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# Development of Fuzzy Inventory Model under Decreasing Demand and increasing Deterioration Rate

**Vikashdeep Yadav[1], B. K. Chaturvedi[2], A K Malik[3*]**
[1]Research Scholar Bhagwant University Ajmer (Rajasthan)
[2]Department of Mathematics, Bhagwant University Ajmer (Rajasthan)
[3]School of Sciences, UP Rajarshi Tandon Open University, Prayagraj (U.P.)
Email: yadav.vikasdeep89@gmail.com; bkchaturvedi9@gmail.com; profakmalik@uprtou.ac.in

**Abstract:**

This research study proposed an inventory model with both the time varying variable deterioration and demand rate under the fuzzy environment. Fuzzy set theory is generally consider with imprecision and uncertainty nature of quantitative coefficients. In this system, we assumed the linearly increasing and decreasing function of time for deterioration and demand respectively. In this research work, we discuss a fuzzy inventory model solving by signed distance method where demand follow time varying.

**Keywords:** Decreasing demand, increasing deterioration rate, inventory, and fuzzy theory.

## Introduction

In today's business scenario, the highly business asset plays a vital role in manufacturing and warehouses management. A large number of raw material (especially sessional items) is required for starting the production which is based on highly financial structure. The inventory system is an important part of supply chain management system that observes each and every effort in whole production system from initial to final stage. The main work of inventory system is to maintain the complete record of any product. In business industries, manufacturer need to planning to new advanced strategies due to the customer's attraction and retaining is a very challenging task. In inventory models, there are uncertainties in cost coefficients and demand of products. In this research work, the importance of fuzzy in uncertain coefficients to find the optimal results using signed distance method are discussed.

Due to market competition, the replacement policy is much more attractive to the customer these days. Many shopping sites like Flipkart, Amazon, etc. provide the facilities to replace the demise, deteriorating products. Such types of products are packed foods, dry-fruits, pharmaceuticals, clothes, cosmetic items are included in the category which is widely used in every family. Many industrial firms adopt non-instantaneous deteriorating items to enhance their business policy, which is also the most attractive for the customer in a competitive world. The non-instantaneous policy for products attracts the customer's interest and the product can be freshly used for some time and get more benefit. These policies are applied in cosmetics, pharmaceuticals, packet food, eggs, fish, dry fruits products, etc.

Inventory control and management plays a vital role in any business enterprises. The most popular inventory models which is based on demand and supply: Economic Order Quantity (EOQ) and Economic Production Quantity (EPQ) inventory models. The first inventory system established by Harris (1915) was an EOQ inventory model. Later Hadley and Whitin (1963) examined the study related inventory system in which both types of parameters constant and variable form, varieties of inventory models and the inventory costs, etc. The main factor in inventory management to obtain the optimal profit before minimize the total inventory cost function for any industries. Recently, research work on

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inventory problems has received some attention Sharma et al. (2013); (Singh and Malik (2008, 2009, 2010, 2011); Kumar et al. (2016, 2017 & 2019); Malik et al. (2016, 2017, 2019); Malik and Sharma (2011); Vashisth et al. (2015, 2016); Yadav and Malik (2014); Singh et al. (2011, 2014)). These inventory models consider that the input parameters and the output variables are described as crisp environment or having fixed values. The research work written by Malik et al. (2018) presented a mathematical model with variable cost coefficients and the optimum result. The article of Gupta et al. (2013) investigated a mathematical model to obtain the optimal result for non-instantaneous deteriorating products, also determine the optimal ordering policies. The inventory model has been used for solving in many fields including supply chain management, sustainable development and engineering of many industrial and business companies. Malik et al. (2008) introduced a new preference system for the inventory model which is based on time-dependent demand rate and Malik et al. (2010) presented a comprehensive review of the developments and research work directed on supply chain management in industrial aspects. As the result of new technologies, market dynamics, increased competition day by day in business companies maintaining and controlling the inventory is more difficult and complex. Due to uncertainty, the fuzzy theory is an option for determining the optimum result, comparing it with traditional optimization techniques in a crisp environment for the inventory system.

