CONCURRENT ENGINEERING: Research and Applications

The Development of Project Risk Metrics for Robust Concurrent Product Development (CPD) across the Supply Chain

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Abstract: Many companies report that they can attain a competitive product development advantage from strategic relationships with key suppliers, but even the successful relationships are not without their challenges. Industry has expressed a need for robust concurrent product development (CPD) practices to include supplier issues. Unfortunately, most of the practices currently available provide little to quantitatively analyze the product development process and to identify risk as a direct result of supplier interactions. This study develops metrics that characterize product development project risk that results from supplier interactions by using the concepts of degree of design customization (DoDC) and coupling ratio (CR). A correlation analysis based on HP LaserJet development projects demonstrates that the proposed metrics for DoDC and CR are good indicators of the likelihood of product development efficiency. Furthermore, there was enough evidence to use the interaction term, the CR multiplied by the DoDC, as a risk index. An important implication of using the coupling assessment as part of the project risk assessment is that the same process can address both project and product risks.

Key Words: concurrent engineering, supply chain, project management, product development risk, supplier relationships, original design manufacturer.

1. Introduction

1.1 Background

As many industries move toward global sourcing of engineering services, product developers face an increasing challenge in dealing with key partners and suppliers, who have a significant role in the design of their product's major subsystems. Conversely, suppliers of major components and assemblies must also coordinate their technology development and product design efforts with companies that integrate the product. As these partnerships become more global, managing concurrent design across the supply chain becomes a key element in accelerating development cycles and enhancing quality. The authors refer to this emerging field in design for manufacturability (DFM) as concurrent product development (CPD) across the supply chain. Esterman and Ishii [1] surveyed the challenges faced by companies during CPD across the supply chain and identified three common issues faced by these companies. They are (1) overcoming cultural barriers, (2) reaching a common understanding of the product definition, and (3) the need for robust technical product development practices. The aim of this research is to develop a set of metrics and a process to aid product development practitioners and managers with product design decisions that span the integrator–supplier interface.

Esterman and Ishii [2] defined a set of requirements that are essential to a robust CPD strategy across the supply chain.

- Identify CPD risk areas from supplier interactions.
- Explicitly link the voice of the customer (VOC) to the risk assessment process.
- Prioritize system level engineering metrics (EMs) and supplier level EMs based on this risk.
- Guide risk mitigation and management.
- Allow analysis throughout the CPD life cycle.

To address these requirements, the concepts of degree of design customization DoDC and degree of coupling were introduced as a framework by which to evaluate the risk introduced into the product development process by suppliers. This risk needs to be considered at four levels: (1) the product development program level, (2) the supplier subsystem level, (3) the EM level, and (4) the component level. The focus of Esterman and

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Ishii's work [2] was at the EM level. This study seeks to extend that work by considering risk at the program and supplier subsystem levels.

1.2 Project Risk Assessment

A key element of traditional project management is risk assessment. The most common treatments of project risk involve three key steps: (1) identify risks, (2) analyze risks, and (3) develop actions to eliminate or minimize risks [3,4]. Typically, each step is assessed by engineering judgment. Brainstorming techniques and past experience are the most common methods used to identify risks. Criteria, such as impact and likelihood based on a high/medium/low scale are typically used to analyze risks. More sophisticated methods, such as Monte Carlo simulation, are usually reserved for more severe risk consequences. Last, developing actions to address the risk areas is dependent not only on the quality of the solution chosen, but on the quality of the identification and analysis steps.

The remainder of this section summarizes three alternate methods to analyze project risk: project failure modes and effects analysis (FMEA), construction management practices, and the design structure matrix (DSM).

1.2.1 *PROJECT FMEA*

Kmenta [5] has developed Advanced FMEA (AFMEA) to improve the FMEA process. AFMEA uses behavior modeling to identify and to analyze complex process failures [6]. Adapting it to analyze product development project risk requires one to look at the ways that product development design tasks can fail [5]. One example is that the task may not be executed properly, which can impact dependent downstream tasks, and ultimately result in designs that are too costly or have poor performance. Another may be that the task is not executed at all or it may take too long to execute, which could result in project cancellation or delays.

While this approach is useful, the main problem is that the analysis on a key supplier requires the system integrator to have access to the supplier's key subsystem tasks and their dependencies. This information may not be readily available, and if it is, the supplier may not be willing to share such information.

1.2.2 *CONSTRUCTION MANAGEMENT PRACTICES*

Gould and Noyce [7] have documented some of the more common problems that result in construction project failures. These are summarized here.

- Separated Functions – In the construction industry, the design of the project and the execution of the project are usually carried out by entirely different entities. In addition, a third player is usually the owner. Communication between these entities is critical to project success, and failure to do so will result in schedule delays, cost overruns, and quality problems.
- Scope Creep – Construction projects usually involve complex and highly political organizations, which makes consensus very difficult to attain, makes miscommunication easier, and makes it easier to miss key input into the planning process. It is common for this to result in project scope changes, which usually results in higher costs.
- Project Acceleration – The obvious benefits of early project completion are lower costs and a feeling of satisfaction from all participants. However, the main risk of project acceleration is poor planning in the design stage that results in delivering less than expected value to the owner.
- Poor Working Relationships – In the construction industry, relationships tend to be one-time. The result is miscommunication and has been already discussed.

In the risks already described, it is obvious that partnerships and suppliers are key contributors. This is not surprising since subcontractors perform a large percentage of the work on most contracts [7].

Two common ways to minimize risks are to allocate risk between owner, contractors, and subcontractors through contract agreements and to select the appropriate project delivery type [4,8–10]. The design-build approach (in which the design firm is also the construction firm) is a project delivery method that has been growing in use. The major benefit is reduced communication issues, which is at the heart of much of the construction project risks.

A brief survey of the literature on project risk characterization showed that contractors and subcontractors do impact project performance [11–15]. However, the recommendations are at a high level and are better suited for guiding management decisions rather than design decisions.

1.2.3 *DESIGN STRUCTURE MATRIX*

The design structure matrix (DSM) is a tool for representing and analyzing task dependencies. Other common tools include Gantt Charts, PERT Charts, and Critical Path analysis. However, the strength of the DSM is that it identifies tasks that are sequential, parallel, and coupled. Coupled tasks are mutually dependent, which means that each must be completed for the other to be executed. The net effect is that each task must be completed simultaneously with continuous exchange of information or it must be carried out in an iterative fashion [3].

The DSM is the basis for more advanced research on project management and product development [16–22].

The concept of coupling is relevant to CPD across the supply chain. Martin and Ishii [18] further developed this concept to evaluate coupling between components, which is discussed further in Section 3.2.20.

1.2.4 SUMMARY

A common issue that underlies the methods discussed here is communication and sharing of knowledge. Prasad [23] has highlighted the importance of not just information transfer, but knowledge transfer as an important enabler to meet product realization goals in a concurrent engineering environment. Clearly, the utilization of knowledge and the sharing of knowledge across the supply chain is an important activity. One of the aims of this work is to develop risk metrics and an assessment process that enable the system integrator and the supplier to be less reliant on that knowledge stream. The idea of robustness is useful in this context because one can view the variation in that knowledge stream as a source of noise. The development of the risk metrics broadens each party's knowledge with less reliance on each other.

2. Risk Framework

Robust CPD across the supply chain is achieved by identifying the risks introduced into the product development process by suppliers. This guides mitigating action to eliminate or minimize these risks. One can argue that CPD uncertainties arise because of the added complexity that is introduced into the development process. There are two dimensions that define complexity, a quantity measure and a difficulty measure [24]. With respect to CPD across the supply chain, it is useful to think of complexity as a function of the DoDC of the supplier subsystem and its interactions, or coupling, with the rest of the system. The DoDC refers to the spectrum bounded by an off-the-shelf product on one end and to a totally new subsystem design on the other. It is related to a quantity measure since the greater the DoDC, the greater the number of design tasks to be executed by the supplier. The supplier coupling is related to a difficulty measure, since even with a small number of design tasks if there are many interactions between the subsystem and the rest of the system, the likelihood of issues increases.

2.1 Defining Risk

The definition of risk has been well documented [25–27]. In this work, risk is characterized by a chance element and a consequence element [25]. Program level risk relates to the success or failure of the overall product development project. Supplier subsystem risk relates to the product development issues that arise with each supplier.

2.1.1 CONSEQUENCE ELEMENT OF RISK

At the program and supplier subsystem levels, the three measures that characterize the consequence element of risk are product-related performance (e.g., features, services offered, etc.), time-to-market (TTM), and cost. These measures relate directly to the dimensions of product development success. For the correlation study discussed here, these measures are TTM, number of design issues logged during the product development process, and the failure rates as reported in use of the product after its release. The third dimension, cost, was not tracked due to difficulties in allocating development costs between programs.

2.1.2 CHANCE ELEMENT OF RISK

It was already postulated that DoDC and coupling are indicators of risk and hence represent the chance element of risk. The focus of this study is to validate these claims. Section 3.2 will further define the terms of coupling and DoDC.

3. HP Correlation Study Design

To validate the postulated framework, a study of actual product development projects was undertaken. This study was conducted at Hewlett-Packard Imaging and Printing Systems in Boise, Idaho, and focused on laser printer systems development projects, which rely on a key relationship with a leading Japanese supplier, Canon. HP takes responsibility for controller and printer performance and quality. Canon takes responsibility for engine performance and quality, and drives improvements to remedy identified problems. Figure 1 illustrates the printer supply chain for one of the more complicated printer systems.

3.1 Correlation Study Objectives

If the risk framework proposed here is true, then the following hypotheses should hold:

(1) Programs that have a high DoDC and are highly coupled
- take a longer time to be introduced into the market,
- generate more design issues during development, and
- generate more field failures after product release.

(2) Supplier subsystems that have a high DoDC and are highly coupled
- generate more design issues during development and
- generate more field failures after product release.

Thus, if the hypotheses are true, the metrics developed for DoDC and coupling should correlate with TTM,

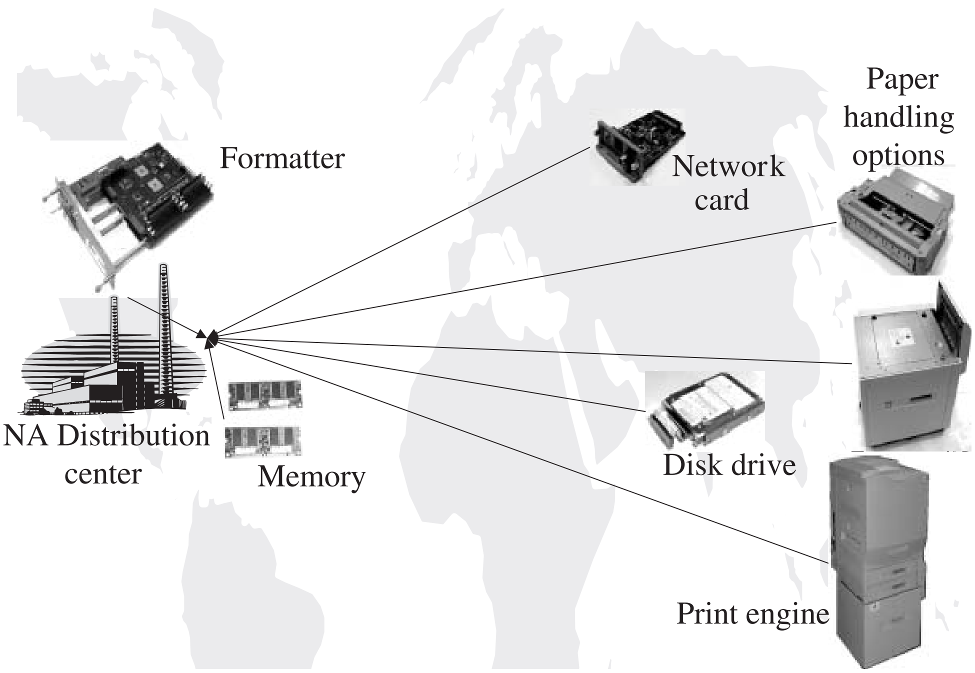

Figure 1. Laserjet supply chain for North America.

number of design issues logged, and field fail rates. The following sections will do just that.

3.2 Correlation Study Metrics

3.2.1 DEGREE OF DESIGN CUSTOMIZATION

As previously mentioned, DoDC is evaluated at the program level and at the supplier subsystem level. In each case, the following rating system is applied:

- 9 – A totally new subsystem design
- 6 – Customization of an existing design
- 3 – Minor modifications to an existing design
- 1 – No modifications to an existing design

The idea is that on one end of the spectrum, there are many design tasks that range from conceptualization to design to manufacturing and on the other end, the existing design need only be integrated into the system design, which requires far fewer design tasks. This idea closely parallels Prasad's [23] idea of 'window of rewards' in which the risks, and hence the profitability, are linked to the type of changes being made to the product. The categories identified by Prasad [23] were: features currently available in existing product or competitive products (low risk, low reward), mild modifications to features in existing or competitive products (medium risk, medium reward), and development of new features (high risk, high reward). These categories are similar to the ones already presented.

In addition to the number of tasks, the collaborative supply chain sharing patterns and the amount of knowledge exchanged are closely linked to the DoDC metric, with a higher DoDC corresponding to a greater amount of information exchange.

At the subsystem level, the implementation of DoDC was based on collective HP engineering judgment. At the program level, engineering judgment again proved to be the better method. Averaging the subsystem DoDC scores was attempted, but a problem arose, which is illustrated by the following example. On one of the color platforms, there were four paper-handling devices that had been proven on other platforms. When a simple average was taken of all subsystems, this resulted in a disproportionate weighting to those four devices, which artificially lowered the system DoDC score. Since the system design was new and used unproven technology, a rating of 9 was the better assessment for the system.

3.2.2 Coupling

The coupling definition adopted in this work is derived from the following: 'Two components are considered coupled if a change made to one of the components can require the other component to change' [28]. In this case, the component of interest is the entire subsystem that has been assigned to a particular supplier.

The coupling measures are derived from the matrix illustrated in Figure 2. For this study, each cell was populated if the following condition was met:

- A change or failure to meet the supplier EM would require a change to the system level EM.

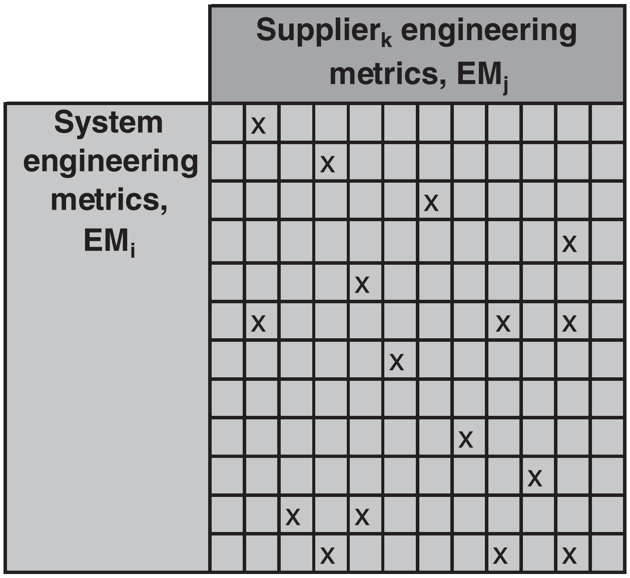

Figure 2. Coupling ratio matrix.

As an example, consider the print engine supplier subsystem EM of engine speed. If the supplier made a change to this metric or failed to meet the target, clearly the system level EM of first page out time would need to change and thus the two EMs are coupled.

Note that this assessment is architecture dependent and the engineer's knowledge of the existing design embodiment is an implicit part of the evaluation process. Consider the engine supplier EM of optical density variation. If the supplier were to fail to meet the EM, one might naturally think that the system level EM of color consistency would have to change. However, if there is a feedback control system that is implemented to control color consistency, then the degree of variation that can be tolerated from the engine is much greater. Thus, strictly speaking, the two EMs are coupled but for evaluation purposes the team may consider the EMs to be decoupled because it would take a very large change on the supplier's part to affect the system EM.

After populating all the cells, the coupling measures of system coupling count and the coupling ratio (CR) were derived. The system coupling count is simply a summation of all the interactions between the system EMs and supplier EMs, where the above condition was met (see Equation (1)). The CR is defined as the system coupling count divided by the number of supplier subsystem EMs (see Equation (2)). This is done so that the coupling measure is not artificially increased just because one engineer specifies a subsystem more completely than another.

$$\text{System coupling count} \equiv \sum \text{Interactions} \qquad (1)$$

$$\text{Coupling ratio} \equiv \frac{\text{System coupling count}}{\text{Number of supplier EM}} \qquad (2)$$

Note that only the author populated the coupling matrices as it was difficult to re-engage a design team on a product that had already been released.

Equation (3) shows the program level definition of global coupling (GC).

$$\text{GC} = \text{Max}(\text{CR}_j) \qquad (3)$$

where, CR_j is all of the supplier subsystems for a particular development project.

This definition was chosen because it gave the best results. The supporting rationale for adopting the definition is that the system is as decoupled as the most coupled subsystem.

3.3 Relating Risk to Concurrent Engineering

The ultimate aim of the project risk metrics postulated here is to improve the concurrent engineering process. Prasad [23] thoroughly documents the fundamental principles and essential components of concurrent engineering. The remainder of this section formally links the project risk metrics to these enablers for concurrent engineering.

Prasad [23] cites eight fundamental principles of concurrent engineering: early problem discovery, early decision-making, work structuring, teamwork affinity, knowledge leveraging, common understanding, ownership, and constancy of purpose.

The project risk metrics defined in Section 3.2 can help in four of these areas: early problem discovery, early decision making, work structuring and to some degree, common understanding.

Derivation of the coupling measure is based on the amount of interaction between the system requirements and the subsystem requirements. Embedded in this derivation is information about the areas in the system and subsystems that could potentially be problem areas. Though this is not explicitly discussed in this article, it is the subject of another article, which develops a methodology for CPD across the supply chain.

In addition to identifying problem areas, the proposed metrics can be indicative of the development time and the number of design issues that are likely to arise. This will facilitate decision making and work structuring by focusing resources on potentially problematic subsystems; it could help to identify which platforms and/or combinations of suppliers would be best to pursue; and it could help allocate testing resources. Most importantly, they allow the development and evaluation of risk mitigation strategies. An additional benefit of this early evaluation is that it allows the integrator and the supplier to discuss issues up front and reach a common understanding that is focused on problem resolution and is driven by analysis.

3.4 Correlation Study Design

Twelve product development programs completed between 1995 and 2001 were studied. A variety of projects were chosen to include a mix of factors as follows: monochrome and color products; midrange and high-end products (6–50 pages/min); products with and without paper-handling devices; and new and leveraged platforms.

The consequence risk data were easy to collect. For each project, the total TTM, the number of design issues logged, and the field failure rates were collected. For the latter two items, these were collected at the program and at the subsystem level.

