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# Continuous review inventory model under fuzzy environment without backorder for deteriorating items

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**Abstract**
In this paper we have developed a continuous review inventory model for deteriorating items without shortage under fuzzy environment. Linear demand rate and uncertain cycle time is taken and it is possible to describe it by symmetric triangular fuzzy number. The results are illustrated with the help of numerical example. If the uncertainties are accounted for inappropriate manner, the percent of increase in cycle time is also discussed. A sensitivity analysis is carried out to demonstrate the effects of changing different parameter values on the optimal solution of the system.

**Keywords:** Deterioration, EOQ Model, Fuzzy variable, Inventory, Triangular Fuzzy number

## 1. Introduction

Inventory control plays an important role as the total investment in inventories of various kinds is quite important. Almost every business must carry out some inventory for smooth and efficient running of its operation. The problem is to take decisions that how much should be stocked and when should be stocked for un-interrupted production. First time fuzzy set theory is introduced in fuzzy decision making process by Bellan and Zadeh [12]. It is better to use fuzzy numbers rather than probabilistic approaches for the new products and seasonal items showed by Zadeh [18, 19]. The concepts of fuzzy sets to decision making problems by considering the objectives as fuzzy goals over the α-cuts of a fuzzy constraints set is applied by Tanaka *et al.*[11] and it is showed that the classical algorithms can be used to solve multi-objective fuzzy linear programming problems by Zimmermann [13]. Sometimes the uncertainties can be captured stochastically showed by Liberatore [2]. Economic reorder point for fuzzy backorder quantity is developed by Chang, Yao and Lee [6]. Fuzzy inventory model with backorder for fuzzy order quantity is established by Yao and Lee [10]. A minimax distribution free procedure for mixed inventory model with variable lead time is discussed by Ouyang and Wu [16]. A minimax distribution free procedure for mixed inventory model involving variable lead time with fuzzy demand is developed by Ouyang and Yao [5]. A fuzzy inventory of two replaceable merchandises without backorder based on the signed distance of fuzzy sets is established by Yao *et al.* [17]. Model of Salameh and Jaber [15] is modified in which the author developed an application of fuzzy sets theory to the EOQ model with imperfect quality items by Chang [8]. Inventory model without backorder with fuzzy total cost and fuzzy storing cost defuzzified by centroid and signed distance is developed by Yao and Chiang [14]. New models of continuous review inventory control with or without backorder in the presence of uncertainty are developed by Tütüncü *et al.* [7]. They used fuzzy set concepts to treat imprecision regarding the costs of continuous review inventory control.

The effect of deterioration is very important aspect of inventory systems. Deterioration refers to decay or damage or spoilage or vaporized such that the item can’t be used for its original purpose. Food items, drugs, pharmaceuticals, radioactive substances are examples of that kind of items. This kind of real life situation was first captured by Whitin [4] who considered fashion goods deteriorating at the end of a prescribed storage period. An inventory model with a constant rate of deterioration is developed by Ghare and Schrader [9]. An order level inventory model for items deteriorating at a constant rate was discussed by Shah and Jaiswal [1]. The error of calculating the average inventory holding cost in the work of Shah and

Jaiswal [14] is rectified and reconsidered the model by Aggarwal [3]. An EOQ model for deteriorating items with stock-dependent time varying demand is discussed by Roy and Samanta [23]. A deterministic inventory model of deteriorating items with two different types of rates of production is developed by Samanta and Roy [21]. A production inventory model with deteriorating items is explained by Samanta and Roy [20]. An inventory model of deteriorating items with time varying demand is introduced by Roy and Samanta [22].

In this paper we develop a continuous inventory model without shortage for deteriorating items under the fuzzy environment by assuming linear demand rate. To capture the real life situation we are considering that the cycle time is uncertain and it is possible to describe it by triangular fuzzy number (symmetric). Some assumptions and notation we have considered is as below to develop the model.

## 2. Notations and Assumptions

Following are the notations and assumption used for developing the model.

