Joint Supplier Selection and Product Family Optimization in Supply Chain Design: A Literature Review

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ABSTRACT

In order to incorporate the customer into the early phase of the product development cycle and to better satisfy customers' requirements. A need for effective integration of suppliers into the product value/ supply chain will be a key factor for achieving this goal. Various decision making approaches have been proposed to tackle the problem. This paper provides an extensive review the literature of integrated product family design with supplier selection problem that arises in the design of a multi-products supply chain, with particular reference to the influence of customer flexibly.

Keywords: *Supply chain; Supplier selection; Product Family*

1. INTRODUCTION

Within the last decade, the rapid rate of technological change, shortened product life cycles, and globalization of markets have resulted in renewed executive focus on new product development processes [1]. In a competitive environment, companies are faced with the great challenge that larger product variety and more customized products need to be provided to satisfy diversified customer needs. 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 [1]. Mass customization that can provide personalized products with mass production efficiency becomes the mainstream production mode in the 21st-century.

Product family is an enabling technology for mass customization and has many advantages such as increased flexibility, reduced development cost, and improved ability to upgrade products [58]. The problem of product family design is to determine the optimal settings of the attributes of product variants in a product family with the objective of minimizing performance loss or maximizing expected market profit [58].

Suppliers are an increasingly important resource for manufacturers, and have a large and direct impact on the cost, quality, technology, and time-to-market of new products. Effective integration of suppliers into the product value/ supply chain will be a key factor for manufacturers in achieving the improvements necessary to remain competitive. And also, efficient and effective supplier selection is important issue to be considered for designing flexible and highly competitive supply chains which maximize the manufacturer's total profit and ensure stable material flows. Meanwhile, Product development decisions are organized into four categories, concept development, supply chain design, product design, and production ramp-up and lunch [2].

The supply chain council defines a supply chain as "every effort involved in producing and delivering from the supplier's supplier to the customer's customer" [3]. A frame work of supply chain consists of the supply chain structure, the supply chain business processes, and the supply chain management components. In supply chain network structure the focal company is the center of the supply chain along with multi-tier suppliers to its left and multi-tier customers in the other side [4]. This research proposes the literature for supplier selection problem that arises in the design of a multi-product family supply chain, with particular reference to the influence of customer flexibility.

2. LITERATURE REVIEW

2.1 Supplier Selection: Methods and Criteria

The supply chain systems imply that enterprises seldom produce all components of a product due to company size and various other considerations. "Make and buy" decisions need to be made when considering the supply chain efficiency [5]. In order to gain an understanding of the state-of–the-art, 49 papers were evaluated focusing on supplier selection [6]. Overall, the supplier selection methods are categorized as appraisal methods and mathematical methods. Appraisal methods compare suppliers using criteria ranking or cost to evaluate their performance while mathematical methods involve trade-offs among selection criteria by linear weighting, optimization, statistical or neural network techniques. Supplier selection criteria include product market position, product development strategies and six types of modularity. Quality, cost, technology, production capacities, R&D, delivery and location, performance and service are used as selection criteria [5]. Suppliers are evaluated based on organizational factors as well as strategic performance matrices. Organizational factors cover culture, technology and relationship, and strategic performance metrics contain cost, quality, time and flexibility. Cost includes manufacturing, distribution, inventory and overhead components. Resources cover labor, machine, capacity, and energy utilization. Quality might involve customer dissatisfaction, response time, and on-time delivery, fill rate, stock- out probability and accuracy. Flexibility is the ability of a company to respond to diversity or change. However, no studies point to the supplier selection criteria from a product architecture viewpoint. There is a need to integrate supply chain decisions at product design phase so that the optimal component acquisition and possible alternatives can be evaluated and determined. The supply chain consideration aims to achieve a win-win situation at the supply chain level, which can benefit all practitioners in the supply chain in terms of performance.

In the most recent literature review, Ho et al. [7] presented a categorization of the multi-criteria decision-making approaches for the supplier evaluation and selection processes, and provided also evidence that the multi-criteria decision-making models are better than the traditional cost-based ones. Chkeramy [8] found in the literature that Supplier Selection methods are classified into two main categories, namely:

- Qualitative approaches
- Quantitative approaches: Non-optimization and optimization models.

