

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics



journal homepage: www.elsevier.com/locate/ijpe

Optimal replenishment policy for an integrated inventory system with defective items and allowable shortage under trade credit

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ARTICLE INFO

Article history: Received 31 August 2009 Accepted 20 March 2012 Available online 22 May 2012

Keywords: Supply chain Defective items Return policy Complete backlogging Trade credit

ABSTRACT

This study proposes a single-supplier, single-retailer integrated inventory model that accounts for defective items that arrive in a retailer's order under a full-lot inspection policy. All defective items are returned to the supplier in next delivery. After receipt of the returned items, the supplier will classify them into two types: items that still have some worth and waste items. For those items that still have some worth, the supplier will offer customers a discount in order to minimize losses arising from these defective items. The supplier needs to pay a disposal fee for those items classified as waste items. Shortages are allowed and are fully backlogged. To encourage sales the supplier offers trade credit to the retailer. A two-echelon inventory model is established, and the decision variables include: replenishment cycle time, the time taken to run out of stock and the number of lots delivered from the supplier to the retailer. An algorithm is developed to determine the optimal supply chain strategy and numerical examples are provided to show the solution procedure. Also, a sensitivity analysis is conducted on the main parameters of the model.

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1. Introduction

The ultimate objective of effective supply chain management is the reduction of costs, improvement of cash flow and increased operational efficiency across the entire business through connecting inventory control, purchasing coordination and sales order processing with market demand. In a competitive business environment the ability to integrate one's supply chain is essential for company success. The joint optimization concept for the supplier and retailer was initiated by Goyal (1976). Banerjee (1986) extended Goyal's (1976) model and assumed that the supplier followed a lot-for-lot shipment policy with respect to a retailer. Later, Goyal (1988) relaxed the lot-for-lot policy and illustrated that the inventory cost could be significantly reduced if the supplier's economic production quantity (EPQ) was an integer multiple of the retailer's purchase quantity. Lu (1995) then generalized Goyal's (1988) model by relaxing the assumption that the supplier could supply the retailer only after completing the entire lot size. Many researchers (Goyal, 1995, 2000; Ha and Kim, 1997; Viswanathan, 1998; Hill, 1999; Goyal and Nebebe, 2000: Woo et al., 2001: Pan and Yang, 2002: Khan and Sarker, 2002; Kim and Ha, 2003; Kelle et al., 2003; Yao and Chiou, 2004; Siajadi et al., 2005; Hogue, 2008; Sarker and Diponegoro, 2009; Glock, 2011, 2012) continued to propose more batching and shipping policies for integrated inventory models.

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The above inventory integration models commonly adopt the unrealistic assumption that all units received by a retailer are of good quality when studying strategic production/transportation decisions. In reality, imperfect production process, flaws in the goods transportation process and many other factors inevitably lead to a certain proportion of defective items being received during a production run. Over the years, several different economic order quantity (EOQ) models that account for defective items have been developed. For example, Rosenblatt and Lee (1986) and Porteus (1986) initially considered the effects of an imperfect production process on quality imperfection and on lot size. Salameh and Jaber (2000) extended the traditional EPQ/EOQ model by accounting for imperfect quality items. They considered the issue of poor-quality items being sold as a single batch by the end of a 100% screening process. Wu and Ouyang (2000) considered the potential for an arrival order lot to contain some defective items and the number of defective items in a sampled sub-lot to be a random variable. Currently, several relevant papers exist that study EPQ models for items with imperfect quality such as Ouyang et al. (2002), Chiu (2003), Chang (2003), Balkhi (2004), Hou and Lin (2004) and Papachristos and Konstantaras (2006). These models determine an optimal policy from the perspective of either the retailer or the supplier only. Integrated vendor-buyer models that consider defective items have also been presented (see, for example Affisco et al., 2002; Singer et al., 2003; Comeaux and Sarker, 2005; Huang, 2004; Lo et al., 2007; Chung and Wee, 2008; Maddah and Jaber, 2008; Chiu et al., 2011; Khan et al., 2011).

Enterprises and academic bent on the improvement of production process to eliminate defectives and reduce waste. However, in

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^{0925-5273/\$ -} see front matter @ 2012 Elsevier B.V. All rights reserved. http://dx.doi.org/10.1016/j.ijpe.2012.05.001

practice defective is inevitable (Schwaller, 1988). Facing growing levels of competitive and economic pressures, more and more enterprises have begun to view the defective treatment as a process that may be used to manage costs and drive additional revenues. Also, the growing global concern for the environment has led to increased interest in the treatment of defective. In this paper, a common defective treatment for manufactures of clothing, shoe, accessory, furniture, electronics, toys and bedding is involved. For example, a famous clothing company produces middle and top grade women's apparel. Their brands are sold in China's major cities more than 300 stores. All returns from retailers will be check and classed. While the returned clothes with minor production defects. such as stain, skipped or dropped stitches, wavy bottom hem, sewing thread not matching, etc., will be cut label and sold to wholesalers with discount price. If the defects affecting the usability and salability, such as: fabric hole, shading among panel, wrong measurement, dye patches etc., then the returns will be scraped.

