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Supplier selection-order allocation: A two-stage multiple criteria dynamic programming approach

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ABSTRACT

This paper proposes a two-stage multiple criteria dynamic programming approach for two of the most critical tasks in supply chain management, namely, supplier selection and order allocation. In the first stage, to address multiple decision criteria in supplier ranking, the analytic hierarchy process (AHP) is employed. In the second stage, supplier ranks are fed into an order allocation model that aims at maximizing a utility function for the firm as well as minimizing the total supply chain costs, subject to constraints on demand, capacity, and inventory levels. A dynamic programming approach is crafted to solve the proposed bi-objective model.

1. Introduction

Supply chain management provides an integrated decision-making framework for the planning and control of firm assets, operations, transactions, and information channels in a fashion that maximizes business profitability and customer satisfaction. Purchasing constitutes one of the key strategic functions in supply chain management. For a typical manufacturer, purchased items (such as raw materials) may represent 60% of her total sales, and the purchasing share in the total turnover in industrial companies normally ranges between 50–90% (Boer et al., 2001). It is therefore essential to carefully manage the supplier selection process and the order allocation strategy of the firm in order to establish a competitive and effective purchasing function.

Selecting the right supplier(s) gives a company a competitive edge and is instrumental in reducing costs and improving the quality of end products. As a consequence, there exists a continued interest in the development of suitable frameworks to evaluate and select suppliers. As far as the order allocation strategy is concerned, supply chain management practitioners seek to identify the optimal ordering quantities to be purchased from each supplier over a specified planning horizon. To this end, a wide spectrum of mathematical programming models has been investigated to gain insights into newsvendor-type settings or lot-sizing problems under various assumptions.

This paper develops a multi-criteria decision-making framework that incorporates supplier selection and order allocation decisions under time-varying prices/costs, capacity, and demand volumes and profiles. The novelty of the proposed approach stems from the fact that, to the best of our knowledge, all proposed supplier selection-order allocation frameworks in the literature are based on either static-multiple objective or dynamic-single objective models.

The remainder of the paper is organized as follows. In Section 2, we present a review of the relevant literature. Section 3 provides a formal problem statement, and elaborates on the application of the analytic hierarchy process (AHP) to rank potential suppliers and the proposed bi-objective order allocation model which is solved in Section 4 using an adequate dynamic programming approach. Section 5 discusses a small-sized illustrative example to gain insights into the proposed decision-making framework and the dynamic programming solution. Section 6 concludes the paper with a summary of our findings and directions for future research.

2. Literature review

Traditionally, supplier selection approaches focused on price considerations in supplier evaluation (Degraeve and Roodhoft, 1999). However, companies have long realized that selecting suppliers merely based on this single criterion could be detrimental to their performance. Dickson (1966) introduced a list of 23 criteria to be considered in the process of evaluating and selecting suppliers. Weber et al. (1991) extensively reviewed works published since 1966 and concluded that quality, cost, and on-time delivery are the three most important supplier selection criteria commonly used (see also Guiffrida and Jaber (2008)). Other relevant criteria include production facilities and capacity, technical capability, and geographical location. Environmental considerations are increasingly becoming a significant factor in supplier selection (Humphreys et al., 2003; Lee et al., 2009; Bonney and Jaber, in press). In this

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perspective, a set of standard criteria for evaluating the performance of company were suggested by Supply Chain Council (SCC, 1999), and the concept of designing green, sustainable supply chains has strongly emerged.

Supplier selection processes typically involve conflicting objectives that can be addressed using multiple criteria decision-making (MCDM) models. The analytic hierarchy process (AHP), first proposed by Saaty (1977), is a popular multiple criteria decision-making technique (Wallenius et al., 2008) that is adequate to incorporate both qualitative and quantitative criteria. This methodology has been used to rank potential suppliers in a hierarchical manner (see for instance, Ghodsypour and O'Brien (1998), Kokangul and Susuz (2009)).

To identify an optimal order allocation strategy, various approaches have been utilized, including linear programming (Ghodsypour and O'Brien, 1998), nonlinear programming (Benton, 1991), and mixed-integer programming (Ghodsypour and O'Brien, 2001). Multi-objective optimization models have also been proposed to identify appealing trade-offs between two or more conflicting criteria that are involved in the order allocation process (Liao and Rittscher, 2007; Demirtas and Üstün, 2008; Kokangul and Susuz, 2009). Furthermore, to address uncertainty, a two-stage stochastic programming model was proposed by Xu and Nozick (2009), which is capable of quantifying the trade-off between the risk and cost associated with ordering, thereby determining optimal supplier sourcing decisions for varying levels of risk tolerance. Dynamic programming has also been employed in multi-period order allocation problems. Wagner and Whitin (1958) applied a forward algorithm to a dynamic lot-sizing problem with the objective of minimizing the total cost, under time-varying demand volumes, inventory holding costs, and ordering costs. Basnet and Leung (2005) extended the work by Wagner and Whitin by considering a multi-item order allocation problem, with multiple suppliers over a multi-period planning horizon. Alidaee and Kochenberger (2005) proposed a dynamic programming method to solve the single-sink, fixed charge transportation (SSFCT) problem along with an illustrative example that demonstrates the use of this methodology to determine optimal order quantities from a set of potential suppliers such that the total demand is satisfied and the total cost is minimized. Li et al. (2009) investigated a supplier selection problem with non-stationary stochastic price and demand for which they compared two alternative strategies, namely, periodically purchasing from the spot market versus signing a long-term contract with a single supplier.

