A review of techniques for risk management in projects

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Abstract

Purpose – This paper aims to provide a review of techniques that support risk management in product development projects using the concurrent engineering (CE) philosophy.

Design/methodology/approach – The Australia/New Zealand risk management standard AS/NZS 4360:1999 proposes a generic framework for risk management. This standard was adapted for product development projects in the CE environment. In this paper, existing techniques were reviewed for their applicability to processes in risk management; namely, techniques for establishing context, risk identification, risk assessment and treatment.

Findings – Risk management is an activity within project management that is gaining importance due to current business environment with a global focus and competition. The techniques reviewed in this paper are used on an *ad hoc* basis currently. A more risk focused approach is likely to result in an integration of several of these techniques, resulting in an increased effectiveness of project management.

Practical implications – The techniques reviewed in this paper can be used for the development of risk management tools for engineering and product development projects.

Originality/value – This paper provides a gist of techniques categorized in the form that they are applicable for implementation of risk management functions in product development projects using CE philosophy.

Keywords Risk management, Project management, Product development, Risk assessment

Paper type General review

Introduction

Projects are managed through the concurrent engineering (CE) philosophy for faster time to market and to achieve project objectives through a shorter iterative process. CE is the development of product and process through simultaneous functions that aims at reducing time to market, overall development cost and achieve a high product quality (Salamone, 1995; Caillaud *et al.*, 1999). Owing to the multi-functional nature of teams in CE, product and process information is shared and a quick overall understanding of the product and process is developed. This leads to an achievement of the right design in the first attempt and helps attaining a clarity for the issues in the implementation phase of the project, resulting in an overall lower developmental cost and a quicker response to market as compared to a traditional over the wall approach (Jo *et al.*, 1993).

The design process determines product geometry, materials, functional specifications, machining processes, assembly sequences, tools and equipment necessary to manufacture a product. Production plans, control tools such as inventory controls, resource allocations and job scheduling are other important outputs of the design process. Hence, it can be asserted that design influences to a great extent, the quality and the cost of the product (Salamone, 1995; Jo *et al.*, 1993). Short comings in the product design process results in extra costs generated through project delays, penalties, excess of materials used, labour, additional operations, resource

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reallocations, rescheduling and rework. Hence, risk management in product design is beneficial and should complement project management activities, especially in a CE environment. This paper describes a framework for the risk management process, as proposed by the Australian Risk Management Standard (Risk Management Standard AS/NZS 4360, 1999) and reviews the techniques that can be used for each process within risk management so that a framework can be evolved for designing tools for risk management.

The risk management process

In general, unexpected events occur in projects and may result in either positive or negative outcomes that are a deviation from the project plan. Positive outcomes are opportunities while negative outcomes generate a loss. Risk focuses on the avoidance of loss from unexpected events (Williams, 1995). Several definitions of risk are available in the literature and risk is usually referred to as an exposure to losses in a project (Webb, 1994; Chapman and Ward, 1997) or as a probability of losses in a project (Risk Management Standard AS/NZS 4360, 1999; Larson and Kusiak, 1996a; Remenyi and Heafield, 1996; Jaafari, 2001; Kartam and Kartam, 2001). In this paper, the later definition of risk has been used because this definition implies that risk is quantifiable and lends itself to assessment and analysis through computational methods. A situation where it is not possible to attach a probability of occurrence to an event is defined as uncertainty (Clemen, 1996; Taha, 1997). While uncertainty is not measurable, it can be estimated through subjective assessment techniques (Raftery, 1994).

The risk management process refers to uncovering weaknesses in methods used in product development through a structured approach so that timely mitigation actions are initiated to avoid risk, transfer risk, reduce risk likelihood or reduce risk impact (Risk Management Standard AS/NZS 4360, 1999). The risk management process proposed by the Australian Standard for Risk Management is shown in Figure 1. It is composed of seven iterative sub-processes of establishing the context of risk, identifying risks, analysing risks, evaluating risks, communication and consultation across stakeholders and monitoring and controlling risk events. The risk management process blends itself to CE product design and development, as changes and iterations in the design stage cost less than changes initiated in the implementation phase (Salamone, 1995; Jo *et al.*, 1993). Hence, early discovery of risk events leading to downstream losses is much more preferable than treating losses when they cannot be prevented.

