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Supplier selection and procurement decisions with uncertain demand, fixed selection costs and quantity discounts ☆

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ABSTRACT

In this paper, we study the supplier selection and procurement decision problem with uncertain demand, quantity discounts and fixed selection costs. In addition, a holding cost is incurred for the excess inventory if the buyer orders more than the realized demand and the shortage must be satisfied by an emergent purchase at a higher price otherwise. The objective is to select the suppliers and to allocate the ordering quantity among them to minimize the total cost (including selecting, procurement, holding and shortage costs, etc.). The problem is modeled as a Mixed Integer Programming (MIP) and is shown to be NP-hard. Some properties of the optimal policy are provided and an optimal algorithm is proposed based on the generalized Bender's decomposition. Numerical experiments are conducted to show the efficiency of the algorithm and to obtain some managerial insights.

1. Introduction

In this paper, we study a single period, single item procurement problem under uncertain demand. Specific, a buyer wants to make both supplier selection and ordering quantity decisions to satisfy the uncertain demand in the next year with the minimal total cost. If she (we use *she* for the buyer and *he* for the supplier) orders more than the realized demand, the excess inventory incurs a holding cost. On the other hand, should the realized demand exceed the ordering quantity, the shortage must be satisfied by an emergent purchase at a higher price. Each supplier offers a discount scheme to the buyer based on the ordering quantity placed to him. Once the buyer selects a particular supplier, a fixed selection cost is incurred. The objective of the buyer is to select some suppliers and allocate the ordering quantity among the selected suppliers to minimize the total cost (including selecting, purchase, holding and shortage costs, etc.).

Due to fierce competition, characterized by thin profit margins, high consumer expectations for quality and low price, more and more firms have to manage their complete supply chain effectively from upstream suppliers to the final end users of their products. As noted by Kraljic [17], "purchasing (an operation function) has evolved into supply management (a strategic one)." This is so because good procurement can not only reduce the purchase cost directly, but also save operational cost (maintenance, default, etc.) indirectly. Because of this, supplier selection and procurement decision problem has been studied extensively. Here we review briefly some literature closely related to our study.

Procurement problem involving quantity discounts offered by suppliers has been studied extensively in the literature. Katz et al. [15] and Sadrian and Yoon [19] discussed the advantages of quantity discounts to the buyer and the suppliers. Benton [5] and Rubin and Benton [22] considered multi-item multi-supplier procurement problem in which the suppliers offer quantity discounts (all-unit discount) and the buyer has limit resource. They modeled the problem as a mixed integer programming (MIP) and proposed heuristic methods to solve it. Qi [21] studied the multiple sourcing problem with capacitated suppliers. He developed a heuristic algorithm and a dynamic programming approach to solve it. Goossens et al. [12] studied a multi-item multi-supplier procurement problem in which the suppliers offer quantity discounts and have limit capacities. They showed that the problem is NP-hard and formulated it as a MIP. Branch and bound algorithms were proposed to solve the problem optimally. Crama et al. [7] considered the procurement decision problem faced by a multi-plant company in which suppliers offer total volume discounts. They modeled the problem as a nonlinear mixed 0–1 programming and some linearized techniques were proposed. However, all of the above researches assume the deterministic demand, which must be satisfied, and the objective is to minimize the total purchase cost.

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The main difference of our model from the above literature is that we assume that the demand is uncertain and a holding–shortage cost will be included. The objective is to minimize the total cost including supplier selection, purchasing, holding and shortage costs.

There are some literature studying procurement problem with uncertain demand. Jucker and Rosenblatt [14] discussed the implication of quantity discounts on the newsboy problem with a single supplier. Kelle and Silver [16] studied a continuous review inventory model with stochastic lead-time and found that ordering from multiple suppliers can reduce safety stock. Gallego and Moon [10] considered a distribution free newsboy problem. Parlar and Wang [20] studied newsboy model with supply and demand uncertainty. They compared the costs of single sourcing versus dual-sourcing. Gurnani et al. [13] studied the problem in which the ordering and production decisions are made simultaneously for a two component assembly system facing random demand and yield from two suppliers, each providing a distinct component. The above researches consider only the quantity allocation among the selected suppliers without considering fixed supplier selection costs. Burke et al. [6] addressed the supplier selection and quantity allocation decisions with constant purchasing price and zero fixed selection cost. The number of suppliers selected by the buyer is determined by a diversification function, which reflects buyer's specific supply chain efficiency saving and strategic positioning benefit brought about by selecting multiple suppliers. Awasthi et al. [3] studied the supplier selection and procurement problem under random demand with minimum and maximum order size constraints and proposed a heuristic method for their model. Zhang and Zhang [24] generalized Awasthi et al's model to the case with fixed selection costs and proposed a branch and bound method for it. They did not consider quantity discounts offered by suppliers. Anupindi and Akella [2], Parlar and Wang [20], Dada et al. [8], and Yang et al. [23] studied supplier selection and procurement problem with random yield suppliers and uncertain demand. The above four papers did not consider the fixed selection costs and quantity discounts. Our model considers positive fixed selection costs and quantity discounts offered by suppliers, hence the problem in this paper is more complicated than those in the above literature.

