Computers & Industrial Engineering 88 (2015) 378–385

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Effect of deterioration on two-warehouse inventory model with imperfect quality

Chandra K. Jaggi *, Sunil Tiwari, AliAkbar Shafi

Department of Operational Research, Faculty of Mathematical Sciences, New Academic Block, University of Delhi, Delhi 110007, India

ARTICLE INFO

Article history:
Received 28 January 2015
Received in revised form 19 June 2015
Accepted 27 July 2015
Available online 31 July 2015

Keywords:
Inventory
Deterioration
Imperfect items
Two-warehouse
Inspection

ABSTRACT

The formulation of inventory models is often done with the presumption that all items produced are of perfect quality in nature. However, in real-life scenarios, the lot that arrives in inventory includes a fraction of imperfect quality items due to faulty production or mishandling of goods. It is also a misconception that the goods preserve their characteristics during their presence in the inventory. Thus, these assumptions need to be rectified in the planning/preparation of inventory models. In order to reduce the losses due to deterioration, at times, the retailer is forced to rent other warehouses (RW) with better preserving facilities, owing to the lack of facilities in his own warehouse (OW). The retailer may also rent warehouses voluntarily to store excessive goods that have been obtained at a discounted price or in order to avoid inflation rates. The present research paper is, thus, an attempt to incorporate the aforementioned concepts to develop a new inventory model with two warehouses: for goods that have a fraction of imperfect quality items and those that are deteriorating in nature. The study also states the developed mathematical model along with the solution procedure. Further, the sensitivity analysis of the optimal solution with respect to key parameters of the inventory system has also been performed to develop the managerial insights.

1. Introduction

The traditional Economic Order Quantity (EOQ) model is often based on assumptions that are idealistic and unrealistic in nature. So, the development of the inventory models requires a certain amount of relaxation of these assumptions to represent the actual realistic scenario.

The foremost unrealistic assumption of the EOQ model is that all items produced are of good quality. The truth of the matter is that the goods produced are directly affected by the process of production. The faulty production process introduces a fraction of items that are imperfect in quality and need to be removed by screening so as to meet the demand. A significant amount of work has been done to examine the effect of imperfect quality goods on the inventory. Porteus (1986) followed by Rosenblatt and Lee, had presented the substantial relationship between imperfect quality and lot size. In addition to this, Zhang and Gerchak (1990) had studied a joint lot sizing and inspection policy under an EOQ model, where a random proportion of units were considered defective. Further, Salameh and Jaber (2000) had developed an economic production quantity model for imperfect quality items with a known probability distribution. Therefore, they had suggested that the imperfect quality items are sold as a single batch by the end of the screening process. In the same year, Cárdenas-Barrón (2000) had not deviated from the main idea but had pointed out and rectified an error in the model devised by Salameh and Jaber.

Goyal and Cárdenas-Barrón (2002) had proposed a simple approach to determine the economic production quantity for the model given by Salameh and Jaber (2000). Subsequently, Papachristos and Konstantaras (2006) had examined the issue of non-shortages in the model with proportional imperfect quality, given that the proportion of the imperfects is a random variable. Recently, Sana (2010) had developed a production-inventory model in an imperfect production process. The following year, Khan, Jaber, Guiffrida, and Zolfaghari (2011) extended the work of Salameh and Jaber by assuming that the screening process is not error-free. Jaber, Zanoni, and Zavanella (2013) further proposed an EOQ model with imperfect quality based on entropy. The same year Moussawi-Haidar, Salameh, and Nasr (2013) suggested a model which integrates inventory lot sizing with imperfect quality items and quality control. The ensuing year, Karimi-Nasab and Sabri-Laghaie (2014) formulated a new imperfect production problem that generates defectives randomly. Recent research work about EPQ models with imperfect quality

* Corresponding author. Tel./fax: +91 11 27666672.
E-mail addresses: ckjaggi@yahoo.com (C.K. Jaggi), sunil.tiwari047@gmail.com (S. Tiwari), albrosshafi@gmail.com (A. Shafi).

http://dx.doi.org/10.1016/j.cie.2015.07.019
0360-8352/© 2015 Elsevier Ltd. All rights reserved.

items can be studied in the articles published by Sana (2011), Sarkar, Sana, and Chaudhuri (2010), Sarkar and Moon (2011), Sarkar (2012), Yoo, Kim, and Park (2012) and the references enlisted by them, the details of which are provided in the bibliography. Currently, Moussawi-Haidar, Salameh, and Nasr (2014) had considered the effect of deterioration on the instantaneous replenishment of the lot with imperfect quality items.