Techniques for context establishment

Context establishment in the risk management process involves representation of project units (functional, process, data, etc.) and their inter-relationships (Ahmed *et al.*, 2003a, b). This enables in representing project status in several forms such as resource usage, equipment requirements, budget availability, stakeholder involvement, contract deliverables, strategic goals and schedule, depending on the desirable aspect of the project that is important for any particular purpose.

Project modelling tools and techniques are in general, are also the techniques for context establishment for risk management. These are project network diagram, precedence diagramming method (PDM), generalized activity networks (GANs), design structure matrices (DSM), IDEF3 process modelling and IDEF0 functional modelling. These are described in detail in the following paragraphs.

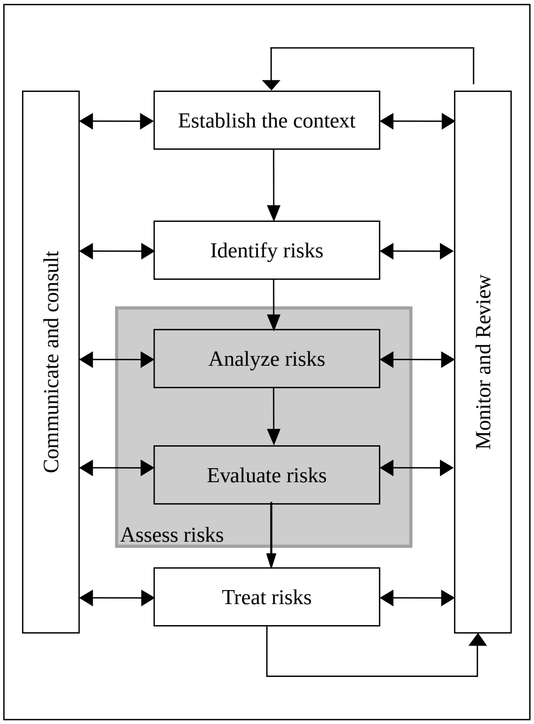

Figure 1.
Representation of the risk management process as per AS/NZS 4360:1999

Project network diagrams

Project network diagramming is a graphical technique used for representing project tasks and precedence relationships (Webb, 1994; Russell and Taylor, 2000; Tavares, 2002). Project tasks or activities are modelled as arrows or nodes through two different methods – activity on node or activity on arrow. A project network diagram provides a simple visual display of tasks in a project, with difficulty in representing complex relationships. Alternative and overlapped activities are also not accommodated in project network diagrams. Critical path method (CPM) and program evaluation and review technique (PERT) are then used for analysis of critical path for the project, identification of critical tasks and estimation of the total project duration. A combination of project network diagramming, CPM and PERT techniques lend themselves into simple schedule focused management of projects (Larson and Kusiak, 1996a).

Precedence diagramming method

PDM is an extension of the project network diagramming technique where overlapped content between two dependent activities can be represented through lead-lag requirement relationships (Wiest, 1981; Badiru, 1993; Badiru, 1996). Lead-lag relationships usually depict that there is overlapping time duration between the completion time of an activity and the starting time of the subsequent activity. Lead-lag relationships are divided into four types:

(1) start-to-start;
(2) finish-to-finish;
(3) start-to-finish; and
(4) finish-to-start.

The overlapping of activities means that the estimation of project duration is usually compressed and results in a shorter completion time when compared to PERT. However, manual computations are tedious, especially for large networks (Badiru, 1996).

