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Solving a vendor–buyer integrated problem with rework and a specific multi-delivery policy by a two-phase algebraic approach

Chao-Tang Tseng [a], Mei-Fang Wu [b], Hong-Dar Lin [a], Yuan-Shyi Peter Chiu [a,*]

[a] Department of Industrial Engineering and Management, Chaoyang University of Technology, Taichung 413, Taiwan
[b] Department of Industrial Engineering & Systems Management, Feng Chia University, Taichung, Taiwan

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ABSTRACT

This paper is concerned with solving a vendor–buyer integrated inventory problem with rework and a specific multi-delivery policy by a two-phase algebraic approach. Conventional method to the problem is to use differential calculus and Hessian matrix equations to prove convexity of system cost function first before determining the optimal production–shipment policy for such a vendor–buyer integrated system (Chiu et al., 2013b). This study presents an alternative two-phase algebraic approach to derive the same optimal policy. The proposed straightforward algebraic derivations can assist practitioners who may not have sufficient knowledge of calculus in understanding with ease such a real life vendor–buyer integrated system.

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1. Introduction

Two fundamental questions to be often answered in most inventory replenishment systems are 'when to order?' and 'how many to order?' (Hadley and Whitin, 1963; Hillier and Lieberman, 2001) When the product demand is deterministic, the replenishment lot size becomes the only question that needs to be answered (Nahmias, 2009). In real life production environments, dealing with random nonconforming items produced during the production cycle, seems to be an inevitable and challenging task for production planner and controller. Shih (1980) studied two extensions of inventory models to the case where the proportion of defective units in the accepted lot is a random variable with known probability distributions. Optimal solutions to the modified system were developed and comparisons with the traditional models were also presented via numerical examples. de Kok (1985) considered a lost-sales production/inventory control model with two adjustable production rates to meet demand. He obtained the practical approximations for optimal switch-over levels to such a model under the service level constraints. Studies that focused on different aspects of imperfect production systems and quality assurance issues have been extensively conducted during past years (see for example: Alghalith, 2013; Chiu et al., 2012; Chiu et al., 2013a; Makis, 1998; Roy et al., 2012; Teunter and Flapper, 2003; Wee et al., 2007).

In vendor–buyer supplier chains environments, multiple or periodic deliveries of finished products are often adopted in lieu of the continuous issuing policy as assumed by classic economic production quantity – EPQ model (Nahmias, 2009). Schwarz (1973) considered a problem of one-warehouse N-retailer inventory system. The objective was to determine the optimal stocking policy that minimizes system cost. He derived some necessary properties for the optimal policy as well as the optimal solutions. Heuristic solutions were also provided for the general problem and tested against analytical lower bounds. Sarker and Parija (1994) studied a manufacturing system which procures raw materials from suppliers and processes them to convert to finished products. They proposed a model that was used to determine an optimal ordering policy for procurement of raw materials, and the manufacturing batch size to minimize the total cost for meeting equal shipments of the finished products, at fixed intervals, to the buyers. Hoque (2008) considered models of delivering a single product to multiple buyers when the setup and inventory costs to the vendor are included. Optimal solution techniques are presented, a sensitivity analysis of the techniques is carried out, and several numerical problems are solved to support the analytical findings. He also highlights the limitation of methods used in obtaining the least minimal total

* Corresponding author. Tel.: +886 4 23323000x4252.
E-mail address: ypchiu@cyut.edu.tw (Y.-S.P. Chiu).

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cost in the single-vendor single-buyer scenario, and the benefit of an integrated inventory is also discussed. Chiu et al. (2013b) used mathematical modeling and differential calculus along with Hessian matrix equations (Rardin, 1998) to determine the optimal production lot size and optimal number of deliveries for a vendor–buyer integrated system with rework and an amending multi-delivery schedule. Many studies have also been carried out to address different aspects of supply chains optimization (see also see for example: Goyal, 1977; Hahm and Yano, 1992; Sana, 2012; Sarmah et al., 2006; Schwarz et al., 1985; Viswanathan, 1998).

