Decision Support Systems 50 (2011) 539–547

Contents lists available at ScienceDirect

Decision Support Systems

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

A production-inventory model of imperfect quality products in a three-layer supply chain

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ARTICLE INFO

Article history:
Received 4 November 2010
Accepted 6 November 2010
Available online 11 November 2010

AMS mathematics subject classification:
90B05

Keywords:
Inventory
Supply chain
Imperfect
Production

ABSTRACT

In this paper an integrated production-inventory model is presented for supplier, manufacturer and retailer supply chain, considering perfect and imperfect quality items. This model considers the impact of business strategies such as optimal order size of raw materials, production rate and unit production cost, and idle times in different sectors on collaborating marketing system. The model can be used in industries like textile and footwear, chemical, food, etc. An analytical method is employed to optimize the production rate and raw material order size for maximum expected average profit. An example is illustrated to study the behavior and application of the model.

1. Introduction

Researchers as well as practitioners in manufacturing industries have given importance to develop inventory control problems in supply chain management. Specifically, the competitive framework stipulates that firms tend to emphasize certain competitive dimensions and develop manufacturing capabilities to achieve the chosen dimensions to enhance their market position. The competitive dimensions are cost, quality, delivery and flexibility. These dimensions relate to production process and control, technology, capacity, facilities, workforce, planning, etc. This research assesses the impact of product rate, production run time, idle time of the systems, inventory level and order fill rates. Order fill rate is defined as order filled complete as a fraction of the total number of orders. In traditional economic order quantity (EOQ) and economic production quantity (EPQ) model, all items are perfect. It is common to all industries that a certain percent of produced/ordered items are non-conforming (imperfect) quality. Among other researchers, Salameh and Jaber [31] developed an inventory model which accounted for imperfect quality items using the EPQ/EOQ formulae. They assumed defective items are sold as a single batch at the end of the total screening process. Cardenas-Barron [4] made a correction of the formula in Salameh and Jaber's [31] model and showed that the error only effects the optimum value of the order size. Goyal and Cardenas-Barron [15] extended Salameh and Jaber's [31] model and proposed a practical approach to determine EPQ for items with imperfect quality. Goyal et al. [17] investigated the model of Goyal and Cardenas-Barron [15], considering vendor–buyer integration. Chung and Hou [12] developed a model to obtain an optimal run time for a deteriorating production system with shortages. Yu et al. [45] generalized the models of Salameh and Jaber [31], considering deterioration and partial backordering. They showed in their study that the influence of imperfect quality, deterioration and partially backordering were significant in the supplier selection.

Zang and Gerchak [46] considered a joint lot sizing and inspection policy with a random proportion of defective units where the defective units were replaced by non-defective ones. Liu and Yang [26] investigated a single stage production system with imperfect process delivering two types of defects: reworkable and non-reworkable items. The reworkable items are sent for reworking, whereas non-reworkable items are immediately discarded from the system. They determined the optimal lot size that maximized the expected total profit over the expected time length of the production cycle. Konstantaras et al. [25] developed a production-inventory model for defective items: sell them to a secondary shop as a single batch and at a price lower to that of new ones, or rework them at some cost to restore its original quality. Huang [21] studied the model of Salameh and Jaber [31] in an integrated production and shipping context; while Wee et al. [40] and Eroglu and Ozdemir [13] extended it independently, allowing shortages. Maddah and Jaber [28] analyzed the effect of screening speed and variability of the supply process on the order quantity, and showed the order quantity in their model was larger than that of the classical EOQ (economic order quantity) model when the variability of the yield rate was reasonable low. Cardenas-Barron [6] presented a simple derivation to find out optimal manufacturing batch size with rework process at single stage

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0167-9236/$ – see front matter
doi:10.1016/j.dss.2010.11.012

production system. Cardenas-Barron [7] developed an EPQ model with planned backorders for determining the production lot size and the size of backorders in an imperfect production process where all defective items were reworked at the same cycle. In practical production environments, the imperfect quality items could be reworked and repaired (Sana and Chaudhuri [34]; Sana [32,33]; Sarkar et al. [35]); hence, overall production-inventory costs can be reduced significantly (Hayek and Salameh [18]; Chiu [9]; Chiu et al. [10,11]).