Li and Zabinsky [18] are closely related to our paper. They considered a supplier selection problem with uncertain supplies and demand, in which the suppliers offer discounts based on the ordering quantity. They applied two-stage stochastic programming and chance-constrained programming respectively to model the problem. However, they did not consider fixed selection costs. Also, they did not propose algorithms for their models. The difference from Li and Zabinsky [18] is that we consider fixed selection costs and propose an efficient algorithm for our model.

Table 1 indicates the contribution of this paper.

The motivation of this study comes from our experiences on a practical project “Supplier Selection and Evaluation” for a telecommunication company, China NetCom (which is now merged with UniCom) in China. In order to reduce the procurement cost, the company has adopted centralized procurement mode recently. At the end of each year, the company has to make procurement budget and decide from whom and how many to buy to satisfy the demand in the next year. However, when she makes these decisions, the demand is uncertain. Moreover, the suppliers offer quantity discounts based on the ordering quantity and a fixed cost (including negotiation, investigating, administration cost, etc.) is incurred if the company places an order to some supplier. We formulate this realistic problem as a nonlinear MIP and propose an algorithm based on generalized Bender's decomposition method to solve it. Also, we propose a simple algorithm for the subproblem based on its special structure. Numerical experiments are conducted to show the efficiencies of the model and the algorithm and to get some managerial insights.

The remainder of the paper is organized as follows. In Section 2, we state the mathematical model. We then provide the algorithm framework for the problem in Section 3. In Section 4, we propose an efficient method for the subproblem and describe the implementation of the algorithm in details. Numerical experiments are reported in Section 5. In Section 6, some conclusions are given.

2. Mathematical model

To state a mathematical formulation of the supplier selection and procurement problem, we use the following notation. We define S as the set of n suppliers, indexed by i, $i=1,\dots,n$. For each supplier i, let K_i be the fixed cost incurred by selecting him. Let the demand faced by the buyer be $D\in(0,\infty)$ with density function $f(x)$, cumulative function $F(x)$, mean $E(D)=\mu$ and variance $var(D)=\sigma$. Let h be the unit holding cost when the ordering quantity is larger than the realized demand, and p be the emergent unit purchase price when the ordering quantity is less than the realized demand. We adopt the definition in Goossen et al. [12] to describe quantity discounts. For each supplier $i\in S$ we associate a sequence of intervals $[l_{ij},u_{ij}]$ $(j\in Z_i=\{0,1,\dots,\max_i\})$. If the ordering quantity from supplier i belongs to $[l_{ij},u_{ij}]$, the unit price is c_{ij}. We assume that the following assumptions hold:

$$\forall i\in S, j\neq j' : [l_{ij},u_{ij}]\cap[l_{ij'},u_{ij'}]=\emptyset; \tag{1}$$

$$\forall i\in S, j\in Z_i\backslash\{\max_i\}; p>c_{ij}\geq c_{i,j+1}; \tag{2}$$

$$\forall i\in S, j\in Z_i, c_{ij}\geq 0, u_{ij}\geq l_{ij}\geq 0. \tag{3}$$

Assumption (1) states that a supplier's interval should not overlap. Assumption (2) implies that the purchase cost of supplier i is not

Table 1
Summary of pertinent papers.

Paper	Discount	Demand	Fixed cost	Supplier
Qi [21]	No	Determinant	Positive	Multiple
Rubin and Benton [22]	All-unit	Determinant	Zero	Multiple
Benton [5]	All-unit	Determinant	Positive	Multiple
Goossens et al. [12], Crama et al. [7]	Total quantity	Determinant	Zero	Multiple
Jucker and Rosenblatt [14]	All-unit increment	Random	Zero	Single
Kelle and Silver [16], Palar and Wang [20]	No	Random	Zero	Single multiple
Gallego and Moon [10]	No	Random	Zero	Single
Burke et al. [6], Awasthi et al. [3]	No	Random	Zero	Multiple
Anupindi and Akella [2], Dada et al. [8], Yang et al. [23], Parlar and Wang [20]	No	Random	Zero	Multiple random yield
Zhang and Zhang [24]	No	Random	Positive	Multiple
Li and Zabinsky [18]	All-unit	Random	Zero	Multiple random yield
This paper	All-unit	Random	Positive	Multiple