focus is to define structures that are able to handle the products and services. This article focuses in defining the structural elements to cover product and service life cycle management and support the continuous change of the life cycle business.

4 Management Architecture for Products and Services

The in order to manage products and services in life business there has to be architecture that is capable of reducing the complexity and handle the dynamics. The management architecture is a framework to manage products, services and related information to support life cycle business processes in the company. The management takes place at three levels: architectural management, content management and use case management (Figure 4).

Figure 4 Management Architecture for Product and Services



4.1 Architecture Management

Architecture management is for defining and managing the product descriptions format in the company. The description consist functional structure, semantic model and interface definition. Using these elements it is possible to create image of the products and services and their substructures. It is a language to express the product and service elements in understandable way in the context of doing business. The description doesn't necessarily need to be attached to any physical artifact or process. This makes it possible to define and communicate the product or service very detailed and precisely before it is created. The description can be used to map the customer requirements.

The functional structure is hierarchic description of the product or service. Functional structure describes the system and its subsystems and how they are related. In modular product architecture the functionality is realized by the single product module and in integral product architecture the functionality is shared with several product modules (Ulrich, 1997). The same function structure can be used to generalize the product description and apply to cover variety of technical solutions of the similar type of products.

By discussing the functionality of the product in external communication it is possible to evaluate product performance in customer process and estimate what functionality is important and has value. Use of function structure reduces complexity in interaction by hiding technical implementation and focusing how the product is used in the customers' process. Company's internal communication functions structure cluster the similar products and product families to share coherent description for the artifacts (products, product modules and parts).

Semantic model is also a hierarchic structure that is used for standardizing the terminology of the products and services and business related information. Semantic model is method not only to manage description language across the systems but also create understanding by giving individual attributes meaning. The terminology in the company is typically spread in different systems (ERP, PDM etc.) and applications. The attributes and item descriptions are often system specific and usability of the data between systems is limited point to point integration definitions. Standardized product and service terminology forms the common semantic infrastructure enabling information exchange between systems.

Life cycle business is knowledge intensive business. Messaging and communication in system environment should transfer the information instead of data. Harmonized terminology and its management using semantic model enable the information messaging. The interoperability is achieved through standardized interfaces and business messages that allow multiple business applications to plug in the system environment.

4.2 Content Management

The content management consist three levels: requirement and platform management, Product and service modeling and product instance management. The requirements are explicit description of the customer needs managed as an autonomous entity. Tracking of the changes in the customers' requirements capture and reflect the market dynamics and carries the changes to the product and service modules in the platform.

Product and service platforms are understood as management of the common modules that can be shared between the products and product families and sharing key technology or competence of the company. Platform management is method to introduce new technology and carry out changes efficiently. Designing of the new platforms is balancing customer value, performance and operational costs.

Product and service models are for managing current offering. Models tie together semantic model and modules. There has to be a distinction of the internal and external description. Internal description is neutral technically oriented set of the attributes to describe the modules and their properties. External description is business related information to reflect the use or requirements of the product or service. External information is described as rule base attributes. The change management of the product and service model is taking place when the modules are technically developed or optimized (internal change) and when the business process or requirements are changing (external change). The division to internal and external changes gives the flexibility and autonomy for maintaining offering. Product or service models are controlling and defining the content of the instances.

Instance management is information management of the product or service individual. Product instances are usually understood "as shipped" or "as build structures". Pre defined products may be also instantiated to express offering. The main purpose for product instance in manufacturing company is to define item structure of the product. For the life cycle services of the installed base the item structure is insufficient description. It can be used for spare part orders but in case of replacement or retrofit the most important issue is to identify whether the use of the product or environment has changed. The requirement specification and product description beside the item structure provide the information of the initial conditions and selection criteria. The changes of operating conditions are taking into account expressed by issuing new version of the requirement definition. Using requirement definition as an interface to define the product it is possible to get the optimum solution from the currently available offering. Managing requirements and product specification information as part of the item structure the engineering work in life cycle services, retrofitting and replacement can drop significantly and the new solution is well optimized based on changed conditions.

4.3 Use Case Management

The use case management is to organize content management to comply and support the business processes. It is typical that the number of people who use the information is much higher comparing to number of people who create the content. Any improvement in usability of information in business processes can have significant impact to organization performance. Product and service information is present in many business processes in the company. Efficient use of product and service information means personalized views and processes. Well organized information management and structured data can provide flexibility to define new use cases and bring the real business benefit. Therefore use cases should be identified as a part of systematic management. Also new business processes and services based on information can take to a scope of innovation.

5 Conclusions

The management architecture presented in this article is developed in the research project of LCB. The management architecture is concept for managing products and services in continuous change and business transformation in a company. Business co-evolution and business transition lean on the semantic structure of architecture in order to manage changes in the offering, business process and system environment.

Common semantic model harmonize the descriptions while detaching them from the content creation process. This enables to define and communicate the offering against the lifecycle requirements in the system environment. The semantic architecture for product and service management is creating infrastructure support product lifecycle management for global operations and optimization of the business processes.

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Product lifecycle management in the ubiquitous world

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Abstract: Ubiquitous availability of information-processing capabilities, computing-power, as well as networking-resources manifests itself in the creation of ubiquitous systems. In this paper, the possible contribution of these 'intelligent' systems to product lifecycle management is analysed. Potential characteristics of supporting systems are presented, which may empower already existing data management systems by functionalities of ubiquity; making in this way a proposal for a possible future development of the product lifecycle management approach (PLM).

Keywords: Ubiquity, future development PLM, innovation

1 Introduction

Enterprises face nowadays great challenges and exigencies in the global, highly competitive, and technology-oriented world, in particular due to the increasing complexity and the variety of products and services demanded to satisfy sophisticated customers requirements. In order to confront these challenges, collaboration across distributed and multidisciplinary teams has become a necessity. The coordination of such knowledge-intensive processes requires a sophisticated ICT supported framework for managing intelligently information about customers, suppliers, partners, and resources throughout the whole product lifecycle.

One of most recent ICT paradigms refers to the ubiquity of information-processing, networking capabilities, and computer-performance through embedding sensors, actuators, and processors in the environment. Moreover, it is assumable that ubiquity may influence the organisation, the management, and even the conception of the processes throughout the product lifecycle. Consequently, Product lifecycle management (PLM) systems may also profit from new ubiquitous functionalities.

This paper presents an approach of how ubiquity can add new functionalities to PLM systems. In particular, here is referred to the potential impact of ubiquity on innovation processes [10], because they represent a significant and important part of the product lifecycle management. First, the foundations of the vision as well as the conception of ubiquitous systems are shortly described in section 2. Then section 3 refers to the possible impact of ubiquity on product lifecycle management, expressed amongst others in the enhancement of innovation activities. Finally, section 4 concludes this paper addressing a validation study and some potential future trends.

2 Ubiquity

2.1 The Basics

Three conceptions that represent the most important aspects of the vision of ubiquity are ubiquitous computing, ubiquitous networking and ambient intelligence. Ubiquitous computing [12] focuses on the creation and/or the augmentation of everyday objects to guarantee ubiquitous provision of operations and services for users. Ubiquitous networking describes an environment for ICT utilization where “a network is connected at any place, at any time and with any object” [5]. Ubiquitous networking accentuates the establishment of networks of persons and objects under consideration of technological aspects, content-based aspects, and organisational aspects [4]. Ambient intelligence is a holistic approach that deals with the arrangement of the architecture, the organisation, and the coordination of all components (especially ubiquitous, embedded, networked, adaptive applications) of the intelligent environment [2]. Ambient intelligence intends to build structures for an optimal self-organisation of the environment with the goal of improving human communication, creating confidence, and providing knowledge and skills for a better quality of life [7].

2.2 Ubiquitous Systems

Ubiquity is embodied through the implementation of ubiquitous systems. Ubiquitous systems refer to systems (assemblage of regularly interacting or interdependent items and/or subsystems forming a unified whole that strives for special goals) characterised by properties of ubiquity.

Properties of ubiquity comprise context-awareness, embedding and miniaturization, ubiquitous availability, reachability and connectivity of sensors, operators, and actuators anytime/anywhere and to anything or anybody, invisibility in terms of calm computing, augmented reality and interactivity.

Context-awareness describes the consideration of context to provide task-relevant information and/or services to a user. Embedding and miniaturisation refers to shrinking sensors, operators and actuators and integrating them into every-day objects in order to realize dimensions of intelligence like perception, interpretation and reaction-capabilities. Ubiquitous connectivity addresses the set up of connections or networks anytime and anywhere, considering technological network issues, configurations, protocols, as well as content-oriented aspects. Availability stands for the expansion of networking, so that it is possible to access information and network resources disregarding the place and the time. Reachability describes the possibility of reaching anyone anytime and anywhere in order to ensure connectivity.

Invisibility illustrates the user’s perception of the application and it is related to the idea of calmness and not disturbing users in their normal activities (calm computing). Its achievement constitutes one of the greatest challenges of ubiquity because it implies technological as well as ethnographic issues.

Augmented reality describes the enhancement of the conditions in the environment extending the perception-capabilities of humans through the integration of the digital and the real world. Lastly, interactivity refers to degree of responsiveness of systems towards the actions of the users.

3 Impact of Ubiquity on Product Lifecycle Management

Performing a successful product lifecycle management is quite challenging and requires new supporting instruments and infrastructure. High levels of interactivity and harmonic work of dispersed actors (designers- and engineering-groups, customers, service-providers, suppliers) enabled by a new quality of information and communication may facilitate overcoming obstacles related to integration, distance, common access, and organisation throughout the product lifecycle. This new quality of information and communication may be enabled by ubiquitous systems, which could even add new functionalities to already existing PLM systems. Approaches in the literature [3] and actual research projects (PROMISE [8]) evidence that (the idea of) implementing ubiquitous features in PLM is very promising.

Under this premise, we propose new ubiquitous functionalities that intend to improve already existing PLM systems.

3.1 Potential Impact of Ubiquity on the Product Lifecycle

Considering that one of the goals of the PLM approach is continuous improvement, innovation management represents a significant part of PLM. For this reason, we will describe possible applications of ubiquity throughout the whole product lifecycle emphasizing in particular on innovation activities.

In the first phases of the beginning of life of a product (while it is imagined and defined) it is necessary to manage efficiently the design activities. Ubiquity could contribute to increase the efficiency of design activities avoiding never-used, not delivered, or nor completed designs. Associating arising ideas with already completed designs, a ubiquitous system could prevent possible repetitions of designs or the creation of very similar ones. By means of multimodal interfaces (voice or handwriting recognition) embedded in the physical environment and interfaces in portable devices (computer, PDA, cell-phone) the system may recognize future possible design-purposes during (design) meetings and provide innovation actors with analogous and useful designs (comparable to Case Based Reasoning systems). Consequently, creativity may be stimulated and ideas may be selected efficiently, contributing to save time and material resources (design rationalisation).

For realising these functionalities following properties of ubiquity could play a relevant role: context-awareness, embedding and miniaturization, calm computing, interactivity, augmented reality and ubiquitous communication and reachability. Context-awareness may support the detection of the "design context", i.e. the logical context of the ideas, e.g. using association techniques. Embedded interfaces in the physical facilities may capture design information on user's demand (calm computing). The user may be enabled to decide whether activate or deactivate the operation of such features. Interactive characteristics may permit the communication of the system with the designers. Augmented reality may upgrade the quality of data related to prior ideas and projects, e.g., multimedia files may support the explanation of designs, or additional information onto the working surface may enable e.g. a proper simulation. Ubiquitous communication and reachability is fundamental in distributed design meetings, particularly because it is necessary to recognize the context of design for localizing and contacting the necessary expertise or experts.

All these ubiquitous functionalities could empower *Pervasive Design Management* as a possible extension of Product Data Management Systems that manage all information around products: CAD models, drawings, their associated documents, product visualizations, etc.

During the subsequent phases of the beginning of life (by the realisation of the product/service) ubiquity can contribute to find out potential improvements in the product or in the (manufacturing) processes using the information related and stored by the product itself and/or by the operation facilities. Ubiquitous functionalities may even facilitate the capture of information/knowledge during the whole life cycle of a product, which is currently very time-consuming and cost-intensive. Seamless information flows for controlling and measuring the performance of the whole life cycle could be enabled by ubiquitous connectivity. Sensing and tracking capabilities may allow attaining information about products and their location. Embedded technology in products may facilitate capturing information during their fabrication, their distribution, and even during their use (middle of life). Ubiquitous connectivity and embedded technology may enable the communication among products, to other objects or to persons. Possessing information about themselves may permit them to decide and negotiate their own destination. Products may communicate to persons, e.g. users/customers, which could voluntarily provide information during the use of the product. This information could be immediately sent out or collected in the memory of the product and made available during the end of life of the product (recycle or decommission). Moreover, invisibility in form of calm computing may be of especial relevance for customers or users during the capture and the provision of data. Users may obviously be aware of and should authorise sending their information if they wish to. Nevertheless, it is important to consider by the development of ubiquitous features that the way of capturing information should be neither intrusive nor disturbing.

Coordinated and decentralised management of information about fabrication, distribution, and use of similar products could support the improvements of already existing products or encourage designing future ones. Hence, this information may give a reference for adding new functionalities in form of additional services. In sum, all these features may enable *Ubiquitous Management of Process and Product Information.*

Integrating customers in the product lifecycle in a more intuitive way than it is possible today could also be realized by means of ubiquity. Three different scenarios of potential implementation are here referred: integrating customers in an ‘artificial’ environment (e.g. living labs)**,** contacting customers directly in the place of consumption or in communal places and creating communities that share similar problems or interests. Discovering errors and malfunctions as well as solving common problems during operation and application may be facilitated through real-time communication between customers and other actors of the product lifecycle processes. Embedded technology in decommissioned or recycled products may allow collecting information about customers’ behaviour during the whole period of use. Context-awareness is crucial for distinguishing different contexts of use or diverse uses of various customers, embedding and miniaturizing are responsible for integrating sensing platforms in the environment and in products; calm computing is essential for not altering the real conditions of use or not disturbing the customer and augmented reality for supporting users by resolving problems during the operation of products. These functionalities may make possible the *Ubiquity-supported Customer Integration* in the product lifecycle.

Ubiquity may enable a better involvement of suppliers throughout the product lifecycle. Adequate suppliers could automatically be contacted according to the actual context of the tasks during the lifecycle or of the product, or to specific conditions. Embedded technology and ubiquitous connectivity may accelerate tagging and reaching all the potential (dispersed) suppliers; even if they are en-route, they can be localized or involved through applications in their mobile personal devices. Context-awareness and ubiquitous connectivity combined may support an intensive but adequate information exchange with the suppliers. Ad-hoc and spontaneous meetings could be autonomously generated but always considering a calm-technology atmosphere in order to respect and not disturb the suppliers' or the other actors' privacy. Augmented reality may add a new dimension of quality to the exchanged information. All these features may permit an *Intelligent Supplier Involvement* in the product lifecycle.

Successful collaboration (co-located and dispersed groups, synchronous or asynchronous, symmetric or asymmetric) is an essential part of the PLM approach. Ubiquity could support the organisation and the technical realisation of collaboration in all its forms. This may be enabled by the coordination of tasks like capturing and exchanging knowledge, distributing experience and skills of multiple team members, etc. Ubiquity may simplify contacting and localizing potential collaborators independent of their location and respecting what they are doing. Embedded and miniaturized software and hardware may augment the capabilities of devices, which are already used for (remote) collaboration. Context-awareness may support the perception of the actual context of the participants so that on the move and without interrupting their main tasks, suppliers, manufacturers, distributors may exchange information at the time that this information arises or when they are disposed to do it. Thus, ad-hoc collaboration and communication of expertise and experience of external collaborators (synchronously or asynchronously) may be empowered. Augmented reality may support the exchange of ideas and concepts preserving the meaning given by their originators. Consequently, through the fulfilment of the previously explained features *Ambient Collaboration Management* during the product lifecycle may be the result.

Project Management throughout the product lifecycle could also profit from ubiquity. Task- and resource assignment, workflow management support and scheduling may be some examples of functions that could benefit from ubiquity. Context-awareness and ubiquitous connectivity may simplify task- and resource assignment. Availability of materials and capacities at any location and at any time may be also enabled through ubiquitous connectivity and reachability of objects and persons. Embedded technology in machinery, resources, and surroundings may enable a dynamic resource allocation and resource mapping. A successful workflow management, based on an efficient diagnostics of errors and an efficient discovery of enhancement potential, may be facilitated through embedded technology in machinery, resources and even in products.

Tracking information flows especially during operations could enable an easy access to common used services and information. Scheduling and coordinating appointment calendars that run in different devices as well as the matching of interactions of users for sharing common goods and services may be supported by context-awareness, ubiquity, interactivity and embedding and miniaturizing. Context-awareness may provide potential participants with the necessary context information. Therefore, it may be possible to know if they are available and with which device or through which communication channel, they should be localized and reached. They could build spontaneous project groups with people dealing with the same topics in which they are working on.

Ubiquitous connectivity may support the provision of information about available resources or services as well the localization of actors. Interactivity may be active in the constant updating of information about realized tasks, used resources and their interrelations. Localizing physical goods, material and disposing information about their actual state in real time could enable a better resource management and having this information before the beginning of manufacture may help not to waste resources because no additional crude materials will be bought if there is enough material stocked. All in all these functionalities may allow *Ubiquitous Project Management*.

Embedding sensors, displays, or multimodal interfaces in prototypes may permit reaching a better quality of the interaction with testers during the creation of the product. More transparency, less failure rate and efficiency in the communication among the different participants as well as in the transmission of their opinion, ideas, and preferences may be afforded because the prototype may carry this information by itself. Experiences with a prototype in specified situations could be recorded and analyzed. In particular invisibility (through multimodal interfaces) and interactivity to promote reaction and feedback of the test persons while using prototypes should be considered in the integration of ubiquitous technology into prototypes. Furthermore, context-awareness may assist by recognizing different behaviours of test-persons according to their actual contexts and embedding and miniaturizing of devices (cameras, sensors) may make new forms of obtaining information about users and their environment more feasible. In other words, *Smart Prototyping* may benefit from ubiquitous technologies.

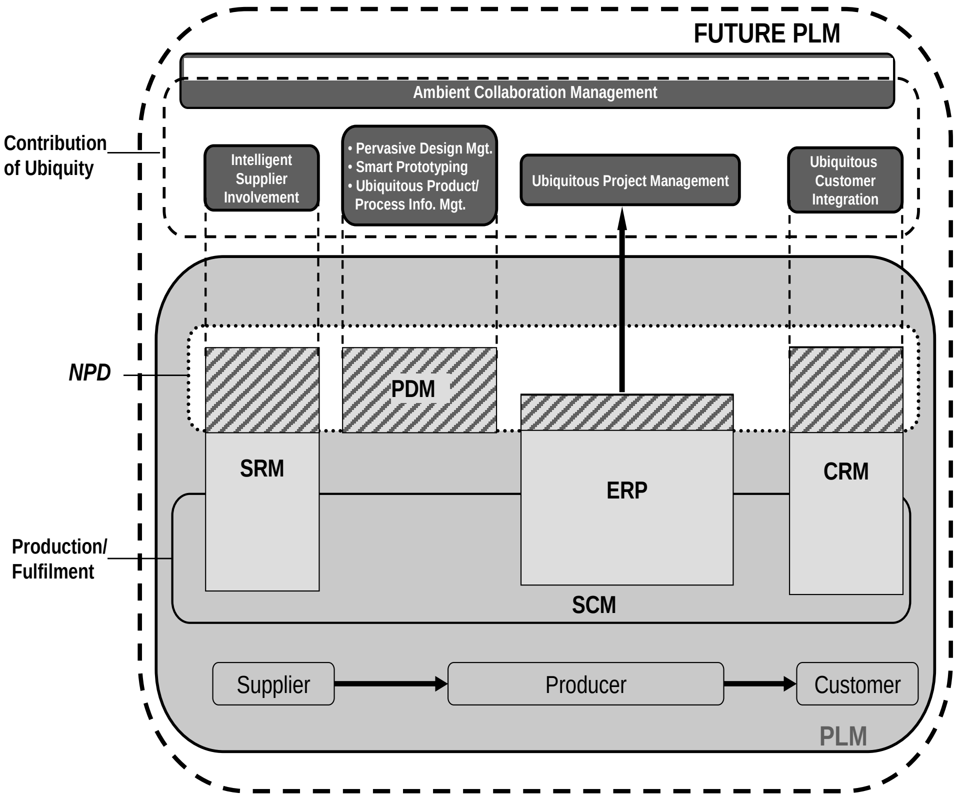
In the last phases of the product lifecycle: during use, maintenance and decommission of products ubiquity can facilitate the integration of customers, the involvement of suppliers and the attainment of information stored during the life of the product. The feedback of customers during the use of product/services as well as their reactions in different contexts of use may be captured and stored. Through mobile applications or interfaces embedded in the utilized products customers may be able to communicate directly with other actors of the product lifecycle, e.g. the innovation team. Customers could provide ideas for new after-market services so that their demands could be fulfilled in short time. Contacting suppliers during the use of the product may enable fast and adequate reactions to the preferences and the demands of the customers for enhancing the product of the next generations. Suppliers could gain ideas for new materials and value added services and develop them in short time. Maintenance may profit from ubiquity, e.g. customers (operators of the machines) can interact with expert technicians, who would be able to get the information stored by the product itself in order to detect malfunctions. Ubiquity may enhance and accelerate the direct communication between technicians and suppliers. As a result, technicians may have access to actual and accurate information for an efficient maintenance. Data about failures and malfunctions of a certain product may reach the design and development team in short time, which enables the quick inclusion of this information in the next products or for the creation of complementary services.

3.2 An extended PLM Approach

PLM systems comprise a collection of hardware and software technologies that support the product lifecycle [11]. An ideal PLM would gather in one electronic space all the digital data that exist or will ever be created for a product; integrating product data management systems (PDM), enterprise resource planning systems (ERP), customer relationship management systems (CRM) and supplier relationships management systems (SRM).

PLM systems may be able to select innovation-related information from the various integrated subsystems. A proposal of in which proportion - either totally or partially- the data captured by the different systems are related to innovation activities is illustrated in Figure 1 by the dashed shades in the different "traditional" PLM systems. Some of them may be of greater influence than others; e.g. PDM systems will be more strongly involved than ERP.

Figure 1 PLM Approach enabled by Ubiquity



As it was described in Section 3.1 ubiquitous technologies may support the collection of all the data from the ideas, designs, and/or computer-based models to information about suppliers, marketing studies, maintenance, and warranty-records throughout the whole life cycle. Thus, it is obvious to assume that ubiquitous technologies may also actively support the innovation activities as it is shown in the Figure 1 through the extension of the selected parts (dashed) of the different PLM systems by ubiquitous features.

Intelligent Supplier Involvement enabled by ubiquitous technologies may represent additional functionalities to the already existing Supplier Relationship Management (SRM) systems specialized on data related to new product/service/process development.

Pervasive Design Management, *Smart Prototyping,* and *Ubiquitous Management of Process and Product Information* could enrich Product Data Management systems (PDM) adding new features. *Ubiquitous Project Management* may be the perfect complement of Enterprise Resource Planning systems (ERP). *Ubiquity-supported Customer Integration* may enhance Customer Relationship Management systems (CRM). *Ambient Collaboration Management* throughout the whole lifecycle may be an integral amelioration of the PLM systems. Due to the fact that collaboration is essential for the realisation of innovation activities, part of this system may be included in the group of subsystems concentrated on enhancing new product development, as it is shown in Figure 1.

Figure 1 provides a principal view on the product lifecycle following the value adding process. Topical conceptual considerations from leading software providers focus on networking and adaptivity and supporting considerably collaboration and ubiquitous awareness of any relevant data along the lifecycle of products. Accordingly, SAP's Adaptive Business Networks conception as a program for the reorganization and synchronization of many businesses through real-time collaborative processes [9, p. 5] is based on 'Real World Awareness'. This term refers to 'specific techniques such as RFID, global positioning system (GPS), mobile applications and other methods of sensing information about the real world and providing data to computer systems'[1].

On the other hand, the ORACLE Product Lifecycle Management application offers various capabilities to accelerate new product introduction, to securely collaborate with extended product teams and to enable workflow-based product idea reviews, feedback, and approval [6]. The ORACLE E-Business Suite is ready to perform most of the ubiquitous features indicated in Figure 1 as well as in the previously presented text, as soon as appropriate sensing and tracking technologies are implemented. The same opportunities can be seized and supported by the mySAP Business Suite not only to create adaptive supply networks but also to establish adaptive product development processes. Altogether, the emergence of ubiquitous technologies will extremely influence the networking and collaboration oriented software systems of the future.

Implementing ubiquitous features to existing PLM-systems may make the product lifecycle more effective and efficient, especially innovation activities could be improved and accelerated. Context-aware information may contribute to make PLM systems more flexible and adaptable. Embedding of miniaturised technology into objects (products, operation facilities, and systems) and ubiquitous connectivity may make available seamless and transparent information around a product/ service/ process.

Peer to peer interaction will be possible through objects carrying and processing information by themselves at the places and at the time it is required. Product-oriented dynamic networks with changing participants according to the requirements could be generated. Augmented reality oriented visualisation techniques and the capability of interacting with information/knowledge on real time and in an unobtrusive way without invading the private sphere of the participants represent some of the benefits expected from ubiquity.

Ubiquity may also enable the intuitive and seamless integration of product design information with customer-, processing-, costs- and resource planning data providing every demanding innovation actor (person or object) inside and outside the firm with the required information at the right time and at the right place. In consequence, the implementation of different processes from different chains in one virtual environment may be possible.

4 Conclusions

We assume that the presented ubiquitous features could be crystallised in form of ubiquitous systems, which may offer a new quality of information for improving data sharing, joint planning, joint problem solving in all activities throughout the product lifecycle. The explained functionalities evidence how properties of ubiquity could contribute to enhance the performance of existing PLM systems. They would make capturing and storing information around a product and its creation during all the stages of the life cycle easier and better organised. Efficient use of information, easier access, and management of product related data in real-time as well as continuous updating of product information would be less difficult or time-consuming.

Beyond all the mentioned opportunities and advantages there are, nevertheless, also numerous constraints or limits of these technologies regarding the current PLM applications and environments. These limitations are partly due to missing technical features, but in particular due to open questions concerning safety, confidentiality and privacy of data captured in a 'ubiquitous world'.

In order to bring these ubiquitous systems into being, we conduct a study, which consists of three parts. In the first part ICT experts evaluate the chances offered by ubiquitous technologies especially for improving collaboration processes. In the second part innovation management experts analyse the potential impact of properties of ubiquity on selected success factors of innovation processes, e.g. robust project management, clearly documented new product development processes, use of concurrent engineering, the existence of cross-functional groups, etc. Thereby the goal is finding out what properties are relevant for the realisation of the success factors. Considering the results of the first and the second part of the study we intend to formulate scenarios for illustrating concrete features and characteristics of future ubiquitous systems for extending PLM systems' functionalities. In the third part of the study PLM engineers and users of PLM systems will evaluate the feasibility of such scenarios, which may provide the perfect basis for the implementation of prototypical versions.

Actually, the first part of the study dealing with the technological evolution of ubiquity and its timing has resulted in a quite 'optimistic' view on the maturity of these technologies within the next decade. In parallel there are careful discussions and significant research approaches in particular towards (intellectual) property protection and privacy of data needed in order to arrive at a common 'social' sense about the acceptance of these types of 'ambient intelligence'.

The results of the second part of the study show also openness for the introduction of these technologies in innovation processes. The consulted experts emphasize in particular the importance of interactivity, ubiquitous connectivity, augmented reality, and context-awareness among the properties of ubiquity for the innovation management.

Both examinations evidence that the world is already prepared for ubiquity. With the results of the third part of the study our expectations towards PLM could legitimately be validated and implemented.

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Life cycle analysis using product semantic model for reliability and maintainability assessment

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Abstract: Product Life Cycle Design is a global design approach aimed to take into account the different factors that may influence the product technical performance and business competitivity Xue (1998). This approach attempts to bring solutions to enhance classical CAD systems that are mainly geometry and topology oriented. This evolution is due to the need to validate the product functionalities and to take care of the impact of the design solutions on the product behaviour with respect to the different criteria like maintainability, reliability. Such criteria are semantically specified and there evaluation evolves the use of approaches that can provide indicators at the early stage in the design process. In this paper we present a product design framework that supports product information along the lifecycle design process. After the introduction, we give in section two a general description of the Product Lifecycle and related data. In section three, we propose the Lifecycle Design Framework using a PLM system for recording reliability field data. In section four, we outline a Lifecycle Analysis procedure using a PLM system for updating reliability field data and maintenance documentation. In section five, an application is sketched for maintenance documentation customization from a generic one.

Keywords: Lifecycle Analysis, Reliability, Maintainability, Customization

1 Introduction

In mechanical systems lifecycle design, Maintainability and Reliability represent important characteristics strongly related to the product serviceability. Recent CAD Systems try to integrate product life cycle knowledge at early design stage. In such systems called Knowledge Based Design systems (KBD) the design environment provides not only geometric features but capture additional knowledge that may be used for further analysis for design solution validation over product lifecycle. This need becomes more crucial in the case of products to long life span in industrial sectors such as aerospace, automotive or maritime engineering. In such sectors products life span lays from five up to 15 years or more. In addition such products are intended to mass customization and to be submitted to a large variety of utilization constraints under

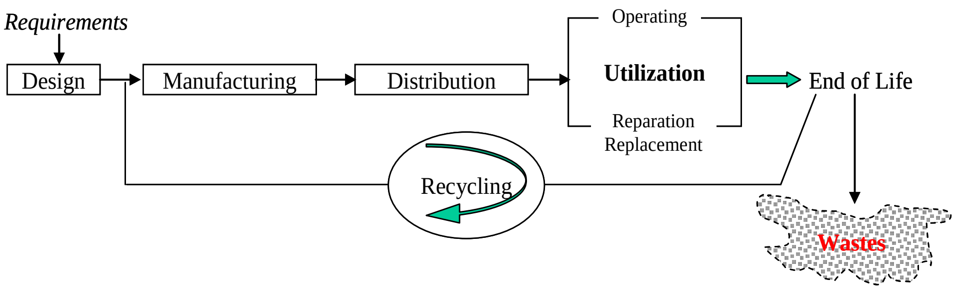
different environmental conditions wind, road or sea turbulence, rainy weather, dusty or corrosive atmosphere and temperature variations, users comfort, etc…[1, 15].
In such conditions the CAD system deals with a great amount of design parameters (geometry and dimensions) and it becomes so heavy and complex to manage additional information related to other lifecycle downstream stages including utilization constraints and maintenance operations management. PLM systems are mainly aimed to solve such problems but of them are generally limited to data management aspects and to not include semantic information analysis functionalities. Various attempts have been made by researchers in developing approaches for evaluation of maintainability and to predict reliability over its lifecycle. In our previous work [2], we proposed an enriched CAD model with behavioral semantic data, in this paper, we propose to build a product lifecycle semantic model to capture field data collected by the customer service to allow continuous recording and up to date reliability and Maintainability assessment.

2 Manufactured Product Lifecycle

2.1 Lifecycle phases

The Figure 1 shows the product lifecycle from the design stage to its destruction or recycling. In this cycle the Design phase is a very crucial step that determines the main decision related not only to the product definition and manufacturability but also to its behaviour during utilization and end of life phases, [18, 19]. As example, the Airbus A380 required about 6 years for development phase and is designed for a mean life time of 30 years.

Figure 1 Manufactured Product Lifecycle



During its utilization period the product performance are commonly defined by its availability, which depends on reliability, safety and maintainability. These three characteristics depend on the product structure and on the utilization conditions. Here we are specially focused on the reliability and maintainability evolution during the life span, Table 1.

Table 1 Life time for some current products

Products	Mean Life time	Reliability	Maintainability
Car	*10 - 15 years*	$R_1(t)$	$M_1(t)$
Plane	*30 – 35 years*	$R_2(t)$	$M_2(t)$
Boat cargo	*20 – 30 years*	$R_3(t)$	$M_3(t)$

The following section describes the product structural data and some analyses performed at design stage for structural validation and functional verification.

2.2 Product Structural Data

Traditionally, the first step in design process deals with the translation of the requirements into functions that the product has to realize and to define the different constraints to be fulfilled. The functional specifications are made using a traditional Functional Analysis diagram. This diagram helps for identifying the product main functions, the constraints to fulfill and the relationships between the product and external elements, [16]. These functional specifications are used as the basis for design requirements validation by designers and customers. Different other virtual reality systems are also used to test the mechanisms functionalities, [10].
The second step defines the different components of the product. Then the product structural model is derived from the functional specifications by matching functions with parts or sub-assemblies that realize each specific function. Note that several functions may be realized by a same set of parts or by a same sub-assembly. Thus each function or group of functions is associated to structural elements. In the following sections

2.2.1 Geometric data

Geometric data are defined by specifying parts geometry, dimensions, other material physical properties and assemblies' topological and mating constraints. These data are defined in the CAD system and used to perform static or dynamic structural analysis. In a few situations fatigue analysis aimed at predicting operating performance of components and systems under fatigue loading [3, 12].

2.2.2 Assemblies data

The product different components are attached to each other by means of links types that are expressed in terms of mating conditions between components C_i and C^j and assembly accessories and fasteners (screw, rivet, welding, etc …).

$$(C_i, C_j, \text{fastener}) \in \{\text{Assembly link types}\} \qquad (1)$$

Very often only topological and mating conditions information are specified in a CAD system and data about links types are not available. In most cases assembly models are used to perform product functional performance analysis by cinematic and dynamic simulations software.
The different analysis at components or sub-systems are intended to develop integrated design approaches which reduce both the time and ongoing cost of the development of innovative products, while at the same time guaranteeing a sufficient level of reliability. But very often, these analysis are focused on some specific and limited set of components and sub-assemblies they do not consider enough the product behavior in future operating conditions. Some works attempt to capture and share product data semantic between designers, but the proposed models are not intended to product behavioral performance assessment, [5, 9, 11].
So such analyses are not sufficient to assess product behavioral assessment. In our previous works [4], we proposed a framework for modeling and assessing behavioral performance. This modeling approach is briefly outlined in the next section. Then we propose a PLM based solution to perform continuous updating of reliability and maintainability evaluation at utilization phase of the product.

2.3 Behavioral Model for Performance Assessment

2.3.1 Components and sub-assemblies semantic data

After the product structure is defined in terms of components and sub-assemblies, assembly links between components, we decompose the product according to reliability and maintainability requirements. Then an object-oriented product model is elaborated including:

- intrinsic factors that depend on the product structure: geometric and dimensional tolerances, material characteristics dispersion…, and
- Contextual factors like: temperature, dust, and humidity depending on the specific environment in which the product will be used.

2.3.2 Semantic Matrix

The product design solution is assumed to consist of multi-components structure built using a set of components which are bind together by different types of assembly links. If some links consist of detachable fasteners, the product is decomposed into sub-systems, or single parts, by removing the links. The Semantic DSM Matrix shown in Figure 4 represents the product CAD model data with additional semantic data concerning non graphical characteristics that may have quantitative or qualitative values. A n-components product is described by its C_i (with $i=1...n$) components. The P_i diagonal elements represent the components semantic properties. So P_i is component semantic attributes vector including various types of information like: material properties, surface state, heat treatments, surface treatments …Then, for component C_i, the attributes vector P_i is defined by:

P_i= Vector (*material properties, surface state, surface treatment, heat treatment, density, volume, surface …)* (2)

Additional characteristics like functional criticality (K_i), reliability (R_i) are also considered in this matrix. The link type for every couple of components (C_i, C_j) = L_k is the assembly type between components C_i and C_j. L_k takes different values depending on how two components are assembled. K_i, and R_i stand respectively for the functional criticality and reliability associated to component C_i. The functional criticality level is estimated by the designer depending on the relative weight of the different components. K_0 is the threshold level of criticality used to identify critical components to be considered for maintainability indicator calculation. R_0 is the product global reliability threshold fixed in the requirements specifications, [14, 2].

So, auxiliary information is captured at two levels: for each component in its semantic vector P_i and for sub-assemblies in the link type describer Link (i, j) between each couple of components C_i and C_j. These information are initialized with default values stored in a database. Then, if necessary, the designer can modify these values to match particular specifications.

To perform the behavioral performances evaluation, we include the semantic matrix information into a FSB (Functional, Structural and Behavioural) product generic model. For a domain D, the criteria are defined as required conditions to ensure an acceptable behaviour; criteria are then used to build a qualitative or quantitative indicator that informs the designer on the proposed design solution referring to D.

Figure 4 Products Semantic Matrix

Components	C_1	C_2	-	-	C_j	-	-	-	C_n	**Contextual influence**	**Reliability**
C_1	P_1	2	0	1	0	1	5	2	0	E_1	R_1
C_2		P_2	2	1	0	0	0	2	0	E_2	R_2
-			-	0	0	0	0	2	0	-	-
-				-	1	0	0	2	0	-	-
-					-	1	0	2	0	-	-
C_i	LinkType ($C_{i,}C_1$)=Li-1				LinkType ($C_{i,}$ C_j)=Li-j	-	1	2	0	E_i	R_i
-							-	2	0	-	-
-								-	5	-	-
C_n									P_n	E_n	Rn
Number links	d_1	d_2	-	-	dj	-	-	-	dn	**E_0** (threshold)	**R_0** (threshold)

2.3.3 Reliability Prediction at Design stage

Different Reliability Database for industrial equipments are available to advice the designers on the choice of components [10]. These data can support equipment availability analyses, reliability and design improvements, maintenance strategies, quantitative risk analyses, and life cycle cost determinations.

For brand new components for which no sufficient statistical data are available the reliability can be estimated using:

- virtual samples tests techniques, [20];
- Accelerated Life Testing technique where the difficulty is how to reproduce contextual conditions and constraints under which the product will be submitted.

In these different cases the components reliabilities are assumed to be constant ($R_i = \alpha_i$) and in most of lifetime distribution models. For reliability prediction at design stage the Weibull distribution is commonly used as in equation 3 and Figure 5.

$$R(t) = 1 - \lambda(t) = e^{\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \quad (3)$$

where:

β is the shape factor;

η is the scale factor

γ is a geometric parameter, γ =0, here.

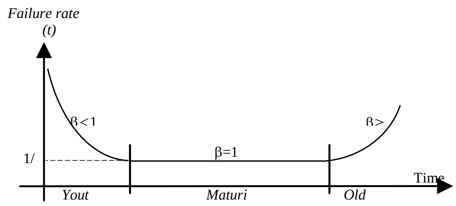


Figure 5: Weibull failure rate distribution

These components reliabilities predictions are mainly used to define:

- critical components checklist;
- spare parts stock;
- preventive maintenance program documentation.

In our previous work, these reliability data are used as input to the product semantic matrix. Then we propose a method for product maintainability index evaluation [4]. This method allows maintainability prediction at design stage.

2.3.4 Maintainability Prediction at Design stage

In practice, to evaluate the maintainability, the 1010/CCT specification defines the MTTR (Mean Time To Repair) as a most significant criterion. It is defined as the total time required for making diagnostic, reparation or replacement and control. For better maintainability the MTTR must be as short as possible to minimize the repair times, thereby minimizing the downtime and increasing the product availability, [7].
To evaluate the MTTR, we consider the criteria related to Disassembly/Assembly operations required to replace or to repair critical components as mentioned in our previous paper [8, 17].
The problem is the following: for long life span products (15 to 40 years), it is well known that the global reliability varies in the time depending on different contextual factors like usage profile (production speed), Temperature, dust. So the product reliability must be updated regularly in order to adjust maintenance documentation. In the next section we propose a PLM Based Lifecycle Design Framework that allows this continuous recording of reliability field data and then reliability updating.

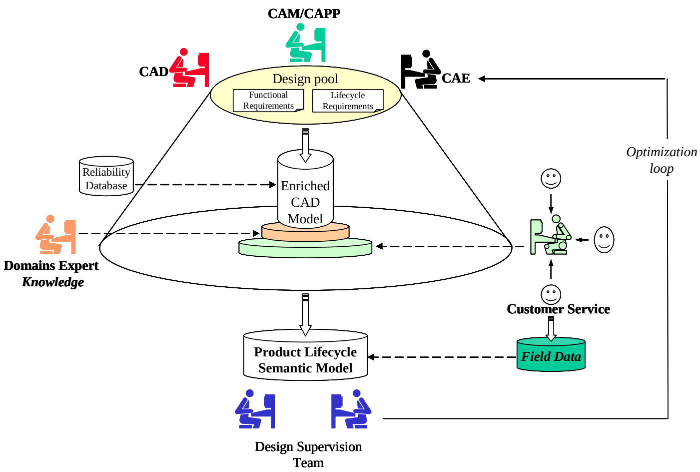
3 PLM Based Product Lifecycle Design Framework

The reliability field data continuous recording functionality is not implemented in traditional CAD Systems. We propose to include into a PLM system package a module dedicated to this purpose.

3.1 Design Framework

Figure 6 outlines the proposed framework including a CAD system, a PLM system and an add-on module that deals with reliability field data recording and downstream statistical calculus.

Figure 6 Lifecycle Design Framework



This framework is aimed to share information among the designers and experts from various skills and know-how, who model and analyze products in various ways. Then the proposed model integrates the various behaviors of the product at any stage of its lifecycle. Product behavior depends on the both its specific characteristics and contextual conditions.

3.2 Reliability Field Data

In utilization the same product may behave very differently depending on the usage profile and other environmental conditions.

3.2.1 Usage profile

This concerns the way in which the product is used for example the same plane can be exploited in a very intensive flight frequency, the long flight, with turbulence conditions, and on different landing runways, [1,13].

3.2.2 Environmental conditions

The same product can be utilized in a very cold/hot temperature, dusty, humid or corrosive atmosphere. In some extends this influence is considered at design stage but the real operating conditions are very often far from that imagined originally.

3.2.3 Failure data

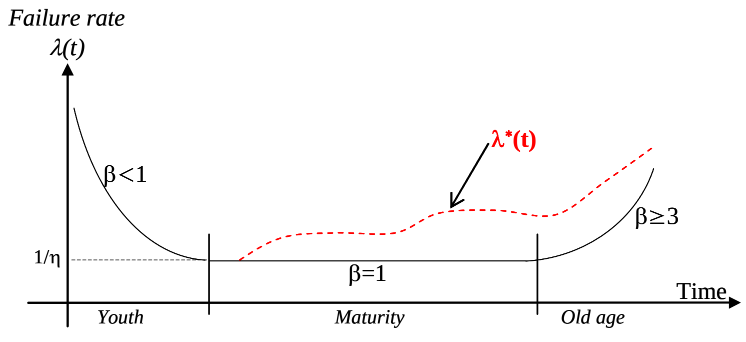
The reliability field data must be collected and sent by customers to the online database dedicated to storage of failure data. Such data must be analyzed by the design supervisors team to update reliability and maintenance documentation.

4 Updating Reliability and Maintainability Analysis using a PLM system

4.1 Lifecycle Assessment of Reliability

Depending on the field data, the actual reliability, R^* may derive from prediction as shown in Figure 7. The variations can be monitored using a PLM system add-on module mentioned above.

Figure 7 Predicted and field reported failure rates



The differences between the predicted and the field failure rates can be detected by statistic analysis of field data as in a format in Table 2.

DATES & TIMES	FAILURES DURATION	CAUSES	COMPONENTS	USAGE PROFILE	- - -	T°C

These data may be sent into the online database daily, weekly or monthly depending on the failures occurrence frequency.

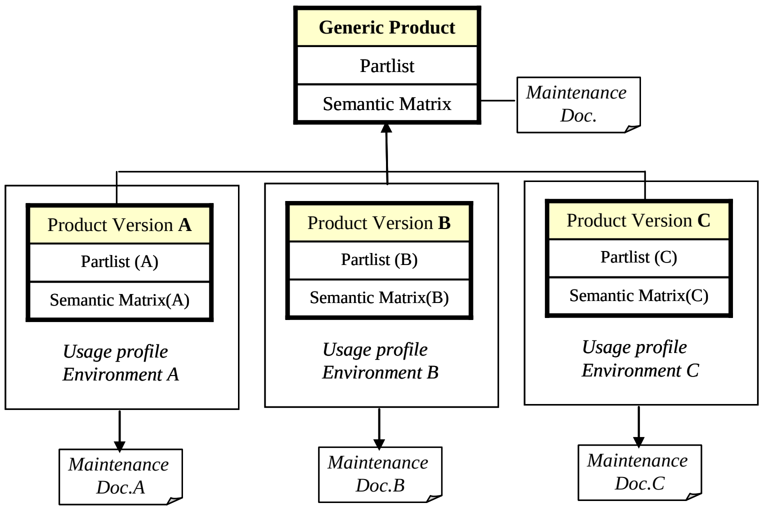
4.2 Lifecycle Assessment of Maintainability

Maintainability assessment over utilization phase must be revised according to the reliability. In fact, the MTTR as defined in our approach depends on the set of critical components and this set may vary with the reported field data, [6].

5 Application for Maintenance customization

As previously mentioned, very big companies in aeronautics and automotive industry whose main job consists of designing and assembling parts are wondering about the reliability and maintainability during the lifecycle of their products. Unfortunately, we benefit most of the time of only one generic maintenance documentation based on parts list. However each product is unique because of its parts provided by different suppliers, due to the large variety of usage profiles constraints in different environmental conditions, kind of technical links between parts, functional options, etc. As a matter of fact, we could have different products with the same parts list, this is especially the case for airplane; each airplane is a unique product [21, 22], Figure 8.

Figure 8 Generic Product and its instance items



However, all these characteristics of the product are not really taken into account so the assessment of the reliability and maintainability is an approximation for a non-real generic product and not for each of the different items of a product. This problem is highlighted in the management of options. Indeed, the actual solution is to have additional maintenance documentations without really taking into account the impact on

reliability and maintainability on a product instance and also without taking into account the interaction between options. This problem is encountered also when the product evolves due to the replacement of some parts.
In a close future, our purpose is to propose a customization procedure of the maintenance documentation production with assessment of the reliability and maintainability for each instance of the product during its lifecycle. To this aim, one mean to identify the structural characteristics of each instance is to download thanks to PLM approach each CAD parts models to build a virtual copy of the real exemplary of the product. Then thanks to existing software developed in ETS, Université du Québec, Ecole de Technologie Supérieure, we can identify similarities and differences between the generic product and each instance. Then we intend to build semi-automatically customized maintenance documentation thanks to Products Semantic Matrix described in Figure 4.

6 Conclusion and future work

For long life span manufactured products the reliability is submitted to important variations depending on the usage profile and environmental conditions. In this paper we propose an approach to allow continuous recording of reliability field data. The system consists of a framework including a CAD system, an add-on recording module that collects and stores field data in an online web database implemented in a PLM solution.
The system is aimed to update reliability assessment in order to adjust maintenance program documentation. So it gives the opportunity to elaborate generic maintenance documentation for typical products lines. As future work we are investigating possibilities for providing customized maintenance documentation for similar items.

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Chapter 10

Lifecycle engineering and assessment

Lifecycle analysis aspects of biofuels

What can be learned from a practical case of inland waterways transport?

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Abstract: An experiment done in Geneva on the river Rhône with a push boat gave the practical frame of a comparative study between 3 fuels: diesel, biodiesel and vegetable oil. Further more in this concrete case the VO used, came from frying oil waste constitutes an interesting illustration of industrial ecology.

The asset of this study on environmental impacts analysis done here is to have used practical measurements of emissions from an engine in function on the push boat in complement to bibliographic sources and Data Base.

Investigating the sensibility of such analysis shows that there are still questions to be answered and that this field is still subject for research.

Finally, it confirms that the environmental gains of biofuels scenarios are not as important as expected, if their vegetable raw material is produced uniquely for energy as in the transport function. They are much more interesting when used in an industrial ecology context where a first cooking function allows dispatching of the production's impacts.

Keywords: industrial ecology, environmental impacts analysis, LCA, biofuels, diesel, biodiesel, vegetable oil

1 Introduction

Biofuels play an important role in R&D of renewable energy. The use of biodiesel or the appropriate mixture of diesel oil with vegetable oil as fuel for diesel engines has the advantage of needing little or no modification of an existing engine.

An experiment done by the SIG (Services Industriels de Genève) at Geneva, consisting in the use of a mixture of diesel oil / vegetable oil in a propelled push boat, used to push barges of waste on the river Rhône gave the practical frame of a comparative study between 3 fuels: diesel, biodiesel and vegetable oil (SVO). Further more in this concrete case the VO used, came from frying oil waste (WVO), which constitutes an interesting illustration of industrial ecology. It is quite important here to point out that in the frame of Agenda 21, the state of Geneva introduced in 2001 a law [1] that encouraged initiatives of industrial ecology. In that perspective, it is important to find opportunities to exchange material waste or energy through a network of industrial partners and to put this in practice.

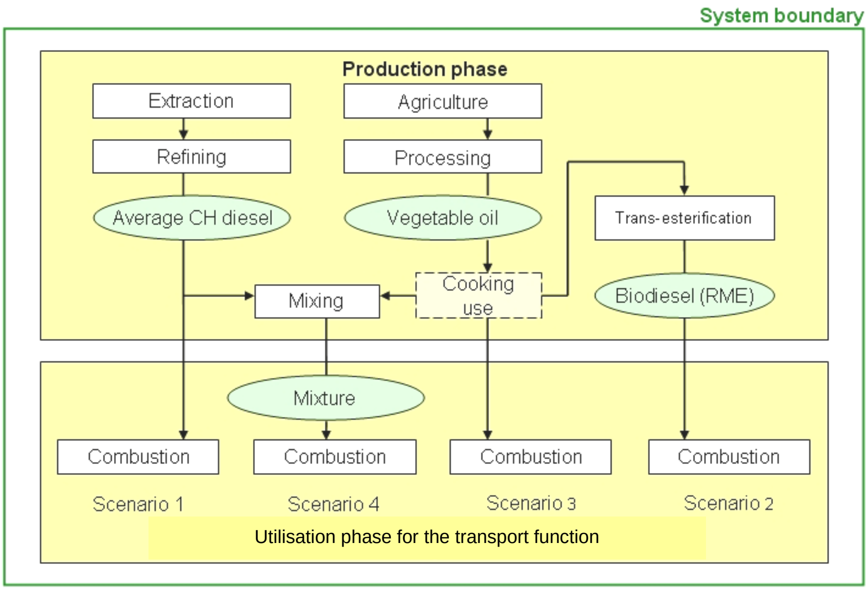
2 Environmental Analysis of the push boats

The study was done in two steps: in the first, the cooking function of VO was not considered, so the results of LCA of fluvial transport using this kind of push boat became as if VO was produced directly to be used as fuel (SVO), which is often the case. In the second step the cooking function was taken in to consideration as well as the sensibility check.

2.1 Definition of the system limits

The push boat has two 6 cylinder engines of 242 kW (325 bhp) at 1800 rpm, direct injection, without neither catalyser nor particles filter. Each barge (or convoy) has a maximum capacity of 170 t. The system boundary covers the fuels production (transport included) and the fuels usage (combustions and emissions). The impacts link to the construction, maintenance, and end of life of the push boat and the fluvial infrastructure were not taken in account in this study.

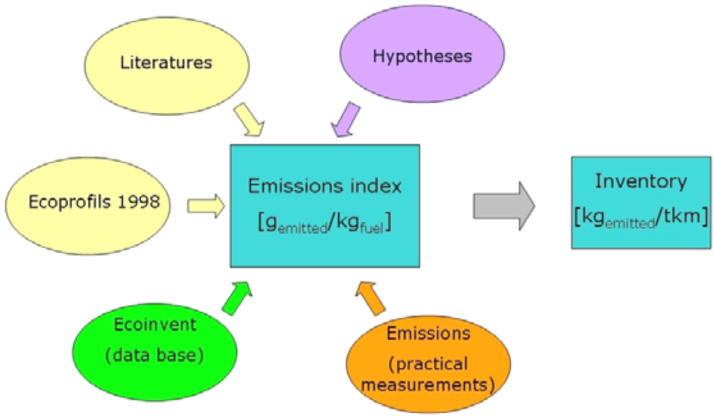
Figure 1 System boundaries



2.2 Inventory

The asset of this study on environmental impacts analysis done here is to have used practical measurements of emissions from an engine in function on the push boat, fed with diesel fuel and a mixture of diesel-VO, and with complementary data research from bibliographic sources and data base (Ecoprofils [2] and ecoinvent [3]). The practical benchmark measurements were made at the laboratory of control of exhausting gases from the University of Applied Sciences of Bienne, Switzerland. All data on emission collected, were reported in the emissions index, and then to the inventory in accordance to the chosen functional unit (FU), which was the ton kilometer “tkm” (one ton moved on one kilometer).

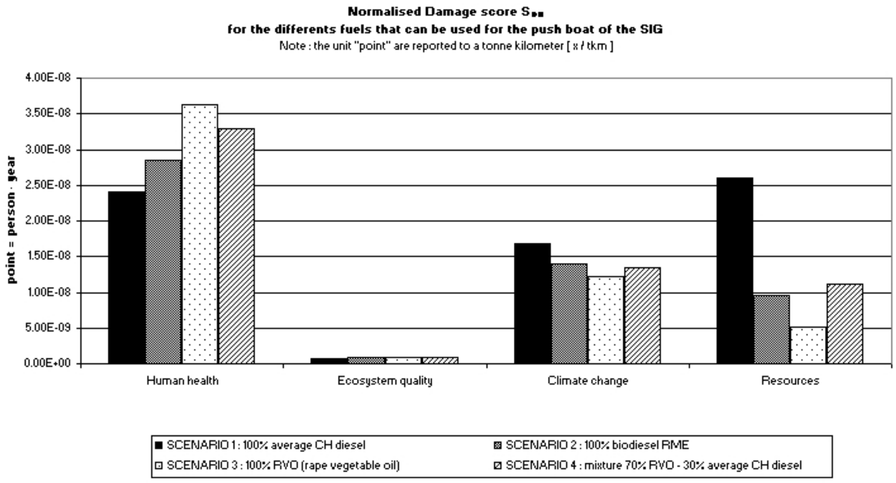
Figure 2 Data sources for the inventory



2.3 Impacts

The method use to evaluate impacts is Imapct2002+ V2.1, is a life cycle impact assessment methodology that propose a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories a method developed by the EPFL, Switzerland [4].

Figure 3 Results - Normalised Damage Score S_{DN} (production + use)



Note: “points” are equal to “pers·yr”. A “point” represents the average impact in a specific category “caused” by one person during one year in Europe.

2.3.1 Interpretations

As we can see (fig. 3), the RVO as the highest damage score in the human health category, principally due to the respiratory effects from high level of NOx and PM in exhaust gas during the utilisation phase for the transport function (combustion). On the climate change, biofuels have lower impact than diesel, but not as much as we could have expected, that is mainly due to the production phase where the agriculture plays a major role, due to the use of mineral fertilizer (nitrogen, N) that partially become N_2O (nitrous oxide) [5], where 1 kg $N_2O \equiv 156$ $kg_{eq}CO_2$ [6]. The resources category, represents the non renewable energy needed, to realise the function (move a ton of waste for a kilometer), as we can see on the figure 3 above, the use of biofuels (RME, RVO, mixture) clearly diminished the need for non renewable energy, this major environmental benefit is largely in favor of biofuels compared to fossil fuels. The higher impact of biodiesel RME compared with RVO, is due to the use of methanol from fossil origin, that is used in the reaction of trans-esterification in the production phase.

A solution to overcome the impact on human health (respiratory effects) and still benefit from the low consumption of non-renewable energy (NRE) from biofuels could be to use a particle filter.

2.3.2 Sensibility: What is the importance of agriculture?

We choose to lead a sensibility test in the resource impact category (which express the NRE demand), because the variation between scenarios are great. We also have well detailed information on each step of production of biodiesel RME and RVO.

We look at the relative importance of NRE consumption used to produce 1 kg of biodiesel RME versus RVO.

Figure 4 Parts of non-renewable energy needed to produce biodiesel RME

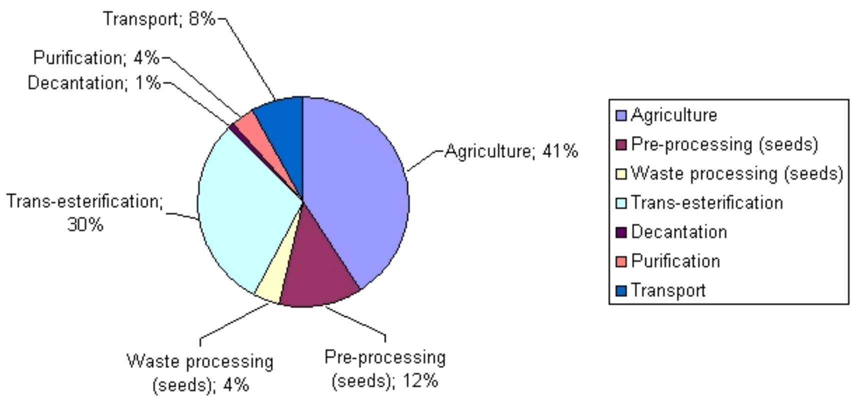


Figure 5 Parts of non-renewable energy needed to produce RVO

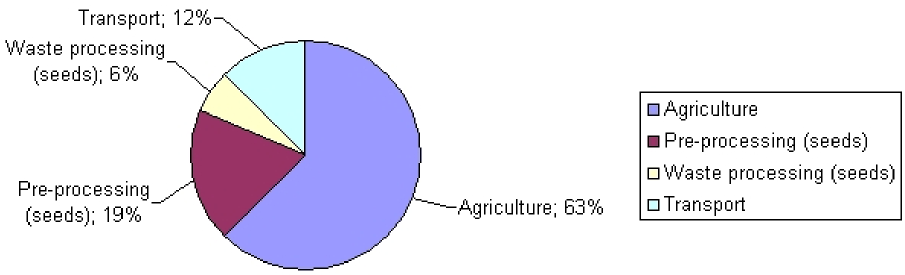
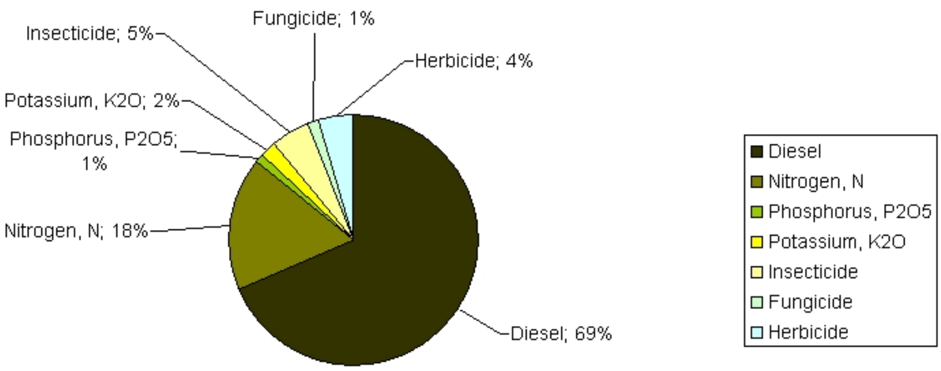


Figure 6 Parts of non-renewable energy needed for the agriculture step in the production of RVO



As fig. 4 and 6 show the main part of NRE is used in agriculture, respectively 41% for biodiesel RME and 69% for RVO, then if we look inside the agriculture phase we see (fig.6) that the use of diesel (fuel for field work) and mineral fertilizer (nitrogen) are the two main contributors to the consumption of NRE, respectively 69% and 18%.