Fuzzy theory is one of the most prominent techniques to obtain the optimality of the function with uncertainty constraints. Inventory cost coefficients like holding cost, deterioration cost, ordering cost is very difficult for determining their accurate value in decision making. However, these cost coefficients can be fixed or uncertain. Demand and cost coefficient uncertainty is very common in inventory management system such as in the field of mathematics, engineering, science, statistics and economics. Zadeh (1965) in the first effort to discuss the new set theory named fuzzy set theory which is based on the uncertain nature of coefficients and functions. Due to the uncertainty of cost coefficients and their objective function, sometimes obtaining the optimal result is not possible due to the fluctuation of their values of constraints. Therefore to obtain the optimal result of the function use the fuzzy constraints.

A fuzzy based approach was developed by Guiffrida (2010) to inventory system with EOQ models and Economic Production Quantity (EPQ) models, developed in a general sense. Bellman and Zadeh (1970) also carried out research work on how to integrate the fuzzy parameters and goals which constituted the decision making that approximated the fuzzy sense for maximization decision is obtained from various knowledge areas. Kao and Hsu (2002) explored the fuzzy mathematical model in which asset trapezoidal fuzzy numbers and fuzzy demand rate. Chang et al. (2006) discussed the optimum cost function with fuzzy lead and fuzzy demand, and also used centroid method to obtain the optimum order quantity. Many researchers were interested in working with fuzzy set theory with inventory cost coefficients like demand, objective function and deterioration by Zimmermann (1985); Chang et al. (2004); Vujosevic and Petrovic (1996); Chen (1985); Halim et al. (2010); Yao and Lee (1999); Guiffrida and Negi (1998); Yung et al. (2007); Jaggi et al. (2013); Lin et al. (2017); Garg (2017); Dubois and Prade (1980); Yong et al. (2010); De (2021), etc., have been developed the various model with fuzzy environment over the last few decades.

Among these uncertainties, the fuzzy Model for uncertain quantity is especially used. The advantages of the fuzzy model include its ability to handle easily and provide a better result in comparison to a crisp model for the benefit of industrial problems. Yao and Chiang (2003) investigated the fuzzy inventory model for optimal ordering quantity and optimal resuly. They used the two methd for solving the model: signed distance and centroid method. Chou (2009) developed a Kuhn-Tucher condition based fuzzy economic order quantity model with trapezoidal fuzzy number based constraints using function principal and Graded mean integration. Keeping in mind that fuzzy environment could be a flexible way of representing the cost coefficients, Malik and Singh (2011 & 2013); Malik et al. (2012) developed the mathematical models with fuzzy and crisp environment considered the fuzzy constraints. Singh et al. (2014) explored the literature review on inventory control with soft computing techniques, which is the most attractive field for a researcher. Daniel et al. (2016) introduced and studied the fuzzy theory and its properties to generalize the decision-making policies for the dynamic models. Shekarian et al. (2017) employed the fuzzy theory to inventory system with systematic sample of large data is assumed for modelling and analyzing.

Priyan and Manivannan (2017) quantify the modeling and analysis of supply chain model for obtaining the optimal inventory policies in a uncertainty environment. Sarkar and Mahapatra (2017) concluded that the fuzzy demand and lead time based inventory models. They assumed the logarithmic

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investment function and used computational algorithms to obtain the expected total cost and optimal cycle length. Malik et al. (2018) presented a numerical and experimental analysis of inventory systems with time-varying demand. A recent addition to the inventory model with Pareto distribution based demand by Hollah and Fergany (2019), they introduced the stochastic deterioration rate for products. Malik and Garg (2021) evaluated the fuzzy inventory model to determine the optimum objective inventory cost function. Demand and supply of items/products is one of the most common activities in our daily life. In this paper, we investigate an inventory system with linearly decreasing demand which is a function of time. Here we recognized an optimum inventory policy for an inventory system for decaying products under both the variable demand and deterioration. We study an inventory system that allows fuzzy constraints with their different values.

