



An operational policy for a three-stage distributive supply chain system with retailers' backorders



Bhaba R. Sarker^{a,*}, Ratkrit Rochanaluk^a, Huizhi Yi^a, Pius J. Egbelu^{b,1}

^a Department of Mechanical and Industrial Engineering, Louisiana State University, Baton Rouge, LA 70803, USA

^b School of Management, New Jersey Institute of Technology University Heights, 3000 CAB Newark, NJ 07102-1982, USA

ARTICLE INFO

Article history:

Received 12 April 2013

Accepted 18 June 2014

Available online 14 July 2014

Keywords:

Inventory

Backorder

Single-producer

Multi-distributor

Multi-retailer

Supply chain system

Meta-heuristic algorithms

Distribution

ABSTRACT

This research deals with a production-inventory problem consisting of three-stage tree-type single-producer multi-distributor and multi-retailer supply chain network where a model has been developed for achieving the lowest total cost for operating a supply chain system with allowable shortage. In this research, the shortage is assumed to occur in a form of backorder. The refrigerator manufacturing can suitably be used to illustrate the scenario which makes the situation more rational and realistic. By assumptions, the customers will not go somewhere else, the cost of lost sale is not included in this case. The total cost of this tree-type distributive supply chain system is comprised of setup costs and holding costs at all echelons, and the backorder cost at retailer level only. A replenishment policy is sought to operate the system at a minimum cost. The problem is formulated as an unconstrained mixed-integer programming problem and a newly developed doubly hybrid meta-heuristic algorithm is adopted as the solution procedure. The solutions which determine the desired replenishment policy for the producer, distributors, and retailers are obtained to minimize the total system cost. A sensitivity analysis is performed to evaluate the outcome of the proposed solution procedure presented in this research. Numerical results are generated to demonstrate the solution procedure, and future research is indicated for further study.

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1. Introduction

A supply chain system deals with the processes of transforming products from raw material to finished goods and transferring them to the end customers. The complexity of supply chain systems vary depending on several factors. It can be as simple as involving only a few parties, or as complex as involving many processes, parts, and several parties.

The supply chain and inventory system of the refrigerator manufacturing company is an excellent fit for the scenario presented in this paper. The manufacturer of a refrigerator model produces and distributes it to the distributors, which in turn supplies them to the company dealerships. There are inventories of refrigerators at all three levels, producer, distributors, and retailers. It is assumed that the holding costs per refrigerator per unit of time at retailers are higher than the holding costs at the producer and distributors levels and this can be explained by the fact that markups at each echelon could cause higher inventory

holding cost at lower echelons (downstream) where the facilities/warehouse cost is usually higher due to highly populated area and land prices. Furthermore, the end customers who have decided on which refrigerator model they want to buy are less likely to go to other dealers who sell refrigerators of other models if the refrigerators they want are not available at the time of their visits to the dealerships. The customers will wait for the desired refrigerators to become available and be shipped to the customers at the dealers' expenses. This paper aims at developing a solution methodology that will help a company determine replenishment policy to minimize the total system cost. Similar scenarios can be identified for many other industrial sectors.

Inventory helps companies deal with unexpected and fluctuating customers' demands. Inventory management, as part of supply chain management, determines the policies on how much inventory a company should carry and when orders should be made to satisfy the customers' demands at the lowest possible cost. Having too low an inventory level could lead to shortage, a situation that could result in a company's inability to satisfy customer's demands. Inventory shortages could lead to more expenses since additional processes would have to be activated to record of the shortage for satisfaction of the demands at later dates. In many cases, shortage would have a long term impact on the companies' sales since it could lead to the permanent loss of sales or customers. On the

* Corresponding author. Tel.: +1 225 578 5370; fax: +1 225 578 5109.

E-mail addresses: bsarker@lsu.edu (B.R. Sarker), r_ratkrit@yahoo.com (R. Rochanaluk), hyi1@lsu.edu (H. Yi), pegbelu@NJIT.edu (P.J. Egbelu).

¹ Tel.: +1 973 596 3314; fax: +1 973 596 3074.

contrary, too much inventory reduces the probability of a shortage to occur, but a company could probably end up with higher inventory holding cost which would lower the company's economic competitiveness.

