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A RISK MITIGATION MODEL FOR NEW PRODUCT AND PROCESS DESIGN IN CONCURRENT ENGINEERING PROJECTS MANAGEMENT

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Abstract. Based on the latest research on the topic of risk types, a new method of risk reduction for obtaining or designing outcomes regarding engineering projects has been developed. First, the most prominent and essential risks in the world have been identified and analyzed. Next, 5 mathematical algorithms have been developed and utilized for finding an appropriate solution for these risks: minimal initial cost, maximal initial risk, lowest cost for initial risk, accidental search and a genetic algorithm. Because of reductions in available budgets and strategic goals of a project, the best strategy suggested to project managers is reduction. The real financial receivable of an industrial project has been utilized as a means of validating its success. Managers are often faced with both pressure and responsibility for controlling risk and unknown options, which put managers in a difficult situation. Utilization of risk engineering in managing projects such as engineering projects, taking into account the complex methods by which projects are implemented, can be used as a means for identifying and omission of items that may force imposition of unnecessary expenses and waste of time without damaging the main objectives of a project. This article focuses on risk types and identification as well as development of risk engineering. It also proposes a model for risk mitigation.

Key words: Design, Concurrent Engineering, Risk Engineering, Product Development, Risk Mitigation

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[5]. The limited information available through knowledge elicitation[4,15], 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[6].

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 utilizing 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.

An Intelligent Risk Mapping and Assessment System 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 organization, project, product and process all through the life-cycle of the project, covering the extended enterprise. Previous and current knowledge on risk events are utilized through lessons learned, case studies, best practices and expert knowledge[8].

This approach enables the concurrency between risk items to be captured and the cumulative effects of dependencies between risk events to be determined. The inheritance of risks between different phases is modeled and quantified, which is impossible by traditional project management techniques[4].

In project management "project risk management includes the processes concerned with conducting risk management planning, identification, analysis, response, and monitoring and control on a project "[10].

Risk management in concurrent engineering (CE) projects is an iterative and continuous process that occurs throughout the lifecycle of projects. Although faster product design, development and delivery are the intended outcomes of CE, one of the undesirable by-products is an increase in risks as a consequence of uncertainties between interdependent processes. Multi-disciplinary tasks, characterized by knowledge sharing and reuse as well as design co-ordination, are conducted concurrently in many product development projects in order to reduce the time needed to market new products or services and to optimize design activities[14]. The complexity and associated risks in planning and managing such projects are increased by the need to integrate the functions of both technical and non-technical (such as marketing and customer support) teams that may be distributed across geographical regions. Every aspect of engineering design and/or manufacturing capability has not been linked with customers and suppliers proactively throughout the product development process as well as lack of collaboration 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[4].

2. CONCURRENT ENGINEERING PROCESS

Concurrent engineering (CE) is recognized as an effective means for industry to achieve improved quality coupled with higher productivity[12]. The overall objective of CE is to integrate such organizational functions as marketing, design, manufacturing, quality control, procurement and accounting into a parallel working relationship when a product is being created (see Figure 1). Through eliminating prototyping and testing, reiterative activity is reduced and the time needed to prepare a product for the market is reduced. In CE environments, new products are no longer the sole domain of the research and development department. An emphasis will be placed on the removal of the traditional forms of demarcation between the divisions of the organization and a premium will be placed on the "search for excellence"[13] in all the functional areas.

In the ideal model of CE, product development should involve all parts of an organization. As a result, effective teamwork will depend on sharing ideas and goals beyond immediate assignments and departmental loyalties. A major feature which will enable this concept to become a reality is the ability to give the broad spectrum of managerial functions capabilities which are pertinent to the concurrently engineered product throughout its lifespan and thus drive the development process from concept initiation to customer delivery [11].

