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Dynamic lot sizing with multiple suppliers, backlogging and quantity discounts

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ABSTRACT

This paper studies the dynamic lot sizing problem with supplier selection, backlogging and quantity discounts. Two known discount types are considered separately, incremental and all-units quantity discounts. Mixed integer linear programming (MILP) formulations are presented for each case and solved using a commercial optimization software. In order to timely solve the problem, a recursive formulation and its efficient implementation are introduced for each case which result in an optimal and a near optimal solution for incremental and all-units quantity discount cases, respectively. Finally, the execution times of the MILP models and forward dynamic programming models obtained from the recursive formulations are presented and compared. The results demonstrate the efficiency of the dynamic programming models, as they can solve even large-sized instances quite timely.

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1. Introduction

In recent global business environment, pressure from competitive markets have forced manufacturers to reduce their operational costs. Many firms deal with different suppliers for procuring their requirements where each supplier reduces the price of a product for the larger purchased amounts. There exist two known discount schemes in the literature. First, the incremental discount scheme, which refers to a situation in which the unit price of a particular discount level is applied just to the amount corresponding to that level. Second, the all-units quantity discount scheme under which a discounted unit price is charged for all purchased amount.

At the same time, inventory holding and backlogging costs are incurred for storing the procured products and not fulfilling the product needs when required, respectively. Therefore, finding the optimal set of suppliers and the quantity of the item to be procured in each period of time, considerably reduces the inventory and supplier related costs of the firm. In this paper, we introduce new and efficient mathematical procedures to manage inventory and supplier selection. Simultaneously, we find the best combination of suppliers and amounts to be purchased over a planning horizon with the goal of minimizing the total inventory and purchase costs.

In the literature of inventory management, dynamic lot sizing problem has received considerable attention especially when a set of planning periods is taken into account. In a seminal paper, Wagner and Whitin (1958) proposed a forward dynamic programming algorithm to solve the dynamic lot sizing problem (DLSP) for a single item and a single supplier. As Wagner and Whitin's (1958) algorithm was too complex to be implemented, Evans (1985), Federgruen and Tzur (1991), Wagelmans, Van Hoesel, and Kolen (1992), Aggarwal and Park (1993), and Van Hoesel, Kuik, Salomon, and Van Wassenhove (1994) proposed other algorithms to enhance its empirical efficiency. Zangwill (1969), Song and Chan (2005), Absi, Kedad-Sidhoum, and Dauzère-Pérès (2011) and Chu, Chu, Zhong, and Yang (2013) studied the DLSP with allowing backlog. In addition, some studies were done in the area of the DLSP extended to quantity discount case in which the unit price varied in diverse amounts of a purchased item. In this field, Callerman and Whybark (1977) and Chung, Chiang, and Lu (1987) introduced a mixed integer programming model and a dynamic programming model, respectively, to obtain the optimal solution. Fordyce and Webster (1985) modified the Wagner and Whitin's (1958) algorithm to a tabular procedure to solve the DLSP with quantity discount. However, Sumichrast (1986) showed that their algorithm did not give the optimal solution necessarily. Federgruen and Lee (1990), introduced algorithms for both incremental and all-units quantity discount cases. Later, Xu and Lu (1998) demonstrated that Federgruen and Lee's (1990) solution for all-units quantity discount case did not give the optimal policy in some special instances; then they presented an optimal method by modifying Federgruen and Lee's (1990) algorithm. Chyr, Huang, and Lai (1999) proposed an

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optimal recursive relationship for the DLSP with all-units quantity discount. Hu and Munson (2002) examined different solution methods regarding the DLSP with incremental quantity discount. Lee, Kang, and Lai (2013) introduced a mixed integer programming model and a genetic algorithm to solve the DLSP with transportation cost and all-units quantity discount. None of the mentioned authors considered the DLSP with quantity discounts and backlogging together, for a single supplier.

Some authors studied the extension of the single item DLSP to the multi-supplier case without quantity discounts consideration (Jaruphongsa, Cetinkaya, & Lee, 2005; Zhao & Klabjan, 2012). In this case, the buyer needs to determine the amount to be purchased in each period and from which suppliers (supplier selection).

With quantity discounts and non-backlog consideration, Tempelmeier (2002) proposed a new mathematical model and a heuristic to solve the problem. Bai and Xu (2011) considered three different cost structures consisting incremental and all-units quantity discounts and multiple set-ups cost, and presented the optimal solutions. Lee, Kang, Lai, and Hong (2013) proposed a mixed integer programming and an efficient genetic algorithm for solving the problem. None of the mentioned papers considered the backlogging cost along with quantity discount. However, Kang and Lee (2013) supposed the problem with stochastic demands, shortage cost and the objective of minimizing the total cost and maximizing service level. Then, they derived a multi-objective programming model, a mixed integer programming model and a heuristic dynamic programming as a solution methodology. Parsa, Khiav, Mazdeh, and Mehrani (2013) considered the problem of lot sizing for the case of a single item along with supplier selection in a two-stage supply chain. The suppliers could also offer either all-unit or incremental discount schemes and a dynamic programming methodology is provided to solve the proposed model. In a similar study, Mazdeh, Emadikhiav, and Parsa (2015) investigated single-item dynamic lot sizing problem with supplier selection under incremental and all-unit quantity discounts. Due to problem complexity, a new heuristic was developed to solve the problem.