1. Qualitative Approaches:

In general, qualitative papers address the following aspects of the supplier selection problem: identification of suppliers, evaluation of suppliers, negotiations with suppliers, strategic partnerships, etc. Masella and Rangone [9] compared four different vendor selection systems, which depend on the time-frame (short-term versus long term) and on the content (logistics versus strategic) of the co-operative customer/supplier relationships, by considering various sets of measures. Then Pidduck [10] presented a partner negotiation model for the identification of the most significant issues for the partner negotiation and selection processes. Beil [11] described the typical steps of a supplier selection process: identifying suppliers, soliciting information from suppliers, setting contract terms, negotiating with suppliers, and evaluating suppliers. Moreover, Beil highlighted also why each of these steps is important, how the steps are interrelated, and how the resulting complexity provides fertile ground for operations research and management science research.

2. Quantitative Approaches

2.1 Non-Optimization *Models:*

Non-optimization models provide usually a ranking of the candidate suppliers based on a set of predefined selection criteria that address the necessary information for a buyer to make a decision. Non-optimization techniques include among others statistical and financial models, multi-criteria techniques, and computer-based models. Petroni and Braglia [12] presented an alternative multi-criteria decision-support model for evaluating the relative performance of suppliers based on the statistical multivariate Principal Component Analysis. Degreave et al. [13] adopted the concept of TCO as a basis for comparing vendor selection models. They proved for a specific case study that, from a TCO perspective, mathematical programming models outperform rating models and multiple item models generate better results than single item one. Chen and Huang [14] integrated AHP in a software agent technique, so as to take into account both qualitative and quantitative attributes in supplier selection. Liu et al. [15] presented a methodology of applying DEA to compare overall supplier performances and demonstrated the applicability of their model through a case study for a manufacturing firm. The objective of this DEA application is to aid decision-making for reducing the number of suppliers and to provide improvement targets for suppliers. Jalao and Martinez [16] systematized the supplier selection process for long-term purchasing with the use of a computer-based ES that mimics the purchasing decisions of a purchasing professional. The proposed expert system is called contract ES, and is composed of four functional modules: configuration, supplier evaluation, supplier selection and supplier performance monitoring. Celebi and Bayraktar [17] presented a novel integration of Neural Network (NN) and DEA techniques for the evaluation of suppliers under incomplete information for the selection criteria. Finally, Temur et al. [18] presented a study in order to give insights for the supplier assessment process by comparing NN and Discriminate Analysis methods, applied to real world data from 51 long term suppliers of a medium sized company from German Iron and Steel Industry. The criteria that they considered were the following: material quality, distance, discounts on amount and discounts on cash, annual revenue, payment terms, and delivery length.

2.2 Optimization Models

Optimization models minimize a cost objective function, as a rule, in order to assist decision- makers in finding the optimal solution for the investigated problem. These techniques include among others mixed integer-programming (MIP), multi-objective programming (MOP), goal- programming (GP), and simulation models. Amid et al. [19] developed a fuzzy MOP model, assigning different weights to various criteria in order to overcome the vagueness of the information that arise in practice, regarding goals, constraints and parameters in the vendor selection problem. Kumar et al. [20] formulate the vendor selection problem as a fuzzy mixed integer GP problem, including three primary goals: minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries subject to a set of realistic constraints (e.g. buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items, budget allocation to individual vendors, etc.).In order to take into account the uncertainties in the supplier selection problem, Ding et al. [21] presented a simulation methodology that is composed of three basic modules: a genetic algorithm optimizer, a discrete-event simulator and a supply chain modeling framework. Furthermore, Wu and Olson [22] considered three types of vendor selection models: chance constrained-programming, DEA, and MOP, so as to provide alternative tools for the evaluation and improvement of the supplier selection decisions in an uncertain supply chain environment. Table 1 summarizes the above methodologies.

Table 1: Supplier selection past research papers

Methodology	***Papers***
Analytic hierarchy process	14,17,23-25
Case-based reasoning	26
Chance constrained-programming	22
Cluster analysis	27
Conceptual framework	9,10,11,28
Conjoint Analysis	29
Data envelopment analysis	15,22,30
Discriminate Analysis	18
Expert systems	16, 31
Fuzzy set theory	20, 32
Goal-programming	20,33
Intelligent Software Agent	34
Linear-programming	35
Market research	36
Mixed integer-programming	37,38
Multi-objective programming	19,22,39
Multiple regression analysis	40
Neural network	17,18
Principal Component Analysis	12
Simulation	21
Total cost of ownership	41

