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Intra-supply chain system with multiple sales locations and quality assurance

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ABSTRACT

The emergence of the global economy has transformed the interdepartmental nature of a transnational enterprise into a highly collaborative oriented team. This transformation enables the enterprise to lower its transaction and coordination costs and increase its competitive advantage in the global market. This study investigates such a so-called intra-supply chain system that exists in present-day transnational firms, wherein a single production unit manufactures products to meet the demands of multiple regional sales offices and incorporates quality assurance in its production. The objective of the present study is to determine an optimal production quantity and shipment policy that minimizes the integrated production–inventory–delivery costs for the intra-supply chain system. In this study, considerations related to a product's quality assurance include inspection for quality, rework of defective items and failure in rework. Delivery of the finished products starts when quality of the entire production lot is assured. Multi-shipment policy is used to synchronously transport finished items to multiple locations for satisfying customer demands in each cycle. Mathematical modeling along with Hessian matrix equations is employed to solve the proposed intra-supply chain system. A numerical example with a discussion and cost-benefit analysis of outsourcing work to an external distributor is presented to demonstrate the practical applicability of the obtained results.

1. Introduction

Intra-supply chain system exists in the present-day transnational firms, wherein a single production unit manufactures products to meet the demands of multiple regional sales offices. In such a supply chain system, management would delight in figuring out the best production- shipment policy in order to minimize the long-run expected system costs. 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. Schwarz, Deuermeyer, and Badinelli (1985) studied the fill-rate of a one-warehouse *N*-identical retailer distribution system. An approximation model was adopted from a prior study to maximize system fill-rate subject to a constraint on system safety stock. As results, properties of fill-rate policy were suggested to provide management when looking into system optimization. Hahm and Yano (1992) studied the frequencies of production and delivery of a single component with the objective of minimizing the long-run average cost per unit time. Costs considered in their study included production setup costs, inventory holding costs at both the supplier and the customer, and transportation costs. They assumed that the ratio between the production interval and delivery interval is an integer and derived an optimal solution accordingly. They used the obtained results to characterize situations in which it is optimal to have synchronized production and delivery, and discussed the ramifications of these conditions on strategies for setup cost and setup time reductions. Banerjee and Burton (1994) used series of simulation experiments to show that classical lot sizing models do not adequately describe a situation where a single vendor produces and supplies a product to multiple industrial customers, buying in discrete lots. They suggested a common replenishment cycle based, coordinated inventory control model and show that this approach is superior to independent optimization. Aderohunmu, Mobolurin, and Bryson (1995) showed that a co-operative batching policy based on cost information exchange between the vendor and the buyer, can significantly reduce total cost in the just-in-time (JIT) environment. The impact of such co-operation on total costs was examined which including: ordering, set-up, transportation and inventory holding costs for a long-term supply relationship. Their study showed that joint optimization of both the vendor and the buyer's operations do not necessarily result in a common lot size. Sensitivity of the resulting cost savings due to the exchange of cost information to changes in the relevant operating parameters was also analyzed. Lu (1995) examined a one-vendor multi-buyer integrated model with the objective of minimizing a vendor's total annual cost, subject to the maximum

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costs that buyers may be prepared to incur. The buyer's annual demand and previous frequency of order are assumed to be known information in this model. As a result, an optimal solution for the one-vendor one-buyer case was obtained; a heuristic approach for the one-vendor multi-buyer case was also provided. Hill (1996) considered a model in which a manufacturing company purchases a raw material, manufactures a product (at a finite rate) and ships a fixed quantity of the product to a single customer at fixed and regular intervals of time, as specified by the customers. The objective was to determine a purchasing and production schedule which minimizes the total cost of purchasing, manufacturing and stockholding. Parija and Sarker (1999) studied an ordering policy for raw materials as well as an economic batch size for finished products that are delivered to multiple customers, with a fixed-quantity at a fixed time-interval to each of the customers. In their model, an optimal multi-ordering policy for procurement of raw materials for a single manufacturing system is developed to minimize the total cost incurred due to raw materials and finished goods inventories. A closed-form solution to the problem was obtained for the minimal total cost and the algorithm was demonstrated for multiple customer systems. Viswanathan and Piplani (2001) proposed a model to study and analyze the benefit of coordinating supply chain inventories through the use of common replenishment epochs or time periods. A one-vendor, multi-buyer supply chain for a single product was analyzed. Under the proposed strategy, the vendor specifies common replenishment periods and requires all buyers to replenish only at those time periods. The vendor offers a price discount to entice the buyers to accept this strategy. They determined the optimal replenishment period and the price discount to be offered by the vendor. Khouja (2003) formulated a three-stage supply chain model where a firm can supply many customers. He dealt with three inventory coordination mechanisms between chain members and solved a cost minimization model for each. He also provided some insights into when the added complexity of the second and third coordination mechanisms lead to significant cost reductions. Hoque (2008) examined models of delivering a single product to multiple buyers when the set-up and inventory costs to the vendor are included. His models assume a close relationship between a manufacturer and buyers for a costless way of benefit sharing. Three models were developed, two of which transferred with equal batches (part of a lot) and the third one with unequal batches of the product. 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. Additional studies addressing different aspects of supply chain issues have also been extensively carried out (Chen, Wu, Chiu, & Lee, 2012; Chiu, Liu, Chiu, & Chang, 2011a, Chiu, Lin, & Chang, 2012a, Chiu, Chiu, & Yang, 2012b; Lee, Chiu, & Chang, 2011; Taleizadeh, Niaki, & Makui, 2012).

