Expert Systems with Applications 38 (2011) 5373–5383

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A methodology to generate a belief rule base for customer perception risk analysis in new product development

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ARTICLE INFO

Keywords:
Belief rule base generation
Risk analysis
New product development

ABSTRACT

New product development (NPD) is crucial for a company's success in a competitive market. Meanwhile, NPD is a process associated with great complexity and high risk. To ensure its smooth operation, risks involved in an NPD process need to be analyzed in a proper way. In this paper, a novel method is proposed to generate a belief rule base (BRB), which is the basis of the Belief Rule-Base Inference Methodology using the Evidential Reasoning (RIMER). Due to its capability in dealing with complex reasoning problems under uncertainty, RIMER is then applied to assess customer perception risk (CPR) in an NPD process. To test and validate the method proposed in this paper, a case study of an "Interactive Doll" is conducted at the end of the paper.

1. Introduction

New product development (NPD) projects, especially for those involving radical innovation, are usually risky but bring considerable returns (Keizer & Halman, 2007). During the NPD period, although primary customer information is captured, target customer's attitudes and perceptions would not keep unchanged due to various reasons, e.g., variation of market situations in fashion and trends and rapid changes in technologies (McDermott & O'Connor, 2002). The risk incurred by changes in target customers' perceptions towards the new product in NPD process is to be explained by the customer perception risk (CPR) in this paper.

In current literature, many risk analysis methods have been introduced. However, most of them are based on qualitative analysis or oversimplified realities, thus, there is a need to find a method that can provide an analytical and realistic way to analyze risks with different kinds of uncertainties taken into consideration. The Belief Rule-Base Inference Methodology using the Evidential Reasoning (RIMER) (Yang, Liu, Wang, Sii, & Wang, 2006a) is such a method, which can provide a realistic and informative way for risk analysis. However, how to generate a belief rule base (BRB), which is the basis of RIMER, is seldom discussed.

Facing this situation, this paper is intended to propose a novel method to generate a BRB. The method establishes the relationship between Bayesian Network (BN) and BRB and provides a way to measure the influence of different antecedent attributes on the consequence in a belief rule in a quantitative way. More importantly, it can reduce biases and inconsistencies involved in the BRB generation process. Based on the generated BRB, RIMER (Yang et al., 2006a) can then be applied for CPR analysis.

The paper is organized as follows. In Section 2, relevant literature is reviewed. Section 3 is dedicated to introducing BRB and its advantages comparing with traditional rule base. In Section 4, CPR analysis model is proposed. The method to generate BRB is proposed in Section 5, followed by a case study to demonstrate the proposed method and the application of RIMER in CPR analysis in Section 6. The paper is concluded in Section 7.

2. Related research

2.1. Risk, risk management and risk in NPD

Risk is an inherent part of business, and it is usually modeled by probability of occurrence of undesirable events and impact of the corresponding consequences (Kallman, 2005; Webb, 2003).

As taking a certain level of risk in an appropriate manner could lead to a certain level of return (Kallman, 2005), companies usually make tradeoffs between benefits and risks (Ogawa & Pillar, 2006; Tchankova, 2002). Therefore, understanding and managing risks are utmost important (Gidel, Gautier, & Duchamp, 2005). One of common risks encountered is the gap between the assumed product strategies and the actual customer perceived image of new products (Cheng & Liao, 2007). In other words, customer perceptions towards new products may deviate from company

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doi:10.1016/j.eswa.2010.10.018

expectation. Such a risk may lead to loss of customers or even threaten overall business performance (Langerak, 2001).

2.2. Research on risk analysis techniques in NPD

Different decision tools have been applied to conduct risk analysis in NPD, including behavioral models (Leithhead, 2000; Mobey & Parker, 2002; Mullins & Sutherland, 1998), Failure Mode and Effects Analysis (FMEA) (Carbone & Tippett, 2004), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Kahraman, Buyukozkan, & Ates, 2007), Analytical Hierarchy Process (AHP) (Chen, Lee, & Tong, 2006; Lam & Chin, 2005; Roger, Calantone, Anthony, & Jeffrey, 1999) and its generalization (Chen, Lee, & Tong, 2007), Analytical Network Process (ANP) (Ayag & Ozdemir, 2007; Cheng & Li, 2005; Meade & Presley, 2002; Meade & Sarkis, 1999), BN (Cooper, 2000; Nadkarni & Shenoy, 2001), etc.

However, there are limitations in applying the above-mentioned methods to NPD risk analysis. For example, a behavior model can neither deal with complex analysis tasks, nor can it offer quantitative analysis results. FMEA is often criticized for its oversimplification since it is based on a scoring method, which expresses human's judgments in just a single score. When applied in NPD risk analysis (Kahraman et al., 2007), TOPSIS can only deal with problems which can be constructed into a strict hierarchical structure. AHP also requires that a problem must be constructed in a strict hierarchical structure and that the elements in the same level of a hierarchy be independent of each other, which severely limit the scope of its application since NPD risk analysis is normally conducted in a complex environment with many inter-related elements. The above requirements of AHP are somehow relieved by the introduction of ANP. However, ANP cannot quantify and explicitly demonstrate influences among elements and it is incapable of updating judgments when new evidence becomes available, which is usually the case in an NPD process.

