Applied Mathematics and Computation 229 (2014) 139–150

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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

# A three layer supply chain model with multiple suppliers, manufacturers and retailers for multiple items

Shib Sankar Sana [a,*], Jaime Acevedo Chedid [b], Katherinne Salas Navarro [c]

[a] Department of Mathematics, Bhangar Mahavidyalaya, Bhangar, 743502 South 24 Parganas, India
[b] Department of Industrial Engineering, Universidad Tecnológica de Bolivar, Cartagena, Colombia
[c] Department of Industrial Engineering, Universidad de la Costa, Barranquilla, Colombia

ARTICLE INFO

*Keywords:*
Inventory
Defective
Supply chain

ABSTRACT

The replenishment size/production lot size problem both for perfect and imperfect quality products studied in this paper is motivated by the optimal strategy in a three layer supply chain consisting of multiple suppliers, manufacturers and retailers. In this model, each manufacturer produces each product with a combination of several raw materials which are supplied by each supplier. The defective products at suppliers and manufacturers are sent back to the respective upstream members at lower price than the respective purchasing price. Finally, the expected average profits of suppliers, manufacturers and retailers are formulated by trading off set up costs, purchasing costs, screening costs, production costs, inventory costs and selling prices. The objective of this chain is to compare between the collaborating system and Stakelberg game structure so that the expected average profit of the chain is maximized. In a numerical illustration, the optimal solution of the collaborating system shows a better optimal solution than the approach by Stakelberg.



## 1. Introduction

The industrial engineers and practitioners have accepted the application of just-in-time (JIT) philosophy in manufacturing systems because it improves product quality and productivity through minimize waste from all operations. They suggested that frequent shipment of purchased raw materials and manufacturing small lots could eliminate waste. Quite often, small lots generate higher productivity through high quality of the products, lower levels of inventory and scrap. The classical economic order quantity/production quantity models are developed for perfect quality items only. In practice, all items are not perfect quality. Inspection/screening process is the method that is used to separate the acceptable/perfect quality of the products from whole lot. At the end of screening process, the imperfect/defective items are sold at a lower price or reworked at cost or returned to the suppliers who are charged the transportation and handling cost or disposal cost. Several researchers have enlightened on this field. Among them, some noteworthy research articles are mentioned as follows. Zhang and Gerchak [31] investigated an EOQ (Economic Order Quantity) model for joint lot sizing and inspection policy with random proportion of defective items. They obtained an optimal order quantity and inspection fraction by considering the case where the defective units could not be used and thus might be replaced by non-defective ones. Liu and Yang [19] developed a single stage production system in which two types of defective items, rework able defects and non-rework able defects, are produced. They found an optimal lot size by maximizing the expected profit over the expected production cycle length. Salameh and Jaber [21] studied an EOQ/EPQ model for imperfect quality products assuming 100% inspection policy. In this

* Corresponding author.
*E-mail addresses:* shib_sankar@yahoo.com (S.S. Sana), jacevedo@unitecnologica.edu.co (J.A. Chedid), ksalas2@cuc.edu.co (K.S. Navarro).

