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Supplier selection in make-to-order environment with risks

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ABSTRACT

The problem of allocation of orders for parts among part suppliers in a customer driven supply chain with operational risk is formulated as a stochastic single- or bi-objective mixed integer program. Given a set of customer orders for products, the decision maker needs to decide from which supplier to purchase parts required for each customer order to minimize total cost and to mitigate the impact of delay risk. The selection of suppliers and the allocation of orders is based on price and quality of purchased parts and reliability of on time delivery. To control the risk of delayed supplies, the two popular percentile measures of risk are applied: value-at-risk and conditional value-at-risk. The proposed approach is capable of optimizing the supply portfolio by calculating value-at-risk of cost per part and minimizing mean worst-case cost per part simultaneously. Numerical examples are presented and some computational results are reported.

1. Introduction

An important issue in supply chain risk management is how to best allocate the orders for parts among various part suppliers to fulfill customer orders for products at low cost and to mitigate the impact of risk. The selection of supply portfolio in the presence of supply chain delay risk, i.e., the supplier selection and order allocation under uncertain quality of supplied materials and reliability of on-time delivery, is based on price, quality (defect rate) and reliability (on-time delivery rate) criteria that may conflict with each other. Furthermore, to reduce the fixed ordering costs, the number of suppliers and the total number of orders should be minimized. However, to mitigate the impact of delay risk the selection of more suppliers sometimes may divert the risk of unreliable supplies.

In spite of the importance of supplier selection and order allocation problems, the decision making is not sufficiently addressed in the literature (for a recent review, see [1], in particular for the make-to-order manufacturing environment, e.g. [2–6]. The vast majority of the decision models are mathematical programming models with either a single objective, e.g. [7,8] or multiple objectives, e.g. [9–13].

The models developed for supplier selection and order allocation can be either single-period models (e.g. [9,11]) that do not consider inventory management or multi-period models (e.g. [8,12,14,15]) which consider the inventory management by lot-sizing and scheduling of orders. Since common parts can be efficiently managed by material requirement planning methods, this research is focused on custom parts that can be critical in make-to-order manufacturing. For custom-engineered products no inventory of custom parts can be kept on hand. Instead, the custom parts need to be requisitioned with each customer order and hence the custom parts inventory need not to be considered.

When selecting suppliers and allocating orders to generate a supply portfolio, the producer faces uncertain costs and must place orders with a set of suppliers with different quality and reliability. In stochastic supply settings, supplier selection allows the producer to decide whether it should cooperate with low cost, yet risky suppliers over more expensive but possibly more reliable suppliers. A common risk-neutral objective of minimizing expected cost is therefore influenced by

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uncertainty and risk. As a result, new non-risk-neutral objectives of minimizing the number of outcomes that could occur above an acceptable cost level are observed in practice.

Although, the supplier selection problem is stochastic in nature, research seldom considers uncertainty and risk (see, [16]). For example, chance-constrained programming models were developed by Kasilingam and Lee [7] to account for stochastic demand and by Wu and Olson [13] to consider expected losses from quality acceptance inspection or late delivery. Feng et al. [17] use the stochastic integer programming to model the relationship between manufacturing cost, quality loss cost, assembly yield, and discrete tolerances.

In Sawik [5], a portfolio approach is proposed for the problem of allocation of orders for custom parts among suppliers in make-to-order manufacturing. The problem is formulated as a single- or multi-objective mixed integer program with the risk of defective or unreliable supplies controlled by the maximum number of delivery patterns (combinations of suppliers' delivery dates) for which the average defect rate or late delivery rate can be unacceptable. Then, in Sawik [6] the portfolio approach has been enhanced to consider a single-period supplier selection and order allocation in the presence of supply chain disruption risks. In this paper, the portfolio approach presented in [5,6] has been enhanced to consider a single-period supplier selection and order allocation in the make-to-order environment in the presence of supply chain delay risk. The mixed integer programming models are proposed for a single- or bi-objective static supplier selection and order allocation, that is for the allocation of orders for parts among the suppliers with no timing decisions. In contrast to the dynamic portfolio, which is the allocation of orders among the suppliers combined with the allocation of orders among the planning periods. The proposed portfolio approach allows the two popular in financial engineering percentile measures of risk, value-at-risk (VaR) and conditional value-at-risk (CVaR) to be applied for managing the risk of supply delays. The proposed mixed integer programming models provide the decision maker with a simple tool for evaluating the relationship between expected and worst-case costs. This paper demonstrates that for a finite number of scenarios, CVaR allows the evaluation of worst-case costs and shaping of the resulting cost distribution through optimal supplier selection and order allocation decisions, i.e., the selection of optimal supply portfolio.

VaR and CVaR have been widely used in financial engineering in the field of portfolio management (e.g. [18]). CVaR is used in conjunction with VaR and is applied for estimating the risk with non-symmetric cost distributions. Uryasev [19] and Rockafellar and Uryasev [20,21] introduced a new approach to select a portfolio with the reduced risk of high losses. The portfolio is optimized by calculating VaR and minimizing CVaR simultaneously. For example, this approach has been applied to solution of the newsvendor problem (e.g. [22]) or recently to risk averse selection of orders, where the approach is combined with a scenario-based method [23].

The paper is organized as follows. In Section 2 a description of the supplier selection problem in a customer driven supply chain with risks is provided. The mixed integer programs for a single objective selection of supply portfolio to minimize either the expected cost per part or expected worst-case cost part are developed in Section 3. The trade-off (mean-risk) model for a bi-objective selection of supply portfolio is presented in Section 4. Numerical examples and some computational results are provided in Section 5, and final conclusions are made in the last section.

2. Problem description

In the supply chain under consideration various types of products are assembled by a single producer to satisfy customer orders, using custom parts purchased from multiple suppliers (for notation used, see Table 1). Each supplier can provide the producer with custom parts for all customer orders. However, the suppliers have different limited capacity and, in addition, differ in price and quality of offered parts and in reliability of on time delivery of parts. Let $I = \{1, \ldots, m\}$ be the set of m suppliers and $J = \{1, \ldots, n\}$ the set of n customer orders for the products, known ahead of time. Each order $j \in J$ is described by the quantity d_j of required custom parts and by requested delivery date, where the latter need not to be explicitly considered when selecting a supplier. Denote by c_i the capacity of supplier $i \in I$, by o_i the cost of ordering parts from supplier $i \in I$, and by p_{ij} the purchasing price of part for customer order $j \in J$ from supplier $i \in I$.

The ordered parts are dispatched to the producer after the completion time of their manufacturing to meet the requested delivery dates. For each supplier, however, the delivery date and the corresponding reliability of on-time delivery may randomly vary. Likewise, the quality of parts delivered by each supplier may randomly vary. When the suppliers are selected the risk of defective and unreliable (late) deliveries can be considered using past observations. The supply delays may result in the shortage of required parts and the corresponding delay penalty costs of delayed customer orders should be incorporated into the model. Clearly, the producer does not need to pay for ordered and defective parts, whereas parts delivered late may be paid for at a reduced price. However, the producer can be charged with a much higher penalty cost of delayed customer orders for products, caused by the shortage of required parts due to defective or delayed supplies. Since different suppliers may deliver the ordered parts with different delays with respect to requested dates, a different operational risk can be associated with each supply portfolio.

Denote P_s as the probability that delivery scenario s is realized, where each scenario $s \in S$ is a unique combination of m delivery delays, one for each supplier and S is the index set of all scenarios. Let $\delta_{is} \geq 0$ denote the random delivery delay (e.g. number of days behind the requested delivery date) of supplier i in scenario s, with $\delta_{is} = 0$ for on-time delivery.

In addition, let q_i be the expected defect rate of supplier i and $\overline{q}$, the largest acceptable average defect rate of supplies. Similarly, define by $r_i = \sum_{s \in S} P_s \delta_{is}$, the expected delivery delay of supplier i, and let $\overline{r}$ be the largest acceptable average