Sensibility: What about considering the cooking function?

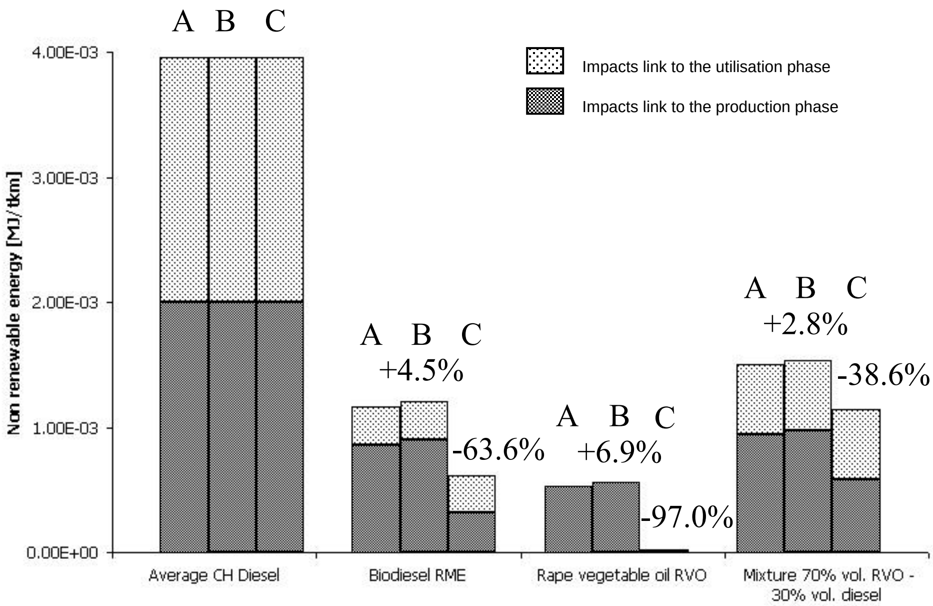
To test the sensibility we modified:

A) Standard case, VO directly produced for energy use (no modifications).

B) The type of agriculture, the hypothesis is: adding +20% of fertilizer, +20% pesticide involving +7% diesel in consumption for fieldwork.

C) The financial allocation of impact. According to WVO supplier information, we considered that the WVO has a cost to get rid off, so we dispatched them between the first “cooking function” and the second “transport function”, the impacts from agriculture, pre-processing (seeds), waste processing (seeds) is then allocated to the first function.

Figure 7 Non-renewable energy impacts / Results sensibility on agriculture and allocation



The variation of impacts of case B: agriculture (+20% fertilizer, +20% pesticide, 7% diesel) compare to the impacts of the standard case are very small, almost negligible, but if doses and/or transport are increased it may lead to much higher variations, this is of some concern when the vegetable oil comes from plants other than rape (e.g. peanuts oil).

The important variations between standard case A and the case C is due to allocation : part of the impact is reported to the "cooking function" and so disappears from the "transport function". The way you chose to allocate is predominant. In our case the WVO costs restaurants to get rid off, so we have to attribute the impact due to production (agriculture, seeds pre-processing, seeds waste processing) to the cooking function (case C); but if the WVO had a value, we should attribute a part of those impacts to the transport function. But the concern is that the cost of waste can fluctuate depending on the demand, so the impact changes according to the value of WVO, that does not represent the global reality: that is impact stay the same (it is not changing with the cost or price), but they are just dispatch differently between the cooking function and the transport function. So financial allocation has to be considered with caution.

3 Conclusion

The innovativeness of this study is to have mixed some literature data with some practical measurements of the gas emission coming out of the engine as basis of the life cycle inventory for the environmental impacts analysis. This study has also shown that allocation is a major concern when considering impacts.

This study has been focused on RVO and RME, the evaluation of the sensibility of the environmental impact has shown the importance of the agriculture phase. This will be important when considering VO if coming from other plants, and it shows that research still has to be done in this area.

We also see that using WVO as fuel should be considered in the perspective of industrial ecology: VO after use in the cooking function (as frying oil) is considered as waste, but it is considered as raw material (resource) for the transport function. In this case there is a problem of concept: how to measure impacts of successive functions? Should the impacts of the production of VO be attributed uniquely to cooking function or should they be dispatched between the two successive functions? The technique of allocations allows solving the problem in a more or less satisfying way; it is a difficult question which disserves discussion and that this case study can enlighten.
The so-called "financial allocation" reports the impacts due to production on the cooking function and in consequence the transport function impacts decrease (price could depend on demand, tax, etc.) This means that some impacts disappear from transport function and appear on the cooking function – is this very fair? This involves the splitting of the VO life cycle, in our case the question of the CO_2 should be treated in particular way: it is absorbed on the 1st part of the cycle and restituted in the 2nd part of the cycle. So this splitting in two of the cycle is uncomfortable – in this situation of industrial ecology, we clearly have one cycle with 2 functions that should not ignore each other. The kind of environmental benefit that appears on the 2nd part of the cycle is in fact the benefit of industrial ecology.

Finally this study allows us to confirm that the environmental gains of biofuels scenarios are not as important as we first thought, if their vegetable raw material is produced uniquely for fuel use. They are of much more interest when used in an industrial ecology context where a first cooking function allows dispatching of the impacts due to production.

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Glossary

CH	Confoederatio Helvetica, means Swiss Confederation or Switzerland.
CO_2	Carbon dioxide.
EPFL	École Polytechnique Fédérale de Lausanne (EPFL) is the Swiss Federal Institute of Technology.
eq.	Equivalent (e.g. 1 kg $N_2O \equiv 156\ kg_{eq.}CO_2$).
FU	Functional unit.
LCA	Life Cycle Assessment, sometime call ecobilan
N_2O	Nitrous oxide.
NOx	Nitrogen oxide (e.g. NO, NO_2).
NRE	Non-renewable energy.
PM	Particles matter, in this study particles PM10 (particles with aerodynamic diameter less than 10 µm) and PM2.5 (less than 2.5 µm) have been taken in account.
point	“points” are equal to “pers·yr”. A “point” represents the average impact in a specific category “caused” by one person during one year in EU.
R&D	Research and development.
RME	Rape methyl ester, biodiesel made from rape oil
RVO	Rape vegetable oil.
SIG	Services Industriels de Genève, semi-public company which provide (e.g. water, electricity, waste disposal).
SVO	Straight vegetable oil.
VO	Vegetable oil.
vol.	Volume.
WVO	Waste vegetable oil.

Life cycle engineering, product lifecycle management and sustainability

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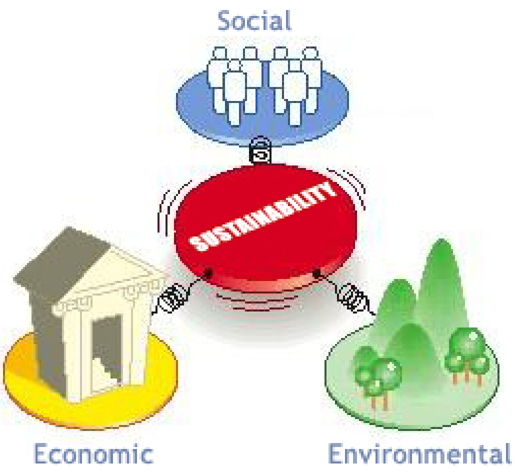
Abstract: The reduction of product lifecycle-related environmental impacts is prerequisite to sustainability. Life Cycle Engineering (LCE) can be defined as engineering activities focused on the design and production of products that have minimal environmental impact during their entire life cycle. Product lifecycle management (PLM) can be defined as a business approach for managing a company's product throughout its life cycle. Despite the promised opportunities for competitive advantage resulting from sustainability, the implementation of this concept has not reached companies worldwide, mainly due to the gap between product-oriented (PLM) and environment-oriented (LCE) research. The goal of this paper is to explore the complementarities between LCE and PLM by presenting them as complementary knowledge areas influencing the main business processes that deal with product lifecycle. By doing this the aforementioned gap can be bridged and sustainability can be reached alongside with competitiveness.

Keyword: life cycle engineering, product lifecycle management, sustainability

1 Introduction

Sustainability has many definitions but the basic principles and concepts remain: balancing the economy aspects, protection for the environment, and social responsibility (Figure 1). These aspects together lead to an improved quality of life for ourselves and future generations.

Figure 1 Sustainability aspects



The goals of economic, ecological, and social well-being are often referred to as a "triple bottom line" that expands upon the financial bottom line [1]. Corporations all over the world are beginning to realize that sustainability makes good business sense and is essential to their survival and growth [2]. This shift in thinking is due to growing recognition among leaders in the global business community that profitability alone is an inadequate measure of success, and that many of the intangible concerns associated with sustainability are fundamental drivers of long-term shareholder value [3].

The rising consumption of products is, directly or indirectly, at the origin of most of the pollution and depletion of resources that our society causes [4]. Hence, since sustainability demands the balance between environmental and business aspects the reduction of product lifecycle-related environmental impacts is prerequisite to sustainability. Life Cycle Engineering (LCE) is an approach that deals with the challenge of reducing product lifecycle environmental impacts by using a set of engineering-oriented methods and tools. Product Lifecycle Management (PLM) can be defined as a business approach for managing a company's product throughout its life cycle by using a set of business solutions. Despite the promised opportunities for competitive advantage resulting from sustainability activities (based on the win-win paradigm [5]), the implementation of this concept has not reached companies worldwide, mainly due to the gap between product-oriented (PLM) and environment-oriented research (LCE). In order to achieve the aforementioned sustainability benefits, both perspectives must come together in a complementary way.

This paper argues that this can be done by addressing LCE and PLM as complementarities approaches in managing the lifecycle of products. In so doing, product lifecycle-related environment impacts may be avoided (by adopting LCE) and the company's profitability may be increased (by adopting PLM) at the same time—just like the win-win paradigm advocates.

The goal of this paper is to explore the complementarities between LCE and PLM, which are seen here as complementary lifecycle-oriented knowledge areas that influence the main business processes (BPs) that deal with product lifecycle. Since the reduction of product lifecycle-related environmental impacts is prerequisite to sustainability and due to the fact that environmental impacts produced during a product life cycle are, to a large extent, determined in the new product development process (NPD), especial attention will be paid to the influence of the LCE on this BP (NPD).

2 Literature review

2.1 Life cycle engineering

A definition [6] for LCE is: "Engineering activities which include: the application of technological and scientific principles to the design and manufacture of products, with the goal of protecting the environment and conserving resources, while encouraging economic progress, keeping in mind the need for sustainability, and at the same time optimizing the product life cycle and minimizing pollution and waste". LCE can also be seen [7] as a methodology centered on the design and production of products that have minimal environmental impact during their entire life cycle. According to EPA [8], the LCE is an ongoing, comprehensive examination with the goal of minimizing adverse environmental implications throughout the life cycle, providing means to:

- Communicate the relationship between environmental implications and engineering requirements and specifications;
- Assess environmental implications of alternatives; and
- Identify improvement opportunities throughout the product life cycle

LCE can also be seen as an aegis (Figure 2) under which many current approaches to environmental management can be placed [6].

Figure 2 LCE as an aegis for several environmental management approaches [5]

In accordance with Hauschild et al [9]: "LCE covers the engineering activities addressing industry's environmental impacts in a product life cycle perspective".

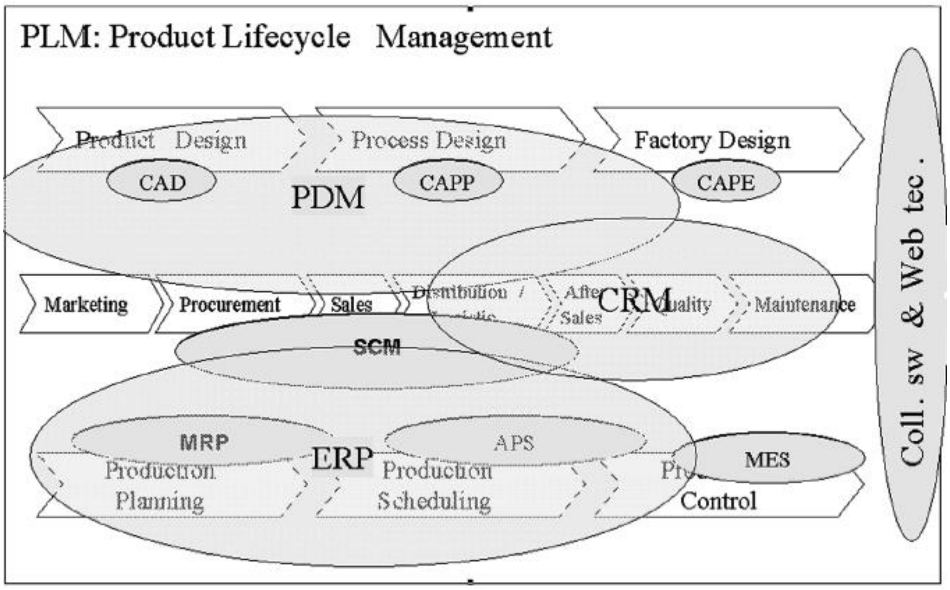
It is important to notice the diversity of definitions and that no definition is given in the Handbook of LCE [10]. In short, it is possible to say that LCE is a product lifecycle-oriented approach that encompasses a set of environmental management-oriented engineering methods and tools that deal with the challenge to fulfill product-related human needs in line with sustainable development principles.

2.2 Product lifecycle management

A short definition for Product Lifecycle Management states that PLM is a concept for the integrated management of product-related information throughout the entire product lifecycle [11]. This concept is rather broad, but it is in accordance with the CIMDATA [12]: “PLM is a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life—integrating people, processes, business systems, and information”. One can see that this concept is closely associated with ICT (Information and Communication Technology).

Garetti [13] innovates when he shows the correlation between PLM and the main business process (BP) and solutions (software) of companies (Figure 3). A PLM implementation project is related to these business processes (BPs) and thus they must be very well understood.

Figure 3 PLM context [13]



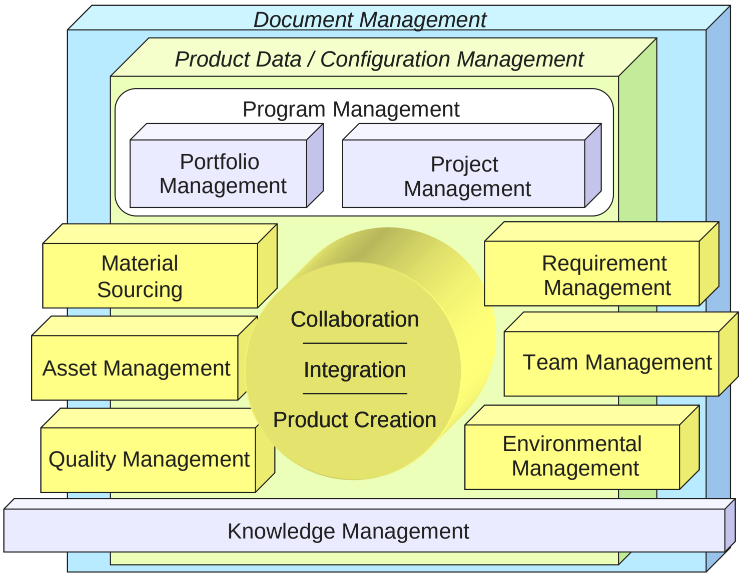
Stark [14] in his book states that PLM represents an approach for effectively managing a company’s product throughout its life cycle. He presents an extensive list of needs, justifications, strategies and implementation activities for PLM. Indeed, he emphasizes Product Data Management (PDM) when discussing software. One can come to the understanding that PDM is the heart of PLM, which might be true if the PLM solutions available on the market are analyzed. Nevertheless, project management functionalities are also presented in most existing PLM applications.

It is important to point out that the term “PLM” represents an approach as well ICT solutions. The PLM approach is concerned with the product information during all phases of product lifecycle, but it is assisted by PLM solutions. Even PLM solution vendors always mention that this is an approach, but after a short initial statement they emphasize the functionalities of their solutions. Solution proposals differ slightly depending on the vendors’ origin: ERP vendors or CAD/CAE vendors (some today sell VPD solutions – Virtual Product Development). ERP vendors emphasize the integration of PDM and project management functionalities with the company’s financial backbone. They offer integration with the VPD world. The CAD/CAE vendors see the product realization tools as the center of their solutions, which are integrated with ERP systems. There were also PDM vendors that just added project management functionalities in a robust way and others that simply changed the name of their solution without offering new functionalities.

It is important to define that a business process represents a collection of activities that produces a result (product or service) for a specific group of customers. This definition does not equate to generally defining that a process simply transforms inputs in outputs. A BP aggregates many activities that are normally spread out in different organizational entities (e.g., departments or divisions). Activities of same nature can also be grouped in knowledge areas known as process areas, such as project management, requirement management, cost management and so on. PLM is defined in this paper as an approach related to the main BPs that deals with products: R&D, NPD, order fulfillment (including sales and production), customer service and end-of-life (EoL).

Notice that marketing, for instance, is not considered as a BP but as a knowledge area, since many marketing activities may belong to different BPs. In the same way PLM is not only an approach (implementation oriented), but also a knowledge area, since there are many PLM activities in the aforementioned BPs that deal with product information. PLM also refers to a class of integrated solutions that support the manipulation of product lifecycle information. These integrated solutions comprise the main functionalities (or behaviors in the object-oriented paradigm) of former PDM and project management solutions. Figure 4 indicates other functionality groups found in PLM solutions, both from ERP and CAD/CAE vendors.

Figure 4 PLM functionality groups



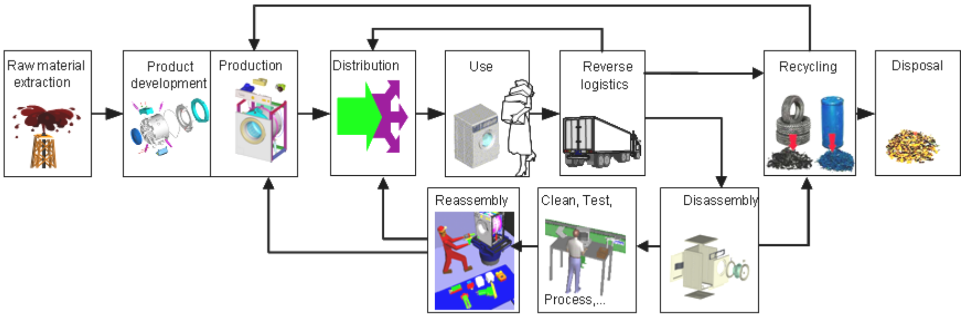
3 LCE and PLM: complementary approaches toward sustainability

3.1 LCE and PLM as product lifecycle-related knowledge areas

A knowledge area can be defined as the sum of knowledge, concepts, methods and tools that deal with a specific research field. For instance the Project Management Body of Knowledge (PMBOK) from Project Management Institute (PMI) brings nine different knowledge areas influencing project management research field. Hence LCE and PLM can be seen as complementary lifecycle-oriented knowledge areas influencing the main business processes that deal with product lifecycle where LCE is environmentally-oriented and PLM is product-oriented (mainly oriented toward project and product information management).

The way that LCE and PLM knowledge areas influence the aforementioned BPs varies according to their relationship with the phases of product lifecycle. Figure 5 shows the product lifecycle phases, where different End-of-Life scenarios are presented [15].

Figure 5 Product life cycle phases [15]



Since the reduction of product lifecycle-related environmental impacts is prerequisite to sustainability and due to the fact that environmental impacts produced during a product lifecycle are considerably determined in the product development phase, especial attention have to be paid to the influence of LCE methods and tools on new product development process (NPD).

3.2 The influence of LCE on new product development process

It is well documented that NPD is important for both economical and environmental reasons. According to Boothroyd et al [17] 70% of product costs are defined at the early steps of NPD. Considering environmental requirements at the beginning of the design phase it can be reduced by an estimated 70% [18]. Hence, taking environmental aspects into consideration during the design stage of a product plays an essential role in reducing environmental impacts of product lifecycle. LCE-related methods and tools that deal with the integration of the environmental issues into NPD are known as ecodesign methods and tools.

Ecodesign (Europe) and Design for Environment (North-America) are used as synonymous. They define a new way of developing products where environment aspects are given the same status as functionality, durability, costs, time-to-market, aesthetics, ergonomics and quality. Ecodesign aims at improving the product environmental performance and may be seen as a way to develop products in line with the concept of sustainable development [19] [20] [21] [22] [23] [24]

Regarding existing ecodesign methods and tools, Baumann et al [25] identify more than 150 methods and tools to implement what they call environmental product development (EPD). These authors carried out a literature survey in this field from the engineering, policy and business perspectives and used the term tool "for any systematic means for dealing with environmental issues during the product development process" [25]. Luttropp and Lagerstedt [26] present a reading list in ecodesign tools and references divided by:

- Tools focused on a specific kind of product
- Tools that incorporate lifecycle orientation
- Tools that concentrate on resources and dematerialization
- Tools that cover the whole process of design ("encyclopedia of Ecodesign")

Hauschild et al [22], addressing the existing ecodesign approaches, say that "the variety of methods and tools range from the general to the specific, focusing on parts of the life cycle (typically use and disposal) or on certain types of products or services. Some methods were intended for use early in the design process while others were aimed at use during the detailed design phase".

As one can see there are a lot of ecodesign methods and tools to support the designer's activities in improving product sustainability. The task of identifying the most appropriate methods and tools for each company should be carried out by designers, who in turn should take into account the dynamics of their activities and their previous knowledge about ecodesign. This selection may be assisted by a specialist. A useful approach to assist this process is to organize ecodesign workshops for awareness raising or to discuss methods, tools and strategies [24]. However, in order to ensure concrete results with the selected methods and tools it is necessary to introduce the topic of sustainability into the company's business core. In agreement with IISD [27] the following seven steps are required to manage enterprise according to sustainable development principles: 1) Perform a stakeholder analysis; 2) Set sustainable development policies and objectives; 3) Design and execute an implementation plan; 4) Develop a supportive corporate culture; 5) Develop measures and standards of performance; 6) Prepare reports and 7) Enhance internal monitoring processes.

A similar phenomenon takes place as regards PLM. Since most of product information is also determined during the NPD the PLM knowledge also strongly influence this business process and the available PLM solution should be addressed by members of a product development team in their daily activities.

4 Conclusions

Sustainability demands the balance between economical, social and environmental aspects. Most part of the existing environment impacts is product-related. Thus, a significant decrease in product-related environmental impacts is prerequisite to sustainability.

LCE and PLM are lifecycle-oriented complementary approaches capable of bridging the gap between product-oriented and environment-oriented research and make the sustainability happen. In order to do it both LCE and PLM have to be considered as knowledge areas influencing the main BPs that deal with product lifecycle where the way that LCE and PLM influence these BPs varies according to the relationship between these BPs and the phases of product lifecycle. Thus all the product lifecycle phases should be analyzed as well as their relationship to the product related BPs. Only in this way it is possible to determine the potential impact that LCE and PLM knowledge areas on all business process activities related to all product lifecycle phases. By doing this product lifecycle can be managed according to PLM and LCE perspectives and sustainability can be reached alongside with competitiveness.

NPD is especially influenced by LCE and PLM knowledge areas, for in it most of the information related to the product lifecycle is generated and most of environmental impacts are determined. There are several LCE methods and tools that can be employed in NPD to increase the environment performance of products. The task of identifying the most appropriate methods and tools for each company should be carried out by designers, who in turn should take into account the dynamics of their activities and their previous knowledge about ecodesign.

However, regardless of the designers' previous knowledge about ecodesign it is necessary to introduce the topic of sustainability into the company's business core in order to ensure concrete results with the selected methods and tools. Only by taking LCE and PLM as complementary lifecycle-oriented knowledge area products lifecycles can be managed in sense sustainability can be reached alongside with competitiveness.

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A design for environment product analysis

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Abstract: Environmental legislation is holding electrical and electronic manufacturers accountable for the disposal of their products at end of life. In order to reduce disposal costs, manufacturers are seeking to optimise product design. Supporting tools are essential at this stage in managing environmental information in order to reduce the products environmental impact. This paper presents findings from an environmental product redesign case study. Specifically, it presents the findings of the Design for Environment Workbench (DFE Workbench) software, in redesigning a torch. The aim of this research is to establish whether the DFE Workbench is adept at reducing the environmental impact of a product. A comparative analysis of the case study results is carried out using a second software tool, Sima Pro. This verifies the 9% reduction in environmental impact achieved through the use of the DFE Workbench. This supports the use of the DFE Workbench as successfully reducing environmental impact.

Keyword: Information management, Tools, Environmental design.

1 Introduction

Inefficient natural resource use is ensuring fossil fuel depletion is occurring at a faster pace than necessary, causing concern for future economic stability. Resultantly, excessive harmful emissions are being produced. This is increasing the rate of climate change with serious implications for health and agriculture internationally. Legislation is targeting electrical and electronic manufacturers to combat this rising trend, as such products account for the fastest growing waste stream in Europe (European Commission 2000). Furthermore, domestic electrical appliances constitute the second largest consumer of electricity (International Energy Agency 2003). The purpose of the legislation is to focus attention on improving environmental product design in order to reduce the inefficient use of materials (and thus natural resource use) and energy e.g. electricity use (and thus excessive greenhouse gas emissions). Legislation has ensured environmental design remains an important company objective by holding manufacturers accountable for the costs associated with product disposal and ensuring financial penalties are in place for non-compliance. This has compelled product manufacturers to consider environmental design, as waste arising from product take-back can often be prevented or minimised by incorporating features that support disassembly, reuse and recycling.

Design for Environment (DFE) is seen as an effective approach for manufacturers in developing environmentally superior products. DFE is a strategy to minimise the use of natural resources and the consequent impact on the environment. It involves the adoption of life cycle thinking, which ensures the consideration of all life cycle stages during the product design stage (Charter and Tischner 2001). This guarantees that environmental burdens are not simply displaced from one life cycle phase to another.

Design is an information transformation process that needs tools to help integrate additional aims such as DFE. Tools assisting in introducing DFE at the design stage are used to provide: direction, information management and environmental evaluation. DFE tools vary in their proficiency. Quantitative DFE tools range from those that: assist only one life cycle stage to all stages; those that can be learnt over a short period or require an expert user; can offer a simple environmental assessment or a detailed one; and, those which can offer a timely environmental assessment to offering a more time intensive one. This shows that a wide range of DFE tools are available. Baumann et al (2002) and Lindahl (2006), state that too many papers in the area of DFE concentrate on the development of new tools rather than focusing on the degree to which the multitude of already available tools meet the needs of DFE in the design process. Therefore research focusing on already available tools would be an advantage.

This research dealt with these problems by demonstrating the use of one currently available environmental software tool, the DFE Workbench (Roche 2001). This work presents selection criteria detailing desirable attributes of an environmental support tool. The DFE Workbench and its features are discussed to establish to what extent it meets these requirements. The aim of this research is to establish whether the DFE Workbench is adept at reducing the environmental impact of a product. To that end, the DFE Workbench is applied in the environmental analysis and improvement of a torch design. The results of this product analysis show a 9% reduction in the products environmental impact. A comparative analysis of the case study results using a second environmental software tool, Sima Pro, is used to verify the DFE Workbench findings. The findings support the use of the DFE Workbench as able to successfully reduce product environmental impact.

To begin this process, a synthesis of literature in this area will highlight certain traits that maximize the potential for DFE design success in aiding the reduction of environmental impact. This will be followed by a discussion on the DFE Workbench and how it aligns with this assessment criterion.

2 DFE tool assessment criteria

Product designers are in charge of creating profitable product designs that meet the consumers needs. They form the link between the user and a product. Charter and Tischner (2001) state that 80% of the environmental impacts incurred during the life of a product are as a result of the product design stage. The designer although not an environmental expert, plays an important role in influencing this situation (Charter and Tischner 2001; Ernzer and Wimmer 2002; Lindahl 2006). They are involved in the initial product design and development, a phase which influences the way that products are formed and consumed in terms of (Charter and Tischner 2001):

- Fulfilling users needs
- Materials and manufacturing technologies used

- Product lifetime
- Recycling and disposal of the product

The literature suggests that in order to allow for better integration into the final design and to lower the environmental impact of the product life cycle, environmental aims should be introduced as early as possible into design development (Ardente 2003; Charter and Tischner 2001; Fiksel 1996; Goosey 2004; Kuo 2001). The introduction of environmental aims at a later stage, e.g. at the detailed design stage, would result in the introduction of design alterations in a less cost effective manner as many of the important decisions would have already been made (Kuo 2001). For these reasons, it is necessary that a supporting DFE design tool can be used at the concept development stage to ensure greater chance of environmental design success.

Many DFE tools exist. Those used at the design stage assist in the efficiency and success of this phase by helping navigate designers through the unlimited possibilities available (Jensen et al 1999). At a simplified level, DFE tools have two fundamental traits: product improvement and analysis. Tools offering improvement during the design process direct the activity and provide information to the designer (Ferrendier et al 2002). The intention of analysis tools is to measure environmental impact. This may occur before design has begun using a previous design, or after the design is completed to demonstrate the evolution of the design. The presence of metrics assists in confirming environmental practice effort, and helps a firm to monitor and control DFE (Sroufe et al 2000). Glazebrook et al (2000), Lenau and Bey (2001) and Nielsen and Wenzel (2002), also support the use of quantitative methods. They state that such methods are useful at the design stage when deciding on the optimal environmental design, as it enables the designer to compare concept designs in terms of quantifying saved environmental impact. Tools that provide improvement and quantified assessment are therefore an advantage when aiming to reduce environmental product impact.

The tools available have a varying range of functions, from the environmental impacts they account for, data input required and the quality of results that can be obtained. As the number of environmental impacts (effects and emissions) accounted for increases, data pertaining to the products life cycle increases as well as the resource input required. As detail develops the quality of analysis can be said to increase. However, detailed assessments (Full life cycle analysis) tend to be limited in their ability to offer improvement suggestions to the designer, as the detail required for the assessment is often not accessible until the design is in its final stage of development. The literature suggests that a full life cycle analysis is too resource demanding for complex products, to be of practical value to the designer (Fussler 1996; Lenau and Bey 2001; Myklebust et al 1997; Nielsen and Wenzel 2002). Less detailed (Simplified life cycle analysis) tools use approximate data values for calculating the environmental impact of a product. This ensures a much quicker assessment can be carried out and thus environmental improvement to occur at the design stage (Baayen 2000), including easy comparison of the total impact of a product or design possibilities (Glazebrook et al 2000). Whether the tool can be completely utilised at the design stage, is therefore an important feature.

Another aspect of interest, when assessing tools, is whether a software version is available. During the design process a large number of design possibilities are generated. These are then analysed and the best one chosen. Tools enabling quick environmental analysis at the early design stage allow environmentally aware designs to be produced (Baayen 2000). This need for prompt answers is compounded by the fact that short innovation cycles are prevalent in the electrical and electronic sector (Schischke et al, 2002).

The last criterion of interest, when assessing tools, is the experience of the actor required to use it. That is, whether an environmental expert is required or whether a person can be easily trained to use it. A tool that is easy to use increases the users speed in adapting to the use of the software and the uptake of tool use during the design stage. It is believed that this would also assist in reducing the intrusion on the design activity (Roche 2001). Lenau and Bey (2001) argue that the purpose of having easy-to-use tools is to allow designers, who have limited environmental knowledge, a chance to learn as they design and because they also have limited time for product development the tool should require minimal effort.

This synthesis of literature has highlighted certain traits that maximize the potential for DFE design success in aiding the reduction of environmental impact. Key assessment criteria include: whether the tool can be used in the product design stage, the degree to which it is improvement and assessment based, the scope of the tool, whether it has a software version available and if it is easy to use. A discussion on the DFE Workbench now follows, setting out how it aligns with this assessment criterion.

3 DFE Workbench

The DFE Workbench is a software tool suitable for integration into a Computer Aided Design (CAD) environment. It provides analysis, synthesis, evaluation and improvement for the whole of the products life cycle (Roche 2001). Five elements make up the structure of the tool, including: the Impact Assessment System, the Structure Assessment Method, an advisor agent, a knowledge agent and a report generator. The *Impact Assessment System* (IAS) is based on a simplified life cycle analysis quantitative method – Eco indicator 95. The IAS enables management of information from across a products life cycle, as well as assessment and prioritization of this data. The *Structure Assessment Method* (SAM) centers on the structure of the products CAD prototype. SAM retrieves data such as: material type, % recycled material content, disassembly time, number and type of fasteners among others. These elements are quantified and form part of the assessment of the overall product impact. SAM also allows for automatic recalculation of the products impact should an aspect of the product (e.g. component type/material) be changed. The *Advisor Agent*s job is to provide a prioritization list. This is produced from the IAS and SAM modules, detailing aspects of the products design that is causing most impact. This agent also offers suggestions to the user regarding changes that could be made to the structural characteristics of the product to reduce environmental impact. The *Knowledge Agent* is a consultative aspect of the tool. The user can seek advice from this module for example, if they wanted a material with specific mechanical properties (Roche 2001). The fifth element of the DFE Workbench is the *Report Generator*. This aspect allows for easy comparison of the initial selections against the final ones. This information can be saved in various electronic formats or printed, depending on the users needs.

The traits of the DFE Workbench in relation to the assessment criteria will now be summarised. The tool is such that it can assist with all life cycle stages. Due to the analysis method used, timely data analysis can occur to allow for a high rate of improvement to be introduced early in the product design phase. A medium level of assessment can be obtained - although this is not ideal, this does allow for improvement to be implemented at the product design stage. In terms of Ease of Use, the author has rated this area highly, having used a number of software tools for the compilation of this research (Dobbs 2007).

4 Product Analysis

Due to changes in legislation, disposal of electrical and electronic products is now the responsibility of the manufacturer. In order to reduce disposal costs, the manufacturer is seeking to improve the environmental design of their products. Design for Environment (DFE) is seen as an effective approach for manufacturers in developing environmentally superior products. Design is an information transformation process that needs tools to help integrate additional aims such as DFE. However, a wide range of DFE tools are available. Baumann et al (2002) and Lindahl (2006), state that too many papers in the area of DFE concentrate on the development of new tools rather than focusing on the degree to which the multitude of already available tools meet the needs of DFE in the design process. Therefore research focusing on the degree to which already available tools meet the needs of the environmental product design stage would be an advantage. This research focuses on one, currently available environmental software tool, the DFE Workbench. Selection criteria detailing desirable attributes of an environmental support tool were highlighted and the degree to which the DFE Workbench met these criteria discussed. The aim of this research is to establish whether the DFE Workbench is adept at reducing the environmental impact of a product. This section presents results of the DFE Workbench having been used in the environmental analysis and improvement of a torch design (figure 1). The environmental profile below (section 4.1) presents the environmental impact analysis carried out after design improvements were introduced.

Figure 1 Exploded view of torch

4.1 Environmental Profile

Through the use of the DFE Workbench prioritisation and advisor agent, improvements were made to the overall environmental design of the torch. The new environmental profile of the product is detailed below. The degree of improvement is also listed and was established by comparing the original analysis of the product with the new environmentally improved design.

Mass of overall product: 0.124kg – no change
Materials used in product composition: Linear Low Density Polyethylene (LLDPE), copper, and one type of steel. Material variety reduced from five to three. This shows a 40% improvement in material variety.
Processes used to make components: Injection moulding and metal cutting – no change
Transport: Truck, 500km – no change
Energy Use: 4.5 Volts – no change
End-of-life strategy: Due to the addition of product labelling, much of the product can now be recycled. This results in a 58% improvement.
Fasteners used: Screwed (2) – reduced by two, snap fit (4) – increased by two, fit in (2) and press fit (6) methods. Changing two of the fastening methods to a snap fit assisted in reducing disassembly time.
Disassembly time: Originally 112s, now 100s, an 11% improvement.

Having completed the environmental improvements for the product, a reassessment of the products environmental impact was carried out using the DFE Workbench. This showed that the overall environmental impact decreased to 1.091mPt (its eco-indicator value), a 9% improvement of the products environmental performance. A comparative analysis of these case study results using a second environmental software tool, Sima Pro, will now be used to attempt to verify the DFE Workbench findings. The findings will then be discussed to account for any result discrepancies that may have arisen.

4.2 Comparative Analysis

The tool used for the primary environmental assessment was the DFE Workbench. The analysis module of this tool uses a Simplified Life Cycle Analysis (SLCA) method, Eco-indicator 95. So that an evaluation of the DFE Workbench results can occur, the tool selected to provide comparison must be of the same family of tools. The tool chosen for this purpose is Sima Pro (Version 7). This tool is within the SLCA grouping, but uses the Eco-indicator 99 assessment method. This section details the results obtained through the use of Sima Pro in the analysis of the improved torch design.

Figure 2, illustrates the findings of the environmental analysis of the torch using the Sima Pro software. The graph shows the analysis of the three main sub-assemblies of the torch, with each bar accounting for their respective eco-indicator value. Figure 2 shows the sub-assembly causing the greatest impact is the body of the torch, followed by the base and then the head. It is not possible to compare scores of the Sima Pro analysis with that of the DFE Workbench since more aspects are taken into account with Sima Pro and a different weighing approach has been used. However, as can be seen from this initial visual inspection of the Sima Pro analysis, the results convey the same message as the DFE Workbench. This can be clearly displayed by comparing the graphical display of Sima Pro shown in figure 2 with that of the DFE Workbench in figure 3. This shows the order of environmental impact for each sub-assembly (body, base and then head) is the same for each assessment method.

Figure 2 Sima Pro graph showing torch product analysis

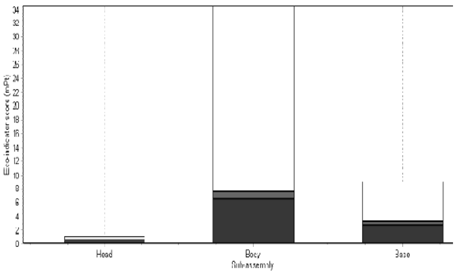
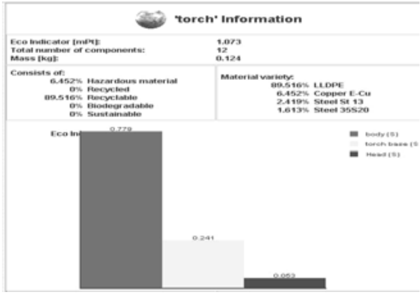


Figure 3 DFE Workbench graph showing torch product analysis



A closer look at the results obtained for one of the sub-assemblies of the torch established whether the results for these two assessment methods were also similar at a more detailed level. Figure 4 shows the environmental impact evaluation for the body of the torch using Sima Pro. Figure 5 shows the same sub-assembly but using the assessment results from the DFE Workbench analysis tool. On comparing these two sets of results it can be seen that the bar that accounts for the greatest environmental impact from each bar chart, differs in each. In figure 4, the Sima Pro results for the torch body show that, that which causes most impact is the Linear Low Density Polyethylene (LLDPE) material content (i.e. main body plus button, as Sima Pro groups like materials together). Copper follows this, which is the material of the electric contact. In figure 5, the DFE Workbench analysis results for the torch body shows that the Copper content in the sub-assembly creates most impact. This is followed by the 'main body' which is the part made from LLDPE and then thirdly by the 'button' which is also made from LLDPE.

Figure 4 Sima Pro impact analysis of body sub-assembly

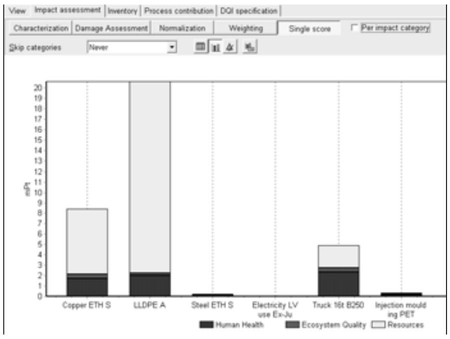


Figure 5 DFE Workbench impact analysis of body sub-assembly

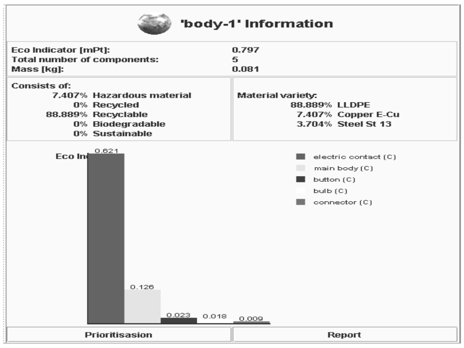


Figure 6 Sima Pro impact analysis of base sub-assembly

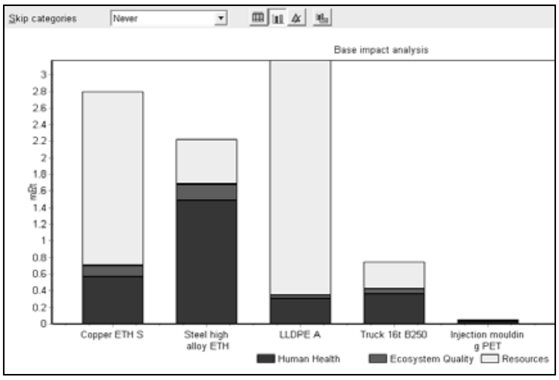
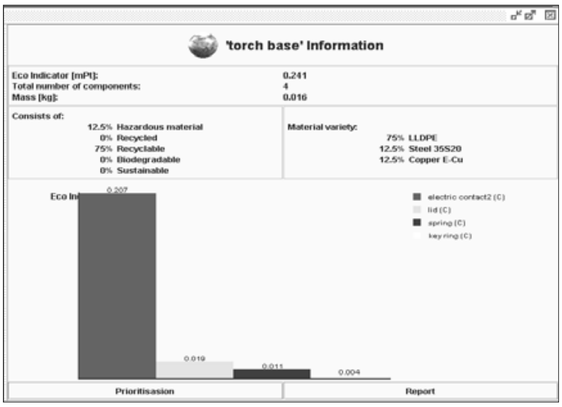


Figure 7 DFE Workbench impact analysis of base sub-assembly



The variance in ranking of the first three elements of the Sima Pro (Eco-indicator 99) results when compared with that of the DFE Workbench (Eco-indicator 95) demonstrates one significant difference. Those materials or processes that have resource input show a higher ranking in the Sima Pro analysis. This can be explained as follows. Eco-indicator 99 accounts for a wider range of effects, one of which is resource depletion, it is reasonable therefore that some of the impacts indicated in the Sima Pro analysis that use fossil fuels are rated as having greater impact than in the DFE Workbench. An example of this is the placement of LLDPE in the Sima Pro analysis of the torch body as creating most impact. However this material accounted for in the DFE Workbench is regarded as the second greatest impact. This same trend can be viewed in the analysis results of the base sub-assembly. Figure 6, the Sima Pro results for the base, shows that LLDPE accounts for the highest impact, followed by the copper and then the steel content. The DFE Workbench (figure 7) results for this same sub-assembly, shows the copper (electric contact2) being placed as causing greatest impact, followed by the LLDPE (Lid) and then the steel (spring). This trend in the relationship between these two sets of results confirms that materials or processes containing resource input are ranked as causing greater impact in the Sima Pro analysis compared with the DFE Workbench. The slight differences between these two analysis results at the detailed sub-assembly level can thus be accounted for due to the heavier weighting, within the Sima Pro analysis, of fossil fuel based materials. On completion of analysis, a common trend can thus be found for the improved torch design by comparing the DFE Workbench results with those of Sima Pro.

5 Conclusion

Supporting tools are essential at the design stage in managing environmental information in order to help reduce a products environmental impact. However a wide range of DFE tools are available, leaving it difficult for the manufacturer to decide which one is suitable. In addition to this, too many papers in the area of DFE concentrate on the development of new tools rather than focusing on the degree to which already available tools meet the needs of DFE in the design process. This research dealt with these problems by demonstrating the use of one currently available environmental software tool, the DFE Workbench. This work presented selection criteria detailing desirable attributes of an environmental support tool. The DFE Workbench and its features were discussed to establish to what extent it met these requirements. The aim of this research was to establish whether the DFE Workbench is adept at reducing the environmental impact of a product. To that end, the DFE Workbench was applied in the environmental analysis and improvement of a torch design. Improvements were made to the environmental design of the product using the DFE Workbench. A second environmental analysis using the DFE Workbench showed a 9% reduction in the products environmental impact. A comparative analysis of these results using a second environmental software tool, Sima Pro, was then carried out. Although some slight variances in the results arose, these could be explained due to awareness of the varying characteristics between Eco indicator 95 (DFE Workbench) and Eco indicator 99 (Sima Pro). The comparative analysis confirmed the DFE Workbench findings. This showed that the DFE Workbench is thus valid in its attempts to implement environmental improvement. The successful validation of the case study findings has ensured that the main goals of this research have now been met.

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A life cycle management guidance system for maritime industry

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Abstract: Today, there are missing a manageable over-all solution for a ship's life cycle management as well as an organizational and a software integration of life cycle management systems. A so called life cycle management system combining and analyzing the appropriate data supports a reduction of costs for the ship's operation, servicing, maintenance and repair. By using such a system, servicing cycles can be adapted tailored to the ship's needs and maintenance activities can be executed quick and targeted. Also damages will be prevented because of an in time replacement of component parts. Further more, repairs are executed quicker and cheaper and, finally, the costs for the ship's recycling will be reduced.

Keywords: Life Cycle Management, Concurrent Engineering, Maritime Industry, Product Data, Operating Data, Guidance System, Scenarios

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1 Introduction

The very high demands of ship owners concerning the efficiency and effectiveness of operation, servicing, maintenance and repair of ships needs access to comprehensive and well structured ships' life cycle information and data. Today, there are missing a manageable over-all solution for life cycle management of ships as well as an organizational and a software integration of life cycle management systems. If ship owners already at the beginning of a ship's life cycle invest in a broad documentation of created data, information and knowledge as well as in a continuous storage of the ship's working data there will be the chance to detect the technical condition of the ship and its components at every time of the ship's life cycle. By combining and analyzing the appropriate data, there would be realized a reduction of costs for the ship's operation, servicing, maintenance and repair. Thus, servicing cycles can be adapted tailored to the ship's needs and maintenance activities can be executed quick and targeted. Further more, damages can be prevented because of the in time replacement of component parts, repairs are executed quicker and cheaper and, finally, the costs for the ship's recycling will be reduced.

This paper gives an overview of the life cycle management guidance system for maritime industry and it single modules developed within the German funded research project called *MarLife*. The LCM guidance system aims at bringing together a high number of existing life cycle management solutions and at linking the available information. Thus, on the one hand, a better survey of the actual condition of the ship will be realized; on the other hand, data relevant within a ship's life cycle will be prepared according to the needs of the particular situation. The life cycle management guidance system is conceived as a system which supports a connection of the sub-systems to absorb and to combine the information needed for specific decisions within a ship's life cycle [1].

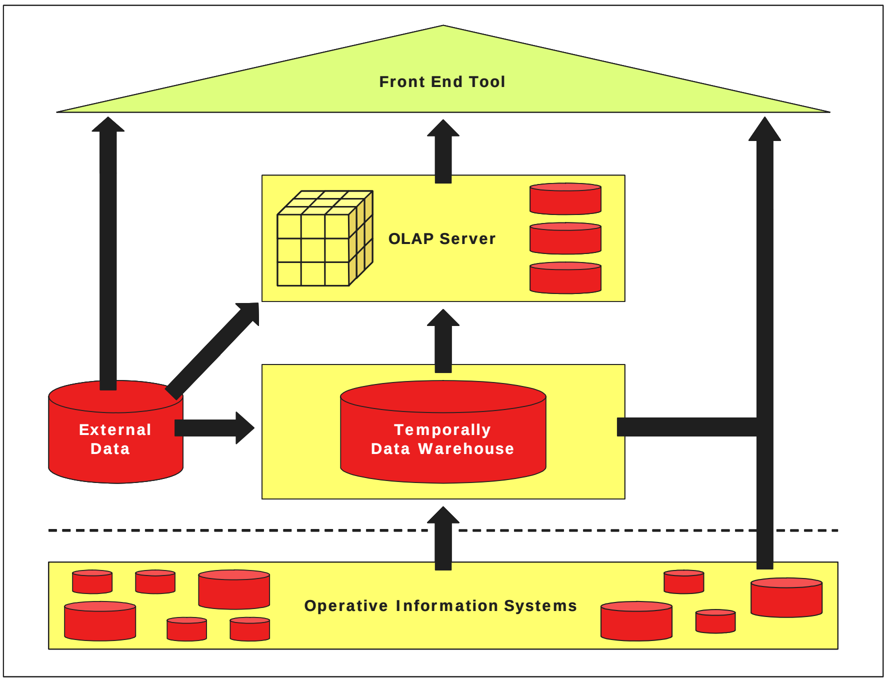
2 Relation to Existing Theories and Work

Life cycle management aspects become more and more important in a wide range of industrial sectors. Especially, in automotive and electrical industry life cycle management concepts such as reverse supply chain management and the integration of searching and tracing mechanisms into the life cycle management are confirmed elements of product development. These elements are used for monitoring relevant data of components, substances and raw materials, for planning of affiliated preventive activities as well as for the realization of a higher product quality [2].

The main pre-condition for a successful life cycle management is the availability of precise and reliable information about a product in every single phase of its life cycle. The purpose of supporting software solutions so called life cycle management systems – is to capture, to administrate and to make available this information. The use of modern LCM software tools in industry leads to a distinct reduction of information access time and a reduction of data redundancies [3]. The specificities of life cycle management systems mainly are influenced by the developed product itself as well as by the aims of the system's users. The different views of manufacturers and customers have impact on the characteristics of the life cycle management system as well. Customers are asking for a very high control of a product's condition, especially for products which are at the high end of the scale of complexity, e.g. airplanes, ships or industrial plants. The system diversity as well as the dependencies of those products can not be overviewed or managed, respectively, by their users [4].

For the creation of the life cycle management guidance system there must be revert to concepts of analytical information systems because in these systems the basic requirements to the needed system architectures are comparable. The central element is a so called temporary data warehouse which aims at creating a company wide, decision oriented data pool. In case of the guidance system the relevant data are not filed permanently. In fact, they will be connected for their logical combinations and their conjunct requests. Thus, on the one hand, a redundant data filing of big data bases is avoided, on the other hand, the actuality of the data to be processed is ensured. Additionally, within the temporally data warehouse the holding-times of the particular data are fixed and by this also the intervals for the actualization of the data base. Figure 1 shows the architecture of the life cycle management guidance system.

Figure 1 Architecture of the life cycle management guidance system [4]



Operative information systems describe systems which are already used by the shipping companies for servicing and maintenance of the ships, e.g. the software systems GL Ship Manager, Titan or MainStar. Further systems are monitoring systems which make available the relevant data throughout sensor technology. These systems can, if necessary, be used as triggers for data transfer to the life cycle management guidance system.

The element external data includes information sources which scarcely change during a ship's life cycle. These external data are information and documents of the shipyard which has built the ship as well as regulations and guidelines for operating the ship. They can be actualized during longer time periods und do not necessarily need an online access.

The OLAP (On-Line Analytical Processing) server controls the deposition of the logical data linkage. Throughout this server queries concerning the status to the temporary data warehouse are processed which are controlled by certain incidents, in specific time-periods, or permanently. Within this component the logic of making available the information according to specific needs during a ship's life cycle is deposited.

The front end tools of the life cycle management guidance system are on board or office clients, respectively. These clients are the graphical interfaces to the users of the system.

3 Research Approach

The core aim of the life cycle management guidance system in maritime industry lies in a significant optimization of shipping companies' fleet operation so that a distinct improvement of the companies' global market position will be realized. Gaining the aimed outstanding market position needs the reduction of the ships' operating costs. An important requirement to the life cycle management guidance system is its independency of single software solutions which means that this system needs universal interfaces to every kind of sub-systems. Besides the operation of the fleet the life cycle management guidance system must detect and save the costs which are generated during a ship's life cycle. Especially, the costs of damages have to be made transparent to be able to predict how costs for repairs and for insurances will develop. Further more, making available a ship's building documentation must be realized by the LCM guidance system. The status `as built' has to be actualized continuously during the ship's life cycle phases to be able to organize repairs and rebuilds quick and easy. Thus, there have to be linked a product data management system to the LCM guidance system which operates and files those data, information and documents representing the design and production data of a ship.

Three main elements determine the design of the life cycle management guidance system which are, firstly, the basic conditions, secondly, the IT solution, and, thirdly, scenarios which have to be built up. The basic conditions describe the organizational as well as the technical requirements for a well working LCM guidance system in maritime industry. Thus, there is analyzed and verified which modules of the IT solution must be located at what actors. Further more, the organizational and technical requirements at shipping companies, shipyards, logistics providers, other service providers, and authorities for a well working LCM guidance system are formulated. These analyses result in a specification which summarizes the identified preconditions.

The IT solution is represented by the life cycle management guidance system itself. This system consists of different sub-systems and combines data which are extracted from completely different sources. Additionally, the LCM guidance system structures these data and makes it available according to the needs of the users. The life cycle management guidance system aims at a structured collection and combination of all relevant data which are needed along the whole life cycle of a ship starting from its conception and design to the point of its breaking. Further more, the LCM guidance system aims at storing, structuring and newly combining these data according to the demands of the system users. Finally, the system makes available selected data and information as a reliable basis of actions and decisions during the operation of the ship [1, 5].

The built up scenarios aim at three points. Firstly, they support the identification of the life cycle data which are needed within these scenarios, Secondly, they give hints how these life cycle data have to be linked to each other so that significant information are created and a maximum benefit of the life cycle management guidance system is realized. Thus, the scenarios are an element of the LCM guidance system. Thirdly, they are the basis for verifying the cost reduction being achieved by the use of the life cycle management guidance system. The verification of the costs is done throughout a comparison of the same scenarios – one time without using the LCM guidance system, another time by using it. The comparison aims at demonstrating that already in the early phases of a ship's life cycle a distinct reduction of costs can be achieved by using the LCM guidance system.

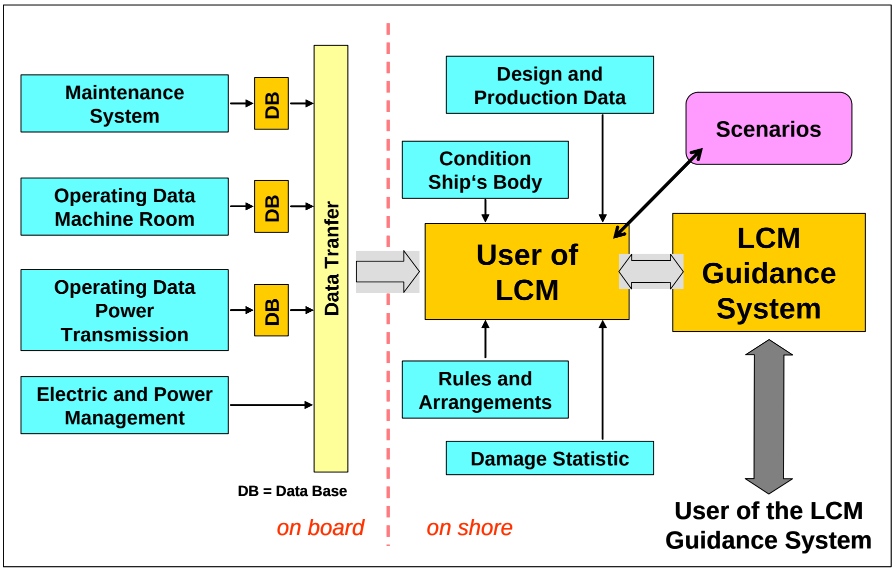
4 The Life Cycle Management Guidance System

The life cycle management guidance system consists of different elements all of which have a specific function. These elements can shortly be described as follows:

- The system makes available data, information, knowledge, and documents which have been created during the conception and design phase of a ship and which ideally are filed within a product data management system. It has to be made sure that the ship's product data are actualized continuously and that they reflect the actual building state of the ship itself. As a basis for the representation and documentation of the data a product data model is needed which describes a ship from different points of view (cp. [1]).
- The data which are created during the operation of a ship concerning services, maintenance, and repairs have to be transferred into the LCM guidance system. They have to be made available if needed. For this, the maintenance systems of shipping companies as well as the usability of the data which are generated by these systems have been analyzed.
- If operating data must be made available according to specific needs the gathering and treatment of the technical condition of a ship's core systems which are the body of the ship, its power system as well as the electrical system are of specific relevance. There are specific software systems supporting the monitoring and analyzing tasks. From these systems interfaces to the LCM guidance system are developed to transfer the operating data as well as the analyzed data to the life cycle management guidance system.
- A further element of the LCM guidance system is rules and specifications of the IMO, the coast states, and the classification societies. Thus, a better self control according to the adherence of the rules and specifications as well as a simplification of classifying activities is aimed at.
- The already mentioned scenarios are the fifth element of the technical life cycle management guidance system solution.

Figure 2 gives a rough survey of the single partial solutions of the life cycle management guidance system. According to this figure there is an on board partial solution as well as an on shore partial solution. The on board solution accesses to data which are generated during the operation of the ship, while the on shore solution is fed by basic data which are created during the ship's life cycle phases lying before the operation of the ship.