(i) $f(t) = at + b$ is the demand rate at time $t$ defined in the interval $(0, T)$ where a and b are positive constants.

(ii) Replenishment is instantaneous and lead-time is zero.

(iii) No shortage in inventory is allowed.

(iv) $C$is the unit cost of the item.

(v) $h$is the holding cost per unit per unit time.

(vi) $A$is the replenishment cost per cycle.

(vii) $T$is the length of a cycle and it is uncertain.

(viii) $\theta$is the constant deterioration rate where $0 < \theta << 1$.

## 3. The Mathematical Model and Its Analysis

First we will discuss about crisp model. Let $Q(t)$ be the on-hand inventory at time $t$ where$0 \le t \le T$. In this model, uniform replenishment rate starts with inventory level $q$. The inventory level decreases due to both demand and deterioration. Ultimately the inventory reaches 0 at the end of the cycle time $T$. Then the differential equation governing the instantaneous state of $Q(t)$ at any time $t$is given by:

$$\frac{d}{dt}Q(t) + \theta Q(t) = -at - b; \text{Where } Q(0) = q \text{ and } Q(T) = 0. \quad (1)$$

Solving the above linear differential equation we have,

$$Q(t) = \frac{-a}{\theta^2}(\theta t - 1) - \frac{b}{\theta} + Ce^{-\theta t}, \qquad \text{Where C is constant of integration} \quad (2)$$

By substituting $Q(0) = q$ in (2) we have

$$C = q - \frac{a}{\theta^2} + \frac{b}{\theta}$$

Therefore from (2),

$$Q(t) = \frac{-a}{\theta^2}(\theta t - 1) - \frac{b}{\theta} + \left(q - \frac{a}{\theta^2} + \frac{b}{\theta}\right)e^{-\theta t} \quad (2a)$$

Again by substituting $Q(T) = 0$ in (2) we have

$$q - \frac{a}{\theta^2} + \frac{b}{\theta} = \left[\frac{a}{\theta^2}(\theta T - 1) + \frac{b}{\theta}\right]e^{\theta T}$$

From (2a) we have,

$$Q(t) = \frac{-a}{\theta^2}(\theta t - 1) - \frac{b}{\theta} + \left[\frac{a}{\theta^2}(\theta T - 1) + \frac{b}{\theta}\right]e^{\theta T}e^{-\theta t} = \frac{a}{\theta^2}\left[(\theta T - 1)e^{\theta(T-t)} - (\theta t - 1)\right] + \frac{b}{\theta}\left[e^{\theta(T-t)} - 1\right]$$
$$= \frac{a}{\theta^2}\left[(\theta T - 1)\left\{1 + \theta(T-t) + \frac{\theta^2(T-t)^2}{2!} + \frac{\theta^3(T-t)^3}{3!} + \frac{\theta^4(T-t)^4}{4!} + \cdots\right\} - (\theta t - 1)\right]$$
$$+ \frac{b}{\theta}\left[\left\{1 + \theta(T-t) + \frac{\theta^2(T-t)^2}{2!} + \frac{\theta^3(T-t)^3}{3!} + \frac{\theta^4(T-t)^4}{4!} + \cdots\right\} - 1\right]$$
$$= \frac{a}{\theta^2}\left[\theta(T-t) + (\theta T - 1)\left\{\theta(T-t) + \frac{\theta^2(T-t)^2}{2!} + \frac{\theta^3(T-t)^3}{3!} + \frac{\theta^4(T-t)^4}{4!} + \cdots\right\}\right]$$
$$+ \frac{b}{\theta}\left[\theta(T-t) + \frac{\theta^2(T-t)^2}{2!} + \frac{\theta^3(T-t)^3}{3!} + \frac{\theta^4(T-t)^4}{4!} + \cdots\right] \quad (3)$$

