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Deterioration and its Uncertainty in Inventory Systems

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Abstract

Deterioration cannot be avoided in business scenarios. Deterioration is defined as change, damage, decay, spoilage obsolescence and loss of utility or loss of original value in a commodity that results in the decreasing usefulness from the original one product. Normally inventory models of deteriorating items, such as food products, vegetables, etc. involve imprecise parameters, like imprecise inventory costs, fuzzy storage area, fuzzy budget allocation, etc. In this paper, it is observed that time to time different EOQ models have been developed for deteriorating items for fixed deterioration rate in fuzzy environment, along with the models with fuzzy deterioration rate. Fuzzy set theory which is primarily concerned with how to quantitatively deal with imprecision and uncertainty, is an important tool used by the decision makers in modelling real-world problems. The present study investigates different fuzzy economic order quantity models for deteriorating items. Fuzziness is applied by allowing the cost components (holding cost, deterioration, shortage cost, etc) to be imprecise; also considering the uncertainty of several other parameters which are represented by different fuzzy numbers.

Keywords: Inventory cost; deteriorating items; uncertainty; Fuzzy inventory; fuzzy numbers; inventory cost parameters; fuzzy deterioration rate; defuzzification

INTRODUCTION

An important part of cost controlling in business is Inventory management and control. For the last thirty years, researchers in this area have extended investigation into various models with considerations of item shortage, item deterioration, demand patterns, item order cycles and their combinations. In an inventory model deterioration plays an important role. Deterioration is defined as decay or damage in the quality of the inventory. Foods, Drugs, pharmaceuticals etc. are some examples of deteriorating items. During inventory there are some losses of these deteriorating items; consequently this loss must be taken into account when analyzing the system.

Inventoried goods can be broadly classified into four main categories:

(1) *Obsolescence* which refers to items those lose their value through time due to rapid changes of technology or the introduction of a new product by a competitor;

(2) *Deterioration* which refers to decay, damage, spoilage, dryness, vaporization, obsolescence, pilferage, and so forth of the products that results in decrease of usefulness from the original one;

(3) *Amelioration* which refers to items whose value or utility or quantity increases with time;

(4) *No obsolescence/deterioration/amelioration*.

All these categories have very short life cycle. If the rate of obsolescence, deterioration, or amelioration is not sufficiently low, its impact on modelling of such an inventory system cannot be ignored.

Deterioration has been considered in many inventory researches in the last decades. It is reasonable to note that a product may be understood to have a lifetime which ends when utility reaches zero. Commonly used commodities such as fruits, vegetables, meat, medicines and foodstuffs are subject to direct spoilage during storage period. The highly volatile liquids such as perfumes, gasoline, alcohol, and turpentine undergo physical depletion over time through the process of evaporation. The electronic goods, radioactive substances, photographic films and grains deteriorate through a gradual loss of potential or utility with passage of time. These items lose part or total value through time because of new technology or the introduction of alternatives, like computer chips, mobile phones, fashion and seasonal goods, and so on. Thus, the deteriorated items' repairing is a major problem in the supply chain of most of the business organizations.

The classical EOQ model developed in 1915 had the specific requirements of deterministic costs and demand and lack of *deterioration* of the items in stock. Gradually the concept of *deterioration* in inventory system caught up the mind of inventory researchers. The first attempt to describe optimal ordering policies for deteriorating items was made by Ghare and Schrader (1963). They developed an EOQ model for an item with exponential decay and constant demand. Covert and Philip (1973) extended the model to consider Weibull Distribution deterioration. Misra (1975) formulated an inventory model with a variable rate of deterioration with a finite rate of production. Dave and Patel (1981), developed the first deteriorating inventory model with linear trend in demand. They considered a linear increasing demand rate over a finite horizon and a constant deterioration rate. Sachan (1984), extended Dave and Patel's model to allow for shortages. Several researchers like Cohen (1977), Goyal and Gunasekaran (1995), Benkherouf (1997), Kang and Kim

(1983), Giri and Chaudhuri (1998) have developed the inventory models of deteriorating items in different aspects. Recently, Kar et al.(2001) developed a two-shop inventory model for two levels of deterioration. Nahmias (1982) reviewed perishable inventory theory. A comprehensive survey on continuous deterioration of the on-hand inventory has been done first by Raafat (1991) and later by Goyel and Giri (2001). Goyal and Giri (2001) investigated recent trends in modelling of deteriorating inventory. Bakker et al. (2012) reviewed the inventory systems with deterioration since 2001. Through investigating these reviews and some other papers it is seen that the deterioration rate was considered constant in most of previous researches. But, in the real world, deterioration rate is not actually constant and slightly disturbed from its original crisp value. Deng (2005) improved inventory models with ramp type demand and weibull deterioration. Chen et al. (2006) developed an EOQ model with ramp type demand rate and time dependent deterioration rate. Banerjee and Agrawal (2008) developed a two-warehouse inventory model for items with three-parameter weibull distribution deterioration, shortages and linear trend in demand. Dye et al. (2007) determined optimal selling price and lot size with a varying rate of deterioration and exponential partial backlogging. Sarker and Sarker (2013) improved an inventory model with partial backlogging, time varying deterioration and stock-dependent demand. Several researchers have extended their idea to different situations in deterioration on inventory model. The models for these type products have also been developed by Bhowmick & Samanta (2011), LiqunJi (2008), Misra, Sahu, Bhaula and Raju (2011).