Figure 2 Model of the life cycle management guidance system



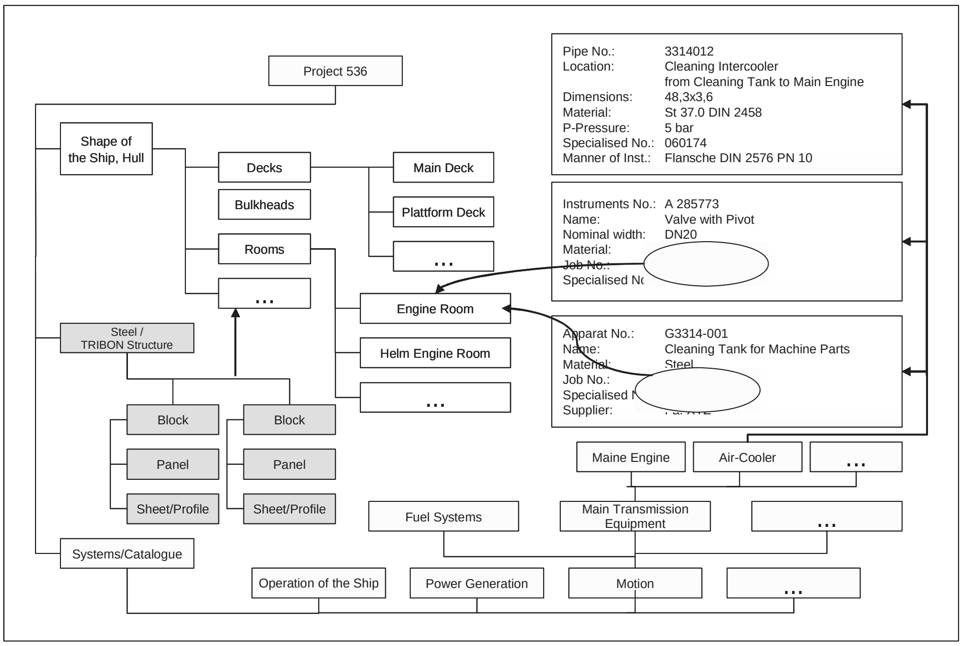
Because of the separation of the on board partial solution and the on site partial solution of the life cycle management guidance system there must be a data exchange from the on board system to the shipping company's central on site system. Throughout this transfer all the information on board is sent to the LCM guidance system module at the shipping company. The information transferred to the LCM guidance system module at the shipping company is created in many individual systems serving as data bases for the LCM guidance system. Every single of these individual systems must be tied to the life cycle management guidance system so that a well directed transfer of specific data to the guidance system via interfaces can be realized. The life cycle management guidance system further more must support a flexible retrieval of data as well as the use of specific data. It has to support a flexible combination of data sources.

4.1 Elements of the life cycle management guidance system

The main elements of the life cycle management guidance system described in this chapter are the design and production data sub-system storing the data which are created during a ship's conception and design life cycle phase and its related product data model, the maintenance system creating and storing the ship's operating data, the condition monitoring system creating and storing data concerning the technical condition of the ship's systems, a module storing general legal and environmental rules and specifications and, finally, the scenarios describing specific situation during a ship's life cycle.

A usable product data model for the representation and documentation of a ship's data within a design and production data sub-system of the life cycle management guidance system has been developed in an already finished research project [6]. According to the product data model for shipbuilding industry the necessity of different views on the ship's product data which are, firstly, a view on the ship's hull, secondly, a so-called "room" view and, thirdly, the view on the ship's systems is detected. The view on the ship's hull represents the containment of the ship itself. The room view structures the ship by dividing it into physical rooms as well as into technical rooms, which may completely differ from the physical rooms of the ship. It derives from the following two design elements: (a) the hull of the ship and (b) the main dimensions which are decks and important vertical zonings. The hull of the ship is represented by the ship's body which is created by a planar model. The main dimensions are defined by a grid which is valid for all persons involved in the construction process. Higher-ranking rooms, e.g. coordination areas, zones or panels are derived from this grid. By combining the hull and the main dimensions the concept model is created as a basis for the following segmentation of the rooms. By "cutting" the body along the main dimensions and the room zoning working areas could be created which are necessary for construction.

Figure 3 Product data model of a ship [6]



The room view of the ship's product data model is represented by defined objects which give a clear description of the single components or parts the complete artifact or a system consists of. The combination of these key objects which identify the ship's component parts with the conceived general cooperation model for shipbuilding and its different views leads to a total of 13 data objects. Each of the objects represents an attribute which gives a unique characterization of a specific component or part. The basic attributes valid for every of the defined objects are an identification number, the name of the object, the object description and a values list.

Besides the room view a system view of the ship was developed which is especially relevant for the definition of systems by suppliers. It allows a representation of the ship's systems independently from the ship itself. Within this view the ship's component parts can be classified along the systems of a ship like fuels, ventilation, power supply, equipment, etc. To create the view on the ship's systems an assembly unit directory is used which gives a unique filing structure for all parties involved in a shipbuilding project.

So called *plant maintenance systems* support servicing, maintenance, and repairs of a ship. These software systems are time based, which means that they use technical systems as well as the given run-times and intervals of the manufacturers as a basis for the supervision of servicing. The comparison of the existing run-time (operating hours) which must be read in manually creates information concerning the needed servicing actions, work plans, purchase of spare parts, etc. Every plant maintenance system includes a transfer module for the exchange of operating data between the ship and the office.

Servicing actions and intervals are fixed within a so called *condition monitoring system* in dependency of information of the technical condition of a ship's core systems. This information is based on measurements using specific diagnostics methods. The state of the art in information technology basically allows the acquisition, filing and operation of complex measured data in real time.

The life cycle management guidance system must be able to operate general legal and environmental rules and specifications in that way that they in case of needs can be combined with the data, information, knowledge and documents existing in the single individual systems. Thus new findings for specific needs can be created.

The built up scenarios related to specific cases help to identify the information needed to manage these cases and show how specific situations are processed. To do so, the life cycle management guidance system seizes exactly that information from its sub-systems and combines them to each other which are needed in a particular case. By using the life cycle management guidance system, a reduction of process time compared with the original process without using the guidance system will be realized.

4.2 Functions of the life cycle management guidance system

Some functions the life cycle management guidance system covers and which are demanded by the potential users of the system can be described as follows:

- There have to be deposited fixed requests or statistics according to certain questions within the life cycle management guidance system. Further more there has to be built up the possibility to create a flexible evaluation of data. The individual evaluation of the data could be customized by the users.
- Besides the numerical evaluations of the data graphical presentations of these evaluations will be supported by the life cycle management guidance system as well.
- The system supports an evaluation of the operating data (daily checks engine room) to make predictions concerning the technical condition of single aggregates or components. Further more it supports the derivation of rules for controlling the components.
- The damage statistics which is included in the system supports the shipping companies when there are damages or accidents. Thus, it provides standardized forms along the handling of damages, it supports an IT-based evaluation of damages reports and it evaluates the costs of damage and of the follow-up costs, such as off-hire times or costs for transportation.

- The life cycle management guidance system specifies critical components and parts within the damage statistic. Defects during the phase of warranty as well as damages are captured within a data base. The data base integrates the costs for repairing the damages and the reasons of the damages as well. Further more, it supports servicing and repairs based on life cycle data.
- Critical components and parts, especially, for the scheduling of building up new ships, for the identification of cost drivers caused by damages, and for the control of aimed actions in critical areas can be identified throughout the life cycle management guidance system.
- The life cycle management system supports the gathering of planning data and information for leasing concepts in maritime industry. Additionally, the system supports the creation or actualization of a ship's documentation during the whole ship's life cycle.

An important factor which will be realized within the life cycle management guidance system is a consistent naming of the ship's aggregates, components, and parts. Thus, a glossary is made available throughout the system which realizes a standardization of the entries in this system. Further more, a neutral standard will be established by the guidance system which realizes an appropriate documentation of the ship's aggregates, components and parts.

5 Conclusion

The life cycle management guidance system gives access to all the data needed during the whole life cycle of a ship. These data are analyzed throughout the system and serve as a decision base for running the processes in specific situations of the life cycle.

By using the life cycle management guidance system an increase of the availability of a ship is expected. The proof of this effect can be done throughout the facts that there are less repairs and docking times of a ship and that service and maintenance activities are accelerated. This results in a strong reduction of a ship's life cycle costs.

Acknowledgment

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Optimization of environmental and social criteria in the textile supply chain: European state of the art and perspectives of research

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Abstract: Sustainable development in the textile industry is not a recent issue. Firstly, scientists and industrial actors were interested in researching new ways for cleaner production especially in the part of the supply chain concerning finishing treatments and dyeing. But nowadays, an analysis of the whole supply chain is needed to locate the most polluting parts and main social impacts, and to learn where and how it is preferable to intervene. Various methods and guidelines for a simplified and balanced LCA for textiles are proposed by European organisations. The authors' main research objective is the definition of a decision support system based on multi criteria analysis to evaluate environmental and social considerations within the whole textile chain. In this paper, the traditional textile production chain is presented and its critical points analysed following the sustainable development point of view. Then the paper proposes to design a green textile supply chain.

Keyword: Sustainable development; Life Cycle Assessment (LCA); social responsibility; green supply chain, textile industry.

1 Introduction

Sustainable development, the concept popularized over the world by Brundtland [1], has reached a period of maturity as regards implementing its principles. During the last ten years, in the textile field, preserving the environment in an era of economic growth is becoming an industrial reality. As it is known, the finishing treatments and dyeing processes are strongly polluting because of the emission of chemicals in wastes and the high water consumption. That is why researchers as well as industrials looked for using other ways of production called Best Available Technology (BAT) in order to minimize environmental problems related to this part of the textile chain. However, in a lifecycle perspective not only production and waste treatment have to be taken into consideration but interactions between actors, logistics improvements, definition of critical points and alternative products scenarios, should be as important as the selection of the right material especially in textile industry. This problem, clearly identified, has given rise to numerous attempts to develop tools and methods intended to evaluate environmental impacts of each activity constituting the textile supply chain [2] and go towards a “green supply chain” [3,4,5].

It is commonly accepted that Lifecycle Assessment (LCA) methods are needed in order to reduce direct environmental impacts. In addition to that, optimizing costs and designing a green supply chain concern two pillars of sustainable development: economy and environment. But a little attention was paid to the third pillar which is the social aspect. Currently, European textile industry suffers dramatically from the declining market production prices because of cheap imports of textiles from countries without or with very low environmental and social regulations. This lays to considerable moves of NGOs and associations to provide standards and rules that take into account the social responsibility. In Europe, since 2000, systems were put in application like EMAS and standards were provided like SA8000 (Social Accountability Standard 8000).

LCA tools based on guidelines for both environmental and social issues according ISO or a textile index would be suitable instruments for control, analysis and evaluation of the respect of the textile supply chain towards the three pillars defining sustainable development. That is our main research objective which consists in conceiving a decision support system based on a multi criteria analysis to evaluate both environmental and social impacts of the entire textile supply chain. At first, we redefine the “green” textile supply chain that will be extended with adding operations like recycling and re-use. This redefinition requires the identification of inputs and outputs of each process within the textile supply chain with resource consumption and environmental and social considerations.

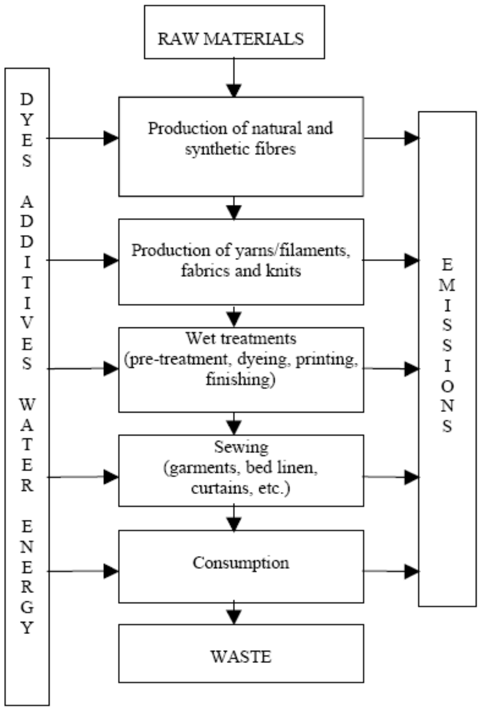
This structures the paper into the following sections: First, a brief description of the traditional textile production and the location of critical points regarding environmental and social impacts are given in section 2. Then, the complexity of the textile supply chain and the diversity of its processes related to divergent logistics policies and a wide number of products categories are described in section 3. In section 4, a list of the most frequently used ecolabels and the realistic use of LCA and Eco-design methods in European textile industry within three brief illustrative examples of textile industrials are provided. Finally, in section 5, a proposal about the manner of designing a green textile supply chain socially responsible to respond to the global concept of sustainable development is shown. The study was based on the collection of all available information and the state-of-the-art of research and technological development as well as some illustrative case studies from literature.

2 Textile production and supply chain

2.1 Processes of textile production

In this study, we focus on European textile apparel industry for which the production chain can be described as figure 1. From fibre production to final product delivery, several steps are necessary. Fibres are spun before being sent to the next stage which is weaving or knitting for making traditional tissue, or directly processed for making non woven fabrics. Textile products can have largely diversified applications (from traditional usage as in apparel and linen, to technical textiles: composite materials, non woven materials etc.) and the destination of yarns and filaments at this point of the chain depends on the nature of the final product and its use. For instance, yarns are knitted to make a T-shirt, woven to make suits and made like non-woven for cleaning wipes. Most of the time, the fabric is treated, dyed and finished before being sewed.

Figure 1 Textile production chain with environmental consideration according to E.Kalliala [6]



2.2 Location of critical points

Two types of industry are involved in the textile supply chain. The upstream industry (fibre industry, dyeing, weaving, knitting and non woven industry) are capitalistic and machine intensive, with the main concern about environment, whereas the downstream industry (mainly the garment industry) is labour intensive, mostly delocalized to low salary and has the most impact on the social aspects either in the origin or the destination countries. Whereas, there are environmental problems related to transports along the whole supply chain.

2.2.1 Regarding environmental impacts

The life cycle of textile products contains certain special features which may be problematic for the environment. For instance, the production of cotton fibres requires water and pesticides to grow culture, and to obtain wool fibres water and chemicals are used to clean animal fleece. So, these emissions to land or water are a threat to the environment. During spinning, weaving and knitting processes, the focus is on energy consumption, fibre wastes and sometimes chemicals.

In the last decade, industrials as well as researchers become aware of the pollution generated by textiles finishing which is very polluting and demands high consumption of water that contains chemical emissions after being used. For example, in finishing, 150 litres of water are used for 1 kg of product and thus, one T-shirt consumes 25 litres in finishing process. This is mainly the result of EU research projects concerning the environmental responsibility of European textile industry [7]. E. Nieminen et al [8] cited new ways of cleaner production (BAT). A proposal for a simplified life cycle assessment on the textile supply chain is also developed for a focused group of products, selected from the range produced in the Action member countries, in the purpose of dematerialization: reduction of material, energy and waste flows within the whole textile supply chain. However some parts of the chain, like fibre production were not analysed due to many reasons: lack of available data, simplification due to a complex allocation problem [8].

The manufacturing of fibres, fabric material, and most of finished products takes place outside Europe or in the Eastern Europe countries, areas where the management and the monitoring of environmental effects is only now being developed. Long-haul transportation and several intermediate warehousing stages involving packaging materials are a strain on the environment. For example, packaging, transport and sale of cotton and polyester garments add an extra of 30-40% to the environmental burden of the manufacturing process [9].

2.2.2 Regarding social impacts

Nowadays, market prices are declining strongly (in France, -40% in 10 years) and cheap imports of textiles from countries without or with very low environmental and social regulations are increasing. After the expiration of the global textile quotas system on the last day of 2004, Chinese importation in Europe on the first quarter of 2005 increased of +534% for pullovers, +113% for men's trousers and + 186% for shirts, whereas US imports of cotton trousers from China increased 1,500% and those of knit cotton shirts 1,250% from the same period in 2004. On the other hand, textile industry suffers from lack of respect of social aspect in some countries that are actors in textiles production (work of children is not banned, working conditions and wages are not adequate, etc…)

Actually, industrials should take into account social criteria since it becomes the demand of the society and especially a pressure by the NGOs... In France, 38% of consumers affirm that they take into consideration social duty in their purchases. Then, according to the sustainable development strategy, the social responsibility must be standardized. That is why the International Standard Organization is creating ISO 26000 for corporate social responsibility for all fields. It will contain guidelines and will be published by 2009.

3 Complexity of textile supply chain

The diversity of processes for textile product makes the design of the textile supply chain specific to each one. Therefore, environmental impacts are very different and the application of LCA tools is difficult.

3.1 Complexity related to production

The complexity of the textile production is due to the diversity of processing ways for the same product category. For instance, when making a T-shirt, the choice of the material has a big influence on the production in addition to diverse environmental features. The choice of a synthetic fibre such as polyester which is a material manufactured from plastic polymers (petrol) leads to the problematic use of non-renewable resources. Moreover, natural material, like cotton, is not satisfying since it generates chemical wastes. Nearly 1/5 of the pesticides used allover the world are used in growing cotton culture. In the second step, the spinning process for cotton fibre which is a short fibre is different from polyester, so energy consumption is not the same. The dyeing, finishing treatments are different as well because they are related to the fibre properties. The used dyes and additives are different since the polyester is hydrophobic and the cotton is hydrophilic, so they don't have the same reaction finishing agents and processes temperatures are also different. However knitting and sewing processes are the same.

3.2 Complexity related to logistics policies

Compared to former economic eras, actual textile apparel industry is subject to a widespread introduction of information technology needed for increasingly flexible and ever faster action and reaction schemes. The subsequent changes from supply-side to demand-side markets, possible mass customization and changes in industry structures lead to more divergent ways of distribution related, in fact, to variable replenishment strategies and different stock management methods. Surely, these trends clash with traditional hierarchy in organizations that is characterized by slow decision mechanisms and inefficient use of available knowledge. Quick response and just-in-time production methodology should lead to a better response to the demand, an increased supply chain efficiency and a reduction of production loss at any stage. However, the globalization strategy geographically extends of the textile supply chain, and the large delay of delivery separates the production decisions from the demand. In addition to that, the competitive environment and the segmentation of the consumer demand increase the number of product variety, making forecasting and supply chain planning difficult and imprecise. Despite the existence of powerful information and communication technology, most of the apparel items are produced in large quantity nearly six months before the sales period, and many SKU (in model, color or size) are overproduced.

This diversity add to the complexity of the textile supply chain and to the difficulty to choose the less polluting distribution way that depends on the product category, the demand of consumer and the geographical location of manufacturers, warehouses and retailers.

On the other hand, beyond the distribution process, an important logistic activity should be considered: it concerns product return management. In addition to that, recoverable product is environmentally conscious system where products are returned from end users to be reused. There are two ways: selling textiles as used (remanufacturing) or material recovery (recycling).

3.3 Complexity related to use

The huge diversity of textile product categories is related to many factors like the choice of raw materials and the use of the product. For example, it is clear that fashion clothes have a short lifetime because of the influence of fashion trends, so, necessarily one should think about the waste of these textiles in end use to avoid the environmental burden associated with these wastes and the manufacture of new products made of new materials. However, household linen must have a long lifetime which is a preference of the consumer. In this case, one should pay attention to the laundering behaviour. With regards to its environmental effects, the washing of textile products may be the most harmful stage in the entire production chain, if the volume of washing and drying energy and the discharges of washing chemicals are taken into account [6]. The table below shows some examples from textiles categories and the associated impacts on environment and eventual solutions.

Table 1 Classification of textiles and related environmental features vis-à-vis lifetime criteria

Product categories		Criteria of classification	Environmental effects	Eventual solutions
Fashion wears		Short lifetime	Textile wastes	Re-use, recycling [9,10]
Baby wears		Short lifetime	Textile wastes	Re-use, recycling
Casual wears		Long lifetime	Laundry behaviour	Improvement of quality factors: durability, colour fastness, stability of dimensions, etc. [6]
House-hold linen	Bed sheets	Long lifetime	Laundry behaviour	Improvement of quality factors: durability, colour fastness, stability of dimensions, etc.
	Wipes for cleaning	Short lifetime	Textile wastes	Recycling

4 Environmental labels, LCA tools and Eco-design methods in the European textile industry

The need to preserve environment from emissions, wastes and excessive use of raw materials is the essential motivation of rules, standards and labels in the textile industry.

4.1 Textile ecolabels

Initiated by the authorities (International organizations, Global Ecolabelling Network associations, , NGOs, etc.), the ecolabels guarantee at the same time the quality of use of the ecological product and its characteristics since they inform the consumer about the quality of raw material, recyclability, energy consumption, etc.

On a world wide scale, the development and the practical application of these labels are managed by the International Standard Organization by the means of standards [11] classified as below:

- Standards like ISO 14020 (1998): general principles
- Type I standards like ISO 14024 (1999): principles and methods
- Type II standards like ISO 14021 (1999): self-declarations (Claims made by producers and suppliers on the labels of products)
- Type III standards like ISO TR 14025 (2000): Eco-profile (standardization for quantified environmental data for products)

Moreover, Öko-Tex developed three labels that are classified according to the respect either to environment (Öko-Tex 1000) or to the health (Öko-Tex 100) or to both of them (Öko-Tex 100+).

In Europe, many labels are created [12]. Although, in this paper, we list only the most frequently used ones. The most used labels are the EU ecolabels (The flower, 1992), the Nordic ecolabels (The Nordic Swan, 1999) and the Öko-Tex standards, of which the Öko-Tex 100 (1992) is the one most often used in the EU countries.

Öko-tex standards, that cover thousands of certified textile products instead of only 45 EU ecolabelled textile products, focus on determining harmful substances in intermediate and finished products in contrast to The EU and Nordic environmental label which are based on the LCA idea. On the other hand, we have to mention that the comparison of products carrying different labels is almost impossible due to the divergent labeling criteria.

Based on the life cycle thinking, environmental labels look for decreasing environmental effects across the entire supply chain from the production of raw material to waste management. The quality of the product is also included in determining the criteria (dimensional stability, colour fastness...) [13, 14, 15, 16].

Currently, the need is to enlarge the number of textile labeled products using LCI and LCA methods which concern each part of the product lifecycle. Hence, we realize better Eco-efficiency[1]* by adding value with a lower environmental impact.

4.2 Life cycle assessment and Eco-design of textile products

Eco-design (and DFE: design for the environment) is a helpful, emerging tool to improve companies' environmental performance by addressing product functionality while simultaneously minimizing lifecycle environmental impacts. This is not automatically related to lower quality or poor design. That is why it is important to convince consumers that ecological clothes can be as fashionable as the others. The Eco-design of textile products seems to be very important since it insures an ecological and fashionable design with keeping the same quality. Further more, this method helps designers to reduce eventual extra costs due to alternative raw materials or new "cleaner" production processes which are sometimes more expensive. This preventive method is based on LCA thinking. Thanks to the environmental evaluation of an existing product, using a LCA tool (gathering together the environmental information on all manufacturing processes used in the supply chain: the raw materials used, energy and other natural resources, process chemicals and emissions), the main polluting parts of the supply chain are identified. Hence, anticipated interventions are allowed to minimize the environment burden.

The efficiency of these methods is justified by their increasing application in the textile industry. In this paper we mention some successful examples from France (LAFUMA), Sweden (H&M) and Germany (OTTO).

4.3 Study cases from European textile industry

4.3.1 LAFUMA

LAFUMA is a French group specialised in sport nature equipments (textiles, footwear…) which is present in 45 countries. They started using eco-design methods and LCA tools in 2000. Their objective now, is to set out a line of eco-designed products in each category (textiles, footwear, furnishing, equipments) and their long-term vision is to produce the whole category of eco-designed products. For example, compared to traditional shoes, the eco-designed ones have 10% less impacts according to Eco-indicator 99. They also were able to divide by 6.5 the water consumption by recycling used water in one of their dyeing workshops and to minimize 14 tonnes of COV per year by using BAT [19, 20].

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[1] Eco-efficiency invented by the World Business Council for Sustainable Development in the book Changing Course [17]. It can be defined as the ration of a product or service value and the resulting ecological impact indicator. [18]

4.3.2 H&M

H&M is a Swedish clothing retailer; it has a big market place in the world. They communicate a list of prohibited chemical substances of use by the suppliers, based on the strictest legislation among the countries of sale of the H&M products, and on certain criteria of Öko-Tex and the European ecolabel. In 2004, some children wears were made of 5% of bio cotton (400 000 articles that represents 5 tonnes of bio cotton). In 2005, they realised 40t instead of 20t (fixed objective) [21].

4.3.3 OTTO

OTTO is German retailer and is the largest mail order business in the world. In 2002, 600t of bio cotton were used for textiles, which places Otto in position of leader on the market of the suppliers of bio cotton for textiles. It created 2 ecological labels [21] for its clothing tendency at accessible prices: the label "Hautfreundlich" and the label "Pure Wear", for the cotton bio, which aims to environmental excellence throughout textile life cycle account for 97% of the clothing sold by Otto. This proportion was only 45% in 1998. The entire product life cycle is taken into account. This process allows savings of water and energy, (for example water 50% saved for the woven products). Otto attempts to arbitrate the costs and the emissions of carbon dioxide at the time of the choice of the way and the means of transport of the products.

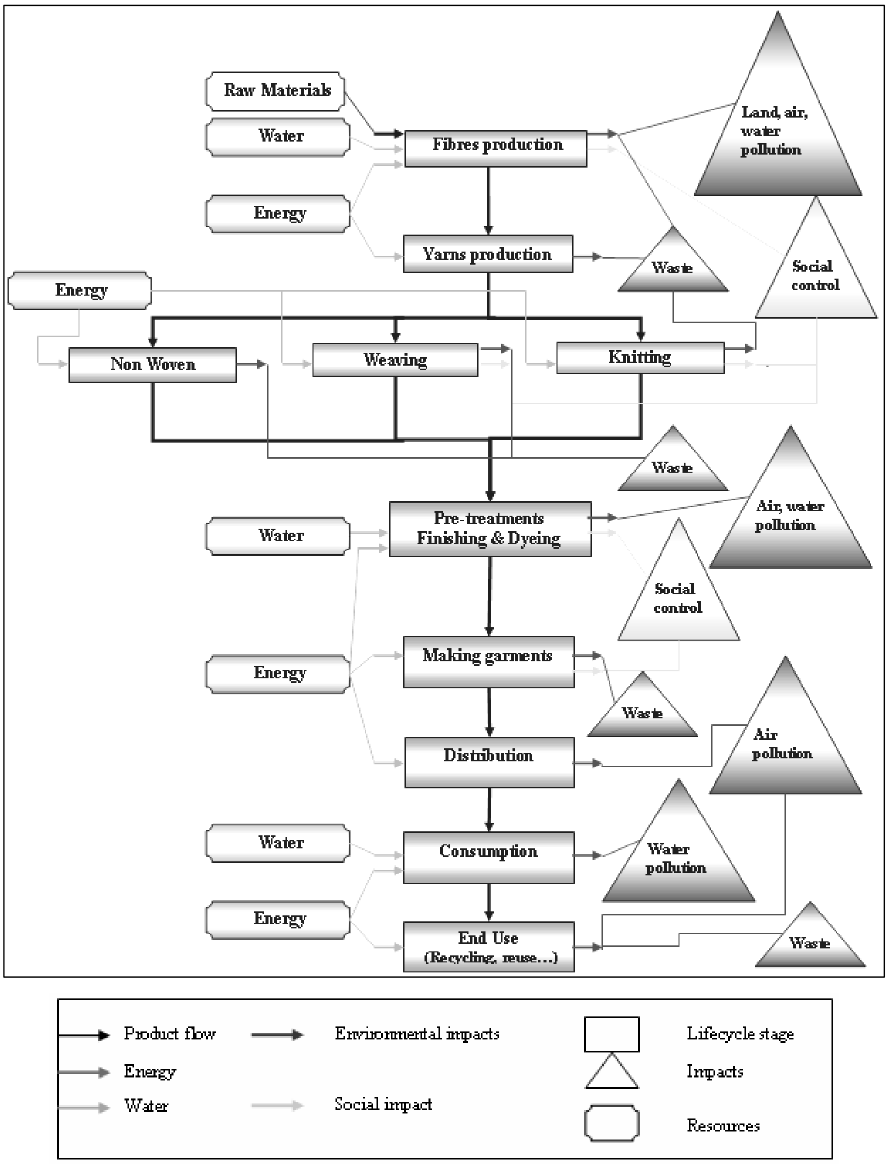
5 Research objectives: Towards a green textile supply chain socially responsible

According to the sustainable development strategy, industrial development and environmental and social protection must coexist. Thus, the idea is to redefine the basic structure of the entire textile supply chain, by accommodating either environmental concern associated with waste and resource use minimization and social concerns associated with countries actors in the supply chain.

First of all, processes must be identified for each product separately (because, as it was said in section 3, textiles production chains are very divergent). The second step is the identification of all inputs and outputs. In order to quantify this information, the LCA method is the most suitable. Recycling and reuse of wastes are extra operations that should be added to the supply chain everywhere recoverable wastes are located as shown in figure 2. For instance, water can be recycled in finishing for further use and used textiles can be collected and sold as used. The need to integrate the flows back from the customer is also recognised, so called reverse logistics [10]. These activities must be value-creating and environmentally and socially respectful. Therefore, LCA tools must be also applied to evaluate and compare these activities. For example, we have to be sure that recovering used materials by recycling is less harmful and more profitable than producing original materials [9].

In the last decade, consumer becomes more aware of the gravity of pollution as well as researchers and industrials are looking for preserving the planet. They also agree that pollution prevention instead of pollution control; waste minimization and source reduction are more convenient. That is why researchers think about minimizing risks at earlier stages in a supply chain especially in the textile industry that is known of its polluting production. Sustainability in this field is fundamentally about identifying problematic social, environmental and economic issues throughout the supply chain, assessing their impacts and risks, and then trying to improve them. Here we are subject to a multi-criteria analysis in conceiving our decision support system in order to respond to the sustainable development policy. LCA tools are the most suitable to quantify and evaluate environmental impacts within the entire textile supply chain. The next research aim is to add social considerations to this tool and thus conceive a decision support system based on the application of multi-criteria analysis on a LCA idea.

Figure 2 Proposed redefinition of Green textile supply chain



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EoL framework for design advisory

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Abstract: Sustainable product development has risen to be a concern of many product manufacturers in recent years. Manufacturers are adopting the life cycle approach in managing the development of products and they are in favour of closing the product life cycle loop by incorporating the end of life stage into the design process. With this, there is the urgency to fill up the knowledge gap between the end-of-life stage and design stage. More tools and methodologies for Design for End-of Life (DfEoL) are needed to assist designers to design products with better end-of-life performance. In this paper, a novel methodology for capturing, representing, classifying, retaining and analyzing the knowledge from the end-of-life stage to be made available for the designers is proposed. An overall end-of-life index for a design will be elaborated.

Keyword: End-of-Life Management; Design for Environment; e-waste

1 Introduction

In the last decade, a myriad of efforts have been made in sustainable product development by international organizations, governments, companies and consumers. Driven by legislations and corporate social responsibility, many manufacturers are channeling more resources into practicing sustainable manufacturing over the entire product development life cycle. This is particularly evident in the electrical and electronics sector where the fast advancement in technology leads to short product lifespan, and hence rapid accumulating of electronic waste (E-waste) causing pollutions.

A fundamental approach to overcome the problems is to take End-of-Life (EoL) management as an integral part of product development life cycle so as to alleviate the problem of e-waste. Studies have shown that a large part of the cost and environmental impact locked at the design stage where most decisions on the use of materials and processes are made (Lofthouse and Bhamra, 2005, Bhander et al., 2003). Currently, however, the EoL management activities are disjointed from the rest of the product lifecycle activities and focus more on remediation than prevention (Bhander et al., 2003, Rose et al., 2002). This is not economically and ecologically sound in most cases. The shift in product development paradigm requires the designers to consider EoL performance of a product in the design stage, or Design for EoL (DfEoL), forming a close-loop of the product life cycle.

DfEoL is to improve the environmental performance of products throughout the life cycle by systematic integration of environmental aspects of the EoL stage in the product design. Since 1990s, there have been research efforts in the area of DfEoL ranging from design for disassembly, recovery times, EoL strategies for different products and design for recycling techniques but there is no one that encompasses every aspect of EoL (Huisman et al., 2003, Silva et al., 2006, Herrmann et al., 2006). A critical shortcoming is that the data are often too technical in nature and not communicated well enough for the designers to use early in design stage. They are also focused on specialized areas rather than holistically considering all the EoL options. There is an urgent need for methodologies and tools that allow designers to analyze all possible EoL options. Also, the SortED (Lofthouse and Bhamra, 2005) tool is a tool that helps designers to understand and interpret the WEEE (EU, 2003) requirements with respect to the category of products that they are developing. It only helps to provide the designers with information from WEEE but not from the EoL stakeholders thus it is more towards for compliance aid and not information management. ELDA (Rose et al., 2002) failed to consider the hazardous substances while strategizing EoL options at the design stage.

In the work of this paper, a novel index for evaluating EoL performance of products is developed. The index gives aggregate values representing the relative performance of a design under available EoL options during design. It can hence act as a design advisory for designers to judge available design options for optimal EoL performance. The framework and methodology of the index is presented.

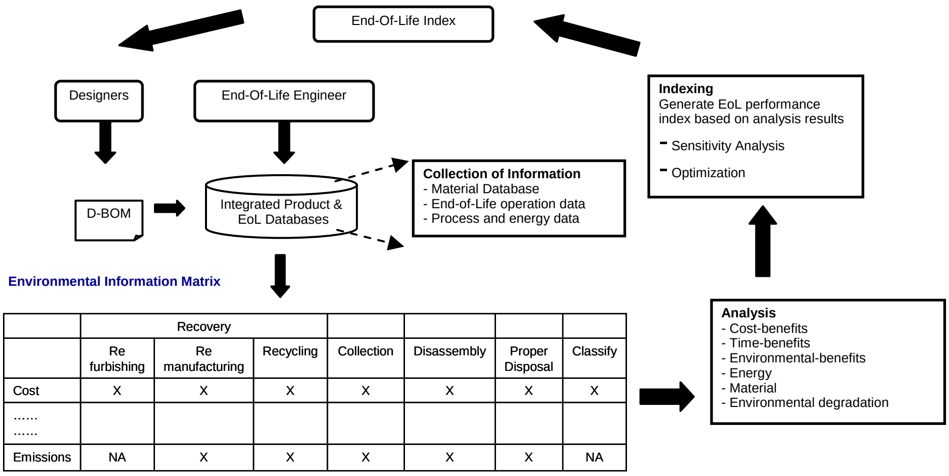
2 EoL Management Framework

Product environmental information is very important to the success of sustainable product development and good product information is needed for effective implementation to improve environmental performance of the product. The EU has commissioned a study to establish a framework for introducing and implementing product environmental information as the current drivers for good information management is weak and barriers are steep (Ryder, 2006).

In order to define the EoL index, an EoL information management framework shown in Figure 1 is established. The framework includes the capturing, representing, classifying, retaining, retrieving and analyzing of knowledge from the EoL stage for design decision-support. Here, the availability and accessibility of the information to the designers are very crucial. Many designers do not have the proper know-how for designing a product with ecologically sound EoL considerations as communication between design stage and EoL stage is virtually non-existent. The framework is designed to overcome the issues.

EoL management is a relatively new area in product design and development. Past works have noted that there is a lack of information and coordination in the EoL stage also (Lee et al., 2005). As such, there is still a lack of established EoL management framework that adopted a holistic and integrated approach in handling and planning the EoL activities systematically. To further substantiate, many researchers conclude that current existing concepts are not related or compatible to general frameworks available as well as traditional product development methods (Kara et al., 2005). There is also no system that bridges the information gaps between the EoL stage and design stage being developed yet.

Figure 1 End-Of-Life Information Management Framework



As shown in Figure 1, the first stage is to identify the necessary information that is required by the framework. There is abundance of data available and hence the need to determine what kind of information needed for this purpose. The different type of information needed will come from the different stages of the product lifecycle in particular the design and EoL stage. The information needed will be collected at the EoL stages and be captured into the EoL databases that will be linked to the other databases in the framework to form the integrated product and EoL databases for both the designers and EoL stakeholders to use. Next, the collected information will be classified in the different tables according to the nature of the information and where it will be used in. The tables are designed to consolidate and store the information in a useful manner to be referred easily. The EoL information is arranged according to the different type of sub-indices that they will contribute to. Then these numbers will be selected and represented in a matrix for calculation according the respective sub-indices to give the various indicator values which will eventually be aggregated to give an overall index. After the index is being obtained, the designers will review the design and any additional information and decisions will be stored back to the integrated databases.

3 EoL index Methodology

This is an index for measuring and evaluating the forecasted performance of a product at the end of its life. This index is designed to be holistic and inclusive of many aspects of End-of-Life options. There are three main categories for the sub-indices to represent the three important aspects of EoL management, namely disposal, recovery and disassembly. This is a two-dimensional indexing method. The index is being generated from the product structure point of view and from the three main sub-indices point of view.

For the product structure, the top level is product, which is separated into smaller modules, and loose components that do not belong to any modules at the second level. Then modules are further split into sub-assemblies and loose components that do not belong to any sub-assemblies at the third level. Finally sub-assemblies are broken down into components level. The different components of the index are summarized and presented in Table 1. It shows all the sub-indices for the different product level and the rows record all the sub-indices for the same level according to decomposition in product structure.

Table 1 Different types of sub-indices at different level

	Disposal	Disassembly	Recovery (RI)		Total
			Recycling	Remanufacturing	
Components	DI_C	-	RCI_C	RMI_C	CI_T
Sub-Assembly	-	DAI_{SA}	RCI_{SA}	RMI_{SA}	SA_T
Module	-	DAI_M	RCI_M	RMI_M	MI_T
Product	-	DAI_P	RCI_P	RMI_P	PI_T
Total	DI_C	DAI_T	RCI_T	RMI_T	

Equation 1 depicts the general form of equation for the overall index

$$\text{Product Index, } PI_T = \alpha DAI_P + \beta RI_P + \sum_{k=1}^{n} \gamma MI_T + \sum_{j=1}^{m} \lambda CI_T \quad (1)$$

Where DAI_P is the disassembly sub-index for the product,

RI_P is the recovery sub-index for the product,

MI_T is the module overall EoL index of modules in the product,

CI_T is the components EoL index of the loose components attached to the module directly,

n is the total number of modules in the product

m is the total number of the loose components attached to the module directly

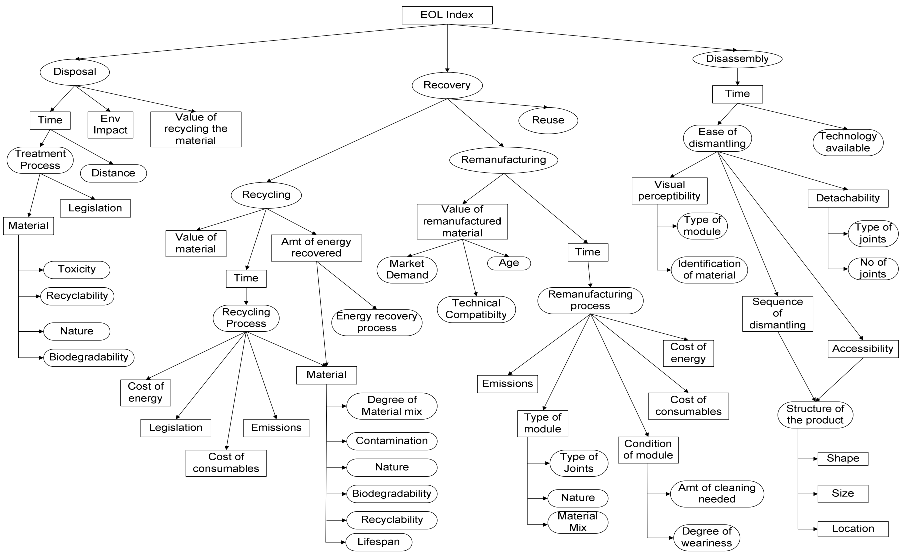
α, β, γ, λ are weighting factors for the indices

This index is obtained by aggregating the disassembly index (DAI), disposal index (DI) and recovery index (RI) from the lower level to form the higher level index. RI can be represented by recycling index and remanufacturing index. It starts by using the base factors affecting the three main sub-indices as shown in figure one to sum up from the component level to product level through the sub-assembly and module level. At each level, there are different base factors that contribute to the sub-indices and different inputs are needed for the different sub-indices at each level. As shown in equation 1, the product overall index is a summation of disassembly index which measures the disassembly process of the product into its modules; recovery index which reflects the reuse or remanufacturing feasibility of the product as a whole and lastly the disposal index which represents the cost of disposing the product.

3.1 Sub-Indices

The three main sub-indices are disposal, disassembly and recovery. For each of the sub-index, further decompositions are done until the simplest measurable contributory factors are obtained. Figure 2 show the breakdown of all the factors affecting EoL under each sub-index.

Figure 2 Different Factors affecting the EoL Index



3.1.1 Disposal Sub-Index

Disposal is the most common option for EoL as it is always the last resort and it is the easiest to handle from the view of consumers. There are two main types of disposal methods available, general waste disposal and disposal with proper treatment. Under the general waste disposal, there are incineration and landfill and they are treated as one general category. As for disposal with proper treatment, the different treatment processes are considered depending on the products being investigated. This is an important factor as it will directly affect the environment if not done properly and it will increase the cost of disposal thus making recovery a more attractive option. Under the disposal sub-index, the different types of disposal are being studied and decomposed into the affecting factors. Here it is assumed that the product will go through disassembly to component level before being disposed.

The total cost of disposal is determined by the amount of time needed, the environmental impact created by the disposal and the value of recycling the material. The higher the environment impact, the higher the cost will be. The value of recycling the material is to compensate for the loss of value that the material can generate when recycled. It will lead to higher disposal cost if the material has high value after recycling.

From here, time can be further broken down into a function of treatment and distance to the dumping ground. Treatment process needed before the disposal is crucial to time as it will translate into additional disposal cost if the process is more tedious. Distance to the disposal site is instrumental in determining the time as it will affect the transportation time. The time is directly proportional to the distance needed to travel to the disposal site. Treatment process is dependent on the materials present in the product and current legislations in force for the materials. The stricter the legislations the higher will be the cost of the treatment process and hence increasing the index for treatment process

Total cost of disposal, TC_{DI} = f (Time- t_{DI}, Environmental Impact- EI, Value of recycling the material- VaRM) = $\alpha_{TCDI}\, t_{DI} + \beta_{TCDI}\, EI + \gamma_{TCDI}\, VaRM$ (2)

t_{DI} = f (Treatment Process - P_T, distance - Dt) = $\alpha_{DI}\, P_T + \beta_{DI}\, Dt$ (3)

PT = (Material - M_{DI}, Legislations - L) = $\alpha_{PT}\, M_{DI} + \beta_{PT}\, L$ (4)

M_{DI} = f (Toxicity, Tx, nature of material, NaM, biodegradability, Bg)

= $\alpha_{MDI}\, Tx + \beta_{MDI}\, NaM + \gamma_{MDI}\, Bg$ (5)

Material will directly affect treatment process depending on the level of toxicity, nature of the material and biodegradability. The level of toxicity is defined by the amount of hazardous substances present and how does it degrade of the natural environment and human health. The higher the level of toxicity, the higher the material index will be. Nature of the material refers to the broad category that the material belongs to. This nature of material will determine generally how the treatment process is like. Biodegradability is needed here to indicate if disposal of this material will cause more pollution or not. Then higher the biodegradability it is, the lower the environmental cost will be and hence material index will be lower.

3.1.2 Disassembly Sub-Index

Disassembly is the process of physically separating a product into its modules, sub-assembly or components. It is a major compulsory stage that most EoL product will go through during the EoL stage especially for recovery purposes. This is one of the main determinants to decide whether recovery is viable or not. Disassembly occurs at different levels of the product structure and different factors are being considered at different level. The total time will be determined by the ease of dismantling and technology available for disassembly. Technology available refers to available equipment and how established as well as how commercialized the technology is in dismantling certain joints. Ease of dismantling is defined by the summation of visual perceptibility, accessibility, detachability and sequence of dismantling. Of which each of the factor is further compounded by other sub-factors. They are determined by equation (6)-(13).

Total Cost of Disassembly TC_{DAI} = f (Time,t_{DAI}) = $\alpha_{TC}\, t_{DA}$ (6)

t_{DAI} = f (Ease of dismantling-Ed, technology available-Tech)

= $\alpha_t\, Ed + \beta_t\, Tech$ (7)

Ed = f (Visual perceptibility-Vp, Accessibility-Acc, Detachability-Dt, sequence of dismantling-Sd) = $\alpha_{Ed}\, Vp + \beta_{Ed}\, Acc + \gamma_{Ed}\, Dt + \delta_{Ed}\, Sd$ (8)

Vp = f (Type of modules-Mod, Identification of material-ID)

= $\alpha_{Vp}\, Mod + \beta_{Vp}\, ID$ (9)

Dt = f (Type of joints-J, number of joints-No_J) = $\alpha_{Dt}\, J + \beta_{Dt}\, No\_J$ (10)

$$Sd = f\text{(Structure of the product-St)} = \alpha_{Sd}\, St \quad (11)$$

$$Acc = f\text{(Structure of the product-St)} = \alpha_{Acc}\, St \quad (12)$$

$$St = f\text{(depth-dp, location-Loc, shape-Sp, size-Sz)}$$

$$= \alpha_{st}\, dp + \beta_{st}\, Loc + \gamma_{st}\, Sp + \delta_{st}\, Sz \quad (13)$$

Visual perceptibility will depend on the type of modules and identification of the materials presents in the product. The easier the identification of the material and modules especially the joints, the higher the visual perceptibility it will have and it will be easier to take out. Both the sequence of dismantling and accessibility are dependent on the structure of the product, which is determined by the depth, location, shape, and size of the components. Product, modules and components with regular shapes, non-bulky size, lesser depth and visible locations are easier to access for detachment and have lesser sequence for dismantling. Type of joints and number of joints will affect the detachability. Products with non-permanent joints like snap fit and screws are easier to detach then permanent joints like welding and soldering.

3.1.3 Recovery

Under recovery sub-index, recycling and remanufacturing are two main activities. Recycling refers to the reprocessing in a production process of waste materials for the original purpose or for other purposes but excluding energy recovery. Remanufacturing refers to the reuse of components or modules for the same purpose in the same type of products or other type of products after refurbishment. The third recovery option, which is the direct reuse of the products after refurbishment, such as selling in second hand market, is not included. Recovery is one of the most useful ways to reduce the environmental burden on the limited resources and the impact on land usage. Recycling process is being carried out at material level mainly while the remanufacturing process is normally considered only at the module and sub-assembly level.

Recycling

The total cost of recycling is made up by the amount of time needed for recycling to take place, the value of the material and the amount of energy recovered through the entire recycling activity. The longer the time taken, the higher the cost will be. Both the value of material and amount of energy recovered will help to reduce the cost as they increase.

$$\text{Total cost } TC_{RC} = f\text{(Time-}T_{RC}\text{, Value of recycling the material-VaRM, Amt of energy recovered-Engy)} = \alpha_{TCRC}\, T_{RC} + \beta_{TCRC}\, VaRM + \gamma_{TCRC}\, Engy \quad (14)$$

$$TC_{RC} = f\text{(Recycling Process- }P_{RC}) = \alpha_{TCRC}\, P_{RC} \quad (15)$$

$$P_{RC} = f\text{(Material-}M_{RC}\text{, Legislations-L, cost of energy-Cost}_{E}\text{, Cost of consumables-Cost}_{C}\text{, emissions-E)} = \alpha_{PRC}\, M_{RC} + \beta_{PRC}\, L + \gamma_{PRC}\, Cost_{E} + \delta_{PRC}\, Cost_{C} + \varepsilon_{PRC}\, E \quad (16)$$

$$Engy = f\text{(Material-}M_{Engy}\text{, energy recovery process-}P_{Engy})$$

$$= \alpha_{Engy}\, M_{Engy} + \beta_{Engy}\, P_{Engy} \quad (17)$$

$$M_{RC} = f\text{(Recyclability-R, Contamination-C, Nature of material-NaM, Lifespan-Ls, Biodegradability-Bg, Degree of material mix-DegM)}$$

$$= \alpha_{MRC}\, R + \beta_{MRC}\, C + \gamma_{MRC}\, NaM + \delta_{MRC}\, Ls + \varepsilon_{MRC}\, Bg + \eta_{MRC}\, DegM \quad (18)$$

Time is a factor entirely dictated by recycling process. Recycling process is a function of materials present in the product, existing legislations for the products, cost of energy, cost of consumables and emissions given out during the process. The stricter the legislations are, the more tedious the recycling process will be, leading to longer time needed. Cost of energy and cost of consumables are set to bring up the recycling process index as they increase. Emissions will drive up the recycling process index as more of them are being generated too. The material being used and the type of energy recovery process determine amount of energy being recovered during recycling process. Certain material will provide more recovered energy and certain recovery process are more environmentally friendly.

The most important factor in this sub-index is material as it is the most basic element that can decide the recycling process and the amount of energy that can be recovered. The recyclability of the material, contamination of the material, the nature of the material, the lifespan of the material, biodegradability and degree of material mix are the determinants of the material index for recycling. The higher the recyclability of the material, the better the material index will perform. This is an important consideration of recycling. Then contamination and degree of material mix will increase the index if both are high. Contamination refers to the conditions of the materials as in how dirty is it and is there any other contaminants like adhesives. Degree of material mix will refer to the number of different substances present in the materials. Nature of the material is an indication of what broad category does the material belong to. These categories include glass, metal, polymer, plastics and ceramics. Lifespan measures the expected lifespan of the material.

The final recycling sub-index is an aggregation of all the factors from the lower levels. Starting from the lowest level, material index is a summation function of recyclability, contamination, nature, lifespan, biodegradability and degree of material mix. Then in turn amount of energy recovered index is dependent on material index and energy recovery process. Together with legislations, cost of energy, cost of consumables and emissions, material index will also determine the recycling process index.

Remanufacturing

The total cost for remanufacturing is defined by the amount of time taken for remanufacturing process and the value of the remanufactured products. Time taken for the remanufacturing process to take place is entirely dictated by the remanufacturing process needed. The more tedious the remanufacturing process is, the more time is needed and it will be more costly. The value of the remanufactured product is determined by the technical compatibility of the old module with the new product, the age of the module and the market demand for that particular module. Both technical compatibility and market demand have a positive relationship with the value of remanufactured product whereas age of the module varies inversely. The higher the value of the remanufactured product, the lower the cost of remanufacturing will be.

Total cost TC_{RM} = f (Time-t_{RM}, Value of remanufactured product-VaRP)

$$= \alpha_{TCRM}\, t_{RM} + \beta_{TCRM}\, VaRP \qquad (19)$$

VaRP = f (technical compatibility-TechC, age-A, market demand-d)

$$= \alpha_{VaRP}\, TechC + \beta_{VaRP}\, A + \gamma_{VaRP}\, d \qquad (20)$$

$$\text{Time, } T_{RM} = f(\text{remanufacturing process, } P_{RM}) = \alpha_{TRM}\, P_{RM} \qquad (21)$$

P_{RM}= f (condition of module-CMod, type of module-TMod, cost of energy-$Cost_E$, cost of consumables-$Cost_C$, emissions-E)

$$= \alpha_{PRM}\, CMod + \beta_{PRM}\, TMod + \gamma_{PRM}\, Cost_E + \delta_{PRM}\, Cost_C + \varepsilon_{PRM}\, E \qquad (22)$$

CMod = f (degree of weariness-DegW, amt of cleaning needed-AmtCl)

$$= \alpha_{CMod} \text{ DegW} + \beta_{CMod} \text{ AmtCl} \quad (23)$$

TMod = f (material mix-MMix, Nature of module-NMod, Type of joints-J)

$$= \alpha_{TMod} \text{ MMix} + \beta_{TMod} \text{ NMod} + \gamma_{TMod} \text{ J} \quad (24)$$

Remanufacturing process is a function of the condition of the module, type of module, amount of emissions, cost of consumables and cost of energy. The emissions, cost of consumables and cost of energy are the same as those in the recycling index. As for the conditions of the module, it is measured by the degree of weariness and amount of cleaning needed. Those that are cleaner and work better will contribute to a higher index since less cleaning is needed and lesser degree of weariness.

The type of module is a function of material mix in the module, nature of the module and the joining method of the module. The higher the material mix, the harder remanufacturing process will be due to the fact that more compatibility must be met.

Having defined and elaborated all the relationships between the factors that made up the sub-indices, the next step is to detail the scale of each of the individual factor that the designers can use to give a rating. However, this will not be in the scope of this paper.

4 Discussion

In the previous section, the definitions of the three sub-indices are being elaborated respectively. The follow up to this paper is to generate an overall index to give an estimate of the EoL performance by combining all the three sub indices using a case study but it will not be illustrated here.

By using a modular approach in building up the indices, the method is made simpler for designers to use and interpret the results. Firstly, the index is being decomposed into the various factors that are measurable and easy to obtain. This lead to a more systematic and straightforward way to get the parameters needed for the index to be calculated. The complex nature of the EoL management is being simplified by the hierarchical breakdown of factors into sub-clusters. Then it also allows the designers to look at the individual breakdown of the factors affecting the EoL performance of a product. The weaknesses and strengths of the product in EoL performance can be identified and analyze from the departmentalization of the factors. Furthermore, the measurements are simple and not difficult to determine the value of each factor using the normalized scale. This index is also flexible in the sense that in different scenarios different factors will be used and some factors are not applicable for certain scenarios. This is made possible by the modularity. For example at the component level when recycling after shredding is being considered, the number of joints and type of joints are not applicable. Finally, each designer can input the priorities to get an evaluation with respect to their preferences. This helps the designers to specify certain aspects that matters more and get a better performing product. This index is designed to be simplified yet still rather effective in pointing out the weaker environmental aspects.

Some possible uses of the EoL index are in EoL planning, design planning and design evaluation. This index can indicate to the EoL stakeholders about the different performance of the product at EoL, make decision for the EoL options and improve the EoL process. The same benefits will apply to the planners and designers at the design stage. They can forecast and estimate the EoL performance of the product at the design stage and redesign the product accordingly to improve the environmental performance. Comparisons of alternatives can also be aided by using this index as one of the yardstick.

5 Conclusion

With sustainable product development getting important and the tremendous pressure from the international community to push for better management of e-waste to reduce the environmental and health impact, it is important that designers start to incorporate EoL considerations into the design stage and close the product life cycle to promote more recovery in order to achieve waste minimization. This paper has proposed an EoL framework and indexing methodology for the designer to evaluate and estimate the EoL performance at the design stage.

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Recycling electrical and electronic equipment: the recovery management system introduced by the WEEE directive

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Abstract: This contribution focuses on the product recycling management system introduced by the WEEE Directive in order to recover electrical and electronic waste. By underlying that the recovery network is in continuous evolution and the difficulty to reach a consensus between stakeholders is one of the major problems, we try to address what are the main critical factors at the institutional, configuration and operational level. The possibility to measure performances and plan improvements is strictly related to a stabilization of the system. Future research is oriented to define a performance measurement system which will allow planning improvements and periodically access the efficiency of the recovery chain. The Danish WEEE implementation process is used as a case study.

Keyword: recovery management system, Waste of Electrical and Electronic Equipment (WEEE).

1 Introduction

While traditional manufacturing systems can rely on the possibility to plan according to forecasting and knowledge of the market, return flows are affected by an inherent uncertainty related to the product infrastructure (products range, materials types and related quantities, potential hazardous substances, product design and manufacturing technology) which affects the recovery network infrastructure (timing, returned quantity and quality, points of collection, transportation and recovery/treatment installations capacity). Furthermore, reverse logistics activities have been seen for long as a necessary service to provide the customers. The result is that the focus has traditionally been in minimizing costs ensuring a reasonable costumer service support. Over time, the recognition of increasing value of products and technology created in the field at the end of the direct supply chain and the impact of the green laws, has moved companies’ focus to different types of recovery programs. While refurbishing, remanufacturing, repair and direct reuse represent possible sources of direct gains for the Original Equipment Manufactures (OEMs), recycling and recovery are often promoted by regulations which aim at minimizing the environmental impact of discharged products (End of Life - EoL, End of Use - EoU).

In the remaining of this section, we present the main aspects of the reverse supply chain: drivers, recovery options, characteristics of the returned products, involved actors and reverse phases. The combinations of these factors identify different types of reverse networks.

The rest of the paper is organised as follows. Section 2 shortly presents the European Directive which has forced OEMs to recover their product individually on by means of consortiums. Section 3 addresses the implementation of the Directive in Denmark and it describes which products recycling system it enacted at the institutional, configuration and operational level. Section 4 present downsides and specific critical aspects of the of product recovery management system. Conclusions and indications for further research follow.

1.1 Drivers

Economic as well as environmental factors are commonly recognized as drivers for product recovery. In [1] a distinction is made between drivers for the receiver and drivers for the sender. The drivers from the receiver perspective (meaning the producer) are categorized in economics (direct and indirect), legislative and corporate citizenship. Particularly in Europe, the legislation remains the main driver for most of the product recovery networks. The drivers from the sender perspective are related to the functioning or obsolescence of the products and they can be distinguished in manufacturing, distribution, service and EoL/EoU returns.

1.2 Recovery options

The potential of the recovery process is various and different options relate to the product life cycle phases: direct reuse (typically in the case of commercial returns), resale or transfer of ownership (sales on secondary markets), repair, refurbishing, remanufacturing, cannibalization, recycling, until final disposition in the forms of incineration or landfill. Most of the authors refer to [2] where different recovery options are describe into details. Five alternatives are given: repair, refurbishing, remanufacturing, cannibalization and recycling. From repair to recycling, the level of disassembly increases and the possibility to preserve intact the product structure decreases.

1.3 Types of returns

Manufacturing and commercial return, product recalls, warranty and service returns, EoU and EoL returns represent the different returns types. We make a distinction between EoU and EoL returns which in the view of the author represent two very well distinguished types of returned products: EoU products, on the contrary of EoL products, might still preserve intact the functionality. EOU products are usually generated by major technological breakthroughs which cause obsolescence or simply by customers changed preferences.

1.4 Actors

Type and number of actors varies a lot according to the type of recovery network, if the disposed product flows back into the original forward chain (closed loop chain) or if it enters an alternative chain, and when an alternative chain is undertaken. A distinction can be made in: actors of the original forward chain (suppliers, manufactures, wholesalers, retailers) and actors of specialized recovery networks (recycling companies, logistics providers, transporters, municipalities, governmental agencies, brokers, etc, [1]…).

1.5 Phases

The last reverse chain factor deals with the steps the product undertakes when disposed of. Depending on the kind of network, the type and number of the recovery phases might change. Anyway, the following set of activities appears to be recurrent: acquisition/collection, transportation which might also follows inspection and separation, inspection/selection/separation, reprocessing, disposal. Reconditioning, redistribution and sales are typical of recovery networks that reintroduce remanufactured/refurbished products in the original and/or in the secondary markets.

1.6 Recovery network types

The combination of recovery options, types of returned items, drivers and design parameters determines different networks types and configurations. In [3] three network types are identified:

- Bulk recycling networks characterized by low value per volume collected and high investment costs which determine the necessity to exploit economies of scale.
- Assembly product remanufacturing networks which has added-value recovery as main driver. Since remanufacturing requires product knowledge mainly OEMs carried out the process.
- Re-usable item networks. Only minor reprocessing is required, therefore rather flat network, with levels that correspond to depots.

2 The WEEE recycling network

The WEEE directive – Waste of Electrical and Electronic Equipment – approved by the European Parliament the 27 January 2003 imposes take-back and recycling of those products which are classified as electrical and/or electronic equipment [4].

