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Modeling the consignment inventory for a deteriorating item while the buyer has warehouse capacity constraint

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ABSTRACT

In this article, we consider a single-manufacturer–single-buyer supply chain problem in which the manufacturer produces a single deteriorating product and delivers it to the buyer on the basis of a consignment policy. An integrated inventory control model, jointly determining the manufacturer's production batch and the replenishment lot sizes, is proposed to minimize the manufacturer's total cost per unit time. Both scenarios of the buyer with and without warehouse capacity constraint are presented. The characteristics of the model are discussed. In addition, the impacts of the buyer's warehouse capacity constraint on the manufacturer's total cost, production batch, and replenishment lot sizes are also presented through numerical illustrations. This model generalizes those published results and enables managers to move from a reactive mode to a proactive one by taking the supplier's perspective.

1. Introduction

This research was motivated by problems encountered in the subject of our case study, Chang Gung Memorial Hospital, a medical center in Taiwan affiliated with the authors' university. Currently, the hospital's supply chain department utilizes consignment purchasing policy on certain surgical materials used by cardiac, orthopedic, and ophthalmology units. Having gained a lower inventory holding cost and enjoying more flexible cash management in procurement, the hospital's top management would like to extend the consignment program to as many other medical materials as possible.

The consignment purchasing policy has been utilized in automotive manufacturing and health care industries for years (Fenton and Sanborn, 1987; Valentini and Zavanella, 2003). The *APICS Dictionary* defines consignment as "the process of the supplier placing goods at a customer location without receiving payment until after the goods are used or sold" (Blackstone, 2008). In the consignment purchasing policy, the buyer provides warehouse space for the supplier to stock, thus allowing the latter generous savings in inventory carrying costs; on the other hand, the buyer can defer payment until those stocks are actually consumed. This implies that a consignment program might create a condition of shared benefits for both the supplier (manufacturer) and the buyer (consignee). As with most consignment agreements, the buyer is responsible for any loss or damage of stocked goods, and the supplier is no longer responsible for storage or material handlings. For this reason, it is no surprise that the supplier would like to stock as much inventory as possible in the buyer's warehouse. In contrast, the buyer would rather stock a lower level of inventory as long as it is sufficient to buffer against demand uncertainty. Thus, how to negotiate and reach an agreement between both parties regarding the consigned inventory levels becomes a critical issue.

None of the previous studies have incorporated the major buyer characteristics such as maximum available warehouse space, which may largely impact optimal vendor behaviors in consignment policy. Lee and Wang (2008) were the first to take into account this important factor. They studied the impact of the buyer's warehouse capacity constraint on the manufacturer's total costs, when both the supplier and buyer in the supply chain agree to adopt a consignment purchasing policy. In this paper, we extend our results in Lee and Wang (2008) to a case in which the product is deteriorating. We consider a single-manufacturer–single-buyer supply chain problem where a manufacturer produces a single deteriorating product and then delivers it, in a constant lot size, to the buyer on the basis of a consignment policy. An integrated inventory control model, jointly determining the manufacturer's production batch and the replenishment lot sizes subject to the buyer's warehouse capacity constraint, is constructed to minimize the manufacturer's total cost per unit time.

2. Literature review

Research related to consignment purchasing contracts has been prevalent recently. Braglia and Zavanella (2003) were the first to propose a consignment inventory model for solving the joint

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economic lot size (JELS) problems, followed by Zanoni and Grubbstrom (2004), where an algorithm was proposed. Wang et al. (2004) studied the consignment contract with revenue sharing and showed how overall supply channel performance critically depends on demand price elasticity and the buyer's share of channel cost. Gumus et al. (2008) addressed the impact of consignment inventory and vendor-managed inventory for a two-party supply chain. Li et al. (2009) continued to analyze how the system parameters impact the optimal supply chain decisions and supply chain performance. Zavanella and Zanoni (2009) showed that the consignment stock policy works better than uncoordinated optimization for an industrial case of a single-vendor and multiple-buyer productive situation. Zanoni et al. (2011) considered the learning and forgetting effects in a two-level supply chain with one vendor and one buyer; the paper compared different policies that the vendor may adopt to exploit the advantages offered by the consignment agreement when the vendor's production process is subject to learning flexibility. Note that these JELS models deal with how the supplier and buyer should coordinate in determining supplier batch and customer ordering lot sizes; none of them consider the deterioration property of inventories, despite the fact that some items inevitably deteriorate over time.