Generalized activity networks
A GAN is a graphical representation of the probabilistic branching of activities (Dawson and Dawson, 1994, 1995, 1998). Uncertainty is represented as alternative paths with a probability attached to it, providing an illustration of all possible paths or scenarios that can be described for a project, including loops. GAN also becomes very complicated when the number of nodes increase, with an added difficulty of quantification of branching probabilities as an output from every activity node.

Design structure matrices
A design structure matrix (DSM) represents precedence relationships of project tasks on a square matrix containing equal number of rows and columns representing the number of tasks (Steward, 1981; Kara *et al.*, 1999; Eppinger *et al.*, 2001). Existence of a precedence relationship between two tasks is represented through a binary code, with a mark "X". Absence of the mark means that no precedence relationship exists between the two tasks. DSM depicts three different types of precedence relationships between tasks. A sequential relation indicates that the precedent task must be completed before the subsequent task commences. A parallel relationship indicates that two tasks are carried out independently, while a coupled or a circuit relationship indicates that the two tasks are interdependent, requiring input from each other (Steward, 1981; Kara *et al.*, 1999; Eppinger *et al.*, 2001). DSM provides a capability of representing task relationships in a complex system and lends itself to analysis through matrix manipulations leading to the isolation of group of coupled tasks. However, decision points are not represented into the DSM structure and alternative paths are not realized.

IDEF0 functional modelling
IDEF0 is a graphical representation of a system through a functional perspective (Colquhoun *et al.*, 1993; Sarkis and Lin, 1994; Malmstrom *et al.*, 1999). In IDEF0, a box represents an activity or a function while arrows represent inputs, outputs, controls and mechanisms operating on activities and on the project as a whole (Colquhoun *et al.*, 1993; Sarkis and Lin, 1994; Malmstrom *et al.*, 1999; Ang and Gay, 1993; Kusiak *et al.*, 1994). An input is a requirement that a functional unit needs to perform, while an output is the outcome of that function or a combination of functions. Controls are constraints that dictate functions such as regulatory environment and budget, while mechanisms are supports that advocate performance of that function such as people, computer systems and machines. IDEF0 provides an overall view of the project at the top level and successively more details deeper into subsequent levels. This provides a model that is relevant to all functional levels in the organization.

IDEF3 process modelling

IDEF3 is a graphical method used for modelling sequence of tasks in a system through process or object-oriented perspectives. Process-cantered view emphasizes process flow and relationships between tasks, while object-cantered view highlights change in states of objects as a process flows (Larson and Kusiak, 1996a, b; Mayer *et al.*, 1995). In a system, tasks are defined as units of behaviour (UOB); relationships are represented as links and logical branching as junctions. Logical branches or junctions are usually decision points in the system and they could be of – AND, OR, or EXCLUSIVE OR types. An AND junction means that all UOB connecting this junction must be performed, an OR junction means that at least one UOB connecting this junction needs to be performed while, an EXCLUSIVE OR junction indicates that only one UOB connecting this junction can be performed. Fan-in and fan-out junctions indicate multiple paths in the process flow with fan-in junctions indicating convergent paths, while fan-out junctions indicate divergent paths in the process flow.

IDEF3 allows greater flexibility in modelling alternatives in design processes and is suited for the CE environment and lends itself as a foundation for further risk analysis (Kusiak and Zakarian, 1996). Since, processes can be represented in layers with the top layer providing the overall view, an IDEF3 model could be as simple as it is desired to be or dig down into details in each subsequent lower layers.

Techniques for risk identification

Risk identification is studying a situation to realize what could go wrong in the product design and development project at any given point of time during the project. Sources of risk and potential consequences need to be identified, before they can be acted upon to mitigate. Experts in their own domain have intuitive methods of recognizing a risk situation. As such, the identification tools presented in this section are more general in nature and need a collaborative approach so that all aspects of the project are examined for risk situations.

Checklists

Checklists are a trivial method of risk identification where pre-determined crucial points are examined for symptoms of potential risk situation (Webb, 1994; Duncan, 1996; Kumamoto and Henley, 1996; Cross, 2001). These are simple to use and usually evolve over time through contributions from various functional experts and collective experiences (Chapman and Ward, 1997; Ward, 1999).

