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Integrated product line design and supplier selection: A multi-objective optimization paradigm

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ABSTRACT

Product line design is commonly used to provide higher product variety for satisfying diversified customer needs. To reduce the cost and development time and improve quality of products, companies quite often consider sourcing. Conventionally, product line design and supplier selection are dealt with separately. Some previous studies have been attempted to consider product line design and supplier selection simultaneously but two shortcomings were noted. First, the previous studies considered several objectives as a single objective function in the formulation of optimization models for the integrated problem. Second, positions of product variants to be offered in a product line in competitive markets are not clearly defined that would affect the formulation of marketing strategies for the product line. In this paper, a methodology for integrated product line design and supplier selection is proposed to address the shortcomings in which a multi-objective optimization model is formulated to determine their specifications and select suppliers for maximizing the profit, quality and performance as well as minimizing the cost of the product line. In addition, joint-spacing mapping is introduced to help estimate market share of products and indicate positions of product variants. The proposed methodology can provide decision makers with a better tradeoff among various objectives of product line design, and define market positions of product variants explicitly. The results generated based on the methodology could help companies develop product lines with higher profits, better product quality and larger market share to be obtained. A case study of a product line design of notebook computers was performed to illustrate the effectiveness of the proposed methodology. The results have shown that Pareto optimal product line designs and the specifications of product variants can be determined. Suppliers of components and modules can be selected with considerations of minimum sourcing cost, and maximum performance and quality of product variants. Prices and positions of the product variants can also be determined.

1. Introduction

Nowadays, companies are faced with the great challenge that larger product variety and more customized products need to be provided to satisfy diversified customer needs (Tseng & Jiao, 2007). It is believed that increasing product variety could help to increase sales volume and generate more profit. However, an increasing variety of products would raise the total product development cost. This situation poses the dilemma for companies that they need to balance their product variety and the extent of complexity of product differentiation.

Product line design has been recognized widely as an effective method for targeting fragmented market niches with ideal scales of resource utilization and investment (Krishnan & Ulrich, 2001). The product line design problem is about the determination of product variants to be offered within a product line, and the level settings of attributes of the product variants. Its objectives generally include maximizing the total profit and market share, and minimizing development cost and development time (Thakur, Nair, Wen, & Tarasewich, 2000).

Successful product line design requires close integration between the marketing and engineering issues of products. Some previous studies have investigated product line design with various marketing issues. Balakrishnan, Gupta, and Jacob (2004) proposed an artificial intelligence approach to deal with produce line design and market share. Chen and Hausman (2000) developed a choice-based conjoint analysis to model product line selection and customer preference. Michalek, Ebbes, Adigüzel, Feinberg, and Papalambros (2011) presented a comprehensive methodology which incorporated analytical target cascading to coordinate marketing and engineering issues for product line design. Luo (2011)

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introduced a concurrent optimization method to determine a product line with profit maximum while engineering criteria can be satisfied. Some previous studies addressed the determination of optimal product line design with pricing. Hanson and Martin (1996) presented a logit profit function to optimize product line and perform pricing. Kannan, Pope, and Jain (2009) examined optimal pricing policies of product lines. Michalek, Ceryan, Papalambros, and Koren (2006) incorporated market performance and manufacturing requirements in discussing the tradeoffs between design and manufacturing cost and quantified market revenue. Lin and Okudan (2013) proposed to perform planning for multiple-generation product lines using dynamic variable state models.

Various methods for optimizing product line design can be found in the literature. Green, Krieger, and Zelnio (1989) first applied the coordinate ascent method to solve the product line design optimization problem. This method selects a product line randomly and evaluates its profitability. Balakrishnan et al. (2004) applied a hybrid genetic algorithm with beam search on product line design optimization. They suggested that the integrated approach is robust and can get near optimal solutions more quickly than traditional genetic algorithm. Kwong, Luo, and Tang (2011) introduced multi-objective genetic algorithms to optimize product line design based on conjoint analysis and MNL choice rules. A nested partitions heuristic was proposed by Shi, Ólafsson, and Chen (2001) to solve optimal product line design problems. They considered dividing the optimal solution space to various different regions, and dividing the most promising region into smaller ones for further action. Alexouda (2005) employed evolutionary algorithms to optimize product line design. Luo, Kwong, Tang, and Tu (2012) developed a conjoint based one-step optimization model for product line positioning and an interval-analysis-embedded tabu search was proposed to solve the model. Kumar and Catterjee (2013) proposed a mathematical model to consider simultaneous decision on pricing and product line optimization.