**Assumptions and Notations**

This research work considered the following assumptions and notations {~ sign used for the fuzzy parameters} in this developed system based on fuzzy inventory model for time varying deterioration and demand rate:

(i) Demand of the product is $D(t)=a_1-a_2t$ and deterioration rate of the product is $\theta(t)=\alpha t+\beta.$

(ii) Consider two fuzzy numbers $\tilde{U}$ and $\tilde{V}$: $\tilde{U}\oplus\tilde{V}=(u_1v_1,\ u_2v_2,\ u_3v_3,\ u_4v_4)$, where $\tilde{U}=(u_1,\ u_2,\ u_3,\ u_4)$ and $\tilde{V}=(v_1,\ v_2,\ v_3,\ v_4)$.

(iii) Triangular fuzzy number $\eta=(\eta_1,\eta_2,\eta_3)$, where $\eta_1=\eta-\Delta_1,\ \eta_2=\eta,\ \eta_3=\eta+\Delta_2$.

(iv) The membership function of $\eta$ is

$$\mu_\eta(\tilde{\eta})=\begin{cases}\dfrac{\eta-\eta_1}{\eta_2-\eta_1} & \eta_1\le\eta\le\eta_2\\ \dfrac{\eta_3-\eta}{\eta_3-\eta_2} & \eta_2\le\eta\le\eta_3.\\ 0 & \text{otherwise}\end{cases}$$

| | |
|---|---|
| $C_O$ | Ordering cost |
| $C_h$ | Holding cost |
| $Q_1(t)$ | Inventory level in interval $(0, t_0)$ |
| $Q_2(t)$ | Inventory level in interval $(t_0, T)$ |
| $Q_0$ | Initial inventory level |
| $\theta(t)$ | Deterioration rate |
| $C_d$ | Deterioration cost |
| $A_{TIC}$ | Inventory cost function |
| $\tilde{A}_{TIC}$ | Inventory cost function in fuzzy sense |

**Crisp Model**

For the developed system, we considered a system with both linearly time varying demand and deterioration rate. In the develop system consideration the initial stock level $Q_0$ in which decreases by a unit rate, over the whole cycle as exposed in the figure.1. Hence, the inventory level $Q_1(t)$ describing in the following differential equation:

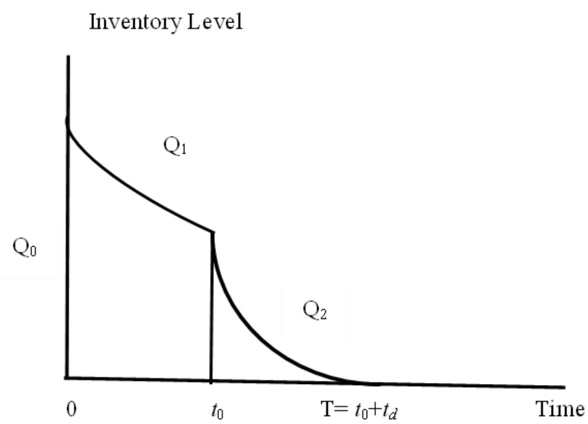


**Fig. 1 Graphical representation of Inventory system**

$$\frac{dQ_1(t)}{dt}=-(a_1-a_2t),\qquad 0\le t\le t_0 \qquad \ldots(1)$$

with the boundary condition

$$Q_1(0)=Q_0 \qquad \ldots(2)$$

The result of the above differential equation (1) is

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$$Q_1(t)=Q_0-\left(a_1 t-a_2\frac{t^2}{2}\right), \qquad 0\le t\le t_0 \qquad \ldots(3)$$

