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Assessing new product development project risk by Bayesian network with a systematic probability generation methodology

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ABSTRACT

New product development (NPD) is a crucial process to keep a company being competitive. However, because of its inherent features, NPD is a process with high risk as well as high uncertainty. To ensure a smooth operation of NPD, the risk involved in the process need to be assessed and the uncertainty should also be addressed properly. Facing these two tasks, in this paper, the critical risk factors in NPD are first analyzed. Since Bayesian network is specialized in dealing with uncertainties, those risk factors are then modeled into a Bayesian network to facilitate the assessing of the risk involved in an NPD process. To generate the probabilities of different kinds of nodes in a Bayesian network, a systematic probability generation approach is proposed with emphasis on generating the conditional probabilities of the nodes with multi-parents. A case study is also given in the paper to test and validate the critical risk factors as well as the probability generation approach.

1. Introduction

In response to a competitive business environment, new product development (NPD) has been playing an essential role in the success of many companies (McCarthy, Tsinopoulos, Allen, & Rose-Anderssen, 2006). NPD, by nature, is a relatively risky activity (Kahraman, Buyukozkan, & Ates, 2007; Kayis, Arndt, & Zhou, 2006; Ozer, 2001) as market competition and product technology advancement are often intense (Di Benedetto, 1999; Mullins & Sutherland, 1998; Srinivasan, Haunschild, & Grewal, 2007). Because of NPD's inherent features, NPD decisions inevitably encounter a considerable amount of uncertainties which may result in negative consequences of the targeted performance (Kahraman et al., 2007; Kayis et al., 2006). Managing risks of NPD projects is therefore becoming important as it is a means to evaluate and mitigate risks of NPD projects (Cooper, 2003; Kayis, Arndt, & Zhou, 2007; Smith, 1999). However, several researchers have found that risk handling in NPD projects in many organizations is often done by using informal and unsystematic methods and based largely on management perceptions (Calantone, Di Benedetto, & Schmidt, 1999; Cooper, 2006; Gidel, Gautier, & Duchamp, 2005; Griffin, 1997). There is an increasing need to develop a systematic and effective method to assess the NPD project technical risks at the early design stage which helps designers to make decisions among alternative designs from project risk point of view.

On the other hand, Bayesian network (BN) is a probabilistic graphical model that represents a set of variables and their probabilistic dependencies. Generally speaking, BN can represent the complex relationship among the elements in a reasoning process. It is a computational model of human reasoning, and of how people integrate information from multiple sources to create coherent stories or interpretations (Cooper, 2000; Eleye-Datubo, Wall, & Wang, 2008; Ren, Wang, & Jenkinson, 2007). BN can imitate human's reasoning process in a quantitative and relative accurate way, and more importantly, it can update the knowledge when new evidence becomes available. This is considered as its prominent merit because it is helpful in a dynamic environment, such as the NPD environment, where new evidence is available from time to time. However, most of the current BN research in NPD project only focuses on the construction of the structure of BN and on the inference of BN, not on the determination of probabilities in BN, which is a necessity before the inference in BN can be performed. Monti and Carenini mentioned a probability generation approach in BN (Monti & Carenini, 2000), but such an approach is only restricted to generating the conditional probability of a node with a single parent. It is thus not applicable for most BN problems with multi-parents, such as NPD.

Based on what has been mentioned above, this paper, with the development of a systemic probability generation methodology, attempts to propose a BN based assessment method, fitting to

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multi-parent situation, to evaluate the NPD project risks. Two areas have been investigated and described in this paper. The critical risk factors in NPD project execution and their interrelationship will be firstly investigated and presented. The second is to develop a BN network for these factors with a systematic probability generation approach, with emphasis on generating the conditional probabilities of the nodes with multi-parents, to facilitate the assessment of NPD project risks. An industrial case is used to demonstrate the effectiveness of this proposed methodology.

2. Literature review

This section consists of two main parts. The definition of NPD project risk factors and existing studies in NPD project risk factors are discussed in the first part. Then, the current risk analysis methods are elaborated on in the second part.

2.1. NPD project risk factors

Risk is an inherent part of business and public life (Tchankova, 2002). It is the opportunities and dangers associated with uncertainty caused by incomplete data and information, or with uncontrollable outcomes. Risk management is the process of understanding potential risks and making positive plans to mitigate, eliminate or take advantage of them (CIMA, 2002; Shaw, Burgess, & Mattos, 2005). It can be realized by a three-step process that includes understanding all the uncertainties, attributing measures to uncertainties and optimization (Focardi & Jonas, 1998). NPD project is a stochastic problem which could be considered as multiple levels of tasks (Anderson & Hoglejar, 2005; Gidel et al., 2005). The NPD project risk is defined as an uncertain event or condition which could result in a negative effect on NPD technical project's objectives. The accomplishment of NPD milestones could be influenced if the associated risks are not managed properly. Furthermore, evaluation of potential project risks prior to the implementation of NPD projects should be made so that projects with higher probability of failure can be determined and as a result companies can handle it before making substantial investment in NPD projects. NPD project execution risk has not been highly focused on in literatures. Although some studies have been done in the area, their essence does not pinpoint at risk factors of NPD project execution. Risk-based NPD evaluation remains vague in many areas (Keizer, Vos, & Halman, 2005; Shaw et al., 2005). In consideration of the theoretical interpretation of risk factors, existing studies in NPD risks can be categorized into three main streams.