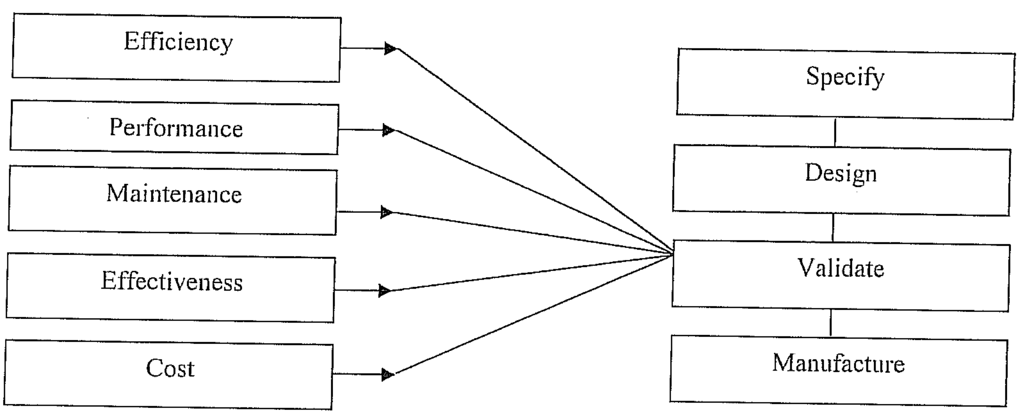


FIGURE 1. Parallel Processes in Concurrent Engineering

3. RISK ENGINEERING

Risk engineering is a systematic and powerful process which assists us to make identification, analysis and reactions to the projects risks, the mitigation of the projects risks to maximize the upshots of the positive eventualities and to minimize the impact of the occurrence of horrendous events upon the projects objectives. Risk engineering is a process which contributes to the better comprehension of the projects. Thus it facilitates a better more precise programming of the projects from the aspects of the expenditures and timing. Risk management or engineering signifies the utilization of the individuals' or collective proficiencies to ensure the identification of all the risks, their gauging and implementation in projects [8].

Risk engineering assists us to:

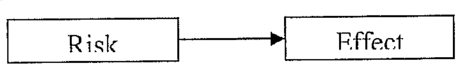
1) Identify the itinerary in a better more precise manner to make out risks of achieving the objectives.
2) To adopt better decisions.
3) To view the projects in a realistic manner.
4) To identify / control and convey unexpected factors and perils in a facile manner.
5) To intensify the competitions [8].

4. RISK ANALYSIS [1]

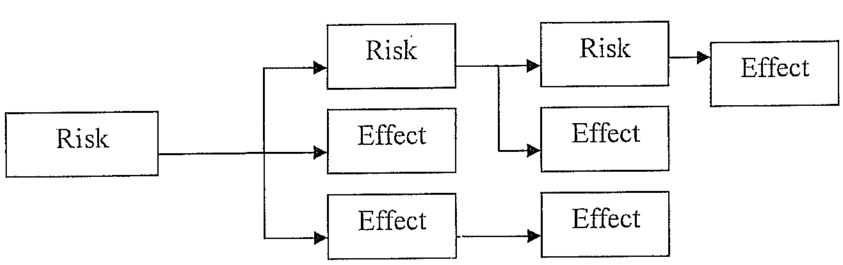
There is never enough time to do something right on the first attempt, but if something goes wrong there will be opportunities to do it again. The definition of risk is deviation of actual results in relation to expected results. It's becoming more and more evident that risk analysis in project management is unavoidable. Nowadays it is common to ask project managers to identify and assess risks and to find ways for reducing them. Experts in risk have transformed their knowledge into a type of science with emphasis on statistics, making access and comprehension difficult for non-experts.

Risk types can be categorized as follows[1]:

- Isolated risks: Share the common characteristic of having a definite beginning and end during a set period of time.



- Linked risks: Are a group of occurrences appearing to be associated with risk.



- Concurrent risks: Are composed of two or more situations associated with independent or linked risk occurring during the same time period.

5. THE SUITABLE TIME TO EFFECTUATE RISK MANAGEMENT

Risk occurrence in the life cycle is not an identical project. It differs based upon the stage in which the project is effectuated. Risk probability is very high in the initial project implementation stages due to the fact that there are numerous unknown parameters in the project. Risk effects are slight at the beginning of the project ascribable to the fact that nothing has been done yet. The further the project makes headway, the more prominent such repercussions manifest because most of the possible risks actualize during the project progress and manifest their effects. Risk repercussions maximization spot is at the end of the projects where all the probable risks have either taken place or have gone through the process of manifesting their consequences. Completion time of risk analysis is at the beginning of the project but completion time of risk management is when operating of project to end of working [1],[4].