The inventory level $Q_2(t)$ describing in the following differential equation:

$$\frac{dQ_2(t)}{dt}+(\alpha t+\beta)Q_2(t)=-(a_1-a_2 t), \qquad t_0\le t\le T \qquad \ldots(4)$$

with the boundary condition

$$Q_2(T)=0 \qquad \ldots(5)$$

The result of the above differential equation (4) is

$$Q_2(t)=\begin{pmatrix} a_1\left\{T-(1+\beta T)t+\beta t^2\right\}+b_1\left(T^2-t^2\right) \\ +b_2\left(T^3-t^3\right)-b_3\left(T^4-t^4\right)\end{pmatrix} \qquad \ldots(6)$$

where

$$b_1=\left(\frac{a_1\beta-a_2}{2}\right),\ b_2=\left(\frac{a_1\alpha-2a_2\beta}{6}\right),\ b_3=\frac{a_2\alpha}{8}.$$

Due to continuity, inventory levels $Q_1(t)$ and $Q_2(t)$ at the time $t_0$ are equal So we have

$$Q_0=a_1t_0-a_2\frac{t_0^2}{2}+a_1\left\{T-(1+\beta T)t_0+\beta t_0^2\right\}$$
$$+b_1\left(T^2-t_0^2\right)+b_2\left(T^3-t_0^3\right)-b_3\left(T^4-t_0^4\right) \qquad \ldots(7)$$

**Ordering Cost** $OC=C_O$ … (8)

**Holding Cost**

$$IHC=C_h\left(\int_0^{t_0}Q_1(t)dt+\int_{t_0}^{T}Q_2(t)dt\right) \qquad \ldots(9)$$

**Deteriorating Cost**

$$IDC=C_d\left(\int_{t_0}^{T}(\alpha t+\beta)Q_2(t)dt\right) \qquad \ldots(10)$$

**The Inventory cost function is**

$$A_{TIC}(t_0,t_d)=\frac{1}{T}\ (OC+IHC+IDC) \qquad \ldots(11)$$

For determine the optimal solution of the values of $t_0$, T, $Q_0$, $A_{TIC}$ for this inventory system. For minimize the objective function (total inventory cost $A_{TIC}$), we have

$$\frac{\partial A_{TIC}}{\partial t_0}=0,\ \frac{\partial A_{TAC}}{\partial t_d}=0,$$

$$\left(\frac{\partial^2 A_{TIC}}{\partial t_0^2}\right).\left(\frac{\partial^2 A_{TIC}}{\partial t_d^2}\right)-.\left(\frac{\partial^2 A_{TIC}}{\partial t_0\partial t_d}\right)^2>0$$

and $\left(\frac{\partial^2 A_{TIC}}{\partial t_0^2}\right)>0.$

**Fuzzy Inventory Model**

Due to uncertain behaviour of constraints of inventory system such as price, demand and costs are not provide the optimal result. Therefore to get the approximate result, used the fuzzy parameters which are provide the best result comparison to crisp environments. In many day-to-day real life problems and almost every engineering, sciences, industrial and management problem solving fuzzy theory has a great role. Generally the researcher assumed the constant demand and deterioration rate in the inventory system but due to uncertainty of constraints assumed fuzzy inventory costs, such as holding costs, ordering costs and deterioration cost.

