



Distribution-free approach for stochastic Joint-Replenishment Problem with backorders-lost sales mixtures, and controllable major ordering cost and lead times



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ABSTRACT

In this paper, we study the periodic-review Joint-Replenishment Problem (JRP) with stochastic demands and backorders-lost sales mixtures. We assume that lead times are made of two major components: a common part to all items and an item-specific portion. We further suppose that the item-specific component of lead times and the major ordering cost are controllable. To reflect the practical circumstance characterized by the lack of complete information about the demand distribution, we adopt the minimax distribution-free approach. That is, we assume that only the mean and the variance of the demand can be evaluated. The objective is to determine the strict cyclic replenishment policy, the length of (the item-specific component of) lead times, and the major ordering cost that minimize the long-run expected total cost. To approach this minimization problem, we present a first optimization algorithm. However, numerical tests highlighted how computationally expensive this algorithm would be for a practical application. Therefore, we then propose two alternative heuristics. Extensive numerical experiments have been carried out to investigate the performance of the developed algorithms. Results have shown that the proposed alternative heuristics are actually efficient and seem therefore promising for a practical application.

1. Introduction

In practice, there exist conditions under which coordinated replenishments may be economically beneficial. Goyal [1] cited cases where the output of a batch production is placed in different packages, or where different items are all procured from the same supplier. Questions related to the optimization of such inventory systems belong to the Joint-Replenishment Problem (JRP).

In the standard JRP, each item purchased from the same supplier is characterized by an ordering cost that is charged every time that item is ordered and is independent of the amount of units ordered. Moreover, there exists a major ordering cost that is incurred for each order, independently of the variety of items procured. This cost structure reveals economies of scale that can be exploited with the combination of different items in the same order [2, 3].

In literature, numerous works about JRP can be found. The most recent review considers papers published between the years 1989 and 2005 [2]. More recently, additional papers have been presented,

though. We can classify these papers into two main groups, depending on whether demands are deterministic or stochastic: deterministic JRP and stochastic JRP. In the deterministic JRP group, Narayanan and Robinson [4] presented two heuristics to solve the capacitated, dynamic lot-sizing JRP with time-varying demands. Tsao and Sheen [5] studied a two-actor, multi-item supply chain with a credit period and weight freight cost discounts. Zhang et al. [6] developed a JRP model with complete backordering where demands of some minor items are correlated with that of a major item. Amaya et al. [7] presented a new heuristic approach based on linear programming to solve the JRP under deterministic demands and resource constraints. Tsao and Teng [8] developed two heuristics to solve the JRP under deterministic demands and trade credit. Wang et al. [9–11] used meta-heuristics and fuzzy set-based modelling to approach the problem. In the stochastic JRP group, Paul et al. [12] studied a JRP model in presence of a random percentage of defective units in each replenishment and with price discount, considering deterministic and constant demands. Kiesmüller [3] compared two different continuous-review

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policies, assuming that the demand process is a compound renewal process, and taking into account a constraint on the total amount of products to be ordered. Narayanan and Robinson [13] carried out a study to evaluate the performances of nine joint replenishment lot-sizing heuristics and policy design variables in a dynamic rolling schedule environment with normally distributed demands. Tanrikulu et al. [14] developed a continuous-review policy taking into account a constraint on the transportation capacity. They assumed that demand for each item follows an independent Poisson process.

Real inventory systems are typically subject to various uncertainties; therefore, a model that include random aspects is more practical. In a stochastic environment, an important issue is to reduce or, rather, to control replenishment lead times. According to the Just-in-Time (JIT) philosophy, reduced lead times may lower the safety stock, improve the customer service level, and reduce both the stockout loss and the expected total costs [15]. Although controllable lead time is an important aspect in inventory management, it has rarely been considered in the JRP.

Another key aspect of JIT is ordering/setup cost reduction, which may lead to improved quality and flexibility, stock reduction, and increased effective capacity. Although several researchers have taken into account this issue (e.g., [16–20]), little effort has been made to include it into the JRP framework.

Stochastic inventory models should not neglect backorders-lost sales mixtures. In fact, it is reasonable to assume that only a fraction of the demand during the stockout period is backordered, while the remaining quota is lost. For example, customers whose needs are not critical can wait (these demands are backordered); while others cannot wait and require their needs be satisfied elsewhere (these demands are lost). Numerous inventory models include this feature (see, e.g., [21–24]). However, in the JRP, it has seldom been addressed.

