Risk Quantification for New Product Design and Development in a Concurrent Engineering Environment

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ABSTRACT

The challenges of product design and development in concurrent engineering are analysed. Bayesian Belief Networks are applied to map the relationships between risk events in a product's life-cycle. 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. The combination of these factors has resulted in a user-interactive, unique dynamic risk management software package, which has been commercialised and deployed successfully by a major international manufacturer.

Keywords: Product Development, Concurrent Engineering

1 INTRODUCTION

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 [1]. 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. According to Tseng et al [2], 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.

The effectiveness of frameworks that aim for risk management in CE projects is determined by the degree of data sharing and reuse, as well as the available support for decision making processes within the projects [3,4]. Knowledge within such frameworks, encapsulated in the form of standardized operating procedures, can be used to generate scenarios that simulate the consequences of different risk management decisions. These results are useful in supporting decision making processes and augmenting critical dependencies between project risks, which are in turn used as feedback to risk analysis processes, hence creating the iterative nature of risk management processes.

This paper presents an Intelligent Risk Mapping and Assessment System (IRMAS™) that is developed to capture, assess, organize, store, share and update project related knowledge to support risk management in multi-site, multi-partner CE projects. It describes the utilisation of decision trees to map the relationships between risk item events in several phases of a product's life cycle, modeled in IRMAS™, by applying Bayesian Belief Networks. This approach enables the concurrency between risk items to be captured and the cumulative effects of dependencies between risk item events to be determined. The inheritance of risks between different phases are also modeled and quantified. Additionally, validation of the model is discussed by using financial measurements gathered from industry.

The core of the research is a reasoning methodology used for Knowledge Elicitation which will not only support the decision-making process of the user, but also aid the knowledge retrieving, storing, sharing and updating process of manufacturing organisations. A total of 589 risk factors were identified for different project types, and information on 4372 factors and 136 lessons learnt were collected from previously completed projects. The system has been validated in industry and deployed by a major international manufacturing company.

This research also provides a systematic engineering approach to risk management of concurrent product and process development based on Risk Management Standards [5] and the Project Management Institute's Guide to the Project Management Body of Knowledge [6].

2 THE INTELLIGENT RISK MAPPING AND ASSESSMENT SYSTEM (IRMAS™)

A review of current commercially available off-the-shelf risk management tools used for multi-site engineering projects by Zhou et al. [9] identified that these tools generally lack a systematic "risk roadmap" required to identify, capture, and visualize the causal relationship of risk factors and their accumulated and inherited impacts in CE product development projects. It was also found that commercial risk management tools available are unable to readily leverage off lessons learnt from previous projects. As a result, the effectiveness of knowledge sharing, re-use and management within the tools are limited to existing pre-defined knowledge [10]. Although new knowledge based on lessons learnt may be inserted into knowledge repositories, the process is usually manual and time-consuming.

IRMAS™ is designed as an agent-based project risk mapping and assessment tool in a web-based project collaborative workbench, aiming to support a 'Design WITH' approach. Figure 1 shows the conceptual structure of the system workbench and is briefly explained below.

