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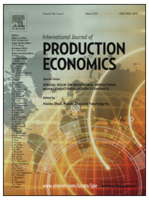

# Safety measures in the joint economic lot size model with returnable transport items

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ABSTRACT

The literature on the joint optimization of order and production quantities had a major focus on managing the downstream flow of materials in the past. Just recently, researchers have started to analyze packaging material that is required for transporting products along the stages of a supply chain as well. So-called ‘returnable transport items’ (RTIs), such as pallets or containers, are a special case of packaging material. RTIs may be used more than once for transporting products, which is why both the downstream and the return flows of these items need to be coordinated to permit a smooth flow of the finished product through the system. If RTI return times are stochastic, delays may occur, which can lead to stockouts at downstream stages of the supply chain. This paper studies alternative safety measures that help to avoid stockouts, namely I) RTI safety return times, II) RTI safety stocks, and III) a combination of both measures. The results of the paper support decisions on which safety measure should be used under which conditions.

## 1. Introduction

For many decades, researchers have discussed different safety measures a supply chain can adopt to protect itself against disruptions. If customer demand or supply lead times are uncertain, for example, then keeping safety stocks in the supply chain reduces shortages and increases service levels (e.g., Silver et al., 1998). Similarly, placing an order earlier than required on average and thus adding a safety lead time helps to reduce the risk of stockouts. It is clear that both measures help to lower costs and improve the competitive position of the supply chain. For a comparison of the relative performance of safety stocks and safety lead times, the reader is referred to van Kampen et al. (2010).

Works that focus on inventory replenishment decisions at the supply chain level surprisingly had a one-sided focus on analyzing the impact of stochastic demand on the system, while stochastic lead times have only very infrequently been studied (Glock, 2012). One of the few works in this area is the one of Sajadieh and Jokar (2009), who studied a supply chain consisting of a single vendor and a single retailer, and who assumed that the vendor's delivery lead time is stochastic and uniformly distributed. The authors used a $(Q,r)$ inventory control policy to determine order quantities for the retailer. A closely related model was published by Sajadieh et al. (2009), who used an exponential distribution to describe the stochastic lead time. Sajadieh and Thorstenson (2014) extended these models to take account of a second vendor, and compared the dual-sourcing scenario to a situation where only a single vendor is used. The results of their study indicate that dual sourcing is beneficial particularly in situations where lead time is highly variable, delivery delays result in very high shortage costs, holding costs are considerably higher for the buyer than for the vendor, and the vendors' setup costs are low. Hoque (2013a) proposed another extension of these models and assumed that lead times are normally distributed. For this scenario, he proposed a more precise calculation of the inventory carrying costs of the system. Hoque (2013b) finally compared equal-sized and unequal-sized batch shipments in a JELS model with normally distributed lead time.

A closer look at the literature shows that the focus of research on the implementation of safety measures in supply chains has thus far been on raw materials, semi-finished products and finished products, but that packaging material has not received much attention. If the inventory level of packaging material is not well managed, however, manufacturers may be unable to deliver products to their customers, even though enough products are available that would facilitate a shipment. Delays that result from shortages in packaging material may lead to excessive inventory carrying costs, deterioration or stockouts at downstream members of the supply chain. Kim et al. (2014), for example, reported the case of a producer of tangerines facing shortages of containers that were required for shipping tangerines to downstream stages of the

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supply chain. Shortages in containers led to stockouts at the retail level and to tangerines deteriorating during delays. The authors showed that the supply chain can control the stockout risk for containers by varying order and production cycles, which led to lower inventory and deterioration costs in the supply chain.

Just recently, researchers have started to investigate interdependencies that exist between the inventories of finished products and the availability of packaging material. Despite the work of Kim et al. (2014), Glock and Kim (2015) studied a single vendor-single buyer supply chain where reusable containers are employed for transporting a finished product from the vendor to the buyer. The authors assumed that all model parameters are deterministic and that a certain fraction of containers has to be replaced from cycle to cycle. The aim of their work was to analyze how the downstream and upstream shipment frequencies influence the performance of the supply chain. Glock and Kim (2014), in turn, studied the case of a single vendor delivering a finished product in containers to multiple buyers. Apart from the production and order quantities of the finished product, the authors considered the container size and the delivery sequence as decision variables. The results of the paper indicate that coordinating the inventory replenishment processes at the buyers closely helps to reduce the number of containers that have to be kept in the system as well as the costs associated therewith. Other related aspects that have been studied in this area include the forecasting of container return times and return quantities or the management of container deployment quantities, among others (e.g., Goh and Varaprasad, 1986; Kelle and Silver, 1989a, 1989b; Buchanan and Abad, 1998).

