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Combining an improved multi-delivery policy into a single-producer multi-retailer integrated inventory system with scrap in production

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ABSTRACT

Operating in highly competitive global markets, management of the contemporary corporations constantly seeks to cut down various operating costs, such as inventory holding costs in the production units and their affiliated retailers. For the purpose of reducing stock holding cost, this paper combines an improved multi-delivery policy into a single-producer multi-retailer integrated inventory system with scrap in production. We extend a study by Chiu et al. (2013a) by augmenting an alternative $n + 1$ product distribution policy to their integrated inventory system. An initial delivery of finished items is shipped to multiple retailers to meet demand during the production unit's uptime. After the remaining production lot is produced and screened, fixed quantity n installments of the finished products are delivered to retailers at a fixed time interval. With the help of a mathematical model along with Hessian matrix equations, the closed-form optimal operating policies for the proposed system are derived. Further, the study demonstrates, through a numerical example, significant savings in stock holding cost for both the production unit and retailers.

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1. Introduction

The classic economic production quantity (EPQ) model considered production planning for single product with perfect manufacturing process and a continuous inventory issuing policy for its finished goods (Taft, 1918). However, in real production–shipment environments due to various uncontrollable factors, generation of defective items is inevitable and the multi-delivery policy is often used in lieu of the continuous issuing policy. During past decades, many studies have been carried out to address different aspects of imperfect production systems (Alghalith, 2013; Barlow and Proschan, 1965; Chelbi and Rezg, 2006; Chen et al., 2012; Chiu et al., 2012; Chiu et al., 2013b; Hariga and Ben-Daya, 1998; Rubio and Jáuregui-Correa, 2012; Sarkar and Sarkar, 2013; Schwaller, 1988; Shih, 1980). Shih (1980) considered two inventory models where the proportion of defective units in the accepted lot is a random variable with known probability distributions. Optimal solutions for the proposed systems were developed, and through numerical examples, comparisons to the traditional models are presented. Schwaller (1988) studied EOQ model by adding both fixed and variable inspection costs, for finding and removing a known proportion of defective items in incoming lots. Hariga and Ben-Daya (1998) examined the EPQ model in the presence of imperfect processes. The time to shift from the in-control state to the out-of-control state was assumed to be flexible, and they provided distribution-based and distribution-free bounds on the optimal cost. For the exponential case, they compared the optimal solutions to approximate solutions proposed in the literature. Sana (2010) developed a model to determine the optimal product reliability and production rate that achieves the biggest total integrated profit for an imperfect manufacturing process. The paper provided an optimal control formulation of the problem and developed necessary and sufficient conditions for optimality of the dynamic variables. Then the Euler–Lagrange method was employed to obtain the optimal solutions for product reliability parameter and dynamic production rate.

Studies that related to various aspects of multi-delivery vendor–buyer systems are surveyed as follows. Schwarz (1973) examined a simple continuous review deterministic one-warehouse N-retailer inventory problem with the purpose of deciding the stocking policy, for minimizing the average system cost. Goyal (1977) investigated an integrated single supplier–single customer problem. He presented a method that is typically applicable to the inventory problems where a product is procured by a single customer from a single supplier using examples to demonstrate his proposed model. Schwarz et al. (1985) considered the system fill-rate of a one-warehouse N-identical retailer distribution system as a function of warehouse and retailer safety stock. They employed an approximation model from a prior study to maximize system fill-rate subject to a

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constraint on system safety stock. As a result, properties of fill-rate policy lines are suggested. Hall (1996) examined how attributes of the distribution system affect inventory accounting and EOQ/EPQ decisions. He developed a range of "characteristic inventory curves" to represent situations encountered in integrated production/distribution systems, and showed how system attributes define the inventory curve, and the resulting EOQ/EPQ equations. He concluded: (1) accounting for inventory at both the origin and destination can yield significantly different EOQ/EPQ results, but relatively modest regret; and (2) failure to account for consolidation effects among multiple products sent to a common destination can lead to substantial errors. Sucky (2005) focused on supply chain management from the perspective of inventory management. The coordination of order and production policies between buyers and suppliers in supply chains was of particular interest. This study provided several bargaining models depending on alternative production policies of the supplier. With these bargaining models the offered cooperative policy and the offered side payment can be derived. Abdul-Jalbar et al. (2008) considered a multi-echelon inventory system in which one vendor supplies an item to multiple buyers. It was assumed that the vendor produces the item at a finite rate and customer demand occurs at each buyer at a constant rate. The goal is to determine the order quantities at the buyers and the production and shipment schedule at the vendor in order to minimize the average total cost per unit time. The problem was formulated in terms of integer-ratio policies and a heuristic procedure was developed. Both solution procedures were illustrated with a numerical example. Performance of the heuristic for computing integer-ratio policies was demonstrated. Chiu et al. (2013a) studied a single-producer multi-retailer integrated inventory system with scrap in production. They considered all random defective items produced as scrap items and a multi-shipment policy was used to synchronously deliver finished items to multiple retailers in order to satisfy customer demands. An optimal production lot-size and shipment policy that minimized the expected system costs was derived with the help of a mathematical model. Additional studies that related to various aspects of supply-chain issues can also be found among other articles (for example, Acosta-Cano and Sastrón-Báguena, 2013; Chiu et al., 2013c, d; Gayon et al., 2009; Glock, 2012; Hill, 1995; Lee et al., 2011; Lin and Chiu, 2012; Lin et al., 2013; Pal et al., 2012; Sana, 2012; Thomas and Hackman, 2003; Viswanathan, 1998).