Neglecting higher powers of $\theta$ we have,

$$Q(t) = \frac{a}{\theta}(T-t) + a(T-t)(\theta T - 1)\left[\frac{1}{\theta} + \frac{T-t}{2} + \frac{\theta(T-t)^2}{6} + \frac{\theta^2(T-t)^3}{24}\right] + b(T-t)\left[1 + \frac{\theta(T-t)}{2!} + \frac{\theta^2(T-t)^2}{3!} \ldots\right] \quad (4)$$

The inventory $I_T$ in a cycle is given by:

$$I_T = \int_0^T Q(t)dt = \frac{a}{\theta}\int_0^T (T-t)dt + a(\theta T - 1)\int_0^T \left[\frac{(T-t)}{\theta} + \frac{(T-t)^2}{2} + \frac{\theta(T-t)^3}{6} + \frac{\theta^2(T-t)^4}{24}\right]dt$$

$$+b\int_0^T\left[(T-t)+\frac{\theta(T-t)^2}{2}+\frac{\theta^2(T-t)^3}{6}\right]dt$$
$$=\frac{a}{\theta}\frac{T^2}{2}+\ a(\theta T-1)\left[\frac{1}{\theta}\frac{T^2}{2}+\frac{1}{2}\frac{T^3}{3}+\frac{\theta}{6}\frac{T^4}{4}+\frac{\theta^2}{24}\frac{T^5}{5}\right]+b\left[\frac{T^2}{2}+\frac{\theta}{2}\frac{T^3}{3}+\frac{\theta^2}{6}\frac{T^4}{4}\right]$$
$$=a\left[\frac{T^3}{3}+\frac{\theta T^4}{8}+\frac{\theta^2T^5}{30}\right]+b\left[\frac{T^2}{2}+\frac{\theta T^3}{6}+\frac{\theta^2T^4}{24}\right] \tag{5}$$

Total deterioration in a cycle:

$$D=q-\text{Total demand}=q-\int_0^T(at+b)dt$$
$$=\left[\frac{a}{\theta^2}(\theta T-1)+\frac{b}{\theta}\right]e^{\theta T}+\frac{a}{\theta^2}-\frac{b}{\theta}-\frac{aT^2}{2}-bT$$
$$=\frac{a}{\theta^2}\left[\left(\theta T+\theta^2T^2+\frac{\theta^3T^3}{2}+\frac{\theta^4T^4}{6}\right)-\left(1+\theta T+\frac{\theta^2T^2}{2}+\frac{\theta^3T^3}{6}+\frac{\theta^4T^4}{24}\right)\right]+\frac{b}{\theta}\left(1+\theta T+\frac{\theta^2T^2}{2}+\frac{\theta^3T^3}{6}\right)+\frac{a}{\theta^2}-\frac{b}{\theta}-\frac{aT^2}{2}-bT$$
$$=\frac{a\theta T^3}{3}+\frac{a\theta^2T^4}{8}+\frac{b\theta T^2}{2}+\frac{b\theta^2T^3}{6} \tag{6}$$

The average system cost:

$$C(T)=\frac{1}{T}[A+CD+hI_T] \tag{7}$$
$$=\frac{A}{T}+C\left(\frac{a\theta T^2}{3}+\frac{a\theta^2T^3}{8}+\frac{b\theta T}{2}+\frac{b\theta^2T^2}{6}\right)+ah\left(\frac{T^2}{3}+\frac{\theta T^3}{8}+\frac{\theta^2T^4}{30}\right)+bh\left(\frac{T}{2}+\frac{\theta T^2}{6}+\frac{\theta^2T^3}{24}\right) \tag{8}$$

**4. Fuzzy Continuous Review Inventory Model without Backorder**

Let us consider that the cycle time is uncertain and it is possible to describe it with triangular fuzzy number (symmetric). Then the cycle time is $\tilde{T}=(T-\Delta,T,T+\Delta)$.