In the last few decades, inventory models have been widely applied in business world. In conventional inventory models, various types of uncertainties are classically modelled using the approaches from the probability theory.

However, one of the weaknesses of current inventory models is the unrealistic assumption that all items produced are of good quality. In the crisp environment, all parameters in the total inventory cost such as holding cost, ordering cost, set-up cost, production cost, reworking cost, backorder cost, production rate deterioration rate and demand rate etc. are known and have definite value without ambiguity. Some of the business situations fit such conditions, but in most of the situations and in the day-to-day changing market scenario the parameters and variables are highly uncertain or imprecise. In real life, it is not always possible to obtain the precise information about inventory parameters. This type of imprecise data is not always well represented by random variables selected from probability distribution. So decision making methods under uncertainty are needed. To deal with this uncertainty and imprecise data, the concept of fuzziness can be applied. The concept of soft computing techniques (fuzzy logic) was first introduced by Zadeh (1965). Bellman and Zadeh (1970) developed the difference between randomness and fuzziness by showing that the former deals with uncertainty regarding membership or non-membership of an element in a set while the later is concerned with the degree of uncertainty by which an element belongs to a set. The fuzzy set theory is developed for solving the phenomenon of fuzziness prevalent in the real world. Different types of fuzzy sets are defined in order to clear the vagueness of the existing problems. Membership function of these sets, which have the form A: R → [0, 1] and it has a quantitative meaning and viewed as fuzzy numbers. A fuzzy number, is a quantity whose values are imprecise, rather than exact as in the case with single-valued function. So far, fuzzy numbers like triangular fuzzy numbers, trapezoidal fuzzy numbers and pentagonal fuzzy numbers are introduced with its membership functions. The inventory cost parameters which are assumed to be flexible i.e. fuzzy in nature can be represented by fuzzy numbers. Demand rate, production rate, deterioration rate, also being imprecise in nature can be represented by fuzzy numbers. An efficient method of ranking fuzzy numbers has a very important role to handle the fuzzy numbers in a fuzzy decision-making problem. Zimmermann (1985) has given a review on fuzzy set theory and its applications.

Fuzziness of Deterioration

The inventory problem of deteriorating items has been extensively studied by researchers. Looking through the inventory models with deteriorating items shows that the deterioration rate is considered constant or some real – valued functions in most of the previous researches. But, in the real world, deterioration rate is not actually constant or some pre-defined function and slightly disturbed from its original crisp value. However, the uncertainties due to deterioration cannot be appropriately treated by using usual probabilistic model. Therefore, it becomes more convenient to deal such problems with fuzzy set theory. Many inventory models are now being developed considering deterioration rate to be imprecise or fuzzy.

Here follows some of the interesting works relating to fuzzy deterioration in inventory management problems:

- Sujit D. Kumar, P. K. Kundu and A. Goswami (2007) developed an economic production quantity model with fuzzy demand and deterioration rate.
- A. Roya, M. K. Maiti, S. Kara, M.Maiti (2007) developed an inventory model for a deteriorating item with stock dependent demand under two storage facilities over a random planning horizon, which is assumed to follow exponential distribution with known parameter. They are the first to consider planning horizon of seasonal products as random in nature especially when deterioration is imprecise. For crisp deterioration rate, the expected profit is derived and maximized via genetic algorithm (GA). On the other hand, when deterioration rate is imprecise then optimistic/pessimistic equivalent of fuzzy objective function is obtained using possibility/necessity measure of fuzzy event.
- In the paper by S. Shabani, A.Mirzazadeh , E. Sharifi (2014) a more realistic inventory model with fuzzy deterioration and fully backlogged shortage under inflation is considered. The mathematical model is formulated to obtain the optimal value of the fuzzy total cost.
- B. Naserabadi, A. Mirzazadeh, and S. Nodoust (2014) developed an inventory model for items with uncertain deterioration rate, time-dependent demand rate with non increasing function, and allowable shortage under fuzzy inflationary situation.