Influence diagrams

An influence diagram is graphical representation of the structure of the decision context such that decisions, uncertain events, consequences and their interrelationships are graphically enumerated (Clemen, 1996; Clemen and Reilly, 2001). Owing to the visual display, cause-and-effects of risk situations are described and can be used for identifying risk situations before they eventuate.

Cause-and-effect diagrams

A cause-and-effect diagram or a fish bone diagram is a graphical representation of root causes of quality problems, where major causes of the ultimate problem are grouped and broken down into detailed sources (Russell and Taylor, 2000). Though, cause-and-effect diagrams are easy to use, they do not provide a foundation for further analysis such as relative importance of individual causes of a problem. Hence, cause-and-effect diagrams are used for deterministic problems in a very specific domain.

Failure mode and effect analysis

Failure mode and effect analysis (FMEA) provides a structure for determining causes, effects and relationships in a technical system. FMEA is used to determine failures and malfunctions through exploration of failure modes, consequences of a system component failure so that solutions for rectifying these problems can be visualized (Risk Management Standard AS/NZS 4360, 1999; Kumamoto and Henley, 1996; Cross, 2001).

Hazard and operability study

Hazard and operability study (HAZOP) is an extension of FMEA where check words are applied to process parameters in order to identify safety and operational problems, usually in new systems (Cross, 2001; Lawley, 1974; Roach and Lees, 1981; Kletz, 1985). Check words create other perspectives to the overall process and focus attention on unforeseen areas in the process. In risk management for projects, HAZOP can be applied by considering project parameters such as strategy, budget and schedule to identify risk situations.

Fault trees

Fault tree analysis is a visual technique for breaking down failure in the system into source events (Kumamoto and Henley, 1996; Cross, 2001; Kletz, 1985; Dhillon, 1982; Birolini, 1993). Fault trees use event and gate symbols to structure cause and effect relationships of a failure. It is a simple technique and helps in reflecting on logical sequences that lead to failure. In project risk analysis, this technique is complicated due to the large number of events and gates; however, it could be used in a smaller domain to analyse a particular failure.

Event tree

Event tree analysis is a graphical representation of potential consequences arising from a failure where possible consequences are generated and broken down from an initial event (Kumamoto and Henley, 1996; Cross, 2001). In project risk analysis its application is similar to fault tree analysis and works only on small zone of influence of potentially damaging consequence arising from a risk event.

Techniques for risk analysis

After risk events are identified, their characteristics need to be assessed so that it is determined whether the risk event is worth further analysis. Once it is decided that a risk event needs analysis then it needs to be determined whether the risk event information can be acquired through quantitative or qualitative means. Measurement metrics for risk also need to be determined so that these metrics can be used for computation of risk magnitude and risk analysis leading to risk mitigation plans (Amornsawadwatana *et al.*, 2002).

Risk is measured using two parameters – risk probability and risk consequence (Risk Management Standard AS/NZS 4360, 1999; Chapman and Ward, 1997;

Ward, 1999; Boehm and DeMarco, 1997; Conroy and Soltan, 1998; Duncan, 1996; Baccarini and Archer, 2001; Patterson and Neailey, 2002; Pyra and Trask, 2002). Risk probability or likelihood indicates a chance of a risk event occurring while risk consequence, severity or impact represents an outcome generated from the risk event. Risk magnitude is the product of risk probability and consequence. To measure risk magnitude, probability and consequence of a risk event needs to be determined, which constitute the risk assessment function.

