



Multi-objective models for lot-sizing with supplier selection

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ABSTRACT

In this paper, two multi-objective mixed integer non-linear models are developed for multi-period lot-sizing problems involving multiple products and multiple suppliers. Each model is constructed on the basis of three objective functions (cost, quality and service level) and a set of constraints. The total costs consist of purchasing, ordering, holding (and backordering) and transportation costs. Ordering cost is seen as an 'ordering frequency'-dependent function, whereas total quality and service level are seen as time-dependent functions. The first model represents this problem in situations where shortage is not allowed while in the second model, all the demand during the stock-out period is backordered. Considering the complexity of these models on the one hand, and the ability of genetic algorithms to obtain a set of Pareto-optimal solutions, we apply a genetic algorithm in an innovative approach to solve the models. Comparison results indicate that, in a backordering situation, buyers are better able to optimize their objectives compared to situations where there is no shortage. If we take ordering frequency into account, the total costs are reduced significantly.

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1. Introduction

Recently, the 'Dynamic version of the economic lot size model' paper by Wagner and Whitin (1958) was elected one of the ten most influential publications in the first half century of Management Science (Wagner, 2004), which is an indication of the importance of lot-sizing problem in the area of management science. The authors investigated a single product, multi-period lot-sizing model. In later decades, this problem was extended in several directions. In a comprehensive literature review, Karimi et al. (2003) represented a number of important characteristics of lot-sizing models, including the planning horizon (long term versus short term), number of levels (single level versus multi-level), number of products (single item versus multiple items), capacity or resource constraints (capacitated versus incapacitated), deterioration of items, demand, setup structure and shortage. Interested readers are referred to Robinson et al. (2009), Ben-Daya et al. (2008) and Karimi et al. (2003) for different models and classifications of the lot-sizing problem.

One recent approach to this problem, examining the increasing importance of supply chain management (SCM), takes a combined look at lot-sizing and supplier selection. Few papers in this area (e.g. Rezaei and Davoodi, 2008; Dai and Qi, 2007; Basnet and Leung, 2005)

discuss situation where buyers can simultaneously select the most suitable suppliers for each period and optimize the lot size of each product. The implicit assumption of these papers is an arm's length relationship between buyer and supplier, as they merely emphasize the role of costs in the decision-making process, ignoring the potential role of other essential factors in facilitating cooperation (Mentzer et al., 2001; Morgan and Hunt, 1994), which means that in these papers, the problem has been formulated in a single objective format based on purchasing cost, holding cost and ordering cost.

Although transportation costs form a substantial part of the total logistics costs of a product, they are surprisingly often ignored in the bulk of lot-sizing research (van Norden and van de Velde, 2005). Ertogral et al. (2007) explicitly integrated the transportation cost in the single-vendor single-buyer problem and concluded that this combination can reduce the overall costs of a system.

In this paper, we combine the lot-sizing problem with supplier selection and present two multi-objective models with regard to shortage occurrence. Although, in the framework of SCM, where there is some agreement between buyer and supplier, for instance in the form of a *procurement collaboration* (Meyr et al., 2008), it is possible to avoid shortage, it sometimes is inevitable or planned (Sharafali and Co, 2000). Large companies that have successfully implemented SCM, like Dell, Cisco Systems and HP, are sometimes faced with inventory shortage (Walsh, 2010; Gollner, 2008). There are several causes for inventory shortage, including part variations, mis-operation, inventory reduction (Jiang et al., 2010), small number of suppliers, conservative production plan of suppliers (Xu, 2010) and supplier's service level. As such, the problem should

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be studied in two different situations: (1) when shortage is avoidable and (2) when shortage is inevitable or planned. Taking these two different scenarios into account, the first model is formulated assuming the shortage is not allowed, whereas in the second model the shortage is assumed to be allowed and backordered.

Thus far, only a few researchers have used genetic algorithms to try and solve the inventory and lot-sizing problems in general (Gupta et al., 2007; Rezaei and Davoodi, 2005; van Hop and Tabucanon, 2005; Dellaert et al., 2000; Disney et al., 2000) and 'lot-sizing with supplier selection problem' in particular (e.g. Sadeghi Moghadam et al., 2008; Rezaei and Davoodi, 2008, 2006; Liao and Rittscher, 2007; Xie and Dong, 2002; Dellaert et al., 2000). In this paper, we look at some robust and unique characteristics of genetic algorithms, especially those dealing with multi-objective problems, and adopt a genetic algorithm approach to solve these problems, introducing a new flexible approach to dealing with hard constraints in multi-objective optimization problems.

The remainder of this paper is organized as follows. In Section 2, we present the formulation of the models. In Section 3, we present a genetic algorithm to solve these models. In Section 4, two numerical examples and comparison results are presented. Finally, in Section 5, we provide our conclusions and offer suggestions for future research.

2. Mathematical modeling

In this section, we present two multi-objective mixed-integer non-linear programming (MOMINLP) models: (1) an MOMINLP model without shortage and (2) an MOMINLP model with backordering, both of which with three objective functions and a set of constraints. We use the following notations to formulate the models.

