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Incorporating uncertainty into a supplier selection problem

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A R T I C L E I N F O

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A B S T R A C T

Supplier selection is an important strategic supply chain design decision. Incorporating uncertainty of demand and supplier capacity into the optimization model results in a robust selection of suppliers. A two-stage stochastic programming (SP) model and a chance-constrained programming (CCP) model are developed to determine a minimal set of suppliers and optimal order quantities with consideration of business volume discounts. Both models include several objectives and strive to balance a small number of suppliers with the risk of not being able to meet demand. The SP model is scenario-based and uses penalty coefficients whereas the CCP model assumes a probability distribution and constrains the probability of not meeting demand. Both formulations improve on a deterministic mixed integer linear program and give the decision maker a more complete picture of tradeoffs between cost, system reliability and other factors. We present Pareto-optimal solutions for a sample problem to demonstrate the benefits of the SP and CCP models. In order to describe the tradeoffs between costs and risks in an analytical form, we use multi-parametric programming techniques to more completely analyze the alternative Pareto-optimal supplier selection solutions in the CCP model. This analysis gives insights into the robustness of the solutions with respect to number of suppliers, costs and probability of not meeting demand.

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1. Introduction

Under the pressure of global competition, companies strive to achieve excellence in delivering high quality and low cost products to their customers on time and rely on the efficiency of their supply chain to gain competitive advantage. At the frontier of a supply chain, suppliers act as a key component for success because the right choice of suppliers reduces costs, increases profit margins, improves component quality and ensures timely delivery. Current supplier management trends show increasing interests in global sourcing, reducing the supplier base and establishing long-term relationships with the suppliers (Minner, 2003). Selecting suppliers is no longer an operational function but becomes a strategic level decision (Crama et al., 2004).

When consolidating and reducing the number of suppliers, companies run the risk of not having sufficient raw materials to meet their fluctuating demand. These risks may be caused by natural disasters or man-made actions. A recent example is the fire that happened at one of Phillips' microchip plants in 2000. Phillips lost about $40 million in sales. As a major customer of the chip plant, cell phone manufacturer Ericsson lost $2.34 billion in its mobile phone division (Bartholomew, 2006). The risks are further amplified by the current focus on supply chain efficiency and lean practices. A small disruption may ripple along the whole supply chain and cause significant business losses. As a result, there is a need to be able to evaluate the tradeoffs between the benefits of managing a few selected suppliers and the risks of not being able to meet the required demand. There can be substantial benefits if the companies plan flexibility into their supply chain to handle risks proactively.

Another source of risk is associated with global sourcing. With long lead times and transportation routes, the expanded supply chain is vulnerable to disruptions along the routes. Even though overseas suppliers offer competitive price schedules, they also increase the risk of late delivery of sufficient quantity. Instead of increasing inventory levels to ensure a sufficient supply of raw materials, another option is to strategically determine the number and location of suppliers. By establishing relationships with carefully selected local and overseas suppliers, companies can add flexibility to their supply chain and reduce the risks of disruption without stockpiling.

We develop stochastic mathematical programming models to capture the risk associated with uncertain customer demand and supplier capacity and to create a strategic purchasing plan. Moreover, we use multi-parametric programming techniques to analyze tradeoffs and determine a robust set of suppliers with balanced costs and risks.

Recognizing the importance of the supplier selection decision, an extensive literature exists to address this kind of decision. These existing decision making models are essentially trying to answer the following basic questions: how many suppliers are

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appropriate, which suppliers to choose, and what is the optimal ordering/replenishing policy. Many deterministic models have been developed to answer these questions with varying considerations of quantity discount, lot size, or inventory management decisions (e.g., Dahel, 2003; Dai and Qi, 2007; Ghodsypour and O'Brien, 2001; Narsimhan et al., 2006). The main disadvantage of deterministic models is their incapability of handling randomness embedded in the real system. Other researchers have been working on various probabilistic models and demonstrate the importance of incorporating randomness in the supplier selection problem. Typically they study the effect of random customer demand but do not incorporate uncertainty in the supply and the impact of potential disruption (Gutiérrez and Kouvelis, 1995; Kasilingam and Lee, 1996; Velarde and Laguna, 2004). Two studies make an all-or-none assumption for supplier availability (Berger and Zeng, 2006; Ruiz-Torres and Mahnoodi, 2007).

Another complication to the supplier selection decision is the multi-criteria aspect. However, most of the literature that addresses uncertainties focuses on a single objective (e.g., Basnet and Leung, 2005; Bollapragada et al., 2004; Dada et al., 2007; Yang et al., 2007). Dickson (1966) listed 23 selection criteria; however, quality, delivery and price have been identified as the prime criteria when purchasing industrial raw materials (Akarte et al., 2001; Cameron and Shipley, 1985). Price mentioned here has a broader meaning nowadays; it includes the costs associated with the whole purchasing process and over the purchased item's entire life in addition to the purchasing price. Among these costs, transportation and inventory costs constitute a significant bulk. Therefore, our models consider quality, delivery, and cost (including the transportation and inventory costs) as selection goals in addition to a probabilistic measure of risk.