Generally speaking, a good management is trying to align and coordinate the business process and activities of the channel members to improve the overall performance and effectiveness of supply chain. All steps from supply of raw materials to finished products can be included into a supply chain, connecting raw materials supplier, manufacturer, retailer and finally customers. Supply chain coordination depends on the development and implementation of various strategies to ensure better supply chain performance in terms of cost, timely supply, quantity discount, buyback/return policies, quantity flexibility, commitment of purchase quantity, fill rate order size, etc. Weng [41] considered both all unit and incremental quantity discount policy under price sensitive demand. He showed the benefit for the buyer and supplier by maximizing the supplier's profit and the joint profit respectively. Lu [27] obtained a heuristic solution for the single vendor multiple buyer problem. Goyal [14] incorporated a policy where size of successive shipments from manufacturer to customer within a production cycle increased by a factor equal to the ratio of production rate and the demand rate. Goyal and Gunasekaran [16] developed an integrated production-inventory-marketing model for determining the EPQ (economic production quantity) and EOQ for raw materials in a multi-stage production system. This model considered the effect of different marketing policies such as the price per unit product and the advertisement frequency on the demand of a perishable item. Aderohunmu et al. [1] achieved cost savings of both the vendor and buyer when they followed a cooperative batching policy and shared cost information along with other information in time. Banerjee and Kim [2] developed an integrated inventory model of the buyer, manufacturer and the raw materials supplier in a JIT (Just-in-Time) environment. Thomas and Grifin [36] observed that efficient supply chain management requires planning and coordination among the various channel members including manufacturers, retailers and intermediaries if any. Hill [19] discussed a generalized policy for finding the value of the factor by which to increase the shipment sizes. According to Narasimhan and Carter [30], a well-integrated supply chain involves coordinating the flows of materials and information between suppliers, manufacturers and customers. Hill [20] derived a global optimal batching and shipment policy for single vendor and single buyer integrated problem, combining increasing shipment size policy of Goyal [14] and an equal shipment size policy. Munson and Rosenblatt [29] extended two level supply chain to a three level supply chain, considering a supplier, a manufacturer and a retailer where manufacturer was a dominant member in the channel. Yang and Wee [43] developed a three-stage supply chain model, integrating producer, distributor and retailer. They showed that integrated approach results in a significant cost reduction compared to the independent decision making by each individual entity of the chain. Woo et al. [42] derived an optimal investment and replenishment decisions for both vendor and buyer by reducing joint ordering cost. Boyaci and Gallego [3] focused on inventory and pricing policies that maximized the profit of the channel consisting of one wholesaler and one or more retailers under deterministic price sensitive customer demand. Khouja [24] assumed three coordination mechanisms between the members of the supply chain and showed that some coordination mechanisms lead to significant reduction in total cost. Cardenas-Barron [5] extended the model of Khouja [24] by algebraic method, considering n-stage multi-customer supply chain inventory system. Viswanathan and Wang [38] investigated single vendor–buyer distribution channel coordination, incorporating quantity discount and volume discount. It is common to all enterprises that inventory reductions and cost savings can be reached by implementing collaborative initiatives such as vendor managed inventory (VMI), continuous replenishment, and just-in-time purchasing that allow for information sharing and integration among the enterprises in the supply chain. In this direction, Yao et al. [44] developed an analytical model that helps to provide a better understanding of how important supply chain parameters, namely ordering costs and carrying charges, affect the inventory cost savings. van der Vlist et al. [37] extended the model of Yao et al. [44] with the delivery costs. This extended model is referred to as Yao $^{+}$. In the model of Chaharsooghi et al. [8], the supply chain ordering management (SCOM) problem has been addressed. They proposed first an agent-based supply chain ordering management in which agents manage ordering system of decentralized supply chain, in an integrated manner. In the next, they modeled SCOM as a reinforcement learning problem. They showed also that their proposed model is efficient and can find good policies under complex scenarios where analytical solutions are not available. The note of Wang et al. [39] investigated a paper by Yao et al. [44] and a critique by van der Vlist et al. [37]. According to them, their conclusions about the buyer's order sizes seem to conflict with each other. Their paper summarized the factors that must be stated clearly to resolve the conflict and to avoid the confusion. Huang and Ye [22] resolved the disagreement between Yao et al. [44] and van der Vlist et al. [37] without extra assumptions and special cases. They provided also an intuitive view of the cost functions so that most optimal quantities could be derived from the properties of the EOQ model. Jalbar et al. [23] investigated a multi-echelon inventory system in which one vendor supplies an item to multiple buyers. They formulated the problem in terms of integer-ratio policies and developed a heuristic procedure also.

The proposed model considers a three-layer supply chain involving supplier, manufacturer and retailer who are responsible for performing the raw materials into finished product and make them available to satisfy customers' demand in time. Inventory and production decisions are made at the supplier, manufacturer and retailer levels. The problem is to coordinate production and inventory decisions across the supply chain so that the total expected profit of the chain is maximized.

The rest of the paper is organized as follows: Section 2 provides fundamental assumptions and notation. Section 3 describes the formulation of the model. Numerical examples are illustrated in Section 4. Section 5 concludes the paper. A list of references is also provided.

2. Fundamental assumptions and notation

The following assumptions and notation are considered to develop the model:

Assumptions:

1. Model is developed for single item products.
2. Lead time is negligible.
3. Demand rate is constant.
4. Replenishment rate of manufacturer is instantaneously infinite but it's size is finite.
5. Production rate is a decision variable.
6. Unit production cost is a function of production rate.
7. Joint effect of supplier, manufacturer and retailer is considered in a supply chain management.
8. Defective items at supplier and manufacturer are considered which follow different probability distribution functions.
9. Cost of Idle times at supplier and manufacturer are also assumed.

Notation:

R Replenishment lot size of supplier.

P Production rate of manufacturer that is equal to the demand rate at supplier, i.e., replenishment rate of manufacturer.