2.3 Product Family and Supply Chain Design

The designers and manufacturers in designing a new family of products must define the product family and its supply chain simultaneously. The design of product families has received a great deal of attention in the literature. It is often considered to be an integral design element in mass customization. The goal is to provide broad product diversity with a rationalized product structure [42]. At the very first step of the design process, designers propose various solutions for the set of variants of a product family and their bill-of-materials. The second step is to select some of these variants while choosing the architecture of the supply chain [43]. A product family is composed of similar products which differ in terms of characteristics like options and variants. For example, a personal computer. The basic model contains few options and cheap components to minimize the retail price. Subsequently, this basic model can be modified by adding, say, a graphics card, a DVD player, a Wi-Fi card, and so on [43]. If the customer is unwilling to wait for a product, the strategy is to keep various products in stock. In this case, standardization can be an effective tool in product diversity management. The objective in this case is to stock products which include options to meet various customer requirements. The problem then becomes the selection of a minimum set of relevant standardized products [44]. This strategy makes it possible to serve the customer immediately upon receipt of an order. Unfortunately, the number of finished goods may be too large, which results in unreasonable storage costs. If the diversity and storage costs are too high, a second, extreme strategy is to produce only when an order is received from a customer. In this case, the lead time to produce the item may be too great to satisfy the customer. An intermediate solution would be to finished the products from pre-manufactured components when an order is received. This solution involves producing some parts of the finished product, called modules, to be kept in stock and assembling them when an order is received. Modules can be manufactured in countries where production costs are low, and the final product can be assembled close to the market in order to be responsive to the demand. Simpson proposes various methods for designing such a platform [45]. It is selected based on different indicators, such as commonality, product costs, position of the point of differentiation, and so on. A recent overview of the design of product families may be found in [42], and [46]. Jiao proposes a generic genetic algorithm to maximize the customer-perceived cost/benefit ratio of offering a design alternative under certain constraints [47]. In some cases, oversized (standardized) products, i.e. products containing functions not demanded by the client, cannot be tolerated. Consequently, it is necessary to provide the exact products that correspond specifically to the requirements of each customer. The question is then to define the best set of modular components that enable the assembly of any kind of final product within a predefined period of time. Some attempts have been made to solve that problem by considering minimizing the time of final assembly for a fixed and predefined number of modules with a genetic algorithm [48] or, on relatively small problems, using a simulated annealing method [49]. Internet-based configuration systems allow customers to configure products by selecting desired features. However, maintaining a large number of different product configurations increases production complexity and can extend delivery lead time

[50]. In general, the most research literature is focused on modular product design or product family design. The concept of developing product families and modular architectures are of interest to manufacturing companies in the quest to meet diverse customer requirements while maintaining an economy of scale [51]. Different products can be easily obtained through different combinations of modules. Chakravarty and Balakrishnan [52] argue that modular design of product is one way to achieve higher product performance without increasing manufacturing cost in a disproportionate manner. When designing a new product family, a consistent approach is necessary to quickly define a set of product variants and their relevant supply chain, in order to guarantee the customer satisfaction and to minimize the total operating cost of the global supply chain [53]. Mukhopadhyay and Setoputro [54] develop a model to yield the optimal policies regarding return and the design modularity for BTO products. Their model analyzes the effect of modularity and return policy on the product demand, amount returned, and profit. They propose design modularity as a means of achieving generous and economically viable return policy for BTO products. Lamothe et al. [53], propose a design approach that allows defining simultaneously a product family and its supply chain while facing a customer demand with a large diversity. They present a Mixed Integer Linear Programming (MILP) model to identify the product family and its relevant supply chain, while optimizing a cost function. Their model analyzes three kinds of diversity, namely Market diversity, Product diversity and Supply chain layout diversity.

Zhou et al. [55] propose an optimization method for product configuration considering both customer and designer's viewpoints for Assemble-to-Order (ATO) manufacturing enterprises. They employ a utility function to model and measure customer preference. Subsequently they formulated a mathematical model with the objective of maximizing the utility per cost. They use Genetic Algorithm (GA) to solve the combinatorial optimization problem of product configuration. Song and Kusiak [56] present a general framework of mining Pareto-optimal modules from historical sales data. They consider two different objectives for determining optimal product modules as: minimizing mean number of assembly operations and minimizing the expected pre-assembly cost. They apply an evolutionary computation algorithm to select product modules based on multi objective criteria.