Several researchers generated and developed models to deal with a single-vendor single-buyer inventory problem. Goyal (1977) is claimed to be the first to address an integrated inventory system in which he considered a single-vendor single-buyer model which determined an economic joint inventory policy for both vendor and buyer to share the benefit together. Most early research in integrated inventory problems focused on two-stage supply chains. Banerjee (1986) developed a model that dealt with the case where a vendor produced the products to fulfill an order placed by a customer on a lot-for-lot basis—a vendor delivers a complete lot of products which are produced in one batch. Goyal (1988) extended Banerjee (1986) by allowing the production lot to be shipped in many small shipments and the first shipment does not have to wait until the production of the vendor is complete. Goyal claims that the model provides a lower cost to the system. Lu (1995) developed an optimal solution to single-vendor multi-buyer problem for the case in which all shipment sizes are equal. Lu also allowed shipments to be made before a production batch is completed. With the same assumption by Lu that the shipment can be made before the whole lot is completed, Goyal (1995) presented the case that all shipment sizes are not identical. Hill (1999) and Wee and Yang (2002) developed algebraically the optimal policy of the integrated vendor–buyer inventory system without using differential calculus. Yang and Pan (2004) introduced the integrated inventory system in which the lead time is adjustable; meaning that the lead time can be shortened by paying an extra cost. They also claimed that the model is more profitable than Banerjee (1986) and Goyal (1988). Yang and Pan (2004) presented the integrated inventory model which includes quality issue in consideration. Sajadieh et al. (2010) present a joint economic lot-sizing model for a single-vendor single-buyer problem in which the demand has a positive relationship with the quantities at the buyer's display area. Several algorithms are developed to determine the replenishment policy in terms of three variables. Two-stage supply systems have been addressed and modeled by Kamal et al. (2011) and Ismail et al. (2011) to find order quantity and reorder points. A comprehensive and critical review on the vendor-buyer integrated inventory system under the consignment stocking policy has been addressed by Sarker (2014).

In real life situation, a supply chain network with just one vendor and one buyer does not exist at all times. To address this shortcoming, single-vendor multi-retailer supply chains with two or more stages have grown in recent times to provide research models that more closely capture real world practices. Khouja (2003) studied a supply chain network which has multiple firms at each stage and each firm can have multiple customers. Khouja identified the optimal cycle times under three coordination mechanisms; the equal cycle time mechanism, integer multipliers for the integer multipliers mechanism, and the integer powers of two multipliers mechanism. Wee and Yang (2004) revised an optimal solution (Goyal, 1988) and developed a heuristic procedure for a producer–distributors–retailers inventory system by using the principle of strategic partnership. Abdul-Jalbar et al. (2008) addressed an integrated inventory system problem consisting of a single vendor and two buyers in terms of integer-ratio policies and they developed a procedure for computing an optimal policy. They also developed a procedure to compute the optimal integer-ratio policy. Hoque (2011) proposed two single-vendor multi-buyer integrated models with synchronization and claimed to yield a lower cost comparing to existing models in the literature. Most recently, Hariga et al. (2014) argued that Hoque's

(2011) model are actually based on different treatments of the total ordering costs. As the result, Hoque's (2011) conclusion may be questionable. Distributive supply chain systems have recently been discussed and modeled by Guan and Zhao (2011), and Brijesh and Chandrasekharan (2011) while a closed loop supply system has been modeled by Shi et al. (2011) for multiple retailers. While other models are explained in more details in Rochanaluk (2011), Glock (2012a,b) reviewed most recently joint economic lot sizing problems and coordination of a production network with a single buyer.

It is a very common assumption in literature on just-in-time (JIT) manufacturing systems that suppliers or vendors to a JIT-operated manufacturer should be in the closer proximity, and the downstream replenishment at the distributor and the retailer's levels are assumed to be instantaneous, that is, the lead time is zero (negligible). For example, Toyota and many other companies that operate under JIT philosophy have the arrangement of JIT delivery of parts and components. A positive lead time for replenish is contradictory to JIT philosophy and that's why a closer proximity of the supplying companies is desired and required in such systems (see Schonberger, 1987; Dyer, 1994; Wafa et al., 1996; Monden, 1998; Hutchins, 1999, pp. 125–126). Despite this physical constraint to enhance the productivity of the enterprises, an uncertainty of the demand which no entities in the system can fully control plays a significant role in a supply chain system.

Despite one thing common to the research summarized above is that none allowed stockout to occur. Some researchers have investigated inventory problems in which shortages are allowed but still limited them to a single-vendor single-buyer case. Grubbstrom and Erdem (1999) extend their previous work on EOQ model by taking backlogging into consideration. They mentioned that their model algebraically explains an integrated model that is easy to understand by most practitioners. Cardenas-Barron (2001) extended Grubbstrom and Erdem (1999) model to obtain the EPQ (Economic Production Quantity) with allowable unit shortage cost per unit time. Wu and Ouyang (2003) extended Grubbström and Erdem's method to find an optimal replenishment policy which deals with the integrated single-vendor single-buyer inventory system with allowable shortage. The theoretical result in their research showed that the integrated total cost with shortage is lower than the one without shortage. Zhou and Wang (2007) studied the single-vendor single-buyer problem which also permits shortage. This research fulfills the shortcomings from previously discussed literatures by considering multiple buyers in a tree-type three-stage supply chain with backorders. The structural and methodological comparison of related literature with respect to this research is summarized in Table 1.

Given the current state of the research pursued and the existing problems that call for further investigation, this research undertaking is directed toward studying a tree-type, three-echelon supply chain system that consists of one producer (or interchangeably a manufacturer), multiple distributors and retailers. The manufacturer produces one type of product or component to meet the demands of customers through distributors and retailers. Thus, the objective of the problem is to develop a model and an appropriate solution procedure that determines an optimal replenishment policy for this *tree-type distribution system with allowable backorder* (TDB) at the retailer levels.

2. Assumptions

The following assumptions for a stated single-producer, multi-distributor, and multi-retailer system under consideration are necessary to formulate the problem.

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