2. Problem description, modeling, and system cost analysis

Management of the contemporary corporations that operate in highly competitive global markets constantly seeks to cut down various operating costs, such as inventory holding costs in their production units and affiliated retailers. For the purpose of reducing stock holding cost, this paper combines an improved multi-delivery policy into a single-producer multi-retailer integrated inventory system in Chiu et al.'s (2013a) study.

We adopt the same notations as those used in the mathematical modeling and formulation of Chiu et al.'s (2013a) study in order to ease readability. Consider a product can be made at an annual production rate P by a single production unit, the manufacturing cost is C per item, and all items produced are screened. An x portion of defective items may be randomly produced at a rate d during the production process. All defective items are considered to be scrap items and must be discarded at a unit disposal cost C_S. To prevent shortages the production rate P must satisfy $(P - d - \lambda) > 0$, where λ is the sum of the demands of all m retailers (i.e., the sum of λ_i where $i = 1, 2, \ldots, m$), and d can be expressed as $d = Px$. Cost parameters used in cost analysis include the following: set-up cost per production cycle K; unit holding cost h for item retained by the production unit; fixed delivery cost K_{1i} per shipment delivered to retailer location i; unit holding cost h_{2i} for items retained by retailer i; and unit shipping cost C_{Ti} for items shipped to retailer location i.

T production cycle length,

Q production lot size per cycle — decision variable,

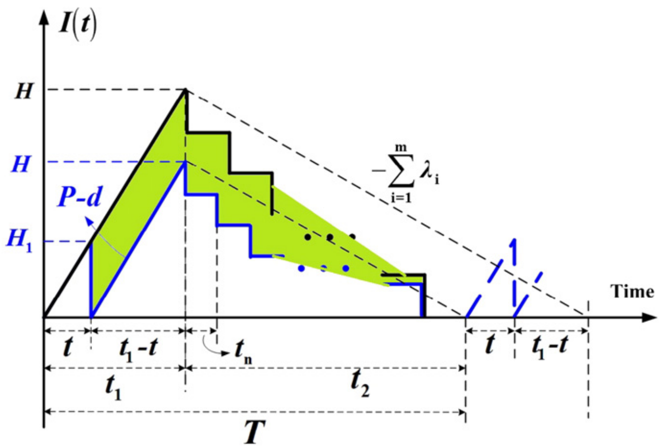

Fig. 1. Expected reduction in the production unit's holding costs (in green shaded area) of the proposed model (in blue) in comparison with that of Chiu et al.'s (2013a) model (in black).

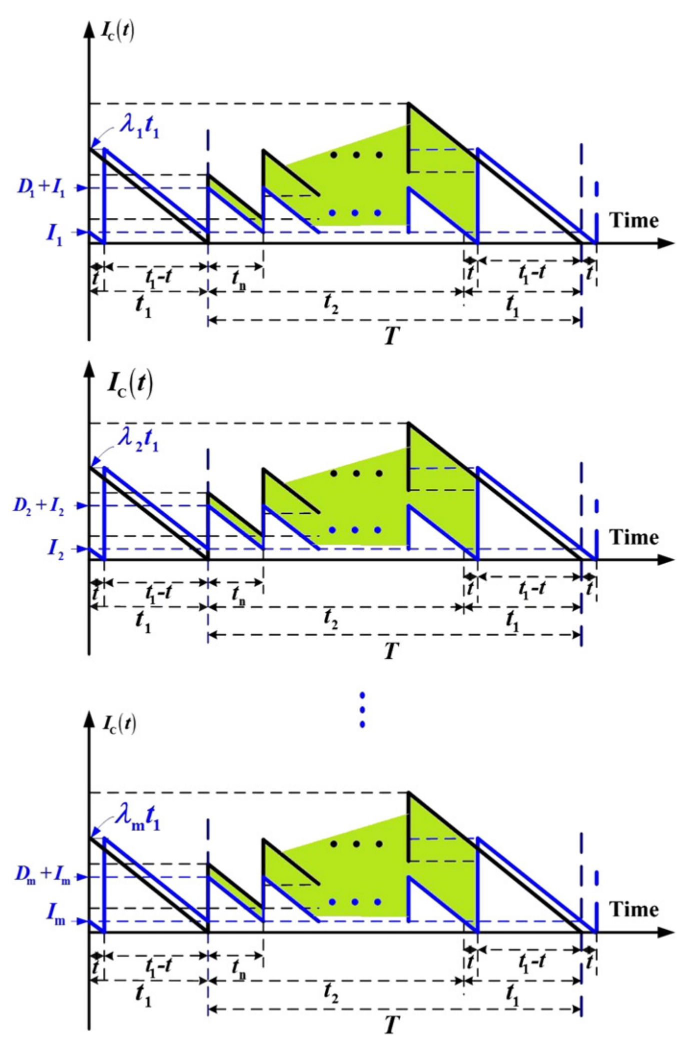

Fig. 2. Expected reduction in retailers' inventory holding costs (in green shaded area) of the proposed model (in blue) in comparison with that of Chiu et al.'s (2013a) model (in black).

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