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A multi-echelon production–inventory system with supply disruption

Brojeswar Pal [a], Shib Sankar Sana [b,*], Kripasindhu Chaudhuri [a]

[a] Department of Mathematics, Jadavpur University, Kolkata 700032, India
[b] Department of Mathematics, Bhangar Mahavidyalaya, University of Calcutta, Bhangar, 24PGS (South), Kolkata 743502, India

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ABSTRACT

The article investigates an integrated multi-layer supply chain model consisting of supplier, manufacturer and retailer while supply disruption, machine breakdown, safety stock, maintenance breakdown occur simultaneously. At beginning of the production, manufacturer keeps some raw materials in stock received from second supplier at high price, as safety stock due to supply disruption of first supplier. Corrective maintenance is done immediately to restore its normal stage when machine breakdown occurs. Stock out situations at manufacturer and retailer are considered due to disruption of production for machine breakdown. The integrated expected costs of the chain in centralized (collaborating) and decentralized (Stakelberg approach) system are compared. A numerical example and its sensitivity analysis are provided to test feasibility of the model.

1. Introduction

Supply chain management plays an important and critical role in any business organization in increasing competition and globalization. In last two decades, multi-stage supply chain management has received a very visible and influential research topics in the field of operations research. In the real world, a chain faces a lot of real problems like supply disruption, production system breakdown, shortages of product, etc. Manufacturing process is one of the most important part to the companies for their business strategy. Careful production planning is necessary to ensure good deliveries and productive efficiencies. The key factors of the production system are planning, organizing, directing and controlling of production activities. Machine breakdown, supply disruptions, shortages of products are common but vital factors for the companies. The researchers and practitioners are facing tough challenging condition to find out the best strategies on production disruption and supply disruption. The maintenance scheduling of systems, safety stock of the products, involving secondary members, etc. may be implemented to rescue from supply disruption and production disruption. Generally speaking, textile, footwear, electronics, etc. industries face such type of bottlenecks. In these industries, raw materials are transported from far side. Consequently, supply disruptions due to transportation problem, labor strike, natural problem, etc. are common factors. In such situations, manufacturers keep stock the raw materials for continuing production process. Moreover, production system disruption is common for all industries due to uncertain machine breakdown. As a whole, the entire channel faces stock out situations. Now, our aim is to study a supply chain model considering the important factors supply disruption, machine breakdown, corrective maintenance, safety stock, backlogging, multi-echelon supply chain.

2. Literature review

Inderfurth [14] studied a procedure for determining the optimal size and distribution of safety stocks in a general serial or divergent production or distribution process ruled by a base-stock control policy. Groenvelt et al. [11] introduced first a production inventory model with machine breakdown where the effect of machine breakdown and corrective maintenance on the economic lot sizing decisions were

* Corresponding author. Tel.: +91 8926007373.
E-mail addresses: brojo_math@yahoo.co.in (B. Pal), sana_sankar@yahoo.co.in, shib_sankar@yahoo.com (S.S. Sana), chaudhuriks@gmail.com (K. Chaudhuri).

