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A Risk Mitigation Methodology for New Product and Process Design in Concurrent Engineering Projects

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Abstract

Based on earlier work on risk quantification, a new risk mitigation methodology is developed for new product and process design in concurrent engineering projects. First the most prominent risks in the product life cycle are identified and quantified. Then five computational algorithms are developed and used to find feasible solutions for mitigating these risks: Least-Cost-First, Highest-Risk-First, Minimum-Cost-Risk-Ratio- First, Random-Search and a Genetic Algorithm. Based on the available mitigation budget and strategic objectives of the project the best mitigation strategy is then recommended to the project managers. Actual financial outcomes of an industry project were used to successfully validate the methodology.

Keywords: Product Development, Concurrent Engineering, Design

1 INTRODUCTION

Numerous studies have been conducted on the complexity of new product and process design in Concurrent Engineering (CE) projects and associated risk factors that impose several strategic, financial and quality concerns to project managers [1,2]. The limited information available through knowledge elicitation [3,4,5,6], as well as every aspect of engineering design and/or manufacturing capability which has not been linked with customers and suppliers proactively throughout the product development process, results in high levels of risk across boundaries. Thus, to expand from designing products to designing the complete product development process is rewarding but challenging as well, introducing several risks to CE projects [7].

An Intelligent Risk Mapping and Assessment System (IRMAS™) developed by the authors provides a systematic approach to quantify potential risks at all stages of the project life cycle. It maps and stores all risks related to organisation, project, product and process all through the life-cycle of the project, covering the extended enterprise. Previous and current knowledge on risk events are utilised through lessons learned, case studies, best practices and expert knowledge [8].

This paper describes a new risk mitigation methodology developed for new product and process design in CE projects based on the above work. It aims at mitigating risks and utilising projects' mitigation budgets effectively. Five heuristic rules are implemented in simulated scenarios. The risk mitigation model may be used as a decision support tool, for project managers to select the best mitigation strategy based on the available mitigation budget and project objectives, as shown by three examples.

2 RISK MITIGATION MODEL

The first requirement in the project and risk management process is to model the project. A process description capture method – the IDEF3 modelling technique - is used to formulate tasks, scope, functions and relationships in the design process. The representation of the process as an IDEF 3 model enables identification of all possible path sets that can be followed for project completion [9]. A path set p_k is a set containing all possible Units of Behaviour (UOB), from source to sink, in a process following a feasible path. In it, any chance of failure encountered in the path set p_k is assessed and calculated.

2.1 Risk Parameters

In a particular UOB, risk factors are estimated according to three parameters: weighted score, risk likelihood, and risk consequence. Both quantitative and qualitative assessments are carried out to quantify numerical values of these three parameters [8]. *Quantitative assessment* is performed with the data obtained from several projects to calculate numerical values of weighted score, risk likelihood and risk consequence. *Qualitative assessment* is conducted when it is not possible to generate numerical values through quantitative assessment. Several managers, engineers and staff are interviewed to gather information which is stored and continuously updated in the knowledge warehouse [8].

The weighted score represents the significance or sensitivity of a particular risk factor to the UOB. For instance, a technical risk might be more important than a network risk in the design process, or the bidding process might be more sensitive to financial risk rather than physical risk. Moreover, different risk factors have different measurement units. Schedule risk is measured in time delay, while the financial risk is measured in terms of additional cost. A weighted score is applied to convert different units from risk factors into the same units. For instance, a delay of one week might be equivalent to the additional penalty cost.

Risk likelihood refers to the probability of a particular risk factor to occur. Risk consequence is the corresponding impact when a particular risk factor has been encountered.

2.2 Risk Measurement

The model is formulated using several sources of risks and their individual or combined exposures on individual UOBs. The model decomposes risks in an individual UOB into sources of risks. Since several risk factors are sources of risks in CE, they may contribute to each UOB. The risk magnitude of a particular UOB is measured considering risk factors and their behaviours. If UOB_i has J risk factors, then the risk magnitude in a UOB_i (R_i) is the summation of influence from all J risk factors in the UOB_i. Hence, the risk magnitude in a UOB is calculated from Equation (1).

$$R_i = \sum_{j=1}^{J} d_{ij}(P_{ij} \times C_{ij}) \quad (1)$$

Where R_i is the risk magnitude in a particular UOB_i.
d_{ij} is the weighted score of risk factor j in a particular UOB_i.
P_{ij} is the likelihood of risk factor j in a particular UOB_i.
C_{ij} is the consequence of risk factor j in a particular UOB_i.

With the abovementioned conversion the measurement unit of risk magnitude R_i is time delay or extra cost overrun generated in UOB_i.