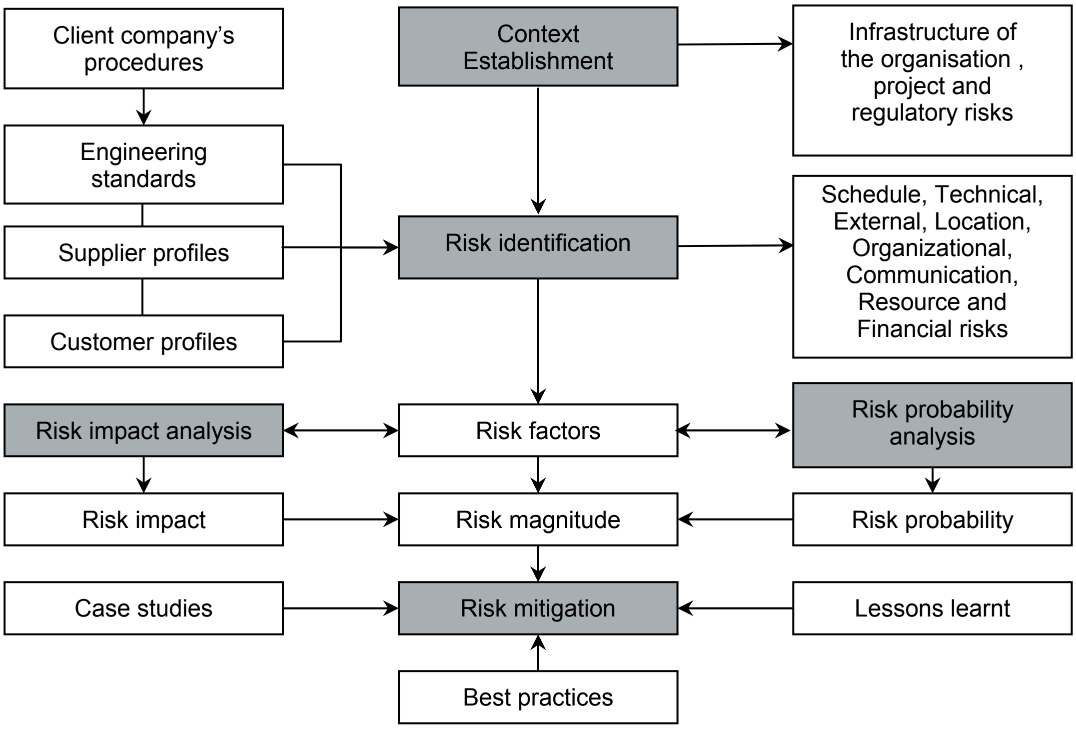

Figure 1: Conceptual structure of the project collaboration workbench in IRMAS™.

2.1 Contextual Establishment Agent

The contextual component of IRMAS™ sets the scene for the organizational, project and regulatory requirements. The users identify possible sources of risks through a series of questions to estimate the inherent risks by assigning a weighting to the existing infrastructure of the organisation. These questions are retrieved from the Expert Interview Facility (EIF); a database where all questions related to each product development phase is stored and displayed to the users via the Virtual Workbench. The Virtual Workbench promotes interactions with multi-site project participants and facilitates communication. The workbench also allows the presentation of computed results in the form of a Risk Registry, after each phase of the project is covered by the user.

The Context establishment agent is built as a Java module and interacts with all other agents as described in the following sections.

2.2 Risk Identification Agent

The risk identification process focuses on product, process and project specific risks through EIF. The risk identification needs to be sufficiently generic enabling applicability for numerous projects, yet with the flexibility to capture critical details for future reference as a “lessons learnt” document. Risks are categorised as Schedule, Technical, External, Organisational, Communication, Location, Resource and Finance related. Six overlapping phases of the product’s life cycle, i.e. conceptual design, preliminary design, detailed design, manufacturing, certification and customer service are covered based on interdependent processes of CE. Then, risk factors are defined within each risk category, narrowing down the scope of risk events. Interaction relationships are then expressed between risk factors through causal diagrams. This also facilitates the design of questionnaires, ensuring that the general risk information gathered is sufficient for the purpose and not repetitive in nature.

2.3 Risk Analysis Agent

After identifying product, process and project related risks, users proceed to initiate the computation of the significance of each risk by using the risk analysis agent. Both qualitative and quantitative techniques are used for calculating the magnitude of risks. The analysis is carried out for both the likelihood and impact (consequence) of all the identified risks.

The impact analysis is carried out using the Analytical Hierarchy Process (AHP) concept [11]. A comparative risk ranking technique is used by asking a comparative question about each risk event compared to another risk event. The information gathered through expert judgements is used to compile pair-wise comparisons to feed the AHP.

The physical form of the Bayesian Belief Network (BBN) [12] is the same as the causal diagrams developed as mentioned in section 2.2, with the addition of entities for user input in a backward chain mechanism. Some risk events are inputs to risk factors while others are outputs from a specific phase. Entities that inherit risks from previous phases are also added. These relationships are defined in BBN and their prior probabilities are determined through knowledge elicitation techniques as described in section 2.5.

The Delphi technique was utilised to collect 4372 items of information, including 1682 items relating to comparative ranking and 2690 to prior probabilities.This method used a written mode of communication for capturing the pertinent knowledge, while the expert interviews used verbal communication to transfer industrial expertise to IRMAS™.

The input data into the BBN as prior probabilities in the form of conditional probabilities were determined by domain experts. Considering that this is a subjective assessment of BBN properties, the conditional probabilities were found to vary depending on a domain expert’s experience and personal convictions. Hence, median values were defined for data sets to define a conditional probability for each pair of related activities in