The second assumption prevalent in many models is that the goods produced preserve their physical characteristics during their stay in the inventory. The reality remains that the items in inventory are subject to several risks such as pilferage, breakage, evaporation and obsolescence. Inventory of certain products such as food items, pharmaceuticals, chemicals, blood, gasoline, and radioactive chemicals deteriorate rapidly over time. Thus, the loss from deterioration cannot be ignored. The phenomenon of deterioration was first introduced by Ghare and Schrader (1963) by assuming the exponential decaying of the items. Covert and Philip (1973) further researched and extended Ghare and Schrader's (1963) model with the assumption of Weibull distribution deterioration. Subsequently, Raafat, Wolfe, and Eldin (1991), Goyal and Giri (2001) and Bakker, Riezebos, and Teunter (2012) surveyed the trends in modeling of continuously deteriorating inventory.

The next problematic presupposition in the development of most of the traditional inventory models is that a single warehouse (OW) has unlimited capacity, which is factually incorrect. The inventory costs (holding cost and deterioration cost) in RW are usually higher than those of OW because of additional cost of maintenance, material handling and better preserving facilities. Despite these facts, the question of survival in an ever-increasing competitive business environment cannot be negated. Discounted price of goods from suppliers, high inflation rates and other such factors often allure the retailer to order an amount that surpasses his own warehouse capacity, thereby compelling him to rent other warehouses.

It is important to substantiate the argument with the help of the research done in this area. The primary notable work can be seen in the Chapter 12 of Hartley (1976) who first proposed a two-warehouse inventory system. This was followed by Das, Maity, and Maiti (2007) who had discussed a joint performance of a supply chain with two warehouse facilities. Hsieh, Dye, and Ouyang (2008) successively built a deterministic inventory model for deteriorating items with two warehouses by minimizing the net present value of the total cost. In continuation, a number of interesting research papers in this area has been published over the last few decades. One may refer to the recent works of Bhunia and Maiti (1998), Zhou and Yang (2005), Lee (2006), Chung, Her, and Lin (2009), Yang (2004, 2006, 2012), Liang and Zhou (2011), Hsieh et al. (2008), Niu and Xie (2008), Lee and Hsu (2009), Jaggi and Verma (2010), Zhong and Zhou (2013) and Bhunia, Jaggi, Sharma, and Sharma (2014) for an extensive study. The complete references have been given in the bibliography.

This paper takes into account a two-warehouse inventory model with items that have a certain percentage of defective items and are of deteriorating in nature. As pointed out earlier, to meet the demand and ensure the supply of perfect quality items, the defective items that result out of a faulty production process, need to be screened out. Thus, if these factors are not taken into consideration, it may lead to shortages and losses for the retailer. In the present analysis, 100% screening is conducted immediately after an order is received, as discussed in Salameh and Jaber (2000). At the end of the screening process, imperfect items are removed from the inventory and then sold as a single batch at a discounted price. The deteriorated items are not replaced as described by Lo, Wee, and Huang (2007). To avoid shortages, it is further assumed that the number of good items that remain after removing defective and deteriorated items meet the demand during screening. Since the rented warehouse has better preserving facilities, the rate of deterioration of goods is less than that of the own warehouse, resulting in higher holding cost of goods in the former. Hence, the model developed takes the LIFO model into consideration, i.e. the items are stocked into own warehouse first and then in rented warehouse. However, while fulfilling the demand the rented warehouse is consumed first. Finally, a numerical example is presented to illustrate the applicability of the proposed model. Sensitivity analysis on key parameters is provided to reveal managerial insights.

The rest of the paper is designed as follows:

Section 2 provides notations and assumptions used in the paper. The models' formulations are studied in Section 3 whereas Section 4 discusses the solution procedure. Section 5 discusses some of the special cases that can be obtained from the proposed inventory model. The proposed model is illustrated numerically along-with Sensitivity analysis in Sections 6 and 7 respectively. Finally, conclusions are made and future research directions are outlined in Section 8.

2. Assumption and notations

The mathematical models of the two-warehouse inventory problems are based on the following assumptions:

1. The own warehouse (OW) has a fixed capacity of w units while the rented warehouse (RW) has unlimited capacity.
2. Lead time is zero and the initial inventory level is also zero.
3. The rate of deterioration of RW (β) is less than the rate of deterioration of OW (α).
4. The screening process and demand proceeds simultaneously, but the screening rate (x) is greater than the demand rate (D), $x > D$.

2.1. Notations

For simplicity, we define the symbols for parameters, decision variables, functions and optimal values accordingly.

Parameters

w	storage capacity of OW (units)
D	annual demand rate known and constant (unit/time unit)
p	percentage of defective items (per unit)
x	screening rate (unit/year)
α	deterioration rate of OW
β	deterioration rate of RW
c	unit purchasing cost per item ($/unit)
k	fixed cost of placing an order ($/cycle)
s	unit selling price per item of good items ($/unit)
v	unit selling price per item of defective items ($/unit)
d	screening cost per unit item ($/unit)
h_r	unit holding cost per unit item per unit time in RW ($/unit/year)
h_o	unit holding cost per unit item per unit time in OW ($/unit/year)
TR_r	total revenue generated per cycle from RW ($)
TR_o	total revenue generated per cycle from OW ($)
HC_r	inventory holding cost of RW ($)
HC_o	inventory holding cost of OW ($)

Decision variables

y	order size per cycle (units)