Although stochastic container return times (Kim et al., 2014) and stochastic container return quantities (Kim and Glock, 2014) have already been discussed in the literature, the implementation of safety measures to assure that packaging material is adequately available in the supply chain has not attracted the attention of researchers so far. The aim of the paper at hand therefore is to close this research gap and to study alternative safety measures for reusable packaging material in a two-stage supply chain model with stochastic container return times. The focus of the paper is on a special type of reusable packaging material, so-called returnable transport items (RTIs). RTIs, such as containers, pallets or crates, are frequently used in practice today, and in some companies they represent an important corporate asset (Rosenau et al., 1996; Carrasco-Gallego and Ponce-Cueto, 2010). The model developed in this paper helps to determine optimal safety stock levels and optimal safety return times for returnable transport items, which, in turn, help to reduce stockout risks and the consequences associated therewith.

The remainder of this paper is structured as follows. The next section introduces the problem studied in this paper. Section 3 develops mathematical models with different types of RTI safety measures, and Section 4 analyzes the performance of these models in an extensive numerical experiment. Section 5 concludes the paper and presents ideas for future research opportunities.

## 2. Problem description

This paper considers a supply chain where a vendor delivers a product to a retailer. To facilitate handling and transporting the product and to protect it from damages during transportation, the vendor stores the product in reusable containers. The retailer returns the containers at some point in time to the vendor, who reuses the containers after cleaning and repairing them. Container return times are assumed stochastic, which could be the result of unexpected damages or be caused by the return behavior of the retailer's customers.

This paper considers four different scenarios:

1. Model 1 assumes that no safety stock is kept in the system. The retailer returns used containers to the vendor $L_0$ units of time before they are needed for shipping products, where $L_0$ is the expected return time. As the vendor plans shipping products to the retailer at the beginning of a cycle, RTIs are returned to the vendor $(T-L_0)>0$ units of time after the start of the previous cycle, where $T$ is the cycle time. Model 1 is used as a benchmark in this paper to assess the performance of the other models.
2. Model 2 assumes that the retailer returns used containers at the end of a cycle (which is the beginning of the next cycle), i.e. $T$ units of time before they are needed. Thus, containers are returned $(T-L_0)>0$ units of time earlier than in Model 1, where $(T-L_0)$ could be interpreted as a safety return time.
3. Model 3 assumes that containers are returned $(T-L_0)>0$ units of time after the start of a cycle, i.e. that no safety return time is implemented. The vendor, however, keeps a safety stock of $S$ containers in inventory to protect itself against stockouts. Thus, if containers are returned late, a shipment is made using the containers in the safety stock to avoid that the retailer incurs shortages. The safety stock shipment is made at the point in time when the inventory of finished products at the retailer is depleted, i.e. at the beginning of the new cycle and only in case the realized return time exceeds $L_0$ units of time.
4. Model 4 assumes that containers are returned at the beginning of a cycle, i.e. $T$ units of time before they are needed (as in Model 2). As in Model 3, the vendor keeps a safety stock of $S$ containers in inventory to protect itself against stockouts. Again, a safety stock shipment is made at the point in time when the inventory of finished products at the retailer is depleted, i.e. at the beginning of the new cycle and only in case the realized return time exceeds $T$ units of time.

The stock levels that result for the four models are illustrated in Figs. 1 and 2.

The difference between the case of stochastic container return times analyzed in this paper and the case of stochastic lead times that has frequently been studied in the literature can be summarized as follows: In the case of stochastic lead times, the final product my arrive early, on time, or late. Depending on the scenario that is realized in a cycle, the system may end up with additional inventory carrying cost for the finished product or shortages. If container return times are stochastic, then the containers may be returned early, on time, or late. The finished product is not affected directly by the stochastic return time of the containers, as its production time is deterministic, and therefore the finished product is always available on time. In the case of an early RTI return, the vendor realizes additional RTI inventory carrying costs, as RTIs have to be stored for a longer period of time at its premises. The finished product is, however, not affected in this case. If RTIs are returned late, in contrast, then the vendor incurs additional inventory carrying costs for the finished product in addition to the stockout costs at the end customer, as the product is ready, but cannot be shipped. It is clear that in case RTI return times are stochastic, interdependencies between the RTIs and the finished products inventory arise, as the inventory of the finished product kept at the vendor (and therefore the inventory that is "at risk" in the case of a late return) depends on the decision variables of the vendor/system.

In developing the proposed models, the following assumptions will be made:

1. Shortages of the finished product are allowed at the retailer, and they are completely backordered.
2. Container return times are exponentially distributed with mean $L_0$. The exponential distribution has frequently been used to model stochastic lead times in the past, see for example Sphicas (1982), Paknejad et al. (1992), Bookbinder and Cakanyildirim (1999), and He et al. (2005).
3. The probability of very long delays in the return shipment is either small enough to be neglected, or the supplier does not

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