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Single vs. multiple objective supplier selection in a make to order environment

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ABSTRACT

The problem of allocation of orders for custom parts among suppliers in make to order manufacturing is formulated as a single- or multi-objective mixed integer program. Given a set of customer orders for products, the decision maker needs to decide from which supplier to purchase custom parts required for each customer order. The selection of suppliers is based on price and quality of purchased parts and reliability of on time delivery. The risk of defective or unreliable supplies is 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. Furthermore, the quantity or business volume discounts offered by the suppliers are considered. Numerical examples are presented and some computational results are reported.

1. Introduction

In make-to-order environment customer-oriented manufacturers should be prepared to produce varieties of products to meet the different customer needs. Each product is typically composed of many common and non-common (custom) parts that can be sourced from different approved suppliers with different supply capacity. An important issue is how to best allocate the orders for parts among various part suppliers to fulfill all customer orders for products and to achieve a high customer service level at a low cost. The decision maker needs to decide from which supplier to purchase parts required to complete each customer order. The above decisions are based on price, quality (defect rate) and reliability (on time delivery) criteria that may conflict each other, e.g. the supplier offering the lowest price may not have the best quality or the supplier with the best quality may not deliver on time. Furthermore, to reduce the fixed ordering (transaction) costs the number of suppliers and the total number of orders should be minimized. On the other hand, 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 Aissaoui et al. [1]), in particular for make-to-order manufacturing environment, e.g. Murthy et al. [2], Sawik [3], Yue et al. [4]. Basically, the authors distinguish between single and multiple item models and supplier selection with single or multiple sourcing, where each supplier can fully meet all requirements (e.g. Akinc [5]) or none of the suppliers is able to satisfy the total requirements, respectively. The vast majority of the decision models are mathematical programming models either single objective, e.g. Kasilingam and Lee [6], Basnet and Leung [7], Jayaraman [8] or multiple objectives, e.g. Weber and Current [9], Xia and Wu [10], Demirtas and Ustun [11], Ustun and Demirtas [12], Pokharel [13].

The supplier selection is a complex decision making problem which includes both quantitative and qualitative factors and one of the disadvantages of the mathematical programming methods is their failure to account for qualitative factors that may affect suppliers performance. In order to consider both quantitative and qualitative factors some researchers propose hybrid approaches that combine different methods. For example, Sanayei et al. [14] propose an integration of multi-attribute utility theory and linear programming, first to rate and choose the best suppliers and then to find optimal allocation of order quantities among the selected suppliers to maximize total additive utility. The combined method allows both quantitative and qualitative factors under risk and uncertainty to be considered as well as to account for the probabilistic nature of supplier performance. Another integrated approach that combines analytic network process and multi-objective mixed integer programming is proposed in [11,12]. First, the potential suppliers are evaluated according to 14 criteria that are involved in the four clusters: benefits, opportunities, costs and risks, to calculate the priorities of each supplier. Then, the optimum quantities are allocated among selected suppliers to maximize total value of purchasing (using the calculated priorities) and to minimize the total cost and total defect rate. However, the disadvantages of the integrated methods usually may affect the performance of hybrid approaches. The other approaches that are also applied to solve the supplier selection

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problem are methods based on fuzzy sets, e.g. a fuzzy multi-objective integer programming Huo and Wei [15] and genetic algorithms (e.g. Liaoa and Rittscher [16], Che and Wang [17]). For example, in [16] a genetic algorithm with problem specific operator is developed to account for the inbound transportation and to combine supplier selection with carrier selection decisions. The fuzzy and genetic algorithms, however, are heuristics that do not guarantee optimality of a solution.

The models developed for supplier selection and order allocation can be either single-period models (e.g. [6,8,9,11]) that do not consider inventory management or multi-period models (e.g. [3,7,12,16], Ghodsypour and O'Brien [18], Tempelmeier [19]) 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.

This paper presents mixed integer programming models for single or multiple objective supplier selection in make-to-order manufacturing for a static supply portfolio in a non-discount or discount environment, that is for the allocation of orders for parts among the suppliers without or with discount and 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 major contribution of this paper is that it proposes a simple mixed integer programming approach for selection of supply portfolio under conditions of operational risk associated with uncertain quality and reliability of supplies. The integer programming models incorporate risk constraints where the risk of defective or unreliable supplies is controlled by the maximum number of delivery patterns (combinations of suppliers delivery dates) for which the average defect rate or late delivery rate may exceed the maximum acceptable rates. The number of maximum delivery patterns and the corresponding maximum rates represent, respectively, the confidence level and the targeted rates above which a risk averse decision maker wants to limit the number of outcomes.

The paper is organized as follows. In Section 2 description of the supplier selection problem in make-to-order manufacturing is provided. The mixed integer program for a single objective supplier selection in a non-discount environment is presented in Section 3. The model enhancements for the supplier selection with a business volume discount or quantity discount are presented in Section 4. The multiple objective approach is proposed in Section 5. Numerical examples and some computational results are provided in Section 6, 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 s_j of required custom parts and requested delivery date, where the latter need not to be explicitly considered when selecting a supplier. Each supplier is assumed to have sufficient capacity to complete manufacturing and to deliver the ordered parts to the producer by the requested dates. All parts ordered from a supplier are shipped together with a single shipment at one of a series of fixed delivery dates (e.g. Hall et al. [20]). The parts are dispatched to the producer at the earliest fixed delivery date after the completion time of their manufacturing. Hence, for each supplier the delivery date and the corresponding reliability of supply depend on the completion time of manufacturing the ordered parts, which is unknown to the producer when the supplier selection decision is made. Likewise, the quality of supply may depend on the completion time. When the suppliers are selected, however, the risk of defective and unreliable supplies can be considered using past observations. Since different suppliers may complete manufacturing of ordered parts at different times, and then deliver the parts at different dates, a different risk can be associated with each combination of suppliers delivery dates.

Table 1
Notation.

Indices	
i	supplier, $i\in I=\{1,\ldots,m\}$
j	customer order, $j\in J=\{1,\ldots,n\}$
t	delivery pattern, $t\in T=\{1,\ldots,h\}$
Input parameters	
c_i	capacity of supplier i
o_i	cost of ordering parts from supplier i
p_{ij}	price of part for customer order j purchased from supplier i
q_{it}	expected defect rate of supplier i for delivery date in pattern t
r_{it}	expected late delivery rate of supplier i for delivery date in pattern t
s_j	number of parts to be purchased for customer order j
D	$\sum_{j\in J} s_j$ total demand for parts
$\overline{q}$	the largest acceptable average defect rate of supplies
$\overline{r}$	the largest acceptable average late delivery rate of supplies
$\overline{v}$	the maximum allowed number of delivery patterns with the average defect rate or average late delivery rate of supplies greater than $\overline{q}$ or $\overline{r}$, respectively

Let us call each combination of m fixed delivery dates, one delivery date for each supplier, a delivery pattern. Each delivery pattern must be feasible in respect to requested delivery dates. The total number of all feasible combinations of m fixed delivery dates consists of h delivery patterns and let $T=\{1,\ldots h\}$ be the index set of all feasible delivery patterns. The probability that is assigned to the occurrence of each delivery pattern is identical and equals $1/h$.

Let c_i be the capacity of supplier $i\in I$, o_i—cost of ordering parts from supplier $i\in I$, p_{ij}—purchasing price of part for customer order $j\in J$ from supplier $i\in I$, and q_{it}, r_{it}—respectively, the expected defect rate, the expected late delivery rate of supplier $i\in I$ for delivery date in pattern $t\in T$. The rates q_{it} and r_{it} are based on past observations.

We assume that the risk of defective or unreliable supplies from the selected suppliers can be measured by the number of delivery patterns for which the average defect rate or the late delivery rate of supplies are unacceptable.

The decision maker needs to decide from which supplier to purchase custom parts required for each customer order to achieve a low unit cost and high quality and reliability of supplies.

3. Single objective supplier selection in a non-discount environment

In this section a mixed integer program is proposed for a single-period supplier selection and order allocation problem in a