The purpose of the Directive is to prevent the creation of electrical and electronic waste and it promotes reuse, recycling and all the other forms of recovery in order to reduce final disposal. It encourages Member States to design and produce electrical and electronic equipment (EEE) which facilitates dismantling and recovery of components and materials by promoting design for environment techniques. In relation to the WEEE from private households, producers can fulfil financial, recovery, treatment and disposal obligations individually or by joining a collective scheme. At the moment there are not reliable indications of the WEEE waste amount generated within the Member States, least of all which of the two sources, households and industry, generates most of the WEEE. In late 1990s, estimations indicated to be 6.5-7.5 million tonnes per years the WEEE generated in Europe being WEEE 4% of the municipal waste and expected to increase of 18%-26% every five years (European Environment Agency, 2003, [5]).

3 The WEEE Danish recycling management system

The WEEE (Waste of Electrical and Electronic Equipment) Directive came into force in Denmark the 1st of April 2006. The Danish government decided to collect the disposed electrical and electronic products into five fractions similar in size and manufacturing technology.

The number and type of actors involved in the WEEE implementation and execution are various: governmental agencies (Ministry of Environment, Environmental Protection Agency), trade associations and collective schemes, consumers, importers, recyclers, transportation companies, etc… Each of them has different responsibilities and roles. Table 1 illustrates actors, responsibilities and processes at the institutional, configuration and operational levels.

Table 1 Actors, responsibilities and processes at the institutional, configuration and operational levels.

Institutional Level		
Actors	Responsibilities	Process
EU commission 25 Member Countries – Danish State and Government Danish Ministry of Environment EPA –Environmental Protection Agency WEEE –System (institutional organism which coordinates the overall recovery system)	The EU Commission has issued the Directive in 2003. The Danish Government and Danish Ministry of Environment has brought into force the Directive. The WEEE–System is responsible for the register and the reporting to the EPA (data aggregation and analysis). The EPA reports back to the European Commission	The Danish Government has transposed the WEEE Directive in 2005 with the Danish Statutory Order no. 664. The EPA and the Danish Ministry of Environment have been the institutional organisms involved in the transposition..
Configuration level		
Actors	Setup configuration	Process
WEEE –System 5 collective schemes Producers and importers	Case 1: producer/importer signs into the WEEE–System and implements its own take back system. Case 2: producer/importer signs in a collective scheme and the collective scheme signs its members in the WEEE–System. Case 3: the producer/importer deals only with business products. Several configurations are allowed (transferred producer	WEEE – System provides general information and information regarding the different available collective schemes. In case 2 companies sign a contract with a collective scheme which takes care of all the operations.

	responsibility, contract disposition agreements).	

Operational level

Actors	Process B2C (Business to Consumers	Process B2B (Business to Business)
Collective Schemes Transportation companies, logistics providers Recycling companies Final consumers/Business users Municipalities	The flow is articulated in: – Collection: The waste is collected into 5 fractions. – Picking and transportation After collection, the recovered products are transported to the recycling plants. Some kind of sorting and grouping might precede the arrival to the final treatment facilities. – Treatment Recyclers treat the WEEE waste. The waste can be exported and treated at recycling plants which are specialized for a certain type of WEEE fraction. The collective schemes coordinate all the intermediate stages previous to treatment handle the administrative tasks, manage the relations with national, the members and all the contractors.	The flow starts from the final user, which is a commercial company. There are several arrangements: Case 1: if the business user assumed the producer responsibility in the buying contract, collection transportation and treatment is performed by the user. Case 2: the business user might rents or owns the containers for collection, placed them at its premises and have a contract with the recycler for the picking and transportation. Case 3: the business user refers to the importer/wholesaler from which the goods were bought. No collective scheme is involved; the responsibility to report back the recovery data to the WEEE–System is on the actor which has the producer responsibility.

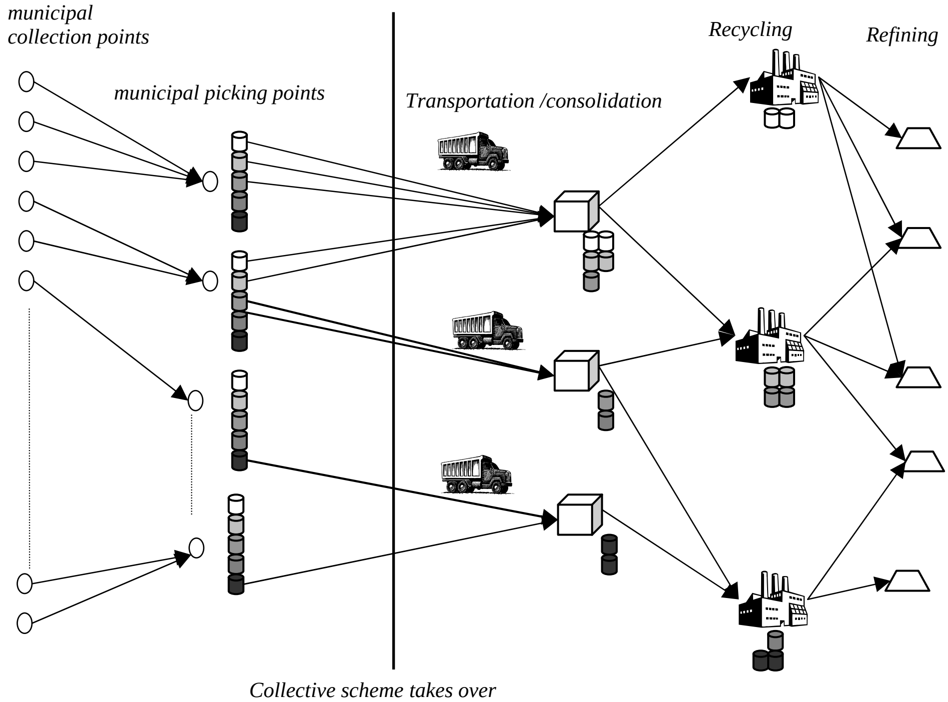
3.1 The operation level into details

We encounter the following stages along the recycling chain (Figure 1):

- The municipalities assign proper areas where the waste can be delivered
- The consumers deliver the waste at the collection station. Other forms of collection exist in the areas with the highest population density.
- At the collection points, the sorting of the waste in 5 different fractions is carried out by the same user or by the municipality personnel; the municipalities can decide how to sort and store the WEEE waste.
- From the consolidation points (picking points), the waste is picked by transporters/ logistics suppliers and deliver to the recycling plants. The recyclers can deploy their own transportation infrastructure or outsource the transportation to dedicated logistics providers. Most of the transportation is in fact outsourced.

- In most of the cases, the waste is consolidated once more before to be sent to the recycling plants. Once the volume reaches a level that assures an efficient truck loading, the waste is delivered to the recycling plants.
- Roughly, the recycling consist of removing hazardous material; the treatment which varies according to the used recycling technology. Valuable materials are sold to refining companies which enhance the purity level of the recovered materials before to sell them in the raw material market. All the rest, which cannot be recovered, is incinerated or sent to landfill.

Figure 1 The B2C configuration into details: collection and picking points, transportation, recycling and refining.



4 Downsides of WEEE product recovery management system

The European directive uses a categorization (10 product categories) that is far from considering how really products are processed at the recycling plants (Table 2). Product groups should reflect commonalities in the required treatment and similarities in materials content.

Table 2 The recycling process for different products types.

Input	Process	Output
Equipments containing CFC (cooling systems)	Manual operations: oil and mercury switches are removed. Then the body is processed on the shredder.	Metals, plastic, and glass are recovered. The rest is sent to landfill.
White goods	Manual operations: cables, asbestos are removed; the rest is processes on the shredder.	Metals, concrete, plastics are recovered, the rest is sent to landfill.
Equipment with CRT (cathode ray tubes)	Manual operations: cover and cables are removed. Printed circuit boards are removed with dedicated technologies.	Metals and plastics are recovered. The batteries are sent to special treatment.
Lamps	First sorting according to the length using specific frames than the mercury is removed. The glass is crushed.	Glass and metals are recovered.
Household appliances	Batteries, asbestos and liquids are removed; the rest is processed on the shredder.	The batteries are sent to special treatment. Iron, aluminum, cupper, alloys, plastics are recovered. The waste is only 1% of the total weight.
IT equipment	Circuit boards, batteries and LDCs are removed, drivers are smashed; the rest is processed on the shredder	The batteries are sent to special treatment. Iron, aluminum, cupper, and alloys are recovered. The waste is only 1% of the total weight.

The Directive also largely promotes all the Design for Environment Techniques (design for disassembly, design for recycling, design for recovery) but it does not provide incentives to reward producers that adopt this methodologies. Furthermore, it does not provide indications of how to link product design with the recycling process, i.e. how to transfer recovery knowledge into product design. The many phases and actors interposed between the OEMs and the recycling companies prevent producers to know how their products affect the recycling phases and due to collective treatment, it results time consuming, costly and difficult to access what products are more recyclable and on what basis. Even if life cycle assessment and product life cycle management are mentioned in the Directive, there is no indication on how these concepts could be included in products evaluation (overall product environmental impact from design, to production, consumption, recycling and disposal). Furthermore, eco-efficiency evaluations, i.e., environmental gains over costs consideration are completed neglected. Downsides of the WEEE implementation in Denmark

While the legislation promotes in principle reuse as first, the way in which the Directive has been implemented in most of the European countries has generated a system which is not capable of an efficient sorting and in order to prevent cherry picking, it forces to convey the entire collected volumes to the recycling plants. Failing in promoting reuse, remanufacturing, repair and refurbishing, only recycling is at the moment performed. Therefore, testing, grading and reuse are neglected while recycling concentrate in removing hazardous substances and limited disassembly.

4.1 Critical factors at the institutional, configuration and operational levels

The main critical factors at implementation at the institutional, configuration and operational levels are hereby presented and mainly derived from the analysis of the recovery management system implemented in Demark.

4.1.1 Institutional level

Even thought the enforcement responsibility lies on the EPA, clear rules on how to proceed in case of free riders or companies do not report the reliable sales information have not been identified.

Beside, the reporting system presents several weaknesses. The collection is in general performed a number of fractions (different from country to country) which does not correspond to the 10 categories of the Directive. To overcome this obstacle, recyclers should periodically separate and process batches of products sorted in categories but no indications on the frequency and sampling accuracy are given.

4.1.2 Configuration level

At the configuration level major problems are encountered in relation to the allocation system for B2C collection.

The allocation process interests the first phase of the recovery flow but it triggers all picking and transportation processes and it allocates the picking points to the collective schemes according to their market share. This represent a typical problem of optimization which can include different objectives as territory coverage, clustering of picking points, ministration of the picking frequency, optimal usage of the transposition capacity, etc…In Denmark the following allocation model has been adopted.

Objective:

– the number of collective schemes assigned to the same picking point is minimized in order to minimize the number of actors each municipality should interface with.

Constrains:

– all waste is collected;
– the market share of each collective scheme is respected;
– each fraction is assigned to only one collective scheme;
– none of the collection scheme is privileged in terms of routings;

4.1.3 Operational level

At the operational level, inefficiencies are registered in the way recyclers are engaged in the picking process (picking frequency versus transportation capacity utilization), where and to which extent to consolidate in order to assure an adequate shipping load and recycling capacity utilization. Since transporters and municipalities have opposite objectives (transporters have the interest to minimize the picking frequency, investments in infrastructures and maximize capacity utilization while municipalities require high picking frequency in order to minimize space deployed to store containers and cages), contractual power is required by the organism which coordinated the process.

Summarizing, the system presents several inefficiencies partly caused by the recovery network complexity, partly due to inappropriate decisions and lacking of coordination.

5 Conclusions and future research indications

The recycling management system presented on this study treats EoU and EoL products dismissed by consumers and business users. The inefficiencies that the system presents could be analyzed by using life cycle assessments tools but the complexity of the assessment rapidly increases considering product categories and the entire WEEE waste as such. A study made by Nokia Corporation concluded in 2005 has shown that a full LCA is not well equipped for making comparisons over different products within short product development and innovation timescales and due to the complex nature of many electrical and electronic products, the potential scope of the data that has to be collected to conduct a life cycle inventory is immense. Beside, the lack of reliable available process and environmental data for many substances is inhibiting the use of the technique. Other quantitative methods can be considered as the ecological footprint analysis or the material input per service unit but they presents similar limitations of the LCA methodology. While the use of simple and well-targeted KEPIs (key environmental performance indicators) could unfold the problems of elaborated quantitative techniques, there are still other aspects of the network that needs to be accurately access, e.g. efficiency of processes and coordination mechanism. Other considerations are related to the recycling technologies. The production technology is stable in some industries, in some others it is subjected to continuous improvement and innovation. This is not true for the recycling technology, which in most of the cases is not mature enough.

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Toward a structured approach for the integration of lifecycle requirements in quality management systems

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Abstract: The fast and continuous markets' change and the growing needs of product quality and efficiency during the entire lifecycle require deep transformations in terms of product quality and quality management. In this context, enterprises should consider a continuous Customer Satisfaction, optimising the entire product lifecycle to be sure to remain competitive in the global worldwide market. In order to carry out these objectives, it is necessary to manage, in a structured way, all he activities that constitute the core processes of engineering, production, product distribution embedded with their Quality Management Systems -QMS. This becomes possible through the application of the Lifecycle Management point of view (PLM) thanks to which we identify a model of business target, from a perspective of the organization and processes management. The proposed work aims at realizing a structured approach, able to embed the actions to be done to establish a Lifecycle Management point of view inside a QMS of a certain enterprise. The first part of the work highlights the lifecycle functions and analyses them through some existing approaches. In the second part, a structured set of actions for a better integration is proposed for the maintenance phase.
The developed methodology has been applied in an enterprise producing power generators where a certified QMS system was already in use. The measurement of the benefits related to the lifecycle integration has been concentrated on the post-sale/maintenance phases.

Keywords: Lifecycle Management, Quality Management System, Maintenance

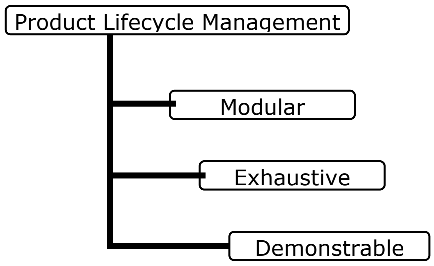
1 Introduction on PLM concept

To obtain better performances, enterprises need management systems that allow a greater synchronization among all functions and activities of the value chain and able to manage, in an integrated way, the answers to the demands of the market [3]. Some demands are quite difficult to achieve and may need many business requirements such as:

1. Times and budget projects' respect;
2. Partners using to promote the innovation;
3. Processes trace;
4. Adherence to the business requisites;
5. Increasing the productivity of the workforce;
6. Re-engineering of slow processes;

The PLM paradigm aims at giving an overall solution, using the product lifecycle as a general supporting framework [7]. It considers the hole phases of the life of this product, from the first footsteps of an idea, crossing its development, launch and, finally, following the market phase, with a careful maintenance (where it is possible) to lengthen as much as possible its useful working life [1]. PLM identifies the necessary contents to the completion of each phase and the critical runs or the flow with the possible "bottle hills" or weak spots of the process [4]. It manages the "knowledge business" in the way to integrate persons, processes and technology, to facilitate the creation, management, distribution and use of all the product related information from its initial conception to the end of its life. The finalities of such PLM paradigm can be summarized as follows (Figure 1):

Figure 1 PLM paradigm specificities



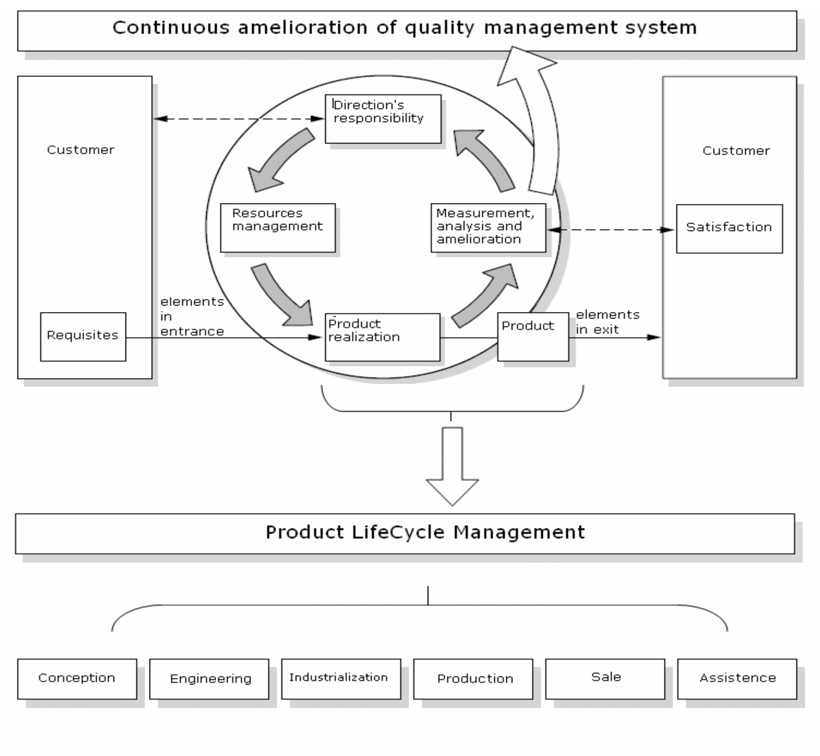
The modular structure makes us able to individuate the possible re-usable components and each component of the system is described in terms of: Requisites, External interfaces, Architecture and documentation of development; and Requisites' tests. The exhaustivity allows to cover all the necessary phases related to the realization of the product; allowing to individuate those that fit better to the particular application. The demonstrability offers the possibility to document the process during its lifecycle across the development of documentation on product, analytical validation of requisites, simulations, and comparison with existing systems. The QMSs, through their specific procedures and modules, deal with all these activities, assuring that they are accomplished according to the enterprise's Policy of Quality and to the objective of level of service to guarantee to the customers.

2 Product Lifecycle Management and Quality Management Systems

As stated, the present paper addresses the issue of improving the development of a QMS according to the objectives linked to the lifecycle of a product. The main task is to embed the main lifecycle concepts while developing the QMSs (for example for an ISO 9000 Certification), facilitating the data sharing and determining an unique path that allows to have a global vision on the whole life of the product [4]. Product Lifecycle Management is able to tie to Quality Systems for defining more in detail the managerial strategies to follow the product during its lifecycle [6]. Figure 2 shows the concept of Deming Quality Wheel, as the concept of quality is linkable to the lifecycle management, starting from the customer's analysis requisites, going to the responsibilities of the direction and the continuous amelioration policy that determines the set in actions of the following known QMS statements [2]:

1. communicate to the organization the importance to comply with the customer requirements and with the legal ones;
2. establish the Quality Policy;
3. assure that the objectives for the quality are defined and known;
4. Make the reviewing of the system by the top management;
5. Assure the availability of resources

Figure 2 Quality Systems and Lifecycle Management



The objective is to ensure that the realization of the product is done in accordance with the predefined qualitative standards. In this context, PLM techniques (through its central functions accomplished by systems such as CRM, ERP, PDM, etc) give the key management strategies to analytically follow the life of the product [4].

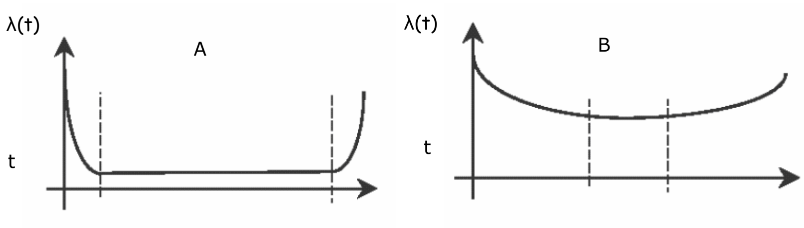
3 Integration of Lifecycle concepts into QMS

The possibility of embedding Lifecycle concepts into a QMS has been structured trough the five phases of a QMS:

Phase 1 – Product conception
Phase 2 – Engineering
Phase 3 – Assembling and/or production
Phase 4 – Logistic
Phase 5 – Assistance and maintenance

In the following paragraphs we will define in details the embedding issues and possible operative tools for the Assistance and Maintenance phase and then we will extend the approach to the other phases. The assistance and maintenance is a phase that may determine the extension of the maturity's period of a product in its lifecycle. During this phase it can be necessary to adopt policies of assistance/maintenance to guarantee to the consumer the possibility of a reliable use of the product for the most part of its useful life. Quality systems do not define specific approaches for the management of the post-sale assistance, but they leave to the organization the freedom to fix its own procedures. The lifecycle links to this phase an approach of Customer Satisfaction with a careful analysis of the product in terms of performances. As well known, the reliability of a product during the lifecycle can be represented through a curve denominated bathtub curve in which λ expresses the failure rate related to the three main life periods of the product (beginning, middle and end of life). To use a lifecycle approach, the enterprise has to individuate the three periods that characterize the product in the bathtub curve: Childish breakdowns, Useful life, and Breakdowns for wearing out. The childish breakdowns are referred to the period of adjustment ("Infantile mortality"), these faults are usually due to wrong design processes, production and/or defective components coming from the suppliers. From a point of view of the customer's satisfaction, the infantile mortalities are unacceptable. Consequently, to avoid the premature mortalities, the supplier of the product has to determine the methods to eliminate the defects. The respect of design specifications, through a correct transmission of the information, is a way that a PLM system should suggest. In addition to better design methods, we need to anticipate the test phases in such a way to evaluate the design weaknesses and discover the specific problems related to both raw material and product components. In the figures 3(a) and 3(b) the two limit cases are depicted. In the first curve the optimal case is depicted because the rate of breakdown is the lowest possible and the useful life is lengthened. The second curve instead, shows a situation of very bad planning in which the useful life is nearly inexistent. The objective of the PLM, in this phase, is to lengthen as much as possible the space of the useful product's life, keeping low the costs of maintenance. For PLM purposes the following maintenance policies can be adopted [8]: Failure maintenance: The maintenance action is performed in consequence of a damage or generally at the moment when happens a breakdown.

Figure 3 A. Project optimal situation B. Project bad situation



Its advantages are low costs, if correctly applied, and the fact that it does not require organized structures and/or complex plannings. The disadvantages are that any breakdown can have safety problems and/or interruption of the working of the product. This type of maintenance does not allow the optimal use of maintenance teams, often left in waiting for the occurrence of breakdowns, and the spare parts waiting can be high. Preventive maintenance: Under this category are included all those interventions performed after a certain time period, defined by the working mean life of each component of the product. Among advantages, it allows a reduction of the breakdowns, a better use of the maintenance's team, and an optimisation of the spare parts waiting times. As well know the adoption of this policyincreases maintenance costs. Furthermore it is applicable correctly only when the breakdown rate λ and its related function $\lambda(t)$ are well known. Predictive maintenance: this type of maintenance is based on the concept that the most part of the breakdowns does not happen instantly but they are related to a certain signals and/or variables measurement in a certain time period. The possible types of measurements are the following: Vibrations measure; Heater analysis; Lubricating oil analysis; Acoustic measures; Process parameters; History of product maintenance. After this first phase of surveys, it is possible to develop activities, of analysis and planning for the actions aimed to increase the useful life of every component, seeking the correct compromise between performances and effectiveness.

Regarding to the lifecycle point of view, the following main actions should be accomplished in the post-sale assistance phase:

1. Decrease as much as possible the "infantile mortality" time through efficient design methods, correct supplier selection and an exhaustive campaign of experiments on the prototypes
2. Define a plan of preventive maintenance through specific contracts of assistance with customers
3. Define some methods of predictive maintenance that can discover the possibility of a fault and suggest the customer to call the assistance before the fault appears. This allows reducing the possibilities of faults and high expensive corrective maintenance actions during the useful life.

The following table 1 shows the actions for the embedding of lifecycle concepts in the maintenance phase, while table 2 makes relationship between the QMS information and the improvements that can be obtained with the introduction of the lifecycle concepts. This analysis has been extended to four other phases of the lifecycle. Table 3 summarizes the relationships that can be set in QMS systems with respect to PLM point of view.

Table 1 QMS needs and lifecycle actions for maintenance phase

Phase	QMS statement	Lifecycle actions	Operational tools for integration with the QMS
Assistance and maintenance	The quality systems assess the maintenance phase as follows: "The organization has to define the activities for the release and the delivery of the product and for the assistance after sale"	- Bathtub curve analysis. - Determination of the critical components of the product - Creation of contracts for planned maintenance - Definition of user and maintenance manuals more directed to the customer with a Frequently Asked Questions section	Definition of a procedure that assesses the creation of specific contracts for preventive maintenance

Table 2 QMS improvements with PLM concepts embedding in maintenance phase

Phase	QMS info	Improvements with a PLM system
Assistance and maintenance	Information on the activities performed by maintenance operator during the post assistance-sale	- Greater prevention to the breakdowns - More complete information on the lifecycle of the product after the sale - Possibility of planning of maintenance activities, with a better use of the maintenance's team and a better optimisation of the spares - Better costs determination from customer side: With a contract of maintenance the customer has the complete control costs during product utilization - Maximization and optimisation of the product's work time - Higher value in case of resale

Table 3 QMS improvements with lifecycle

Phase	QMS statement	Lifecycle actions	Operational tools of integration with the QMS
Product conception	The organization has to define the requirements related to the customer's perception and about how much the organization has satisfied the customer's requirements.	□ Market analysis and results elaboration □ Setting up a system for a better attention to the customer, across the creation of a "listening team" able to understand the real requirements of the consumer □ Development of products, or parts of product in collaboration with the customer □ Creation of personalized offers □ Customer's segmentation	Creation of a form/procedure for customer satisfaction (needs of the customer, possible suggestions to improve the product…) Extension of the procedure "resources management" by creating a new procedure that defines a *listening group*. Creation of a form for customers segmentation (information/data on the customers and their previous transactions)
Design	Elements of entry: functional requisites and performances. Elements of exit: satisfaction of the input requirements with respect to the enterprise's philosophy.	□ Creation of a "Design Team" able to make control and audit in standardized manner. □ Correlations with existing projects. □ Realisation of a dossier for each product that contains information on: CAD ketches, BOM, materials list, production plan □ Sharing design information through business tools (like internet).	Creation of a new form of design history that contains data on existing and previous projects, in order to be able to do correlations Module of Bill of Materials (BoM) that determines a detailed list of the product components
Assembly and/or Production	Definition of processes, documents and specific resources to realize the product Planning of each specific activity of verification, validation, monitoring, inspection for the product and the related acceptance criteria	□ Management of the production team to get the maximum output from the business knowledge □ Definition of measurable and testable steps □ Continuous exchange of information between production departments □ Determination of the product's cost	Definition of an additional procedure (to that one related to product realization) to determine costs and times of production

Logistics	The organization has to assure that the supplied components fit to the specific supplying requisites. The organization has to evaluate and select the suppliers on the base of their ability to supply product in conformity to the enterprises' requirements	• Buffer costing • Control of the products' flows • Identification and scheduling of the processes and the produced components • Packaging analysis • Information on how to retrieve the product 's parts • Knowledge on transport's characteristics, related methodologies and delivery times	Definition of a procedure/form for the determination of: • warehouse costs • transportation flows • transport features that gives additional data related to the supply features

3 Case Study

The possibility of embedding the lifecycle concepts into a QMS for the assistance and maintenance phase has been tested in an enterprise producing power generators. The enterprise is ISO9000 certified and produces 20 different models of power generators in 6 different plants. In our application case we have analysed a new mid-range model of power generator. This model will substitute an old one which is the most known in terms of diffusion and utilisation, representing 15 % of the total sales of the enterprise
The product is made by a steel sheet chassis with a four cylinder engine and the related generator unit. The entire unit is managed through an electronic panel.
The enterprise had a failure-based maintenance system, oin which the maintenance action is activated on the calls of the customers. First, the mean useful life of the machine has been determined. This has been done after an experimental campaign, analysing a production lot of six machines during ten months. The Bill of Materials of the product has been organized into eight sub-products with respect to the possible maintenance activities as follows: Canopy; Fuel tank; Cabin; Engine; Alternator; Battery; Electric panel; Command centre. The first phase of the analysis is related to the break-in period related to 700 working hours, corresponding to three month. This first survey analysis has spotted out the main problems due to welding errors on the fuel tank, while the percentage related to engines breakdown is due to various factors, as the turbine, a defective battery charger, or failures related to the electric starter. During the measurement campaign the mean on the total breakdowns for the six machines observed has been calculated. The results of the breakdown rate (λ) are summarized in table 4.

Table 4 λ values for the first phase of life

Sub-product	λ (%)
Canopy	0.3-0.5
Fuel tank	0÷0004
Cabin	0
Engine	0÷1
Alternator	1÷2
Battery	0.7÷1
Electric panel	0.1÷0.3
Command centre	0.5÷1

After the first phase the useful life of this kind of group is assessed from 700 up to 6000 non stop working hours (24 hours per day) which corresponds approximately to 10 months. These results of the breakdown rate (λ) for this phase is summarized in table 5.
Finally, Table 6 shows the breakdown rate in the last phase of life of the product (> 6000 working hours), which is assessed approximately at two months, while in figure 4 we give the λ curve for one of the sub-products (Alternator).

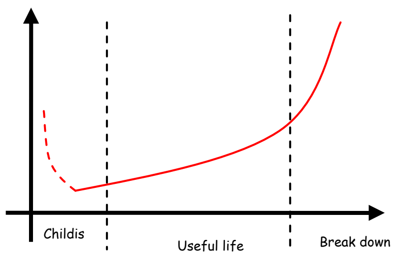
Table 5 λ data for the phase of useful life

Sub-product	λ (%)
Canopy	0.1÷0.2
Engine	0.3÷0.4
Alternator	0.1÷0.15
Battery	0.3÷0.5
Electric panel	0.02÷0.03
Command centre	0.2÷0.3

Table 6 λ data for the last phase

Sub-product	λ (%)
Canopy	0.7÷1
Fuel tank	0.5÷0.7
Cabin	0.4÷0.6
Engine	0.7÷0.9
Alternator	0.3÷0.6
Battery	0.9÷1
Electric panel	0.04÷0.15
Command centre	0.5÷0.6

Figure 4 λ curve for the Alternator



Before the launch of the product on the market the procedure of the QMS has been revisited introducing two modules

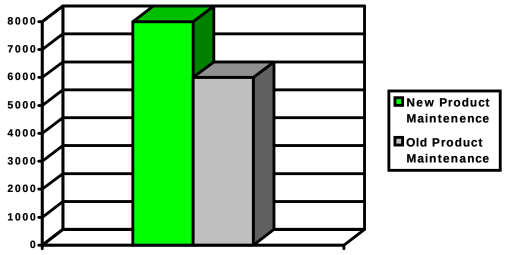
1 A Technical Sheet, to report every maintenance activities made on the machine, the changed parts, the tests and controls made on the machines
2 A Planned maintenance sheet, related to the establishment of a maintenance contract sold with each machine. An extract of the module is reported in table 7:

Table 7 Planned maintenance sheet

Working hours	100	700	2000	4000
Maint. activities	1. Visual inspections; 2. Change of oil and filter of the engine; 3. Main belt control and regulation; 4. Cooling liquid control; **5.** Battery control.	1. Visual inspection; 2. Oil change; 3. Filter change; 4. Cooling liquid refill; 5. Battery control; 6. Screws controlling; 7. Lock of control panel contact clips; 8. Alternator voltage control; **9.** Tank cleaning.	1. Visual inspection; 2. Oil change; 3. Filter change; 4. Cooling belt change; 5. Cooling liquid refill; 6. Battery change 7. Engine valves tune up; 8. Fuel injectors control.	1. Oil change; 2. Filter change; 3. Cooling liquid refill; 4. Tune up Engine valves; 5. Fuel injectors control; 6. Tank cleaning 7. Screws controlling; 8. Lock of control panel contact clips; 9. Control of water pump.

To verify the results, we have compared the total working hours of the previous model and those of the present model after its launch on the market, considering the maintenance data of five groups released between October and December 2005 for 14 months. The results are shown in Figure 5, in which the data related to the total working hours of the previous model (right bar) are compared with the results of total working hours of the new model (left bar), obtaining an improvement up to 20%.

Figure 5 Results related to the total working hours



Finally, we have taken the historical data of the previous model in terms of MTTR (Mean Time To Repair), MTBM (Mean Time between Maintenance) and MTBF (Mean Time between Failures), to compare with the data retrieved from the new one.
The results are shown in Table 8(a) where we can se a huge decrease of MTTR and an increase of the MTBM.

Table 8 (a)Value of maintenance times (a) and Maintenance costs (b) between the old and the new model

(a)

	MTTR		
New model (preventive	1.30 hours	**MTBM**	1700 hours
Old model (failure	10-11 hours	**MTBF**	1500 hours

(b)

	Cost of the	**Yearl y cost**
New model	67.50 €	405.00 €
Old model	495.00 €	1485.0 0 €

As last results we show the maintenance costs related to the previous and the new model, where we can see a great decrease of the cost - Table 8(b).

4 Conclusion

Product Lifecycle is going to be a key issue for product performances improvement both in terms of conformity to design specification and in terms of keeping these performances during the lifetime of the product. For the most parts of enterprises, especially SMEs, the Quality Certification as a performance key, has become a must for keeping them competitive in a global international context.
In this scenario, the present paper has addressed the issue of linking the lifecycle concepts to the requirement of a Quality Management System (QMS) according to ISO 9000 norms. The main objective has been to face these concepts with the requirements related to a QMS, showing the possibilities of integration and related benefits. A general approach has been depicted and an application related to the maintenance area has been detailed.

The obtained results have led to the conclusion that a better diffusion of Lifecycle concepts imbedded into QMS statements can lead SMEs to a deployment of a Product PLM vision. This specific topic can be extended, giving the full managerial guidelines to apply PLM concepts with QMS requirements to the entire lifecycle of the product, towards a complete embedding of the two systems. A deeper analysis of this possibility could be a further development of this work.

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Life cycle assessment of an aspirator/compressor for zootechnical applications

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Abstract: In this paper, the Life Cycle Analysis (LCA) methodology is applied to asses the environmental performance of the production and usage of an aspirator/compressor for zootechnical application. The processes were analysed to investigate the whole production system from “cradle to grave”, considering the main phases: raw material production, component manufacturing, pump assembly, installation process, utilisation and disposal cycles. All the input-output streams of energy and mass were analysed and the environmental impact was rated with the aim of “Eco-Indicator ‘99” assessing method. The obtained results are evaluated and presented, and possible modifications of the system are suggested to obtain suitable improvements.

Keyword: Life Cycle Assessment (LCA), Eco-Indicator’99, Aspirator/Compressor

1 Introduction

LCA is a powerful, systematic and objective tool, capable of assessing environmental incidence of products, processes or activities, including all stages of its life cycle and all its possible impacts without geographical functional or temporal limits. Life cycle assessment is a process that enables to:

(i) evaluate the environmental burdens associated with a product, a process, or an activity by identifying and quantifying used energy and materials and wastes released to the environment;

(ii) assess the impact of those used energy and materials and releases to the environment;

(iii) identify and evaluate opportunities to affect environmental improvements.

The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials (i.e. manufacturing, transportation and distribution) considering use, re-use, maintenance, recycling, and final disposal.

The structural and procedural components of LCA are determined by the international standard series ISO 14040-43 that define LCA as *'a technique for assessing the potential environmental aspects associated with a product (or service) by compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with these inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study'* [1], [2], [3], [4].

Generally there are four interactive steps for a complete life cycle study:

- *planning:* definition of the goals and the objectives of the LCA framework, including the investigation boundaries, breadth and depth of study;
- *inventory analysis:* provides a quantitative input/output account of the product or system (i.e. energy, raw material, air emissions, water-borne effluent and solid waste are examined and measured);
- *impact assessment:* evaluates how the product or system affects the environment, adopting a qualitative and quantitative approach to analyse how raw material use, energy generation, water production, effluent output, air emission and solid waste impacts on the environment;
- *improvement analysis:* involves making improvements to reduce environmental burdens associated with the product or system through taking an objective view of the entire life cycle and assessing the impact that changes would have on the environment.

In this paper a Life cycle assessment of an aspirator/compressor for zootechnical applications is presented. In particular, the impact assessment methods of the whole production process are developed by the use of SimaPro 6.0 software and The Eco-indicator 99 method.

The reminder of the paper is organised as follow. After a brief description of LCA software used for the analysis, the LCA model implementation is reported considering its main phases (i.e. Goal & Scope Definition and Inventory and System definition). Afterward the whole life cycle is analysed, considering the results for production and functioning cycles.

1.1 LCA software

SimaPro 6.0 is the sixth generation of a program developed by Dutch PRé Consultants in 1989 [15]. To quickly build and analyze LCA model, SimaPro contain s inventory data for most commonly used materials and processes, organised in different database, such as ETH-ESU 96, BUWAL 250 and IDEMAT 2001. With SimaPro it is possible to conduct an impact assessment to measure the environmental impacts in LCA, considering different methods, such as Eco-indicator 99, IPCC Greenhouse gas emissions and so on.

2 The model

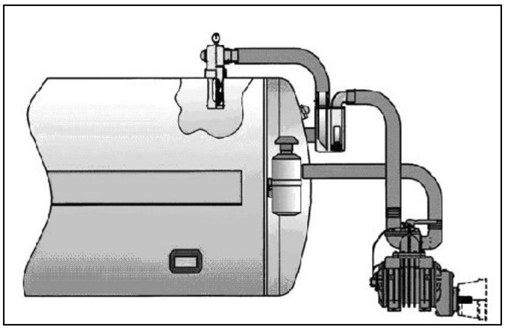
The LCA implementation is explained in the next part of the paper, making reference to the four methodological steps that were previously presented.

2.1 Goal & Scope Definition

The main goal of this case-study is to identify the sub-processes of an aspirator/compressor life cycle, which are responsible for the most significant environmental input and output flows and to assess the environmental performances.

The analyzed product is an aspirator/compressor mainly used for zootechnical applications. It is used to empty cesspool and to transport the sewage to irrigate and fertilize. Typically it is installed on a tank car (figure 1) to fill up it (working as an aspirator) or to empty the tank (working as a compressor).

Figure 1 The aspirator/compressor and the tank car



Some main technical specifications are the following:

- Max. capacity 8.100 [l/min]
- Max. rounds number 1.400 [rpm]
- Max. pressure 1.5 [bar]
- Max empty -0.94 [bar]
- Weight 152 [kg]

The main body of the pump is realized with cast iron GJL 250. The flanges, the rotor, the manifold, the handle bar and the inverter are made with cast iron GJL 200. The oil pump body and its cap are realized with hot-worked steel. In figure 2 a sketch of the product is presented.

2.2 Inventory and System definition

Briefly the life cycle stages of the product can be described as follows:

- raw material mining
- raw material production
- manufacturing process
- other components production
- pump assembly process
- plant assembly process
- using life cycle
- end life cycle

Figure 2 The sketch of the product

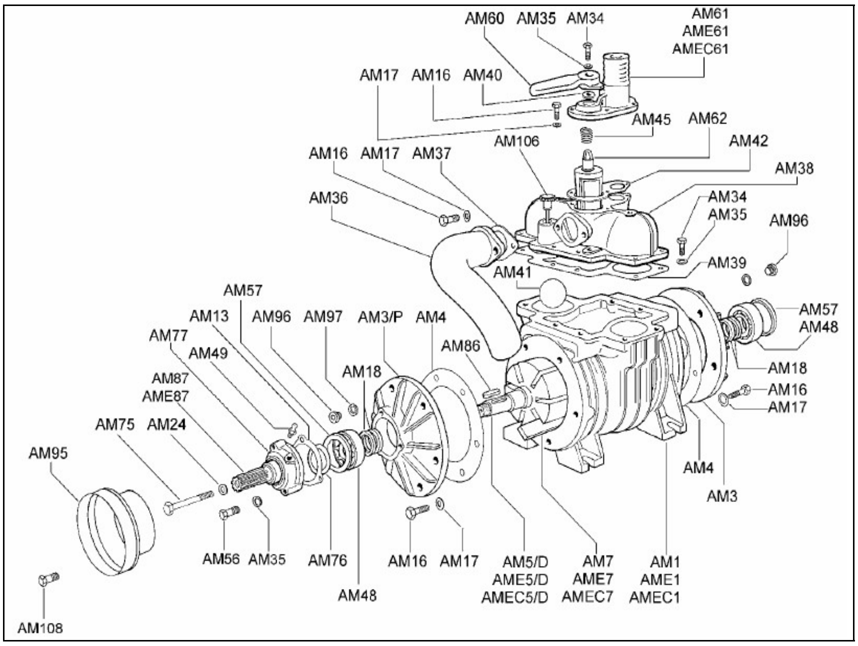
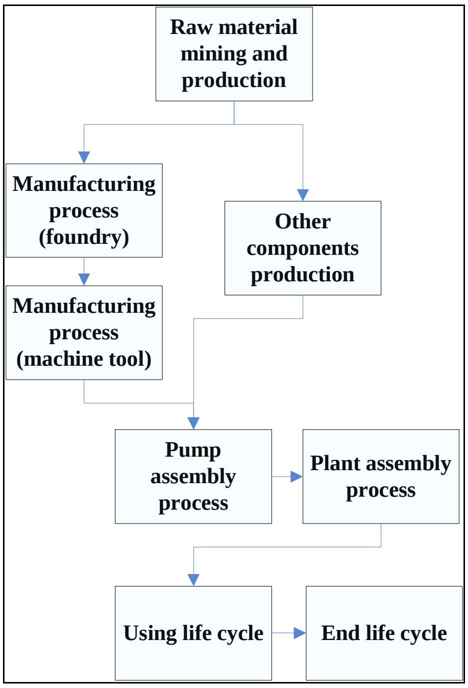


Figure 3 Process Flow-Sheet.



The sequence of the phases is described in figure 3. The established units of measurement for the life cycle definition are the following:

- [kg of drawed material] for raw material mining
- [number of products] for raw material production
- [kg of removed material] for manufacturing process
- [number of products] for other components production
- [number of assembled products] for pump assembly process
- [number of installed products] for plant assembly process
- [number of realized cycles] for using life cycle

7500 functioning cycles are supposed for a single aspirator/compressor. Therefore the data are the following:

- 165,6 kg drawed material,
- 12 products of raw material,
- 24,4 kg of removed material,
- 131 other components,
- 1 assembled pump,
- 1 installed plant,
- 7500 functioning cycles (500 h).

3 Life Cycle Assessment

In figure 4 the characterization diagram is reported. The whole life cycle is composed by the production cycle (i.e. MEC 8000-D – blue color in figure 4) and the functioning cycle (i.e. Aspirator/Compressor – yellow color in figure 4). From the figure and table 1, the preponderance of the functioning cycle can be identified.

Figure 4 Characterization diagram.

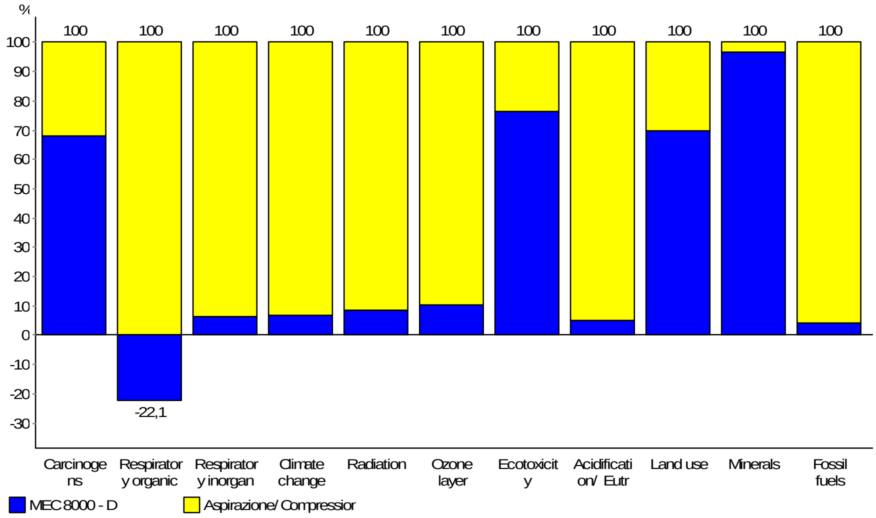


Table 1 Impact results for production and functioning cycles

Impact category	Unit	Total	MEC 8000 – D production cycle	Aspirator/Compressor functioning cycle
Carcinogens	DALY	$1{,}3 \cdot 10^{-5}$	$8{,}83 \cdot 10^{-6}$	$4{,}18 \cdot 10^{-6}$
Respiratory organics	DALY	$2{,}53 \cdot 10^{-6}$	$-7{,}21 \cdot 10^{-7}$	$3{,}25 \cdot 10^{-6}$
Respiratory inorganic	DALY	0,00182	$1{,}13 \cdot 10^{-4}$	0,00171
Climate change	DALY	0,00036	$2{,}36 \cdot 10^{-5}$	0,000337
Radiation	DALY	$2{,}1 \cdot 10^{-8}$	$1{,}72 \cdot 10^{-9}$	$1{,}93 \cdot 10^{-8}$
Ozone layer	DALY	$3{,}57 \cdot 10^{-7}$	$3{,}55 \cdot 10^{-8}$	$3{,}22 \cdot 10^{-7}$
Ecotoxicity	PAF*m2yr	56,1	42,7	13,4
Acidification/ Eutrophication	PDF*m2yr	110	5,25	105
Land use	PDF*m2yr	9,31	6,47	2,84
Minerals	MJ surplus	8,96	8,66	0,296
Fossil fuels	MJ surplus	$1{,}81 \cdot 10^{3}$	73,4	$1{,}74 \cdot 10^{3}$

During the functioning life cycle, it can be known that:

- the most contribution to the Human Health damage is in the Respiratory inorganic category;
- the most contribution to the Eco-system Quality damage is in the Acidification/Eutrophication category;
- the most contribution to the use of Resources is the Fossil Fuels category.

During the production cycle the results are correlated to the following impact categories:

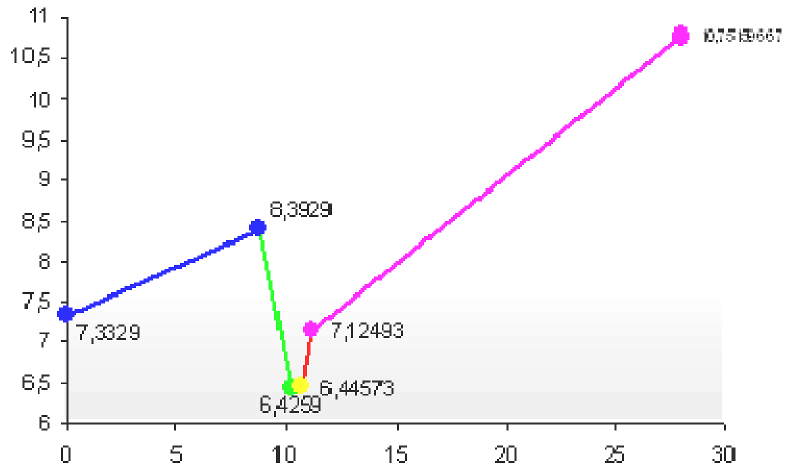
- Respiratory inorganic for Human Health damage;
- Ecotoxicity for Eco-system Quality damage;
- Fossil fuels for resources consumption.

The impacts were calculated for all processes indicated in figure 3 (the process of other components production is excluded because less relevant). Then, the activities of the firm have been evaluated to determine improvement action. These activities, of which the firm is directly responsible, are: transport of raw material, manufactiring process, transport of semi-assembled product, assembly process.

In figure 5 the impact of these activities is reported jointly with the impact of the first 17 hours of functioning (250 cycles). The diagram is the hoarded curve of the impact on time. An important result is that the contribution of the manufacturing process is negative, because during this activity there is an important part of recycled materials.

Based on the reported results, the firm decided to change its typology of transport, to decrease the contribution of the raw material transport, from trucks to train transport. This choice has permitted to decrease the impact of this process of 1,82.

Figure 5 Impact hoarded curve.



Blue (first line) = transport of raw material
Green (second line)= manufacturing process
Yellow (third line) = transport of semi-assembled products
Red (fourth line)= assembly process
Pink (fifth line)= first 17 hours of functioning

4 Conclusions and remarks

In this work the LCA of a aspirator/compressor for zootechnical application is evaluated with “Eco-Indicator ‘99” assessing method. The main result is that the functioning life cycle is more “impacting” than the whole production process. Nevertheless the detailed analysis of each process permitted us to evaluate suitable improvement action to decrease the whole environmental impact. In fact, the firm has adopted a new transport system (from truck to train) decreasing the impact of transport that was the main “impacting” process of which is responsible.

To improve the evaluation of the functioning process in next studies, correlating the environmental impact with different size and characteristics of similar pumps or aspirators/compressors could be interesting. This way, suitable direct data can be obtained to correlate a specific product with its environmental impact value.

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Chapter 11

Promise

Recycling of engineering thermoplastics used in consumer electrical and electronic equipment

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Abstract: Diminishing land fill capacity and increased volume of waste electrical and electronic equipment (WEEE) are the main drivers for the recycling of engineering thermoplastics. WEEE can be recycled in bulk or as separated components of a disassembled machine. Bulk recycling is the economically preferred option, however the blending of incompatible plastics without modification often limits the end use of the recycled plastics. The decision to apply expensive sorting techniques at the end of a products life should be based on mechanical properties and processability of the engineering thermoplastics contaminated by other polymeric materials. This paper investigates properties of various recycled thermoplastic blends to determine the degree of sorting required. Focusing on Acrylonitrile-Butadiene-Styrene (ABS) as the main component, six ABS/PP (polypropylene) blends, three ABS/Nylon and three ABS/HIPS (high impact polystyrene) blends were prepared on a single screw extruder. Mechanical and thermal properties were analyzed by comparison with pure virgin and recycled materials, as well as selected virgin blends. The results show that generally, these thermoplastics should be separated prior to processing to optimize the properties of the recycled plastics. However, some particular blends have sufficient mechanical properties such that they can be used for various applications where the use of sorting techniques is not economically viable.

Keyword: ABS, blends, recycling, thermoplastic, WEEE

1 Introduction

Diminishing land fill capacity is one of the main drivers for plastic recycling, particularly in countries of high population density such as Japan. Other factors include environmental benefits, the rising price of non renewable raw materials and consumers' perception of product stewardship. For instance, recycling of plastics in Victoria, Australia, increased 39% throughout 2003 (exceeding 96,000 tonnes) compared to the previous year (EcoRecycle Victoria, 2004). In 2004 190,979 tonnes of plastic was recycled throughout Australia, compared with the consumption of 1,510,850 tonnes. Two thirds of the material was reprocessed in Australia, the remainder exported to Asia for reprocessing. A large portion (~75%) of the plastic recycled was packaging material (PACIA, 2005). However, as technology advances at an increasing pace, more electrical and electronic equipment becomes obsolete and available for recycling. The casings of the electrical equipment are generally consumer durable thermoplastics. In contrast to packaging material, thermoplastics retain their properties and can be economically recycled into useful products (Scheirs, J., 1998).

The first stage in recycling of waste electrical and electronic equipment (WEEE) is identification and separation. Typically, WEEE is an assembly of metallic and various thermoplastics. Two methods exist for this step, disassembly or bulk recycling (Rios, P. et al, 2003). Disassembly involves spectroscopic identification and separation of the individual components following mechanical disassembly. Depending on the complexity of the equipment, this method tends to be time consuming and uneconomical. On the other hand, in bulk recycling, a fully assembled piece of WEEE is processed. The shredded material can then be separated into the individual materials by a variety of means depending on the property of the materials relative to one another, (i.e. magnetic, density, electrostatic etc). While these methods are effective in the case of separation of metals and plastics, sorting of different plastics is frequently an expensive and unreliable procedure. This study investigates recycled blends of various polymers commonly found in WEEE, thus determining the degree of separation required to produce a material with useful properties. Once a material has been sorted, there are two methods of plastic recycling: (1) reuse in the same or similar application – 'closed loop', (2) reuse in different application – 'cascade', (Scheirs, J., 1998). Reuse of a plastic in closed loop requires that the material retain properties similar to the virgin material used in the original application. Consequently, end use of the plastics is a determining factor in the degree of sorting required before recycling. Acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS) are major component in WEEE, generally used for outer casings based on its high impact strength (Scheirs, J., 1998). Both polymers have high impact resistance attributed to the dispersion of small rubber particles within the brittle matrix (Fried, 2003). ABS and HIPS have similar physical properties, so that separating these two polymers is difficult due to their relatively similar densities (ABS: $1.04 g/cm^3$; HIPS; $1.05 g/cm^3$). Polypropylene (PP) is less frequently used as a major component of WEEE, and is easily separated based on density. Nylon-6 is typically present in WEEE as fittings, but quantities are too small to justify separation. Based on its abundance in the WEEE industry and the difficulty of separation of ABS from other thermoplastics, ABS is investigated as the major component with other thermoplastics added in contaminant amounts.

2 Experimental

2.1 Materials

Granulated injection molding grade virgin materials manufactured by BASF were purchased from Marplex Australia Ltd. The virgin material was reprocessed in a 12mm Axon Pacific laboratory single screw extruder to simulate recycling and to ensure a direct comparison with unprocessed virgin material of the same grade.

2.2 Processing

Blends were prepared on a volumetric basis and blended in the extruder, (*see Table 1* for blend composition). Pelletised extrudate was dried under vacuum, for at least 18 hours, at 90^0C before injection molding mechanical test specimens, (*see Table 2* for processing conditions).

Table 1 ABS content in blend in percent volume relative to minor component

ABS/PP	100, 90, 80, 70, 30, 20, 10, 0
ABS/HIPS	100, 90, 80, 70, 0
ABS/Nylon 6	100, 95, 90, 80, 0

Table 2 Processing temperature variables, extruder zones (T_1, T_2, T_3, T_d, respectively) and injection molding

Material	Temperature Range[1]	Extruder Zones	IM Temperature
Terluran®GP-22 natural (ABS)	220-260^{0}C	210, 220, 230, 235	25, 190, 220, 240
Polystyrol 476L (HIPS)	180-260^{0}C	200, 210, 220, 225	25, 190, 220, 240
Moplen EP203N (PP)		200, 210, 220, 225	25, 190, 220, 240
Ultramid®B3S (Nylon 6)	250-270^{0}C	220, 230, 240, 245	25, 190, 220, 240

2.3 Analysis

2.3.1 Thermal Properties

A TA instruments SDT 2960 was used to indicate the onset of degradation by means of thermal gravimetric analysis. The glass transition temperature, T_g, was measured with the help of differential scanning calorimetry on DSC 2920 (TA instruments) and dynamic mechanical analysis on DMA 2980 (TA Instruments).

2.3.2 Mechanical Properties

The tensile and flexural strength of a material is the maximum amount of stress that it can be subjected to before failure. Tensile properties and flexural properties were measured on a conventional mechanical tester, Zwick model Z010, according to ASTM D 638 and 790, respectively. One of the most significant properties for engineering plastics is impact strength, representing the toughness of a material. Notched samples were analyzed for Izod impact strength conducted on a CEAST Resil impact tester according to ASTM D 256-00.

3 Results

3.1 Processability

Recycling the individual polymers did not alter the processability of the material, but did change the appearance through yellowing. Processability was significantly hindered by the contamination of ABS with Nylon, such that extrusion was interrupted by the breaking of the brittle extrudate strands. Poor processability was also observed for the ABS/Nylon and the ABS/PP blends, where molding of mechanical testing specimens frequently resulted in breaking in the mold cavity.

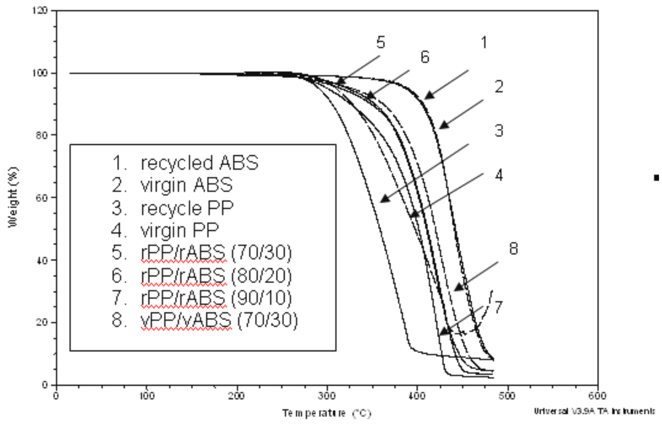
[1] Product data sheet supplied by BASF plastics

3.2 Thermal Analysis

Degradation temperature is the temperature where a material begins to decompose, in the case of polymers by chain scission and vapourisation. Thermal degradation varies between investigated polymers. The extent of the shift in degradation temperature was greatest for Polypropylene. Increasing the amount of PP in the blend decreases the degradation temperature *(see Figure 1).*

Glass transition temperature, Tg, is applicable to amorphous polymers, including ABS and HIPS. At Tg the amorphous phase is converted from a hard glass like state to a rubbery phase, which is important to the mechanical properties of the polymer. The glass transition temperature of ABS and HIPS is approximately 112^0C and 108^0C, respectively. Recycling does not appear to affect the glass transition temperatures of these two polymers. Likewise, blending, with ABS as the major component, does not shift position of Tg for ABS, regardless of whether the contaminant polymer is amorphous (HIPS) or semi-crystalline (Nylon or PP).

Figure 1 TGA plots for ABS contaminated PP



3.3 Mechanical Analysis

The effect of recycling on the tensile and flexural mechanical properties of the individual thermoplastics appeared to be negligible. Similarly, recycling only had a minor effect on the impact strength of the individual polymers. At most, recycling ABS resulted in a 6% reduction in impact strength.

The addition of contaminants to ABS reduced the tensile and flexural mechanical properties. The tensile and flexural properties of the ABS contaminated with HIPS were found to be proportional to the amount of HIPS, as would be expected according to the rules of mixing two materials, (see Figure 2). For example, an addition of 30% volume of HIPS to pure ABS reduces both the tensile and flexural strength by 20%, (see Table 3).

In contrast, the mechanical properties of PP and Nylon contaminated ABS deviate negatively from the rules of mixtures, (see Figure 3 & 4), indicating that these polymer blends are incompatible. For example, 30% PP contamination in ABS reduces the tensile and flexural strength by 40% (see Table 4). The contamination of ABS with up to 20% Nylon only reduces the tensile strength by 5% and flexural strength by 10%, (see Table 5). However, the incompatibility of Nylon in ABS is shown in the impact strength.

