A fuzzy robust evaluation model for selecting and ranking NPD projects using Bayesian belief network and weight-restricted DEA

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1. Introduction

According to a profitability analysis of top 20\% companies conducted by Product Development & Management Association (PDMA), new product sales will contribute as high as 42\% of the profit. This survey also shows that a NPD project failure ratio reaches the 41\%, justifying the importance of NPD and its non-negligible high risk. Subject to limited NPD resources, a company should carefully evaluate and screen NPD projects, before investing tremendous corporate resources, to reduce NPD risk and to promote business profitability. According to the investigation (Cooper, Edgett, & Kleinschmidt, 1999), 37.9\% of firms use a subjective scoring approach for selection of NPD projects. Because top managers often select NPD projects under in an environment of incomplete information and extreme uncertainty, the risk and difficulty in selecting NPD projects are therefore increased dramatically for decision makers. Facing the above mentioned challenge, a company's manager needs to apply a scientific approach to profoundly analyze various risk factors for each candidate NPD project. To effectively solve the foregoing problems, this study uses the Bayesian belief network (BBN) method to construct the Bayesian network diagrams of the time-to-market risk, the manufacturability risk and the expected revenue risk. With logic inference of risk factors, the analysis of the NPD risk dimension can be conducted in a more objective scientific manner. With respect to the dimension of cost and revenue, it includes three criteria, i.e., the development cost, the expected revenue and the technology business value. This study also proposes the corresponding performance evaluation models for these criteria. As the units of the evaluation criteria are inconsistent, the $T$ score or the $Z$ score is often employed when summarizing the assessment performance of various criteria. These measures, however, may distort the original data, and lose the characteristics and the value of original data. To allow the original data to be used for priority ranking of NPD projects and to deal with incomplete information and the uncertain environment, this study applies the fuzzy data envelopment analysis (DEA) to evaluate and to rank NPD projects. When the fuzzy DEA method estimates the efficiency of the decision-making unit (DMU), it is to seek the most favorable criteria weights for each DMU. However, the relative importance of evaluation criteria for NPD projects should be set within reasonable ranges so as to obtain a more objective and reasonable the priority ranking for all NPD projects. In order to assist companies in controlling the initial phase of NPD, this study put forward the evaluation and ranking model for NPD projects combining the fuzzy analytical hierarchy procedure (Fuzzy AHP) with the Fuzzy DEA, to ameliorate the efficacy of NPD project selection and to decrease the NPD failure risk.

The rest of this paper is as follows: Section 2 reviews relevant literature of NPD project evaluation and selection. Section 3 depicts the evaluation and ranking methodology of NPD Projects. Section 4 uses the development projects of the electronic extension cards as a case study for explanation and verification of significant benefits of the methodology proposed by this study.
2. Literature review

Because NPD project selection plays a critical role in future market competitiveness, a company requires a well-rounded consideration when top managers assess and rank NPD projects. To address such complicated decision-making challenges, many studies apply a multi-criteria decision-making model (MCDM) to help high-level managers scientifically select an alternative with a quantitative analysis. For example, Brenner (1994) uses the AHP method to gain criteria weights of NPD and exhibits advantages and disadvantages of each project with diagrams. Al-Harbi (2001) uses AHP to estimate the degree of importance of each assessment indicator for the projects and to calculate an objective weight of each indicator for decision-making. Ahn and Choi (2008) combines the AHP and the simulation methods to create a simulation-based AHP (SiAHP) and verifies the elasticity of this model with an ERP project selection case. Lee and Kim (2000) for aggregation of group opinions and understanding of the relation among the selection criteria, use the analytic network process (ANP) and the zero-one goal programming (ZOGP) to select an information system project. To assist companies in making the most correct decisions and the most effective resource allocation, Meade and Presley (2002) use the ANP technique to quantify the importance of qualitative criteria and to conduct a performance analysis for selection of R&D projects.

DEA has been applied to assessment of alternatives in recent years. The DEA uses the inputs and the outputs of DMU to measure the alternatives’ performance. Linton, Walsh, and Morabito (2002) apply a basic DEA model to R&D project selection and use the diagrams to analyze product portfolios. Sowlati, Paradi, and Suld (2005) employ the AHP to obtain weights for each selection criterion and use DEA to select a NPD project with potential. Eliat, Golany, and Shtrub (2006) use the balanced scoreboard (BSC) method to gain performance assessment values of qualitative criteria and then apply a DEA model for project screening. When calculating the relative efficiency of a DMU with DEA, this method seeks the most favorable criteria weights for the DMU. For decision makers, however, the degree of relative importance of each criterion should be set within a reasonable range. Otherwise, an optimal NPD project may not be selected from the alternatives.

