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Effect of deterioration on the instantaneous replenishment model with imperfect quality items

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ABSTRACT

The assumptions required to justify the use of the economic order quantity model (EOQ) are rarely met. To provide mathematical models that more closely represent real-life situations, these assumptions must be relaxed. Among these assumptions are, first, items stocked are of perfect quality, and second, they preserve their characteristics during their stay in inventory. This paper considers a modified EOQ-type inventory model for a deteriorating item with unreliable supply. That is, a percentage of the on-hand inventory is wasted due to deterioration. Moreover, orders may contain a random proportion of defective items, which follow a known distribution. As soon as an order is received, a retailer conducts a screening process to identify imperfect quality items, which are salvaged as a single batch at the end of the screening process. First, a mathematical model is developed, assuming that no shortages are allowed. For that, it is assumed that the inventory level when placing an order is just enough to cover the demand during the screening period. The concavity of the profit function is established and sensitivity analysis is provided to analyze the impact of changing various model parameters on the optimal order quantity and profit. Then, the assumption of no shortages is relaxed, and a model is developed to incorporate backorders. We analyze the model with backorders numerically and provide managerial insights.

1. Introduction

The mathematical modeling of real-world inventory problems necessitates the simplification of assumptions. Specifically, the classical economic order quantity model (EOQ) is based on assumptions that are restrictive and unrealistic, although this model has been widely accepted by many industries today. Too much simplification results in mathematical models that do not represent the real inventory situation to be analyzed.

One of the unrealistic assumptions of the EOQ model is that items stocked preserve their physical characteristics during their stay in inventory. Items in stock are subject to several possible risks, such as pilferage, breakage, evaporation, and obsolescence. A cost is incurred to account for these risks. Deterioration of items in stock is one important feature of realistic inventory systems, and is defined as decay, damage, or spoilage (Dave [1]). Examples of items subject to deterioration include food items, drugs, pharmaceuticals, chemicals, and radioactive substances. When deterioration occurs while items are in storage, loss must be taken into account.

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A well established and studied example of deterioration is postharvest fruits and vegetables. According to the US department of agriculture, about 18.9 billion pounds of fresh fruits and vegetables are lost annually, which accounts for 19.6% of the US losses of edible food (Kantor et al. [2]). These losses become much more significant in developing countries, with estimates exceeding 50% (Kader [3]). At the retail level, it is estimated that 5.4 billion pounds of food was discarded (Kantor et al. [2]), with half of these losses coming from fresh fruits and vegetables. Moreover, several studies on supermarket discard show that fresh produce and other perishable items make up the largest share of retail food losses (Kantor et al. [2]).

The deterioration of fruits and vegetables is caused by many factors. For example, after harvest, losses of respirable substrates and moisture are not replaced, so dehydration is one factor, which causes decline of the produce and limits its shelf life (Brosnan and Sun [4]). Another cause is physical damage as the result of improper handling. Also, fruits and vegetables are subject to microbial deterioration which leads to quality decline (Brosnan and Sun [4]). The effect of deterioration cannot be completely eliminated. Several studies investigate the deterioration of postharvest vegetation and discuss guidelines on storage and handling to alleviate its effect (Barbosa-Canovas et al. [5]). Brosnan and Sun [4] discuss how to extend the shelf life of fruits and vegetables and retard their deterioration, using techniques such as precooling, low temperature storage, controlled atmosphere storage and minimal processing.

Many researchers have attempted to study the EOQ model under the case of items deteriorating in inventory. Ghare and Schrader [6] were the first to develop an EOQ model for an item with exponential decay and constant demand. Several papers followed that extend their model (e.g. Dave and Patel [1]; Sachan [7]). Hariga [8] further considers the effect of inflation and time value of money. Then, several works analyze the case of perishable products. Jain and Silver [9] develop a stochastic dynamic programming model for determining the optimal ordering policy for a perishable product, with time-dependent demand and random perishability.

Another common unrealistic assumption in using the EOQ model is that all units produced are of good quality. However, inventory systems with uncertain supply are common in manufacturing and retail settings. Several researchers have recognized this fact (see Yano and Lee [10] for reviews of the relevant research). An interesting variant has been proposed by Salameh and Jaber [11] who consider the classical economic order quantity model with a random supply characterized by a probabilistic proportion of imperfect quality items with a known distribution and a screening process. Another variant of economic order quantity model with imperfect items is the work presented in Nasr et al. [12] where the supply process is modeled by a correlated binomial supply model. Several works extend or improve upon this model (see, for example Maddah et al. [13]).

This paper considers an instantaneous replenishment model for defective items, with a percentage of the on-hand inventory being wasted due to deterioration, a characteristic feature of the inventory conditions which govern the item stocked. Defective items are produced due to a faulty production process, damaged items, and breakages during handling or transport. Therefore, the lot sizes received by the retailer may contain a certain percentage of defective items. The imperfect items and items deteriorated, if not accounted for, may cause shortages for the retailer, leading to losses. In this paper, as in Salameh and Jaber [11], we assume that 100% screening is conducted immediately after an order is received. Then, at the end of the screening process, imperfect items are removed from inventory and sold as a single batch at a discounted price. Following Lo et al. [14], we assume that deteriorated items are not replaced. To avoid shortages, we further assume that the number of good items that remain after removing defective and deteriorated items should meet demand during screening.

The paper is organized as follows: We review the literature in Section 2. The mathematical model without shortages is developed in Section 3, which establishes the quasi-concavity of the profit function. Then, we develop a model with shortages in Section 4. The two models are analyzed numerically, and sensitivity analysis is presented in Section 5. A conclusion is provided in Section 6.

2. Literature review

Inventory models in which units deteriorate while in storage have drawn the attention of various researchers in recent years. Efforts in analyzing mathematical models of inventory in which a constant or a variable proportion of the on-hand inventory gets deteriorated per unit time have been made by many researchers. Several papers assume a constant rate of deterioration (e.g. Ghare and Schrader [6]; Dave and Patel [1]; Dave [15]; Skouri et al. [16]; Dye [17]). Other papers assume a time-dependent rate of deterioration (e.g. Covert and Philip [18]; Philip [19]; Mishra [20]; Goswami and Chaudhuri [21]; Shah, Soni and Patel [22]; Sarkar [23]; Sanni et al. [24]). Chang [25] studies the effect of inflation and assumes that the supplier offers the retailer a permissible delay in payment if the order is greater or equal to a predetermined order quantity. Chern et al. [26] assumes partial backlogging and inflation. Sana et al. [27] considers an economic production lot size model for a deteriorating item over a finite planning horizon with a linearly time-varying demand rate and a uniform production rate. They allow for shortages which are backlogged. Jaber et al. [28] suggest a model to improve the performance of production systems using laws of thermodynamics which reduces the system's entropy. This work was extended in Jaber et al. [29] to allow for deterioration.

Among the works that consider the impact of both imperfect production processes and deterioration is that of Lo et al. [14], who consider an integrated production-inventory model for a manufacturer and retailer, with a varying rate of deterioration under imperfect production process. Partial backlogging is allowed at the retailer. Deterioration of an item follows a two-parameter weibull distribution and deteriorated items are not replaced. Jaber et al. [30] present an EOQ model