Procurement planning with batch ordering under periodic buyback contract

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Abstract: This paper deals with the deterministic single-item procurement planning problem with batch ordering under the buyback contract. We assume a buyback contract with returns of unused products at the end of each period to the supplier and we consider a piecewise procurement cost structure composed by a fixed ordering cost, a variable procurement cost and a fixed cost per batch replenished, incurred by the retailer. This problem is studied under various hypotheses: in the first, the acquisition is made in only full batches, in the second, there is no specific assumption on the acquisition quantity, in the third, the procurement must be in only full batches with a possibility of lost sales, and in the fourth, there is just the option of lost sales for the general case. For these four cases, several optimality properties and polynomial time algorithms are proposed.

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1. INTRODUCTION

The procurement planning is the purchasing process of the right quantity of products from the suitable suppliers in time and with minimum costs. The procurement lot sizing problem falls under this category. It assists companies in finding the best trade off between the management of inventory and procurement. Its purpose is to determine two major decisions that are related to the purchasing problem: how much quantity of products to order and from which supplier(s), and in which periods.

In this paper, we focus on a single-item discrete deterministic Lot Sizing Problem with Batch ordering under the Periodic Buyback contract (LSP-BPB) over a planning horizon of T periods, having conditions on batch status and adding a possibility of lost sales. In the following, we give a literature survey on different optimization methods proposed for the classical LSP, the LSP with piecewise cost function, the LSP under capacity reservation contract and the LSP with lost sales. The LSP has also been studied in production and inventory management, and in distribution and inventory management.

The seminal work of these problems was proposed by Harris (1913) in order to minimize the total replenishment and inventory costs of a single type of item with stationary demand for an infinite planning horizon. This model has been extended to consider several features. Work on the production planning involving discrete LSP started with Wagner and Whitin (1958) for the single item, dynamic demand and uncapacitated case. This problem is solvable in O(T^2) time improved to O(T log T) time (cf. Aggarwal and Park (1993)). In these models, all cost functions are linear.

For LSP with piecewise cost function, Lippman (1969) is considered as one of the first authors who incorporated the fixed transportation cost as a stepwise cost in the inventory models. The author proposes an O(T^5) time algorithm for the single-item uncapacitated LSP without setup cost nor backlogging. Pochet and Wolsey (1993) reduced the computational complexity of this problem to an O(T^2 min(T, V)) time, with V the batch size. Li et al. (2004) extend the latter problem by taking into account setup cost, time varying cost parameters and backlogging. The authors propose an O(T^2) time algorithm in the case of ordering a multiple of a constant batch size. The same authors assume a more general cost structure with Truck Load discounts in which the batch replenished can be not complete and propose an O(T^3 log T) time algorithm. Notice that all of these studies assume a stationary batch size.

In this study, we consider the full batch replenishment cost function (Akbalik and Rapine (2013)) as a piecewise cost structure in which the product is ordered at period t in batches of time-dependent size V_t and the customer pays the fixed cost f_t for each order, the concave unit procurement cost p_t and the cost a_t per batch. We have two important variants of the batch replenishment: either the amount of procurement in each period is restricted to a multiple of a batch size or the replenished batch can be fractional. This function is discontinuous, not concave on [0, ∞) and composed of non-negative, non-decreasing, concave functions on [iV_t, (i+1)V_t], with i ∈ N.
In our paper, we are also interested in a special type of Capacity Reservation Contract (CRC). In a general CRC, the buyer reserves a certain capacity in advance from the supplier for a fee $r$, and after that he buys the capacity utilized for an advantageous price. If the capacity utilized surpasses the reserved capacity, he can get the excess amount at a higher price. In the literature, the CRC has often been studied for the risk sharing between the supply chain members, see Serel et al. (2001) and Park and Kim (2014). There are few papers emerging the CRC with LSP. Atamturk and Hochbaum (2001) are the pioneer who investigate the LSP under general CRC to find the compromise between capacity acquisition, subcontracting, production and holding inventory decisions. They propose polynomial time algorithms with a deterministic demand over a finite horizon. Van Norden and Van de Velde (2005) are the first who treat the multi-item LSP with batch transportation under general CRC. They develop a Lagrangean heuristic to solve this NP-hard problem. Lee and Li (2013) study a single-item dynamic LSP in which the consumer orders under a general CRC and the total unit procurement cost is a continuous stepwise function. The general model is NP-hard, but the authors propose for two special cases of this problem polynomial time algorithms.