Figure 2 Tensile and Flexural strength of recycled ABS contaminated with HIPS

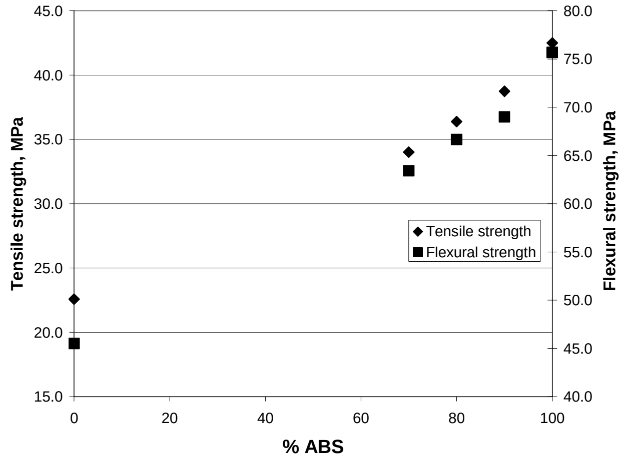


Table 3 Mechanical Strength of HIPS contaminated ABS

ABS content	Tensile strength	% pure	Flexural strength	% pure	Impact strengt h	% pure
	MPa		MPa		kJ/m2	
100	42.5		75.7		20.9	
90	38.7	91	69.0	91	10.4	50
80	36.4	86	66.6	88	7.4	35
70	34.0	80	63.4	84	6.1	29
0	22.6	53	45.5	60	9.0	43

Note: % pure is an indication of the effect of contamination relative to the pure material

Figure 3 Tensile and Flexural strength of recycled ABS/PP Blends

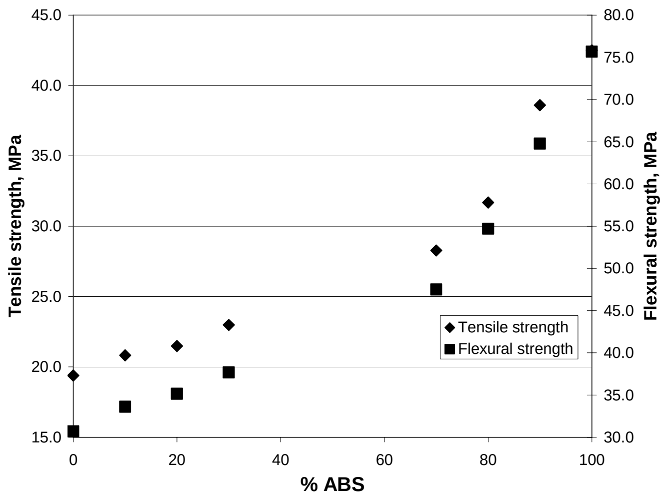


Figure 4 Tensile and Flexural strength of recycled ABS contaminated with Nylon

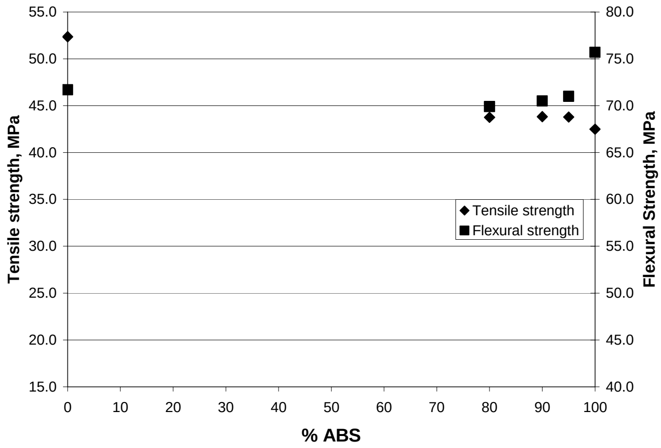


Table 4 (a) Mechanical Strength of ABS contaminated PP

ABS content	Tensile strength	% pure	Flexural strength	% pure	Impact strength	% pure
	MPa		MPa		kJ/m2	
0	19.4		30.7		n/a	n/a
10	20.8	107	33.6	110	n/a	n/a
20	21.5	111	35.2	115	6.37	n/a
30	23.0	119	37.7	123	5.55	n/a

(b) Mechanical Strength of PP contaminated ABS

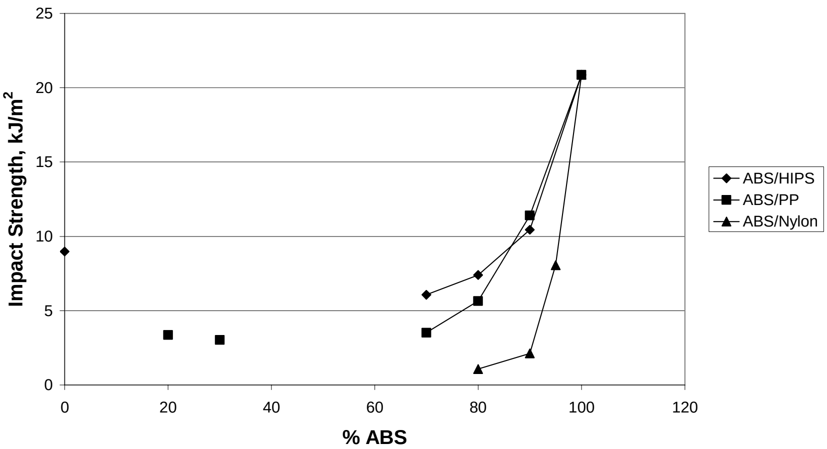
ABS content	Tensile strength	% pure	Flexural strength	% pure	Impact strength	% pure
	MPa		MPa		kJ/m2	
100	42.5		75.7		2.20	
90	38.6	91	64.8	86	3.42	156
80	31.7	75	54.7	72	4.03	183
70	28.3	67	47.5	63	5.59	255

Table 5 Mechanical Strength of Nylon contaminated ABS

ABS content	Tensile strength	% pure	Flexural strength	% pure	Impact strength	% pure
	MPa		MPa		kJ/m2	
100	42.5		75.7		20.9	
95	43.8	103	71.0	94	8.06	39
90	43.8	103	70.5	93	2.12	10
80	43.7	103	69.9	92	1.07	5.1
0	52.4	123	71.7	95	n/a	

Impact strength is most significantly affected by the contamination of ABS. The addition of 10% of HIPS or PP and only 5% Nylon halved the impact strength of the material, *(see Figure 5)*. Gupta et al. (1990) investigated the morphology of an ABS/PP blend and stated that phase separation occurs, forming an ABS skin surrounding a PP-rich core. This leaves the major portion of the fracture surface (the core) ABS free, significantly reducing the impact strength of the blend. ABS contamination of PP increased the tensile and flexural strength by approximately 20%, *(see Table 4)*. In impact testing, a number of samples within a blend broke differently, either complete break or partial break. Different break types in impact testing made it difficult to compare the affect of contamination on the impact strength of ABS contaminated PP, as stated by the standard ASTM D 256-00.

Figure 5 Impact Strength of Recycled Blends



4 Conclusions

Recycling does not affect the thermal properties, including degradation temperature and Tg, of the major electrical thermoplastics, ABS and HIPS. However, thermal reprocessing of these materials contaminated with PP and Nylon lowers the degradation temperature and should be taken into account when operating parameters of processing techniques are identified. Recycling did not substantially affect the mechanical properties of the polymers individually, with the exception of impact strength. Contamination significantly reduces the mechanical properties, such that the properties are lowered beyond additivity based on the proportion of polymers in a blend. The tensile and flexural properties of ABS/HIPS blends are the only exception, following the rules of mixing. This indicates that ABS and HIPS are relatively compatible. A blend of HIPS and ABS containing less than 10% HIPS will be suitable for a similar end use application if a reduction in impact strength can be tolerated. This is advantageous because in a practical recycling operation it would be difficult to completely separate these plastics due to their similar physical properties. ABS contaminated with PP, and vise versa, is difficult to process, and its mechanical properties are generally worse than ABS contaminated with HIPS. Since ABS can simply be separated from PP based on density difference, sorting would produce higher value products that could offset the costs of this operation. Although Nylon contaminated ABS retains tensile and flexural properties, the effect of Nylon contamination on impact strength and processability generally reduces the materials usefulness. In the case of Nylon contamination, separation is essential. Thermal and mechanical properties are almost retained if engineering thermoplastics are completely separated prior to reprocessing. If impact strength is essential, blends with the minor component greater than 10% HIPS and PP, and greater than 5% Nylon, would not be practical, as the impact strength is more than halved. Modifiers would be required if PP and Nylon contaminated ABS were to be considered for closed loop applications. Otherwise, any mixture of polymers can be produced economically, without sorting, to produce low value products, such as fence posts, bollards and railway beams, which are currently manufactured in Australia from post-consumer recycled thermoplastics.

Acknowledgment

This project was funded by the Australian Government through AusIndustry and MRI Australia.

Nomenclature

ABS = Acrylonitrile-butadiene-styrene

HIPS = High Impact Polystyrene

PP = Polypropylene

T_1 = zone 1 in extruder

T_2 = zone 2 in extruder

T_3 = zone 3 in extruder

Td = die temperature

Tg = glass transition temperature

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Integrated assessment of recycling options for mixed waste plastics fractions

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Abstract: An important basis for a sustainable acting in the area of plastics recycling is the using and interpretation of data, achieved by balance sheets which take into account all steps in the life cycle of plastics waste. The paper will set the focus on plastic recycling in the plastics processing industry and the special impact of the treatment, logistics and storing process steps. This shall take into account economic, environmental and social aspects. The first part of the paper shall evaluate the recycling options of different case studies. The second part will be based on a discussion for appropriate methods for the assessment of such evaluation results.

Keywords: plastics waste; recycling; product life-cycle management; decision making

1 Introduction

The life-cycle oriented production requires that certain return facilities have to be provided and maintained. The return of plastics waste is a major problem to the companies involved in life-cycle oriented production schemes. Maintaining appropriate sorting, transport, storage and treatment capabilities requires high financial investments. The major problem that has to be solved is the planning of the required infrastructure that must be established in order to ensure an optimum return policy.

The goal of economic life-cycle approaches is that products have to be returned as cheaply and environmentally friendly as possible. In addition to the environmental aspects social aspects becomes more and more important. Research and regulative initiatives on European and international level underlines this movement.

The planning of the material recycling therefore has to consider these special constraints. To ensure that the recycling concepts cover the above-mentioned aspects a special recycling planning is required. Therefore, the planning of the recycling process and all its related operations has to be conducted very carefully. Due to the fact that different parameters have to be considered when trying to set-up a recycling system, appropriate methods (e. g. Life-Cycle-Assessment methods) are required for the planning of the life-cycle logistic concepts.

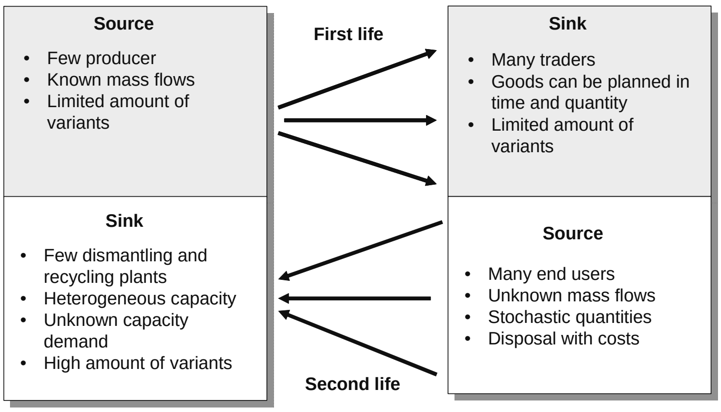
2 Plastics recycling

2.1 Market

The market for second life plastics is two folded (see Figure 1). On the one side the range of plastic products available for recycling is changing and difficult to plan. Too many end users cause unknown mass flows with stochastic quantities and high disposal costs. On the other side the market for recycled plastics is changing. Only if prices for raw material are on a high level, the market for recycled plastics is good. The number of dismantling and recycling plants for a high amount of variants is low. This causes a heterogeneous capacity. One option to buffer this changing situation is the storing of second life plastics, especially if recyclers have long term contracts with their suppliers with a continuous output of plastic waste, like sorting plants for packing materials or recycler of end of life vehicles. If storing is not possible or too expensive, the waste material has to go to disposal or incineration.

The decision finding for such options is difficult and depends on a high knowledge in combination with a good access to global market information.

Figure 1 Market situation for plastics recycling [1, p. 5]

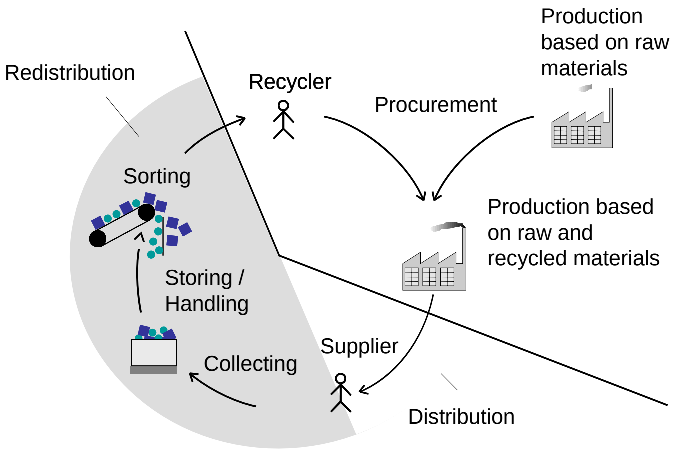


2.2 Process description

The recycling of plastics can be parted in two levels. The first level is using of plastic waste with a high sorting quality, which means that the quality of homogenous material is high, the information related to the material compound is good and the type of plastics material is often state-of-the art material.

If the material quality is on a lower level (second level) the material can be mixed with raw material for improving the material quality of the recycled material (see Figure 2). This enables the recycled plastics a second life also in high quality products, which is mostly on the same level like for plastics raw materials. Like in the market situation it needs special knowledge and a good information access to the customer, production and supplier side for finding the best options in creating new lots for an economic plastics recycling.

Figure 2 Mixing of raw and recycling material



2.3 Legal situation of plastics recycling

The legal situation of plastics recycling in Europe will get a new regulation namely REACH (Registration, Evaluation and Authorisation of Chemicals). The REACH Regulation gives greater responsibility to industry to manage the risks from chemicals and to provide safety information on the substances. Manufacturers and importers will be required to gather information on the properties of their substances, which will help them manage them safely, and to register the information in a central database. A Chemicals Agency will act as the central point in the REACH system: It will run the databases necessary to operate the system, co-ordinate the in-depth evaluation of suspicious chemicals and run a public database in which consumers and professionals can find hazard information [2].

Another example is the International Material Data System (IMDS) database, which was developed by Audi, BMW, DaimlerChrysler, Ford, Opel, Porsche, Volkswagen und Volvo. IMDS is a collective, computer-based material data system from automotive OEMs to manage environmental relevant aspects of the different parts in vehicles.

Through this system, the automotive industry is able to reconstruct the complete material flow. The adoption of the IMDS relies above all on a legislative background, namely:

- Laws & Regulations on hazardous substances: OEMs must eliminate these substances from the supply chain.
- End-Of-Life Vehicles Directive (ELV): It forces car-manufacturers to improve their recycling rates. Therefore all suppliers must deliver accurate material information.

Beside this regulations and directives other examples for European legislative initiatives are the IPP (Integrated Product Policy) the directive on Waste Electric and Electronic Equipment (WEEE).

3 Decision making for technologies in plastic recycling

In this section we look at decision making strategies for selecting appropriate technologies related to the recycling of polymer materials used in the manufacturing of consumer durable products. It is assumed that contemporary white and brown goods, office equipment and other consumer durable products are a complex combination of different plastics, paper, ferrous and non-ferrous metals. Differing possible end usage of the obtained recycled plastics complicates the decision making process even further.

Due to the great variety of materials, the decision making algorithm must be represented with a multi-branched tree with over 40 nodes. In order to simplify visual comprehension, the decision making strategy is represented with the main tree (Tree 1, Figure 3) and a sub-tree (Tree 2, Figure 4) related to commingled plastics. Tree 2 in turn has its own sub-tree (Tree 3, Figure 5) involving non-compatible commingled plastics.

Figure 3 Tree1 - Decision making in recycling of consumer durable products

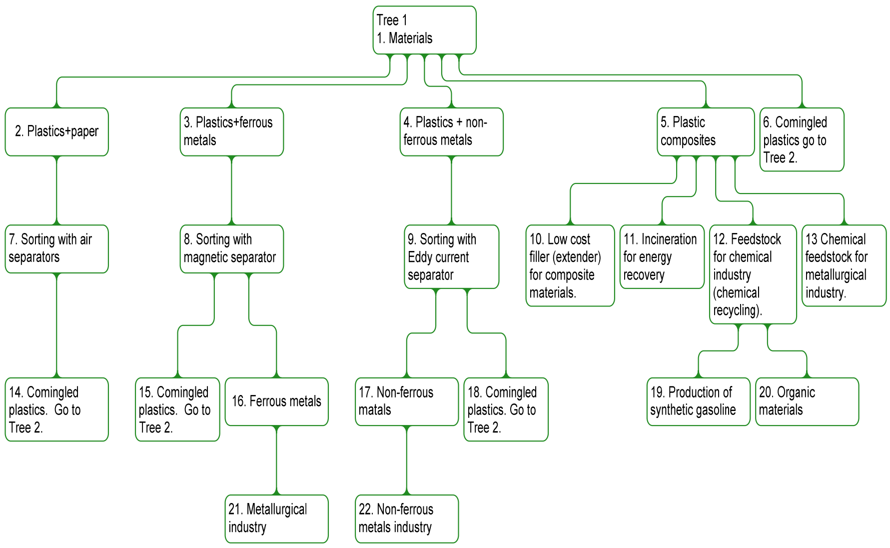


Figure 4 Tree 2 - Recycling of commingled plastics

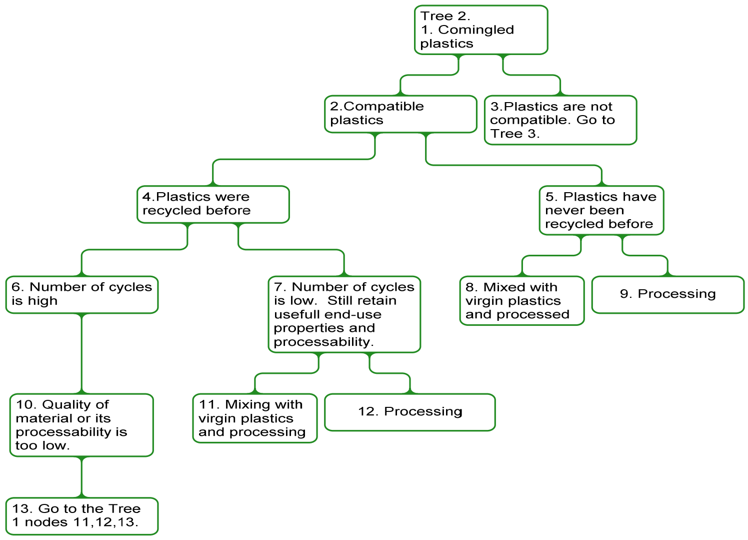
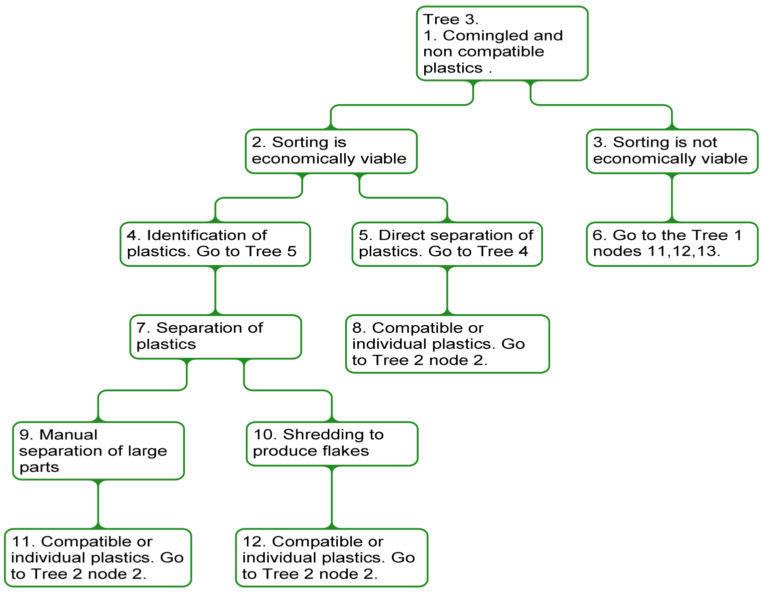


Figure 5 Tree 3 - Recycling of commingled non-compatible plastics.



Two reference trees are also presented to provide information on different available sorting technologies (Tree 4, Figure 6 and plastics identification (Tree 5, Figure 7) techniques. The choice of the particular technique depends upon the physical properties of the plastics, method of product disassembling, presence of different materials, volumes to be processed and financial considerations. These trees will assist management to make decisions to select the most appropriate technologies and methodologies to recycle polymer materials from post consumer durable products.

Figure 6 Tree 4 - Separation methods

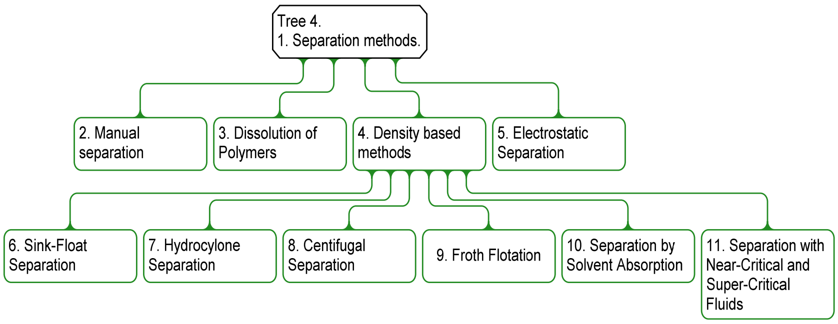
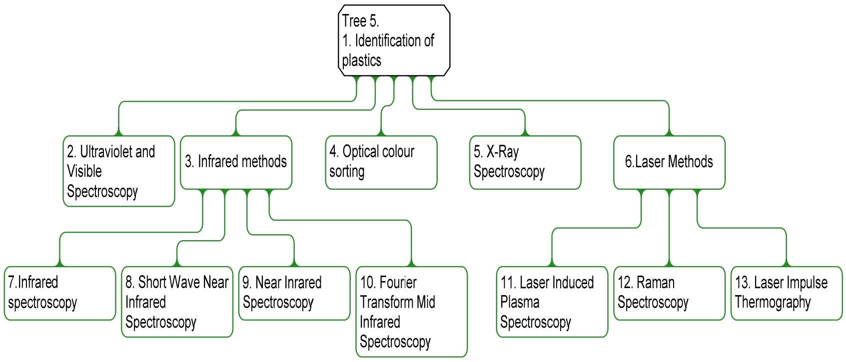


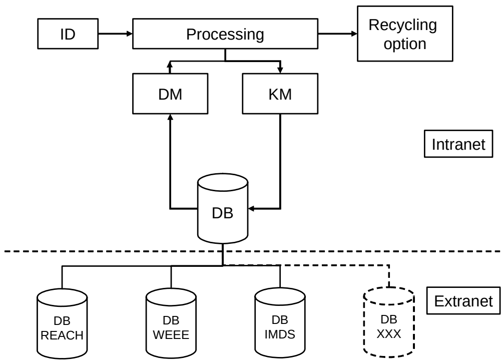
Figure 7 Tree 5 - Methods for plastics identification



4 Assessment methods

Figure 8 describes the integrated assessment of the appropriate recycling option. The user starts with identifying the plastic part (ID). In the best case the part has a fixed identification number e.g. an electronic product code (EPC). The identification result will be processed and passes a knowledge management system (KM), which is connected to an internal database (DB). If the knowledge management system needs additional data, which is not available in the internal database, different databases in the extranet can be connected. This database is already existing (IMDS), is existing on the producer side (WEEE) or are in preparation (REACH). The internal database contains all available data about materials and the economic, environmental and social factors which are related to the different recycling options. This data will support the recyclers decision making (DM). Results of the decision making will be processed and stored in the database.

Figure 8 Software infrastructure



5 Integration of product related data

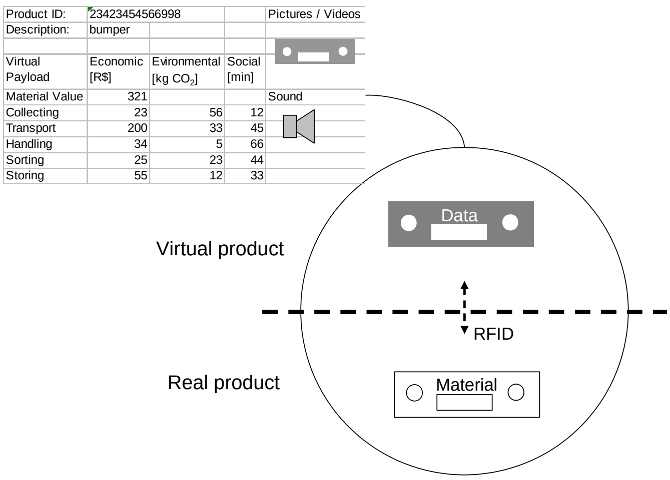
For improving the product related data a decentred database can be included into a device, which is attached to the product (Product Embedded Information Device – PEID). This device collects all relevant data during the product life cycle. Figure 9 describes a concept which enables a continual collecting of data belonging to the product (in this example a car bumper). By using RFID technology data can be stored directly on the PEID and on a back end system as text, pictures, sounds and videos (e.g. for giving instructions on handling, sorting etc). The data can be parted into economic, environmental and social data belonging to the product. In addition to this normative and strategic data [4, p. 135-136] operational data can be stored into this virtual product. The economic impact can be calculated in a specific currency, belonging to the point of origin. The environmental impact can be calculated in CO_2 basis, the social on minutes working time. In addition to textual data also pictures and sound files can be stored and retrieved. This concept has the following advantages:

- All stakeholders (supplier, customer, public authority) can have access to the virtual product for data retrieving
- The economic, environmental and social impact can be used for the controlling of normative or strategic decisions (e.g. reduction of CO_2 in a specific time frame)
- Collected data is available on real time basis
- Existing data is reliable and not based on estimations or external data basis (like a database containing life cycle data valid for a specific product, process and region)

6 Conclusion

Within the paper the requirements and obstacles in the context of stable recycling models for plastics waste were discussed. It appears that a careful planning of the underlying processes is absolutely necessary in order achieve economic and sustainable recycling systems. While planning is straightforward for many recycling activities it is not for plastics waste. The market is difficult and highly dynamic. Finding economic recycling strategies is therefore not trivial. In addition various restrictions related to the recycling processes legal issues have to be included into the planning and decision processes along recycling. Last but least an increased awareness of environmental and social impacts related to industry arose in the last decade. This adds another dimension into the planning complexity. On the other hand various and powerful data sources and IT-supported tools are available to support the underlying planning and decision processes. In combination with PLM approaches as the one presented by PROMISE project, product and material information can be accessed over the whole life-cycle and are therefore also available for the recycling of products after they reached their end-of-life. This represents a tremendous improvement for the recycling industry as the access to product related information was formerly very difficult if not impossible. In combination with existing data-bases as well as approaches supporting decision support powerful planning systems can be developed which are able to support recycling-related problems in the best way. This will improve the way recycling is conducted today and in the future.

Figure 9 Real and virtual product



Product ID:	23423454566998			Pictures / Videos
Description:	bumper			
Virtual Payload	Economic [R$]	Evironmental [kg CO_2]	Social [min]	
Material Value	321			Sound
Collecting	23	56	12	
Transport	200	33	45	
Handling	34	5	66	
Sorting	25	23	44	
Storing	55	12	33	

Acknowledgment

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Tracking and tracing in the end-of-life phase of product lifecycle management

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Abstract: This paper addresses the need for tracking and tracing in the end-of-life phase of product lifecycle management. It specifically addresses the recycling of plastic products, such as automobile bumpers. The paper begins by briefly describing the state-of-the-art in product lifecycle management in this field. It then presents an approach to product lifecycle management in a specific plastics end-of-life scenario in describing a proposal for a supporting system architecture. The scenario is then described in scene-by-scene detail, highlighting how the proposed approach is expected to modify and improve the current scenario.

Keywords: EOL, End-of-Life, Reverse Logistics, Tracking & tracing

1 Rationale for Tracking and Tracing in the End-of-Life Phase of Product Lifecycle Management

According to the Manufuture Strategic Research Agenda 2006 (1), the market is increasingly in demand of a business focus which has shifted from designing and selling physical products to supplying a system of products and services (‘product/services’ or ‘extended products’) that are jointly capable of fulfilling users’ demands, while also reducing total life-cycle costs and environmental impacts. The new focus calls for an integrated system that includes the entire lifecycle of creation, production, distribution and end-of-life treatment of products. (2)

This section describes an exemplary as-is scenario in the plastic recycling industry and highlights the rationale for the application of product lifecycle management on the basis of auto-identification technology.

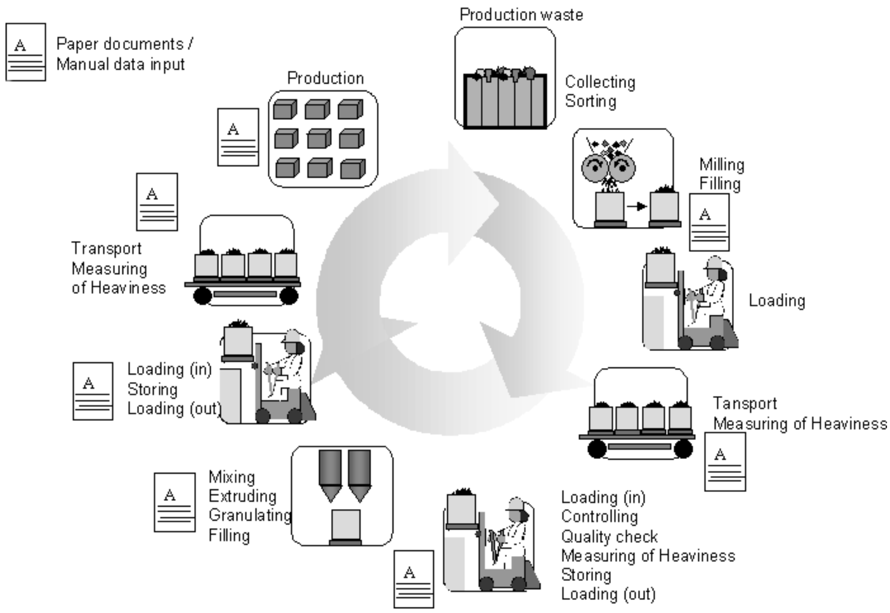
1.1 Current State in Plastic Recycling

The figure below describes a typical real-life application scenario in which major benefits can be generated by the application of product lifecycle management on the basis of auto-identification technology. Specifically, it shows the life cycle of car bumpers the plastics of which are to be recycled at their End-of-Life (EoL).

The EoL phase begins after the dismantling of the respective automobiles. After use and dismantling the individual bumpers or assortment of bumper components are brought to a collection point (for example, an open container).

The milling starts after a sufficient amount of bumpers is available. Before the milling, a manual or automated sorting system sorts the bumpers for recycling from the container fractions. After milling and filling the material goes via a truck to another recycling facility. There the material goes into a storage system. Based on customer demand, this facility produces new plastic granulate, which again is the basis for new plastic products. This process signifies the transition of the EoL phase of one product into the BoL (Beginning-of-Life) phase of another.

Figure 1 The End-of-Life Phase of the Product Lifecycle of Automobile Bumpers

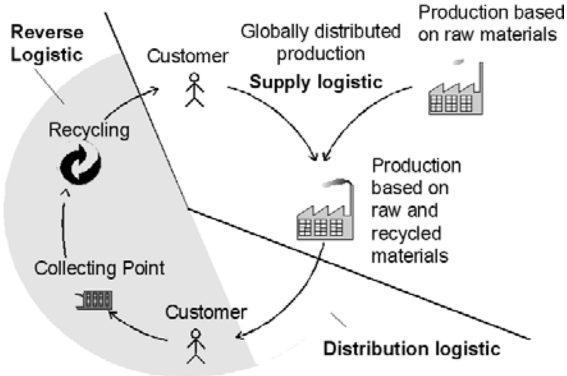


1.2 Product Lifecycle Management in the Reverse Logistics Sector

In the reverse logistic sector there are three major goals which have to be achieved. The first goal is cost optimization of the reverse logistic material flow, the second the quality level of the logistic service units and the third maintaining the flexibility and adaptability of the reverse logistic systems.

In a closed loop (see Figure 2 below) customers have to be served on both the input and output sides. This means that both sides are market driven and depend on approaches which can react in time, can flexibly react to changes in the market are reliable in terms of delivery in time and material quality. If this can be assured, the inclusion of raw materials can be reduced to a minimum (by the reduced mixing of raw materials with recycled materials for improving the quality).

Figure 2 Reverse Logistics System



The tasks in the reverse logistic sector are mainly based on collecting, transport, handling and storing. Each of these processes has a normative, strategic and operative dimension. Each dimension is depending on the available information and information system structure. If the normative and strategic sector have a good information basis for setting up new or improving processes, this effects the operative sector in the same way like an efficient information system.

The available information and information handling in the EOL sector is currently on a lower level in comparison to the distribution sector. Coming from the product identification side, not much information is available about products in terms of material composition, user behaviour and changes to the material or product components during the product life. The collection systems themselves are often based on paper documents, transport boxes are only tagged with paper labels with text based information. In combination with different enterprise software systems, this causes data to be lost or become noisy through manual input, in which all kinds of human errors can occur.

1.3 Distribution of Logistics Costs

Currently, logistics processes in the recycling industry still operate on a low technical level. This is due to the characteristics of the industry, which mainly consists of SMEs, the mixed quality of the processed material and the high distribution level of products foreseen for recycling or disposal.

Related to actual developments in product recycling in the automotive sector (European directive for 95% recycling quota in 2015) or the electric and electronic equipment sector an economic reverse logistics system is required to be established. For example, the introduction of the European Community directive 2002/96/EC on Waste

Electrical and Electronic Equipment Directive (WEEE Directive) together with the Restriction of Hazardous Substances Directive (RoHS Directive) 2002/95/EC force manufacturers to act with regards to lifecycle management in order to retain the profitability of these products.

Table 1 Logistic costs for production and recycling (3)

Sector	Logistics Costs (% of turnover)
Production and Distribution	
Electro	12,6%
Computer, Electronics, Communication	10,3%
Automotive	8,9%
Collection and Dismantling	
Electro and electronic products	> 30%
End of Life vehicles	> 25%

Source Eckart, D. (1996) (1)

Table 1 above describes the logistic costs (% of turnover) between production and distribution versus collection and dismantling. The high logistic costs for collection and dismantling are mainly based on the low product value and the complex redistribution system infrastructure. This means that logistic process optimisation will have a high impact on this sector and increases the recycling rate of EOL products.

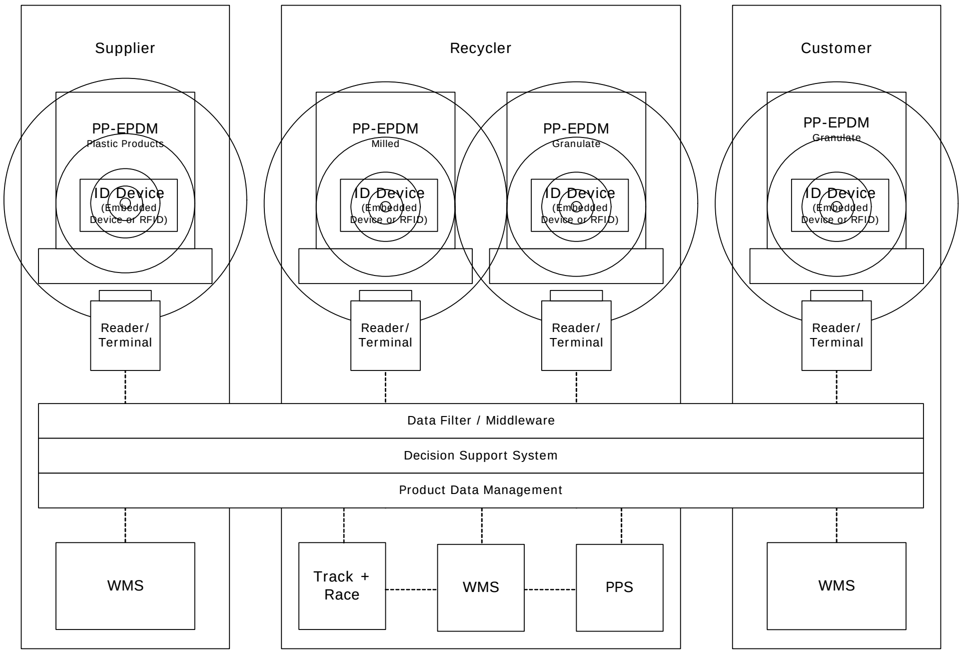
2 Approach to Product Lifecycle Management in the End-of-Life Scenario

Plastic recyclables represent heterogeneous goods which, in logistics processes, are transported employing a variety of containers.

The proposed solution to product lifecycle management within the scenario for such plastics is proposed to be achieved by packaging embedded devices in such a way that they are immersed within the material, as shown in Figure 3 below. These embedded devices provide unique product identification, memory for the storage of product data and sensor facilities, for example a thermometer for the monitoring of easily inflammable plastic granulates.

The embedded devices establish a wireless connection available to arbitrary devices equipped with suitable readers. In Figure 3, terminals are used as an example of such devices and are understood to represent PDAs, workstations or stand-alone readers connected to the main enterprise systems. For example, PDAs or other devices can be employed e.g. by shop floor personnel or logistics operators to carry out a number of operations upon information transmitted by the embedded devices. These devices will then be used as relay stations to backend systems through a dedicated middleware layer which in turn provides input to a Decision Support and Product Data Management system.

Figure 3 Proposed End-of-Life PLM System Architecture



The middleware interfaces to systems a Warehouse Management System (WMS), a Production Planning Systems (PPS) and legacy Enterprise Resource Planning (ERP) systems, employed in the As-Is scenario as shown in Figure 3. Furthermore, the such as track + race Locating System[1] is employed for the automatic positioning of forklift trucks, containers and goods on the basis of RFID or embedded devices within the recycling plant's internal logistics.

The Product Data Management system manages customized product data that is required for the end-to-end management of the product-centric activities within the scenario.

Owing to the event-driven process nature of the scenario, the authors anticipate that the Decision Support System is directed using rule sets mainly in the form of decision trees rather than algorithms based on statistical analysis.

This system interacts with the legacy WMS and PPS. The WMS is used to manage storage orders, manage the identification of the goods and orders to the storage execution systems such as the track + race system. In addition, the WMS is able to dynamically manage all the storage positions of the goods independent of the size of the item(s) to be stored.

The following sections describe the scenario of the entire EOL as envisaged as operating on the basis of the proposed End-of-Life PLM architecture.

[1] The track + race Locating System is a product of INDYON GmbH.

2.1 Incoming Goods

The end-of-life scenario begins in Incoming Goods. Here, containers of incoming materials are delivered by truck. Already offloaded materials are temporarily stored on the floor of this area. Each container may contain heterogeneous types of materials and accordingly, the Decision Support System needs to be capable of differentiating between them. The scenario identifies the containers may carry any of the following possible material combinations:

- plastic granulate,
- sorted plastic components,
- mixed but identifiable plastic components,
- partially non-identifiable components,
- completely non-identifiable components,
- identifiable and hazardous material.

The containers are marked with RFID identification tags. The goods that they contain can be either marked with barcodes and/or working RFID tags, or not marked or carry faulty RFID tags respectively.

The forklift truck approaches and picks any one of the containers. Its on-board tracking and tracing system reads the RFID tag on the container and at the same time determines by its position that this event is taking place in the “Incoming Goods” area.

The Decision Support System now decides to where the container should be moved. This decision takes place on the basis of the product information which is stored within the product data knowledge management component. Depending on the seed data with which the system has been primed, this will be one of the following decisions:

- move container to *Normal Storage*,
- move container to *Monitored Storage*,
- move container to *Production* machine,
- move container to *Sorting*, or
- move container to *Clearings*.

The decision is communicated to the warehouse management system, which in turn informs the forklift driver via the forklift’s onboard display. The forklift driver can then execute the given instructions. The track + race system verifies that the container is taken to the correct destination.

When the container has been delivered to the correct destination, the WMS sends updated product field data (new position) to the product data knowledge management component. This event may be sufficient to initiate activity in another scene, but it may also be necessary for further events to be completed before the Decision Support System makes its next decision.

2.2 Sorting

Activity may begin in this scene at any time a container of materials becomes available for sorting. This activity may be triggered by the arrival of a single container, or it may be more efficient to wait for several. These decisions can be made by the Decision Support System.

For the purpose of this scenario description, the authors assume that activity begins with the arrival of a container of plastics from *Incoming Goods*. The transportation of the proper container to the correct location will already have been verified by track + race.

The logistics operator iteratively takes an item from the incoming container and reads the ID using a barcode and/or RFID reader. If the ID can be read, then the data is sent to the product data knowledge management and Decision Support Systems where the current product data is recorded.

If the system can identify the type of material from its ID and product data already in the product data knowledge management system, it will direct the logistics operator, using the hand-held terminal, to put the item in a sorting container designated for that type of material. The logistics operator will confirm the action and the system can now record the new location (in the container) of that item.

If the system cannot identify the type of material from its ID and product data already in the product data knowledge management system, it will direct the logistics operator, using the hand-held terminal, to put the item in the container designated for receiving items with a valid ID but no available product data. The logistics operator will confirm the action and the system can now record the new location (in the container) of that item.

If the item has no ID device, or it is faulty or unreadable, the logistics operator will place a new passive tag or barcode on the item which will identify the item as an unknown product to the system. The latter will direct the logistics operator, using the hand-held terminal, to put the item in the container designated for receiving items with a valid ID but no available product data. The logistics operator will confirm the action and the system can now record the new location (in the container) of that item.

When the logistics operator signals using the hand-held terminal that a sorting container is full, the product data (Container Full) will be sent to the system, and the Decision Support System will decide to where that container must now be taken (*Storage*, *Production* or *Clearings*), and the track + race system will ensure that it will be taken to the correct location.

These actions are repeated until there is no more material to be sorted.

2.3 Clearings

Activity in the *Clearings* scene may begin any time there is a container of unknown material available for clearing. Activity may be triggered by the arrival of a single container, or it may be more efficient to wait for several. Such decisions can potentially be made by the proposed system. However, because the time taken to identify one item may vary considerably, a container of items will normally be processed as available.

For the purpose of the scenario, we will assume that activity begins with the arrival of a container of plastics from *Incoming Goods* or *Sorting*. The transportation of the proper container to the correct location will already have been verified by track + race .

The logistics operator iteratively takes an item from the incoming container and attempts to read the ID device using a hand-held barcode and/or RFID reader. If the ID can be read, then the data will be sent to a remote system in order to try to extract the necessary product data.

If the item has no ID device, or it is defective or unreadable, the logistics operator will place a new passive tag or barcode on the item which will identify the item as an unknown product to the system.

The logistics operator will then attempt to resolve the identity of the item using, for example, visual recognition support systems or by invoking chemical analysis procedures from which a positive identification may be possible. Some time may have elapsed until this is complete.

When identification is possible, the product ID and product data can be mapped to each other in the system which can then decide into which container the item should be placed.

When the logistics operator signals using the hand-held terminal that a *Clearings* container is full, the product data (Container Full) will be sent to the system, and the Decision Support System will decide where the container should be taken (*Storage* or *Production*). The track + race system will then take over, guiding it to the correct location.

This activity is repeated until there is no more material to be cleared.

2.4 Normal Storage

Whenever goods are placed in normal storage by the forklift truck, the track + race system precisely identifies the coordinates of the position of the product and sends this data will to the system.

Another advantage of any storage area equipped with the track + race positioning system is that even in the event that the ID device attached to the product should be removed or become faulty, the exact position of the product is enough to uniquely identify it.

2.5 Monitored Storage

The action in *Monitored Storage* actually begins when a container of potentially hazardous material is stored there with sensors enabled on an embedded device. However, the decisions, parameters and actions leading to the enabling of sensors and the transport of the goods to *Monitored Storage* are actually made at the end of a *Production* process step, as will be shown later.

Therefore, when the forklift transports a hazardous container into *Monitored Storage* the track + race system fulfils two objectives; firstly it verifies that the hazardous product has been taken to the correct area equipped for monitoring, and secondly, it sends precise position data where this hazardous container is stored back to the Product Data Management system.

The action in *Monitored Storage* can end in one of two ways. In the first case, the hazard monitoring interval, set by the system as a parameter for sensor monitoring in the embedded device, expires. In this case the goods are no longer a hazard, and the system could make a decision to now move them to normal storage.

In the second case, the sensor detects that the product has passed its safety threshold, also set as a parameter in the embedded device. This causes the embedded device to “wake up” and start to transmit its alarm data. Because *Monitored Storage* is equipped with one or more devices capable of communicating with the embedded device, the alarm data is sent to the system. Because the latter knows the exact location of the product sending its alarm, it can trigger appropriate security or emergency procedures. In the demonstrator scenario, this will result in the hazardous material being moved as a matter of urgency from *Monitored Storage* to a supposed "safe" location.

2.6 Production

In this scenario, *Production* is the only scene in which products actually reach the end of their lives and where new products are created and thus enter the beginning-of-life phase. Activity in *Production* begins when the Decision Support System decides which products must be taken to *Production* to be used in a process determined by the Production Planning System (PPS).

The forklift takes containers of material one by one to the production system. Each movement is verified by the WMS and track + race systems so it can be guaranteed that the correct containers were taken to the proper machine.

As each container arrives at *Production*, the device embedded in its container is read and the product ID data is communicated to the PPS. When the process indicates that the contents of each container have been consumed in the process, the production system will communicate an event signaling EoL to the product data knowledge management system. The latter will then record EoL for each product associated with the container.

When the production process indicates that a container of a new product has been produced and is ready to receive identification, the system will first communicate a BOL event for the new product and then initiate the writing of data to the identification device destined for the container. Depending on the produced product, this process may indicate the need for an full-scale embedded device on which sensor parameters need to be set in the case that the Product Data Management system indicates that the product is classed as hazardous goods. Otherwise a simple RFID tag will be used.

Once the writing of product identification data is confirmed, the system can then decide whether the container needs to be sent to *Normal* or *Monitored Storage*, or even directly to *Outgoing Goods* if it contains finished goods ready for dispatch.

The system then sends a transport request to the WMS and the goods movement is again managed and verified by the WMS and track + race systems.

2.7 Outgoing Goods

Activity begins in *Outgoing Goods* when the ERP system identifies a product that is to be shipped. The ERP system uses the system to send a shipment notification to both the system and the WMS.

The system decides if it is necessary to replace an embedded device with a simple RFID tag prior to shipment. If so, it prepares the logistics operator in *Outgoing Goods* to replace the device.

In parallel, the WMS manages the goods movement request to *Outgoing Goods* where track + race verifies that the correct product was taken to the proper destination.

If it is necessary to replace an embedded device, the logistics operator does so and confirms the physical replacement to the system, which then manages the writing of the appropriate BOL product data to the embedded device.

The forklift vehicle loads the product onto the outgoing truck. The WMS and track + race systems verify that the correct product has been loaded and the WMS notifies both the ERP system and the system thus closing the tracking and tracing information loop.

3 Conclusions

The presented scenario clearly demonstrates the opportunities for achieving "paperless" operations in the EoL-phase of Product Lifecycle Management. Hence a significant reduction in handling errors can be achieved by the integration of a technological approach to PLM in this phase, such as by means of the system architecture presented in this paper.

A high level of tracking and tracing on this basis can lead to virtually error-free operations in reverse logistics, effecting significant improvements in operational efficiency. It furthermore plays a major role in closing the Product Lifecycle information loop, by providing the missing Product Data Management link from the end-of-life of one product to the beginning-of-life of the next. This is achieved by demonstrating a high degree of automation and the integration of processes with have hitherto remained completely separate and relying on significant manual intervention in a typical plastics recycling company.

Acknowledgment

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Design improvement method using product usage data in a closed-loop PLM

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Abstract: Recently, companies have been able to gather product usage data during middle of life (MOL) owing to newly developed technologies such as RFID, various sensors, wireless telecommunication, and so on. Even though the technological infrastructure for gathering product usage data is established, the application of newly gathered product usage data is still in its infancy. If MOL data can be transformed into suitable information and knowledge for product design improvement with appropriate methods, it will be fruitful. To this end, in this study, we propose a design improvement method based on product usage data which are gathered by product embedded information device (PEID) in a closed-loop PLM.

Keyword: Product usage data, Degradation, Product improvement, PEID

1 Introduction

With the recent development of technologies such as RFID, various sensors, wireless telecommunication, internet, and so on, companies can gather the usage data of a product during its middle of life (MOL) in a ubiquitous way. Companies can access and monitor products remotely, gather product status data, and handle product working parameters directly. However, even though the technological infrastructure for them is well established, the application method to use newly gathered data is still immature and its infancy. Therefore, there are several research challenging issues to apply product usage data into various areas.

Newly gathered MOL data can be used more effectively for product improvement if they can be transformed into appropriate information or knowledge. For example, the accurate understanding of product status based on usage data helps design engineers to improve weak design points at the beginning of life (BOL) stage, which leads to the reduction of product failures and the high product reliability. These improvements will increase customer satisfaction and therefore assure companies to survive in the market. Hence, it is necessary to develop a method to apply MOL data into product design improvement.

To this end, in this study, we propose a design improvement method using product usage data. In this method, we assume that the product usage data can be gathered by product embedded information devices (PEIDs) such as RFID tags, sensors, on-board computers, and so on, which have been being developed in the PROMISE project (PROMISE, 2004; Kiritsis, 2004; Kiritsis and Rolsadås, 2005). In the first step, we will make a function structure model of a product. Based on the function structure model, we will define a degradation scenario. Then, we will calculate performance degradations of the functions. From those values, the critical degradation time point of functions will be calculated. The degradation scenario and performance calculation are used to find important functions in the context of product degradation. Through comparing the mission profile data at the critical degradation time point with the mission profile data which shows normal degradation status, we will find specific mission profile categories which have an effect on performance degradation. At the last step, using relation matrix between mission profile data and design parameters, we suggest important design parameters to product design engineers in the viewpoint of degradation.

The remaining of this study is organized as follows. In section 2, we introduce previous research works on performance and degradation. In section 3, we propose an overall procedure for applying product usage data into product design improvement with more detailed explanations. In section 4, we deal with a case study to show the effectiveness of the proposed method. In the last section, we will conclude our research and provide some discussion.

2 State-of-the-art

In general, it is useful to measure product performance during product usage period in many industrial fields. If companies know actual status of products in the context of performance, they can provide much effective service such as prognostic maintenance. Furthermore, they can improve product design by fixing the reasons of performance degradation. However, it is difficult to define product performance because of the ambiguity of performance definition. According to Merriam-webster dictionary, the performance is defined as a) the execution of an action, b) something accomplished, and c) the fulfillment of a claim, promise, or request. Osteras *et al.* (2006) showed some definitions of performance and suggested their own definition of performance as a vector of performance variables. In spite of these efforts to explain performance, the definition of performance is still hard to use in a verbal form. To use product performance in the company, it is required to convert product performance into a numerical value. Many previous research works tried to define product performance as measurable values. For example, Wilson *et al.* (1999) used some characteristics of oil as oil performance measure, e.g. wear metals, contaminants, additives, lubricant physical properties, viscosity, wear, and contaminant particles. Furthermore, Crk (2001) monitored sensor voltage according to targeted distance to model product performance. Huitian *et al.* (2001) used the thrust force of a drill bit (in operation) as a physical performance measure for the failure of the drill, which value was measured by a Kistler 9271A force and torque dynamometer. In addition, Coit *et al.* (2005) provided shear strength of the solder joint of circuit board as a performance measure. Recently, Lee *et al.* (2006) showed some examples of performance measure. In the first example of their work, the vibration signal waveform monitored by an accelerometer was used as the performance measure of a bearing. Another example is about controller area network (CAN). In the example, overshoot at which the signal goes beyond the steady state value was used as the performance value.

Based on measured performance values, the performance degradation can be formulated. It can be various depending on the purpose of applications such as design improvement, maintenance, remanufacturing policy, and so on. There have been some relevant research works on it. For example, Djurdjanovic *et al.* (2003) suggested various methods for performance assessment such as statistical overlap between performance related signatures, feature map pattern matching, logistic regression, cerebellar model arithmetic computer (CMAC) neural network pattern matching, hidden markov model based performance assessment, particle filter based, and so on. Bucchianico *et al.* (2004) used the maximum amplitude of the first peak of the current signal as a performance feature. With current signal, they applied wavelet analysis to simplify the description of signal. Then, they used it as features to perform the analysis of variance (ANOVA). Furthermore, Tang *et al.* (2004) used the intensity of LED as a degradation measure. The temperature with time interval is changed and the degradation data of the light emitting diodes (LED) is modeled as a degradation path. Using the degradation path, they proposed an optimal test plan for accelerated degradation test (ADT). Recently, Jayaram and Girish (2005) proposed degradation data model called *generalized estimating equation* (GEE). Using this model, they predicted the characteristics of poisson distribution of degradation data set whose marginal distribution is poisson, from which they could estimate reliability.

Even though there have been much effort on performance degradation definition and modeling until now, there are few applications which focus on design improvement. Moreover, there is the lack of research works which deal with the connection between degradation and mission profile to find the cause of degradation.

3 Overall procedure

To apply product usage data to product design improvement, we propose the following procedure. In the first step, we make the function structure model of a product. The function structure model shows how functions are connected and affected with each other. In the function structure model, the performance measure is defined for each function. From this model, we can clarify the relationship between functions, which will be used in defining a degradation scenario. The degradation scenario describes the relations of functions in the context of degradation. It is similar to a failure scenario (Kmenta and Ishii, 2004) which shows the connection of failure modes. However, the degradation scenario is different in that it focuses on not the failure but the degradation relationship of functions. Hence, degradation scenario helps engineers to find which functions are important in the viewpoint of degradation. With the degradation scenario, it is possible to find root causes of consecutive degraded functions. From the degradation scenario, we can classify important functions which should be focused on. Next, we calculate performance degradation of functions based on gathered product usage data with the proposed performance measure described in the function structure model. In general, the performance degradation changes as usage time goes by, which leads to the generation of a kind of degradation trend. By examining the degradation trend and degradation scenario, we can find the critical time point which shows sudden increase of degradation change. In the next step, using clustering technique, we discriminate the abnormal value of mission profile. With mission profile data in normal status clusters and abnormal mission profile data which are gathered in the critical time point, we find specific mission profile data which seems to have a critical effect on the performance degradation. This mission profile data can be one of possible causes of degradation. Then, we combine design parameters with mission profile data which are chosen from previous procedure using relation matrix so as to find the most effective design parameters. From the result of the relation matrix, we can provide design engineers with important design parameters which are connected to critical function degradation and critical time points. The following are more detailed explanation for this approach.

3.1 Step 1 - Build function structure modeling

In general, a product consists of several functions depending on its purpose. Some functions work together to perform another purpose and others accomplish their purpose without any function combinations. To clarify this relationship, first of all, we should decompose product functions depending on its role and its level. Table 1 shows an example of function decomposition. The product has several functions at the first level. Each function can be divided into several sub-functions as the second level. Sub-function can also be divided into sub-functions as lower level again. The level of function decomposition can be extended depending on function complexity.

Table 1 Function decomposition

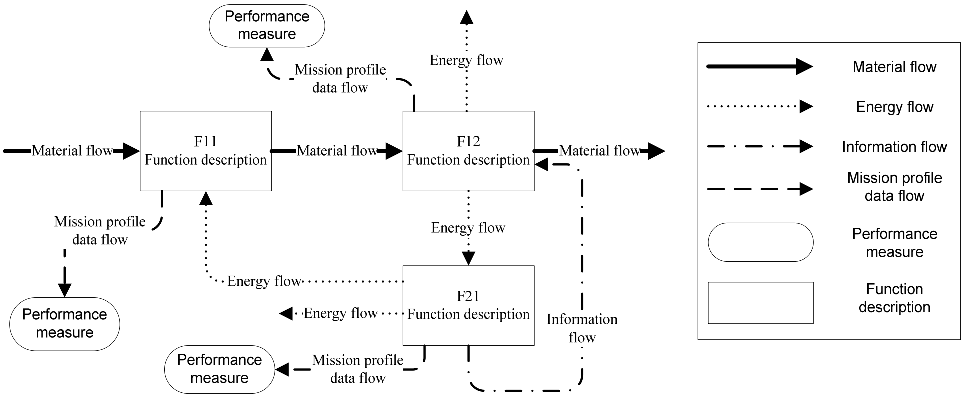
Function	Function description	Sub-function	Sub-function description
F1	'F1' Function description	F11	'F11' Sub-function description
		F12	'F12' Sub-function description
F2	'F2' Function description	F21	'F21' Sub-function description

The decomposed functions are usually connected with each other, which generates complex relations. To show these complex relationships among decomposed functions, we propose a function structure model. Fig. 1 shows an example of the function structure model. In the function structure model, there are several symbols such as function description, material flow, energy flow, information flow, mission profile data, and a performance measure. The functions are connected through the material/energy/information flow. The direction of an arrow shows which direction material/energy/information flow to. Each function has a performance measure. The performance measure is used to calculate function performance degradation later.

3.2 Step 2 - Define degradation scenario

The degradation scenario shows the relationship among functions in the viewpoint of degradation. In this study, the degradation scenario is based on the function structure model. The degradation scenario is closely related with energy/material/information flow

Figure 1 Function structure model



of the function structure model. For example, in Fig. 1, if the material input of F11 decreases, the output material of F11 decreases. The reduced material from F11 makes F12 function work improperly. Hence, the material flow and energy flow can be good references for building up degradation scenario.

Considering possible function relationships, all existing degradation scenarios should be defined. To help making degradation scenarios, we define degradation relationship depending on the degree of relation cardinality. For the single degradation relationship, we define three types: independent, dependent, and interdependent.

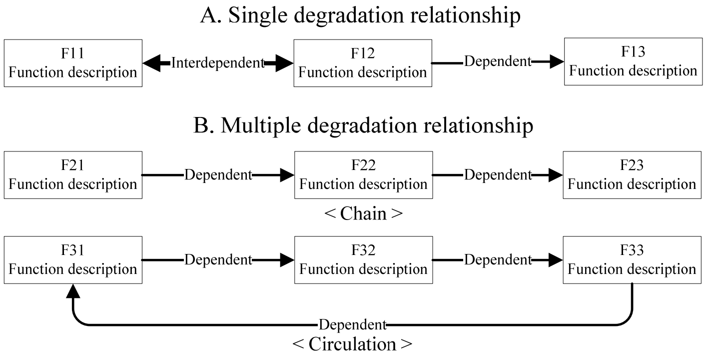
- Independent : there is no degradation relationship between two functions
- Dependent : degradation of one function leads to degradation of the other function, but not vice versa (unidirectional degradation relation)
- Interdependent : degradation of one function can affect that of the other function and also vice versa (bidirectional degradation relation)

For the multiple degradation relationship, we classify it into two types: chain and circulation.

- Chain : a degradation affects other degradation, and in turn affects another degradation one by one but not affect the first function degradation (multiple degradation relation without loop)
- Circulation : A chain degradation affects the first function degradation (multiple degradation relation with loop)

Using degradation scenarios (see Fig. 2), we can choose an important degradation function which leads to other consecutive degradations. For example, in the chain degradation, the first degraded function can be a possible root cause of several functions in degradation scenarios.

Figure 2 Examples of degradation scenario



3.3 *Step 3 - Calculate performance degradation of functions*

Performance degradation can be calculated by performance measures defined in the function structure model. The performance measure such as voltage, vibration, current, speed, and noise can be defined considering the objective of each function. It is used to calculate performance degradation for each function. The performance degradation can be defined as the relative difference between measured performance and expected performance in the design specification, considering performance tolerance. The performance degradation, *D(t)*, is defined as the equation (1).

$$D(t) = \frac{p_d - p(t)}{T}, \ (if \ p_d < p(t), \ D(t) = 0) \tag{1}$$

$D(t)$: Degradation at time t

$p(t)$: measured performance value

p_d : design specification of performance of a function

T : tolerance of p_d

3.4 *Step 4 - Find critical degradation time point of functions*

The *D(t)* is recorded through time *t*. If the performance degradation *D(t)* increases abruptly during a certain time interval, the slope of degradation increases. These increasing moments of degradation can be defined as a set D_{ct} (see equation (2)). The high increase of degradation indicates that the possibility of failure augments. Therefore, the time which shows the highest increase of degradation can be a critical degradation point.

$$D_{ct} = \{t \mid \frac{dD(t)}{dt} \geq S_m, \ 0 \leq t \leq \text{EOL of product}\} \tag{2}$$

D_{ct} : critical degradation time point

S_m : marginal degradation differential value of $D(t)$

From the equation (2) and degradation scenario, we can discriminate the critical time points of functions with respect to degradation.

3.5 Step 5 - Find abnormal mission profile data

In the product degradation analysis, mission profile data should be considered because they are closely correlated. When a critical degradation occurs, it is necessary to find abnormal mission profile data affecting the degradation. In this study, we propose a clustering method for this.

During product usage, various kinds of mission profile data such as outer temperature, voltage, current, speed, and position are recorded using PEID. Mission profile data usually includes various ranges of data since the product is used in the different environment and by different users. For example, a locomotive records various mission profile data such as temperature, speed, position, voltage, and current depending on in which country and by which company the locomotive is used. Therefore, at first, we make clustering of all mission profile data from which shows normal performance degradation status. Then, we calculate mean and variance of each cluster. From this, we can know in which mission profile the product works without any problem. The mean values of clusters become reference values of mission profile which assure normal degradation status. Then, we compare mission profile data which are gathered in the critical time point with normal status mission profiles data. From this comparison, we can discriminate specific mission profile data which are different from normal data. These mission profile data will indicate one of possible causes of degradation.

3.6 Step 6 - Combine mission profile with design parameters

In the last step, we combine selected mission profile data with design parameters of part/component of a product. Mission profile data are selected in the previous step and regarded as a possible cause of performance degradation. Design parameters come from part/component design specification. Part/component are classified and defined by the functions since each function requires part/component to perform its objective.

To make and evaluate relationship between design parameters and mission profile, we use the matrix form (table 2) similar to the house of quality (HOQ) of quality function deployment (QFD) method. Using relation matrix, the mission profile and design parameters can be linked. The degree of relationship is decided by engineers using usual degree such 1-3-5, 1-5-9, low-medium-high, and so on. Then, using similar calculation such as QFD, we can calculate the important rate of design parameters.

Table 2 Relation matrix

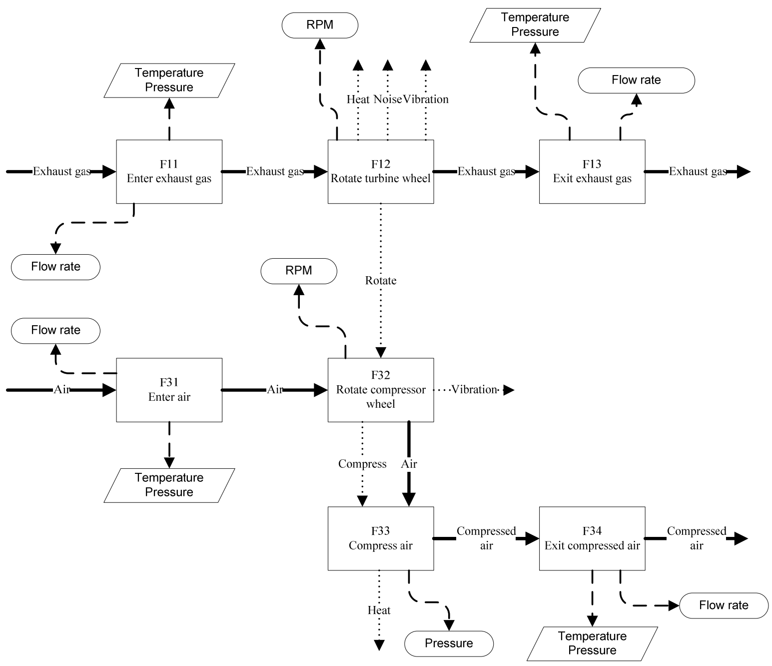
Function	Part/component	Design parameter	Mission profile			Importance rate
			Mission profile data *a*	Mission profile data *b*	Mission profile data *c*	
F11	Part/component	parameter				
	Part/component	parameter		Relation degree		
F12	Part/component	parameter				
F21	Part/component	parameter				

4 Case study – turbocharger

In this section, we introduce a case example to apply the proposed approach into a turbocharger. The turbocharger is an exhaust gas-driven compressor used to compress air that is entering to an engine so as to increase the amount of available oxygen. Using a turbocharger, the engine output power can be increased. Usually, a turbocharger consists of two parts: compressor and turbine. For the simplicity, we consider only these components in this case study.

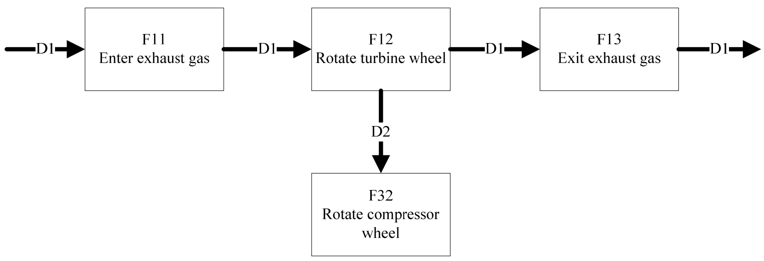
As the first step of the proposed approach, we make the function structure model of a turbocharger as shown in Fig 3. Based on the function structure model of a turbocharger, we build degradation scenarios as shown in Fig. 4. Among possible degradation scenarios, Fig. 4 shows two kinds of degradation scenario. For example, in D1, the shortage of entering exhaust gas can affect the reduced rotate power and the lack of exiting gas. D2 shows that the reduced rotate power can lessen the rotating function of a compressor. Both degradation scenarios have the chain form.

Figure 3 Function structure model of a turbocharger



Then, we calculate the performance degradation of each function by the equation (1). The performance of F11, F13, F31, and F34 can be measured by the flow rate of gas and air. The F12 and F13 use RPM as a performance measure. This degradation calculation is periodically recorded as time goes by. Hence, using the equation (2), we can find critical time point which shows sudden increase of degradation. With performance calculation and degradation scenario, we can decide critical degraded function actually and find the critical time point of the degraded function. For example, in the case that both F11 and F12 show degradation, the F11 can be a cause of F12 degradation at the critical time point.

Figure 4 Degradation scenario



In the next step, we make clustering of mission profile data such as temperature, RPM, pressure, and vibration, which have been monitored during product usage period except the critical time point. For each cluster, we calculate mean and variance. The mean and variance are used as reference values to determine normal mission profile condition. Comparing mission profile data of critical time point of selected functions with mean and variance, we can find abnormal mission profile data.

Regarding selected mission profile data, we combine them with design parameters using a relation matrix (see table 3). For the simplicity, we consider three functions and their design parameters. In this example, we assume that data of temperature, RPM, and pressure are abnormal. Then, from the normal relation matrix, we can suggest important design parameters to product design engineers. According to the result of relation matrix, the turbine shape and turbine wheel number are closely related with degradation. Therefore, engineers should check and modify relevant RPM and pressure.

Table 3 Relation matrix

Function	part/component	Design parameters	Mission profile			Importance rate
			Temperature	RPM	Pressure	
F11	Turbine housing	Diameter of inlet			High (5)	5
		Housing material	High (5)			5
F12	Turbine wheel	Turbine shape		Medium(3)	High (5)	8
		Turbine wheel number		Medium(3)	High (5)	8
	Turbine housing	Shape of housing			High (5)	5
F13	Turbine housing	Diameter of outlet			High (5)	5

5 Conclusion and discussion

In this study, we have proposed a new design improvement method using product usage data in a closed-loop PLM. The proposed method consists of several steps to convert the field data which are gathered by PEIDs into information for product design engineers. The field data can be used for monitoring product degradation. Then, degradation change is used to find related mission profile data which affect abnormal status. The mission profile is connected with design parameters which should be modified so as to reduce degradation and improve product reliability. To show the feasibility of our method, we have applied the proposed procedure into a small case study based on a turbocharger. This approach can be a reference model applying product usage data for product design improvement

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Improving automobile parts recovery using product usage history information

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Abstract: The ability to enhance the quality of product information that is available to make decisions along the product lifecycle is the core output of the PROMISE project. One of the major impact areas of such a capability is in improving the effectiveness of decisions made during end-of-life product recovery. Using a probabilistic approach to quantify the link between product lifecycle information and product quality in the case of a major European automobile manufacturer, this paper illustrates how decision-making during end-of-life product recovery can be improved by collecting critical product information during the vehicle lifecycle and making it readily available to the decision-makers to optimise product recovery processes.

Keyword: Product Lifecycle Information Management, PROMISE, RFID, Product recovery, ELV, DSS

1 Introduction

Greater consumer awareness, constant demand for better products, and rapid development and improvement in technology has resulted in the shortening of product innovation cycles. An upshot of this phenomenon is the tendency of consumers to discard products in lieu of better products with increased functionality, long before the old products reach the end of their useful functional life. Recovering value from these products has been gaining increasing importance in the past few years due to environmental concerns as well as the widespread recognition of the financial benefits that accompany it.

Automated ID technologies such as barcode and RFID can have significant impact on the management of the product lifecycle, and on the effectiveness with which product life-cycle data is generated and shared among suppliers, manufacturers, maintenance providers, remanufacturers etc (Harrison et al., 2004). The introduction of this new technology will enhance the quality of information available to decision-makers during product recovery (Parlikad, 2006).

This paper illustrates how the availability of information regarding the usage of a product can improve the effectiveness of product recovery processes. Using probabilistic techniques, we model the uncertainties in product quality, and the relationship between the product quality and key product parameters in a real industrial scenario, by examining the product recovery operations of a major automobile manufacturer based in Europe. This work was done in conjunction with the PROMISE project (PROMISE, 2006), which is a research project funded by the European Union aimed at improving lifecycle management of products by means of improved information management. Here, we show how ready availability of the values of critical product parameters that indicate the extent of usage of an automobile clutch can improve the effectiveness of the clutch recovery process.

The paper is structured as follows. In section 2, we provide a brief introduction to the automobile remanufacturing sector, and the motivation for this project. Section 3 outlines the processes involved in recovery clutches at the end-of-life of an automobile. In section 4, we present a probabilistic approach to model the clutch recovery process. This model is applied using typical data from a vehicle, and used as a basis for simulating the decision process, the results of which are discussed in section 5. Finally, section 6 concludes the paper.

2 Automobile Remanufacturing

The automobile industry is one of the largest manufacturing industries in the world, and consequently, the automobile remanufacturing and recycling industry is large. However, automobile recycling has mainly been performed by independent junkyard operators with no affiliation with the automobile manufacturers (Ferguson, 2002). In September 2000, the European Commission published the End-of-Life Vehicle (ELV) Directive (European Commissioon, 2000), which required automobile manufacturers to take measures to reduce waste generated from end-of-life vehicles, and provide necessary recycling information to recyclers.

The ELV Directive has given the impetus to automobile manufacturers in Europe to re-examine the way they manage their vehicles throughout the product lifecycle and to provide end-of-life recovery service to their customers. The OEM’s strategy was to turn the legislative ‘threats’ into an opportunity for creating new businesses by examining their end-of-life product recovery processes and investigating means by which they could be made more effective. There are several product recovery options available for the returned automobiles — they can be resold in the second-hand market; or valuable parts and components can be dismantled for reuse in new vehicles and the rest of the vehicle shredded for material recovery.

Recognising that the key barrier to efficient product recovery management is the lack of information associated with its vehicles when they are returned at the end of their life, as part of the PROMISE project, CRF is examining the benefit of collecting critical information associated with the vehicles during its usage and maintenance, and incorporating this information for making product recovery decisions. The clutch of an automobile is one of the components identified to have the potential to be reused.

In the next section, we will describe the process for deciding whether the clutch of a returned automobile can be reused or not.

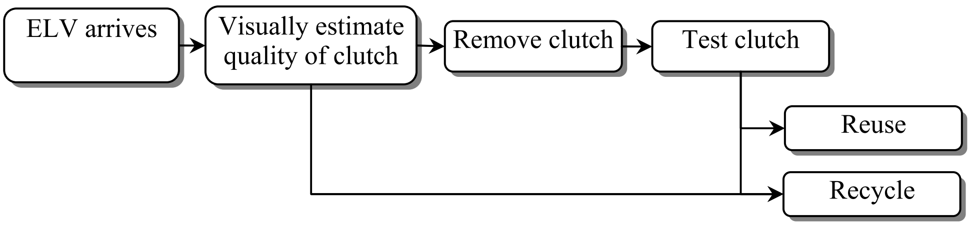
3 Process Description

In this section, we will describe the current decision-making process for deciding the reusability of the automobile clutch. We will then examine the changes to the decision-making process when values of critical usage parameters are available to the decision-maker to estimate the reusability of the clutch.

3.1 Current process

Currently, the recoverer of the ELV makes a judgement about the quality of the clutch by visual inspection to determine whether the clutch should be removed. This process is depicted in Figure 1. The history logbook of the vehicle is also a source for information that would lead to an indication of the quality of the clutch. The logbook ideally should provide information regarding clutch replacement or maintenance. However, history logbooks are most often not updated regularly, and hence, the accuracy of the information provided by logbooks is low.

Figure 1 Existing process for ELV component recovery



According to this judgement, the clutch is removed from the vehicle (if it is deemed to be of good quality) or left in the vehicle to be shredded along with the vehicle. The clutch, if removed from the vehicle is then tested to ensure that its residual life is long enough to enable it to go through another lifecycle safely. Evidently, the first decision is made with very little information, due to which a large number of faulty clutches undergo testing. The objective of this study was to examine whether ready availability of data regarding the usage of the clutch would result in better pre-sorting. Ultimately, the key aim is to test only those clutches that have a high probability of being reusable. We shall examine this scenario in the next section.

3.2 New process

The quality of a clutch at its end-of-life can be estimated by monitoring and collecting a number of usage parameters during its life. From expert knowledge about clutch usage and its effect on its quality, some key parameters were identified that provide the best indication about the quality of the clutch, which are summarised in Table 1.

These parameters are monitored using sensors, and the data is stored on board RFID tags that are attached to individual clutches. The tags would also contain an identification code that uniquely identifies the clutches at the item-level. The key benefit of using RFID technology is that the value of lifecycle parameters collected during the usage phase of the clutch could be readily available when the automobile is returned at its end-of-life.

Table 1 Lifecycle parameters for automobile clutch[1]

Parameter	Description	Unit	Threshold	
			Bad	Good
Number of clutch usages	Number of times the clutch is pressed	Count	X000,000	X00,000
Clutch usage	Total time spent with clutch engaged	Hours	X000	X00
Number of vehicle starts	Number of times the vehicle starts moving (speed = 0 to speed >0)	Count	X00,000	X0,000

It is to be noted that the recovery option to be chosen depends not only on the condition of the clutch (which is estimated here from lifecycle data) at its end-of-life, but also on other parameters such as the model and manufacturer of the clutch. However, for the sake of simplicity, it is assumed here that the remanufacturer would have sorted the end-of-life vehicles on the basis of its model, age, and other factors.

In the modified process, the decision-maker would observe the lifecycle data collected throughout the clutch's lifecycle, and depending on the observed data decide whether the expected quality of the clutch is high enough for testing to be economically viable (as opposed to a decision based on visual inspection).

In the next section, we shall use a probabilistic modelling approach to define this decision process.

4 Modelling clutch recovery decisions

The key elements of the product recovery decision model are (i) modeling uncertainty in clutch quality, (ii) modeling the relationship between lifecycle data parameters and clutch quality, (iii) modeling recovery decisions based on available information. These shall be discussed in subsequent sections.

4.1 Modelling uncertainty in clutch quality

Uncertainty in the quality of returned clutches can be modeling by a probability distribution over the possible states of the clutch. Here, CRF classifies the returned clutches simply into two classes that directly relates to the recovery options, viz., reusable and faulty. Hence the set of possible states of the clutch, H, is given by:

[1] The exact data on this table is masked due to confidentiality reasons. However, it should provide the reader with the order of magnitude of the figures.

$$H = \{h_1, h_2\} = \{reusable,\ faulty\}$$

From past experience, it was estimated that 40% of the returned clutches are reusable. We take this estimation as the basis for assigning the prior probability distribution over the possible states of the clutch. Hence the prior probability distribution is:

$$p(H) = \langle p(h_1), p(h_2) \rangle = \langle p(reusable), p(faulty) \rangle = \langle 0.4, 0.6 \rangle$$

4.2 Modeling the relationship between lifecycle data parameters and clutch quality

The relationship between lifecycle data parameters and clutch quality can be modeled using conditional probability distributions that link each piece of product information to the possible states of the product.

For the first scenario, we have the outcome of the visual inspection. There are two possible outcomes of visual inspection: the recoverer either finds the clutch in an acceptable condition in which case he passes it, or in an unacceptable condition, in which case he fails it. Hence, the set of possible outcomes of visual inspection is given by:

$$E_v = \{e_v^1, e_v^2\} = \{pass,\ fail\}$$

It was estimated that the visual inspection is correct approximately 70% of the time. This yields a conditional probability distribution as follows:

$$p(e_v^1 \mid h_1) = 0.7 \qquad p(e_v^1 \mid h_2) = 0.3$$

$$p(e_v^2 \mid h_1) = 0.3 \qquad p(e_v^2 \mid h_2) = 0.7$$

For the second scenario, we have to model the relationship between the three parameters monitored and collected during the lifecycle of the clutch. We first classify each of the lifecycle parameters into three discrete classes as shown in Table 2.

Table 2 Classification of evidence values

Evidence variable	*Parameter*	*Evidence value*	*Range*
E_{nu}	Number of clutch usages	e_{nu}^1	E_{nu} < X00,000
		e_{nu}^2	X00,000 ≤ E_{nu} < X000,000
		e_{nu}^3	E_{nu} > X000,000
E_{tu}	Clutch usage	e_{tu}^1	E_{tu} < X00
		e_{tu}^2	X00 ≤ E_{tu} < X000
		e_{tu}^3	E_{tu} > X000
E_{ns}	Number of vehicle starts	e_{ns}^1	E_{ns} < X0,000
		e_{ns}^2	X0,000 ≤ E_{ns} < X00,000
		e_{ns}^3	E_{ns} > X00,000

The conditional likelihood distributions for these lifecycle parameters were estimated as follows:

$$p\left(e_{ns}^{1} \mid h_{1}\right) = 0.8 \quad p\left(e_{ns}^{1} \mid h_{2}\right) = 0.1 \quad p\left(e_{tu}^{1} \mid h_{1}\right) = 0.8 \quad p\left(e_{tu}^{1} \mid h_{2}\right) = 0.2 \quad \left(e_{nu}^{1} \mid h_{1}\right) = 0.99 \quad p\left(e_{nu}^{1} \mid h_{2}\right) = 0.19$$

$$p\left(e_{ns}^{2} \mid h_{1}\right) = 0.2 \quad p\left(e_{ns}^{2} \mid h_{2}\right) = 0.2 \quad p\left(e_{tu}^{2} \mid h_{1}\right) = 0.2 \quad p\left(e_{tu}^{2} \mid h_{2}\right) = 0.2 \quad \left(e_{nu}^{2} \mid h_{1}\right) = 0.01 \quad p\left(e_{nu}^{2} \mid h_{2}\right) = 0.01$$

$$p\left(e_{ns}^{3} \mid h_{1}\right) = 0 \quad p\left(e_{ns}^{3} \mid h_{2}\right) = 0.7 \quad p\left(e_{tu}^{3} \mid h_{1}\right) = 0 \quad p\left(e_{tu}^{3} \mid h_{2}\right) = 0.6 \quad \left(e_{nu}^{3} \mid h_{1}\right) = 0 \quad p\left(e_{nu}^{3} \mid h_{2}\right) = 0.8$$

It should be noted here that the above values for conditional likelihoods are approximations. In practice, these values need to be obtained by analysing data collected over sufficiently large number of tests on the same type of clutch.

Using these conditional probability distributions, we can use Bayes Theorem (Bayes, 1763; Dobbs, 1991) to calculate the probability of the clutch being reusable once the values of these lifecycle parameters are known.

4.3 Modeling recovery decisions based on available information

As shown in Figure 1 Existing process for ELV component recovery

, preceding the recovery option decision, the recoverer has to decide whether to test the clutch before choosing the recovery option. This decision is represented by the set:

$$T = \{t_1, t_2\} = \{test, no\,test\}$$

There are two possible outcomes for the test: the test can show that the clutch is reusable, in which case the clutch passes the test; or the clutch can fail the test if it is seen that it is faulty. Hence, the set of possible outcomes of the test is given by:

$$E_t = \{e_t^1, e_t^2\} = \{pass, fail\}$$

Here, it is assumed that the test provides complete and accurate information regarding the quality of the clutch.

As mentioned before, there are two possible actions that the recoverer can take in the case of a returned clutch, which is either to reuse it, or to leave it on the car and recycle (shred) it. Hence, the set of feasible recovery options is given by:

$$D = \{d_1, d_2\} = \{reuse, recycle\}$$

In a decision-problem such as this where decisions are made under uncertainty, choosing any of the decision options available to the decision-maker will result in a particular outcome depending on the state of the system. The decision-maker's preference between the outcomes of choosing each decision option for different states of the system can be captured by a utility function which assigns a single number to express the desirability of the outcome.

According to CRF, there is no substantial benefit of recycling the clutch considered in this study. Hence, the utility of recycling this clutch is zero regardless of its state. The economic benefit of reusing a good clutch is calculated as the difference between the price of a new clutch, say €250, and the price of a reused clutch, say half the price of the new one. On the other hand, if a faulty clutch is reused, CRF estimates a loss of the order of several hundreds of euros (say €500) due to the cost incurred in field replacement, possible customer dissatisfaction etc. Therefore, in this example, the utility function is given by:

$$\begin{pmatrix} u(reusable, reuse) & u(reusable, recycle) \\ u(faulty, reuse) & u(faulty, recycle) \end{pmatrix} = \begin{pmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{pmatrix} = \begin{pmatrix} 130 & 0 \\ -500 & 0 \end{pmatrix}$$

Further, the cost of testing a returned clutch consists of two components: (i) dismantling cost, denoted by C_D and (ii) testing cost, denoted by C_T. Note that the cost for dismantling the clutch will still be incurred when the clutch is not tested, if it is decided that the clutch will be reused. As an example, let us use the following values:

$$C_D = €30 \text{ and } C_T = €40$$

According to the principle of maximum expected utility (von Neumann and Morgenstern, 1944), a rational decision-maker should take actions that maximise the expected utility. For this example, we can formally state that the best decisions for testing t^* and recovery option d^* given the information at the pre-sorting point E_{pr} (this is the visual inspection result in the first scenario, and the lifecycle information in the second) and test result E_t (if the clutch was tested) are as follows:

$$t^* = \begin{cases} t_1 & \text{if} \quad \left(u_{11} p\left(h_1 \mid e_{pr}^l\right) + u_{22} p\left(h_2 \mid e_{pr}^l\right) - C_D - C_T\right) > \left(\max \begin{cases} u_{11} p\left(h_1 \mid e_{pr}^l\right) + u_{21} p\left(h_2 \mid e_{pr}^l\right) - C_D; \\ u_{12} p\left(h_1 \mid e_{pr}^l\right) + u_{22} p\left(h_2 \mid e_{pr}^l\right) \end{cases} \right) \\ t_2 & \text{otherwise} \end{cases}$$

$$d^* = \begin{cases} d_1 & \text{if} \quad \begin{cases} t^* = t_1 \quad \text{and} \quad E_t = e_t^1, \quad \text{or} \\ t^* = t_2 \quad \text{and} \quad \left(u_{11} p\left(h_1 \mid e_{pr}^l\right) + u_{21} p\left(h_2 \mid e_{pr}^l\right) - C_D\right) > \left(u_{12} p\left(h_1 \mid e_{pr}^l\right) + u_{22} p\left(h_2 \mid e_{pr}^l\right)\right) \end{cases} \\ d_2 & \text{otherwise} \end{cases}$$

Having discussed the recovery decision model, we shall, in the next section discuss the results of a simulation analysis whereby the decision model described in this section was implemented using a simulation model.

5 Simulation Analysis of the clutch recovery decision process

In this section, we examine the results of implementing the product recovery decision strategy described in the previous section.

We simulate the recovery process using Arena, which is a commonly used discrete event simulation software. In the next section, we describe the simulation model. Further in section 5.1.2, we present the results of the simulation and comment on the results.

5.1 Simulation model

In this section, we shall describe the design of the simulation model. Two separate models were built to simulate the two scenarios presented in the previous section.

To begin, clutches are "created" in the simulation model and are assigned to one of the two possible states according to the prior probability distribution $p\left(h_1\right)$. The variable that holds the recoverer's belief regarding the quality of the clutch is updated to the prior probability. This variable is updated at various points where additional information regarding the clutch is obtained. Next, the information that is available before the testing decision is made (i.e., visual inspection outcome or lifecycle information) is generated. This is done by assigning the outcome of the parameter on the basis of the conditional likelihood distribution of those parameters. The test decision is now made on the basis of the decision strategy presented in the previous section. If it is decided that the clutch would be tested, the testing cost is deducted from the variable that represents the total utility of the product recovery process. The utility variable is updated every time a decision that affects the total utility of the process is made. Finally, depending on the outcome of the test result (which is again generated according to the conditional likelihood distribution), the recovery option that maximises the expected utility is chosen.

In the next section, we shall present the results of the simulation study.

5.2 Analysis of simulation results

We simulated the decision process as outlined in the previous section for 500 clutches. The simulation was replicated 50 times to ensure statistical validity of results. It was found that the actual utility of the product recovery process where decisions are made on the basis of visual inspection is **€2134.20**, and where decisions are made on the basis of lifecycle information is **€16991.60**. Evidently, there is a consistent substantial increase in utility that is obtained by improving the quality of information that is available for decision-making.

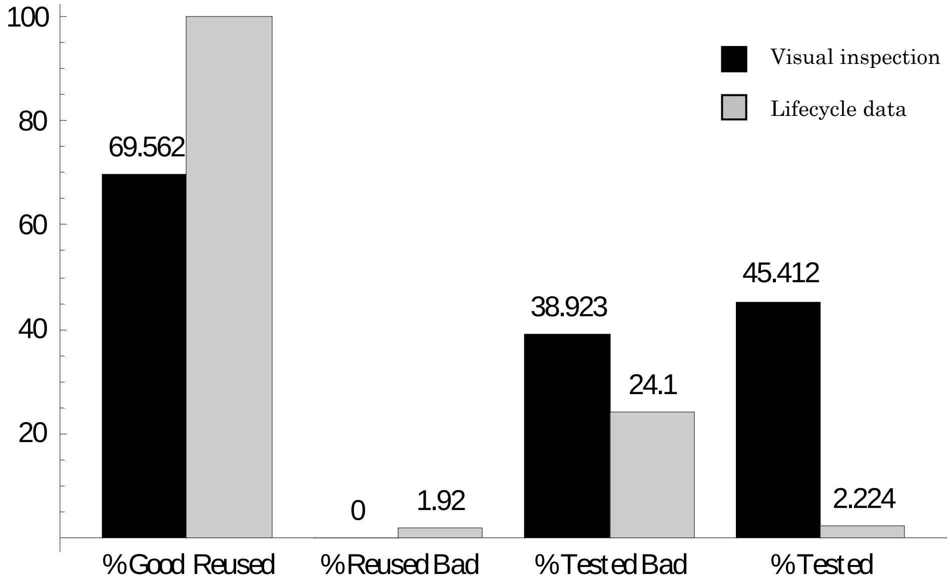
We shall now examine the reasons for this increase in utility by comparing key performance indicators of the decision processes under the two scenarios. Figure 2 summarises the performance of the two scenarios against key performance indicators when the decision is made for 500 clutches.

From **Figure 2**, we can clearly infer the following about the effect of improving the availability and quality of product information available to the recoverer:

1. **Increase in good clutches being reused:** The availability of lifecycle information before testing has resulted in an increase in the fraction of good clutches being reused. In fact, we can see from **Figure 2** that when the decision is made on the basis of visual inspection, only below 70% of the good clutches are reused. However, when lifecycle information is made available, all the good clutches end up being reused.

2. **Decrease in bad clutches being tested:** When the testing decision is made on the basis of visual inspection, we can see that nearly 40% of the clutches that are tested turn out to be faulty. This represents a great drain in the utility of the decision process. However, when the information available for making the testing decision is improved, we can see that this drops to nearly a fourth of the tested clutches. This is due to the fact that improving the information quality lead to rejection of most of the faulty clutches without the need for testing.

Figure 2 Comparison of key performance indicators of the simulation results for 500 clutches



3. **Decrease in the total percentage of clutches being tested:** In addition to the decrease in the fraction of tested clutches being faulty, improving the information available to the recoverer also results in a drastic decrease in the total fraction of clutches being tested. As opposed to around 45% of clutches undergoing testing when the decision is made on the basis of visual inspection, only around 2% of the clutches are tested when lifecycle information is obtained. This results in a huge increase in the utility of the decision process as a majority of clutches are not tested thereby eliminating testing costs. The fraction of clutches that are tested can be further reduced by decreasing the penalty associated with reusing a faulty clutch. This would cause the equilibrium probability to decrease, thereby decreasing the range in which testing the clutch would provide any benefit. However doing so would have an impact in the number of faulty clutches being reused, which we shall discuss in the next point.

4. **Increase in the percentage of reused clutches that are faulty:** As we can infer from **Figure 2**, obtaining more information associated with the clutch could lead to an increase in the reuse of faulty clutches. This is due to the fact that in the second scenario, the information available at pre-sorting does not lead to the recoverer reusing any clutch without testing. Due to our implicit assumption that the test provides perfect information regarding the state of the clutch, in the second scenario, we do not reuse any faulty clutches. The increase in faulty clutches being reused can be attributed to the impact of 'misleading information', which can be eliminated either by improving the accuracy and completeness of information available at pre-sorting; or by increasing the penalty associated with reusing a faulty clutch.

6 Conclusions

In this paper, we illustrated the impact of improving the quality of information available to the product recoverer on the effectiveness of product recovery decisions using a case example. We used a probabilistic methodology to model the product recovery decision process for an automobile clutch, and used the model to analyse the effectiveness of the recovery process under two scenarios which differed in terms of the information available to make the decisions. Using simulation analysis, we examined the results of implementing the decision strategies in the recovery process of clutches. The simulation analysis, which was built on the basis of the decision model, showed that improving the quality of information can result in an increase in the expected utility of product recovery decisions.

The simulation analysis also showed that increasing the amount of information available could lead to an increase in the reuse of faulty products, due to potentially misleading information. However, this depends on the penalty associated with reusing faulty products (€500 in this case), and by increasing this penalty, this can be completely eliminated.

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Tracking and tracing product lifecycle data in a closed-loop PLM

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Abstract: The efficient tracking and tracing method for product lifecycle data is essential for avoiding any delays and errors affecting accuracy and completeness of enterprise applications, especially in the *closed-loop PLM* where several partners and organizations are involved. To this end, we develop an overall framework for tracking and tracing product lifecycle data in the *closed-loop PLM*. It contains an RDF schema to manage huge amount of event data of product embedded information devices (PEIDs), and a processing mechanism to transform the huge data into meaningful information. Based on them, simple tracking and tracing examples are presented with RDF query language. To show the effectiveness of the proposed approach, a simple case study is introduced.

Keywords: Tracking, Tracing, Product lifecycle data, Resource description framework (RDF)

1 Introduction

The advent of emerging product identification technologies such as radio frequency identification (RFID), various kinds of sensor, and AUTO-ID make us easily gather product lifecycle data (e.g. identification, location, product status, etc.), which leads to the closed loops of product lifecycle data and information flows over the whole product lifecycle. We call this environment the *closed-loop product lifecycle management* (*closed-loop PLM*) in this study. Here, product lifecycle data indicates all data collected or processed or reorganized by lifecycle actors (e.g. maintenance engineers) and product embedded information devices (called *PEID*, e.g. RFID tags, sensors, and on-board computers) during the whole product lifecycle. During product lifecycle, the lifecycle data will be gathered periodically or based on events triggering at various operational sources of different lifecycle phases by miscellaneous devices, which leads to enormous data generations. In addition to this, as enterprises become increasingly global and networked (virtual enterprise), product lifecycle data tends to become spread on computer systems of multiple companies. Thus, the amount of product lifecycle data has been grown substantially and needs to be managed. The lifecycle data are usually related with each other in a direct or indirect way. It results in the complex genealogy of product lifecycle data. In this environment, a major challenge is to develop an efficient tracking and tracing approach for complex product lifecycle data in order to support several business applications over product lifecycle phases. The efficient tracking and tracing method for product lifecycle data enables us to avoid any delays and errors affecting accuracy and completeness of enterprise applications, especially in the *closed-loop PLM* where several partners and organizations are involved.

There have been some research works on tracking and tracing for manufacturing or supply chains. For example, van Dorp (2002) overviewed the state-of-the-art on tracking and tracing, and also presented a structure for tracking and tracing in the supply chain, which consisted of three supply-chain layers: item coding (the physical layer), information architecture (the information layer); and planning and control (the control layer). Jansen-Vullers *et al*. (2003) proposed a reference model for information management to support traceability. They applied gozinto graph modeling for the traceability of goods flow in manufacture. Moreover, Kärkkäinen *et al*. (2004) analyzed and addressed the shortcomings of traditional tracking systems in short-term multi-company networks, and presented a new approach for solving the difficulties of tracking in multi-company supply networks. Furthermore, Terzi *et al*. (2005) proposed a meta-model for the traceability of products over the lifecycle, which is a basis on the holonic approach for fostering interoperability along diverse enterprise applications. Wang and Liu (2005) proposed an expressive temporal-based data modeling of RFID data, using a Dynamic Relationship ER model (DRER). With DRER, they also proposed methods for RFID data tracking and monitoring. In addition, recently, Kelepouris *et al*. (2006) analyzed how RFID technology would improve tracking and tracing processes. They demonstrated the business benefits that companies would be able to gain through improved track and trace performance. On the other hand, considerable attention has been paid to the information modeling issues of product lifecycle data. For example, Ferscha *et al*. (2002) presented a generic context information representation framework for the person-thing-place world view, and developed context gathering mechanisms based on time and event triggered context sensors. As an abstract context representation mechanism the Resource Description Framework (RDF) is adopted. They discussed the basic RDF definition as well as an appropriate RDF Schema (RDFS) as a means to provide a vocabulary and structures for expressing the context information gathered from different sensors. Furthermore, in our previous work (Jun *et al*. 2005), we classified product lifecycle data and developed the RDF model for product lifecycle meta data.

Although there have been some research works, however, they have some limitations in the viewpoint of tracking and tracing. Until now very little attention has been paid to modeling product lifecycle information for efficient tracking and tracing. There is the lack of concrete tracking and tracing mechanism. Although government and business interest in tracking and tracing have grown enormously over the last decade, a clear and coherent overview of the topic is still lacking and is not found in (logistic) literature (van Dorp 2002). The problem of storing, querying, and visualizing large amounts of product lifecycle data efficiently has not received much attention. Current RFID data management systems only store and manage events, and state information is implicit and has to be derived. This makes it very complicated to search state information (Wang and Liu 2005). Hence, a well defined framework for tracking and tracing product lifecycle data complying with the characteristics of the *closed-loop PLM* is required. It should be compatible with data gathering mechanism in the *closed-loop PLM*. Furthermore, when considering huge amount of product lifecycle data, efficient data processing mechanism should be developed.

To this end, in this study, we propose an overall framework for tracking and tracing product lifecycle data in an efficient way. The objective of this study is threefold: to clarify the concept of tracking and tracing, and to identify the use of resource description framework (RDF) model for tracking and tracing; to develop a framework transforming PEID event data into meaningful data for tracking and tracing in the *closed-loop PLM*; and to provide a method to facilitate tracking and tracing in the *closed-loop PLM*.

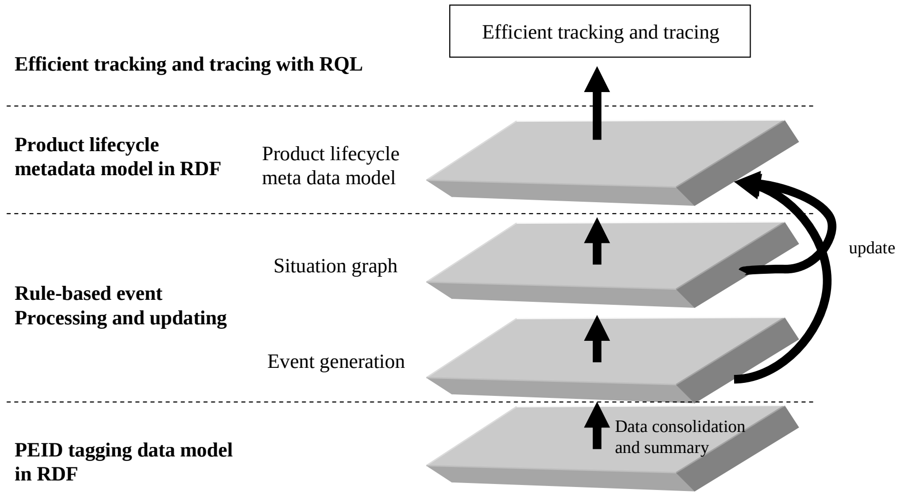
The rest of this study is organized as follows: First, section 2 deals with an overall framework for tracking and tracing the product lifecycle data in the *closed-loop PLM*. In section 3, to show the effectiveness of our approach, a simple case example is introduced.

2 RDF based approach for tracking and tracing

PEID tagging data can be represented in a simple way. Unless we are using sophisticated and expensive tags, all we get is an identification number for the item, and a location (Palmer 2005). Even if sensor data are combined into PEID, the PEID tagging data can be simply represented with 3-tuples. The following is examples of PEID tagging data which has the type of 3-tuples: <*tag_ID321*, *is_read_at*, *20070108.132406*> < *reader_ID332*, *read_at*, *20070108.132406*>. It means that the 'ID332' tag reader read a PEID (tag ID321) at the '20070108.132406' time point. Each PEID reader and PEID have several properties such as identity, location, type, and sensoring parameters, which can be represented with RDF in a simple manner. RDF data can easily describe the relations among resources. RDF incorporates the link structure between URIs. In RDF, a computer program obtains target information by tracing the link structures (Imai and Yukita 2003). In the *closed-loop PLM*, PEID tagging data are generated from various places in a distributed manner. Distributed data is difficult to control, because you have to rely on others to provide it (Miller 2002). Furthermore, in the *closed-loop PLM*, product lifecycle data change over time. Sometimes, we do not know what we might want to combine it with next. In those cases, using RDF is useful. In RDF, we can support the consistency of data semantics with unique IDs of resources, which is suitable for distributed data management. RDF is also flexible so that it is easy to extend the RDF model without destroying it. For these reasons, we use RDF in this study.

Although PEID tagging data can be simply represented with RDF, the number of data generated during lifecycle operations is enormous. For example, EPCglobal's next generation (Gen2) standard of RFID readers specifies read rates of 1800 RFID tags a second (Palmer 2005). It leads to the generation of enormous PEID data in the *closed-loop PLM* where multiple readers exist. Each data just gives only simple information and is not meaningful data as long as each one is not related with others. It means that we should look into the series of simple PEID tagging data for finding meaningful information. It requires an elaborate method to analyze, consolidate, and summarize enormous of PEID tagging data, and infer new events for identifying and providing meaningful data and information. To this end, we should deal with the task of processing multiple streams of simple events with the goal of identifying meaningful events within gathered PEID tagging data and inferring events by analyzing other events. Based on this task, meaningful data should be updated by a suitable updating mechanism.

Figure 1 Overall framework



The updating mechanism can delete PEID data that are superfluous, supplement or enrich raw data with required context and save compressed data into RDF format. It can help track and trace complex data in an efficient way. For this purpose, we propose a framework as shown in Figure 1.

Notations

α PEID

α_x Property x of PEID, $x \in \{\text{location, type, other required properties}\}$

β PEID Reader

β_x Property x of PEID reader, $x \in \{\text{location, type, other required properties}\}$

T Timestamps, $\{t_1, t_2, \ldots, t_T\}$

t_i Instance value of timestamp

The following procedure explains how to process enormous PEID tagging data for efficient tracking and tracing.

RDF based approach for efficient tracking and tracing

Step 1. PEID tagging data model in RDF

PEID tagging data can be modeled in RDF. RDF schema for PEID tagging data model is defined as follows:

Definition RDF schema for PEID tagging data model

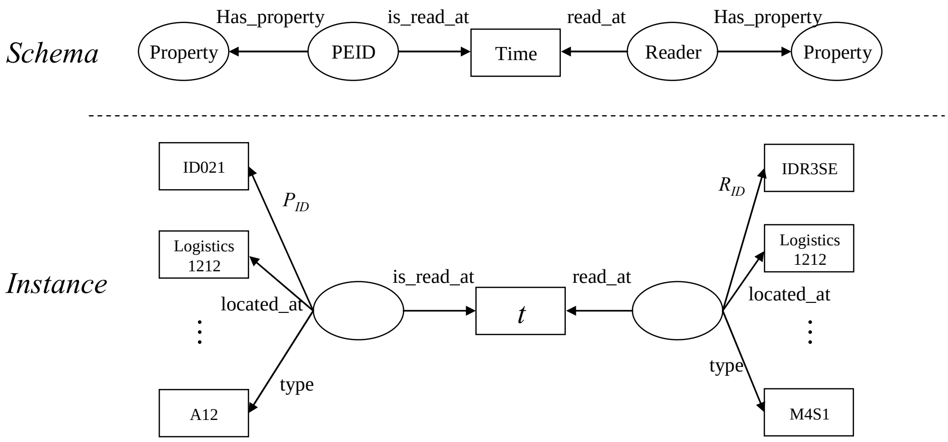
The RDF schema for PEID tagging data model is defined as the set of a directed labeled graph $G_T = (R, \Lambda)$ where R is a set of resources, $\{R_1, R_2, \ldots, R_n\}$; Λ is a set of directed arcs, $\{a_1, a_2, \ldots, a_m\}$. Here, a_i represents a property and is labeled by its property name. R_i and a_i should satisfy the following rules:

(1) $R_i \in \{\alpha, \alpha_x, \beta, \beta_x, T\}$, $a_i = (i, j)$ with $i \in (\alpha$ or α_x or β or $\beta_x)$, $j \in (\alpha$ or T or $\beta)$, and $i \neq j$.

(2) If there is any $a_i = (i, j)$ such that ($i \in \alpha$ and $j \in T$) or ($i \in \beta$ and $j \in T$), then there should be $a_i = (i, j)$ such that ($i \in \beta$ and $j \in T$) or ($i \in \alpha$ and $j \in T$).

Figure 2 shows the RDF schema and instance for PEID tagging data model. Whenever products embedding PEIDs pass over specific points where PEID readers are installed, PEID tagging data can be automatically gathered. In this study, we consider filtered data, i.e. the data without duplicated records due to multiple reading of a product at the same location.

Figure 2 RDF schema for PEID tagging data model



Step 2. Rule-based event processing and updating

The rule-based event processing and updating play a role to transform PEID tagging data into meaningful data. After analyzing gathered PEID tagging data, generate necessary meaningful information and store them into the RDF model for product lifecycle metadata which has been developed by Jun *et al*. (2005). To generate meaningful information, it is necessary to look into the concept of event and situation. An event indicates a piece of information which is generated whenever a meaningful change is detected in the PEID tagging data model. On the other hand, situation can be defined as the important event that should react as a result of relevant event chains. The situation graph can be used to explain when a situation occurs. Events and situations are different from application to application. We can generate events that are derived from continuous data sources by defining specific triggers, like threshold values, or query strings that match different events we are interested in (Ferscha *et al*. 2002). These can be represented with rules.

Definition An event (E) is a fact observable at a given time, which can be defined as a simple statement.

Definition A situation can be described as a directed acyclic graph $G(N, A, \theta)$ where N is a set of events, $N=\{E_1, E_2, \ldots, E_S\}$, A is a set of directed arcs, $\{a_i\}$, and θ is a set of relations, $\theta \in \{\text{AND,OR}\}$. Here, E_i is an event and a_i is a directed arc.

If the truths of all pre-events are presumed, then we can infer that the final event (*Es*), called *situation*, happens. Possible events can be enumerated in advance. Based on them, possible situations can also be designed. Event and situation occurrences can be identified by the following query. In this study, for identifying events and situations, and recording them into RDF model, we use *sesame* RDF query language (SeRQL). The SeRQL is a new RDF/RDFS query language that combines the best features of other languages (RQL, RDQL, N-Triples, N3). In SeRQL, we can generate new information and add them to already existing RDF model by making new RDF statements with 'construct' query.

<Rule based event and situation identification and update>

Events and situations can be identified by the following RDF query (SeRQL). These events and situations can be updated directly into product lifecycle metadata by using construct query.

SELECT *
FROM $\{\beta\}$ *read_at* $\{t1\}$; *has_properties* $\{\beta_x\}$,
$\{\alpha\}$ *is_read_at* $\{t2\}$; *has_properties* $\{\alpha_x\}$
WHERE ($t1 = t2$) AND (the predefined rules are satisfied)
CONSTRUCT
{*Product, Process, Resource, Agent*} *has_operation* {*t1*};
has_property $\{\alpha\}$,
{*Product, Process, Resource, Agent* } *has* {*E*} *has* {*event_code*}

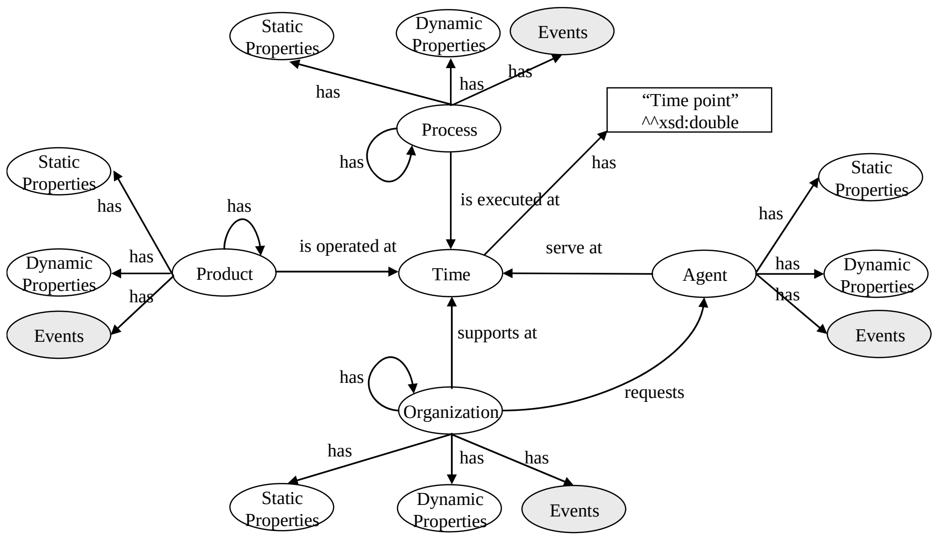
Step 3. Product lifecycle metadata model in RDF

Finding events and situations through analyzing PEID tagging data can provide meaningful information. However, to facilitate the use of information, the information should be stored as certain forms at somewhere. In this study, the generated events and situations are updated into an RDF model for product lifecycle meta data that we have proposed in our previous work (Jun *et al*. 2005). We have established an RDF schema for product lifecycle meta data based on T-PPRA concept, as shown in Figure 3. This RDF schema contains basic relations among product, process, resource, and agent, which is based on a time event. During product lifecycle, all information can be modeled with the concept of T-PPRA.

Step 4. Efficient tracking and tracing with RQL

In general, there is a difference between tracking and tracing: while tracking focuses on data or information at a certain time, tracing deals with the data or information at previous times. In the *closed-loop PLM*, tracking means finding some properties of lifecycle objects (e.g. products, processes, and resources) at a certain point: location, serial number, date of manufacture, date of expiration, and so on. Tracing is used to detect patterns or anomalies in business applications by analyzing the history of lifecycle

Figure 3 RDF schema for product lifecycle meta data



objects. There are several items for tracing: e.g. location, status, ownership, and containment which indicates a hierarchical relationship among objects. For tracking and tracing them, in this study, we apply RQL. From the RDF modeling viewpoint, tracking can be defined as finding a value in a simple chain of RDF triple. On the contrary, tracing can be defined as finding a value through navigating multiple chains of RDF triples. With RQL, we can track and trace RDF data in an efficient manner.

3 Case study

In this study, to evaluate the proposed approach, we carry out a case study based on the *Sesame* framework. The example of the case study is a part of the maintenance operation of *F* automotive company in Italy. The company is now implementing predictive maintenance by analyzing the product status thorough attaching PEIDs into parts or components of automotives. Whenever automotives visit to authorized garages, the status of parts or components will be automatically gathered.

Step 1. PEID tagging data model in RDF

Examples of PEID tagging data for this case study are as follows:

<tagID231, *is_read_at*, 20070120.173221>
<tagID231, *has_type*, product>
<battery_ID112, *is_read_at*, 20070120.173221>
...
<tagID231, *is_read_at*, 20070121.091241 >
<tagID231, *has_type*, product>
<battery_ID438, *is_read_at*, 20070121.091241>
<battery_ID438, *has_battery_status*, 100%>
<tagID231, *has_battery*, battery_ID112>

Step 2. Rule-based event processing and updating

In this example, we can list up the following events.

E_1 A car arrives at a garage.

E_2 Battery status of car is checked and the result is bad.

E_3 Engineer checks the battery of the car and the result is bad.

E_S Replace current battery with a new one.

<E_S generation>

SELECT α, β, *t1*

FROM {α} *is_read_at* {*t1*}; *has_type* {*type*}; *has_battery* {*b_ID1*},
{*b_ID2*} *is_read_at* {*t1*}, {β} *read_at* {*t2*},

WHERE (*t1* = *t2*) AND (*b_ID1* != *b_ID2*) AND (*type* = 'product')

CONSTRUCT

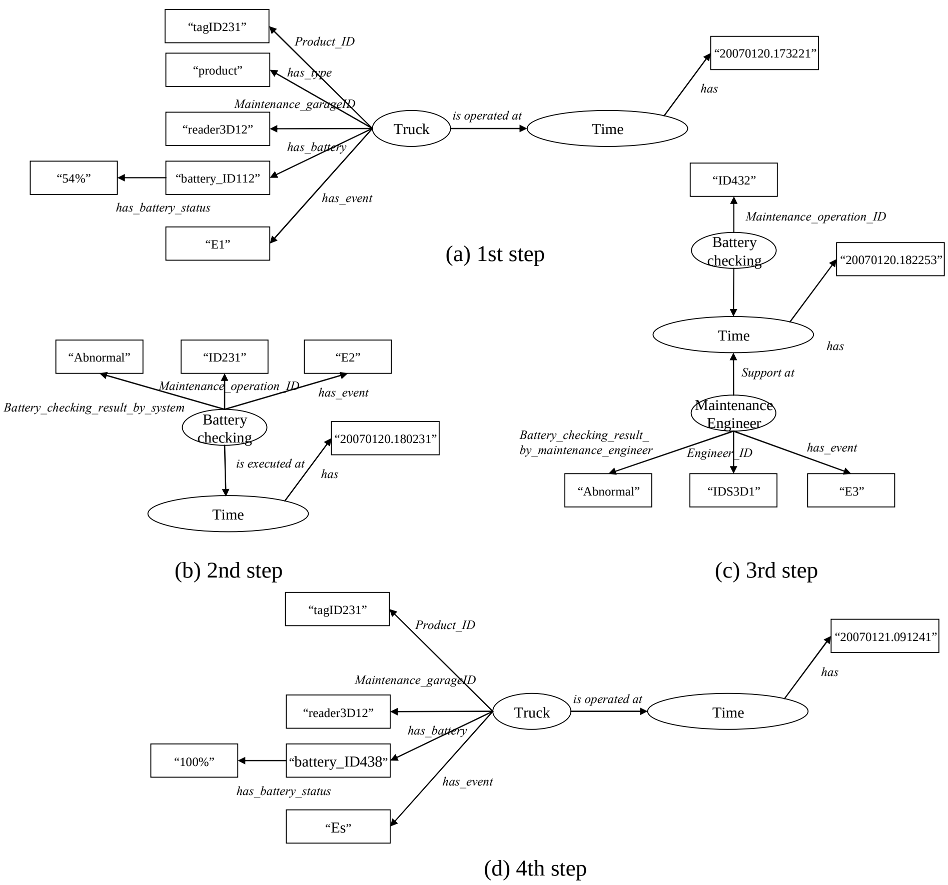
{*P*} *is_operated_at* {*t1*}; *has_ID* {α}; *has_maintenance_garage_ID* {β};
has_battery {b_ID2}; *has_event* {E_S},

{b_ID2} *has_battery_status* {100}

Step 3. Product lifecycle metadata model in RDF

Figure 4 shows an example of RDF model.

Figure 4 Example of RDF model



Step 4. Efficient tracking and tracing with RQL

Tracking and tracing for product lifecycle data can be done with SeRQL as follows:

(1) Tracking: Tracking is to find some objects at a certain time point. SeRQL and our RDF schema enable us to do it in an easy way. The following is a simple query for tracking expressed in SeRQL.

Example 1. Finding the battery status of the car ID "tagID231" at time 20070121.091241

SELECT *b_status*
FROM {*P*} *is_operated_at* {*T*}; *has* {*tagID231*}; *has* {*b_ID*} *has* {*b_status*}
WHERE *T* LIKE *"*20070121.091241*"*

(2) Tracing: Tracing means finding requested information with given conditions by navigating RDF models. By using path expressions of SeRQL, we can trace not only a simple link that has length 1 or 2 but also a more complex link that has an arbitrary length.

Example 2. Find the replacement time of the battery that is a component of truck ID 'tagID231' during the period (20060901.000000~20070122.000000)

SELECT *T*
FROM {*P*} *is_operated_at* {*T*}; has {*b_ID*} has {*b_status*},
WHERE *P* **LIKE** "*tagID231*" AND *b_status* LIKE "*100*" AND (*T* > *20060901.000000*) AND (*T* < *20070122.000000*)

4 Conclusion

In this study, we have looked into a modeling framework for tracking and tracing product lifecycle data in the *closed-loop PLM*. We have reviewed the concept of tracking and tracing, and proposed an overall framework as to how to transfer PEID tagging data into meaningful information for efficient tracking and tracing. As further study, one can develop elaborate query algorithms for tracking and tracing. Furthermore, one may deal with how to process complex PEID event data in an efficient manner. Although the development of more exhaustive and detailed method should be followed, the proposed framework can be a reference model to design and manage raw data for efficient tracking and tracing in the sensor network applications where huge amount of sensing data are generated, like *closed-loop PLM*.

Acknowledgment

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Assessment of item-specific information management approaches in the area of heavy load vehicles

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Abstract: Product lifecycle management (PLM) is often considered an inter-organisational issue, where only organisations produce product information. This view fails to take into account the products themselves as information providers, which occurs mainly during the product's usage phase. The required item-specific information management infrastructure may be a challenge for traditional information systems. In this paper, we study how different approaches of centralized versus distributed information management are suitable for item-specific information management. A real-life PLM application is used for deriving generic assessment criteria. These criteria are then used for assessing the different approaches against the specific application. The results of the paper are the following: 1) a description of different approaches for implementing item-specific information management and 2) a set of assessment criteria for evaluating the approaches and 3) an example assessment for a specific PLM application.

Keyword: Product Lifecycle Management, Instance Specific Information Management, Middleware, Benefit Analysis, Remanufacturing

1 Introduction

Product Lifecycle Management (PLM) aims to improve processes along the complete lifecycle of a product. A product lifecycle is characterised by the following three phases: Beginning-of-Life (BOL), including Design and Production, Middle-of-Life (MOL), including Use, and Services and End-of-Life (EOL), including disassembly, reuse, refurbishing and finally disposal.

Product information is usually created by several different organisations during the product lifecycle. Already product design, manufacturing and marketing are often performed by different organisations but in particular the user of the product (an individual or an organisation) is usually different from any of the other organisations. In many cases, the only contact between the user of the product and the other product stakeholders is when the product is purchased or throughout service events. This organisational and spatial distribution of the product stakeholders is particularly challenging for managing product information. This paper focuses on recent PLM work dedicated to improve MOL and EOL processes. It presents various approaches for item-specific information management (ISIM) and provides an assessment of these approaches under the particular aspect of the spatial distribution of product information (centralized vs. distributed vs. peer to peer) on the basis of a real world application scenario.

2 Caterpillar company and products

Caterpillar (CAT) is famous as a manufacturer of heavy construction and mining equipment. One of CAT's core businesses is also the remanufacturing of CAT engine and engine components. The global remanufacturing industry is a $100 billion business today with an estimated compounded annual growth rate of 5-7%. Amongst the world's largest engine maker, CAT is also one of the world's largest re-manufacturers, processing more than 2 million units annually and recycling more than 100 million pounds of used products each year in its 14 remanufacturing facilities worldwide. CAT Remanufacturing strengths are to maximize the product's lifecycle value of CAT heavy machinery by making rebuild machines as well as Reman engines and components and to provide a portfolio of remanufacturing services to original equipment manufacturers (OEMs).