The above integrated inventory models for items with imperfect quality failed to account for the effect of trade credit on optimal policies. Trade credit is a widespread tool and represents an important proportion of company finance. Businesses, especially small businesses with limited financing opportunities, may be financed by their suppliers rather than by financial institutions (Petersen and Rajan, 1997). Furthermore, offering trade credit to retailers may improve supplier sales and reduce on-hand stock levels (Emery, 1987). Goyal (1985) was the first to establish an EOQ model with a constant demand rate under the condition of a permissible delay in payments. Aggarwal and Jaggi (1995) extended Goyal's (1985) model to include deteriorating items. Jamal et al. (1997) further generalized this issue with allowable shortages. Kim et al. (1995) examined the effects of a credit period on the ordering policies from the supplier's viewpoint. Teng (2002) modified Goval's (1985) model by considering the difference between the selling price and purchase cost, and found that the economic replenishment interval and order quantity decreased under the permissible delay in payments in certain cases. Numerous relevant papers have been produced relating to trade credit such as Huang (2003), Ouyang et al. (2005, 2009), Teng et al. (2005), Su et al. (2007), Chen and Kang (2010a) and Yu (in press).

By taking the considerations of imperfect-item and trade credit as described above, Li et al. (2009) developed a model to determine the retailer's optimal replenishment policy with defective items under conditions of permissible delay of payments. Further, Chen and Kang (2010b) investigated the issue of defective items with a permissible delay in payment from the perspective of both the vendor and buyer. However, in their models the occurrence of shortage in the inventory system is overlooked. In real life, many famous products or modern goods, for example Apple's iPad and iPhone, may cause a situation in which customers may prefer to wait for back orders while shortages occur. Inventory shortage problems can interfere with a company's profits and customer service. Therefore, for inventory managers of manufacturing and retail organizations how to control inventory in the supply chain that enable them to minimize inventory costs and meet customer demand is worth discussing.

This paper proposes a single-supplier, single-retailer integrated inventory model that accounts for defective items that arrive in a retailer's order under a full-lot inspection policy. All defective items are returned to the supplier and classified into two types: items that still useful and waste items. The former are sold to customers in a discounted price and the later cost a disposal fee. Shortages are allowed and are fully backlogged. For the retailer, trade credit is permissible. A two-echelon inventory model is established and the decision variables include: replenishment cycle time, the time taken to run out of stock and the number of lots delivered from the supplier to the retailer. An algorithm is developed to determine the optimal strategy and numerical examples are provided to show the solution procedure. Furthermore, a sensitivity analysis is conducted on the main parameters of the model. Finally, conclusions and possible future research topics are provided.

2. Notation and assumptions

The following notation and assumptions are used throughout this paper.

2.1. Notation

p

Q

t

Т

- D retailer's demand rate per unit time
- Α retailer's ordering cost per order
- F retailer's freight cost
- f fix freight cost per delivery
- value related freight cost γ
- β freight cost per unit
- retailer's unit stock holding cost of good quality items h_{b1} per unit time excluding interest charges
- retailer's unit stock holding cost of defective items per h_{b2} unit time excluding interest charges, where $h_{b2} \leq h_{b1}$
- c_1 retailer's unit purchasing price retailer's unit inspecting cost
- C2
- retailer's unit backlogging cost per unit time C_{2} Ie
- retailer's interest earned per dollar per unit time retailer's interest charged per dollar in stocks per unit I_p time
 - retailer's unit selling price for items of good quality
 - retailer's order quantity of good quality items per order
 - the length of stock-end cycle of the retailer (decision variable)
 - the length of replenishment cycle of the retailer (decision variable)
- supply quantity per delivery from the supplier to the q retailer in a production batch
- λ percentage of defective items in each deliver, $\lambda \in [0,1)$
- w percentage of disposal items in each return, $w \in [0,1)$
- R supplier's production rate
- S supplier's setup cost per setup
- supplier's unit production cost v_1
- supplier's unit inspection cost of returned items v_2
- supplier's unit disposal cost v_3
- supplier's unit clearing price of useable defective items h
- supplier's unit stock holding cost per unit time h_v
- supplier's capital opportunity cost per dollar per unit I_{ν} time
- number of shipments from supplier to retailer per batch т production run, a positive integer (decision variable)
- the length of the trade credit period offered by the М supplier.

2.2. Assumptions

- 1. There is a single-supplier and a single-retailer for a single product in this model.
- 2. Replenishments are instantaneous and the lead time is zero.
- 3. Shortages are allowed and these are fully backlogged.
- 4. Each batch is dispatched to the retailer in m equal-sized shipments, where *m* is a positive integer.
- 5. An arriving lot *q* contains some defective items with defective rate λ .
- 6. The retailer orders a lot of size Q which is the sum of good quality items in *m* equally-sized shipments, i.e., $Q = m(1 - \lambda)q$.

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