Most limitations mentioned above can be overcome by using BN, but BN requires input probabilities be precise and complete, which means the sum of the probabilities of all states at a node should be exactly 1. However, since risk analysis in NPD requires the consideration of multiple factors with various features under different kinds of uncertainties, it is therefore difficult, if not impossible, for experts to provide complete knowledge on estimating precise probabilities. Therefore, a new method is needed which can accommodate various forms of inputs with different kinds of uncertainties.

RIMER, which was proposed by Yang et al. (2006a), can be regarded as a potential alternative to handle the above problems. It is the combination of BRB and the Evidential Reasoning (ER) method (Yang & Singh, 1994; Yang & Xu, 2002), which is based on the Dempster–Shafer theory (Shafer, 1976) and uses belief degrees in the reasoning process. Similar to BN, RIMER can deal with complex problems which can be modeled in network structures, it can provide a reasoning process in a quantitative way, and it can also update knowledge in light of new evidence. Furthermore, RIMER has some unique features which BN does not have, among which the most important one is that RIMER can accommodate different forms of inputs with different kinds of uncertainties, including incomplete judgments. As such, it is expected that RIMER can provide a promising framework for risk analysis in NPD processes.

As the basis of RIMER is a BRB, how to build such a BRB from experts' knowledge in a rational and consistent way is very crucial to the performance of RIMER. However, the analyses and discussions in Yang et al. (2006a) are based on well-established BRBs and little attention has been paid on how to rationally and consistently generate such BRBs, which remains an open and domain dependent research question without a generic solution currently. Facing the above situation, this paper intends to propose a method to generate BRBs from experts' knowledge regarding CPR in NPD process in a rational and consistent way and then apply RIMER in CPR analysis based on the generated BRBs.

2.3. Summary

Risks are prevalent in NPD process, and the gap between the assumed product strategies and the actual customer perceived image of a product is one of the most important risks which need careful investigation and analysis. To analyze risks in NPD process, several methods are proposed, among which RIMER provides a promising framework. However, how to generate BRB, which is the basis for application of RIMER, remains a problem. In this paper a novel method will be developed to generate BRB for RIMER regarding CPR in NPD process, and RIMER will be applied to analyze CPR subsequently.

3. A summary of belief rule base

3.1. Belief rule base and its components

A conventional rule base is composed of simple IF-THEN rules, and the kth rule can be written in the following form:

$$R_k : \text{if } A_1^k \wedge A_2^k \wedge \cdots \wedge A_{T_k}^k, \text{ then } D_k \tag{1}$$

where $A_i^k (i = 1, 2, \ldots, T_k)$ is a referential value of the$i$th antecedent attribute in the kth rule, and it can take different types of value. T_k is the number of the antecedent attributes used in the kth rule. D_k is the consequence in the kth rule. The symbol $\wedge$ refers to the 'AND' relationship among the antecedent attributes.

The rule expressed in (1) is relatively simple. It does not consider the distribution of consequences, the relative importance of each antecedent, or the relative importance of rules in the rule base.

To take the above aspects into consideration, three concepts are introduced:

- Belief degrees of consequence: in a complex situation, it is likely that the consequence of a rule may take a few values with different degrees of belief to express experts' opinions on the extent to which a consequence value may be true. Suppose the consequence D has N different values, $D_1, D_2, \ldots, D_N$, and the belief degree of D_i is represented by $\beta_i (i = 1, 2, \ldots, N)$, then the consequence with a belief structure can be represented by:

$$(D_1, \beta_1), (D_2, \beta_2), \ldots, (D_N, \beta_N)$$

- Attribute weight: as indicated in Yang et al. (2006a), the relative importance of an attribute to the consequence of a rule plays an important role in rule base inference. Thus, there is a need to assign a weight to each attribute to describe such importance.
- Rule weight: in order to represent the relative importance of a rule in the whole rule base, we also need to assign a weight to the rule itself, referred to as rule weight (Yang et al., 2006a).

Based on the above three concepts, the simple rule as expressed in (1) can be extended to the following form (Yang et al., 2006a):

$$\begin{aligned} &R_k : \text{if } A_1^k \wedge A_2^k \wedge \cdots \wedge A_{T_k}^k, \text{ then } \{(D_1, \beta_{1k}), (D_2, \beta_{2k}), \ldots, (D_N, \beta_{Nk})\}, \\ &\sum_{i=1}^{N} \beta_{ik} \leqslant 1, \quad \text{with a rule weight } \theta_k \text{ and attribute weight} \\ &\times \delta_{k1}, \delta_{k2}, \ldots, \delta_{kT_k}, \; k \in \{1, 2, \ldots, L\} \end{aligned} \tag{2}$$

where $A_i^k (i = 1, 2, \ldots, T_k)$ is the referential value of the ith antecedent attribute in the kth rule, T_k the number of antecedent attributes used in the kth rule, $\beta_{ik} (i \in \{1, 2, \ldots, N\})$ the belief degree to which D_i