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Multi-objective decision-making methodology to create an optimal design chain partner combination ☆

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ABSTRACT

In today's highly competitive business environment, many companies adopt the time-to-market strategy to obtain a competitive advantage. To reduce the time and cost of product development and to employ global product development resources, design chain partner evaluation and selection has become a crucial issue. Thus, establishing an optimal design chain partner combination has received significant attention because it has a far-reaching effect on the results of product development. With this perspective, this paper develops an integrated decision-making methodology to assist enterprises as they create an optimal design chain partner combination. First, this study establishes the framework and evaluation models of the criteria for the different roles of design chain partners, including system integration, functional module development and software and component development. Then, this paper applies a weight-restricted DEA (data envelopment analysis) approach to create the models for performance analysis of design chain partners to acquire the performance value of each candidate and select the efficient design chain partners. Moreover, this paper employs the multi-objective performance evaluation model proposed in this paper to analyze the synthesized performance of design chain combinations. Moreover, this research uses a multi-objective genetic algorithm (GA) to search efficiently for the optimal design chain partner combination to minimize product development cost and time and maximize product reliability. Finally, this study employs a derivative new product development project for a digital TV box as a case study to illustrate the efficacy of the proposed methodology.

1. Introduction

Because companies face fierce business competition and the product life cycle is becoming shorter, no enterprises are exempt from the requirement to accelerate product development and innovation. However, the current complexity of product design has significantly increased, and product development involves a wide variety of expertise and professional domain knowledge. Thus, for a single company, it is very difficult to complete all product development activities with limited enterprise resources in a short time. Because of the flourishing development of information technology and the significantly improved network infrastructure, it is possible to establish a virtual product development team to develop a new product collaboratively. Therefore, enterprises can effectively employ the product development and innovation capacity of the design chain members to deliver a low-cost, high-quality, and customer-oriented new product in a short amount of time. It is obvious that a design chain partner combination formed by members of different organizations across geographical barriers will have far-reaching effects on the market competitiveness of a new product and the profitability of a company in the future. However, this new pattern of product development also generates some problems in design chain management: rapidly and effectively evaluating and selecting effective design chain members, considering different partner roles and forming the best design chain partner combination when a company senses new market opportunities. Short product life cycles cause enterprises to evaluate design chain partner combinations constantly. Moreover, to shorten the time to market, companies often adopt the pattern of derivative product development to respond quickly to changes in market requirements. Based on the investigation by Crawford and Di Benedetto (2010), new-to-the-world products only account for approximately 10% of all new products. Therefore, most new products belong to the class of derivative new products which are built around improved preexisting or established technologies, such as consumer electronics, software, airplanes, and cars. If the current product development activity is similar to that of a previous project, the performance of the product development activity can be derived from historical data for the product development partner (Ulrich & Eppinger, 2011). Therefore, this study aims to develop an integrated decision-making

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methodology to assist companies as they create an optimal design chain partner combination for derivative product development.

The organization of this paper is as follows. Section 2 reviews the related papers of partner evaluation and selection. Section 3 describes an integrated decision-making to create an optimal design chain partner combination using weight-restricted DEA and a multi-objective genetic algorithm (GA). Section 4 employs a digital TV box development project as a case to demonstrate the significant contribution of the methodology presented in this paper. Finally, Section 5 makes some conclusions of this study.

2. Literature review

This section reviews the related research for evaluation criteria and methods of partner selection. Wang, Huang, and Dismukes (2004) developed an integrated analytic hierarchy process (AHP) and goal programming (GP) based on a multi-criteria decision-making methodology, which takes into account delivery reliability, flexibility and responsiveness, purchasing cost and assets in supplier selection. Xia and Wu (2007) integrated AHP with multi-objective mixed integer programming to support supplier selection decisions in business volume discount environments. The evaluation criteria of suppliers include the price, the quality and warranty period of components, the supply capacity and the timeliness of delivery. In addition, multi-objective mixed integer programming can determine the number of suppliers and the order quantities allocated to the suppliers; moreover, it can minimize the total purchase cost, minimize the number of defective products, and maximize the number of on-time deliveries while satisfying supply capacity and demand constraints. Wang and Che (2007) proposed an integrated method to model the change behavior of parts and to evaluate alternative suppliers for each part by applying fuzzy theory, T transformation technology, and genetic algorithms. Their model considers assembly cost, purchasing/manufacturing cost and quality level for alternative suppliers. Yue et al. (2010) developed a sourcing partner selection approach for make-to-order manufacturers. The evaluation criteria of their model include capacity, cost, and processing time. In addition, this approach enables the manufacturer to determine the shortest possible date to win the bid without placing additional pressure on the sourcing partners. Che and Chiang (2010) presented multi-objective build-to-order supply chain planning, which integrates supplier selection, product assembly and the logistic distribution system of the supply chain. This multi-objective optimization mathematical model considers three evaluation criteria: costs, delivery time and quality. From the above literature, we can understand that evaluation criteria and methods of supply chain partner selection are based on the premise that product development is being completed. Therefore, the decision-making problems of supply chain partner selection usually need to consider simultaneously the supply capacity, order quantity allocation, on-time delivery reliability, the cost and quality of components, the volume discount and other related factors. Obviously, evaluation criteria and methods of supplier selection fail to be used directly to solve the problem of product development partner selection.