The overall objectives of applying ISIM to the area remanufacturing of engine and components can be considered as twofold. For supply chain process improvements throughout multiple lifecycles of engine and engine components, the objective is to provide information on:

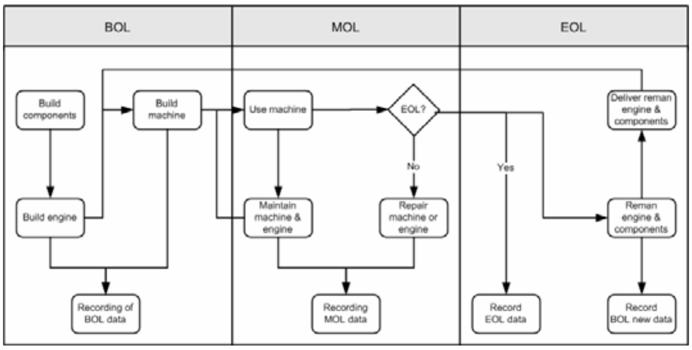
- Components of an EOL engine that can be remanufactured
- Tracking of engine component along the remanufacturing process
- Remanufacturing history of components

For increasing reusability of engine components the objective is to provide information on:

- engine or engine component (built date, fabrication plant, type of machine equipped with the engine…)
- use of the engine (number of total running hours)
- history of service operations incl. exchange of components

at EOL of the engine or one of its components. The simplified overall PLM processes related to the remanufacturing scenario are described in the following graphic.

Figure 1 PLM processes of engine and engine components



Lifecycle of the main engine components can be described as follows:

1. BOL covers the assembly of the individual components, the assembling to an engine and the integration of the engine to the machine.
2. During the MOL of the engine, services as well as part exchange may occur.
3. At EOL of the engine, decisions are made on engine components re-use, re-manufacturability or disposal/scrapping according to their wear status of the component. When an engine component is salvaged, it is going to go through the remanufacturing processes for cleaning, repair if needed and assembly. The remanufactured component then starts a new BOL as a CAT "Reman" sub-assembly or as a CAT "Reman" engine.

The implementation of these processes in a real world scenario would lead to a PLM network with the following characteristics. Nodes of the ISIM network are about 350 to 500 partners which can be considered as at least small or medium enterprises. The considered companies are mainly directly related to the overall CAT organisation. It is expected that the minimum number of organisations to be involved are about

- 10 CAT engine design facilities,
- 10 CAT engine manufacturing facilities,
- 200 CAT dealers,
- 100 CAT Logistics services and
- 20 CAT distribution centres for component storage and
- 10 CAT remanufacturing facilities.

The individual amount of data to be handled in scenario depends on the particular type of event as well as the type of machine, engine or engine component. It is estimated that the amount of data to be transferred for each event ranges from 100 Byte up to 1 Kbytes. It is also expected that for a mature machine a complete set of EOL data is less than 2Kbytes. The overall amount of data to be handled by the ISIM depends than on the average sizes of the machine data sets and the amount of machines associated with the remanufacturing business. Machines to be considered for the MOL processes are about one million units and about 100.000 units for the EOL processes.

3 Item-specific information management and expected benefits

Design and manufacturing information about products is often created by many different organizations that need to be able to exchange information with each other. Various standards, notably the STEP standard has been used for such information exchange. The need for information exchange remains limited when the number of organizations and the number of product types remains limited. If the number of organizations involved increases and the products become more customized, both the amount of product information and the need for information exchange increase. When the usage phase of products is taken into consideration, every product item has at least some information that is specific to that product instance due to different conditions of use. The number of organizations involved also increases, including e.g. the product owner, maintenance organizations, spare-parts manufacturers, recyclers etc.

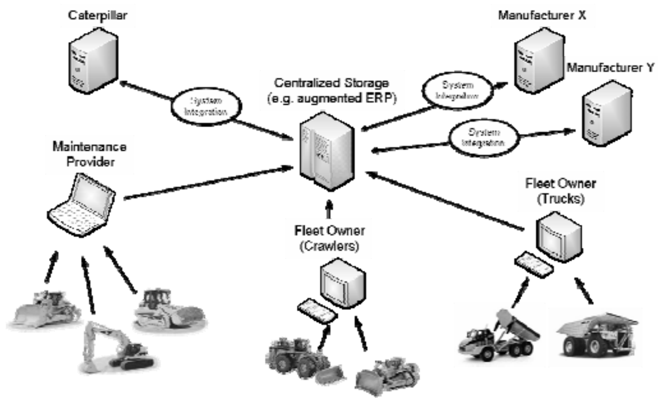
It is a great challenge for current information systems to handle both the increased amount of such item-specific information and make it feasible to perform the necessary information exchange. For instance, *enterprise resource planning* (ERP) systems are originally conceived for centralized, account-centric information storage and processing. The account-based approach is not conceived for and is not appropriate for storing item-specific information [Rönkkö, 2006], while the centralization allows for information exchange only through rigidly specified channels.

The *product-centric* approach has been proposed as an alternative to the account-centric approach for information management in supply chain management [Kärkkäinen et al., 2003]. The main idea in product-centric information management is that products (or shipments e.g. in tracking applications) would be associated with a virtual counterpart called the *product agent* [Främling et al., 2003] or *product avatar* [Hribernik et al., 2006]. The two notions represent essentially the same concept; in the rest of this paper we will use the product avatar notion. A product avatar consists of product-item-specific software and data that can be stored locally with the product itself or be located on one or more remote computers. The minimal information that has to be included with the product itself is a *globally unique product identifier* (*GUPI*) [Främling et al., 2006b] that contains sufficient information for retrieving the Internet address(es) where the remote part(s) of the avatar are located. In the sub-sections that follow, we will study how item-specific information can be performed in a centralized scenario, in a product-centric scenario with explicitly stored references to remote part(s) of the product avatar and in a product-centric scenario where the remote locations are implicitly handled by a peer-to-peer lookup mechanism.

3.1 Centralised information management

Figure 1 illustrates the extreme centralised information management, where all usage information about all products is collected into one single database for PLM data. In this setting, the entire system from the centralised storage “downwards” typically belongs to the same Extranet. Inter-organisational communication happens on backend-to-backend basis, as indicated by the “systems integration” arrows in the figure. The most efficient systems integration method is obtained if all partners use the same software product or at least compatible communication interfaces.

Figure 2 Usage information about products is collected in a hierarchical manner from the product individuals (and possibly from their sub-systems) towards a centralized storage from where it can be accessed by authorized organizations.



The benefit of this solution is high consistency of data ("a single version of the truth"), as there is only one designate place for storing all data. The users can also be sure that they get up-to-date information, as data replication among various databases is not necessary. Moreover, as all access rights and permissions can be maintained in a single location, the management of data security is simplified. From an organisational point of view, it still has to be decided who is eligible to grant or revoke access rights to the data related to the various lifecycle phases.

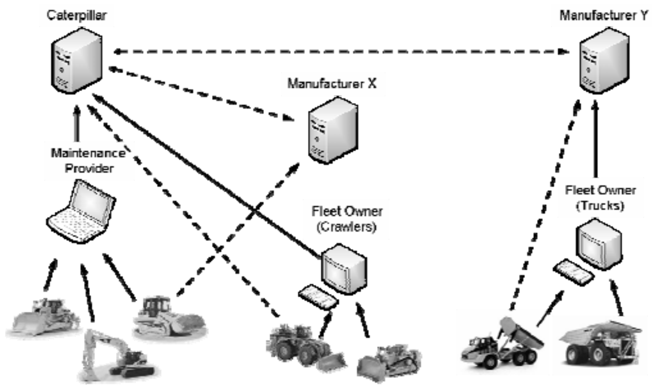
However, it seems evident that the extreme centralised information management solution illustrated in figure 1 is only realistic as long as the number of participating organisations is small. When the number of information sources in the lower part of the figure increases, the amount of collected information becomes overwhelming; the extreme case being that all usage information of all products would be collected to the same place. As, the number of participating organisations increases, the need for network configuration and systems integration also rapidly becomes too complex to handle efficiently. This is why any realistic item-level PLM information management solution must be at least partially distributed as explained in the next section.

3.2 Distributed information management with explicit references

In a distributed information management scheme, information about the same product item can be distributed over different organisations and computers as illustrated in figure 2. This means that the information can either be stored where it is created and accessed from there or transferred/copied to some other place. The product avatar is responsible of keeping track of the information. The product avatar's "access point(s)" are embedded with the product item itself and indicated using e.g. ID@URI references [Främling, 2002] or the combination proposed by EPCglobal of an Electronic Product Code (EPC) together with an Object Name Service (ONS) lookup mechanism for retrieving the network address of the access point(s). A comparison between these approaches can be found in [Främling et al., 2006b]. For keeping track of distributed item-specific information, the product avatar can explicitly store references e.g. using semantic relationships such as "part-of", "wants-location-updates" etc. as explained in [Främling et al., 2006a; Främling et al., 2007]. Such relationships can be created e.g. manually or automatically when a vehicle is assembled or at maintenance by reading a set of identifiers from RFID-tagged parts.

In distributed PLM information management, inter-organisational communication is an essential feature. If dependency on a single software product is to be avoided, communication standards are essential. Unfortunately it seems like comprehensive standards do not exist for the kind of item-specific information exchange addressed in this paper. One of the objectives of the EU 6th framework programme project *PROMISE* (www.promise-plm.org) is to initiate such standards. Meanwhile, the DIALOG open source software developed at Helsinki University of Technology since 2001 (http://dialog.hut.fi) provides a test platform for distributed item-specific information management. DIALOG is still mainly a research and piloting tool that was originally developed for shipment tracking and as a means of implementing the "Internet of Things" concept. The ID@URI and DIALOG concepts are also developed further in the EU 6th framework programme project *TraSer* (www.traser-project.eu). It is unknown to what extent commercial software exists that supports distributed item-specific information management. However, commercial software has developed for the peer-to-peer based extension of item-specific information management as described in the next sub-section.

Figure 3 Usage information can be communicated directly to the "correct" organization, e.g. the manufacturer of the product. Information can also be routed via other organizations (as indicated by dotted lines) that may process the information before sending it onwards, thereby decreasing the amount of data transmitted.



3.3 Peer-to-peer based information management

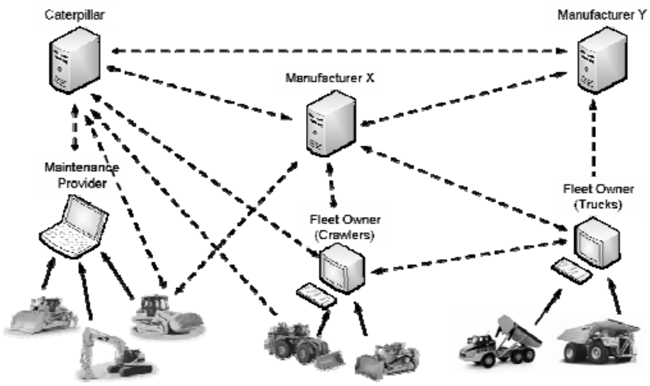
In peer-to-peer (P2P) based information management, information can be stored where it was created and fetched when needed or moved/copied where it is the most appropriate, in the same way as with the distributed information management scheme explained in the previous sub-section. The main difference is that the product avatar does not have a given number of access points indicated by URI. Instead the product identifier can be given as a key to **any** peer (i.e. node in the network) that then takes care of looking up and querying all nodes for the item-specific information that the requesting node is authorized to retrieve. This lookup mechanism makes the P2P approach fault-tolerant because the information lookup will not fail due to the failure of a single node; only specific information stored on the failing node fails to be retrieved. The lookup mechanism does not use the Domain Name Service (DNS).

The P2P concept is from the start conceived for inter-organizational communication. However, the same applies to P2P as to other distributed information management schemes: if dependency on a single software product is to be avoided, communication standards are essential. On the level of personal computing, some P2P applications that use their own communication protocol have been very successful, e.g. Skype, file-sharing applications. For inter-organisational communication, it is less likely that such breakthroughs can be achieved.

The Finnish company Trackway (www.trackway.eu) launched its P2P based software for item-specific information management in 2002. Despite the publication of the World Wide Article Information (WWAI) protocol (www.wwai.org) used by the software, it is still an open question how widely used it will become. In any case, Trackway offers an interesting implementation to study.

P2P software is often associated with spreading as much information as widely as possible (music, video, software etc.). In an inter-organisational setting, the P2P approach (or actually the distributed approach) provides better control to organisations over what information is given to whom than in a centralized approach where the information is stored on third-party servers. The WWAI protocol has an integrated security mechanism that uses X.509 certificates for authenticating nodes in the network, so only authorized and encrypted information is transmitted.

Figure 4 Usage information can be retrieved by using the unique product identifier as a key into the information network, that then gives access to the information (if authorized). Dotted lines indicate alternative communication routes.



To support the selection of an ISIM alternative for the described scenario a range of assessment methods is available providing both qualitative as well as quantitative results. Methods for the quantitative assessment are well known and accepted but rather used for analysis than for assessment purpose. Moreover, apparently quantitative methods are more attractive for decision makers especially in those cases where a comparison of alternatives shall be performed. This is mainly because in IT-system assessment and selection process it is of highly importance to apply rational thus comprehensible decision making methods not just to reduce the risks but also to justify related investments to other parties involved in the decision process.

Although related literature provides a considerable range of quantitative assessment methodologies supporting or enabling the selection process for IT-Systems there is a remarkable lack of information on approaches adapted for the assessment of concepts, technologies or systems supporting the Instance specific Information Management.

The Benefit Analyses (BA) is compared to the more prominent Cost Benefit analysis CBA a simplified method for the quantitative assessment of complex alternatives. Firstly, detailed monetary calculations on initial and ongoing cost versus expected return are contrary to the CBA not necessarily part of the BA method. Additionally the set of criteria is restricted in the BA approach to about 10 criteria. But although simplifying the assessment process drastically it provides depending on the accuracy of criteria definition and weighting comprehensible quantitative result [Zangemeister 1971].

Precondition for the application of the BA method is to define firstly so called knock-out (K.O.) criteria. Based on these criteria a selection of possible alternatives can be performed. K.O. criteria relevant for the given scenario are listed in the description of the ISIM-Network characteristic in chapter 2. The ISIM solutions presented in chapter 3 are consequently capable of enabling an ISIM-Network with the given characteristic.

The individual steps to perform the BA methods are as described in the following. Firstly it is required to define a list of criteria which should not depend on each other. Second step is the individual weighting of criteria. The overall sum of weights has to be 100% which means that the individual weights should be more than 0% and lesser than 100%. Next steps are to assess the individual criteria for each of the given alternatives, to calculate the weighted individual benefit and to sum up the benefits for each alternative.

The following describes the list of criteria as selected by the Caterpillar for the assessment process. Main criteria categories are the expected cost for setting up and running an ISIM system and the characteristics of this system. The category expected cost is covering cost for software licenses, hardware, set-up and maintenance of the overall system and transportation and data storage. It is important to note that it is currently expected that the Caterpillar takes over the complete cost related to the ISIM even those which are originated on the client sides. Second criteria category covers the characteristics of the alternatives in the area of data management, flexibility with respect to changes in the ISIM-network and effort in updating the system over the years to keep the system alive and compatible with the changed technical requirements.

4 Assessment and discussion

Considering the list of possible criteria, weighting and assessment it is important to understand that the assessment process described in this paper is highly end user specific, not just with respect to the very specific Caterpillar scenario but also with respect to the individual viewpoint of Caterpillar which is mainly resulting from Caterpillars role in this scenario. Anyhow, the application of the BA method for the selection process as well as at least some of the given criteria seem to be also useful for other end users with similar scenarios especially in the PLM sector. The assessment of the criteria as described above is depicted in the following table.

		centralized		decentralized		P2P	
Criteria	**w**	**A**	**A*w**	**B**	**B*w**	**C**	**C*w**
Costs	**30%**	**3,48**	***1,04***	**3,09**	***0,93***	**2,94**	***0,88***
License (ISIM, Operating system, tools)	10%	3,00	0,30	3,00	0,30	3,00	0,30
Hardware	15%	4,00	0,60	2,00	0,30	2,00	0,30
Set-Up	15%	2,00	0,30	5,00	0,75	4,00	0,60
Maintenance	30%	5,00	1,50	2,00	0,60	2,00	0,60
Data	*30%*	*2,60*	*0,78*	*3,80*	*1,14*	*3,80*	*1,14*
Storage	60%	1,00	*0,60*	3,00	*1,80*	3,00	*1,80*
Transfer	40%	5,00	*2,00*	5,00	*2,00*	5,00	*2,00*
System	**70%**	**3,75**	***2,62***	**3,08**	***2,15***	**3,08**	***2,15***
Effort to update …	*30%*	*5,00*	*1,50*	*3,00*	*0,90*	*3,00*	*0,90*
Hardware	50%	5,00	*2,50*	4,00	*2,00*	4,00	*2,00*
Software	50%	5,00	*2,50*	2,00	*1,00*	2,00	*1,00*
Data management	*30%*	*3,75*	*1,13*	*3,25*	*0,98*	*3,25*	*0,98*
Data access rights (read, write, change, delete)	25%	3,00	*0,75*	4,00	*1,00*	4,00	*1,00*
Data accessibility	25%	3,00	*0,75*	5,00	*1,25*	5,00	*1,25*
Data consistency	25%	5,00	*1,25*	2,00	*0,50*	2,00	*0,50*
Data security (manipulation, harm on hard- & software)	25%	4,00	*1,00*	2,00	*0,50*	2,00	*0,50*
Flexibility (Effort to...)	*40%*	*2,80*	*1,12*	*3,00*	*1,20*	*3,00*	*1,20*
add or discard partners	20%	2,00	*0,40*	4,00	*0,80*	4,00	*0,80*
add or discard machines	20%	5,00	*1,00*	5,00	*1,00*	5,00	*1,00*
add or discard processes	10%	4,00	*0,40*	2,00	*0,20*	2,00	*0,20*
add or discard types (machine, engine, components)	50%	2,00	*1,00*	2,00	*1,00*	2,00	*1,00*
Overall Benefit Value		**3,67**		**3,08**		**3,03**	

The ISIM assessment criteria table outlines the main differences between centralized, distributed and P2P system approached from the application owner viewpoint. Major costs differences are strong investments for the centralized system while distributed systems have to face higher maintenance costs if maintenance is not performed by the individual partners of the ISIM-network which is currently not decided. In a lower level, hardware costs are more important for distributed systems while data storage costs are more important for a centralized system. Due to the fact that there are no mechanisms implemented to roll out software updates not to mention hardware changes to the nodes of a decentralized ISIM-network these issues are considered as a weak point of the Avatar and P2P solution.

Regarding the data management assessment there are a few aspects which need to be discussed in the future. Main criticism is whether distributed solutions are trustworthy enough to allow Caterpillar to rely on data which is stored and maintained by another partner to assess the value of an engine. Additionally to this manipulation issue it seems to be questionable as how safety data storage can be considered in the distributed solutions. A challenge with the P2P approach is that if the information is partially duplicated in many places, it may be difficult to know what copy of which information is the most recent or accurate. It may also be a challenge to know when old information can be removed, e.g. has the information been retrieved and stored elsewhere before removing it from where the information was created. Finally it should be mentioned that loosing data might result in high cost for some of the involved parties.

As a conclusion on the assessment process and results it can be noticed that the application of the BA method has seriously supported the exploration of possible technological solutions for the realization of the ISIM in the depicted context. Especially the assessment model with the list of criteria and related weighting seemed to be a very helpful structure to simplify the complexity of the solutions and to foster the communication and knowledge exchange of the involved technical and end user parties.

Anyhow, the presented results should be considered carefully especially because of the prototypical status of the assessed systems. Although some of the criticisms mentioned above are related to an inherent characteristic of the particular ISIM solution it seems that some of them might give the technology providers additional hints on the user's demands. This might lead to the implementation of already discussed but not yet implemented functionalities in the near future.

With concerns to the selection of a possible ISIM solution in a real world scenario it was finally obvious to the involved partners that additional surveys especially on the resulting cost need to be performed which will not necessarily lead to the application of another assessment methodology such as the CBA. Furthermore it seems to be highly important that the risks associated to the individual solutions have to be analyzed and considered separately.

Acknowledgment

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An approach to enhance product lifecycle management with intelligent sensors

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Abstract: In traditional Product Lifecycle Management (PLM) systems product information is acquired during manufacturing, transport and storage by sensory deployed throughout the production facilities. This information provides a valuable basis for process optimization or even to early recognize design flaws. As the next step, monitoring of products during their complete lifetime is an upcoming concept. Exploiting real-life usage information opens the door for new strategies like preventive maintenance, adaptive production management or Design for X which will finally create benefit for producers as well as for consumers.

The resulting requirements for products and PLM systems differ significantly from traditional approaches. First, the responsibility to acquire and store information now lies with the product and its integrated sensory itself. This calls for development of intelligent products. Second, diverse sensor types will be needed in order to provide satisfactory usage information. This leads to a highly heterogeneous hardware landscape. Third, product information is available only irregularly e.g. when a product is in a service garage and in changing location. As a result, a much more dynamic PLM system is needed.

In this paper we propose a service oriented approach to meet the requirements of this emerging PLM concept. Key idea is to represent product related information and the sensors they originate from using the notion of services. We will propose mechanisms for interaction between PLM system and hardware and analyze the effects on the respective parts.

Keyword: Service Oriented Architecture; Device-centric SOA; Sensor networks

1 Introduction

In the field of Product Lifecycle Management (PLM), storage of and access to product related information is a major element. While in traditional systems product information had been acquired by external sensory from the product at specific events during its life cycle and stored centrally, the first advancement has been by tagging products with barcodes or RFID labels to simplify their identification. As the next evolutionary step, Product Embedded Information Devices (PEIDs) can be included in products or deployed in the production facilities. These PEIDs are then able provide real-life data about the products state and usage throughout its complete lifecycle. Thus, product related information is kept locally with the product, and is available anywhere and anytime with the product - *Wisdom Within*.

While the new features foster new business opportunities for manufacturers, users, maintenance service providers, and dismantlers, new ways of doing things impose new risks. Risks are seen primarily in two areas. Firstly, full leverage of *Wisdom Within* requires business processes adapted accordingly as a joint effort of at least the majority of the participants in the individual value chains that are now connected by the life-time-long tracking of product related data (e.g. manufacturing and recycling, realizing Design-for-X). Secondly, *Wisdom Within* imposes technical challenges on many layers of the implementation. Low-cost and low-power PEIDs need to be designed, data processing software that allows tracking of real-time data needs to be implemented, and inter-enterprise communication links must be established that reflect the new PLM business chain. One of the greatest technological challenges, however, is the integration of PEIDs into enterprise PLM systems.

The integration of PEIDs into enterprise PLM systems is challenging for many reasons. First, the PEIDs need to be equipped with appropriate communication means which allow data to be transported from the PEID to the PLM system located in to traditional IT landscape. While traditional sensor systems used lean, application-specific proprietary communication technology, the integration into IT systems requires the adoption of standardized internet protocols. Second, on higher layers, the PEID data must be made comprehensive to the PLM software by adding certain semantics to the transmitted data. More precisely, additional to the data which is accessible through the PEID information about its meaning (e.g. temperature), the product, its location etc. is needed. This requires a certain level of self-consciousness from the PEIDs, which is associated with certain minimal computational capabilities. Third and finally, the PLM application needs to cover higher dynamics as PEIDs will be physically or logically re-located due to their connection to the product. The PEIDs must announce their presence when they enter a new IT network so that the PLM application can properly react, and must indicate when they leave. They must tell what they are and what they can do. In one word, PEIDs must provide a dynamic and semantic interface to the *Wisdom Within* of the product they are attached to.

In this paper we will present the approach developed under the umbrella of the EU funded research project PROMISE [10] to realize *Wisdom Within*. By leveraging the service oriented architecture (SOA) paradigm we believe that the problems arising in this area can be solved successfully. Based on a technology survey we will show how PEID integration can be achieved efficiently on both software and hardware level.

The remainder of this paper is as follows. Chapter 2 will present a comprehensive categorization of PEIDs which will provide the necessary basis for our work. Chapter 3 will deal with SOA for devices. Chapter 4 derives meachanisms for homogeneous PEID access using UPnP™. Chapter 5 illustrated how arbitrary PEIDs can be integrated into a SOA based PLM system. In Chapter 6 we outline the current status of the development and give an outlook on future steps.

2 Information Devices in PLM

Before we can derive a concept on how a PEID is integrated into a PLM system, we first need to get a better understanding of the term PEID. As already outlined in the previous chapter, extending the PLM concept to all phases of a product's life calls for monitoring and data storage devices which provide the necessary data basis. For the products to be monitored even when not inside production or maintenance facilities the so-called PEIDs need to be embedded into the product itself. From this follows that every device located on the product which contains product related information is a PEID. Thus, the term PEID can be applied to a great range of devices reaching from simple RFID tags to elaborate on-board systems of cars or trains.

In order to establish a common terminology in this paper, we will group the PEIDs into five categories based on their system contribution and computational capabilities:

- **PEID:0** Identifier-only PEID. The PEID only contains a GUID (Globally Unique ID). The GUID is usually of write-once-read-many type. Examples: barcode or RFID tag or any information device for which only the GUID is accessible, no matter how "computationally powerful" the PEID is.
- **PEID:1** Only identifier and data storage capabilities, no computation capabilities. Data storage can also be re-writable. Examples: barcode and passive RFID tag with data contents in addition to GUID. Intermittent network connectivity through proxy device (e.g. barcode reader, RFID tag-reader)
- **PEID:2** Limited computation power, possibly including sensors and other "measuring" capabilities. Wireless network connectivity when "in range". Examples: active Tags, WiFi-enabled devices etc.
- **PEID:3** Medium-level computation power, sensor connectivity, data processing power. Wireless network connectivity when "in range". Example: on board systems in general, Embedded Control Unit (ECU) of a vehicle (e.g. car)
- **PEID:4** PEIDs with "high" computation power for directly implementing connectivity to PLM systems. Example: full featured PC like systems in locomotives

In traditional approaches the PLM system exploits detailed knowledge about the deployed PLM hardware (sensory/ID tags) in a facility in order to access and interpret the associated information. For a *Wisdom Within* PLM this is more difficult for multiple reasons. First, monitoring the state of a product is likely to depend on diverse PEIDs within a single product. Considering that multiple products will be equipped with PEIDs, we have a considerably higher diversity of hardware that the PLM system needs to handle. Second, hierarchies of PEIDs are likely to be implemented (e.g. the ECU of a car (PEID:3) is connected to velocity and temperature sensors (PEID:2)). The PLM system needs to know how to treat each PEID in order to get to all information available in the hierarchy. Third, the amount of PEIDs now scales with the number of products in contrast to the number of production/storage facilities in traditional systems.

All in all, a *Wisdom Within* PLM needs to interact with diverse PLM hardware in much higher quantities than traditional systems. Against the background of such a scenario it does not seem to be feasible to use a centralized approach in which the PLM system carries the burden of knowing how information is retrieved from every single PEID. Instead, we propose a service oriented approach in which PEIDs are seen as self-contained items. These items provide descriptive information about their capabilities and stored data by themselves using standardized SOA mechanisms. Thus, the PLM system is able to dynamically interpret the information provided by the PEID. This leads to a system which is able to concentrate on interpretation of information rather than on retrieving it.

3 SOA for Devices

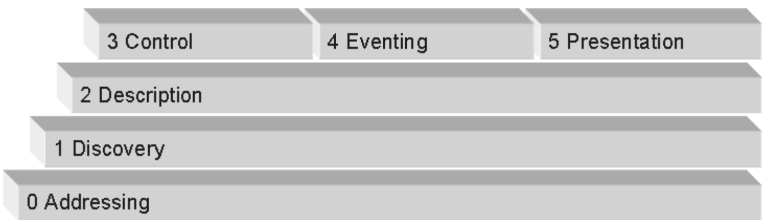
The SOA paradigm originates in the enterprise world where the notion of services has been introduced in order to enhance intra- or inter-enterprise business processes. The core idea is to network software systems using abstract and self-contained entities called services. For this, so called SOA middlewares have been developed for which Web Services is the most prominent example. A SOA middleware defines mechanisms by which services can be found, described and accessed in general. Using a specific middleware, application specific services can be implemented to realize the desired business processes.

In the context of our investigation however, we will use SOA to integrate PEIDs into the PLM system in contrast to integration of software systems which is focus in classical SOA. A group of middlewares that has been developed specifically to support SOA for devices is Jini[7], OSGi[5], UPnP[8] and DPWS[4]. All of these middlewares are good candidates to support the *Wisdom Within* PLM. In the following however, we will specifically pursue the idea of using UPnP^{TM} for PEID integration. Main reason for this is that UPnP^{TM} is already used in commercial products (e.g. WiFi routers) and is natively supported by some operating systems. Thus, it can be considered as a mature middleware. Let us now take a deeper look into UPnP^{TM}.

The Universal Plug and Play (UPnP^{TM}) Architecture uses open and standardized protocols based on XML which allow to describe and control various devices. All communication is transferred over TCP/IP resp. UDP/IP and is thus hardware-independent. The UPnP^{TM} Device Architecture is separated in six parts:

- Addressing: A UPnP^{TM} device requires a network address using a DHCP server or, if none is a available, using Auto-IP.
- Discovery: UPnP^{TM} Devices advertise themselves by multicast messages and react according to search messages.
- Description: UPnP^{TM} Devices and their embedded services are defined by XML description files which have to be provided for HTTP download by the device.
- Control: UPnP^{TM} Devices are controlled by the XML-based SOAP protocol [9] and therefore process XML messages and answer with dynamically created XML messages.
- Eventing: UPnP^{TM} Devices maintain event subscriber lists, accept subscriptions and keep track of subscription durations. When an event occurs, XML-based event messages with dynamic content are sent to each subscriber.
- Presentation: The optional presentation page exposes an HTML-based user interface which may be used for controlling the device by embedded elements like Java applets.

Figure 1 Layers of the UPnP^{TM} Architecture



When we use UPnP^{TM} as communication means between PEIDs and PLM system several advantages arise. First, the PLM system does only need to support the protocols defined for UPnP^{TM} and therefore does not need to deal with hardware specific protocols. Second, the discovery mechanisms of UPnP^{TM} allow the middleware to be aware of the currently available PEIDs. This is of special interest for the *Wisdom Within* PLM, as the products dynamically join (e.g. car enters service garage) and leave the system (e.g. car leaves service garage).

However, adoption of UPnP^{TM} for PEID access is only the first step. UPnP^{TM} alone only provides us with a kind of protocol stack. What is still missing is a description of a PEID in UPnP^{TM} terms and the definition of how information is exchanged. This can roughly be compared to a situation where you have agreed on a common programming language and now need to define a concrete interface containing method signatures and data types.

4 Homogenous PEID Access

There exists a natural grouping of information that can be provided by a PEID. The first group is information that is common to any PEID that is attached to a product. An example would be a unique identifier or the manufacturing date. Regardless of the implementation of the PEID hardware this information will be available. For this kind of information we can precisely define what information is available and the signature of the UPnP^{TM} action[1] to retrieve it. Thus, the PLM system can retrieve this information homogeneously from every PEID in the exact same fashion.

Second, there is information that is specific to the PEID. For example, one PEID might provide temperature readings, while another measures humidity. Although the information itself and its format cannot be specified in general the access mechanism can. We suggest to use a key-value mechanisms to describe and access the specific PEID content.

Third, configuration and maintenance of the PEIDs has to be conducted e.g. specifying measuring intervals or thresholds. The tasks related to configuration and maintenance will be specific to a PEID and thus cannot be described in a generic fashion. However, each PEID should provide a reference to the application specific configuration/maintenance service.

In order to transfer these insights down to the UPnP^{TM} level we need to specify the access mechanisms in a UPnP^{TM} compliant fashion. UPnP^{TM} defines the entity UPnP^{TM} device which provides functionality to the UPnP^{TM} network. This functionality is encapsulated into the device's services. For the *Wisdom Within* PLM the so-called Core PEID Access Container (PAC) is defined. The Core PAC is a UPnP^{TM} device which allows access to general information for one or multiple PEIDs. For this purpose, the Core PAC contains the following services:

- **Info service:** The Info service allows access to common information on the PEIDs contained in the Core PAC in a semantic fashion. For example, it supports reading and writing a unique product identification string, information on the location of the tagged product, the owner of the tagged product, service contact data, series number, manufacturing date, etc.

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[1] A UPnP action can roughly be compared to a method

- **Content service:** The Content service allows access on the content of a PEID in a non-semantic fashion. The semantics and the format of the content is application specific. Therefore, the content is organized in a flat, key-value based structure and provide additional mechanisms that support the introspection of available key tokens.
- **PTInfo service:** The PTInfo service just contains a single action which allows retrieving the association of a PEID with a application specific configuration/maintenance service.

With the specification of the Core PAC and its contained services a homogeneous description and access mechanism for PEIDs is defined which can be used by the PLM system to interact with the PEIDs. The remaining challenge is now to make PEID hardware accessible via the Core PAC. Using UPnP^{TM} as middleware there are multiple ways to achieve that.

5 PEID Integration

Following a top-down-approach, we have until now defined how a PLM system can handle the diversity of hardware in a *Wisdom Within* PLM. The chosen mechanisms are SOA in form of UPnP^{TM} and the Core PAC interface for homogeneous information access. Now we need to analyze how the PEID hardware can implement these mechanisms in order to be leveraged in the PLM system.

In order to make a PEID accessible via the Core PAC it foremost needs to implement the protocols defined by UPnP^{TM}. Thus, it has to communicate using SOAP or other XML based communication protocols on top of TCP/IP. Considering the broad landscape of PEIDs it is not apparent if and how every PEID is able to provide the required functionality especially taking issues like cost and power consumption into account. Let us now go through the different categories of PEIDs presented in Section 2 and draft integration approaches for each group.

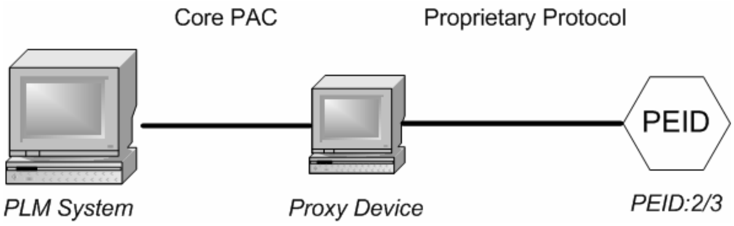
Looking at the category PEID:4 we deal with high performance systems that comprise network connectivity and high computational capabilities. Cost and power consumption are no critical issues here so that support of the Core PAC interface can easily be implemented on the existing hardware. PLM integration of PEIDs from this category is therefore easily possible.

On the other end of the PEID scale we have the categories PEID:0 and PEID:1. These PEIDs are simple devices for identification purposes and/or data storage like barcodes or passive RFID tags. As these devices normally posses very little or even none computational capabilities they cannot implement the Core PAC interface. But as these kind of PEIDs depend on a reader system to be accessed the burden to comply with the interface is rather on the reading system than PEID:0/1 devices themselves.

This leads to devices of category PEID:2 and PEID:3. These include PEIDs with less or moderate computational capabilities like e.g. RFID readers, active tags or on-board computers of cars. Depending on the application it is possible that these PEIDs provide the necessary capabilities to implement the CorePAC interface. For example, advanced RFID readers already contain networking capabilities and a user interface so that the CorePAC can easily be added to its functional range with additional software. However, it is reasonable to believe that especially for cost sensitive applications not all PEIDs will comprise sufficient features to support the CorePAC directly. In order to reduce cost and size of the PEIDs it is common to rather use optimized binary protocols which can easily be interpreted by the PEID than XML based communication as needed for the CorePAC. As these PEIDs cannot comply with the CorePAC interface they cannot be leveraged by the PLM system directly. Fortunately, we can overcome this limitation.

Following the general idea of SOA, the PLM system only depends on the information that is provided by instances of the CorePAC. It is not relevant to the system how or where the interface is implemented as the communication is based on TCP/IP and is therefore hardware independent. This means that for PEIDs which cannot support the CorePAC directly the computational load can be outsourced. This is a common approach to integrate restricted device in SOA systems [2, 6, 3, 1, 11]. In the resulting setup a high-performance PEID will implement the CorePAC interface and interact with the PEID:2/3 using a proprietary protocol to acquire the necessary information. This setup is visualized in Fig.2.

Figure 2 Proxy based Integration of a PEID



In this section we have seen that regardless of the type of PEID it is possible to make a PEID accessible to the PLM system. For full featured PEID direct implementation for the CorePAC is preferred and for less elaborate PEIDs a proxy approach is suitable which is beneficial with regards to cost and power consumption.

6 Status and Outlook

In this paper we have presented the approach developed under the umbrella of the PROMISE project to leverage SOA for integration of PEIDs into PLM system. The resulting concept allows dynamic and homogeneous interaction between the PLM system and PEID which is a prerequisite for a *Wisdom Within* system. Furthermore, we have detailed how integration of arbitrary PEID hardware can be facilitated and that there is room to effectively take device and cost restriction into account.

Currently a first version of a *Wisdom Within* PLM system has been implemented based on the findings presented above. In a first setup sensor hardware and PLM system have successfully been linked via the CorePAC interface which is a first proof-of-concept on the suggested solution.

In the continuation of the project further demonstrators will be created for the automotive, industrial and home automation sector to validate and refine the approach to enhance PLM with intelligent hardware using SOA.

Acknowledgment

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An integrated approach to decision support for maintenance management: a case study for machine tools

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Abstract: This paper presents a case study of maintenance management applied to the field of the machine tools. This market hasn't a very large scale and is characterized by high differentiated products with a deep impact of innovation and technology on the solutions. Maintenance has become a key factor for the machine tools business, giving competition advantage both to the machine manufacturer and the user. The first will be able to provide a life long maintenance service, at competitive prices, the other will have the benefits for the reduction of the costs of the breakdowns and of the maintenance contracts. The result of the work carried out by the authors is an integrated maintenance decision support system; it aims to predict the breakdowns measuring key parameters of the machine behaviour and to support the service provider to interpret the data in order to plan the optimal (technical and economical) maintenance action.

Keyword: decision support systems, PLM, machine tools, predictive maintenance, fuzzy expert systems.

1 Introduction

European manufacturing industry is shifting its production from pure physical products towards knowledge intensive and service oriented solutions to answer to new market requests. This goes in the direction of lifecycle (LC) management view to offer solutions which are reliable and controllable in any phase of their life, solutions which have innovative approach to solve and prevent customer's problems. Smart tags, tracking systems, RFID devices are some of the available systems in the market which can be embedded in the product in order to collect information and data useful in different lifecycle phases.

Most recent ICT platforms are meant not only for collaborative process, exchange of documents and information, but also for online updating of the product status, monitoring performance, online change parameters, collect data on the field in order to connect different product LC phases and also different actors involved in the product LC. This enables the exploitation of the seamless flow, tracing and updating of information about products, after their delivery to the customer and up to its final destiny (deregistration, decommissioning) and back to the designer and producer (Kiritsis et al.). The aim of this work is to propose an integrated approach to predictive maintenance services where starting from real-time monitored data the evaluation of the aging of the components is carries on and used for cost evaluation of different maintenance interventions to improve LC management of machine tools. The maintenance strategy behind the DSS (Decision Support System) compares different maintenance actions according to the evaluation of their effects on the residual life of the product.

2 State of the art in Maintenance management

According to many authors and recent studies, maintenance costs cover a great percentage of the overall costs related to the entire life cycle of many industrial products. Improving maintenance management would consequently have a measurable impact from the point of view of the entire LC of the solution. This improvement can be done both from a technological and an organizational point of view. Recent maintenance policies avoid component breakdown for two main reasons: on one side the failure of components would even jeopardize users' safety in the usage of the product and on the other side non-scheduled stops for component replacement would be definitely more costly than planned maintenance interventions. Maintenance policies can be grouped into different bunches (Fedele et al., 2004), (Swanson, 2001), (Bateman, 1995) according to the way the user deals with breakdowns which means that the most applied systems are reactive policies, proactive policies, and TPM (Total Productive Maintenance) & RCM (Reliability-Centred Maintenance).Some studies propose methodologies for estimating the potential benefits deriving from the application of a certain maintenance approach showing how proactive maintenance can improve company performance compared to others (Swanson, 2001) and explaining how to set up a predictive maintenance approach (Carnero, 2004), and how to choose the best diagnostic system (Carnero, 2005). Proactive maintenance approach has the goal of avoiding as much as possible system breakdowns using historical data, empirical tests and statistical computations to put into direct relation the time (working time and/or lifespan) with the probability of system breakdown. What follows is a planning of the maintenance activities that maintains the risk of system breakdown under a pre-defined threshold. Predictive maintenance provides a picture of its consumption or wear in order to perform maintenance interventions only when needed (Chan et al., 1997) according to forecast on the residual life. According to (Yam et al., 2001) a DSS supporting (esp. predictive) maintenance can rely on: knowledge base, analytic hierarchy process, Petri nets, neural networks, fuzzy logic and fuzzy networks, and Bayesian theory. With the design of an Intelligent Predictive Decision Support System (IPDSS) for Condition-Based Maintenance, Yam et al. integrate equipment condition monitoring, intelligent condition-based fault diagnosis and prediction of the trend of equipment deterioration strongly improving the quality of maintenance decisions.

3 The proposed integrated approach to maintenance management

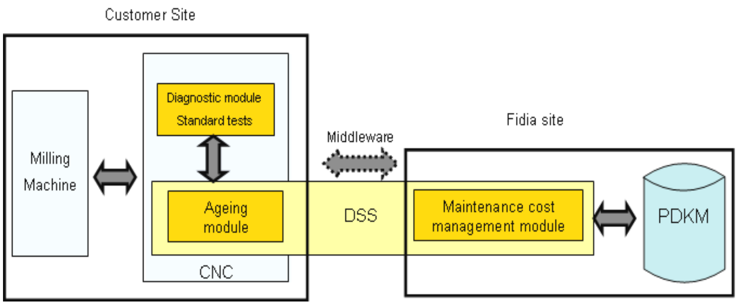
This paper proposes a case study of maintenance management applied to the field of the machine tools. The main features that characterize this market are: high differentiation of the products, production not on a large scale and innovation with significant technological solutions. FIDIA SpA is one main actor in the market of the machine tools manufacturers. The success in this difficult context, has to be reached anticipating the trends of the market with the introduction of innovative products, improving the quality of the offered service and improving the performance of the machines. The maintenance policy affects most of these topics. During the recent years the maintenance management issue has became a key factor for the machine tools manufacturers, more and more important to provide their customers relevant cost reductions due to the decrease of breakdowns (in number and magnitude) and the decrease of the maintenance contracts costs. In the present industrial processes a sudden interruption of the machine, impacts on the competitiveness of the company and it is often the most important contribution in the "total production cost". The integrated Decision Support System goes in the direction of predictive maintenance for machine tools in order to reduce the number of unexpected stops for maintenance and minimize the overall lifecycle costs of the product avoiding component breakdowns. The overall decision support system can have a double impact on maintenance management. In fact it may support:

- machine user who can monitor machine performance and ageing of the components
- maintenance provider who can plan and forecast interventions needed and optimize maintenance costs.

As shown in Figure 1 the three modules composing the system are:

- the diagnostic module that transforms field sensor data in useful indicators of the working condition of the machine
- the ageing module that transforms the previous indicators in an estimate of the wear and the "health state" of the machine
- the cost maintenance module that enables the service provider to interpret the aging data in order to plan the optimal (technical and economical) maintenance action.

Figure 1 System overview.

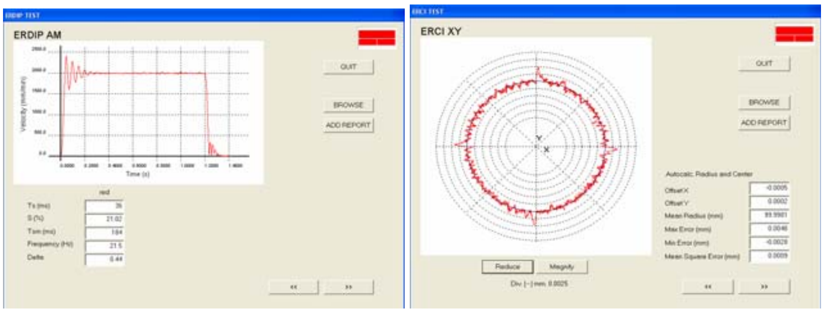


Moreover since the DSS is integrated with a PDKM (product data knowledge management) at the producer site, it permits to integrate and re-use information from different phases of the product life. In fact for example information about components failures and performance can pass from the maintenance provider to the designers for new products features. According to the information collected directly from the previous versions of the product improvement can be easily implemented closing the information loop. Other kind of information can be transmitted also for the recycling and dismissal of product components.

4 Description of the testing module

From the moment when FIDIA delivers a machine to the customer (i.e. the end user of the machine) at present nothing is known about the machine during the normal life until a fault or a breakdown occurs.
For this reason, during the last years, FIDIA has progressively developed a software tool useful for periodical testing of the machine at customer site. Periodically (e.g. at least every 3-6 months or 10.000-20.000 working hours), the user should execute dynamic tests on the machine in order to evaluate the "health state" of the machine and of its subcomponents.
This testing module for Predictive Maintenance has been developed on the basis of theoretical studies and long time experience of technical servicing. It can point out and suggest defective behaviours or malfunctions of the machine.
This Predictive Maintenance software tool, running on the Computerized Numerical Control that equips every milling centre, commands the machine to move its mechanical axes on paths, with pre-defined length and direction. During these tests, sensors installed on the machine (i.e. position transducers, current sensors, etc.) record some useful signals that are graphically displayed. Moreover data coming from sensors are elaborated and significant indicators are extracted.
Figure below, presents the graphical user interface of this testing module. The final result of a testing session is a report listing all the "health state" indicators. This report is provided as input to the next aging module.

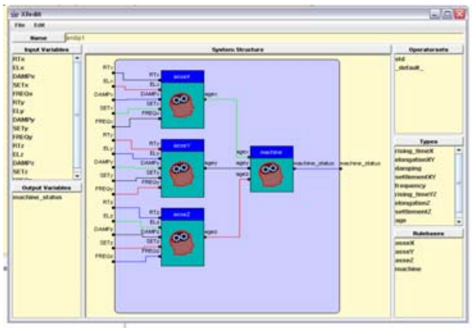
Figure 2 The Graphical User Interface of the testing module.



5 Description of the aging module

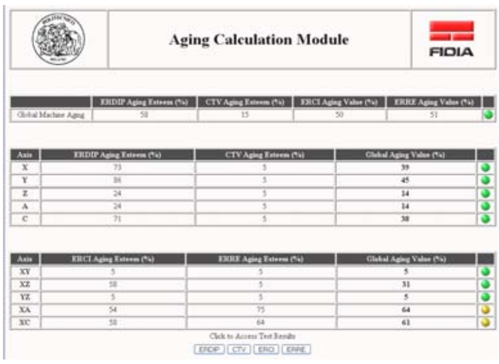
The aging module, takes the global indicators elaborated by the testing module and elaborates them to esteem the wear and the aging of each axis and of the whole the machine. At the beginning it has been developed following a methodology by the same author (Cassina, 2006) on another predictive maintenance application, which exploits self training algorithms, making use of a neural network to train a fuzzy expert system. This approach has been tested, but aging experiments on this kind of products weren't feasible because of their cost and the needed amount of time. So it has been decided to develop the fuzzy expert system, based on FIDIA engineers experience and simulations. Self improvements will be done in the future when enough field data will be available, gathered through the maintenance crews, or the centralized data management infrastructure (PDKM) that is under development. The system is composed by five different expert sub-systems, initially developed with Xfuzzy (**Errore. L'origine riferimento non è stata trovata.**). The first four analyzes the results from each test of the testing module, and are composed by an expert system for each axis, and one afterwards that sums up all the information to provide a global aging status indicator for the machine.

Figure 3 Example of an expert system to analyze the results from a test.



After these, the last module analyzes the results of all the previous systems, giving an indicator of the reliability of the esteemed aging value. The aging module starts automatically at the end of the machine tests, and shows to the user a synopsis of the aging indicators, providing him both the global machine status, and an analysis of status of each axis. All these data have also a reliability indicator, which shows if the esteem is sound. The current interface is shown in **Errore. L'origine riferimento non è stata trovata.**.

Figure 4 Output of the onboard Aging Module



When the aging exceeds a pre-defined threshold, there is the possibility of an incoming breakdown on the machine. The customer is then invited to send data to FIDIA to be analyzed by the maintenance cost management DSS module, that is explained in the next paragraph.

6 Cost maintenance management module

Many studies (Barnes and Langworthy, 2003), (Purdy and Wiegmann, 1987) highlighted the magnitude of maintenance costs on the overall costs for the products. The here described module of the integrated DSS addresses the reduction of this kind of costs through the development of a pilot approach. Starting from real-time monitoring of the actual status of components allows the user to effectively and efficiently manage the maintenance activities on each product. The approach defines maintenance strategies minimizing costs related not only to the maintenance intervention but also to the remaining steps of the components lifecycle. This aspect is especially innovative since previous studies propose methods for optimising maintenance scheduling through the control of pure maintenance costs (Haghani and Shafahi, 2002), (Safaai et al., 1999) but not considering the entire lifecycle costs connected to the choice of performing or delaying a given kind of maintenance of the product.

The maintenance cost management module of the DSS is meant to provide a list of suggested interventions that can be performed on the machine tool when the monitored mechanical components of the axes fail or are expected to fail according to alarms from the aging module for all the machine tools monitored by the maintenance service provider. Residual lifespan of each monitored component is the main input of the DSS and it is acquired from the PDKM where this information is stored after calculation by the aging module. The methodology is based on three macro-scenarios (no intervention, tuning of the parameters, maintenance) related to the mechanical components of the axes . The DSS compares the costs of the three alternative scenarios in order to manage the critical components of the machine tools according to estimated differential costs which are defined for each of the three macro scenarios. The methodology applies calculation to each selected scenario according to known criticalities. The three main scenarios considered are the following:

- Scenario 1: no intervention. In this scenario no maintenance is performed. Costs computed to this scenario can be grouped into three main clusters: costs deriving from a reduced quality of the final products, costs deriving from potential damages on components (due to a delay of the maintenance intervention) and, finally, costs for potential future interventions (taking into account the entire components lifecycle, also future costs have to be estimated and made up to date).
- Scenario 2: tuning of the parameters. In this case machine running parameters are modified in order to preserve product quality. When one of the components of the axes deteriorates, the quality of final products may slow down. Modifying machine running parameters would sometimes preserve the quality at the expense of production efficiency. Reducing working speed of the machine tools is one of the possible adjustments: the productivity of the machine gets worse but the quality of final products is kept over a chosen threshold.
- Scenario 3: replace (i.e. replacing the critical component. For this scenario the DSS calculates the costs for the replacement of the critical component. Main cost entries for the DSS are for example: cost of replacement, cost for damages on components/machine and cost for future interventions. This last cost is linked to historical data and formalized experience.

In the database PDKM, each scenario is described through the following major fields:

- a set of pre-requisites giving a definition of the circumstances and occurrences in which the scenario is feasible, reasonable and consistent (component breakdown, threshold, ...)
- categories of inputs needed in order to perform the computation of the maintenance cost associated to the scenario (type of costs for the component, residual life, …)
- algorithms, thresholds, weights the computation is based on.

The maintenance costs are evaluated with an iterative process on each machine with components exceeding a given threshold value of "criticality". As mentioned above, once the machine user has verified with the other DSS modules the status of the components, an alarm on aging is sent to the Fidia premises which collects the alarms from all the machine tools under maintenance and calculate the economic value of different maintenance actions according to residual life costs estimation.

Input to the calculation of the Fidia DSS module can be grouped into two major subsets:

- data already stored in the DSS because they are similar for most of the machine tools models like for example cost of the machine, costs of each monitored component, the probability that a failure of one component could cause a stop of the machine
- data collected directly from each machine and sent to the maintenance provider from the machine user like costs of maintenance and of residual life including cost of lost production, cost of wastes, type of production, lead time,…These data are specific for each machine, and also for each production undergoing and they may vary the impact of maintenance intervention.

In order to evaluate the robustness and reliability of the decision suggested by the system a sensibility analysis functionality is provided: modifying some of the most important parameters (e.g.: production cost, probability of breakdown), it is possible to evaluate how changes in those parameters could affect the selected maintenance option.

7 Conclusions and further development

In the design of this integrated DSS, different stakeholders requirements have been taken into consideration, referring to actors that will use the tool in different steps of the product lifecycle. The main addressees are in the Middle-of-Life phase: machine user and maintenance crew. However, comparing actual performance of monitored components with reliability and features supported at the beginning of their life the system provides value-adding information also to the design department of the machine manufacturer (Beginning of Life phase) and, finally, to End of Life actors devoted to the re-usage, retrieval and dismantling of the components. The here-described approach is under implementation and testing. Benefits deriving from the adoption of this tool will be weighed up and compared to already existent solution through proper on-the-field inspections. The consideration of Residual Lifecycle cost in the DSS permits to have a wider vision on the product and on the services connected to the product itself. The testing and the aging module will be improved with the feedback coming from the users and the maintenance crews that will use it. At the same time, the Aging Module will use the gathered data to test the self improvements routines and to be self tuned. Concerning the cost maintenance management module further developments in the proposed approach will give the possibility to synchronize the availability of each machine tools (according to their production plans) with the availability of the maintenance provider in the definition of maintenance calendar. The machine tools spread all over the world will be geographically clustered and interventions of machines belonging to the same cluster will be scheduled according to maintenance provider availability. FIDIA expects to reach two main business opportunities deriving from the development of such an integrated DSS that supports Predictive Maintenance for machine tools. In fact the improvement of machine performances, the innovation in maintenance strategy in machine tools field and the consequent breakthrough among the other competitors are expected to increase the machine sales. The innovative approach to machine Service is awaited to provide a positive perception among the customers. So higher quality and lower costs in Service are expected, and this will increase the spreading of this kind of contracts.

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A decision support system for lifecycle management: a cost evaluation approach to maintenance planning

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Abstract: The aim of this work is to propose a Decision Support System to manage product lifecycle in the Middle of Life phase in order to obtain data which may impact on the whole value chain. In particular a new maintenance approach based on the integration of information gathered from different actors is taken under consideration and the evaluation of residual lifecycle costs are used to define and plan maintenance actions. The system permits to create new value by transforming information into knowledge available for all phases of the lifecycle improving product and service quality, efficiency and sustainability.

Keyword: Decision Support Systems, Maintenance costs management, lifecycle

1 Introduction

According to many authors, maintenance costs cover a great percentage of the overall costs related to the life cycle (LC) of many industrial products. Improving maintenance management would consequently have a measurable impact from the point of view of the entire LC of the solution. This improvement can be valuable both from a technological and an organizational point of view changing the business model of the company. This work introduces an approach to maintenance management which starting from real-time monitored data and through a maintenance cost algorithm calculates the residual life cost. The Decision Support System (DSS) collects the status of the components to decide when to do maintenance interventions taking into account all the costs related to the remaining steps of the LC of the considered product in order to reduce the number of product stops for maintenance and minimize the overall LC costs of the product. The DSS integrates and re-uses information from different phases of the product life collected in the so called PDKM (Product Data and Knowledge Management) system. In fact information about components failures and performance can pass from the maintenance provider to the designers for new products features through the PDKM. According to the information collected directly from the previous versions of the product, improvements can be easily implemented closing the information loop. The DSS for cost evaluation of maintenance has been applied to fleet management in the automotive sector and will be extended and adapted also to other cases like the maintenance of machine tools in order to verify its applicability also to other sectors.

2 Cost maintenance management literature

Recent maintenance policies avoid component breakdown for two main reasons: on one side the failure of components would even jeopardize users' safety in the usage of the product and on the other side non-scheduled stops for component replacement would be definitely more costly than planned. Maintenance policies can be grouped into different bunches (Fedele et al., 2004), (Swanson, 2001), (Bateman, 1995) according to the way the user deals with breakdowns (reactive policies, proactive policies, and TPM (Total Productive Maintenance) & RCM (Reliability-Centred Maintenance)). Some studies propose methodologies for estimating the potential benefits deriving from the application of different maintenance approaches showing how proactive maintenance can improve company performance compared to others (Swanson, 2001) and explaining how to set up a predictive maintenance approach (Carnero, 2004), and how to choose the best diagnostic system (Carnero, 2005). Proactive maintenance approach has the goal of avoiding as much as possible system breakdowns using historical data, empirical tests and statistical computations to put into direct relation the time (working time and/or lifespan) with the probability of system breakdown. What follows is a proposal for maintenance planning to keep the risk of system breakdown under a pre-defined threshold. In contrast with mere historical data used in preventive approaches, predictive maintenance is based on data coming from expressly installed sensors, that are devoted to the "measurement" of the actual status of a component, providing a picture of its consumption or wear in order to perform maintenance interventions only when needed (Chan et al., 1997) according to forecast on the residual life. According to (Yam et al., 2001) a Decision Support System (DSS) supporting (esp. predictive) maintenance can rely on: knowledge base, analytic hierarchy process, Petri nets, neural networks, fuzzy logic and fuzzy networks, and Bayesian theory. With the design of an Intelligent Predictive Decision Support System (IPDSS) for Condition-Based Maintenance, Yam et al. integrate equipment condition monitoring, intelligent condition-based fault diagnosis and prediction of the trend of equipment deterioration strongly improving the quality of maintenance decisions. In our case once the evaluation of the residual lifespan is undertaken, an evaluation of the cost of delaying maintenance intervention is compute in order to use the aging of components as an input for a more detailed analysis.