Besides, the foregoing methods cannot deal with uncertainty and fuzziness under subjective judgment. To improve the problem, the fuzzy theory has been gradually applied to project selection (Buyukozkan & Feyzioglu, 2004; Chen, Lee, & Tong, 2007; Huang, Chu, & Chiang, 2008; Machacha & Bhattacharya, 2000). To consider uncertainty as a result of incomplete information in project selection, Feyzioglu & Buyukozkan (2006) combine the artificial neural network (ANN), the fuzzy theory and the Choquet integral model to develop an integrated decision-making method and use past experience to rapidly assess NPD projects. Mahmoodzadeh, Shahrabi, Pariazar, and Zaeri (2007) add conventional AHP into the fuzzy concept to build a fuzzy judgment matrix to indicate the fuzziness of subjective judgment of decision makers and apply the technique for order preference by similarity to ideal solution (TOPSIS) for project ranking. To alleviate the impact of uncertainty in the environment, Wang and Hwang (2007) apply the plausibility theory to develop a fuzzy integer planning model to gain an optimal investment portfolio. Chiu, Chen, Shyu, and Tseng (2006) Wang, Jing, Zhang, Shi, and Zhang (2008) apply the fuzzy concept to the project selection process with the fuzzy multi-criteria decision-making model (FMCDM) to select the optimal alternative. Sun, Ma, Fan, and Wang (2008) use the Fuzzy AHP to establish decision support systems (DSS) for selection of R&D projects. Trappey, Trappey, Chiang, and Kuo (2009) employ the fuzzy theory to screen NPD projects, and then use the evaluation model of resource requirements of product portfolios to create the plausible product portfolios. Finally, according to the revenues and the risks of feasible product portfolios, the optimal product portfolio is created.

From the explanation given above, we can find that DEA is ideal tool for multi-criteria synthesized performance evaluation. As the selection of NPD projects is carried out in an environment of uncertainty, this research uses fuzzy numbers to represent performance assessment values of evaluation criteria. In addition, the DEA method adopts the most favorable criteria weights for the DMUs. However, the relative importance of evaluation criteria for NPD projects should be set within a reasonable range. Therefore, this study uses Fuzzy AHP and Fuzzy DEA to develop a ranking methodology for evaluating and selecting NPD Projects. Moreover, the assessment of NPD project risks is another key issue, thus this paper uses the relationship diagram of Bayesian network influence to evaluate project risk objectively and correctly.

3. Evaluation and ranking methodology for NPD projects

Fig. 1 shows the analytical process of the NPD project evaluation and ranking. This study divides the framework of NPD project evaluation into two dimensions, i.e., the risk dimension and the dimension of cost and revenue. The risk dimension consists of the time-to-market risk, the manufacturability risk and the expected revenue risk. The dimension of cost and revenue contains three criteria, including the development cost, the expected revenue and the technology business value. First of all, in order to obtain the weight range of each criterion for screening the NPD projects, this research applies the Fuzzy AHP to assist the top managers in expressing the relative important degree of each criterion. Afterward, the top managers employ the performance evaluation models of the criteria developed by this study to estimate the performance values of the criteria for all NPD projects. Then, the weight-restricted fuzzy DEA ranking methodology is applied to obtain the ranking for all NPD projects. According to the priority, the top managers can select the most appropriate NPD projects with the greatest potential. The following sections describe each part of the methodology presented in the paper in detail.

3.1. Performance evaluation models for NPD project evaluation criteria

In the risk dimension, this study constructs the Bayesian network diagrams for the time-to-market risk, the manufacturability risk and the expected revenue risk, and then uses the BBN approach to estimate each risk of an NPD project. A Bayesian network is a directed acyclic graph, from which the association among NPD project risk factors can be clearly visible, which therefore helps top managers objectively identify and evaluate the risks of a NPD project. In the dimension of cost and revenue, this study develops fuzzy quantitative estimate models, providing decision makers with triangular fuzzy numbers to express the estimation values of the development cost, the expected revenue and the technology business value. The performance evaluation models of the evaluation criteria for NPD projects are detailed below.

(1) The expected revenue risk: The criterion evaluates the risk that the expected revenue can be achieved after the new product launch. Fig. 2 shows the Bayesian network diagram of the expected revenue risk, in which a node represents an event and the link between two nodes represents the causal relation between events. The degree of the influence of the causal relation is expressed by the conditional probability. There are three situations, the high, the middle or the low for each node. From Fig. 2, the sales volume is influenced by factors such as the product price and the product difference. Formula (1) shows how to estimate the probability of