So from equation (7) & (8) the cost function with fuzzy cycle time is:

$$\tilde{C}(\tilde{T})=\frac{1}{\tilde{T}}[A+C\tilde{D}+h\tilde{I}_T]$$
$$=\frac{A}{\tilde{T}}+C\left(\frac{a\theta\tilde{T}^2}{3}+\frac{a\theta^2\tilde{T}^3}{8}+\frac{b\theta\tilde{T}}{2}+\frac{b\theta^2\tilde{T}^2}{6}\right)+ah\left(\frac{\tilde{T}^2}{3}+\frac{\theta\tilde{T}^3}{8}+\frac{\theta^2\tilde{T}^4}{30}\right)+bh\left(\frac{\tilde{T}}{2}+\frac{\theta\tilde{T}^2}{6}+\frac{\theta^2\tilde{T}^3}{24}\right)$$

To defuzzify the cost function we will introduce the signed distance. We know the signed distance from a to 0 is $d_0(a,0)=a$ for all $a\in R$. Let α be the family of all fuzzy sets $\tilde{B}$ defined on R for which the α -cut $B(\alpha)=[B_L(\alpha),B_U(\alpha)]$exists for every $\alpha\in[0,1]$. Both $B_L(\alpha)$ and $B_U(\alpha)$ are continuous functions on $\alpha\in[0,1]$. Then we can say for any $\tilde{B}\in\ \Psi$ we have

$$\tilde{B}=\bigcup_{0\le\alpha\le1}[B_L(\alpha),B_U(\alpha)]$$

So for $\tilde{B}\in\ \Psi$ we can define the signed distance from $\tilde{B}$to $\tilde{0}$ (Y-axis) as:

$$d(\tilde{B},\tilde{0})=\frac{1}{2}\int_0^1[B_L(\alpha)+B_U(\alpha)]d\alpha$$

For the fuzzy triangular number$\tilde{A}=(a,b,c)$, the $\alpha$- cut of $\tilde{A}$ is$A(\alpha)=[A_L(\alpha),A_U(\alpha)]$ for $\alpha\in[0,1]$, where $A_L(\alpha)=a-(b-c)\alpha$ and$A_U(\alpha)=c+(a-b)\alpha$

The signed distance of $\tilde{A}$ to $\tilde{0}$ (Y-axis) is $d(\tilde{A},\tilde{0})=\frac{1}{4}(3a-2b+3c)$

The signed distance of $C(T)$ and 0 is:

$$d(\tilde{C},\tilde{0})=Ad\left(\frac{1}{\tilde{T}},\tilde{0}\right)+C\left[\frac{a\theta}{3}\left(d(\tilde{T},\tilde{0})\right)^2+\frac{a\theta^2}{8}\left(d(\tilde{T},\tilde{0})\right)^3+\frac{b\theta}{2}d(\tilde{T},\tilde{0})+\frac{b\theta^2}{6}\left(d(\tilde{T},\tilde{0})\right)^2\right]$$
$$+ah\left[\frac{1}{3}\left(d(\tilde{T},\tilde{0})\right)^2+\frac{\theta}{8}\left(d(\tilde{T},\tilde{0})\right)^3+\frac{\theta^2}{30}\left(d(\tilde{T},\tilde{0})\right)^4\right]$$

$$+bh\left(\frac{1}{2}d(\tilde{T},\tilde{0})+\frac{\theta}{6}\left(d(\tilde{T},\tilde{0})\right)^2+\frac{\theta^2}{24}\left(d(\tilde{T},\tilde{0})\right)^3\right) \tag{9}$$