The DoDC data were generated by talking with engineers who had knowledge of past development projects. To construct the coupling data, system requirements and supplier design specifications were collected. In general, the system level specifications were poor and the supplier level specifications were good. The reason for this is that HP specifies systems and subsystems in an incremental fashion. Thus, if the project was a leveraged platform, the system requirements that had been previously met were not explicitly listed. However, if there was a change at the supplier level, this had to be documented.

To arrive at a useable set of system requirement data, a set of core color and monochrome requirements was developed and then each program's set of system requirements was compared to this list and the appropriate additions were made. The final data sets were reviewed to check for consistency with the original system requirements documents.

Given the difficulties in obtaining complete specification sets for all subsystems and the lack of some field data, the final data set consisted of seven product development projects and 16 supplier subsystems.

4. Study Results

This section demonstrates through regression analysis that the consequence element of risk is a function of DoDC and coupling (Equation (4)) at the program and supplier subsystem levels. Ideally, this relationship would be the function of one number, allowing one to assess risk simply by numerical comparison (Equation (5)). Thus, where possible, this relationship is motivated using the interaction term (DoDC $\times$ GC or DoDC $\times$ CR). When that fails, it is necessary to look at the two-factor regression to test for correlation.

$$\text{Risk}_{\text{Consequence}} = f(\text{DoDC}, \text{CR}) \tag{4}$$

$$\text{Risk}_{\text{Consequence}} = f(\text{DoDC} \times \text{CR}) \tag{5}$$

A quasi-validation step is presented that opportunistically takes advantage of data for two additional development programs. These two additional data sets are added from programs that did not have stable field failure rates when the original analysis was conducted. While this validation test cannot be performed on the field failure rates, they are included in the other areas to test the effect of this new data on the conclusions originally drawn. The original data set uses the seven programs that had complete data.

4.1 Program Risk Index versus Time-to-Market

Figure 3 shows the results of the program level analysis for TTM. It is clear from this analysis that

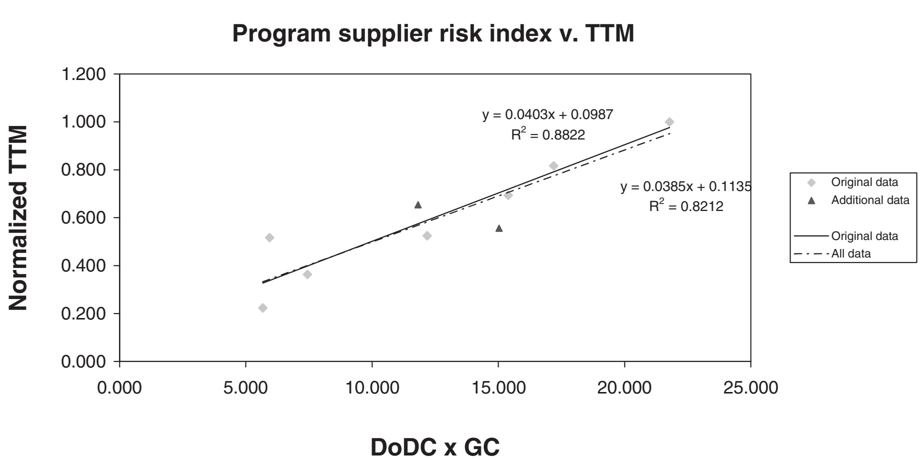

Figure 3. DoDC $\times$ GC vs TTM.

Table 1. Summary of regression results.