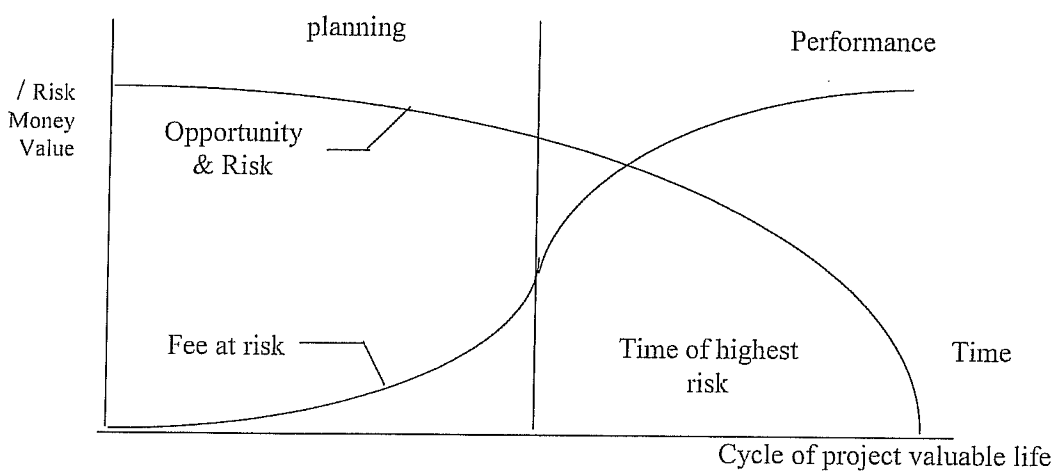


FIGURE 2. Effect value & risk probability in each one of project stages

6. RISK MITIGATION POLICIES

We should reduce risk with 4 methods: modification, mitigation, postponement and prevention. You should consider yourself very fortunate if you are able to prevent, delay, mitigate, or correct a risk. But if it is believed that risk is involved then it is best to find a way to reduce or modify that risk [9].

7. RISK MITIGATION MODEL[7,8]

The first requirement in the project and risk management process is to model the project. A process description capture method - the modeling technique - is used to formulate tasks, scope, functions and relationships in the design process. The representation of the process as a model enables identification of all possible path sets that can be followed for project completion [9]. A path set *Pk* 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 *Pk* is assessed and calculated.

8. RISK PARAMETERS

Just as there is a method for the analysis and calculation of failure or FMEA (Failure Mode Effects Analysis), three parameters can be used to measure the degree of a risk: effect, probability and weight. Therefore, in addition to the two main factors, effect and probability, that are usually considered in measuring the intensity of risk, the weight factor can be utilized as well. 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. 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 [7].

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 [4].

9. 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 behaviors. If UOBi has *J* risk factors, then the risk magnitude in a UOBi *(Ri)* is the summation of influence from all *J* risk factors in the UOBi. Hence, the risk magnitude in a UOB is calculated from Equation (1).

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

where *Ri* is the risk magnitude in a particular UOBi.
dij is the weighted score of risk factor *j* in a particular UOBi.
Pij is the likelihood of risk factor *j* in a particular UOBi.
Cij is the consequence of risk factor *j* in a particular UOBi. With the abovementioned conversion the measurement unit of risk magnitude *Ri* is time delay or extra cost overrun generated in UOBi.

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

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

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 *(dij)* , risk likelihood *(Pij)* , and risk consequence(Ci.).Then, these behaviours are integrated throughout the path set *Pk.*

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.

10. 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 utilize 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 *aij* represent the cost required to spend for mitigating risk factor *j* in a UOBi. 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 UOBi .

