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A multi-echelon inventory system with supplier selection and order allocation under stochastic demand

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ABSTRACT

This paper investigates an integrated supplier selection and inventory control problems in supply chain management by developing a mathematical model for a multi-echelon system. In particular, a buyer firm that consists of one warehouse and N identical retailers procures a type of product from a group of potential suppliers, which may have different prices, ordering costs, lead times and have restriction on minimum and maximum total order size, to satisfy stochastic demand. A continuous review system that implements the order quantity, reorder point (Q, R) inventory policy is considered in the proposed model. The objective is to select suppliers and to determine the optimal inventory policy that coordinates stock levels between each echelon of the systems while properly allocating orders among selected suppliers to maximize the expected profit. The model is solved by decomposing the mixed integer nonlinear programming model into two sub-models. Numerical experiments are conducted to evaluate the model and some managerial insights are obtained with sensitivity analysis.

1. Introduction

In today's increasingly globalized economy, companies are facing increasing challenges to reduce operational costs, enlarge profit margins and remain competitive. People are forced to take advantages of any opportunity to optimize their business processes and improve the performance of the entire supply chain. For most industrial firms, the purchasing of raw material and component parts from suppliers constitutes a major expense. For example, as it was pointed out by Hayes et al. (2005) and Wadhwa and Ravindran (2007), it is expected that more and more manufacturing activities will be outsourced. Hence, among the various strategic activities involved in the supply chain management, the purchase decision has profound impacts on the overall system.

According to Aissaoui et al. (2007), there are six major purchasing decision processes: (1) 'make' or 'buy', (2) supplier selection, (3) contract negotiation, (4) design collaboration, (5) procurement, and (6) sourcing analysis. Among all of them, the supplier selection problem has received great attentions (Weber et al., 1991; Jayaraman et al., 1999; Feng, 2012). Generally, the supplier selection problem is to define which supplier(s) should be selected and how much order quantity should be assigned to each selected supplier. It is a multi-criteria decision making process depending on a wide range of factors which involve both quantitative and qualitative ones (such as quality, cost, capacity, delivery, and technical potential).

Another relevant problem in supply chain management is to determine appropriate levels of inventory in each echelon. It is important to determine the quantity to order, the selections of suppliers and the best time to place an order. To derive optimal inventory policies that simultaneously determine how much, how often, and from which suppliers, typical ordering costs, purchasing costs, and holding costs should be considered. Although there is a plethora of research for the supplier selection model, only limited studies focused on the inventory control policies integrated with supplier selection, especially under stochastic demand. However, considering the cost issue, supplier selection decision is actually highly correlated with some major logistics issues within a company such as inventory (stock level, delivery frequency, etc.) Incorporating the decisions to schedule orders over time with the supplier selection may significantly reduce costs over the planning horizon (Aissaoui et al., 2007). For example, in the article by Mendoza and Ventura (2010), the authors studied both supplier selection and inventory control problems under a serial supply chain system. A mathematical model was proposed to determine an optimal inventory policy in different stages and allocate proper orders to the selected suppliers. It considered the integration of supplier selection and inventory control problems in multi-level systems. However, the mathematical model built in that paper was based on a stationary inventory policy with a constant demand. Moreover, the constant lead time, no backorder allowed and the same order quantity for different suppliers were assumed in the

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paper. These assumptions could be restrictive in reality, and it may not be appropriate to order the same quantity each time from different suppliers due to the different ordering costs and replenishment lead times. Thus, in this paper, we consider stochastic demand and lead time for this problem, which adopts various replenishment policies for different suppliers.

We investigate both supplier selection and inventory control problems in a serial supply chain system in this paper. A two-echelon distribution system with a central warehouse and N retailers is considered to procure from a set of suppliers. The supplier selection process is assumed to occur in the first stage of the serial supply chain, and the decision is made by a single decision maker (i.e., centralized control) who aims to reduce the total cost associated with the entire supply chain. Capacity, ordering cost, unit price, holding and backorder cost are considered as the criteria for the supplier selection. For the inventory control policy, a continuous review system which applies the order quantity, reorder point (Q, R) policy is adopted to determine the inventory level held at each echelon of the supply chains. The objective of the proposed integrated model is to coordinate the replenishment decision with the inventory at each echelon while properly selecting the set of suppliers which meets capacity restrictions. A mixed integer non-linear programming (MINLP) model is established to determine the best policy for the supplier selection and replenishment decisions.

