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An improved way to calculate imperfect items during long-run production in an integrated inventory model with backorders

Min-Soo Kim[a,b], Jong-Soo Kim[a], Biswajit Sarkar[a,*], Mitali Sarkar[a], Muhammad Waqas Iqbal[a]

[a] Department of Industrial & Management Engineering, Hanyang University, Ansan, Gyeonggi-do, 15588, South Korea
[b] Department of Applied Mathematics, Hanyang University, Ansan, Gyeonggi-do, 15588, South Korea

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ABSTRACT

This paper investigates an improved way to calculate imperfect items in an integrated inventory model with distribution free approach for lead time demand to simultaneously optimize lot size, safety factor, number of shipments, and lead time. The backorder rate depends on the reduced lead time. Due to the quality of products, each item is inspected by the buyer and defective items are sent to the supplier during delivery of the next lot. Some investments are used to improve the quality of products and reduce the setup cost. The model is solved by using distribution free approach with known mean and standard deviation. An improved solution methodology is designed and a lemma is constructed to obtain global optimum solution of the integrated model. An improved algorithm is designed to approach the global optimal solution. Five numerical examples and two special cases are provided to validate the suggested model. A case study is conducted for which the global optimum solution is obtained using the proposed solution methodology. Simplified versions of the proposed model, illustrated through numerical examples as special cases, converged over the existing theories. Some managerial insights are provided to help managers implement the suggested model in real time situations.

1. Introduction

The traditional inventory or production models assume that the quality of products is always perfect. The assumptions for inventory/production models are rarely satisfied. In practice, imperfect production often produces the defective products due to incomplete process control, long-run of machine without maintenance, or human mistakes. These defective products incur costs such as rework costs and repair costs. In addition, those products may change the planned strategies to infeasible because of unexpected early shortage and high quality-related cost. For these reasons, quality management has been studied and many firms pay considerable attention on the production processes and products they produce.

In this direction, Salameh and Jaber [1] extended the traditional EPQ/EOQ model for imperfect production system with 100% inspection process. Since then, large numbers of researchers extended the inventory model with imperfect production and inspection process. Initial models on this research assumed defective rate of production as constant, but as the defective rate could be controlled, researchers started to consider the defective rate as controllable variable. Not surprisingly, the mathematical models became gradually complex and it was difficult to prove that the models gave global optimal solution.

The aim of this research is to develop an improved way to solve this problem. By using the improved way, researchers and practitioners would be able to obtain the global optimal solutions of the integrated inventory models. In contrast to many previous studies, this paper develops and solves the imperfect production model to obtain the global optimal solution by using an improved method, which can be used for better results than exiting literature.

The rest of this paper is organized as follows: Section 2 discusses a review of related research and Section 3 provides problem definition, notation, and assumptions. Section 4 formulates an improved mathematical model. Section 5 offers five numerical examples, special cases, sensitivity analysis, and managerial insights. Section 6 provides conclusions and future extension of this paper.

2. Literature review

An imperfect production process usually causes some problems either during production run or during delivering perfect products to retailers. For example, defective products incur quality-related costs, such as rework and repair costs. Even these products may convert as perfect products, but the industry has to face some unexpected early shortages and higher costs related to product's quality. In order to

* Corresponding author.
E-mail addresses: bsbiswajitsarkar@gmail.com, bsarkar@hanyang.ac.kr (B. Sarkar).

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Table 1
Contributions of different authors.

Author	Global optimum	Controllable process quality	Distribution free approach	Order quantity	Backorder rate (Lead time dependent)	Reorder point	Lead time	Setup cost	Process quality
Salameh and Jaber [1]	√			√					
Huang [2]	√			√					
Huang [3]	√			√					
Ben-Daya and Hariga's [4]				√		√	√		
Wee et al. [5]	√			√					
Khan et al. [6]	√			√					
Ouyang et al. [7]		√		√					√
Dey and Giri [8]		√		√		√			√
This paper	√	√	√	√	√	√	√	√	√