Suppose the decision variable *Xij* refers to an action for a particular risk factor *j* in a UOB where:

Xij = 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 minimize 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).

$$\min W = A - \sum_{\forall i \in pk} \sum_{j=1}^{J} \frac{a_{ij} \times x_{ij}}{d_{ij}(P_{ij} \times C_{ij})} \geq \mathbf{0} \qquad (3)$$

$$B - \sum_{\forall i \in pk} \sum_{j=1}^{J} (a_{ij} \times x_{ij}) \geq \mathbf{0} \qquad (4)$$

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 organizations 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.

11. ALGORITHMS

11.1 Least Cost First (LCF)

The LCF algorithm aims at minimizing mitigation costs. In this algorithm, a mitigation solution *(Xij)* is determined based on the mitigation cost of risk factors, by mitigating the risk factor *j* in a particular UOBi 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.

11.2 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 *(Xij)* is generated based on the risk magnitude by mitigating the risk factor *j* in a particular UOBi 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.

11.3 Minimum Cost-Risk Ratio First (MCRF)

The minimum cost/risk ratio first (MCRF) algorithm aims at the maximizing the cost effectiveness of the risk mitigation budget. In this algorithm, the solution *(Xij)* is generated based on the risk factor *j* in a particular UOBi 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 the next lowest mitigation cost/risk ratio. The algorithm continues as long as the objective value is greater than zero, or the mitigation budget *(B)* runs out, or there are no further risk factors to be mitigated.

11.4 Random Search (RS)

In the Random Search (RS) algorithm, decision variables recommending to mitigate risk factor *j* in a UOBi are randomly generated and tested with the objective function, until a feasible solution is found. However, RS consumes longer processing time since the solution is randomly searched. The processing time is proportional to the number of UOBs and risk factors considered.

11.5 Genetic Algorithm (GA)

The GA generates a new set of solutions by performing crossover and mutation on some elements in the selected solutions. Solutions are tested in Equations (3) and (4). If they are not feasible, a new population is generated from the current population. The process is repeated until the feasible solution is found.

12. COST / RISK VALUE (CR)

Results obtained from the mitigation model in equation (3) provide recommendations to mitigate risks in the project and will assist project managers to be proactive. With personal experience and results obtained from equation (3) and (4), more effective mitigation decisions result, due to additional .information available on the feasibility of the solution. Accordingly, after the ratio of mitigation cost and risk magnitude are taken into account to determine the cost/risk value for each algorithm as shown in equation (5), the one with the lowest cost/risk value is selected. It is worth noting that, since five algorithms may generate different recommendations, the final decision on mitigation actions needs to rest with the project manager.

$$CR = \frac{\sum_{\forall i \in pk} \sum_{j=1}^{J} (a_{ij} \times x_{ij})}{\sum_{\forall i \in pk} \sum_{j=1}^{J} dij\,(p_{ij} \times c_{ij})} \qquad (5)$$

13. VALIDATION

The methodology presented is validated by an industry project which aims to design, test and manufacture a carbon-fiber composite (CFC) component. It consists of fourteen UOBs and six risk factors. Hence, there are 284 or 1.934281311x102s possible solutions. The summary of the risk magnitude *(Rij)* and mitigation cost *(aij)* of risk factor *j* in each UOBi and *Rij* which represents the potential cost overrun incurred are gathered in monetary units ($) when a risk factor *j* is encountered in a UOB. Table 1 summarizes the possible path sets defined in the project.

K	Path Set P_K
1	1,2,3,4,5,8,9,10,12,13,14
2	1,2,3,4,5,8,9,11,12,13,14
3	1,2,3,4,5,8,9,10,11,12,13,14
4	1,2,3,4,6,7,8,9,10,12,13,14
5	1,2,3,4,6,7,8,9,11,12,13,14
6	1,2,3,4,6,7,8,9,10,11,12,13,14

TABLE 1. Path sets

A. Case 1 - Normal Case

Risk is converted into additional cost overrun. The acceptable risk magnitude is $100,000 ($100K). Hence, any risk factors that generate an extra cost of more than $100K are mitigated. The available mitigation budget is $200,000 ($200K). The result is shown in Table 2, where cost is the amount that is actually spent to mitigate risk. Risk refers to risk magnitude that is mitigated or saving from potential cost overrun. In this case, *MCRF* generates the best solution because it gives the minimum *CR*. Decisions are made on 18 risk factors in the path set *P6*.