In practice, the risk quantities are either quantitative or qualitative in nature. The quantitative approach to determination of risk parameters requires analysis of historical data through statistical analysis. In many instances, quantitative data is hard to achieve and is restricted to very small domain of the problem where historical trends could be sustained. An example of quantitative data for determining risk consequence is a historical record of money spent on correcting non-compliance of tooling usually used in fabrication of the type product being currently developed. Though, the risk may not eventuate, there is a fair estimate of the cost of the risk actually eventuating. Quantitative data is not always available when needed or not in the form required, hence a qualitative approach using subjective assessment techniques are often more appropriate for risk management. The subjective approach utilizes mainly the relative measures of human judgments, feelings and opinions in comparison to ideal situations. Though the subjective approach is influenced by individual bias, preferences and expertise, it provides a basis for risk assessment where it is more important to highlight risk events that are possible, rather than an exact prediction of a catastrophic event. An example of qualitative assessment is that the impact of the non-conformance of a fabrication tool to be used in the project is very high, but the chance of such an eventuality is very low. Though, the terms very high and very low can be represented on a nominal scale, it is not an exact measure. Organisations employ qualitative assessment techniques to identify risk because an expert opinion is the best source available, rather than an unreliable quantity.

Techniques for risk analysis

The function of risk analysis is to determine influence of risk factors on the system as a whole. Risk events form a cumulative effect on one or more aspects of the project and it is easier to mitigate risk events if they can be bunched in groups and preferably dealt at a higher level in the long run than focusing on one particular risk event, in which case the project is likely to be micro-managed. Several techniques in the literature that are currently applied for project analysis can also be applied for risk analysis. These are summarized in this section.

Probability and impact grids

Risk events represented on a grid consisting of probability on one axis and impacts on another are often used to define threshold regions on the grid, which represent high risk events based on past experience or organizational procedures (Risk Management Standard AS/NZS 4360, 1999; Chapman and Ward, 1997; Ward, 1999; Pyra and Trask, 2002; Stewart and Melchers, 1997; Royer, 2000). Probability and impact grids provide a simple format for showing relative importance of risk events. Figure 2 shows an example of a probability and impact grid (Royer, 2000).

Estimation of system reliability
System reliability estimation is technique of determining chance of a system element such that it is functioning without a failure in a specified time period (Dhillon, 1982; Birolini, 1993; Henley and Kumumoto, 1991). System elements are integrated together as having either a serial or a parallel relationship and traditional reliability calculations are then used to determine the overall reliability of the system, representing its health. Hence, cumulative effects on the critical components of the project are determined as the system reliability.

Fault tree analysis
Fault tree analysis determines the chance or a failure event occurring in the project structure represented in a fault tree (Cross, 2001; Dhillon, 1982; Stewart and Melchers, 1997). Further, the top-level chance or a failure is determined from events in lower levels passing through logical gates. This analysis provides an overview of risk in the overall project through top-level analysis or specific components of the project through analysis at lower levels.

Event tree analysis
Event tree analysis determines how likely a particular event represented on an event tree is likely to happen from an initial event (Cross, 2001; Stewart and Melchers, 1997). The probability of occurrence of a particular outcome is determined as a product of all probabilities of occurrence in the associated branch. Owing to this examination of all failures that are possible for an outcome, event tree analysis leads to a comprehensive mitigation plan.

Sensitivity analysis and simulation
Sensitivity analysis is a what-if type of analysis to reflect on responses by the system as project conditions change (Clemen, 1996; Clemen and Reilly, 2001; Perry, 1986). A baseline for the project metrics is generated as a precursor to a what-if analysis and then project conditions are manipulated to determine their effect on the project metrics. This leads to an understanding of the system response to changing project situations.

Simulation is used as an extension to the sensitivity analysis (Berny and Townsend, 1993). In simulation, a system model is constructed to reflect actual processes with project parameters and constraints. Then, the values for the risk parameters and constrains are randomly selected in a predefined range (Ahmed *et al.*, 2003a, b). A collation of the effects are tabulated and statistically analysed to provide an insight into the system behaviour under various conditions (Duncan, 1996). Simulation is a flexible technique for risk analysis, but requires large simulation runs to provide sufficient data for statistical analysis.