The main contribution of this paper is to develop a multi-echelon inventory model for supplier selection problem under stochastic demand and lead times. To the best of our knowledge, this is the first work to tackle such a problem. The remainder of this article is organized as follows. In Section 2, previous work related to the supplier selection is summarized. In Section 3, we present our problem definition and assumptions. In Section 4, the development and formulation of the proposed multi-echelon inventory model with supplier selection is presented. We implement the model by conducting numerical experiments in Section 5. Finally, a summary of our work and an outlook on future research directions are presented in Section 6.

2. Literature review

The supplier selection problem has attracted great attentions of a number of researchers who proposed various decision models and solutions. Some previous review works for these decision methods have been presented in the literature. Weber et al. (1991) classified 74 related articles published from 1966 to 1990 which have addressed supplier selection problems based on different criteria and analytical methods. It was found that price, delivery and quality were the most discussed factors. Later in 2000, Degraeve et al. (2000) adopted the concept of Total Cost of Ownership (TCO) as a basis for comparing supplier selection models. They illustrated their model through a case study, and concluded that from the TCO perspective, mathematical programming models outperformed rating models and multiple item models generated better results than single item models. Recently, Ho et al. (2010) surveyed the literature of the multi-criteria decision making approaches for supplier evaluation and selection based on 78 international journal articles gathered from 2000 to 2008, which were classified based on the applied approaches and evaluating criteria. They observed that price or cost is not the most widely adopted criterion. Instead, the most popular criterion used for evaluating the performance of suppliers is quality, followed by delivery, price or cost, and so on. For some other review articles of the supplier selection problems, refer to Boer et al. (2001) and Aissaoui et al. (2007). The following part of this section summarizes the contribution in the literature related to this paper.

Various types of mathematical programming models have been formulated for the supplier selection problem, such as linear programming, mixed integer programming and multi-objective programming. We first review some papers which adopted linear programming. Ghodsypour and O'Brien (1998) proposed an integration of an analytical hierarchy process and linear programming to consider both qualitative and quantitative factors in choosing the best suppliers and placing the optimum order quantities. Later in Talluri and Narasimhan (2003), a unique approach called 'max–min' for vendor selection was proposed by incorporating performance variability into the evaluation process. The authors built two linear programming models to maximize and minimize the performance of a supplier against the best target measures. Ng (2008) developed a weighted linear program for the multi-criteria supplier selection problem with the goal to maximize the supplier score, and studied a transformation technique to solve the proposed model without an optimizer.

As for the mixed-integer programming technique, Kasilingam and Lee (1996) proposed a mixed-integer model to select vendors and determine the order quantities based on the quality of supplied parts, the cost of purchasing and transportation, the fixed cost for establishing vendors, and the cost of receiving poor quality parts. Tempelmeier (2002) developed a single item supplier selection and order sizing model for dynamic deterministic demands. Two versions of mixed-integer optimization model were built separately for the cases of all-units discounts and the incremental quantity discounts. Later in Hong et al. (2005), the model which can determine the optimal number of suppliers, and the optimal order quantity so that the revenue could be maximized was built in a mixed-integer linear programming formation, followed by three steps: preparation, pre-qualification, and final selection. Recently, Hammami et al. (2012) developed a mixed-integer programming model for the supplier selection problem that took into account of inventory decisions, inventory capacity constraints, a specific delivery frequency and a transportation capacity based on multiple products and multiple time periods.

Due to the multi-criteria nature of the supplier selection problem, more and more researchers began to adopt multi-object programming since 2005. Narasimhan et al. (2006) developed a multi-objective model to choose the optimal suppliers and determine the optimal order quantity, which considered the following criteria: cost minimization, transaction complexity minimization, quality maximization and delivery-performance maximization. Xia and Wu (2007) studied the situation of price discounts on total business volume and proposed a multi-objective mathematical model to minimize the total purchase cost, reduce the number of defective items, and maximize total weighted quantity of purchasing. The model was also built to simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing, multiple products, with multiple criteria and with supplier's capacity constraints. In Demirtas and Ustun (2009), to evaluate the suppliers and to determine their periodic shipment allocations given a number of tangible and intangible criteria, a two-stage mathematical approach was proposed by a multi-objective mixed integer linear programming model. Some other recent works which adopted multi-objective model can be found in Amid et al. (2009) and Feng et al. (2011).

Another part of the literature which is related to this paper is the multi-echelon continuous review inventory systems. Here we review several articles in this field. Research on multi-echelon inventory systems started more than two decades ago. Svoronos and Zipkin (1988) developed an approximation model for a two-level distribution system under stochastic Poisson demand, which adopted mixture of two translated Poisson distributions (MTP) for