The goods are not deteriorating upon reception, but the deteriorating starts after elapsing a specified time. Furthermore the following different deterioration rates have been considered: for the first case we consider fuzzy deterioration rate and for the second case we assume that the deterioration rate is time dependent and follows Weibull distribution with three known parameters. In most of the previous inventory models with Weibull deterioration rate,the location parameter (λ) of Weibull distribution is considered to be equal to zero but we consider this parameter in our model. This means that the goods start deteriorating after elapsing a specified time (λ). Since the inflation rate, deterioration rate, and the lead time are fuzzy numbers, the objective function becomes fuzzy. Therefore the estimate of total costs for each case is derived using signed distance technique for defuzzification. Different from the previous studies here they have considered the rate of deterioration as two kinds beside each other and compare the solutions of these two cases with each other when all of the other parameters are the same. The results show that the total cost in the second case (considering stochastic deterioration) is more than the first case (considering fuzzy deterioration).

- S. Kumar, U. S. Rajput (2015) considers an inventory model for deteriorating items with time dependent demand rate and partial backlogging. Shortages are allowed and completely backlogged for the next replenishment cycle. Due to the uncertainties in the demand rate, deterioration rate and backlogging rate they are assumed as triangular fuzzy numbers. For defuzzification by signed distance method and centroid method it has been observed that the total profit decreases as the optimal cycle time decreases and the profit given by the signed distance method is minimum as compared to the centroid method.

- K. Jaggi, S. Pareek, A. Sharma, Nidhi (2012) present a fuzzy inventory model for deteriorating items with allowable shortages in which demand is an increasing function of time. The demand, deterioration rate, inventory holding cost, unit cost and shortage cost are represented by triangular fuzzy numbers.For defuzzification, graded mean, signed distance and centroid method are employed to evaluate the optimal time period of positive stock and total cycle length which minimizes the total cost. By given numerical example it has been tested that graded mean representation method gives minimum cost as compared to signed distance method and centroid method.

- C. K.Jaggi, A.K. Bhunia, A. Sharma and Nidhi (2012), in their study, develop a crisp inventory model with constant deterioration, price dependent demand and time varying holding cost and partial backlogged shortages. Thereafter, to develop the corresponding fuzzy model, trapezoidal fuzzy numbers have been used to represent the uncertainty in all the parameters namely, demand, ordering cost, holding cost, purchase cost, deterioration rate, shortage cost and lost sale cost. Now for defuzzification, the well known Graded Mean Integration method has been employed to find the average profit and also to derive the optimal order quantity, the profit function has been maximized. To show the validity of the model a numerical example has been considered and solved. From the numerical example, it is observed that the optimal profit of fuzzy model is lesser than that of crisp one. The reason behind this is due to uncertainty of several parameters. Hence we conclude that the average profit will be reduced when uncertainties are accounted in large manner.

- Umap (2010) formed a fuzzy EOQ model for deteriorating items with two warehouses. He considered fuzzy numbers for the parameters such as holding cost and deteriorating cost for two warehouses. He used signed distance method and function principle method for defuzzification of total inventory costs as well as optimum order quantity.
- N.K. Sahoo, B. S. Mohanty and P.K. Tripathy (2016) investigate the development of a fuzzy inventory model with time-varying demand, deterioration and salvage. The deterioration rate, demand, holding cost, unit cost and salvage value are taken as trapezoidal fuzzy numbers. Both graded mean integration and signed distance method are used to defuzzify the total cost function. Numerically comparing the crisp model with fuzzy model it is seen that if the uncertainties are accounted for in an appropriate manner, the time would decrease. In comparison with the crisp model, the fuzzy model is giving the relatively better optimal solution. Sensitivity analysis is carried out to see how far the output of the model is affected by changes in its input parameters.
- J.Sujatha, P.Parvathi (2015) developed an EOQ model for variable deteriorating items with Weibull demand and time- varying holding cost in the fuzzy sense and when the supplier offer a trade credit period. The supplier offers credit period to the retailer who has the reserve money to make the payments, but decides to avail the benefits of credit limit. Shortages are allowed and partially backlogged. The deteriorating cost, shortage cost and opportunity cost are represented by trapezoidal fuzzy numbers. The optimum results of fuzzy model are defuzzified by signed distance method.
- M.Maragatham, P.K.Lakshmidevi (2016) study develops a fuzzy inventory model to find the minimum relevant inventory cost per unit time for non instantaneous deteriorating goods over a finite time horizon with exponentially declining demand for n-cycles. The shortages are allowed and back ordered. Under the situation of delay in payments, the inventory model in this study is divided into four cases by the time of shortage, deadline of delay in payment. The holding cost, shortage cost, deterioration cost, purchasing cost and selling price are considered as trapezoidal fuzzy numbers. The signed distance method is used for defuzzification
- H. Nagar and P. Surana (2015) developed the corresponding fuzzy inventory model for fuzzy deteriorating items with fuzzy demand rate under full backlogging. The average total inventory cost in fuzzy sense is derived. All inventory parameters including deterioration rate are fuzzified as the pentagonal fuzzy numbers. The fuzzy model is defuzzified by using the graded mean representation method.
- Liang-Yuh Ouyang, Jinn-Tsair Teng And Mei-Chuan Cheng (2010) explored and understood that in studies related to trade credit assumption that the interest rate is