0096-3003/$ - see front matter 
http://dx.doi.org/10.1016/j.amc.2013.12.006

model, the defective items are sold, as a single batch, to the secondary shop at the end of screening process. Cárdenas-Barrón [1] drew an observation on economic production quantity model both for imperfect and perfect quality products. Goyal and Cárdenas-Barrón [15] found a simple approach to evaluate the EOQ while a random proportion of the whole products were defective. Chan et al. [12] generalized the model of Salameh and Jaber [21], assuming that the defective items could be reworked instantly, could be rejected at a cost or sold at a lower price. Chiu [13] determined an optimal lot size and backlogging for an imperfect production system where random defective items were reworked at a cost. Jamal et al. [16] developed an inventory model dealt with optimum batch size in which rework was done by assuming two different operational policies to minimize the total system costs. The first policy considered that the defective products were reworked within the same production cycle, whereas the defective products were reworked after $N$-cycle, in the 2nd policy. Papachristos and Konstantaras [20] revisited and extended the papers of Salameh and Jaber [21] and Chan et al. [12] considering the timing of withdrawing the imperfect quality items from stock. Konstantaras et al. [17] proposed a joint lot sizing inventory model for imperfect quality products. In their model, two options of the defective products are proposed: one is to sell them at a price lower than the unit purchasing price, second is to rework them to acceptable quality. Cárdenas-Barrón [2] corrected the solutions of two numerical examples present by Jamal et al. [16]. Cardenas-Barron [4] corrected the solutions of the model of Jamal et al. [16] where main idea and contribution of the pare were not affected. Cardenas-Barron [5] proposed the EPQ (economic production quantity) model with planned backorders for determining the production lot size and backorder size in an imperfect production system while all defective items were reworked in the same cycle. Sarkar [23] investigated an economic manufacturing quantity (EMQ) model for price and advertising sensitive demand in an imperfect production process under the effect of inflation. Konstantaras et al. [18] studied an economic quantity model with shortages for conforming and non-conforming quality products in the light of learning opportunities in logistics and inventory systems. Sarkar and Sarkar [24] proposed an economic manufacturing quantity model for exponential demand with deterioration in a production system over a finite time horizon under the effect of inflation and time value of money.

In recent years, many industries have been involved in various forms of supply chain collaboration in order to survive increasing competition in oligopoly marketing environment. It has been observed that a company can increase its market share by collaborating with other partners of the channel. All steps, from supply raw materials to finished product and end customers, are included into a supply chain. Supply chain coordination ensures better supply chain performance in terms of cost, quantity discount, timely supply, buyback/return policies, quantity flexibility, ordering size and commitment of purchase quantity, etc. Goyal and Gunasekharan [14] discussed a multi-stage production system in order to determine the optimal EPQ (economic production quantity) and EOQ (economic order quantity) for raw materials considering the effect of different marketing policies. Wang and Gerchak [30] developed a collaborating system of two-echelon channel with an initial stock dependent demand. They assumed the case of single manufacturer who offers a product to a retailer at the whole sale price. Zhou et al. [32] investigated the coordination issues of decentralization of two-echelon supply chain, involving stock-dependent demand of the retailer. Sana [22] proposed three layer supply chain involving single supplier, single manufacturer and single retailer who are responsible to satisfy the end customers' demand. Cárdenas-Barrón et al. [10], Cárdenas-Barrón et al. [11] studied an economic manufacturing quantity (EMQ) model with rework and multiple shipments to derive the optimal replenishment lot size and optimal number of shipments jointly. Recently, several researchers [3,6–9,27–29] have enlightened the enormous efforts of supply chain mechanism in order to optimize profit/cost of the supply chain from different perspectives.

In the proposed model, the authors extend a three layer supply chain model for multiple products, consisting of multiple suppliers, multiple manufacturers and multiple retailers as channel members. Each product is manufactured by combination of several raw materials which are delivered by each supplier to each manufacturer. Each manufacturer produces all types of products. Each retailer satisfies the demand of all type of products which are received from each manufacturer at a percent of their requirements. Finally, average profits of all members of the chain are formulated by considering the selling prices, set up costs at different stages, inventory costs, screening costs in order to find out optimal order/production quantity. The centralized and decentralized (Stakelberg approach) are discussed analytically as well as numerically.

The rest of the article is organized as follows. Fundamental assumptions and notations are adopted in Section 2. Section 3 formulates the proposed model. Numerical example is illustrated in Section 4. Section 5 concludes the achievements of the article.

## 2. Fundamental assumptions and notations

The following assumptions and notations are used to develop the model.

### 2.1. Assumptions

The following assumptions for suppliers, manufacturers and retailers are considered to analyze the model:

#### 2.1.1. At supplier

s.1: There are multiple suppliers ($s$).