Algebraic method for determining the economic order quantity model with backlogging was presented by Grubbström and Erdem (1999). They proposed algebraic derivations to find the optimal order quantity without reference to the first- or second-order derivatives. Similar approaches have been applied to various EPQ-based problems and different supply chains systems (Chen et al., 2012; Lin et al., 2008; Wu and Ouyang, 2003). This paper extends such an algebraic approach to reexamine a specific vendor–buyer integrated system (Chiu et al. (2013b)) and demonstrate that the optimal policy for the system can be derived without derivatives.

2. Problem description, modeling and analysis

This study uses a two-phase algebraic approach to solve a vendor–buyer integrated system with rework and a specific multi-delivery policy as examined by Chiu et al. (2013b). To ease the readability, in problem description and modeling section of this study, we use the same notation as in Chiu et al. (2013b). Consider that a production process may randomly produce an x portion of nonconforming items at a production rate d. Among the defective items a θ portion is assumed to be scrap and the other $(1\text{-}\theta)$ portion can be repaired at a reworking rate P_1 in the same cycle right after the end of regular production process. Under a specific $n + 1$ delivery policy, the first installment of finished products is transported to customer to satisfy demand during uptime t_1 and rework time t_2 (see Figs. 1 and 2). At the end of rework, fixed quantity n installments of the rest of the finished lot are delivered to customer at a fixed interval of time during the delivering time t_3.

Fig. 1 illustrates the vendor's on-hand inventory level of perfect quality items for the proposed vendor–buyer integrated system with rework and a specific $n + 1$ multi-delivery. Fig. 2 depicts the stock level at buyer's side for the proposed system.

Under the operating policy of no shortage permitted, we further assume that the constant production rate P is larger than the sum of demand rate λ and production rate d. Thus, $(P\text{–}d\text{–}\lambda) > 0$; where $d = Px$. Notations used for system cost parameters include: production setup cost K per cycle, unit production cost C, unit inventory holding cost per year h, unit rework cost C_R, unit holding cost per reworked item h_1, disposal cost per scrap item C_S, the fixed delivery cost K_1 per shipment, and unit delivery cost C_T.

Additional parameters used in the present study include:

Q production lot size per cycle – a decision variable,
n number of fixed quantity installments of the remaining finished items to be delivered to customers during t_3 – the other decision variable,
T cycle length,
H the level of on-hand inventory for satisfying product demand during vendor's uptime t_1 and rework time t_2,
H_1 maximum level of on-hand inventory in units when regular production ends,
H_2 the maximum level of on-hand inventory in units when rework process finishes,
t_n a fixed interval of time between each installment of products delivered during t_3,
t the production time needed for producing enough perfect items to satisfy customer's demand during t_1 and t_2,
t_1 the production uptime,
t_2 rework time,
t_3 production downtime, (time to deliver the remaining quality assured finished products),
I demand during production time t, i.e. $I = \lambda t$,
D demand during time between deliveries t_n, i.e. $D = \lambda t_n$,
$I(t)$ the level of on-hand inventory of perfect quality items at time t,
$I_c(t)$ the level of buyer's on-hand inventory at time t,
$TC(Q, n)$ total production–inventory–delivery costs per cycle for the proposed model,
$E[TCU(Q, n)]$ the long-run average costs per unit time for the proposed model.

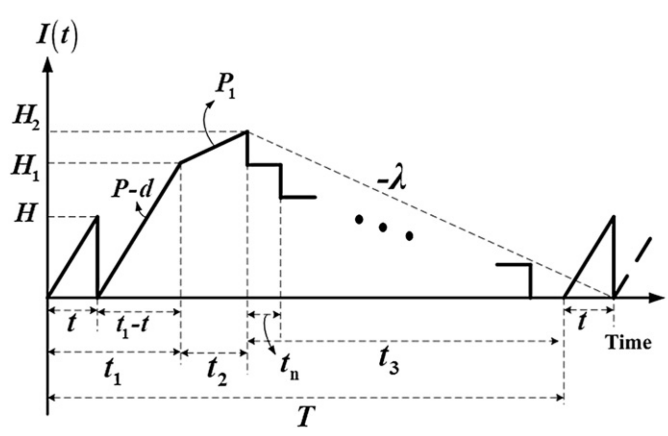

Fig. 1. The vendor's on-hand inventory of perfect quality items for the proposed vendor–buyer integrated system with rework and a specific $n + 1$ multi-delivery policy (Chiu et al., 2013b).

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