It is common nowadays for companies to develop their new products with the involvement of suppliers (Salvador, Forza, & Rungtusanatham, 2002). Supplier selection is a critical process that affects cost, quality and performance of products. Previous studies found that sourcing cost can take up more than 50% of product cost (Love, Barton, & Don Taylor, 2003; Luo, Kwong, Tang, Deng, & Gong, 2011). Therefore, product cost could be reduced through the selection of right suppliers and the customer satisfaction and competitiveness of products would be enhanced (Awasthi, Chauhan, Goyal, & Proth, 2009). A number of methods have been attempted in supplier selection such as AHP, ANP, cost ration method and goal programming. Since this research does not aim to develop a new method of supplier selection, literature review of it will not be provided here. Comprehensive review of supplier selection methods can be found in Chai, Liun, and Ngai (2013) and Liao and Kao (2010).

Conventionally, supplier selection is conducted after a product design is completed. Specifications of components for a product line are usually defined first by product development teams, and then the suppliers offering the lowest component prices are selected (Zhang, Huang, & Rungtusanatham, 2008). Nonetheless, the two separate processes can lead to suboptimal cost-saving or even poor product solutions in view of product cost, quality and performance (Gupta & Krishnan, 1999). The advantages of integrating product line design with supplier selection have been realized. However, very few studies so far have focused on developing methodologies for integrating the two issues. Gupta and Krishnan (1999) proposed an integer-programming model and a decision support methodology to solve the problem of integrated component design and supplier selection. Components which are served as equivalent functions are clustered into a replaceable component set (RCS). Objectives of their model are to minimize design cost and procurement cost. Balakrishnan and Chakravarty (2008) proposed a mathematical model considering product design and supplier selection for OEM companies. In their research, the proposed model was used to trade off the focused vendors and general vendors for identifying an outsourcing strategy regarding discount issues of component price. As customer needs for products are dynamic and uncertain, product architectures should be varied to meet the changes. Thus, the supplier selection is required to be robust. Tenneti and Allada (2008) defined the robustness of suppliers as a set of suppliers with minimum total supplier acquisition cost. Luo et al. (2011) developed a model to decide product configurations, and select suppliers for various target markets for maximizing total profit. Part-worth utility from conjoint analysis was determined to evaluate the utility surplus of a product and the product with maximum utility surplus value was chosen. A genetic algorithm was applied to find the optimal solution. However, those previous studies have attempted to deal with the integration problem by considering several objectives and they all have developed a single function that contains those several objectives as an objective function for the formulation of an optimization model. In addition, although specifications of product variants, that are offered under a product line, can be obtained in the previous studies, positions of the product variants in a competitive market are not clearly defined that would affect the formulation of proper marketing strategy for the product line.

2. Proposed methodology

In this paper, a methodology for integrated product line design and supplier selection is proposed to address the shortcomings of the previous studies as described in the end of Section 1. It is developed based on a multi-objective optimization paradigm and a joint spacing mapping technique is introduced to indicate market positions of product variants that are offered under a product line together with the positions of competitive products. The proposed methodology mainly involves the following steps. First, a market survey is conducted for understanding customers' preferences and their perceptions of competitive products. The survey results are then used to generate a joint space map. Based on the joint space map, a market share model is developed. On the other hand, a product quality model, product performance model, revenue model and cost model of a product line are developed. The next step is to define objective functions and constraints for the integrated problem. After doing that, a multi-objective optimization model for the integrated product line design and supplier selection is formulated. Once the component information including the component quality assessment scores, component performance scores and component costs is input, the formulated optimization model is solved by non-dominated sorting genetic algorithm II (NSGA II). After the solving, product line design solutions, selected suppliers for individual components are obtained. Details of the proposed methodology are described in the following.

2.1. Market survey and joint space mapping

In the proposed methodology, a market survey needs to be conducted for understanding customer preferences and their perceptions on competitive products. Questionnaires are adopted to conduct a survey in this research. The questionnaire contains a list of attributes of a product such as quality and user-friendliness and customers are asked to indicate their preferences for the attributes. The customer preference information to be collected is in the form of a quantitative measure. In addition, the questionnaire contains various types of information about competitive products including