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CONCURRENT ENGINEERING : THE MANUFACTURING PHILOSOPHY FOR THE 90'S

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ABSTRACT

Concurrent Engineering (CE) has recently been recognized as a more integrated approach to develope high quality products and bringing them to highly competitive global market at lower price and in significantly less time. In the past few years, an increasing effort has been made to understand and implement the principles of CE. However, there has been insufficient attempt to document these principles systematically. This paper examines the subject of CE and the ongoing studies which emphasize its various functions. A summary is presented and the projection of possible future research is discussed.

INTRODUCTION

The world-wide competitive economy is forcing us to produce high quality, well designed products at lower prices and in less time. As a more systematic approach addressing the above issue, increasing awareness is being directed to the product design phase. It is reported [Smock 1989] that the Ford Motor Company estimates even though product design accounts for only 5 % of total cost, 70 % of the cost is influenced by the design. Gatenby and Foo [1990] esitmate even higher percent (from 80 to 90) of the total life-cycle cost of a product is determined during the design phase. These figures demonstrate product design should lend itself to all its related manufacturing processes so that manufacturing objectives can be optimized through the optimized product design. I n this context, Concurrent Engineering (CE) has been recently recognized as a viable approach in which concurrent design of a product and all related processes in a manufacturing system are taken into consideration, ensuring the optimal matching of the product's structural and functional requirements and the associated manufacturing implications.

A survey of the literature reveals the lack of comprehensive study of the challenging concept of CE and there seems to be a pressing need for an in-depth study of all aspects of CE to rebuild the manufacturing competitive edges.

BACKGROUND OF CONCURRENT ENGINEERING

The product developement cycle begins with the conception of a product based on the market analysis or Research & Development (R&D) activities. Conventionally, a series of sequential steps are followed to design the product, identify the processes, machine the parts, assemble the components, and ship the products to the market. This traditional sequential path has not entailed the dialog between design and the downstream processes except a series of standard engineering change orders (see Figure 1).

However, the design decisions made early in the product development cycle can have a significant effect on the manufacturability, quality, product cost, product introduction time, and thus ultimate marketplace success of the product. It implies that all the system wide information should be used to augment the design information to arrive at the finalized product design for manufacture. This is the philosophy of concurrent engineering (CE), an integrated approach that entails concurrent design of products and their related processes in a manufacturing system, enabling to produce high quality, well designed products at lower price and in less time.

The philosophy of CE is not entirely novel. Pioneers of the automobile industry, like Henry Ford and Ransom Olds, practiced to a certain extent the philosophy of what we now call concurrent engineering [Evans 1988, Donovan 1989]. Owing to them and many others, the automobile companies as well as other

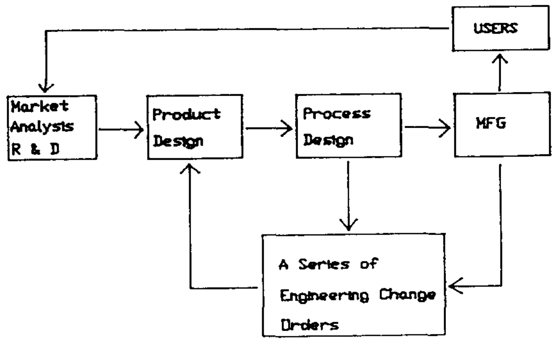

FIG.1 Conventional Product Development Cycle

companies have grown to become giant corporations with numerous departments each specialized in a task. This specialized separation actually contributed to the further development of special functions in the deaprtments. But it also caused some inimical effect to the corporates as a whole, mainly due to the lack of communications among those departments. This pracitce, however, was good enough to make profits in the era of tranquil prosperity. And it seems to be inevitable for those large corporate organizations to unfold their numerous tasks to several specialized departments.

As the world became more technologically competitive, people began to realize the importance of efficient utilization of manufacturing resources. Gladman [1968] emphasized that products should be designed "right-first-time for production" so that the manufacturing resources were used effectively to enjoy the maximum benefits. During the late 1970s and early 1980s in the U.S., a few individuals recognized the tremendous benefits that might be provided by more efficient product design for manufacture. Achterberg [1974], Boothroyd [1978, 1982], Datsko [1978] standed out as some of principal pioneers in tnis efforts to understand and practice the CE philosophy. Now as U.S. industries compete in the global market, the old ideas of design for manufacture is being rediscovered to restore the manufacturing competitive edges.