From the definition of signed distance we can write $d(\tilde{T},\tilde{0}) = T$ (10)
and as $\tilde{T} \in \Psi$ where $\Psi$ be the family of all fuzzy sets $\tilde{T}$ defined on R for which $\alpha$-cut$T(\alpha) = [T_L(\alpha), T_U(\alpha)]$exists for every $\alpha \in [0, 1]$ and both $T_L(\alpha)$ and $T_U(\alpha)$ are continuous functions on $\alpha \in [0, 1]$. Then for $\tilde{T} \in \Psi$, the signed distance is:

$$d\left(\frac{1}{\tilde{T}},\tilde{0}\right)=\frac{1}{2}\int_0^1\left[\left(\frac{1}{T}\right)_L(\alpha)+\left(\frac{1}{T}\right)_U(\alpha)\right]d\alpha$$

$$=\frac{1}{2}\int_0^1\left[\frac{1}{T-\Delta+\Delta\alpha}+\frac{1}{T+\Delta-\Delta\alpha}\right]d\alpha$$

$$=\frac{1}{2\Delta}\log\left(\frac{T+\Delta}{T-\Delta}\right) \tag{11}$$

Using equations (10) & (11) in equation (9) the defuzzified total cost is:

$$C(T) = d(\tilde{C}(\tilde{T}),\tilde{0})$$

$$=\frac{A}{2\Delta}\log\left(\frac{T+\Delta}{T-\Delta}\right)+C\left(\frac{a\theta T^2}{3}+\frac{a\theta^2T^3}{8}+\frac{b\theta T}{2}+\frac{b\theta^2T^2}{6}\right)+ah\left(\frac{T^2}{3}+\frac{\theta T^3}{8}+\frac{\theta^2T^4}{30}\right)+bh\left(\frac{T}{2}+\frac{\theta T^2}{6}+\frac{\theta^2T^3}{24}\right) \tag{12}$$

Theorem: - The average system cost function $C(T)$ given by equation (12) is strictly convex.
Proof:-

$$\frac{dC(T)}{dT}=\frac{-A}{T^2-\Delta^2}+C\left(\frac{2a\theta T}{3}+\frac{3a\theta^2T^2}{8}+\frac{b\theta}{2}+\frac{b\theta^2T}{3}\right)+ah\left(\frac{2T}{3}+\frac{3\theta T^2}{8}+\frac{2\theta^2T^3}{15}\right)+bh\left(\frac{1}{2}+\frac{\theta T}{3}+\frac{\theta^2T^2}{8}\right) \tag{13}$$

$$\frac{d^2C(T)}{dT^2}=\frac{2AT}{(T^2-\Delta^2)^2}+C\left(\frac{2a\theta}{3}+\frac{3a\theta^2T}{4}+\frac{b\theta^2}{3}\right)+ah\left(\frac{2}{3}+\frac{3\theta T}{4}+\frac{2\theta^2T^2}{5}\right)+bh\left(\frac{\theta}{3}+\frac{\theta^2T}{4}\right)>0 \tag{14}$$

Therefore $C(T)$ is strictly convex.
Since $C(T)$ is strictly convex in $T$ , there exists a unique optimal cycle time $T^*$that minimizes $C(T)$. This optimal cycle time $T^*$is the solution of the equation $\frac{dC(T)}{dT} = 0$.
If there is no uncertainty($\Delta = 0$) then the fuzzy model will convert into the crisp model. From the first term of the equation (12) we have,

$$\frac{1}{2\Delta}\log\left(\frac{T+\Delta}{T-\Delta}\right)=\frac{1}{2\Delta}\left[\log\left(1+\frac{\Delta}{T}\right)-\log\left(1-\frac{\Delta}{T}\right)\right]=\frac{1}{T}\left[1+\frac{1}{3}\left(\frac{\Delta}{T}\right)^2+\cdots\right] \tag{15}$$

If we consider the limit as $\theta \to 0$ for equation (13) and put $\frac{dC(T)}{dT} = 0$, we have

$$\frac{2ahT}{3}+\frac{bh}{2}=\frac{A}{T^2-\Delta^2}$$

Since $\Delta = 0$, we have, $\quad 4ah(T^*)^3 + 3bh(T^*)^2 - 6A = 0$
Again as $\theta \to 0$, From equations (12) and (15) we have,

$$C(T^*) = \frac{A}{T^*}+\frac{1}{3}ah(T^*)^2+\frac{1}{2}bhT^*$$

## 5. Numerical

Given $A = 51, a = 5, h = 12, \theta = 0.01, \Delta = 0.05, C - 10\ and\ b = 1$.
For crisp model, cycle time $T = 1.036586$, total cost $C(T) = 77.2468$
and for fuzzy model, cycle time $T = 1.037425$, total cost $C(T) = 77.2855$
So the result shows that if the uncertainties are accounted for in appropriate manner the cycle time would increase 0.08%.