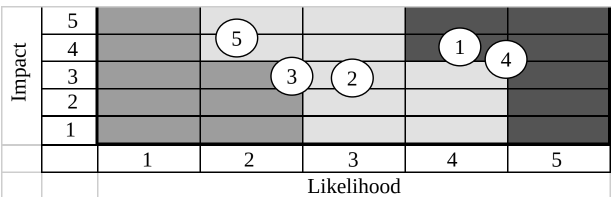

Figure 2.
Probability and impact grid

Techniques for risk evaluation

Risk evaluation is the function of risk management where risk events need to be prioritised so that risk mitigation plans are determined either based on past experience, lessons learnt, best practices, organizational knowledge, industry benchmarks and standard practices (Ahmed *et al.*, 2003a, b). In risk evaluation, different aspects of the project – strategic, budget or schedule may be considered in light of a risk event to determine risk mitigation options and incorporate the most suitable option into a mitigation plan. This section describes several evaluation techniques that can be applied for risk evaluation.

Decision tree analysis

Decision tree analysis is used to structure a decision process and evaluate outcomes from uncertain events (Webb, 1994; Clemen, 1996; Taha, 1997; Russell and Taylor, 2000; Duncan, 1996; Clemen and Reilly, 2001; Perry and Haynes, 1985). In decision trees, decision nodes and chance nodes are represented graphically and expected monetary values (EMV) are attached to the nodes. EMV is then used to calculate expected returns from decisions and select the decisions that generate the maximum returns (Clemen, 1996; Russell and Taylor, 2000; Clemen and Reilly, 2001; Perry and Haynes, 1985). Figure 3 shows decision tree analysis for an investment. Decision tree analysis incorporates probability of returns associated with decisions and estimation of expected returns, which could be misleading in situations that are out of the normal. As such decision tree analysis should be used with caution for risk analysis.

Portfolio management

Portfolio management compares multiple projects with respect to risk in investment and returns (DeMaio *et al.*, 1994; Clarke and Varma, 1999; Dickinson *et al.*, 2001). Projects are positioned on a matrix of risk magnitude and return, with high risk low return projects being located at a different location to low risk and high return projects. This enables decisions to be derived for corporate governance, based on the company strategy and the maximum portfolio value, through calculation of a utility value for a project (DeMaio *et al.*, 1994). In project risk management, multiple risk events may be compared by placing them on a matrix of risk magnitude against a return. Mitigation options are then derived from predefined utility values.

Multiple criteria decision-making method

Multiple criteria decision-making method considers different project attributes including the negative and the positive factors of a decision (Webb, 1994; Remenyi and

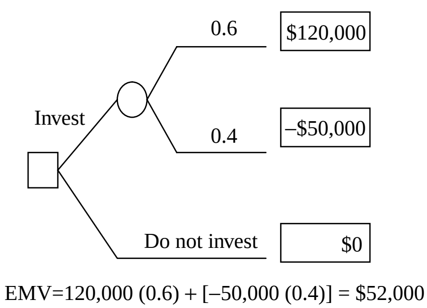

Figure 3.
Decision tree analysis

Haefield, 1996). Project attributes are weighted according to project predominance of the predefined criteria. The product of the relative weight and the score for an attribute gives a weighted score for that attribute. The project is then evaluated through a difference from a standard project attribute. If the total weighted score turns out to be positive, then the project should be selected; otherwise, the project should be rejected. This technique can be applied to risk analysis if risk events are compared to standard events and weighted against them.

Risk mitigation

Risk events diminish project objectives when harmful effects realize due to unforeseen circumstances. Risk management attempts at studying in detail, all aspects of project management, so that all controllable events have an action plan or a risk mitigation plan. A reactive approach or a feed back approach refers to risk mitigation actions initiated after risk events eventuate and can be seen as initiation of contingency plans. On the other hand, a pro-active approach or a feed forward approach refers to actions initiated based on chance of a risk event occurring, such as insurance (Kartam and Kartam, 2001; DeMaio *et al.*, 1994). A combination of these two approaches is applied to risk management to avoid risk, reduce the likelihood of risk, reduce the impact of risk, transfer risk, or to retain the risk (Risk Management Standard AS/NZS 4360, 1999).