Deterioration is broadly defined as decay, damage, spoilage, evaporation, obsolescence, pilferage, and loss of entity or loss of marginal value of a commodity that results in decreasing usefulness from the original (Wee, 1993). The deterioration of goods is a common phenomenon; therefore in inventory systems the effect of deterioration is very important and resulting losses cannot be neglected. We can distinguish between two kinds of deterioration: perishability and continuous decay. Perishabilty corresponds to the situation in which an item may be retained in stock for a fixed period of time with no loss in utility; however, if the inventory has not been used before the expiration date, it is obsolete and must be discarded. Noticing the obsolescence of products causes an increase in total supply chain costs, Persona et al. (2005) were the first to take into account the effects of obsolescence in a consignment inventory model. Battini et al. (2010a) made an extension to the above study and considered new critical factors in industrial environments such as stock-out risk due to demand variability and obsolescence risk for the perishable materials. The model proposed by Battini et al. (2010b) is also an extension of Persona et al. (2005), which deals with a multi-echelon inventory system in which one vendor supplies an item to multiple buyers.

Instead of imposing an item's life period, continuous decay corresponds to the situation where a fixed fraction of stock on hand is deteriorating throughout the planning horizon where the utility for the stock decreases exponentially over time. Examples of inventory which exhibit exponential decay include radioactive material or fuels and volatile liquids such as alcohol and gasoline (Nahmias and Wang, 1979). Ghare and Schrader (1963) were the first two researchers to consider continuously decaying inventory for constant demand. Bhunia and Maiti (1998) developed a deterministic inventory model with one owned and one rented warehouse, and allowed different levels of item deterioration in both warehouses. Yang (2004) proposed an alternative model for determining the optimal replenishment cycle for the two-warehouse inventory problem under inflation, in which the inventory deteriorates at a constant rate over time and shortages are allowed. Dye (2007) proposed a model jointly determining the pricing and replenishment schedule for a deteriorating inventory while allowing backlogging. Dye et al. (2007) considered the limited capacity of the owned warehouse, allowing for shortages in the owned warehouse and assuming that the backlogging demand rate was dependent on the duration of the stockout. Ho et al. (2007), Lodree and Uzochukwu (2008), and Chang et al. (2010) also studied the possibilities and effects of buyer–vendor integration and cooperation of deteriorating items. Yan et al. (2011) developed an integrated production-distribution model for a deteriorating item in a two-echelon supply chain. The most recent Liao et al. (2012) developed an inventory model to determine economic order quantity, which links to trade credit, for deteriorating items with two warehouses; the problem involved how retailers decide whether to rent an additional warehouse to hold more items and thus obtain a trade credit period; however, they did not investigate either the consignment inventory policy or the warehouse space constraints.

The remainder of this paper is organized as follows. Section 3 depicts the problem and gives the assumptions and notations used. Both scenarios of the buyer with and without warehouse capacity constraint are modeled in Sections 4 and 5 as the capacitated and uncapacitated cases, respectively, and the relevant inventory costs of the vendor and the buyer are derived. Section 6 presents a numerical example for illustration and addresses the impact of the consignee's warehouse capacity constraint on the manufacturer's total cost, as well as on the manufacturer's production and replenishment lot sizes. Ultimately, Section 7 concludes that the proposed models are more general than those relevant results in literature.

3. The problem

Under the consignment purchasing policy, it is the vendor's responsibility to monitor the buyer's warehouse inventory level, and the manufacturer can take advantage of the buyer's warehouse space to store more inventories and increase the production lot size, resulting in significant savings on set-up costs. In this particular supply chain, two costs charged to but not incurred by the supplier are the buyer's inventory holding cost and deterioration cost. In addition, four more costs at the expense of the manufacturer include the production set-up, holding, and deterioration of the finished goods on the manufacturer's side, plus the cost for replenishment from the supplier to the buyer.

Fig. 1 depicts the trends of the manufacturer's and buyer's inventory levels when both parties do not have warehouse capacity constraint. Fig. 2 illustrates a scenario in which only the buyer has warehouse capacity constraint. According to the consignment contract, the manufacturer will trigger replenishment during its production period, as soon as its cumulative production volume reaches the planned lot size. The manufacturer immediately delivers the replenishment to the buyer as long as the latter's warehouse is capable of accommodation; if there is not enough space in the buyer's warehouse, the replenishment has to be postponed until there is sufficient capacity.

3.1. Notations

To minimize the vendor's total cost in a consignment cycle by jointly determining the production batch and replenishment lot sizes, notations used throughout the paper are defined as follows:

D	the buyer's constant demand rate (units/year);
P	the vendor's constant production rate (units/year);
α, β	deterioration rates in the buyer's and the vendor's warehouses, respectively;
R_{vb}	cost per replenishment to the buyer, but charged to the vendor in the consignment purchasing policy ($/replenishment);
S_v	the vendor's production set-up cost ($/set-up);
h_b, h_v	unit holding cost of the buyer's and the vendor's inventory, respectively ($/unit/year);