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A closed-loop supply chain for deteriorating products under stochastic container return times

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ABSTRACT

This paper studies a two-stage supply chain where returnable transport items (RTIs) are used to ship finished products from the supplier to the buyer. Empty RTIs are collected at the buyer and returned to the supplier. The return time of RTIs is considered to be stochastic in this paper, and further finished products are assumed to deteriorate during potential delivery delays. First, the paper develops an analytical model of this supply chain, and then it discusses the properties of the model. Secondly, it presents the results of a simulation study in which the behaviour of the model is analysed. The results of our analysis indicate that the supply chain can influence both the risk of RTI stockouts at the supplier and the deterioration rate by changing the value of the return lot size of RTIs. Further, the results indicate that realising the optimal value for the RTI return lot size is especially important in case the mean return time of RTIs is short, while in case of a long RTI return lead time, an approximation of the optimal RTI return lot size is also acceptable.

1. Introduction

The study of closed-loop supply chains, which explicitly take account of product returns, in addition to the downstream flow of materials, has become more and more popular in recent years [1–3]. Including reverse operations in the management of supply chains enables companies to recycle used products, which then eventually re-enter the forward supply chain [4]. Closed-loop supply chains therefore contribute to initiatives that focus on the reduction of resource consumption and waste generation, and thus support the critical role industrial companies play in achieving global sustainability [5].

Apart from the flow of materials and finished products, the transportation equipment used in a supply chain also needs to be coordinated. In many industries, so-called returnable transport items (RTIs), such as containers, pallets or crates, are used to avoid that packaging material needs to be disposed of each time it has been used [6]. Management actions associated with the use of RTIs include the initial purchase and the replacement of damaged or lost units, the collection and return of used items as well as the organisation of cleaning and repair processes [7]. Coordinating the use of RTIs in a supply chain helps to lower the cost of purchasing new RTIs and the cost of disposing used packaging material. It also contributes to a reduction in packaging waste, which assists companies in meeting waste reduction levels specified by governmental regulations [8–10].

The present paper studies a problem that is very common to the supply chain of agricultural products. After products have been harvested, processed and packed by the supplier, they are stored away in boxes or containers to facilitate safe transport to the customer. Once a shipment arrives at the customer's end, the products are unpacked and the packaging material is collected, cleaned and sorted and returned to the supplier. In many practical cases, delays in returning empty RTIs may occur at the buyer's end, which may, for example, be due to (unexpected) damages of RTIs that need to be repaired or the fact that the customer (temporarily) does not have enough personnel resources for treating both RTIs and products simultaneously. In the latter case, the customer may decide to concentrate on the processing of finished products before empty RTIs are returned to the supplier. At the supplier's side, however, delays in the return of empty RTIs may lead to stockouts, which render it impossible to dispatch the next shipment of finished products on time. As the shelf life of agricultural products is limited in most cases, deterioration may become an issue during the delay, which may cause serious financial losses to the supplier. To balance these losses, the supplier may decide to keep a safety

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stock of RTIs or try to give the buyer an incentive to return RTIs on time.

This paper develops a model of such a supply chain by assuming that the products produced at the supplier are stored in RTIs during transportation, and that the return time of RTIs is stochastic. If a stockout of RTIs occurs at the supplier, products are assumed to deteriorate. The intention of this paper is to analyse how delays in the return of RTIs impact the expected total cost of the supply chain, and to develop guidelines which assist decision makers in minimising expected total cost. The results of our study indicate that the mean return time of RTIs is critical for the model and that a higher return lot size should be selected as the mean return time increases. In addition, we show that if products deteriorate quickly, companies should produce in small lots to dampen the deterioration effect.

The remainder of the paper is structured as follows. The next two sections give an overview of related works and outline the assumptions and definitions that will be used in the remaining parts of the paper. Section 4 develops a model of a closed-loop supply chain with stochastic return times and deteriorating products, and Section 5 presents a case study and numerical experiments. Section 6 concludes the paper and provides suggestions for future research.