In some practical situations, information about the demand distribution may be rather limited. That is, the decision-maker may only know an estimate of the mean and of the variance, but not the specific distribution type. In this circumstance, the traditional approach is to treat the demand within a given period as a normally distributed random variable [25]. This also follows from the assumption that individual demands are independent and identically distributed (i.i.d.) random variables, and then, according to the central limit theorem, the gaussianity of their sum can readily be deduced. However, this procedure is hardly valid in reality, as single demands are generally not i.i.d. random variables [26]. In addition, one should also consider that the normal distribution is not recommended for items characterized by demand with a large coefficient of variation [27].

Under the condition in which (i) only an estimate of the mean and of the variance of the demand is available and (ii) it is not possible/practical to hypothesize a specific demand distribution, it is reasonable to follow a conservative procedure [25]. That is, the replenishment policy can be optimized considering the worst non-negative distribution with the given mean and variance. This is called “minimax distribution-free approach”. Due to its practicality (easy to use) and optimality (under certain conditions), it has received great attention in the inventory management literature. The reader is referred to some of the most recent works, e.g., [28–31]. In this paper, we include this approach into the JRP context. To the best of our knowledge, this is the first attempt to apply the distribution-free procedure to the JRP.

Owing to what said above, this paper investigates the periodic-review stochastic JRP with backorders-lost sales mixtures under the minimax distribution-free approach. We assume that lead times are made of two major components: a common part to all items and an item-specific portion. We further suppose that the item-specific component of lead times and the major ordering cost are controllable. The purpose is to determine the strict cyclic replenishment policy, the length of (the item-specific component of) lead times, and the major ordering cost that minimize the long-run expected total cost.

We present a first optimization algorithm, which may however

result computationally expensive for a practical application, as numerical tests showed. Hence, to overcome this limitation, we then propose two efficient alternative heuristics. Although they follow the same logic, they differ in the fact that one of them works on an approximated expression of the expected total cost function obtained by means of an *ad hoc* Taylor series expansion. The results of numerical experiments will initially serve to investigate the performance of the developed algorithms. Then, we will evaluate, numerically, the percentage cost difference between our distribution-free model and the same inventory model in the case in which the demand in the protection interval is Gaussian.

The remainder is as follows. Section 2 defines the notation, the assumptions and the problem. Sections 3 and 4 present the first optimization algorithm and the alternative heuristics, respectively. Section 5 deals with the numerical study. Section 6 discusses conclusions and further remarks.

2. Notation, assumptions and problem definition

We set the stage by describing the inventory system under analysis. We consider a family of items procured from one supplier. The inventory of each item is managed according to a periodic-review policy, taking into consideration a stochastic demand. Each item is characterized by a minor ordering cost paid every time the item is purchased, which happens at regular time intervals specified by an integer multiple of a basic cycle time. The minor ordering cost of a given item is independent of the other products. A major ordering cost is charged with frequency established by the basic cycle time. This cost is independent of the number of items acquired. Each item features a deterministic lead time made of two main parts: a common component to all products and an item-specific component.

We adopt the following notation:

Decision variables

T	Cycle time or review period, <i>i.e.</i> , time interval between orders (time unit).
L_n	Item-specific component of the lead time of item n (time unit).
z_n	Safety factor of item n .
R_n	Target level of item n . An equivalent decision variable to z_n (quantity unit).
k_n	Integer multiplier of the replenishment cycle time T relevant to item n .
A	Major ordering cost (money/order).

Parameters

a_n	Minor ordering cost of item n (money/order).
h_n	Unit holding cost of item n (money/quantity unit/time unit).
ρ_n	Fixed penalty cost per unit shortage of item n (money/quantity unit).
π_n	Marginal profit per unit of item n (money/quantity unit).
D_n	Average demand rate of item n (quantity units/time unit).
σ_n	Standard deviation of demand rate of item n (quantity unit/time unit).
β_n	Fraction of shortage (<i>i.e.</i> , demand during the stockout period) of item n that will be lost.
L	Common lead-time component to all items (time unit).

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