address such issues, many researchers and practitioners have studied imperfect production processes and they incorporated several inspection processes. In this direction, Salameh and Jaber [1] developed an inventory model with random production of defective items and added inspection process. Their model has received a significant attention in the literature and naturally has become more complex. Huang [2,3] extended the work of Salameh and Jaber [1] by developing a single-supplier single-buyer model in an imperfect production system with an inspection activity in a just-in-time (JIT) environment. Ben-Daya and Hariga [4] developed a single-supplier and single-buyer imperfect production model to determine optimal lot size, reorder point, and number of shipments. They assumed that demand during lead time follows a normal distribution. They assumed that lead time depends on lot size and transportation time. Wee et al. [5] investigated an inventory model with an inspection process and backorders. They assumed that the quantity of defective products follows a given probability density function. They considered constant demand rate, deterministic lead time, and instantaneous replenishment. Khan et al. [6] extended the work of Salameh and Jaber [1] by considering inspection errors. They assumed defective rate is constant. Ouyang et al. [7] developed a single-supplier and single-buyer model with inspection process and constant demand rate. They considered the defective rate of the imperfect production can be controlled through joint investment from the supplier and buyer. Their model lack a proof of global optimal solution.

Dey and Giri [8] developed a single-supplier single-buyer model with inspection process and quality improvement. They assumed that demand during lead time followed a normal distribution by considering backordered shortages. Their model also could not serve the theory with a global optimal solution. Sarkar [9] developed a supply chain coordination model by considering SSMD (Single-Setup-Multiple-Delivery) between vendor and buyer. He proved that the supply chain players can save more cost by considering quantity discount strategy with variable inspection. Majumder et al. [10] suggested a supply chain model for quality improvement of the products by considering setup cost reduction under controllable lead time. Kim and Sarkar [11] discussed a multi-stage production model by considering an investment to reduce the probability of defective production. They assumed stochastic lead time and used the idea of lead time crashing cost to reduce the lead time. Diabat et al. [12] suggested an inventory model within supply chain systems for deteriorating products with partial downstream and upstream payments. Sarkar and Saren [13] studied deteriorating/imperfect production process which randomly shifts to “out of control state”. Taleizadeh et al. [14] proposed a production system with imperfect items assuming that machine breakdown follows some probability distribution.

There is a close relationship between the models of imperfect production and perishable/deteriorating products, though the production and inventory decisions vary according to the system under consideration. Similarly, the inspections and repairing processes within both type of systems are differentiated with respect to the nature of the product. Several authors investigated the inventory and production models for perishable/deteriorating products. Dye [15] proposed a supply chain model for perishable products with variable rate of deterioration that can be controlled with preservation methods. Sarkar [16] informed that the rate of deterioration increases with time and depends on maximum lifetime of the product. The same idea was used by Chen and Teng [17] in their model for perishable products. The concept of stochastic rate of deterioration in a two-echelon supply chain model was introduced by Sarkar [18] considering three probabilistic (uniform, triangular, beta) deterioration rates to find the optimum lot size and number of deliveries. Qin et al. [19] discussed an inventory system considering deterioration of a product's quality and quantity simultaneously. They assumed that the rate of deterioration is linearly proportional to the time and exponentially proportional to the storage temperature. Hiassat et al. [20] discussed a location-inventory-routing problem for perishable products. They developed a meta-heuristic method to solve the proposed model in practically in a reasonable time. Moreover, the idea of converting deteriorated items into new secondary products has been recently introduce by Iqbal and Sarkar [21].

This proposed paper extends the work of Ben-Daya and Hariga [4] by using an improved method to obtain global optimum solution. Specifically, this paper develops a joint economic-lot-size (JELS) model with inspection process and quality improvement. This paper uses the distribution free approach for lead time demand distribution as well as considers variable backordering rate, and discrete setup cost reduction. The improved solution methodology proves the global optimality of the model despite of its complexity. The major contribution of this paper is the development of improved method such that the global optimum solution is obtained. The contribution of this paper is illustrate in Table 1.

3. Problem definition, notation, and assumptions

This section contains problem definition, notation, and major assumptions.

Problem definition

There are several research model in the JELS field of research. Many researchers considered fixed setup cost for supplier or vendor and consistent quality during production, which are very restrictive in general. This paper uses two types of investment to reduce setup cost and improve the quality of products (refer to Porteus [22]). Many models considered either constant lead time or negligible lead time or continuous lead time, which are not always realistic. Contrarily, this model uses a discrete crashing cost to reduce the lead time. For the rapid production, the supplier did not inspect any product, but to maintain the brand-image the buyer inspects 100% production. For reduction the defective items, the investment is used to improve the quality of products such that the number of inspected items are less comparing to previous. Comparing with the pervious studies, this paper develops a JELS model to show the superiority of the improved model, by fulfilling the gap of finding global optimal solution.