We develop two optimization models to find a minimal set of suppliers to achieve quality and delivery goals while minimizing cost and the risk of having insufficient supply to meet demand. We incorporate uncertainties that may originate at the suppliers, or may be due to uncertain demand in our models. We also include business volume discounts to represent financial advantages in consolidating the supplier base. Globalization in the supplier base is reflected implicitly by the supplier capacity, the quoted price, the transportation cost, and the pipeline inventory cost in this study. Our models provide a means to explore the balance between the risk of not meeting the demand, the benefits of reduced number of suppliers, and the cost. The uncertainties in demand and supplier capacity are captured either by scenarios or with a probability distribution in the models. Not only the optimal supplier set but also ordering quantities are determined by the models. A multi-parametric analysis provides a means to explore tradeoffs between cost, risk, and number of suppliers in a closed form. A sample problem demonstrates the possibility to guard against supplier disruption by carefully weighing costs and risks in selecting a robust set of suppliers.

This paper is organized as follows: Section 2 gives the problem formulations of a stochastic programming model and a chance-constrained programming model. Section 3 presents numerical results obtained from a sample problem and provides some guidelines for the sourcing decision. Section 4 discusses the multi-parametric programming approach to analyze the robustness of solutions and illustrates it on the sample problem. Section 5 summarizes this paper, points out the importance of inclusion of uncertainties into modeling, and the advantages of using a chance-constrained programming model with multi-parametric analysis to determine the robustness of the supplier selection decisions.

2. Mathematical models

We formulate a stochastic programming (SP) model, and a chance-constrained programming (CCP) model for a multi-criteria supplier selection problem. We incorporate the uncertainty of demand and supplier capacity with either probabilistic scenarios or a closed-form probability distribution. Our SP model is scenario-based and includes a second-stage recourse problem for the order quantities. Our CCP model uses probability distributions for demand and supplier capacity, and assumes independence. Our models also include business volume discounts, transportation costs, as well as costs associated with pipeline inventory. Lead time differences among suppliers are captured in the transportation and inventory costs. Since our models involve high level decisions, the problem has no time dimension. Both models obtain a minimal set of suppliers that balance risks and costs.

We consider a set of plants which demand different sets of components. Coordination between plants is allowed to enable plants to use the business volume discounts offered by suppliers. However, there are certain costs associated with the coordination between plants. The initial set of potential suppliers includes their individual capacities, quality, and delivery performances. Each supplier offers its own business volume discount schedule on the total dollar amount of sales awarded with applicable discount rates. Since not only domestic suppliers but also overseas suppliers are considered in this problem, there are different transportation and pipeline inventory costs associated with the suppliers.

The multiple objectives include: (1) minimizing the total purchasing and shipping costs; (2) maximizing the probability of satisfying demand and staying within supplier capacity; (3) minimizing the total number of chosen suppliers; (4) maximizing the quality of received components; and (5) minimizing the late deliveries. Other models (e.g., Basnet and Leung, 2005; Narsimhan et al., 2006; Velarde and Laguna, 2004) assign a fixed cost per supplier to capture the effects of reducing the number of suppliers. However, we avoid the use of a fixed cost in this paper, because this fixed cost is very difficult to quantify and interpret in practice. Instead we present the Pareto-optimal solutions so that the decision maker can evaluate the tradeoffs and sensitivity associated with changing the number of suppliers. Since quality and on-time delivery are crucial factors when making the supplier selection decision, companies generally will not consider any supplier which may have a problem with quality and delivery. Therefore, we include (4) and (5) as hard constraints in the following two models. However, the right-hand-sides of the quality and delivery constraints can be modified to explore alternative solutions. In this case, it is equivalent to treating them as multiple objectives.

We use our optimization models to create a set of efficient solutions (also known as Pareto-optimal solutions) which achieve an optimum in one objective with compromises in other objectives. We apply the $\varepsilon-$constraint method (Deb, 2001) to approach this multi-objective problem because it is suitable for mixed integer programs, whereas manipulating a weighted objective function does not guarantee an efficient frontier in the presence of non-convexity (introduced by the binary variables). The $\varepsilon-$constraint method keeps one of the multiple objectives as a single objective in the model (cost in our models), and restricts the rest of the objectives in the constraints (e.g., number of suppliers and risk). A set of Pareto-optimal solutions can be found by changing the specified right-hand-sides (ε) for the objectives included in the constraints. In this paper, we apply the $\varepsilon-$constraint method to find the Pareto-optimal solutions and conduct a sensitivity analysis on the ε values to provide insights into this multi-objective supplier selection problem.