## 6. Sensitivity Analysis

The sensitivity analysis is performed by changing the value of each of the parameters by –50%,-20%, 20% and 50%, taking one parameter at time and keeping the remaining parameters unchanged. We now study sensitivity of the optimal solution to changes in the values of the different parameters associated with the system based on the above example.
A careful study of Table 1: sensitivity analysis reveals the following points:

(i) Cycle time $T$is constant to changes in the values of the parameters $C, \theta$ and it is slightly sensitive to changes in the values of the parameters $h, a$ and it is moderately sensitive to changes in $\Delta, A$.

(ii) Crisp system cost is unchanged to changes in the values of the parameters $\Delta$ and moderately sensitive to changes in $C, \theta$ and highly sensitive to changes in $h, a\ and\ A$.

(iii) Fuzzy system cost is slightly sensitive to changes in the values of the parameters $\Delta$ and it is moderately sensitive to changes in $C, \theta$ and highly sensitive to changes in $h, a\ and\ A$.

Here we have assumed that insensitive, moderately sensitive and highly sensitive imply % changes are +10 to –10, +50 to –50 and more respectively.

**Table 1:** Sensitivity Analysis

| Parameter | % Change | % Change in T | % Change in Crisp cost | % Change in Fuzzy cost |
|---|---|---|---|---|
| C | -50 | 0.0809 | 0.15003 | 0.15017 |
| | -20 | 0.0809 | 0.06001 | 0.06007 |
| | 20 | 0.0809 | 0.06001 | 0.06007 |
| | 50 | 0.0809 | 0.15003 | 0.15017 |
| H | -50 | 0.049639 | 21.70427 | 21.71888 |
| | -20 | 0.06908 | 7.62976 | 7.63624 |
| | 20 | 0.09207 | 6.74258 | 6.74961 |
| | 50 | 0.10794 | 15.673 | 15.69138 |
| A | -50 | 0.05487 | 16.8691 | 16.88367 |
| | -20 | 0.07116 | 5.95544 | 5.9616 |
| | 20 | 0.09001 | 5.26887 | 5.27533 |
| | 50 | 0.10278 | 12.24233 | 12.25887 |
| θ | -50 | 0.0809 | 0.21857 | 0.21884 |
| | -20 | 0.0809 | 0.08752 | 0.08763 |
| | 20 | 0.0809 | 0.08764 | 0.08775 |
| | 50 | 0.0809 | 0.21933 | 0.21959 |
| Δ | -50 | 0.02024 | 0 | 0.03759 |
| | -20 | 0.05179 | 0 | 0.01805 |
| | 20 | 0.11644 | 0 | 0.02206 |
| | 50 | 0.18182 | 0 | 0.06268 |
| A | -50 | 0.2979 | 35.70245 | 35.68183 |
| | -20 | 0.21299 | 13.29267 | 13.28449 |
| | 20 | 0.15983 | 12.39356 | 12.388 |
| | 50 | 0.13658 | 29.71629 | 29.70163 |

## 7. Conclusions

In this paper we have developed the fuzzy continuous inventory model without shortage for deteriorating items. To capture the real life situation we have considered that the cycle time is uncertain and it is possible to describe it by symmetric triangular fuzzy number. Numerically we tried to compare the crisp model with fuzzy model and we concluded that if the uncertainties are accounted for in appropriate manner the cycle time would increase. Sensitivity analysis is also carried out to see how far the output of the model is affected by changes or errors in its input parameters based on the numerical example. In future we will study the fuzzy continuous inventory model with shortage.

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