3 The proposed approach

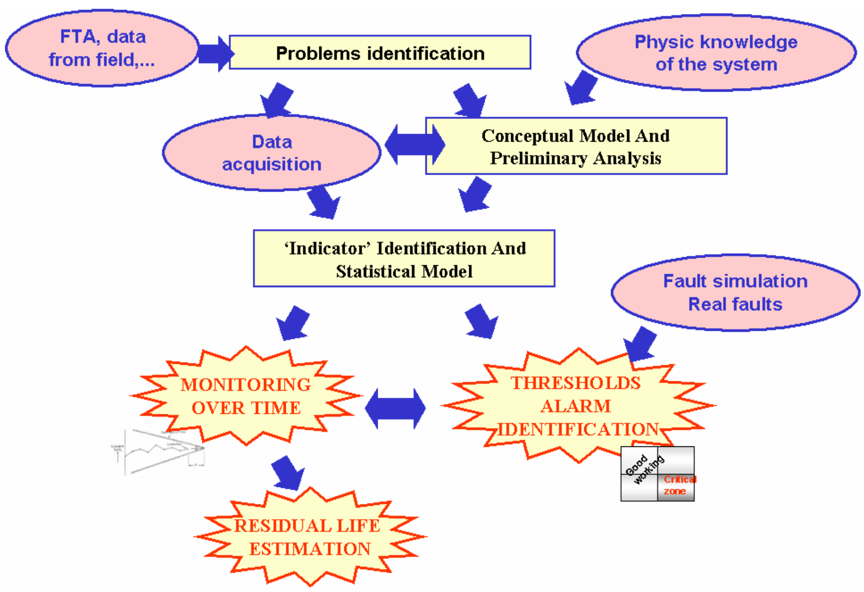
Many studies like for example Barnes and Langworthy, 2003, or Purdy and Wiegmann, 1987 highlighted the magnitude of maintenance costs on the overall costs for the automotive life cycle. The described system addresses the reduction of this kind of costs through the development of a pilot approach. Having a real-time monitoring of the actual status of components allows the user to effectively and efficiently manage the maintenance activities on each product. The approach here described is specifically applied to the automotive sector considering the maintenance management of a fleet of vehicles. Residual lifespan of components are input for the DSS and can be computed through data collected by sensors installed on the components themselves. Conventional maintenance strategies consist of corrective and preventive maintenance. In corrective ones, the system is maintained on an “as-needed” basis, usually after a major breakdown. In preventive maintenance, components are replaced based on a conservative schedule in order to “prevent” commonly occurring failures. Although preventive maintenance programs increase system availability, they are expensive because of frequent replacement of costly parts before the end of their life; another disadvantage is that it is time-based, while, frequently, the wear out depends on the type of rather than the time of usage.

In order to overcome these difficulties in recent years has been introduced condition-based predictive maintenance using embedded diagnostics and prognosis to predict future system’s health. Prognostics goals are to identify slow degradation as much as possible in advance of the failure itself and to make explicit the residual life of the component in order to better manage total Life Cycle Cost (LCC).

3.1 The data collection and residual life calculation

The “prognostics” strategy described in the following paragraphs relies on the available physical knowledge and integrates the information acquired via experimental activity. It tries to capture cause-effect relationships based on a-priory knowledge of a system and its physical links and to use data to estimate and validate a statistical model. The flowchart of activities is shown in **Errore. L'origine riferimento non è stata trovata.** below.

Figure 1 Steps for model identification



In Figure 1 above, the main steps of the statistical analysis are:

- conceptual model identification: the “conceptual model” is based on the analysis of the physics of the component/system and builds all the links between the variables involved in the problem are made explicit. The conceptual model identification is done considering not only the physic of the system, but also the malfunctioning modes and the functional relationship and correlation between the possible indicators. After a sufficient number of acquisitions, time-histories analysis (plotting over time, correlation, range of variability and distribution,…) is necessary in order to identify components working conditions and to verify coherence between the variables and to exclude the acquisition errors. Time-histories are acquired from vehicle sensors (for example with frequencies 1-10 Hz) and plot the temporal evolution of a characteristic system’s quantity.
- identification of the statistical indicators through preliminary analysis and statistical model estimation: in order to assess the working condition of each component, it is necessary to identify one or more predictive indicators, i.e. quantities that vary in dependence of internal or external system’s parameters, from which it is possible to achieve the system’s efficiency state. The indicator must be able to describe normal conditions and, at the same time, to find out abnormal situations. A first identification a priori of such indicators is not always immediate and begins from a physical-engineering knowledge of the system under study. The postulation of a first conceptual model helps in identifying these indicators. Usually a quantitative model emphasises the dependence of the predictive indicators from the parameters that influence the system component’s work. Modelling allows to analyse the “residuals”, differences between observations of the monitored systems and the expected conditions (i.e. predicted measurements) [Jobson, 1991]: the value of predictive indicators strongly depends on working condition, making difficult the determination of the alarm thresholds, whereas the residuals are more stable as they are referred to the model itself. According to the conceptual model complexity, several statistical approaches and modelling techniques can be used (multivariate regression, principal component analysis, ANOVA, etc.).
- identification of the working domain and alarm conditions. The statistical analysis allows the identification of the working domain in normal condition. Residuals trend evaluation allows to find out system’s critical points and consequently a first idea of alarm thresholds. In normal operating conditions, if the model is adequate, the residual remains close to zero, when the fault occurs the residual deviates significantly. In order to evaluate these ‘abnormal’ conditions a plan of faults simulations, representative of real breakdowns, or data of real faults are very useful; if it isn't possible, statistical indicators like standard deviation or percentiles on working conditions can be used. Then, fixed the two types of risk (the probability to give a false alarm and the probability to not recognise a failure), different thresholds individuate:
    - normal condition zone
    - pre-alarm zone
    - alarm zone
- A potential fault can occur in two different ways:
    - instantaneous fault identified when at least one value of the indicator is in the alarm zone.

- o deviation towards critical situations (movement of the indicator values from the normal condition zone to pre-alarm and alarm zones).
- The identified indicators can be monitored also using suitable Statistical Process Control methods (SPC involves many methods for monitoring and presenting measurement variables and permits to test if the 'process' is changing from its historical levels identifying slow trend as well as single outlier observation). According to the specific SPC methodology used, it can be identified both slow trend or sudden deviation from the optimal/target values. Both these methodologies could be implemented also when fault simulations are not feasible, but they give only an information related to the deviation from previous conditions, not a deep information related to the criticality of the situation.

3.2 Cost maintenance evaluation based on residual life

The main objective of the cost maintenance evaluation module is to identify time intervals to perform maintenance activities on trucks at garage. The DSS identifies maintenance strategies minimizing costs related to the remaining lifecycle of the components at each of the feasible time interval. Previous studies propose methods for optimising maintenance scheduling through the control of pure maintenance costs (Haghani and Shafahi, 2002), (Safaai et al., 1999) but not considering the entire lifecycle costs connected to the choice of performing or delaying a given kind of maintenance on components.

In this cost maintenance DSS the evaluation of each maintenance action is based on:

- residual life estimation (aging of the component)
- estimation of future cost intervention
- estimation of the value of the component at the end of the life
- probability of wear linked to the aging of the component according to a function based on historical data.

The main steps of the DSS can be so summarized like that (see fig.2 below): the DSS receives from the PDKM the residual lifespan for each component for each truck. The garage manager defines the availability on different days specifying also the amount of intervention that can be done in each time interval which means how many components can be changed on that day. After this, the fleet manager specifies fleet characteristics (trucks models, number of trucks) and truck characteristics (average truck mileage costs) and chooses some of these time intervals according to the travels already planned for the future for each truck of the fleet.

The DSS elaborates data and calculates residual lifecycle costs for each truck for each intervention possibility and minimizes the cost of residual lifecycle for the entire fleet sending to the Garage manager and fleet manager suggested maintenance stops. The fleet manager communicate to the truck owner- onboard the next maintenance stops.

In particular for each component *c* (in the DSS prototype it was considered break, gear, oil) of each truck, the Life Cycle Residual Cost (LCRC) is calculated like:= $LCRC_c$ (t), expressing the cost of performing maintenance on component *c* in time window *t* taking into account the following cost entries:

- Costs of maintenance intervention (Material, Manpower, Waste disposal)
- Costs due to vehicle unavailability as a loss of productivity

- Extra costs due to intervention delay (function of the extra mileage) linked to:
    - Vehicle inefficiency
    - Risk of major failure with economical loss
    - Risk of failure with potential hazard for the vehicle / people

Once the cost for each component is computed, a set of Life cycle residual costs is defined also for each truck like: = $LCRC_{TR}$(T) where [T] is the array of *t* time windows for each of the components under maintenance:

$$LCRC_{TR}(\hat{T}) = \sum_{t=\hat{T}} LCRC_c(t_i)$$

$$\mathrm{LCRC_{TR}}\,(\hat{\mathrm{T}}) = \text{Life Cycle Residual Cost for each truck in } (\hat{\mathrm{T}})$$

$$\mathrm{t_i} = \text{time interval for maintenance on component } \mathrm{c_i}$$

$$\hat{\mathrm{T}} = \text{selected array of time intervals for a truck}$$

$$\mathrm{c_i} = \text{component; } \mathrm{c} \in \{\text{break, gear, oil}\}$$

Life Cycle Residual Costs for the different components monitored on a single truck are put together and computation of costs for each single truck is performed. A matrix with the LCRCs of performing maintenance on the components of the truck on the various time interval is obtained.

Using the point of view of the fleet manager, however, optimising the maintenance actions for all the trucks is the final aim. All the data of the different trucks belonging to a fleet are collected at the ground-station, in order to simultaneously take into account the different needs and availability of all the trucks.

In this contest considering the whole fleet, residual lifecycle cost ($LCRC_f$)can be defined as:

$$LCRC_f([T]) = \sum_{TR,T\in[T]} LCRC_{TR}(T)$$

Where [T] is the matrix obtained juxtaposing the different arrays T of all the trucks.

The $LCRC_f$ matrix for a fleet with nTR (number of trucks) and nT (number of time intervals during which each truck is available for maintenance) is given by nTR X N where N = nT + nT*(nT-1)*k + nT!/(nT-k)! (in the simple case of a fleet composed of 10 trucks, with 3 components under maintenance and 6 time intervals the matrix dimension is 10X216).

The output of this step consists of a calendar where dates for interventions to be performed for each truck and each component are shown. The algorithm minimizes the fleet LCRC to identify the scheduling of maintenance interventions on each component of each truck of the fleet.

This is computed taking into account also maintenance crew availability (in order to avoid the simultaneous stop of a number of trucks exceeding the garage man hours availability at a certain time interval) and respecting each truck declared availability.

In this model it is assumed that no mutual effects in terms of costs derives from performing maintenance on the different trucks simultaneously (or separately) which are considered anyway of minor impact. Given this assumption, the lowest $LCRC_f$ is the sum of the lowest $LCRC_{TR}$ of each truck:

$$LCRC_f([\hat{T}]) = \underset{[T]}{MIN} \sum_{TR,T \in [T]} LCRC_{TR}(T) = \sum_{TR} \underset{T}{MIN}(LCRC_{TR}(T))$$

Under the constraint that the number of maintenance interventions at each time t_i on components $NC_{TR}(t_i, c_j)$) does not overcome the Garage Availability in each t_i, $D(t_i)$, which means that the maintenance crew (garage manager) express the number of possible interventions for each day of availability.

$$\sum_{TR} \sum_{j} NC_{TR}(\bar{t}_i, c_j) * tm(c_j) \leq D(\bar{t}_i), \forall \bar{t}_i \in \bar{T} \qquad (1)$$

$$NC_{TR}(t,c), D(t) \in \{\text{int}\}$$

This first version of the DSS takes decisions according to the assumptions that time intervals are all equal to one day. Moreover the constraint (1) is relaxed and an iterative approach of minimization is applied as from the following steps:

- Put $[\widehat{T}]$ As the matrix of T that minimizes the overall costs for maintaining the whole fleet
- Verify whether the selected $[\widehat{T}]$ is "affordable" by the garage or not which means to verify if constraint (1) is respected. In particular: if the set of interventions required by $[\widehat{T}]$ is affordable by the garage, $[\widehat{T}]$ is the final solution.
- if $[\widehat{T}]$ is not affordable, for each truck a set of $\Delta_{i,i+1}(LCRC_{TR}[T])$ is calculated, through the following steps:
  a) $LCRC_{TR}[T]$ are ranked (from the lowest to the highest: $LCRC_{TR}[T_{i+2}] \geq LCRC_{TR}[T_{i+1}] \geq LCRC_{TR}[T_i]...$)
  b) $\Delta_{i,i+1}(LCRC_{TR}[T])$ is calculated as follows: $\Delta_{i,i+1}(LCRC_{TR}[T]) = LCRC_{TR}[T_{i+1}] - LCRC_{TR}[T_i]$
  These Deltas represent the costs due to passing from a certain solution T_i to T_{i+1}.
  c) A *Ranked_Deltas* array is defined, where all the Deltas of all the trucks are ranked from the smallest to the highest
  d) Choose $\min \Delta_{i,i+1}(LCRC_{TR}[T])$
  e) Calculate the new $LCRC_f([T']) = \sum_{TR} \underset{T}{MIN}(LCRC_{TR}(T)) + \Delta_{1st}$

f) Update *Ranked_Deltas*: *Ranked_Deltas* = *Ranked_Deltas* \ Δ_{1st} ;
then: re-rank Deltas

- Is this new solution "affordable" by the garage? (is the constraint verified?)
  - If yes: that's the final solution
  - If no: Is *Ranked_Deltas* = {0}?
    - If yes: no solution found. Ask the truck owners to change availability
    - If no: go back to step d)

The system here described has been implemented within a web based framework for Middle of life support under the context of lifecycle management of products. The system is under testing at the garage level and will be further developed refining some characteristics.

4 Conclusions

In the definition and implementation of this DSS, different stakeholders requirements have been taken into consideration, referring to actors that will use (or interact with) the tool in different steps of its lifecycle. The main addressees are in the Middle-of-Life phase: truck drivers/owners, fleet manager and maintenance crew. However, comparing actual performance of monitored components with reliability and features supposed at the beginning of their life provides value-adding information also to the design department of the truck manufacturer (Beginning of Life phase) and, finally, to End of Life actors devoted to the re-usage, retrieval and dismantling of the components. The here-described approach is still under development and the underlying project is on going. The collection of costs from many different actors is necessary to have an overview on the lifecycle costs, but it is also difficult to put them together. Anyway the consideration of Residual Lifecycle cost in the DSS permits to have a wider vision on the product and on the services connected to the product itself.

Benefits deriving from the adoption of this tool have been weighed up and compared to already existent solution through proper on-the-field inspections. In the commercial vehicles industry, nearly 80% of the trucks belong to a fleet of more than 15 vehicles. The availability of the means is a must, which puts high pressure on the correct and timely diagnostics and maintenance. The approach proposed here focuses on the optimisation of the fleet maintenance. All truck OEMs are currently involved into what is "static" maintenance supported by telematics systems: systems such as Blue and Me Fleet (IVECO), Fleetboard (DaimlerChrysler), Dynafleet (Volvo) propose services taking care of the (fixed) calendar of maintenance, with timely reminder to managers and drivers. In parallel, other automotive companies (e.g. GM with the Onstar service) propose remote evaluation and diagnostics of car components without embedded sensors, that is, only based on an analysis of their use.

The approach proposed here is an extension of both approaches towards what can be called a "dynamic" maintenance. This concept is based on the statistical analysis of the use of various selected components coupled with an analysis of the failure costs (mainly the unavailability of truck) and the maintenance costs (availability of garage operators, cost of resources). The result is the optimal timing for the substitution of several trucks components. The here described approach is thought not only to enable the optimisation of assets for fleet operators, but also optimise garage activities and decrease logistics costs (supply and stock).

5 Acknowledgements

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Proposal of a PLM standard for mass products

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Abstract: This paper presents the semantic data model behind a new-generation closed-loop PLM system. The model s able to fully address the requirements of a real-world closed-loop approach to PLM. In this approach, data on product instances, gathered from the field via smart embedded information devices, are used both to manage the lifecycle of existing product units, and to create, update and manage proper knowledge about the product, useful for the improvement of the future product generations. An exhaustive overview of the semantic model is carried out in order to describe how the model addresses the requirements cited above.

Keyword: Closed-loop PLM, Enterprise Product Data standards, Product lifecycle

1 Introduction

Within the globally scaled scenario, the product and its related management is becoming a key-aspect, definitely creating a product-centric or product-driven strategic problem. PLM has emerged as a feasible and promising enterprise solution. Its approach implies that all software systems, such as CAD (Computer-Aided Design), PDM (Product Data Management), CRM (Customer Relationship Management), ERP (Enterprise Resource Planning), etc., used throughout the value chain for the management of the product lifecycle have to be properly integrated. Nevertheless, PLM is not primarily an IT (Information Technology) problem but, at first, it represents a strategic business orientation of the whole enterprise [1].

The PROMISE (PROduct lifecycle Management and Information tracking using Smart Embedded systems) project’s approach to PLM aims at developing a new-generation product information tracking and flow management system. This system will allow all actors playing a role in the lifecycle of a product (managers, designers, service and maintenance operators, recyclers, re-manufacturers, etc.) to track, manage and control product information at any phase of its lifecycle, at any time and in any place in the world. The present paper mainly describes the conceptual semantic model behind one of the main components of this new closed-loop PLM system, the so-called PROMISE PDKM (Product Data and Knowledge Management) system. This system is devoted to the integration and management of product lifecycle data from different sources, with a major emphasis on field data sources, and to the creation, update and management of knowledge concerning the product, to optimize maintenance of the current products and to improve future generations of products. The model is being proposed as a new standard for product data and knowledge management in closed-loop PLM contexts. The need of developing a new standard arises from the fact that none of the existing enterprise product data standards is capable of addressing the whole set of requirements of the closed-loop approach to PLM. The shortcomings of the most important existing standards are briefly cited in the following pages.

2 The PROMISE approach to closed-loop PLM

The PROMISE EU-funded project is developing technologies, including product lifecycle models, Product Embedded Information Devices (e.g. RFID systems and bar-code systems) with associated firmware and software components, and tools for decision making based on data gathered during a product's life. The aim is to enable and exploit the seamless flow, tracing and updating of information about a product, after its delivery to the customer and up to its final destiny (e.g. deregistration, decommissioning), and then back to the designer and producer [2].

The prototypical PROMISE PLM system is currently being applied to ten application scenarios, covering the whole set of product lifecycle phases in the automotive, railway, heavy-load vehicles, instrumental and white goods sectors. The PROMISE PLM system is composed of many software and hardware systems and related infrastructures, some of which are listed in the following.

- The PROMISE PDKM (Product Data and Knowledge Management) system, is devoted to the management of both product data, collected from the field via smart product-embedded devices, and of the knowledge created and updated starting from this data, in order to enhance the product with new services and possibilities like, for example the design of new products in the future. The present paper is mainly concerned with the conceptual semantic model being at its basis.
- The PROMISE DSS (Decision Support System), which is part of the PDKM system, is devoted to the support of lifecycle decision making activities, thus providing the analytical basis to the PROMISE PLM system. Decision strategies to be applied in the different application scenarios (current and potential PROMISE products), and the related algorithms implementing these strategies, are the basic building blocks of the PROMISE DSS.
- A set of PEIDs (Product Embedded Information Devices), i.e. RFID (Radio Frequency IDentification) active and passive tags, bar-codes, sensors and on-board computers, with the related embedded and backend software systems, are the means by which field data is collected in the different product lifecycle phases.
- A PROMISE Middleware that provides means and an interface that allow different products to communicate in a common way to other products or computers and eventually to a centralized server.

3 Data and knowledge management requirements in closed-loop PLM

For the PROMISE approach to closed-loop PLM to become reality, and thus be applied to real-world products, product lifecycle data management must go well beyond its commonly known frontiers. In particular:

- the focus must be shifted from information on product types to information on product items, virtually each product item of any given product type. This is a new approach to tackle PLM, which requires:
    - the identification and tracing of each physical product entity;
    - the access to all data available on each physical product entity, with a major focus on the field-data collected while the product is being operated/used;
    - the use of these data by the decision support systems to be adopted in each real-world scenario to support decision makers in the value creation process.

Product items at the different levels of the structure of the physical product must be identified, and the related information must be properly collected, updated and managed. This must be possible for products with structures ranging from a very low degree of complexity, eventually one-piece products, up to a very high degree (such as cars, trucks or locomotives). Due to this variety of products within PROMISE it was required that the implementer of the single user case would be able to select the level of detail of the standard, which cannot be pre-imposed. The management of product structures must also be supported at the product-type level, i.e. at the level of the product "as-designed", such as in the most typical PLM/PDM systems.

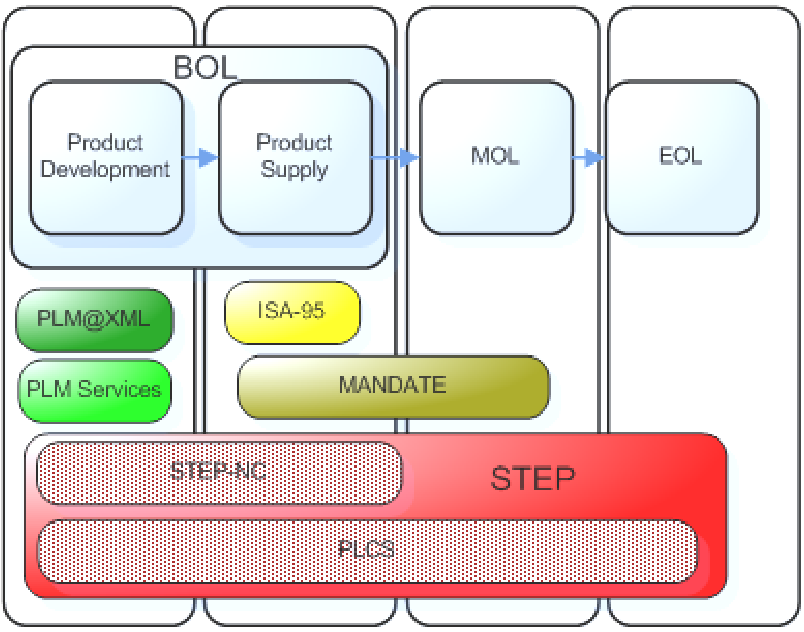
The problem of correctly identifying and tracing each item (so even each physical product component) during its life must be properly tackled. Moreover the approach to product data management should be compliant with the already existing approaches to product identification and traceability. All the field-data collected on physical products, assemblies/subassemblies and components, must also be properly modeled, before being properly managed. Pieces of information such as "who/what" collected each data record, "what" is the meaning of each record, "when" it was collected and "where" each record can be retrieved, should be available, virtually for each field-data type. Useful knowledge must be created, updated, managed and used, starting from the collected field data, with the aim of supporting both decisions on the currently existing product units, e.g. some the decisions concerning the maintenance actions to be performed, and the development of better new generations of products. It must be possible to support the semantic description of the different aspects concerning the product life cycle phases in which each real-world scenario is interested. This should comprise information on the major lifecycle events that are expected to happen, on the different PLM activities related to each particular scenario, as well as on the equipment, personnel and other resources involved in the closed-loop approach to PLM.

4 Shortcomings of existing enterprise standards

An analysis of existing PLM standards revealed that many proposals exists, but each one is focused on a specific area of the product lifecycle and none, except one, includes all the pieces of information needed to be managed during the whole lifecycle chain, as shown in the next figure. The only standard that includes all the lifecycle phases is PLCS, but this standard has been developed aiming to complex products with high support requirements and includes a set of procedures that have to be followed to use it properly. For its high complexity it cannot fit into the requirements of the PROMISE project, neither can be used for consumers and mass goods.

For these reasons a new data management model had to be developed for the PROMISE project, then, since it has been successfully implemented in the eleven application scenarios, it is proposed as a possible way to fill the lacks of a PLM standard for mass and consumer products.

Figure 1 Standards through Life Cycle Phase



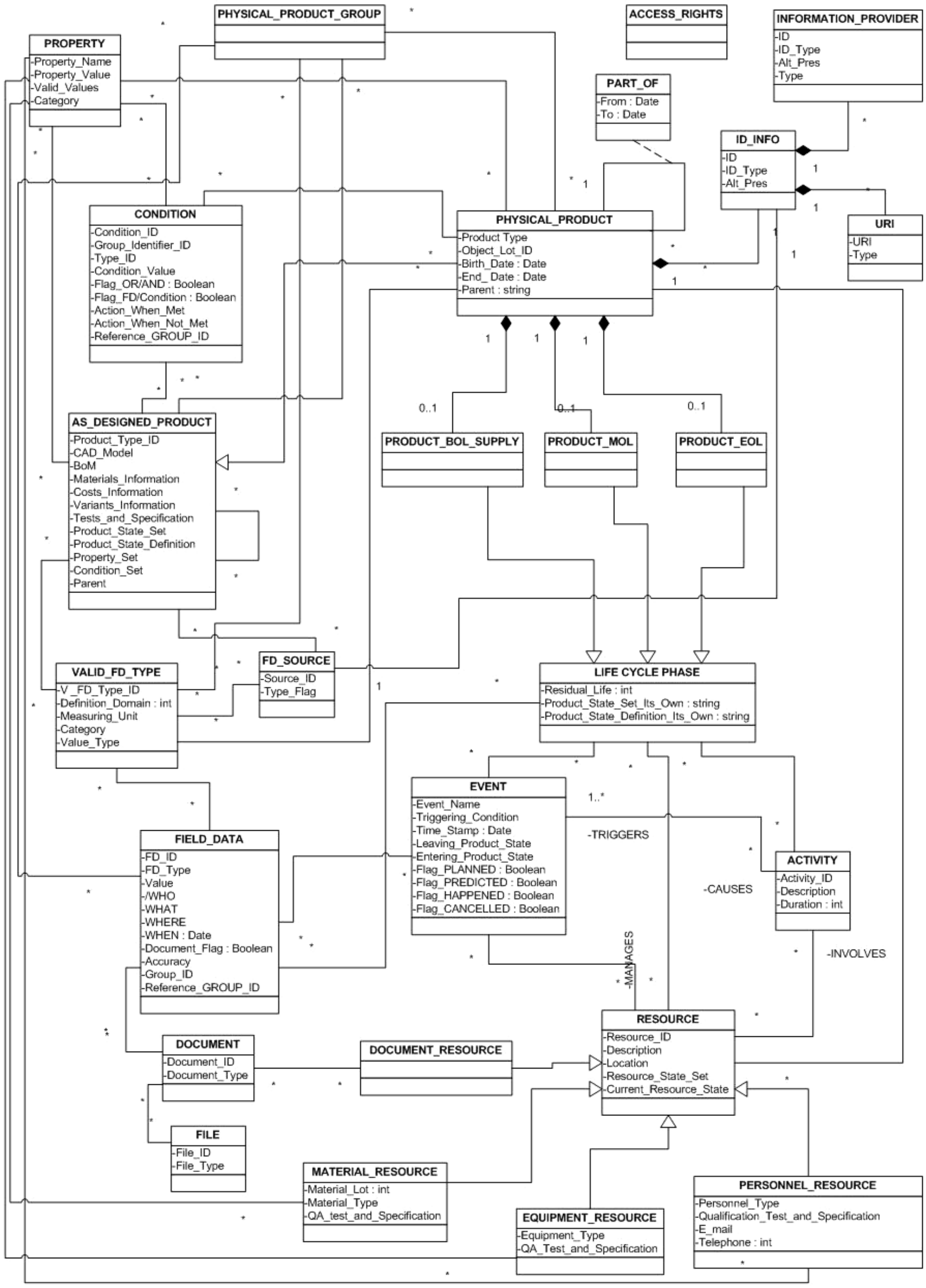
5 The semantic data model of the PROMISE PDKM system

Errore. L'origine riferimento non è stata trovata. represents, via the well-known class diagram of the UML de-facto standard, the semantic model of the PROMISE PDKM system. As foundation for the development of the proposed model, an existing approach was used, based on the Holon concept [3and developed within Politecnico di Milano, with the support of the CRAN research lab [4, 5]. In the following sub-sections the modeling elements are exhaustively described, in order to outline how the requirements listed in section 3 are met by the proposed set of classes, attributes and associations.

5.1. Identification and traceability of product items

A correct identification process of physical products and components is tackled within the PROMISE approach moving from the concept of PEID (Product Embedded Information Device), as defined in Section 2, which is intended as the joint between a product/article/machine/component and its electronic representation within an information system.

Figure 2 The semantic model of the PROMISE PDKM system



The PEID is responsible for uniquely identifying a component and is also means for collecting information on the product from the environment, either directly or via reference to a backend system. As the PEID may not be connected to the backend system all the time, it should provide means of local information storage, until the information can be relayed to the backend system at a later point in time. The communication with the backend system can either be carried out directly from the PEID using GPRS, internet connection, etc., or via a PEID reader (device controller). Examples of PEIDs can be bar-code tags, RFID passive and active tags, or even on-board computers, depending on the specific product. These capabilities of the PEID concept and related physical devices must be captured by the semantic model. With a special focus on the identification problem, the information model is compliant, at least in a conceptual viewpoint, with the most common traceability and identification systems, e.g. the Dialog System, developed by the Helsinki University of Technology [6], the WWAI-World Wide Article Information concept, and the AUTO-ID EPCGlobal proposal [7], just to cite some of them. The UML classes defined for item identification, tracking and tracing purposes are the PHYSICAL_PRODUCT, the ID_INFO, the INFORMATION_PROVIDER and the URI classes, which together enable the identification of product instances and the retrieval of the related information.

The PHYSICAL_PRODUCT class is intended to represent physical unique instances of products, assemblies/subassemblies and components. This class states the product/component type, the lot to which it belongs, the “birth date” of the product/component, and the “end date” in case the product/component has reached the end of its life, or it has am expiration date.

Another key role is played by the ID_INFO class, where one can find the item identifier (ID attribute), the coding schema used (ID_Type attribute) and eventually the representation of the identifier in other additional/alternative formats (Alt_Pres attribute). There are then two types of links to additional information, represented by the URI and the INFORMATION_PROVIDER classes. The former identifies the external data sources which are linked to the id, when relevant for some scope (as in the Dialog System, where URI stands for Uniform Resource Identifier), via e.g. the related IP addresses. The latter contains heterogeneous information that can be used to control requests for information by a traceability system, such as the definition of the adopted inter-enterprise communication systems (which, in traceability systems, take care of identifying the information providers).

Finally, the ACCESS_RIGHTS class plays a more abstract role and is a conceptual representative of the infrastructure aiming at the control of user access, by verifying rights and capabilities associated to user profiles and user roles, which is generally different depending on the way the semantic model is implemented.

5.2. Description of product structures

In order for the model to represent both “atomic” products, i.e. one-piece products, and complex products, some classes and attributes were devoted to the representation of product structures.

A first example is provided again by the PHYSICAL_PRODUCT class, where the Parent attribute acts as a link to the father node in the tree representing the product physical structure. The PART_OF association class was developed to update the list of components/assemblies/subassemblies being attached to the same physical product instance: the From and To attributes are there to represent the time instants when the component/assembly/subassembly is respectively attached to and detached from the physical product. It is also possible to keep record of past components/assemblies/subassemblies, based on previous records of objects of this association class.

The AS_DESIGNED_PRODUCT class describes on the other hand the product "as designed" structure, with all the needed information, such as CAD data (CAD_Model attribute), Bill Of Materials (BoM attribute), information on product costs and variants, on product materials, and all the other pieces of information which are typically stored and managed by PDM (Product Data Management) as well as common PLM systems.

The self-association between AS_DESIGNED_PRODUCT and itself, together with the Parent attribute, play a similar role to those of the PHYSICAL_PRODUCT class, in representing complex structures.

Product_State_Set and Product_State_Definition provide respectively the list of states a physical product can pass through during its lifetime, and the definition of the set of parameters identifying each state. The definition of how it can be concluded that the product has entered or left a given state is also provided here.

Finally, the set of properties and conditions applicable to the given product type are also referred by the Property_Set and Condition_Set attributes respectively. Section 5.3 is devoted to a discussion on the use of these particular attributes.

5.3. Properties and Conditions

The proposed model can also represent specific properties and conditions which must be verified, or must hold, for some specific product type and/or product item.

The PROPERTY class, originally inspired by the ISA-95 standard, defines the name of the property (Property_Name attribute), the possible values (Valid_Values) the property can take, the actual value (Property_Value), and some other kind of specifications (Category), if needed. This class is associated to both the PHYSICAL_PRODUCT class and the AS_DESIGNED_PRODUCT class.

The CONDITION class was developed to define some either atomic or complex condition which must be checked in some product life cycle scenario. For instance, it can be important to check if the current reading of some sensor attached to the product is over a pre-defined threshold, and eventually to start the activities in order to perform the needed maintenance, before the product breaks down. The Condition_ID attribute univocally identifies the condition, while the Group_Identifier_ID and Reference_Group_ID attributes are used to define complex conditions, by grouping atomic conditions together. The Type_ID attribute states if a condition relates to a property of a product type/instance or to some type of data collected on the field and concerning a specific product item (in this case, the field data type must be specified, as well as the interested data source). Finally, the actions to be taken in case the condition is met/ not met must be specified (Action_When_Met and Action_When_Not_Met attributes respectively).

5.4. Field Data

A fundamental of the diagram is the FIELD_DATA class, which enables the overall PROMISE approach to closed-loop PLM, by collecting product data from the field.

Field data can be of different types (VALID_FD_TYPE class), and is collected by means of sources such as sensors (FD_SOURCE class). It might be organized in documents (DOCUMENT class) with physical files (FILE class) attached.

The FD_ID attribute univocally identifies each field data record, while the FD_Type attribute states the type of field data (e.g. that it is a temperature of a certain sensor). The Document_Flag attribute says if the field data has an attached document related to it, while the Value and Accuracy attributes should be self explaining.

The WHO attribute states the source of the field data. This information can be also derived from the corresponding object of the FD_SOURCE class linked to the same FIELD_DATA object. The WHAT attribute explains the meaning of the data itself, while the WHERE attribute states the location where the measurement was carried out. The WHEN attribute then represents the timestamp indicating the moment in time when the measurement was carried out.

Finally, the Reference_GROUP_ID and the Group_ID attributes are used when there is the need of grouping some records of the same field data type together, e.g. because of the need of clustering in some way the data before analyzing it.

Field data have to be used to manage simple and repetitive life cycle data, such as the already cited data coming from the sensors attached to the product. On the opposite, they are not expected to store data regarding complex situations, which are instead represented by the EVENT, RESOURCE and ACTIVITY classes, discussed in next section.

5.5. Life Cycle Phases: Events, Resources and Activities

Different PLM scenarios have different requirements, not only in terms of how many components must be identified and/or are prone to be subject to life cycle field data collection, but also in terms of the number of life cycle phases during which the product items are monitored, identified, tracked and traced.

The semantic model can also model the whole set of information on the lifecycle phases considered in each application case. Different applications are related to a different set of life cycle phases: the proposed model must cover their different needs. For this reason, the three classes named PRODUCT_BOL_SUPPLY, PRODUCT_MOL and PRODUCT_EOL were created. The names of these classes reflect the PROMISE viewpoint on the set of product lifecycle phases to be considered. The first class refers to information related to the BOL (Beginning Of Life) phase of a product instance, from the production phase to the final delivery to the customer. Information concerning the design of the product is excluded from this class, because are described into the AS_DESIGNED_PRODUCT class.

The PRODUCT_MOL class refers to information related to the MOL (Middle Of Life)of a product instance, i.e. the usage phase and the maintenance/service phase. Then, the PRODUCT_EOL class refers in general to information related to the whole set of possible EOL (End Of Life) scenarios of a product instance (e.g. the remanufacturing phase, the recycling phase, etc.). Cardinalities of the composition associations linking these three classes to the PHYSICAL_PRODUCT class are there to indicate that only one object of each of these classes can be instantiated for each physical product item. Above all, it is in principle not mandatory to instantiate the object of the PRODUCT_EOL class, since this depends again on the specific application, which may e.g. only involve MOL issues: for instance, in a PLM scenario focused on predictive maintenance of boilers or machine tools only the PRODUCT_BOL_SUPPLY and the PRODUCT_MOL objects must be instantiated for a given physical product. On the opposite, a PLM scenario managing the whole life of a car, in compliance with the existing laws (see the E.U.

directives on ELV – end-of-life-vehicles) must also comprise the detailed description of the EOL information.

The LIFE_CYCLE_PHASE class then describes some important issues such as the residual life of a product component (Residual_Life attribute), or the definition of the set of states in which a product item can be at a given moment in time (Product-State_Set_Its_Own and Product_State_Definition_Its_Own attributes). In this last case the attributes on states definition are not part of the physical object, and the reason is that for different lifecycle phases a different state list is indeed defined.

Finally, in order to describe in more detail each lifecycle phase the model makes use of the EVENT, ACTIVITY and RESOURCE classes. These represent the second and most detailed method, apart from field-data recording, to manage physical product's information within the model. The associations among these classes basically state that an event triggers an activity that uses some resources, which in turn manage the event.

Examples of possible uses of these classes are, within a maintenance scenario, events such as "product breakdown happened" or "maintenance mission finished". These *events* must be properly managed, in the context of the maintenance *activities*, by using *resources* such as maintenance teams, spare parts and tools

6 Conclusions and further development

This work proposed a new model for the management of both product data and knowledge in a closed-loop PLM context. The conceptual semantic model at the basis of this new standard proposal was developed within the PROMISE project and in this paper is described in detail, showing in particular the way how the different requirements of closed-loop PLM are addressed by the elements of the model.

The model has been successfully implemented using MySAP-PLM database, and is used in eleven applications within the project consortium, ranging from plastic materials, to households to cars and even locomotives, which represent the maximum level of complexity achievable by this model. Due to these successes this model has been proposed as a possible solution for the lacking of a standard that can be implemented in a simple, fast and inexpensive way for products with a low and medium complexity, such as the consumer goods. For this standardization effort the semantic reference model will be improved with the contribution of interested people within the PLM community; moreover an XML exchange format and a MySQL reference implementation are currently under development.

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Assessing complex product lifecycle management and technology development research projects

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Abstract: This paper explores how complex R&D projects working in an iterative way and is in progress, can be assessed and how the assessments can be used in the projects in order to ensure success. Based on experiences from the PLM-related PROMISE and IT-development PRIME projects we will present how such processes have been carried out, and present a framework for assessment of complex R&D projects with feedback loops to the stakeholders and the project itself.

Keyword: Assessment, R&D projects, toolbox, framework

1 Introduction

The EU-Commission has funded the two research projects PROMISE (Product Lifecycle Management and Information Tracking using Smart Embedded Devices) and PRIME (Providing Real Integration in Multi-disciplinary Environments). Both projects are complex technology development projects with million Euros in development cost, and involve research and industrial partners from more than 10 European countries.

PROMISE is a complex PLM-project and the solutions will not suit the industrial partners unless working on their needs and develop solutions that will fulfil these needs. A total number of ten industrial cases/demonstrators are to be developed and implemented based on the developed solutions related to product embedded information devices (PEIDs), middleware, product data knowledge management (PDKM) systems and decision support systems (DSS). Together these technologies are designed to close the life-cycle information loop for products from beginning-of-life (BOL) to middle-of-life (MOL) and to end-of-life (EOL) and back to BOL.

PRIME is developing a game as a tool for experimental learning for professionals in strategic manufacturing by trying out new ideas in a virtual reality. Without developing a game with realistic approach to the companies' real life and problems, it will have no relevance.

The success of both PROMISE and PRIME is strongly connected to the cooperation between research partners and the industrial partners.

The challenge in these kinds of projects is that they are developing solutions that are in the forefront of R&D, for use in the companies of the participating industrial partners.

The main question is how to ensure that the solutions will fulfil the requirements of the industrial partners and how these requirements are influencing the R&D process. From a general perspective, industrial partners join such projects fascinated by the idea behind the project and convinced that the solution will give a positive contribution to the company shown in e.g. the bottom line through e.g. new services/products. Further, they need to participate in these kinds of projects because the R&D challenges are too huge for a single industrial company to carry out on its own. In many cases, the technological insight in specific solutions for e.g. PLM possibilities are not present, only the possible idea of how such technologies could be used for new service offerings and/or products. On the contrary, the research partners have the idea of what they are developing, but have too little knowledge and/or are too little concerned about developing a solution to fit the market for direct application.

To solve this challenge, the industrial partners and research partners need to work in an iterative process. This way of working indicates that the feedback and requirements from the industrial partners will develop during the time of the project as a result of a maturity process. The industrial partners' feedback should be included in the technological development to be able to make good solutions. It is easy to see the need for feedback from the industrial partners into the development process, but it is hard to work this way while a project is in progress, especially for complex research projects with a large number of geographically dispersed participants. However, this is important as it gives a project the possibility to adjust its direction towards the overall objectives.

The complexity of assessing such R&D projects becomes even more challenging as they might involve partners with different business models, visions and goals even though the partners apparently have common project objectives.

This paper explores how complex R&D projects working in an iterative way and is in progress, can be assessed and how the assessments can be used in the projects. Based on experiences from PROMISE and PRIME we will present how such processes have been carried out in these projects.

2 Assessing complex R&D projects

2.1 Purpose of assessing complex R&D projects

The purpose of carrying out assessments of large R&D projects while they are running is to identify if the project is on the right track regarding e.g. objectives, development work, communication/co-operation, exploitation and implementation. One of the most important aspects is whether the research activities really fulfills the needs and requirements of the real-life applications that are to be developed and implemented by the industrial partners.

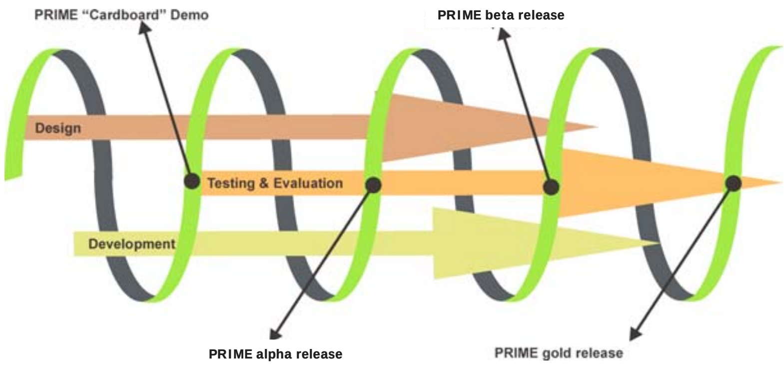
There exist many methods for assessing complex research projects where implementation and exploitation of the ongoing results are central. Vital for the assessment is the aspects that are to be covered. In this respect we are focusing on project management, technical, functional, performance and economic aspects.

A challenge in carrying out assessment is the iterative spiral approach used in complex R&D projects such as PROMISE and PRIME

2.2 The spiral approach to R&D

Both PRIME and PROMISE use an iterative method as a working process. Using an iterative method means there is a stepwise movement towards the goal, instead of a linear process from goal to solution [16]. The projects therefore must be assessed during progress and necessary steps must be taken to ensure that the process is "on track" towards the solution. Figure 1 shows the spiral approach as it is used in PRIME. In this project there are three processes which works in parallel (design, development and testing & evaluation). The testing & evaluation process is being repeated at each iteration to make sure that the project is on track.

Figure 1 Spiral Approach taken in PRIME



The basic idea behind iterative enhancement is to develop e.g. a software system or a product etc incrementally, allowing the developer to take advantage of what was being learned during the development of earlier, incremental, deliverable versions of the system [17]. Learning comes from both the development and use of the system, where possible. Key steps in the process are e.g. to start with a simple implementation of a subset of e.g. the software requirements and iteratively enhance the evolving sequence of versions until the full system is implemented. At each iteration, design modifications are made and new functional capabilities are added. The same is true for PROMISE where many iterative processes must be carried out when e.g. developing, implementing and testing technological capability of the developed solutions for PLM handling across the lifecycle of a product.

This method for working in projects can be constructive in securing that all available possibilities for having the best product in the end of the project. By assessing and testing the product during the process you can avoid different uncertainties and surprises in the project. The challenge in using these methods is when the project is large, have many different partners from different countries and cultures, like in PRIME and PROMISE. If the project workers test and assess, and see that the product needs to change, and give the developers new instruction too often, how can one secure that one reach the projects main objectives? If the iterative process always comes with new demands for the product, instead of getting closer to the solution, when will the project reach its goal?

The iterative working process with its constant replanning stands as a contradiction to project management, with clear and specified objectives and a clear workplan. However, when managing projects like PROMISE and PRIME this must be taken into account on the planning and replanning phases of the projects. As such, assessments of the ongoing projects become important. An analogy for reaching the overall project objective could be hunting a wild-boar in the forest. The wild-boar is the objective, however, the route will change and the activities to overcome and adapt to changing conditions in the forest becomes vital in order to reach the objective. Assessing and evaluating the surroundings during progress and giving feedback are therefore vital in order to adjust e.g. course. For complex R&D projects, project management, technical, functional, performance and economic aspects are here proposed as the main aspects to have in focus when assessing the projects.

2.3 Aspects proposed to be covered in assessing complex R&D projects

There are many aspects that are central for assessing complex R&D projects. In the PROMISE and PRIME project, the following aspects have been focused: project management, technical, functional, performance and economic aspects.

Assessing and accurately monitoring R&D projects across their lifecycle is difficult [1]. Based on a study carried out in 159 R&D projects, 10 critical success factors in R&D projects ranging from project mission to communication have been identified [1]. [4], [5], [6], [7], [8] and [9] all identify various aspects related to project management vital for success, among them: overall project objectives, strategies and activities. Together, these sources form the basis for overall project assessment.

Measurement of innovation maturity is another important dimension [2]. Here, aspects related to R&D projects are covered from a different angle, where the focus is more on the organization's ability to identify and implement R&D projects (including the process of resource allocation, R&D transfers and learning). The link between the project and the business product strategy which is important to succeed as an R&D project should also be part of an assessment [3].

Further, technical (e.g. transfer rate) and functional aspects (e.g. PEID able to securely communicate sensitive product data to database) are unique to each project and must be assessed accordingly. E.g. is the understanding of one specific functionality understood correctly by all participants in a project, or are there discrepancies in understanding. Assessing the correct technical, functional and performance aspects are difficult due to the nature of large complex R&D projects with many partners and cultures involved. More specifically, the spiral approaches adopted in PRIME and PROMISE further complicates the issue of assessment as there is a continually developing progress of the project based on the previous steps and results achieved.

An important aspect exploitation-wise is the economic aspect. One way or another all projects are supposed to justify the resources invested. This might be obvious for commercial partners, but also academic partners are expected to exploit results of R&D projects even if they might be counted in terms like number of articles, spin-off projects instead of money values, market shares etc. With external funding partners such as the EU, a project will normally also face quite strong expectations of proving a positive impact in private, public and social areas. From an exploitation view, these requirements must be addressed in the project, and the results must be measured. The challenge is how to measure these effects.

Normally such measures must be made at partner level. This means to measure the effects for each partner and try to figure out the overall effect of the project as a total and maybe added synergy effects.

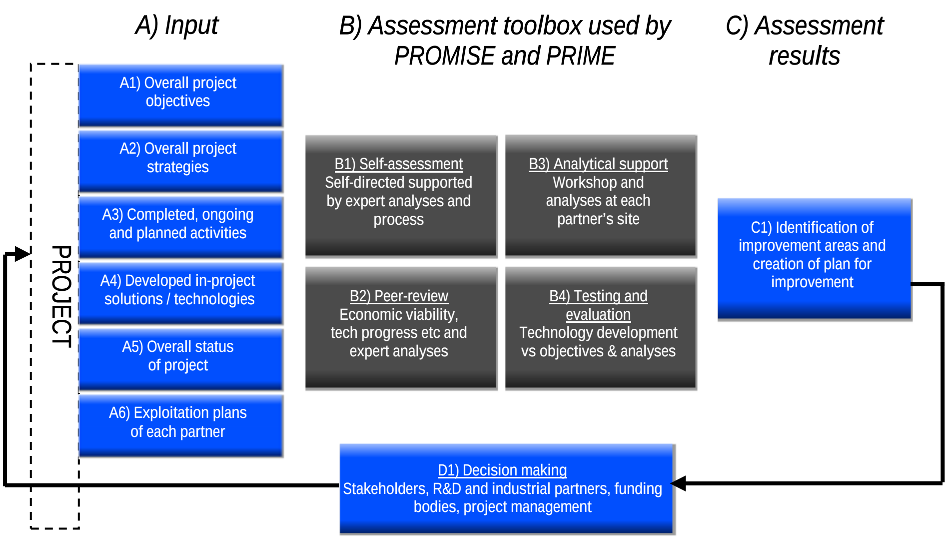
The most common way of measuring exploitation is using a cost/benefit approach. The cost/benefit analysis attempt to predict the financial impacts and other business consequences of the project. Often the project and its partners are expected to prove effects of resources invested as early as possible in the project. But this might be difficult in the early phases of a R&D – project as solutions etc might not be known well enough to quantify cost and benefits. As a R&D-project progresses, it enables the information gathering of the solutions, thus enabling more advanced cost/benefit analysis.

All these aspects contribute to what assessments should include. Further, methods for carrying out analyses of the gathered assessment data/information must also be specified.

3 Proposed framework for assessing complex R&D projects based on the PROMISE and PRIME experiences

Based on the experiences from carrying out assessments of PROMISE and PRIME, the following analytical framework is proposed (Figure 2).

Figure 2 Proposed framework for assessment of complex R&D projects based on the PROMISE and PRIME experiences



The inputs from the project(A1 to A6), ranging from overall objectives to developed technologies/solutions are used as basis for the tools in the Assessment toolbox(B1 to B4). The choice and use of the tools depends on what specific assessment(s) is/are to be carried out. One or more tools can be used in order to achieve the desired assessment. Each assessment tool consists of methods for carrying out the assessment and how to analyse the results. Based on the assessments carried out, summary analyses are carried out and identification of e.g. improvement areas are identified(C1). Here also status reports regarding the overall technological progress of the project as seen from the partners and other reports can be generated. The important feedback loop from the assessment is then initiated and is fed back to the decision making process(D1). Here, stakeholders of the project, project management, R&D and industrial partners will use the results for taking vital decisions related to go/no-go decisions, partial implementation and/or commercialization, leaving the project, reallocation of resources, what sort of e.g. improvement items are to be implemented/adapted in the project.

Experiences from PROMISE and PRIME have yielded the necessity to create a toolbox for assessment that consists of Self-assessments, Peer-reviews, Analytical support and Testing and evaluation All or some of these can be used together giving the status and identification of possible improvement areas and plans for implementing improvements in the project, i.e. a feedback loop.

3.1 Framework components

3.1.1 Inputs (A1 to A6)

The inputs to the framework are dependent upon what the objectives of the assessment are. As such, the shown inputs in figure 2 might be broadened or narrowed accordingly. However, the proposed inputs in the framework are those that based on research and experiences from the PROMISE and PRIME project are the most vital for carrying out assessments.

3.1.2 Assessment toolbox – Self-assessments (B1)

Organizations that perform successfully have a clear vision of why they exist, what they want to achieve and how well they are achieving it. They plan their work keeping in mind a clear set of objectives, activities, outputs, outcomes and measures. To take stock of their progress, they measure and assess as they go. They adjust their plans and approaches as required, on the basis of what they have learned [10].

Based on this, organizations need to assess their own performance within technical, functional, performance and economic aspects from a project point of view. An effective self-assessment, supported by an integral quality improvement plan that takes into account the outcomes of inspection, is the key to improvement [11].

Self-assessment is a systematic and comprehensive review of an organization's activities that should result in planned improvement actions [12]. The process helps organizations to identify their strengths and weaknesses [13]. The main point is to identify areas that require additional effort, while continue support for those processes which are already satisfactorily [14]. From a R&D project point of view, the aggregation of results from the self-assessments are important in order to not only assess the separate organizations, but also the overall project. This is a challenge as each organization has their separate internal objectives, while the larger R&D project with many partners may have other objectives that also must be fulfilled. However, the individual self-assessments can also be used as a communication tool and create understanding throughout the overall project. Even though there are separate individual internal objectives for each participating organization, such as in PROMISE, using a self-assessment also enables the possibility of benchmarking related to the exploitation of developed technologies and solutions. The self-assessments also include analytical frameworks in order to enable analyses (like impact in private, public and social areas, return on investment, evaluations of objectives reached, communication, technical and functional aspects etc) of the results found.

3.1.3 Assessment Toolbox – Peer-reviews (B2)

In complex R&D projects, it is important to have someone outside the participating partners / project to ensure validity of the project results. This is proposed carried out by peer-reviews. Peer-reviews make use of the opinions and judgments of recognized experts in particular fields to evaluate/assess publications, individual research projects, research programs, organizations, and fields of research [15]. A peer is defined as a person with expertise in the specific or allied technical area of the research being reviewed or in technology, systems, and operational areas that may be impacted in the future by the research being reviewed. [15] further states that peer review is the primary method used by US Federal agencies to assess the value of their research activities. The peer-review process in the Assessment toolbox, also contains analytical frameworks in order to enable analyses of the results found.

3.1.4 Assessment Toolbox – Analytical support (B3)

A crucial tool in regard of aiding the assessment of a project is the Analytical support process. The main objective here is to carry out workshops at each partner's site in order to e.g. aid/broaden the self-assessment. In Analytical support a pre-defined process has been established where e.g. market potential, technological challenges and other issues are covered and will be worked through with 3-4 persons from each partner (typically senior personnel and others involved in the project), and project assessors. The analytical support also includes analytical frameworks in order to enable analyses of the results found.

3.1.5 Assessment Toolbox – Testing and evaluation (B4)

Testing and evaluation is the process used to help identify how far the developers have come in developing the technology according to the projects objective. This can be done through testing the technical aspects of the technology, and e.g. identifying how far the technology is from being completed, what quality it is etc. It is a process of revealing quality-related information about the product with respect to the context in which it is intended to operate. The testing should reveal information of interest to someone who matters within the project community [18]. There are different methods of doing testing and evaluation of a project in progress. Examples of testing methods are unit testing (is the detailed design for the unit correctly integrated), integration testing (how does all the elements of the technology work together as a whole), system testing (are the retirements met), functional testing (testing that the product work according to the programmers) and e.g. testing according to what stage the technology has reached (alpha testing and beta testing). Testing can e.g. be done by surveys, interview guides, test cases and observation.

3.1.6 Assessment results (C1)

Even though each of the assessment tools have their own analytical process associated with them that gives assessment results, it is important to consolidate the results. These consolidated results contain clearly identified improvement areas and plans for implementing necessary actions in the project. The Assessment results are the foundation for decision making.

3.1.7 Decision making (D1)

The results of the analysis will serve as input for decision making for the different stakeholders of the project. From e.g. a business point of view, this will often be based on some kind of cost-benefit analysis. Which costs and benefits that are relevant, and the actual analysis will differ between the stakeholders and the concrete decisions that are to be taken. The decisions are at both project- and partner level. At partner level decisions will often be related to exploitation of business potential, whether to implement project outcomes, and when to implement. Decisions might also be whether to continue or withdraw from the project, reallocate resources etc.

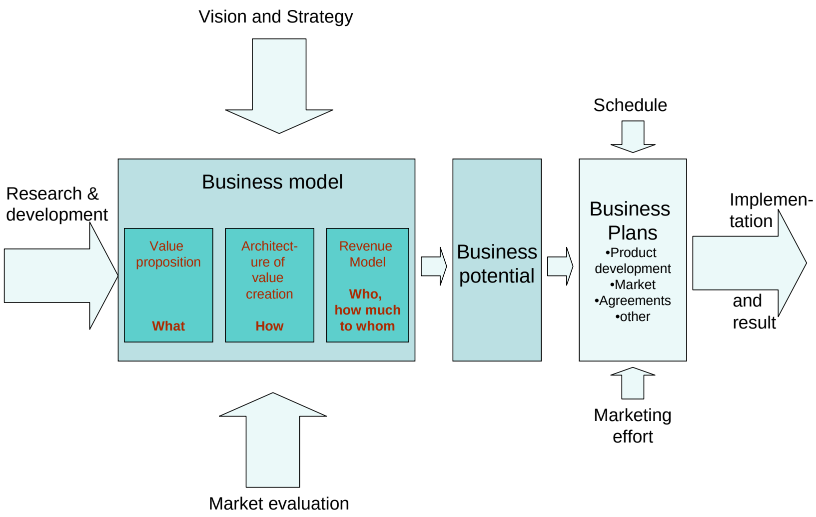
4 Experiences from using the proposed framework

This section presents some of the experiences from using the proposed framework shown in Figure 2.

PROMISE has carried out an extensive self-assessment and peer-review. The self-assessment of PROMISE explored 49 generic functions claimed by the industrial partners to be part of their applications. Functions were also identified by the research partners. The main objective of this assessment was to see if all the correct functions had been identified, if all understood the intricate connections between them in order to make information/data flow freely through the lifecycle of the products and generate knowledge in e.g. design or for the EOL-phase of dismantling. Further, 112 parameters/questions were of general nature related to project management, general technical aspects and economic factors such as return on investment. The final section of the PROMISE self-assessment addressed the economic and performance figures that could be used for cost/benefit analyses covering 87 parameters. Based on the self-assessments, it became clear that also the Analytical support tool had to be used in order to further explore the results and further aid the identification of cost/benefit items. At present time, PROMISE is halfway through its 48 months duration. As such, the spiral approach of R&D in the project yields more and more detailed knowledge of e.g. cost/benefit items and technical aspects. However, there is a clear need for further analysis and assessment of these items as more information becomes available. Together with the self-assessment, an extensive peer-review was initiated. The process of identifying peer-reviewers proved to be a more comprehensive task than first imagined. Even though the PLM technologies are known, extensive R&D is carried out in order to improve and integrate technologies ranging from, in some cases, RFID to advanced decision support systems. Therefore, identifying the correct peer-reviewers proved hard. However, the results from the peer-reviews that were carried out by creating application-specific peer-review packages have yielded important feedback information for the decision making process related to the progress of the project. The peer-reviewers assessed the purpose of the application, objectives, current state & technology, innovation, system architecture, business opportunities, and risks.

One example for use of the Assessment results in the decision making of the stakeholders could be illustrated by figure 3, where the assessment results impacted the business model development of the partners. Findings from the assessments carried out showed a lack of business potential identification. As such, plans were made to ensure that the development and refinement of business models for the industrial partners were improved.

Figure 3 Example of assessment results affecting the business model



The goal of the PRIME-project is to develop a game. In game development testing is crucial. There are different purposes for using testing as an assessment tool. During the game development new releases of the game are regularly tested to test the functionalities and for bugtesting. This testing is carried out by programmers and academic partners in the project and is to be considered as traditional testing. In addition, it's important to arrange testing which involves the participating companies – the end-users of such a game. The main objective for this testing in PRIME, is to ensure the game to be suitable for the involved companies. This is carried out in three ways in PRIME: Use of eRoom (web-based project workspace), use of testcases and finally assessment. First of all, new releases of the game are put on the eRoom once a week. All project members can volunteer to test the game if they want to, and give feedback to the developers. Second, the development of testcases is a structured way of using the participants in the project from the companies to go through testcases and give feedback from using them. The testcases can be done during the project meetings, or between the meeting with guidance by the responsible for the testing. Finally, the project has planned an assessment at the end of the development of the demonstrator of the game. This will be useful after the project for the further development of the game.

5 Conclusion

In order to work iteratively in complex research projects, the projects themselves must have a clear strategy in order to assess direction and work in order to tune the effort towards the correct direction. In this paper, a framework for assessment of such projects has been proposed. Experience from two large EU-funded projects shows that it works, but different approaches in the different projects require that the choice of assessment tools and contents of these tools must be adapted to the specific project. However, the framework itself, and the overall processes associated with it has proven to be a good method to structure the work of assessing progress in complex research projects.

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