There may be two basic approaches for implementing the concurrent engineering practice : teamwork-based and computer-based approaches. The teamwork approach is human-oriented in that it consists of designers and individuals from all other related functional areas. Team members are selected for their ability to contribute to the design of product and processes by early identification of potential problems and timely initiation of actions to avoid a series of costly reworks [Pennell et al. 1989]. With the emerging representation schemes of manufacturing knowledge and knowledge-based expert systems, the teamwork approach is being enhanced by the computer-based approach in which the concurrent engineering philosophy is woven into on-line knowledge bases and algorithms (or logics), enabling design justification or optimization without any human dialog.

COMPUTER-BASED CE ENVIRONMENT

The underlying prerequisite to the computer-based approach is to acquire and represent concurrent engineering knowledge systematically, with which computers can perform required analyses. Figure 2 shows a conceptual model of the approach. In the Figure, the outer layer of the "Concurrent Engineering Wheel" is the advanced product modeler that provides the designers capability to invoke all inner layer functions to evaluate or optimize their designs without human intervention.

Product Modelers

It has been widely recognized that the integration of a CAD/CAM system as a continuum is a must to meet today's highly competitive market demands. However, there has been an apparent gap between design and manufacturing. In bridging the gap, the development of more versatile product modeling software should play the major role.

For a ideal computer integrated manufacturing system, one of the very basic requirements is that the part design feature as well as its dimensions must be readily available to a set of analysis software for justification of the design or to a process planner. Since the most current CAD systems do not store features and their attributes explicitly, a generic methodology for automatic feature recognition and extraction is required to make the manufacturing system as an integrated continuum.

Choi et al. [1984] proposed an algorithmic procedure to identify the features directly from its 3D Boundary representation model. They define a feature type as a pattern of faces and used a syntactic pattern recognition method to extract the features. Another method of extracting the feature from 3D Constructive Solid Geometry (CSG) model is proposed by Perng et al. [1990]. And an article [Pande and Prabhu 1990] reports an expert system for automatic feature extraction, constructed by using the OPS5PLUS expert system shell.

However, those attempts would be unnecessary if a methodology could be developed, in which all the feature information were retained in the geometric modeler. This idea led to the development of a modeling scheme called "Design with Features", in which the product is represented by features from the outset. Features are stored in a computer base as entities and the part functionalities can be represented by combining the related features.

Computer-Aided Process Planning

As previously mentioned, the philosophy of CE entails that product design and process plan be developed smultaneously. Ahluwalia and Ji [1990] proposed a structure of CAPP system in CE environment. The major three components of the structure are : interface to CAD and manufacaturing data base, process selection advisor, and process planning advisor. Major functions of the interface module are to identify manufacturing features of the part from the CAD data base and process-related data such as functioanality and capability of machines, cutting tools, workholding devices, machining parameter, etc. from manufacturing data base. Process selection advisor may communicates with manufacturability advisor for evaluation of each feature and select main manufacturing operations. The process planning advisor provides detailed information about the selected operations.

Design for Manufacturability

In concurrent engineering environments, the time to develope a new product can be significantly reduced by avoiding design errors and features difficult to machine before process planning begins. Anjanappa et al. [1989] propose an approach which uses a data base of flexible manufacturing cell capabilities in order to analyze a design for manufacturability, known as the Rapid Prototyping Protocol (RPP) developed at the University of Maryland. The RPP covered a wide variety of manufacturing constraints, providing the system the ability to reject the design which the cell protocol is unable to produce and suggest a design that may be more manufacturable to the user.

Lu and Subramanyam [1988] describes another structured design environment based on the knowledge-based systems to design part and process simultaneously . It consists of features data base, user interface, and manufacturability advisor. Feature-based part representation scheme using the features data base is selected to describe the design at any iteration of design stage, representing the details of the engineering part drawing by parametric descriptions of features. The user interface is the primary mode of interaction between the designer and the system in which the designer interacts with the system. The manufacturability advisor is modeled using the Multiple Cooperative Knowledge Sources (MCKS) paradigm under which a problem is solved by cooperative effort between a hybrid collection of multiple knowledge sources. The advisor module interacts with the manufacturing knowledge base and manufacturing cell data base to evaluate the preliminary design of a part.

Design for Assembly

Assembly is often the most labour intensive operation and accouts for major portion of the total costs. The concept of Design For Assembly (DFA) has been arised in the hope that all discrete component parts will be designed so that they are easily assembled and the cost is significantly reduced. A DFA system, the UMass, was developed at the University of Massachusetts [Boothroyd 1982] for rating the efficiency of assemblability based on two factors : the easiness of handling and assmbling of component parts and the number of parts used in the product. If the rating is low, then redesign is recommended.