**Signed Distance Method**

For developing this system, we used Signed distance method for obtained the optimum objective cost function. Here the fuzzy parameters of the examined inventory model are ordering cost ($\tilde{C}_O$), holding cost ($\tilde{C}_h$) and deteriorating costs ($\tilde{C}_d$) are defined as

$$d\left(\tilde{C}_h,0\right)=C_h+\frac{1}{4}(\Delta_2-\Delta_1),$$

$$d\left(\tilde{C}_O,0\right)=C_O+\frac{1}{4}(\Delta_4-\Delta_3),$$

and $$d\left(\tilde{C}_d,0\right)=C_d+\frac{1}{4}(\Delta_6-\Delta_5)$$

The fuzzy based objective inventory cost functions $\left(\tilde{A}_{TIC}\right)$ can be written as in form

$$\tilde{A}_{TIC}(t_0,t_d)=\left(A_{TIC1},A_{TIC2},A_{TIC3}\right)$$

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$$A_{TIC1}(t_0,t_d)=\frac{1}{T}\left(\begin{aligned}&(C_O-\Delta_3)+(C_h-\Delta_1)\left\{Q_0t_0-a_1\frac{t_0^{\,2}}{2}+a_2\frac{t_0^{\,3}}{6}\right\}\\&+\alpha.(C_d-\Delta_5)\left(\begin{aligned}&a_1\left\{\begin{aligned}&T\frac{(T^2-t_0^{\,2})}{2}-(1+\beta T)\frac{(T^3-t_0^{\,3})}{3}\\&+\beta\frac{(T^4-t_0^{\,4})}{4}\end{aligned}\right\}\\&+b_1\left(\frac{T^4}{4}-\frac{T^2t_0^{\,2}}{2}+\frac{t_0^{\,4}}{4}\right)+b_2\left(\frac{3T^5}{10}-\frac{T^3t_0^{\,2}}{2}+\frac{t_0^{\,5}}{5}\right)\\&-b_3\left(\frac{T^6}{3}-\frac{T^4t_0^{\,2}}{2}+\frac{t_0^{\,6}}{6}\right)\end{aligned}\right)\\&+\begin{pmatrix}(C_h-\Delta_1)\\+\beta(C_d-\Delta_5)\end{pmatrix}\left(\begin{aligned}&a_1\left\{\begin{aligned}&T(T-t_0)-\left(\frac{1+\beta T}{2}\right)(T^2-t_0^{\,2})\\&+\frac{\beta}{3}(T^3-t_0^{\,3})\end{aligned}\right\}\\&+b_1\left(\frac{2}{3}T^3-T^2t_0+\frac{t_0^{\,3}}{3}\right)+b_2\left(\frac{3}{4}T^4-T^3t_0+\frac{t_0^{\,4}}{4}\right)\\&-b_3\left(\frac{4}{5}T^5-T^4t_0+\frac{t_0^{\,5}}{5}\right)\end{aligned}\right)\end{aligned}\right)$$

$$A_{TIC2}(t_0,t_d)=A_{TIC}(t_0,t_d)$$

$$A_{TIC3}(t_0,t_d)=\frac{1}{T}\left(\begin{aligned}&(C_O-\Delta_4)+(C_h-\Delta_2)\left\{Q_0t_0-a_1\frac{t_0^{\,2}}{2}+a_2\frac{t_0^{\,3}}{6}\right\}\\&+\alpha.(C_d-\Delta_6)\left(\begin{aligned}&a_1\left\{\begin{aligned}&T\frac{(T^2-t_0^{\,2})}{2}-(1+\beta T)\frac{(T^3-t_0^{\,3})}{3}\\&+\beta\frac{(T^4-t_0^{\,4})}{4}\end{aligned}\right\}\\&+b_1\left(\frac{T^4}{4}-\frac{T^2t_0^{\,2}}{2}+\frac{t_0^{\,4}}{4}\right)+b_2\left(\frac{3T^5}{10}-\frac{T^3t_0^{\,2}}{2}+\frac{t_0^{\,5}}{5}\right)\\&-b_3\left(\frac{T^6}{3}-\frac{T^4t_0^{\,2}}{2}+\frac{t_0^{\,6}}{6}\right)\end{aligned}\right)\\&+\begin{pmatrix}(C_h-\Delta_2)\\+\beta(C_d-\Delta_6)\end{pmatrix}\left(\begin{aligned}&a_1\left\{\begin{aligned}&T(T-t_0)-\left(\frac{1+\beta T}{2}\right)(T^2-t_0^{\,2})\\&+\frac{\beta}{3}(T^3-t_0^{\,3})\end{aligned}\right\}\\&+b_1\left(\frac{2}{3}T^3-T^2t_0+\frac{t_0^{\,3}}{3}\right)+b_2\left(\frac{3}{4}T^4-T^3t_0+\frac{t_0^{\,4}}{4}\right)\\&-b_3\left(\frac{4}{5}T^5-T^4t_0+\frac{t_0^{\,5}}{5}\right)\end{aligned}\right)\end{aligned}\right)$$