Framework for risk management tools

A framework for risk management tools can be developed in relation to the risk management process in Figure 1 and is shown in Figure 4. Context establishment function is accomplished through techniques presented in the third section of this

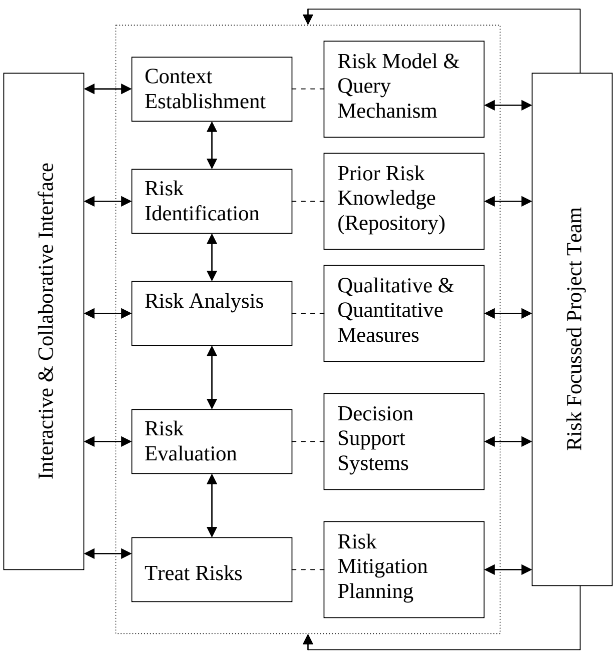

Figure 4.
Framework for risk management tools

paper and the result is an establishment of a risk structure that will facilitate the subsequent functions in the risk management process. For example, in process focussed risk management context, the risk model could be a process model. Then, information features such as technical, financial, schedule, organisational, etc. aspects may be tagged to the process units to provide a relevance for risk assessment. A risk query mechanism may then be formulated through techniques presented fourth section and imposed on the process model through interactive or collaborative interfaces to collect quantitative and qualitative data as described in fifth section. The risk evaluation consists of decision support systems using techniques presented in sixth section of this paper. Risks worth investigating further due to their high chance of occurring or high potential impacts or leading to new opportunities are then pursued leading to being treated. This whole process of risk management is collaborative and requires incremental contributions from all participants within the organization and supplementing project management approach, which is more proactive.

Conclusions

Project risk management endeavours to supplement project management practices by investigating project structure, organizational environment, external environment, products, processes and procedures in detail. It further, supplements the existing knowledge with lessons learnt, best business practices, industry benchmarks and case studies such that risk mitigation plans are in place when risk events do eventuate. This prevents crisis situations and also provides future avenues for opportunities.

This paper presents techniques that are commonly used in project management and elsewhere, outlining their usefulness to project risk management, especially in CE projects. These techniques add to an understanding of risk management functions and build on team communication and collaboration, not necessarily completely dependent on a collaborative computer network or a computer application. All the techniques presented in this paper have their own characteristics and a specific realm of application. As such, a combination of these techniques is likely to fulfil most needs for risk management by a project team and evolve tools that are tailored for their needs but are generic in structure. Several software tools are also commercially available for risk management, but they address only a specific aspect of risk management using limited number of techniques presented in this paper. The framework for risk management tools presented in this paper provides an integrated approach to risk management in projects that can be used for development of risk management tools that suit specific domain but are generic in structure and may or may not be in the form of computer applications.

Current state of development in hardware and software technology enables integration of applications for the techniques presented in this paper. There are many risk management tools commercially available to support project management but tend to address either a limited scope of application or limited processes in risk management. Future developments in integrated and generic tools will lead to widespread use of risk management principles in project management, retain organisational knowledge and provide a competitive business edge.

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