Notations

I	number of products
J	number of suppliers
T	number of periods
x_{ijt}	number of product i ordered to supplier j in period t
p_{ij}	net purchase cost of product i from supplier j
o_j	ordering cost for supplier j
g_j	transportation cost for supplier j per vehicle
y_{jt}	binary integer: 1, if the order is given to supplier j in period t , 0, otherwise
h_i	holding cost of product i per period
d_{it}	demand of product i in period t
f_{ijt}	quality level of product i offered by supplier j in period t
s_{ijt}	service level of product i offered by supplier j in period t
λ_{ij}	quality level growth rate of product i offered by supplier j
γ_{ij}	service level growth rate of product i offered by supplier j
β_j	ordering cost reduction rate for supplier j
c_{ij}	capacity of supplier j in production of product i per period
b_i	backordering cost of product i
w_i	occupied space by product i in warehouse or vehicle
W	total storage capacity
v_j	vehicle capacity for supplier j

2.1. MOMINLP model without shortage

In this model, there are three objectives: total cost, total quality level and total service level, and a set of constraints. The problem is to determine which products to order in which quantities from which suppliers in which periods, in order to satisfy overall demand. The main assumption is that shortage is not allowed. In the following section, we describe the components and formulation of the problem.

2.1.1. Objective functions

Total cost: The sum of the purchasing costs, ordering costs, holding costs and transportation costs in all periods should be minimized. Most existing studies only include the first three types of costs and ignore transportation costs. The total purchasing costs are the sum of the purchasing costs of all products from all selected suppliers in all periods. In most cases, ordering costs are formulated as $o_j y_{jt}$ where o_j is the ordering cost for supplier j and y_{jt} a binary variable that is 1 if an order is placed with supplier j in time period t and that otherwise is 0. However, in most real situations, this is not the case, especially in an SCM framework. As pointed out in many studies (e.g. Spekman et al., 1998; Lambert, 2008), the key driver of buyers in SCM is cost reduction. As Woo et al. (2001) have found, reduction in ordering cost is positively related to ordering frequency, in other words, the higher the ordering frequency, the higher the ordering cost reduction, which is why we propose an exponential relationship between the total ordering cost for supplier j and the number of orders (order frequency) placed with that supplier ($\sum_{k=1}^t y_{jk}$), which results in the following cost formula: $o_j e^{-\beta_j \sum_{k=1}^t y_{jk}}$. In formulating the holding costs, we should note that, because the supplier's service level is not necessarily 100%, the total number of received items in period t is not necessarily equal to the total number of ordered items in the same period.

With regard to transportation costs, we assume that the buyer, based on criteria like geographic distance to the supplier, uses different vehicles with different capacities. However, these vehicles can be used for all kinds of ordered products.

Therefore we have:

$$\begin{aligned} \min z_1 = & \sum_i \sum_j \sum_t p_{ij} x_{ijt} + \sum_j \sum_t o_j e^{-\beta_j \sum_{k=1}^t y_{jk}} y_{jt} \\ & + \sum_i \sum_t h_i \left(\sum_{k=1}^t \sum_j x_{ijk} - \sum_j (1 - s_{ij0} e^{\gamma_{ij} t}) x_{ijt} - \sum_{k=1}^t d_{ik} \right) \\ & + \sum_j \sum_t g_j \left\lceil \frac{\sum_i w_i x_{ijt}}{v_j} \right\rceil \end{aligned} \quad (1)$$

Total quality level: Product quality is defined in terms of conformance to product-related customer requirements, where customer requirements are the requirements that should be fulfilled to meet the customer's needs (Berdin et al., 2000). The overall quality level of all the products ordered from all suppliers in all periods should be maximized. In existing literature (e.g. Liao and Rittscher, 2007; Amid et al., 2006), the quality level of products is implicitly assumed to be equal in all periods. However, product quality may vary over time. In this paper, we use an exponential time-dependent function for the quality level of individual products as $f_{ij0} e^{\lambda_{ij} t}$, where f_{ij0} is the quality level of product i offered by supplier j at the first point of planning horizon. If the buyer predicts that the quality level of product i offered by supplier j will have an increasing trend $\lambda_{ij} > 0$, otherwise $\lambda_{ij} \leq 0$. This results in the following formula:

$$\max z_2 = \sum_i \sum_j \sum_t f_{ij0} e^{\lambda_{ij} t} x_{ijt} \quad (2)$$

Total service level: We adopt the β service level from Schneider (1981) and, for the purpose of this paper, define the service level of supplier j for product i in period t as follows:

$$s_{ijt} = \frac{\text{satisfied ordered items of product } i \text{ to the supplier } j \text{ in period } t}{\text{ordered items of product } i \text{ to the supplier } j \text{ in period } t}$$

Because the supplier's service level affects the buyer, especially with regard to safety stock levels and costs, the buyer wants to maximize the overall service level of all products ordered from all suppliers in all periods. The construction of this function is similar

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