Using Signed distance method, the objective inventory cost function is

$$\tilde{d}(A_{TIC})=A_{TIC}(t_0,t_d)+\frac{1}{T}\left(\begin{aligned}&\frac{(\Delta_4-\Delta_3)}{4}+\frac{(\Delta_2-\Delta_1)}{4}\left\{Q_0t_0-a_1\frac{t_0^{\,2}}{2}+a_2\frac{t_0^{\,3}}{6}\right\}\\&+\alpha.\frac{(\Delta_6-\Delta_5)}{4}\left(\begin{aligned}&a_1\left\{\begin{aligned}&T\frac{(T^2-t_0^{\,2})}{2}-(1+\beta T)\frac{(T^3-t_0^{\,3})}{3}\\&+\beta\frac{(T^4-t_0^{\,4})}{4}\end{aligned}\right\}\\&+b_1\left(\frac{T^4}{4}-\frac{T^2t_0^{\,2}}{2}+\frac{t_0^{\,4}}{4}\right)+b_2\left(\frac{3T^5}{10}-\frac{T^3t_0^{\,2}}{2}+\frac{t_0^{\,5}}{5}\right)\\&-b_3\left(\frac{T^6}{3}-\frac{T^4t_0^{\,2}}{2}+\frac{t_0^{\,6}}{6}\right)\end{aligned}\right)\\&+\begin{pmatrix}\dfrac{(\Delta_2-\Delta_1)}{4}\\+\beta\dfrac{(\Delta_6-\Delta_5)}{4}\end{pmatrix}\left(\begin{aligned}&a_1\left\{\begin{aligned}&T(T-t_0)-\left(\frac{1+\beta T}{2}\right)(T^2-t_0^{\,2})\\&+\frac{\beta}{3}(T^3-t_0^{\,3})\end{aligned}\right\}\\&+b_1\left(\frac{2}{3}T^3-T^2t_0+\frac{t_0^{\,3}}{3}\right)+b_2\left(\frac{3}{4}T^4-T^3t_0+\frac{t_0^{\,4}}{4}\right)\\&-b_3\left(\frac{4}{5}T^5-T^4t_0+\frac{t_0^{\,5}}{5}\right)\end{aligned}\right)\end{aligned}\right)$$

Which is the objective inventory cost for the examined of the fuzzy based inventory model for linearly decreasing demand and linearly increasing deterioration rate.

## Conclusion

This article deals with a fuzzy-based inventory system where the fuzzy approach is applied to obtain the optimal inventory cost function in an uncertain environment. The demand function is linearly decreasing function of time and the deterioration rate is linearly increasing function of time. For the proposed model, a method of defuzzification, namely the signed distance method is employed to determine the optimal inventory cost in the fuzzy sense. The present work model will be useful to decision makers to determine the optimal order quantity and minimize the system cost of products like medicine, cosmetic and pharmaceutical products etc., for the benefit of company. A relative research study that assumed our examined policy with the most relevant inventory policies from the literary work which we adopt in our inventory system is shown. A future work will be further incorporate in the developed model by introducing shortages, partial backlogging, trade credit, profit based, inflation and production based in this imprecise environments. The proposed system is also applicable to another inventory system under an uncertain environment.

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