The first stream focuses on NPD project management, such as Ayag and Ozdemir (2007), Dey and Ogunlana (2004), Lee, Tsai, and Jih (2006) and Nadkarni and Shenoy (2001). For instance, Nadkarni and Shenoy (2001) proposed a casual map for product development decisions, in which three major industry factors are developed, namely market dynamic, product life cycle and market share distribution. However, the decision context lacks theoretical explanations and is not specially focused on the NPD project risk. Although Dey and Ogunlana (2004) identified some risk related factors for an innovative project, the scope of the study was distinctively devoted to the build-operate-transfer construction project only. To sum up, the first stream of NPD study is not directly related to risk factors of NPD projects. Though the second set of literature addresses the risk related factors in NPD projects, they focus more on a general discussion of risk factors of NPD process (Kahraman et al., 2007; Leithhead, 2000; Mobey & Parker, 2002; Mullins & Sutherland, 1998). Risks factors in terms of technology, human and organization, have been highlighted in the study of Mobey and Parker (2002), but it paid little attention to the interpretation of factors and their sub-categories. Furthermore, business operation risk rather than NPD project execution risk was concentrated on. Similar situation has also been found in the study of Kahraman et al. (2007), risks factors in terms of finance, technique, management and personnel were pointed out but not extensively discussed. The third stream research focuses more on risk management in NPD project (Calantone et al., 1999; Chen, Lee, & Tong, 2007). However, they were not devoted to risk factors of NPD project execution. Calantone et al. (1999) and Chen et al. (2007) emphasized the importance of risk management in NPD activities and proposed a hierarchy for NPD project selection. Nevertheless, their models only coped with the generalized operational considerations in NPD projects than specifically in NPD project risks. In general, the theoretical interpretation of the NPD project execution risk has not yet been supported and an in-depth investigation in the area deems necessary.

2.2. NPD project risk analysis

Many decision methods and techniques have already been employed for risk analysis, such as: behavioral model, failure mode and effects analysis (FMEA), technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP), analytical network process (ANP), Bayesian network (BN) etc. However, all these tools mentioned, to some extent, have some underlying weaknesses when applied in a complex situation, such as the NPD environment.

Behavior models (Leithhead, 2000; Mobey & Parker, 2002; Mullins & Sutherland, 1998) can neither accommodate complex decision making nor analyze uncertainties quantitatively. As for the application of FMEA (Carbone & Tippett, 2004), since FMEA is in essence a scoring method, it can only indicate the average of performance in a single score and cannot present the true diverse nature of an assessment. On the other hand, a human's judgment, e.g., the human's knowledge on the distribution of different risk states, cannot be modeled by just a precise number by pre-aggregating various types of information. Therefore, FMEA can only be used as a tool for an initial assessment or a rough assessment categorization tool. Kahraman et al. (2007) proposed a fuzzy TOPSIS to analyze the decision-making process in NPD based on the technique of TOPSIS developed by Hwang and Yoon (1981). In such a method, the analysis model of NPD decision making is constructed in a strict hierarchy. However, the practical decision analysis of NPD is a complex problem and thus the analysis cannot always be modeled in a strict hierarchy.

AHP has also been applied in NPD risk analysis (Chen, Lee, & Tong, 2006, 2007; Lam & Chin, 2005; Roger, Calantone, Anthony, & Jeffrey, 1999; Saaty, 1980). On one hand, AHP is a rather straightforward approach which is very easy to understand and implement. On the other hand, the successful application of AHP is based on the assumption that the problem can be constructed in a strict hierarchy in which the elements in the same level are independent of each other. This independency assumption, however, is often difficult to be met in practical applications, especially when there are many aspects to be considered and the relationship among those aspects are very complicated.

To solve the independency problem of AHP, analytic network process (ANP) was then proposed by Saaty (1996). ANP is a more general form of AHP to handle more complicated interrelationships, including dependences, interactions, feedbacks etc., among the elements both in the same level and in different levels. With such a feature, ANP has already been successfully applied in many fields including NPD analysis (Ayag & Ozdemir, 2007; Cheng & Li, 2005; Meade & Presley, 2002; Meade & Sarkis, 1999). Despite the above applications, there are also limitations concerning ANP. For example, ANP can only express relationships among different elements through relative weights generated from pair-comparisons