Thus, some papers have addressed the important issue of design chain partner selection. For example, McGrath (2003) established the evaluation criteria of design chain partners, which include technology, development capabilities, organization alignment, process compatibility, financial viability, and pricing as well as financial arrangement. Cao and Wang (2003) integrated Monte Carlo simulation with a GA to evaluate and select design chain partners, and to maximize the chances of success in new product development under the R&D time and cost constraints. Wang, Yang, and Ip (2001) applied fuzzy theory in GAs and took the risk and duration of a new product project into account to find an optimal partner combination. Ip, Huang, Yung, and Wang (2003) used a GA to solve the partner selection problem, which takes into consideration the project start and completion times, as well as penalties incurred due to the product development activity delay. Mohanty and Deshmukh (1993) stated that the partner evaluation and selection issue is a highly complex and unstructured decision-making problem, which requires quantitative tools and multi-criteria methods to determine optimal partners. The AHP can address the decision-making problem with multiple criteria to obtain criteria weights and the relative performance of alternatives through the pair-wise comparison approach. Until recently, many applications of the AHP have been used to solve partner selection problems (Chan, 2003; Chu, Tso, Zhang, & Li, 2002; Sevkli, Koh, Zaim, Demirbag, & Tatoglu, 2007). However, a decision maker cannot always accurately express his preferences for criteria in practical applications when facing unstructured problems in an uncertain environment. Therefore, Buckley (1985) presented Fuzzy Hierarchical Analysis (FHA) to resolve this problem. Chan, Kumar, Tiwari, Lau, and Choy (2008) used FHA to solve the decision-making problem of supplier selection considering cost, services, quality and risk. Mikhailov (2002) selected partners by FHA using financial stability, price, quality, and customer services as criteria. However, FHA ignores the constraint-type criteria. Therefore, Wang and Lin (2006) proposed a fuzzy hybrid decision-support model for partner selection. The model uses a fuzzy multi-criteria outranking method to first obtain performance evaluation for design chain partners using the pair-wise comparison approach. Then, by setting the objective function of the design chain partner combination to be the sum of all the partners' performance values, the GA is applied to find the optimal combination under the time and cost constraints. However, this design chain partner selection model fails to directly use raw data to express the performance values of quantitative criteria. Once the original performance values are presented by the pair-wise comparison, the original data may be distorted. Moreover, there are no pre-screening procedures provided in this method to reduce the number of candidate partners. Therefore, the GA will spend more time acquiring an approximate optimal solution.

To evaluate and select partners using the original performance values of qualitative and quantitative criteria, some academic papers apply Data Envelopment Analysis (DEA) (Celebi & Bayraktar, 2008; Chiang, Lin, Che, & Chuang 2011; Narasimhan, Talluri, & Mendez, 2006; Weber, Current, & Desai, 1998) to solve the above-mentioned problems. Because the CCR-DEA model (1978) assumes constant returns to scale (CRS), it implies that a given increase in inputs would result in a proportionate increase in outputs. As a result, the CCR-DEA model should not be applied in a wide variety of practical situations (Ray, 2004). Therefore, Banker, Charnes, and Cooper (1984) proposed a BCC-DEA model to exhibit increasing, constant, or diminishing returns to scale. However, DEA adopts the most favorable criteria weights for the decision making unit (DMU). For managers, the criteria weights should have reasonable ranges (Chiang & Che, 2010). Thus, Thompson, Singleton, Thrall, and Smith (1986) proposed the concept of ranges of criteria weights, i.e., the assurance region. Liu (2008) indicated that the weight-restricted concept can be applied to restrict the ratio of any two weights to a range to prevent the evaluated alternatives from ignoring or relying too much on any criterion in evaluation. Thus, to find effective design chain partners, this paper adopts an input-oriented weight-restricted BCC-DEA model to develop an approach for performance analysis of design chain partners.

In addition, the design chain partner combination is a multi-objective decision-making problem. However, few studies have focused on developing an evaluation model of a multi-objective design chain partner combination. Based on the above review, this study combines FHA and DEA to develop a weight-restricted DEA