Algorithms	Budget	Cost	Risk magnitude	CR
	Case 1			
LCF	200	194	4745	0.0409
HRF		200	5134	0.0390
MCR		182	5791	0.0314
RS		196	4551	0.0431
GA		195	4471	0.0436
	Case 2			
LCF	250	237	6083	0.0390
HRF		249	6441	0.0387
MCR		241	6965	0.0346
RS		249	4913	0.0507
GA		228	5776	0.0395
	Case 3			
LCF	150	149	4494	0.0332
HRF		148	4582	0.0323
MCR		133	4651	0.0286
RS		147	3155	0.0466
GA		127	4301	0.0295

TABLE 2. Comparison of heuristics and their associated Cost/Risk (CR) values under different budget constraints ($1000). For confidentiality reasons, the monetary values used do not reflect the actual financial figures.

B. Case 2 - Higher Mitigation Budget

From Table 2, the best solution is obtained from *MCRF* since its *CR* = 0.0346 is the lowest. The mitigation cost incurred is $241 K and the potential saving from cost overrun is $6965K. The 21 decision variables *(Xij)*- XI,S, *X2,4, X2,6, XJ,4, XJ,s, X4,2, X4,J, X6,1, X6,2, X6,4, X6,6, XS,J, Xg,s, X11,2, X11,J, XII,4,* X11,S, *X12,* 4, *XI2,S, XIJ,J, XI4,J* are equal to 1 indicating that these decision variables associate with risk factor *j* in a UOBi and should be mitigated.

C. Case 3 - Lower Mitigation Budget

The available mitigation budget is reduced to $150K. The results are shown in Table 2. *MCRF* generates the lowest *CR* = 0.0286. The mitigation cost incurred is $133K and saving from potential cost overrun is $4651 K. Decision variables *(Xij)- X2,4, X2,6, X4,2, X6,1, X6,2, X6,6, XS,J, Xg,S, XII,4, XII,S, XI2,4, XI2,S, X13,J, XI4,J* are equal to 1, suggesting that a risk factor *j* in a UOBi should be mitigated.

14. CONCLUSION

There is no doubt that the appearance of projects is to a large extent decorative and suggestive of the lack of confidences that have the potential to affect their end goals. It is also evident that some of these doubts may be beneficial if they materialize. In many instances it can also be a source of harm to the organization. Appliers of risk engineering have for the most part accepted this fact to the point that risk can be defined as "doubts that can affect results" including both opportunities and threats. Nowadays corporations are facing increased complexities and uncertainties, in turn making it difficult to manage specialized risks and businesses. Both shareholders' and society's tolerance of failure in risk engineering has diminished. In addition, laws and regulations have implemented tougher requirements. Therefore, failure in the face of such risks can be fatal, which makes control and maintenance more and more critical. However there are ongoing discussions about the definition of this word between experts. At any rate whatever definition is used, there is no denying that both threats and opportunities must be actively managed by project managers. The question that arises is that is it possible to find an effective way to establish an association between the two.

This is where a new risk mitigation methodology is described for new product and process design in CE projects. The developed risk mitigation approach is successfully validated in industry. It aims to 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. Five heuristic rules- *LCF, HRF,* MCRF, *RS,* and *GA* are implemented in three simulated scenarios. Results indicate that the MCRF generates the most cost effective solution. In this research, a cost effectiveness approach is used as an objective in order to achieve the mitigation trade-off strategy. However, other measures may be used to generate recommendations for mitigation actions. For example, Concurrent Engineering projects emphasize more on "time-to-market" rather than "product development costs". Therefore, "time" could be used as a factor as well. The proposed risk mitigation approach is beneficial in both risk and project management in manufacturing projects. Consideration of several possible mitigation actions and cost estimations, for each risk factor, in every manufacturing task, helps project managers to stay proactive and thus provide mitigation actions consistent with project objectives.

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