2. Literature review

In a survey of the literature, we identified three research streams that are of special importance to this paper. The first stream of research studies stochastic lead times in inventory models. Early works in this area are the ones of Liberatore [11], Sphicas [12], Friedman [13] and Sphicas and Nasri [14], who derived cost functions for the economic order quantity (EOQ) model under stochastic lead times, and who analysed the properties of the optimal solution. Kim et al. [15] studied a (Q, R) inventory model and assumed that lead time is stochastic and Erlang distributed. Their intention was to provide practitioners with a simple, accurate mechanism that can give them insights into stochastic lead times and their effect on inventory policy. Nasri et al. [16,17], Paknejad et al. [18] and Sarker and Coates [19] extended these models and assumed that the setup cost or lead time variance can be reduced at an investment. The authors showed that by modifying the parameters of the model, the expected total cost of the system can be reduced. Bookbinder and Cakanyildirim [20] studied two (Q, R) inventory models with stochastic lead time, one in which lead time is exogenous, and one where it is endogenous and dependent on an expediting factor. For each model, they developed expected total cost functions and obtained the global minimiser. In addition, they showed that expediting lead times may reduce the expected total cost of the system, and that a lower value of the expediting factor achieves the same effect as shortening the tail of the lead time distribution. Sajadieh and Jokar [21] studied the case of a supply chain consisting of a single supplier and a single buyer and assumed that the lead time of the supplier is stochastic. The authors differentiated between two cases, one where the reorder point exceeds the maximum lead time demand and one where the opposite scenario occurs, and developed and solved cost functions for both cases.

A second stream of research that is relevant to our paper studies the use of RTIs in supply chains or predicts the time, quantity and quality of returned products, such as RTIs. Despite works that focused on the use of RFID to simplify tracking and handling of RTIs [7,22,23], some papers developed optimisation models that help decision makers in determining deployment quantities and dates for RTIs. Buchanan and Abad [24], for example, studied the inventory control problem for containers and considered the returns in a given period as a stochastic function of the number of containers in the field. Using dynamic programming, the authors derived the optimal inventory control policy for the system. Another paper in this line of research is the one of Chew et al. [25], which developed performance measures to monitor and control the deployment of containers. Toktay et al. [26] considered the problem of procuring new products in a supply chain where used products are returned to the manufacturer for recycling, and developed an optimal ordering policy for this system. The authors assumed that the customer-user stage of the supply chain cannot be observed by the manufacturer, and used a queuing network to model the downstream flow of materials through the system and the dependence of the return flow on past sales. Clottey et al. [27] developed an inventory model for planning the production of new products and the recycling of used items, and combined it with a forecasting approach to determine the distribution of returns of used items. Toktay et al. [26] and Clottey et al. [27] both included methods to estimate return times (so-called distributed-lag-models). de Brito and van der Laan [28] studied the effect of imperfect information on the planning of a supply chain with product returns. They compared different forecasting methods for estimating product returns and came to the conclusion that the method that uses the most information does not necessarily provide the best forecast. Hess and Mayhew [29] developed a forecasting approach based on a regression analysis to predict product returns for direct marketing companies. Their approach is able to consider several product characteristics, such as price or product category, in predicting product returns.

A third research stream that we would like to discuss here studies inventory policies for deteriorating items. Deterioration, in this context, refers to a process in which products decay, get damaged or spoiled over time such that they cannot be used for their original purpose anymore [30]. Early works in this area are the ones of Ghare and Schrader [31], Covert and Philip [30], Dave [32] and Elsayed and Teresi [33], who developed functions to approximate deterioration and who studied the impact of deterioration on inventory policies. Yang and Wee [34] analysed deteriorating items in a vendor–buyer supply chain and showed that higher deterioration rates increase the relative advantage of coordination in the supply chain. Yang and Wee [35] and Huang and Yao [36] extended this paper to account for multiple buyers. Lo et al. [37] analysed a varying deterioration rate by assuming that deterioration follows a two-parameter Weibull distribution. As a consequence, the deterioration rate increases with the time a product is kept in stock. The model further included an imperfect production process, inflation and partial backordering at the buyer, and assumed that defective items can be reworked, whereas deteriorated items have to be disposed of. Cai et al. [59] studied a three-level supply chain with a distributor of a deteriorating product, a logistics service provider, and a buyer. They assumed that customer demand is sensitive to the selling price of the product and its freshness, and derived optimal decisions for the three supply chain members for this scenario. Wang and Li [60] developed a dynamic quality-based pricing model and assumed that customers are sensitive to product price and the remaining shelf life of the product. Since shelf life decreases continuously once a product has been produced, the retailer has to reduce the price over time to make sure that the partially deteriorated products are still bought by the customer. The authors studied single- and multiple-markdown policies and showed how these policies may influence the retailer's profit. Another work in this stream of research is the one of Law and Wee [61], which assumed that the inventory of a single-vendor–single-buyer supply chain is subject to deterioration and amelioration simultaneously. Amelioration, in this context, refers to a process in which the value of a product increases over time, which is the case for several agricultural products such as cheese or wine, for example. Considering amelioration and deterioration leads to an initial growth