Development efficiency metric	Interaction term regression result (R^2) (%)	Interaction term regression result with additional data (R^2) (%)	Comments
Program TTM	88	82	
Program design issues logged	95	81	
Program field failure rates	26	–	Two-factor regression result: $R^2 = 95\%$ with original data; $R^2 = 88\%$ with additional data
Supplier subsystem design issues logged	79	70	Controller supplier excluded due to nature of relationship
Supplier subsystem field failure rates	60	54	

TTM has a strong correlation to the interaction term, DoDC $\times$ GC. When the two additional data points are added, more scatter is introduced, but the general relationship still holds. It is interesting that while the general relationship holds, the new data point with the higher risk index actually had the faster TTM. This just emphasizes the point that what is of interest in this analysis is a general trend and not the determination of a fundamental relationship. Figure 3 is typical of the results obtained for the other metrics of product development efficiency. Table 1 summarizes the results for the reminder of the metrics, which are discussed here.

4.2 Program Risk Index versus Design Issues Logged

Similar results as already mentioned are obtained for the program analysis on design issues logged. There is a strong correlation in the original data for the interaction term and the number of design issues logged. The relationship is weakened a bit after the additional data are included. However, the original trend still holds and in this case, the additional data point with the higher risk index has more design issues logged.

4.3 Program Risk Index versus Field Failure Rates

In the case of program level field failure rates, there is no good correlation with the interaction term. In addition, the field failure rates for the two additional data points are not stable. However, there is a technique for projecting the stable failure rate based on early performance, given that the product follows past historical patterns. For one of the programs, this projected estimate is included in the analysis. For the second platform, this estimate could not be used because there is strong evidence that the historical pattern does not apply. The reason is that this platform experienced a few major issues in the field that should not have escaped the development process and it is clearly an outlier data point. To motivate a relationship between the failure rate and DoDC and GC, a two-factor regression analysis is necessary. As is summarized in Table 1, the two-factor regression results show a strong correlation between DoDC and GC whether the original data are used or the data set with the additional data is used. Note that the p-values for the two terms in each case are ≤ 0.05, which suggests that DoDC and GC do indeed correlate with the failure rate.

4.4 Supplier Subsystem Risk Index versus Design Issues Logged

With the original data, there is little correlation between the number of design issues logged at the supplier subsystem level and the interaction term. The main reason for this result is the controller subassembly. Interestingly, this supplier was a one-time relationship and HP had no prior experience with them. Given that this supplier violates the assumption of a pre-existing relationship and that it only represents two out of sixteen data points, excluding them from the analysis seems reasonable. If this supplier is excluded, the correlation greatly improves. In addition, the conclusions drawn do not significantly change when the data from the additional programs are added.

4.5 Supplier Subsystem Risk Index versus Field Failure Rates

Table 1 summarizes the results of the program analysis for field failure rates. Including the additional data adds an engine subsystem to the analysis, which does not change the conclusions of the analysis. In either case, there is a reasonable correlation between the risk index and the field failure performance.

5. Discussion

The aim of the analysis in Section 4 is to demonstrate that DoDC and coupling (GC and CR) are, in fact, indicators of product development risk at both the program level and at the supplier subsystem level.

The data analysis supports all five hypotheses set out in Section 3. Thus, DoDC and the coupling metrics developed are good indicators of the likelihood of product development efficiency. Furthermore, in four out of the five cases, there was a correlation between the risk metrics and the interaction term with R^2 values ≥ 0.6. Thus, it is reasonable to conclude that risk at the program and subsystem levels can be characterized by the interaction term.

While the R^2 values are actually quite high, these are not fundamental relationships that have been demonstrated. The results do suggest that in most cases, good decisions will be made if these metrics are employed. The addition of more data demonstrated that the scatter in the regression results increased. It is encouraging that the additional data do not significantly change any of the conclusions drawn. However, since the original data led to the definition of these new metrics, this is not sufficient to consider the metrics validated.

Also note that the proposed risk metrics only allow evaluation of relative risk by comparing the risk indices. Further research is needed to determine if specific numerical ranges correspond to certain levels of risk.

Last, a good result is that the coupling measure was constructed from existing product development data and specifications using a simple method. QFD matrices did not have to be generated from scratch. However, the method is consistent with QFD so if those data are available, they can also be used.

6. Conclusions and Future Work

6.1 Characterizing the Supplier's Influence on Product Development

The proposed framework introduced the concepts of DoDC and degree of coupling to evaluate the risk introduced into the product development process by suppliers. This framework is appropriate for evaluating risks at the program level and at the supplier subsystem level. A correlation study tested and validated the hypotheses stated in Section 3.1. The results suggest that DoDC and the coupling metrics are good indicators of the likelihood of product development efficiency. Furthermore, there was enough evidence to use the interaction term, the CR multiplied by the DoDC, as a risk index. The use of these results as part of the robust CPD methodology is left to another article.

6.2 Product Architecture-based Project Risk Assessment

The fact that the coupling assessment is based on the product architecture and that it can be used for project-based risk analysis distinguishes it from the other project management methods. Project management risk analysis (including the DSM and Project FMEA) is typically based on the required tasks, which does not lend itself very well to identifying risks in the product design. In addition, the greatest benefit of the analysis is early on in the product development cycle. Conversely, FMEA and AFMEA are well suited for identifying risks in the product design but they only provide a small portion of the picture when dealing with project risks.

An important implication of using the coupling assessment as part of the project risk assessment is that the same process can address both project and product risks, unlike other methodologies, which focus on one area or the other. The key reason for this advantage is that, in addition to looking at the number of tasks (DoDC accomplishes this), project risk is also a function of the system architecture (the CR).

One possible way to look at the impact of such a methodology is to refer back to Figure 3. This figure summarizes the relationship between the risk index and TTM. While these data are transformed to protect HP proprietary information, one can make a few assumptions to get a sense of the potential benefits of applying this methodology. Note that this is a very rough analysis to give an idea of the impact.

The TTM versus the risk index relationship has a slope of 0.04. If one assumes that the maximum development time was 36 months, a one unit incremental reduction in the risk index would result in $\approx$1.5-month reduction in TTM. A new design requires a reduction of the GC by $\approx$0.1. In a 10×10 system to subsystem EM matrix eliminating one subsystem EM dependence on a system EM accomplishes this 0.1 reduction. This rough analysis shows that even modest decreases in coupling can potentially have significant impacts on the product development process. A similar analysis relating field failure rates to warranty dollars is possible and should show similar results if those data could be shared.

6.3 Future Work

The following section presents the two key areas for future work: (1) validation work, and (2) improvements to the methodology.

6.3.1 VALIDATION

This research has only taken a first step toward formalizing methods to aid in product development with suppliers. The first phase of the research used actual product development projects to develop concepts and metrics to assess risk at the project level. However, one cannot consider the correlation study as a validation of the proposed risk metrics, since the data from Section 4 led to the definition of the metrics by optimizing the data set. To validate the results of that study, a similar correlation study with the metrics proposed would be necessary, using a new set of development projects to see how well the risk indices perform at predicting product development success.

In addition, it would be valuable to conduct similar studies in other industries. The main questions that the new study should focus on: (1) Are the concepts of DoDC, and EM coupling useful in these industries? (2) Can meaning be assigned to the numerical values of the risk index? This study would be powerful in determining the breadth of applicability of this risk assessment process.

Last, another way to validate the utility of the methodology is to apply it on a product that is already under development. This would provide the opportunity for real-time feedback on the utility of the methodology. If it is a tool that provided the program management team and engineers insight that they would not have ordinarily have had, then there is value in the methodology.

6.3.2 IMPROVEMENTS TO THE METHODOLOGY

Section 5 described the risk index as a relative measure of risk that requires other risk assessments to make meaningful comparisons. By performing case studies on other products and industries, it may be possible to establish interpretation of the numerical value of the risk index.

Another possible improvement to the process would be to make the DoDC a function of the number of design tasks. The advantage of this is that there is one less judgment-based evaluation step. This information could be collected from project management records and a similar study to that in Section 3 could test for the correlation between the number of design tasks, coupling, and the project success metrics.

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