Incorporation of quality assurance in the production unit is a common but critical operations strategy for maintaining company's reputation in terms of its product quality. In real world manufacturing environment, due to different unpredictable factors it is inevitable to have random defective items produced. Therefore, many studies have been conducted during past decades to address different aspects of imperfect production systems with quality assurance issues (Barlow & Proschan, 1965; Chiu, Lin, Wu, & Yang, 2011b, 2012c, 2012d; Giri & Dohi, 2005; Lin & Chiu, 2012; Rosenblatt & Lee, 1986; Silver, Pyke, & Peterson, 1998). This study investigates an intra-supply chain system with quality assurance in its production. The objective of the present study is to determine an optimal production quantity and shipment policy that minimizes the integrated production–inventory–delivery costs for the proposed system. Because little attention has been paid to this area, this paper is intended to bridge the gap.

2. Modeling and formulation

This study investigates such a so-called intra-supply chain system that exists in present-day transnational firms, wherein a single production unit manufactures products to meet the demands of multiple regional sales offices (see Fig. 1). Our objective is to determine an optimal production quantity and shipment policy that minimizes production–inventory–delivery costs for the intra-supply chain system.

Consider a product can be manufactured at an annual rate P by a single production unit and an x portion of nonconforming items may randomly be produced at a rate d during the production process. All items made are screened and inspection cost is included in the unit manufacturing cost C. All defective items are reworked right after the regular production ends in each cycle at a rate of P_1 and there exists a failure-in-rework rate θ_1. Under the normal operation assumption, to avoid shortages from occurring the constant production rate P must satisfies $(P - d - \lambda) > 0$, where λ is annual demands of all customers (i.e. the sum of individual demand rate λ_i), and d can be expressed as $d = Px$. Delivery of the finished products starts when quality of the entire production lot is assured. Multi-shipment policy is used to synchronously transport finished items to multiple locations for satisfying customer demands during the production downtime t_3 in each cycle (refer to Fig. 2).

In addition, the proposed model includes the following cost parameters in its cost analysis: unit holding cost h, set up cost per production cycle K, unit cost C_R and unit holding cost h_1 for each reworked item, unit disposal cost C_S for failures in rework, the fixed delivery cost K_{1i} per shipment delivered to regional sales office i, unit holding cost h_{2i} for item kept by sales office i, and unit shipping cost C_{Ti} for item shipped to sales office i. Additional notation used in this study includes.

Q	production lot size per cycle, the decision variable
n	number of fixed quantity installments of the finished batch to be delivered to sales offices in each cycle, another decision variable
T	production cycle length
t_1	the production uptime
H_1	level of on-hand inventory in units when regular production process ends
t_2	time required for rework of nonconforming items in each cycle
H	maximum level of on-hand inventory in units when the rework process ends
t_3	time required for delivering all quality assured products to sales offices
t_n	a fixed interval of time between each installment of finished products delivered during t_3
m	number of sales offices
$I(t)$	production unit's on-hand inventory level of perfect quality items at time t
$I_d(t)$	production unit's on-hand inventory level of nonconforming items at time t
$I_c(t)$	regional sales offices' 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 expected total production–inventory–delivery costs per unit time for the proposed model

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