Previously published studies assert that there are 8 mechanisms of CRC : pay-to-delay (Wu et al. (2006)), take-or-pay (Kaiser and Tumma (2004)), backup agreements (Eppen and Iyer (1997)), deductible reservation (Jin and Wu (2007)), minimum commitment (Bassok and Anupindi (1997)), quantity flexibility (Tsay (1999)), revenue sharing (Cachon and Larivière (2005)) and finally buyback contract which is the focus of our study between a retailer and a supplier.

In general, a buyback contract, called also returns policy, is defined as an agreement between the buyer and the seller, whereby the buyer purchases $Q$ units with a fee $p$ and returns $N$ units such that $N \leq \rho Q$ units at the end of the selling season to the seller for a price $p^b$ being less or equal to procurement cost $p$. $\rho$ represents the maximum return percentage (0 $\leq \rho \leq 1$). Thus, the buyer reserves in advance $Q$ units for a cost $p - p^b$ and pays a fee $p^b$ for a procurement of quantity used of $Q - N$ units. This is a proof that the buyback contract is a CRC. A large number of papers studies the buyback contract to design its parameters, to evaluate its effectiveness in supply chain configurations and to compare with other contracts, refer to Pasternack (1985), Krishnan et al. (2004) and Hou et al. (2010).

In this paper, we concentrate on the integration of buyback contract into the LSP. Our problem assumes that the supplier buys back the whole quantity of unsold items from the retailer at the end of each period. Our LSP-BPB is important to be solved in the case where the product has a limited shelf life (e.g., dairy products, newspapers, fashion wear and books) and a retailer can not carry stocks over to the next period due to expensive inventory costs. For example, in the Hungarian book market, the retailers could return monthly the copies unsold without any or with a small charges (Dobos and Wimmer (2010)).

Another concept added in our paper is the one of lost sales whereby the retailer has to decide whether or not to satisfy the totality of the demand in a period. He has the possibility to serve only one part of the demand, if this is more profitable. In lost sales, the demand in every period cannot be backlogged (Aksen et al. (2003)). The classical decision of how much and when to procure of the lot sizing is extended to a twofold decision which takes into account the determination of lost sale levels. Some papers studying the LSP with lost sales are presented in the literature. We quote Sandbothe and Thompson (1990) as the first article which tackles the capacitated LSP including lost sales by proposing a dynamic programming algorithm of $O(T^3)$ time improved by Aksen et al. (2003) to $O(T^2)$. See Hwang et al. (2013) and Absi et al. (2011), for more details on the LSP with lost sales. We outline the contributions of our article compared to the closest papers as follows:

1. Our goal is to solve an unexplored LSP under the specific CRC, buyback contract, while Atamturk and Hochbaum (2001), Van Norden and Van de Velde (2005) and Lee and Li (2013) are the only ones that integrate the general CRC into LSP.
2. To our knowledge, the batch ordering problem has never been addressed with lost sales. Indeed, Aksen et al. (2003) study the LSP with lost sales but without batch ordering and Li et al. (2004) treat the LSP with batch ordering but without lost sales.

For the remaining sections, we describe the LSP-BPB, hypotheses and mathematical formulation, we develop properties for four cases of LSP-BPB followed with the appropriate algorithms and finally we conclude the paper by citing some perspectives.

2. DESCRIPTION OF LSP-BPB, ASSUMPTIONS AND MATHEMATICAL FORMULATION

In our study, we assume that at the beginning of each period $t$, the retailer can order a certain quantity denoted by $x_t$ from an external supplier in $A_t$ batches of size $V_t$, where both parts sign a buyback contract. The demand $d_t$ is known for each period $t$ over a planning horizon of $T$ periods. Therefore, if there is an order in period $t$, the retailer pays a fixed ordering cost $f_t$ where a binary setup variable $y_t$ receives the value 1, and a cost of $a_t$ for each batch replenished in addition to a unit procurement cost $p_t$. Besides, there is an inventory holding cost $h_t$ incurred for each unit remaining in stock, $s_t$, at the end of period $t$. For simplicity, we admit that the initial inventory of the horizon $s_0$ is zero.

In the buyback contract we assume, the return policy can be at the end of each period $t$. Under this contract, the supplier allows the retailer to return a maximum of $x_t$ units, by considering that $\rho = 1$, at a certain return price $p^b_t$ with $0 < p^b_t < p_t$.

Our buyback contract is said partial refund because we have $p^b_t < p_t$ and full return because $\rho = 1$, so this shows that the retailer returns all the unsold units at the end of each period $t$. Therefore, there is no remaining stock at retailer level and our planning problem over a horizon of $T$ periods is divided into $T$ independent problems. The latter is reduced to a Single-Period procurement Planning
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