Runciman and Swift [1985] developed an expert system that estimates the costs of handling and assembly equipment for a given part design in two dimension. The system informs the designer with any difficulties that part presents for automatic handling during manufacture and suggestions for the improved design.

Holbrook and Sackett [1988] studied existing DFA methodologies and classified them into four groups : specific assembly operation theories, unstructured rules and concepts, procedural methods of applying rules, and expert system/knowledge based systems.

Cost Prediction

CE should also address questions about how product costs can be predicted at designing stages so that the product's profitability is determined. If the projected cost of the product being designed exceeds the cost limit, then an analysis software may suggest to discontinue the further development or redesign the product.

The most important factor of cost prediction is construction of cost models that can derive meaningful cost estimates based on the collected data. The model required to track costs in CE facilities will be different from the usual models for estimating product costs. Moore and Creese [1990] describe the new accounting philosophy for the model that may be used in CE environment. First, Engineering Change Order (ECO) has to be
assigned to specific products. secondly, overhead must be held to a minimum so that as many costs as possible can be assigned to products as direct costs. Finally, cost changes in machining, quality control, and inspection must be tracked so that the cost model adapts itself to treat the change as costs per unit change.

Wong et al. [1991] propose a Totally Integrated Manufacturing Cost Estimating System (TIMCES), which can be easily integrated with the other engineering software systems. The input to the proposed TIMCES system will be provided by several databases including CAD, CAPP, material cost, labor cost, etc., which is a very important characteristic required in CE environment.

FUTURE TRENDS

The implementation of CE principles will utilize new hardware as they become available. For instance, sensor-equipped intelligent robots will be emerged and used for fully automated assembly. This will be able to relax the constraints imposed on the product design from the standpoint of assemblability, enalbling the product with more power and sophistication be made in CE environment.

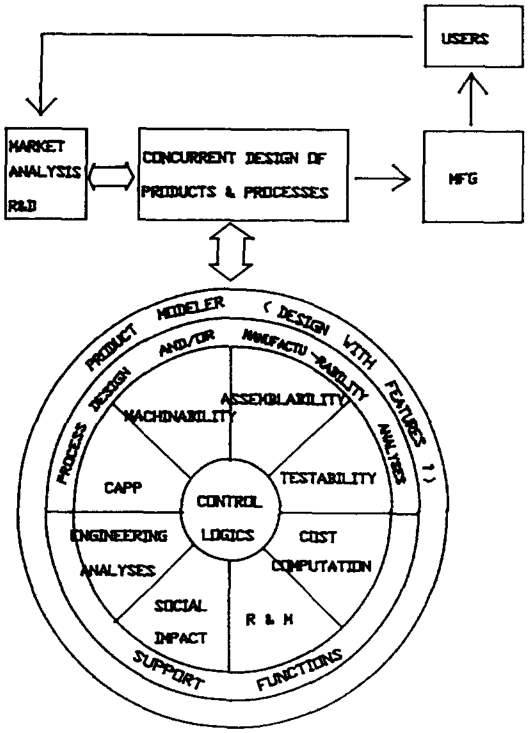

FIG.2 'Concurrent Engineering Wheel'

The product data representation schemes currently available are far from satisfaction and the subject is considered one of the bottlenecks to integrate manufacturing system as a continuum. It appeared that the product representation schemes and feature recognition/extraction methodologies will be a topic for further development effort.

Also it is not hard to anticipate there will be an effective combination of human and artificial intelligence, with the human intelligence creating a design and the artificial intelligence analyzing every designing phase and suggesting the possible improvements based on previously constructed knowledge base.

CONCLUSIONS

A survey of Concurrent Engineering (CE) has been conducted and found that CE is a huge subject spanning manny disciplines and points of view. Furthermore, CE is essential to attain the truly integrated manufacturing system and will be a challenging task for manufacturing society to implement the philosophy.

If the "Concurrent Engineering Wheel" is carefully designed, constructed, and spun in industries, then it may become the "Wheel of the Fortune".

The Computer Integrated Manufacturing (CIM) milieu in the 21st century is conceptually described [Goldhar and Jelinek 1990] as a situation called "the automation of custom manufacture" where the customer participates at least some degree in the design of the product he wants and decides how much "service" in terms of custom requirements and speed of delivery he is willing to pay for. The gap between this concept and reality will be diminishing if CE is understood and become a part of our industrial practice.

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