The research model in this point is close to Agard [57] approach that consists of providing a quantitative decision aided tool for the design of a large product family. This approach consists of the minimization of global costs, including management and production costs, in a distributed supply chain. The main difference is that we propose an evolutionary computation algorithm that mining Pareto-optimal modules for a product family described by a set of attributes, where each attribute is associated with a set of components and designing its supply chain simultaneously during the optimization process.

2.4 Joint optimization of product family design and supplier selection

The problem of joint optimization of product family design and supplier selection can be described as follows: a company plans to design a family of products to satisfy the diversified demands of customers. A product consists of a number of components that may be shared with other products in the family. Manufacture of the components is outsourced to qualified suppliers with different given bidding price. The problem of the optimization is to select the appropriate configuration and suppliers for the product family with the objective of maximizing the overall profit.

Recently, some scholars found that decoupling the supplier selection and product family design may lead to infeasible or suboptimal solutions [59]. Some research has proposed integrating supplier selection into product family design, but most of these studies are about qualitative analysis and case analysis. Among the exceptions, Product development teams determine optimal levels of the attributes of components for each product variant which is offered in a product family, and then purchasing departments choose the qualified suppliers with the lowest cost after the product family design is completed. Gupta and Krishnan proposed an integer-programming model to integrate component selection and supplier selection for a product family [59]. Their work complemented Goldberg and Zhu's work by considering one-way component substitutability [60]. However, a product variant may have different utilities for heterogeneous consumers [61]. The assumption of one-way component substitutability may not be true in product family design. Balakrishnan and Chakravarty formulated the integration of product variants selection and supplier selection as a profit-driven decision-making problem, established a mathematical model for finding an optimal set of product variants and suppliers from given reference sets [61]. However, their model for product family design is based on a two-step approach [62]. 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 [67] defined the robustness of suppliers as a set of suppliers with minimum total supplier acquisition cost. As the problems involve a large number of components, reference-set enumeration in this approach can become formidable [63]. Luo et al. proposed a one-step mixed-inter nonlinear programming optimization model that integrates supplier selection into product family design with the objective of maximizing the total profits [58]. Deterministic choice rule was adopted in their optimization model to simulate consumer choice behavior. Since deterministic choice rule assumes that consumers only choose the products with the highest utility surplus, this rule is too rigid and restrictive; moreover, evidence exists that for many product categories, consumers may purchase several similar products at the same time [64]. Xing Gang Luo [65] his research is an extension of Luo et al.'s [58] research. As discussed above, although deterministic choice rule is mathematically simple and easy to be embedded into an optimization model, it overestimates the market share of a product if its utility surplus is the highest and underestimates the market share if its utility surplus is not the highest. As a result, the calculated market income is not accurate and thus the obtained solution may deviate from the optimal one. To overcome this limitation, his research adopts multinomial logit (MNL) consumer choice rule to formulate consume behavior during the modeling. As a kind of widely used discrete choice model, the MNL choice rule is regarded to be more realistic in simulating consumer purchase behavior and more flexible in approximating deterministic choice rule [66]. Based on the MNL consumer choice rule, a one-step product family optimization model integrating supplier selection decision is established.

3. Conclusions

Conventionally, product family design and supplier selection are dealt with separately. The above previous studies have been attempted to consider product family 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.

So, for the above mentioned approaches for the joint problem, more constraints needed to be added, such as component quality, durability and lead time. In these approaches, the qualified suppliers are selected only according to the cost. However, in practical applications, the process of supplier selection usually involves evaluation of many other aspects of a supplier, such as quality, durability, and lead-time. Therefore, it is necessary to consider them as selection criteria and explore the possible influence toward the product family configuration in the joint optimization model. Since multiple objective functions are used, the optimization model will be multi-objective and multi-objective meta-heuristic algorithms are required to be specially design to achieve the non-dominated solutions.
It would be interesting to consider the impact of bidding price discount and risk of component supply in this optimization problem. In practical scenarios, suppliers may provide special price discounts if the order size is large enough or ordered components are similar in functions or structure. Sometimes a company would like to split a component order to several parts and sign contracts with multiple suppliers. In case one of the suppliers has a serious problem (e.g. bankruptcy or natural disaster), other suppliers can take additional component orders to avoid the failure of the whole product family project. Taking consideration of bidding price discount and risk of component supply may increase the complexity of the optimization problem.

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