To the best of the authors' knowledge, the integrated supplier selection and order allocation problem with time-varying demand and cost parameters and multiple objectives have not been addressed in the literature. This paper examines this problem using a two-stage solution methodology. In the first stage, the AHP is employed to rank the potential suppliers using both qualitative and quantitative criteria. In the second stage, the established supplier ranks are communicated to an order allocation model that aims at maximizing a utility function for the company and minimizing the total supply chain cost, subject to constraints on demand, capacity, and inventory levels. A dynamic programming approach is devised to solve the proposed bi-objective optimization problem, thereby determining optimal ordering quantities to be purchased from each supplier over a multi-period planning horizon.

3. Supplier selection and order allocation

3.1. Problem statement

Consider a manufacturer who needs to fulfill her/his purchasing requirements from n potential suppliers over a planning horizon of T periods. Using AHP (as described next in Section 3.2), potential suppliers are ranked based on 4 utility criteria of price performance, quality, delivery performance, and environmental performance, which themselves are decomposed into 21 sub-criteria as shown in Fig. 1 (Humphreys et al., 2003; Kokangul and Susuz, 2009). Using this ranking, the manufacturer seeks to determine optimal ordering quantities from the different suppliers in a fashion that minimizes the total cost of purchase (TCP) and maximizes the total value of purchase (TVP), which represents a manufacturer's utility function based on the ranks (scores) of potential suppliers as discussed in Section 3.3.

3.2. Supplier ranking using AHP

Once the set of criteria for assessing the performance of suppliers is identified (Fig. 1), the relative weights (scores) of suppliers can be obtained using a multiple criteria decision analysis framework such as the AHP based on qualitative and quantitative factors. Let $i=1,\ldots,n$ index the different potential suppliers and p_{ij} represent the extent to which supplier i is preferred over supplier j with respect to a given criterion. For illustrative purposes, Table 1 shows a pair-wise comparison matrix $P=[p_{ij}]$ for four supplier selection criteria (Price Performance, Delivery Performance, Environmental Performance, and Quality) with respect to the overall goal of supplier selection. Pair-wise comparisons in Table 1 are obtained using a scale from 1 to 9, where 1 is for equal importance, 3 for moderate importance, 5 for strong importance, 7 for very strong importance, and 9 for extreme importance. In addition, the even values 2, 4, 6, and 8 are used to reflect intermediate nuances in this scale. Also, note that the condition $p_{ji}=1/p_{ij}$ (Saaty 2000) needs to hold, as shown in Table 1. Let λ_m be the largest Eigenvalue of matrix P (for a perfectly consistent pair-wise comparison matrix, one should have $\lambda_m=n$). To measure the inconsistency of pair-wise comparisons, Saaty proposes the following consistency index (CI):

$$CI=\frac{\lambda_m-n}{n-1}$$

To check if the value of CI corresponds to an acceptable level of inconsistency, it is compared with a random consistency index RI, which is obtained as the average consistency index of a large sample of randomly generated reciprocal matrices (Saaty (1977) used a sample of 500 matrices). The level of inconsistency in the judgment matrix is considered acceptable if the consistency ratio (CR) satisfies

$$CR=\frac{CI}{RI}\leq 10\%$$

The second step is to obtain the score, or relative weight, of each alternative with respect to each criterion. This score is the average of the normalized comparisons, computed by

$$w_i=\frac{\sum_{j=1}^{n}\overline{p}_{ij}}{n}$$

where

$$\overline{p}_{ij}=\frac{p_{ij}}{\sum_{k=1}^{n}p_{kj}}$$

The upward composition of these weights (from the lowest level towards the top level) generates the ranking scores (weights) of elements at the lowest level (i.e. suppliers) in fulfilling the top-most objective (i.e., suppliers ranking).

3.3. Order allocation model

The suppliers' weights (utility scores) obtained from AHP are used to build a utility function for order allocations called the total value of purchase (TVP), where the optimal allocation is the