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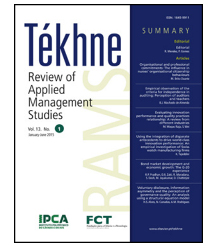

ARTICLE

A volume flexible deteriorating inventory model with price sensitive demand

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Abstract This paper deals with a single item deteriorating production inventory model with price sensitive demand. Items deteriorate at a constant rate. The rate of production is finite and controlled by modern technology, capital investment and number of labors. Demand is adjusted by flexibility of inventory level and this flexibility is introduced through the determination of optimal production stopping time, number of labors and unit selling price of the product. The total profit is determined by trading of selling price, production cost, deterioration cost and holding cost. The paper aims to maximize total profit per unit time in a production cycle. A real coded genetic algorithm is proposed to find out maximum total profit per unit time and to determine optimal production stopping time, number of labors and unit selling price of the product. Finally, a sensitivity analysis is performed to indicate the effects of the parameters on total profit, unit selling price, number of labors and optimal production stopping time.

1. Introduction

After the introduction of Wilson's square root formula (Wilson, 1934) under the assumption of constant demand rate in the earlier part of twentieth century, the EOQ inventory models have long been attracting considerable volume of research attention. For the last twenty five years or so forth, researchers in this area have extended investigation for various models with consideration of item shortage, item order cycles, item deterioration, various demand patterns, item production plans as well as their combinations. In the context of the demand pattern, it is found in real market that the demand of a product is always in dynamic state and this dynamicity occurs due to variability of time, price or even of the instantaneous level of inventory displayed in retail shop. The variability in demand rate was started

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with the work of Silver and Meal (1969), who determined the EOQ by a heuristic approach in the general case of a deterministic time dependent demand pattern. Donaldson (1977) gave a full analytic solution of the inventory replenishment problem with linear trend in demand over a finite time horizon. Peterson and Silver (1979) noted that sales at the retail level tend to be proportional to inventory displayed. In the last few years, researchers like Baker and Urban (1988), Datta and Pal (1990), Mondal and Phaujdar (1989), and Pal, Goswami, and Chaudhuri (1993) focused on the analysis of inventory system which described the demand rate as a power function and dependent on the level of on hand inventory. However, many super market managers have observed that a portion of the buyers is directly related to the amount of selling price of some products and the sales are affected for higher price of the product. This situation can be expressed mathematically by considering the demand as linear in selling price, a constant demand minus a portion of demand loss due to the price sensitivity (Modak, Panda, & Sana, 2015, Modak, Panda, & Sana, 2016a, 2016b, 2016c; Panda & Modak, 2016). In this research, we have considered the demand as linear price sensitive and this is quite justified for some items like vegetables, fruits, fishes, in which some demands are lost due to the price sensitivity. Nahmias (1982) classified perish ability in terms of fixed life time and random lifetime. Fixed lifetime products (e.g. human blood, drugs) have a deterministic self-life while the random lifetime scenario assumes that the useful life of each unit is a random variable. The random lifetime scenario is closely related to the case of an inventory that experiences continuous physical depletion due to deterioration or decay. Ghare and Schrader (1963) were the first proponents for developing a model with constant decaying rate and they categorized it into three types: direct spoilage, physical depletion and deterioration. Thereafter, a lot of work has been done on deteriorating inventory system. Researches on deteriorating items are important because in real life, milk, drug, food, vegetables do deteriorate significantly. Deterioration is defined by Yang and Wee (2003) as decay, damage, spoilage, evaporation, obsolescence, loss of utility, or loss of marginal value of a commodity that results in decreasing usefulness form the original one. Sarkar, Mandal, and Sarkar (2017) formulated a deteriorating inventory model under stock-dependent consumption rate to determine the optimal replenishment and preservation technology investment strategies. Panda, Modak, and Basu (2014) used disposal cost sharing mechanism for coordination to overcome the product deterioration problem. In this direction, the work of Giri and Chaudhuri (1998), Sana (2008, 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, 2013, 2015), Sana and Chaudhuri (2004), and Sarkar (2013, 2016) should be noted.

All the above researches are restricted to pure inventory replenishment situations i.e. items are purchased or ordered in batches. On the other hand researches on production inventory models have emphasized on various production factors, the setup time, production learning and forgetting effects etc. Peterson and Silver (1979) represented a model where the setup cost and unit variable manufacturing cost are constant and independent of order quantities. Sule (1981) studied the effects of learning and forgetting in the determination of economic product quantity. Again the classical Economic Production Lot Scheduling (EPLS) model (Hax & Candea, 1984) dealt with the availability of inventories at a constant rate where the production rate might be changed (Schweitzer & Seidmann, 1991). Sarkar and Majumder (2013) developed an integrated vendor–buyer supply chain model to reduce the total system cost by considering the setup cost reduction of the vendor. Schweitzer and Seidmann (1991) first introduced the concept of flexibility in the machine production rate and they discussed the processing rate optimization for a flexible manufacturing system (FMS). FMS can be described simply as the manufacturing environment where the production is made according to the demand and the production rate can be slow down or increased according to the decision makers' desire. Not only that there should be a better coordination among the different sections of the entire production unit. Using preventive maintenance, Modak et al. (2015) proposed a mathematical model to prevent sudden failure as well as maintain the quality of the production system. During the preventive maintenance, a just-in-time buffer inventory is proposed to maintain the normal operation. Silver (1990) enlightened the effects of slowing down the production rate for the production of a family of items assuming a common production cycle for all items and Gallego (1993) extended it to different production cycle for different items. In this direction, the work of Moon, Gallego, and Simchi-Levi (1991), Khouja (1995), Khouja and Mehrez (1994), Kazemi, Olugu, Abdul-Rashid, and Ghazilla (2015), and Panda, Modak, Sana, and Basu (2015) are worth mentioning.

One of the major problems for people dealing with uncertainty-based business is: how to make a better coordination between excessive stocks and shortages. For this, determination of proper selling price of the product is very important due to the price sensitive demand as the sales volume is directly related to it. Again, the hire and fire scenario for the last few years inspired them to determine the exact number of labors for their production. Not only that the intense competition and frequent price reduction of the products by the competitors forced them to make a better coordination between procurement and making decision to get rid of excessive stock due to lower sales volume and shortages when demands are high. This problem further increases when the product deteriorates. The effective way to overcome this problem is to introduce flexibility on inventory level by determining proper production stopping time, proper selling price of the product and proper amount of variable factors of the production system.

In this paper, a manufacturing inventory system is considered where the demand is price sensitive and the items deteriorate at a constant rate. Production process depends on several fixed and variable factors such as buildings, machinery plants, land, raw materials, fuel, power, and ordinary labor. The model considers Cobb–Douglas production function to assess effect of technology, investment and labors on it. This model assumes that applied technology, capital investment and numbers of labors control the rate of production. The objective of the present model is to maximize total profit per unit time in a production cycle. Total profit per unit time, optimal unit selling price of the product and the number of labors are determined by trading of production cost, holding cost and deterioration cost of inventories. A real coded genetic algorithm is used to achieve maximum average profit and to determine