Roodhooft and Konings (1996), Rosenblatt, Herer, and Hefter (1998), Dai and Qi (2007), discussed other forms of the single item supplier selection problem without considering the DLSP and quantity discounts. With the assumption of quantity discounts' availability, Chaudhry, Forst, and Zydiak (1993) considered incremental and all-units quantity discounts, quality and capacity limitations and proposed a mixed integer linear programming approach to minimize the procuring costs over a single period. Chang (2006) brought up the problem studied by Rosenblatt et al. (1998) in the field of economic order quantity with multiple capacitated suppliers, and proposed an exact approach that also held for all-units quantity discount case. Chang, Chin, and Lin (2006) introduced a mixed integer method to determine the economic order quantity where assumed some other real-world conditions in the problem like resource limitations and variable lead-time. Burke, Erenguc, and Vakharia (2008) proposed a branch and bound algorithm to find the optimal quantity to be purchased from a set of capacitated suppliers offering incremental quantity discount.

This paper considers the DLSP with multiple suppliers backlogging, and incremental and all-units quantity discounts. The most related articles to the current paper are the ones by Fordyce and Webster (1985), Federgruen and Lee (1990), Chyr et al. (1999) and Hu and Munson (2002), for the single supplier case, and Tempelmeier (2002), Bai and Xu (2011), Lee, Kang, Lai, and Hong (2013) and Mazdeh et al. (2015), for the multiple supplier case.

Therefore, realizing that the existing models in the literature do not develop a deterministic model when backlogging, quantity discounts and single or multiple suppliers are considered at same time, we propose two new models by combining them. To our knowledge, there exists no study in the DLSP literature to consider backlogging and quantity discounts together where the demand is deterministic. In summary, we make the following contributions in this paper: we study an extension of DLSP by backlogging, multiple suppliers and quantity discounts consideration. We establish new mixed integer linear programming models for both incremental and all-units quantity discount cases which are solved optimally using a commercial optimization software. For each case, a recursive formulation and its efficient implementation are also developed yielding an optimal solution for incremental discount case, and a near optimal solution for all-units discount case. We perform the corresponding numerical studies which suggest that for incremental discount case, the dynamic programming model obtained from the efficient implementation of the recursive formulation provides the best performance, as it can timely and optimally solve even large sized instances. For all-units discount case, MILP model can only solve small sized instances optimally in a reasonable time whereas the dynamic programming model obtained from the efficient implementation of the recursive formulation reaches a near optimal solution quite timely even for large sized instances.

The rest of the article is organized as follows: in Section 2, the problem description and notations are presented. In Section 3, we establish the new mixed integer linear programming models and the recursive formulations to solve the problem for both incremental and all-units quantity discount cases. Numerical examples, computational results and conclusions are stated in Sections 4,5 and 6, respectively.

2. Problem explanation

Consider a buyer procuring his known demands over multiple periods from a variety of qualified suppliers. Each supplier presents different quantity discount levels for each period and charges the buyer with lower unit prices for greater purchased quantities of each order. In this study, two discount schemes are considered; incremental and all-units quantity discounts.

Furthermore, the buyer pays unit holding costs if the demand of a period is procured in earlier periods. Unit backlogging costs are incurred when the demand of a period is not satisfied on time. There is also a fixed ordering cost for each periodic order from each supplier. The objective is to find an ordering plan that minimizes the total costs over the planning periods.

The dynamic lot sizing problem (DLSP), refers to minimizing the total inventory holding costs and fixed ordering costs over multiple planning periods where there is only one supplier. Therefore, the problem discussed in this paper is the extension of the DLSP to the backlogging, quantity discounts and supplier selection.

In this paper, the dynamic lot sizing problem (DLSP) with multiple suppliers, incremental discount and backlogging is considered by P1, and the DLSP with multiple suppliers, all-units discount and backlogging by P2.

In order to depict the mathematical models and formulations of this article, the following notations are considered:

Indices:

- s index of suppliers ($s = 1, \ldots, S$).
- t index of time periods ($t = 1, \ldots, T$).
- l index of discount levels ($l = 1, \ldots, L$).

Parameters:

- d_t demand of the item in period t.
- Q_{lst} the upper bound quantity of discount level l for supplier s in period t, where $Q_{0st} = 0$.

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