both fixed and predetermined is not true especially when interest rates fluctuate. In order to fill this gap, they recast Chang *et al*.'s (2003) model by further fuzzifying the rate of interest charges, the rate of interest earned, and the deterioration rate into the triangular fuzzy number. They construct three different intervals to include the rate of interest charges, the rate of interest earned, and the deterioration rate, thus deriving the fuzzy total relevant inventory cost. By the signed distance method of defuzzification, they derive the estimate of the total relevant inventory cost in the fuzzy sense.

- H.P. Umap (2014) considered a multi item EOQ model with stock dependent demand for deteriorating items in fuzzy environment. Inventory costs such as holding cost and setup cost have been represented by exponential membership function and profit, deteriorating rate and total investment constraint are represented by linear membership functions. The model has been solved by fuzzy non-linear programming (FNLP) method. Results have been presented along with those of corresponding crisp model and a sensitivity analysis.
- I. Sangal, A. Agarwal, S. Rani (2016) present a crisp and fuzzy inventory model for non-instantaneous decaying items with shortages considering demand rate is time dependent. The demand, deterioration rate, ordering cost and shortage cost are represented by triangular fuzzy numbers. For defuzzification signed distance method is utilized to evaluate the optimal total cost.
- A K Malik, Y. Singh (2013) deal a fuzzy based inventory model for deteriorating items with linear demand and two warehouse facilities. The proposed model can be used in inventory control of deteriorating items such as fashionable items, medicines, food items, electronic components such as mobile, machines, circuit, toys and fashionable commodities etc. Deterioration rates in both warehouses are considered to be different due to change in environment. To deal with uncertainty in the real life and global market situations, a fuzzy model is considered in which holding costs assumed in warehouses, ordering cost and deteriorating cost are assumed to be fuzzy. Well-known triangular membership function is used for all the fuzzy numbers.
- S. K. De, A. Goswami (2006) study develops an EOQ model with a fuzzy inflation rate and fuzzy deterioration rate, and a delay in payment is also permissible. They have derived the corresponding fuzzy cost function, and the solution procedure has been explained with the help of a numerical example. A sensitivity analysis has also been carried out.
- Mandal, W. Akram Islam, Sahidul (2016) in their paper analyze fuzzy inventory system for deterioration item with time depended demand. Shortages are allowed under fully backlogged. Fixed cost, deterioration cost, shortages cost, holding cost are the cost considered in this model. Fuzziness is applying by allowing the cost components (holding cost, deterioration, shortage cost, holding cost, etc). In fuzzy environment it considered all required parameter to be triangular fuzzy numbers. One numerical solution of the model is obtained to verify optimal solution. The purpose of the model is to minimize total cost function.

Likewise many fuzzy models for deteriorating items by fuzzifying all the costs of the model as triangular, trapezoidal, pentagonal fuzzy numbers (PFN) or hexagonal fuzzy numbers are also being developed by the researchers. The other types of membership functions such as piecewise linear, cubical parabolic, L-R fuzzy number, etc. can be considered to construct the membership functions for the inventory parameters and then models can be easily solved.

The models are being analysed in both crisp and fuzzy senses. The crisp model can be viewed as a special case of the fuzzy model. It is observed that In comparison with the crisp model, the fuzzy model is giving the relatively better optimal solution. Numerical examples are given in each of the models to demonstrate the optimal decision for the retailer. The sensitivity analysis is carried out to analysis the changes in the changes in optimal solution with respect to other different parameter. Different methods for defuzzification, such as signed distance method, Graded Mean Integration Representation Method , Centroid methods etc. have been employed to evaluate the optimal solution of the fuzzy models. Some of the models have been also solved by fuzzy non-linear programming (FNLP) method. In some of the models like Kasthuri et al. (2011), Kuhn-Tucker conditions for defuzzification can be used.

Thus, when developing an optimal inventory policy for many products, the loss of inventory due to deterioration cannot be ignored. The researchers have continuously modified the deteriorating inventory models so as to more practicable and realistic. Fuzzy set theory is primarily concerned with how to quantitatively deal with imprecision and uncertainty, and offers the decision maker another tool in addition to the classical deterministic and probabilistic mathematical tools that are used in modelling real-world problems. To define inventory optimization tasks in such an unpredictable environment and to interpret optimal solutions, fuzzy set theory in inventory modelling gives an authenticity to the model formulated since fuzziness is the closest possible approach to reality.

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