Since a path set p_k contains UOBs from source to sink, the risk magnitude in a path set p_k (R (p_k)) is the summation of all risk factors and their parameters throughout. Hence, R (p_k) is calculated from Equation (2).

$$R(p_k) = \sum_{\forall i \in pk} \sum_{j=1}^{J} d_{ij}(P_{ij} \times C_{ij}) \quad (2)$$

From Equation (2), the risk magnitude of the project is calculated by decomposing the behaviours of risk factor(s) in an individual UOB into three parameters: weighted score (d_{ij}), risk likelihood (P_{ij}), and risk consequence(C_i.).Then, these behaviours are integrated throughout the path set p_k.

From the risk measurement model in Equation (2), it must then be established *which are the risk factors in which UOBs that should be mitigated or not according to the available budget.* This is described in the next section where a risk mitigation model is developed.

2.3 Risk Mitigation

An approach is introduced to select the best decision based on a limited project mitigation budget. The risk factors need to be prioritized to utilise the mitigation budget effectively. The mitigation plan must identify risk factors associated with low mitigation cost but with high risks. Additionally, from the project manager's perspective, the risk mitigation needs to cover risk factors with unacceptable risk magnitude. Thus, screening out large numbers of risk factors and including only crucial risk factors is of strategic importance.

Let a_{ij} represent the cost required to spend for mitigating risk factor j in a UOB_i. It refers to the extra cost incurred from additional resources, working hours, equipment, and consultancy fee required to take an action on a particular risk factor j in a UOB_i.

Suppose the decision variable X_{ij} refers to an action for a particular risk factor j in a UOB where:

X_{ij} = 1, if a risk factor j in a UOB should be mitigated
= 0 , otherwise.

The decision to mitigate or not mitigate risks usually rests with the project or operations manager of the project.

The objective function W is introduced in Equation (3) to minimise the difference between the upper bound mitigation cost/risk ratio and the mitigation cost/risk ratio generated from the project, to determine the practical recommendation for mitigating risks. The result indicates which risk factors in which UOBs should be mitigated, based on the cost-effective approach and to satisfy the budget constraint in Equation (4).

$$\text{Min } W = A - \sum_{\forall i \in pk} \sum_{j=1}^{J} \frac{a_{ij} \cdot X_{ij}}{d_{ij}(P_{ij} \times C_{ij})} \geq 0 \quad (3)$$

Subject to

$$B - \sum_{\forall i \in pk} \sum_{j=1}^{J} (a_{ij} \cdot X_{ij}) \geq 0 \quad (4)$$

Where:
A: the upper bound cost-risk ratio.
B: the limited mitigation budget available.

The upper bound cost-risk ratio *(A)* refers to the most effective risk mitigation target (threshold). Practically, A may be determined using historical data from several previously completed or on-going projects, or subjective assessment by a project manager, or after consultation with related parties, in order to use a realistic estimate. The upper bound of each individual project is different since each project inherits unique attributes. A project may require different mitigation actions and has different mitigation costs compared to others. Moreover, different project managers and organisations have different attitudes, biases, preferences, networks, backgrounds, etc. Consequently, the upper bound cost/risk ratio *(A)* of a particular project is a subjective value.

The summation of the cost-risk magnitude ratio must not violate the upper bound, nor should it be too far below A . Otherwise, the effective recommendation is not achieved. A strives to select the combination of risk factors which achieve the most effective recommendation. Also, A reflects the flexibility of the risk mitigation strategy. A higher upper bound allows more flexible combination, while a lower upper bound tends to generate a more effective solution. To solve the objective function in Equation (3) and satisfy the budget constraint in (4), five computational algorithms are developed as detailed in the next section.

3 SOLUTION ALGORITHMS

3.1 Least Cost First (LCF)

The LCF algorithm aims at minimising mitigation costs. In this algorithm, a mitigation solution (X_{ij}) is determined based on the mitigation cost of risk factors, by mitigating the risk factor j in a particular UOB_i that has the lowest mitigation cost. Subsequently, the next risk factor is selected with the second lowest mitigation cost. The algorithm searches risk factors to be mitigated until the mitigation budget *(B)* runs out, or there are no other risk factors remaining which are in need of mitigation. The LCF algorithm is simple and only consumes short computational time to generate the final result. It is capable of generating solutions in a large problem space with many UOBs. However, the solution obtained from LCF does not consider the magnitudes of the risks that may occur.

3.2 Highest Risk First (HRF)

The HRF algorithm aims at mitigating risk factors with a high magnitude of risk in the project. In this algorithm, the solution (X_{ij}) is generated based on the risk magnitude by mitigating the risk factor j in a particular UOB_i that has the maximum risk magnitude first. The algorithm continues until either the objective value reaches the upper bound, or the budget constraint is violated, or if there are no further risk factors to be mitigated.

3.3 Minimum Cost-Risk Ratio First (MCRF)

The minimum cost/risk ratio first (MCRF) algorithm aims at the maximising the cost effectiveness of the risk mitigation budget. In this algorithm, the solution (X_{ij}) is generated based on the risk factor j in a particular UOB_i that has the minimum cost/risk ratio first. The next risk factor is selected for mitigation of a risk factor in any UOB that has