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considered. They also showed that the optimal lot size of their model would always be larger than that in a deterministic EPQ case. Groenvelt et al. [12] extended their previous model by including general random repair times and a safety stock policy. Minner [21] studied a multi-stage safety stock policy where each stock point of the inventory system follows a periodically reviewed order-up-to policy. Moinzadeh and Aggarwal [22] studied an unreliable bottleneck production/inventory system with a constant production and demand rate that is subject to random disruptions. They considered restoration time is constant and the time between breakdowns is exponential. Makis and Fung [20] presented an EMQ model with inspections and random machine failure and obtained the formula for the long-run expected average cost per unit time under the assumption of generally distributed failure and replacement times, constant inspection times and zero restoration times. Graves and Lee [9] introduced a single machine scheduling problems where the machine maintenance must be performed within certain intervals and hence the machine is not available during the maintenance periods. Their main purpose is to schedule the maintenance and jobs to minimize some performance measures. Khouja [15] developed a three-stage, multi-customer, non-serial supply chain model where a firm can supply two or more customers. He analyzed the model with three inventory coordination mechanisms between chain members and solve a cost minimization model for each. Lin and Gong [18] introduced an EPQ model for a deteriorating product where manufacturing system faced a random machine breakdown and also considered a fixed corrective maintenance period. Chiu et al. [4,8] developed an economic production quantity model with scrap, the reworking of random defective items, and stochastic machine breakdowns under no-resumption (NR) inventory control policy. Cardenas-Barron [3] introduced an n-stage-multi-customer supply chain inventory model where retailer can supply products to several customers and he obtained the optimal equal cycle time and the optimal total annual cost. Leung [16] extended the work of Khouja [15] considering the integer multipliers mechanism and next individually derive the optimal solution to the three-stage and four-stage model using the perfect squares method. Leung [17] extended the previous paper [16] by considering with/without lot streaming and with/without complete backorders under the integer multiplier coordination mechanism, and then individually derive the optimal solution to the three- and four-stage model. Ben-Daya and Al-Nassar [2] studied with inventory and production co-ordination in a three-layer supply chain where lot produced at each stage be sent in equal shipments to the downstream customers. Sana [26] developed an integrated production–inventory model of perfect and imperfect quality products in a three-layer supply chain. Ayed [1] studied a production inventory model where they derived a joint optimization of maintenance and production policies considering random demand and variable production rate. Chiu et al. [5] demonstrated the optimal replenishment run time for a production system with stochastic machine breakdown and failure in rework. Lin and Chiu [19] presented a direct proof of convexity of long-run average cost function of the paper of Chiu et al. [5]. Pal et al. [23] investigated an imperfect production inventory model with stochastic demand where the regular maintenance is performed after each production run-time and free minimal repair warranty in a just-in-time production process is also provided to the customers. There are several interesting and relevant papers related to multi-stage inventory model such as [6,7,10,13,24,25,27–30], etc. In this article, we develop a multi-echelon supply chain model where raw material supplier may face supply disruption for different natural and mechanical reasons. The supplier supplies an ordering lot size of raw material to the manufacturer's warehouse but it may be disrupted by unnecessary conditions. At beginning, warehouse stores a safety stock of raw material from the another supplier with a high price to avoid the effect of supply disruption. The production may be disrupted by machine breakdown of manufacturing system after a random time. It may be taken a random time to return the production system at the initial condition by corrective maintenance. The inventory level of manufacturer may fall into shortages for the breakdown of production system and inventory of finished products at retailer may also fall into shortages. Finally, individual expected cost functions of suppliers, manufacturer and retailer are formulated by trading off inventory and set up costs at each state, cost of raw materials, labour/energy and tool/die costs for production, maintenance cost and shortage costs. The above costs functions are analyzed in the light of collaborating and Stakelberg approach. The rest of the paper is organized as follows: Section 3 illustrates fundamental assumptions and notations. Mathematical formulation and analysis of the model is discussed in Section 4. Section 5 demonstrates integrated inventory model. Stakelberg approach is delivered in Section 6. Section 7 analyzes numerical analysis. Sensitivity analysis and managerial insights are discussed in Section 8 and finally conclusion of the paper is provided in Section 9.

3. Fundamental assumptions and notation

3.1. Assumptions

The following assumptions are made to develop the model:

(i) The chain is developed for single item product.
(ii) Order lot size of supply chain is a decision variable.
(iii) Supplier may face supply disruption after a random time.
(iv) Production rate of manufacturer is greater than the demand rate of retailer.
(v) During regular production run-time, the production system may be disrupted and take a random time to restore the system to the working condition.
(vi) During the maintenance time of production system, the manufacturer's finished product inventory may fall into shortages.
(vii) Demand rate of the supply chain is deterministic and constant.
(viii) Safety stock of raw-materials which are stored in the manufacturer's warehouse, are supplied by other supplier with more price.
(ix) Retailer inventory level may fall into shortage for the breakdown of production system.

3.2. Notation

The following notation are used through out the model: