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FUZZY EOQ MODEL WITH PENALTY COST USING HEXAGONAL FUZZY NUMBERS

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ABSTRACT

In this paper, a fuzzy inventory model for time-degenerating items using penalty cost under the conditions of infinite production rate is formulated and solved. Here, the penalty cost is assumed under two cases such as linear and exponential. The holding cost and setup cost and the demand rate are assumed to be fuzzy. In fuzzy environment all related parameters are assumed to be hexagonal. Representing these three costs by hexagonal fuzzy numbers, the optimum order quantity is calculated using signed distance method for defuzzification .Numerical examples have been given in order to show the applicability of the proposed model.

Keywords: Fuzzy inventory model, Hexagonal fuzzy number, Penalty cost, Defuzzification.

I. INTRODUCTION

Inventory control is essential for our day-to-day life problems and theoretical research oriented problems. In conventional inventory models, the uncertainties are treated as randomness and handled by using probability theory. The most widely used inventory model is the economic order quantity (EOQ) model. This model was developed by Harris [3], Wilson [13].Later Hadley [2] analyzed many inventory systems. But uncertainties due to fuzziness primarily introduced by Zadeh [15].Zadeh et al [15] proposed some strategies for decision making in fuzzy environment.Kacpryzk et al [5] discussed some long-term inventory policy making through fuzzy-decision making models.

Products like fresh vegetables, fruits, bakery items etc. do not deteriorate at the beginning of the period but they continuously deteriorate after some time. As a result, the selling price of such product decreases which can be considered as a penalty cost.Srinivastava and Gupta [10] have proposed an EOQ model for time-deteriorating items using penalty cost.

Fujiwara and Pereira [1] have proposed an EOQ model for time continuously deteriorating items using linear and exponential penalty cost.Pevekar and Negara [9] developed an inventory model for timely deteriorating products considering penalty cost and shortage cost. Park[8] and Vujosevic et al [8] developed the inventory model is fuzzy sense whereas ordering cost and holding cost are represented by fuzzy numbers.Maragatham and Lakshmi Devi [6] have proposed a fuzzy inventory model for deteriorating items with piece dependent demand.

In this paper, fuzzy EOQ model for time deteriorating items using penalty cost is considered where holding cost setup cost and demand rate are assumed as hexagonal fuzzy numbers. For defuzzification of the total cost function, signed distance method is used.

II. DEFINITIONS

Hexogonal fuzzy numbers

A fuzzy number on $\tilde{A}$ is a hexagonal fuzzy number, denoted by A = $(a_1, a_2, a_3, a_4, a_5, a_6)$ where $(a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6)$ are real numbers satisfying $a_2 - a_1 \le a_3 - a_2$ and $a_5 - a_4 \le a_6 - a_5$ and its membership function $\mu_{\tilde{A}}(x)$ is given as

$$\mu_{\tilde{A}}(x)=\begin{cases}0, x<a_1\\ \frac{1}{2}\left(\frac{x-a_1}{a_2-a_1}\right), a_1\le x\le a_2\\ \frac{1}{2}+\frac{1}{2}\left(\frac{x-a_2}{a_3-a_2}\right), a_2\le x\le a_3\\ 1, a_3\le x\le a_4\\ 1-\frac{1}{2}\left(\frac{x-a_4}{a_5-a_4}\right), a_4\le x\le a_5\\ \frac{1}{2}\left(\frac{a_6-x}{a_6-a_5}\right), a_5\le x\le a_6\\ 0, x>a_6\end{cases}$$

Fuzzy arithmetical operations

Suppose $\tilde{A}=(a_1,a_2,a_3,a_4,a_5,a_6)$ and $\tilde{B}=(b_1,b_2,b_3,b_4,b_5,b_6)$ are two hexagonal fuzzy numbers, then the arithmetic operations are defined as

1. $\tilde{A}+\tilde{B}=\left(a_1+b_1,a_2+b_2,a_3+b_3,a_4+b_4,a_5+b_5,a_6+b_6\right)$
2. $\tilde{A}*\tilde{B}=\left(a_1b_1,a_2b_2,a_3b_3,a_4b_4,a_5b_5,a_6b_6\right)$
3. $\tilde{A}-\tilde{B}=\left(a_1-b_6,a_2-b_5,a_3-b_4,a_4-b_3,a_5-b_2,a_6-b_1\right)$
4. $\frac{\tilde{A}}{\tilde{B}}=\left(\frac{a_1}{b_6},\frac{a_2}{b_5},\frac{a_3}{b_4},\frac{a_4}{b_3},\frac{a_5}{b_2},\frac{a_6}{b_1}\right)$
5. $\alpha\tilde{A}=\begin{cases}\alpha a_1,\alpha a_2,\alpha a_3,\alpha a_4,\alpha a_5,\alpha a_6,\alpha\ge 0\\ \alpha a_6,\alpha a_5,\alpha a_4,\alpha a_3,\alpha a_2,\alpha a_1,\alpha<0\end{cases}$

III. SINGNED DISTANCE METHOD

Let A = (a,b,c,d,e,f) be a hexagonal fuzzy number then the signed distance method of $\tilde{A}$ is defined as

$$d\left(\tilde{A},0\right)=\frac{1}{2}\int_0^1\left(A_\alpha,\tilde{0}\right)d\alpha$$

where $A_\alpha=\left[A_L(\alpha),A_M(\alpha),A_R(\alpha)\right]$

$$A_\alpha=\left[a+(b-a)\alpha,d+(d-c)\alpha,e+(e-f)\alpha\right],\alpha\in[0,1]$$

Assumption

(i) A single product is considered over a prescribed period of T unit of time.
(ii) The replenishment occurs instantaneously at an infinite rate.
(iii) No back order is permitted.
(iv) Delivery leads time zero.

Notation

Q= Number of items received at the beginning of the period.
D= Demand rate.
H= Inventory holding cost
A= Setup cost per cycle

μ = Time period at which deterioration of product start.
C(T)= Average total variable cost per unit time.
T= Length of replenishment cycle, which will not exceed product lifetime.
T*= Optimum value of T.
Q*= Optimum value of Q.
$\tilde{H}$= Fuzzy inventory holding cost.
$\tilde{A}$= Fuzzy setup cost per cycle.
$\tilde{D}$= Fuzzy demand rate $\tilde{D}$.
$\tilde{C}$(T)= Average total fuzzy variable cost per unit time.
C_{ds} (T)= Defuzzified value of $\tilde{C}$(T) by applying signed distance method.

IV. MATHEMATICAL MODEL

Crisp model
In this context, we have considered two types of penalty cost function of age.

- Linear
- Exponentials penalty cost functions, as a measurement of utility of the product.

A linear penalty cost function

$$P(t)=\begin{cases}\pi(t-\mu), t\geq\mu \\ 0, otherwise\end{cases}$$

which also gives the cost of keeping one unit of product in stock until age t, where μ be the time period at which degeneration of product starts and α and β are constants.

The total variable cost per cycle time consists of the inventory holding cost, setup cost and penalty cost. Since,

- The demand rate is D unit per time.
- The total demand is one cycle of time interval is T = DT.
- The number of items received at the beginning of the period is Q = DT ------- (1)

Inventory model in crisp sense

Case I (When linear penalty cost function is used)
A linear penalty cost function P(T) = $\pi(t-\mu)$ $t\geq\mu$ which gives the cost of keeping one unit of product in stock until age t where μ be the time period at which degeneration of product starts and π is constant.

The cost due to the degeneration of the product delivered during the period (t,t+dt) is given by $\pi(t-\mu)Ddt$.
Thus penalty cost due to the degeneration of the product delivered during the time interval (μ ,T) is given by

$$\int_{\mu}^{T}\pi D(t-\mu)dt=\pi D\left[\frac{T^2}{2}-\mu T+\frac{\mu^2}{2}\right] \qquad \text{------------------ (2)}$$

Now, inventory holding cost for the period (O,T) is given by

$$\mathrm{H}\frac{1}{2}\mathrm{QT}=\frac{1}{2}\mathrm{HD}T^2 \qquad (\because \mathrm{Q}=\mathrm{DT})$$

Therefore, the average total cost per unit time C(T) is given by

$$C(T)=\frac{1}{T}\left[A+\frac{\pi D\mu^2}{2}\right]+\left[\frac{HD}{2}+\frac{\pi D}{2}\right]T-\pi D\mu$$

The optimal solution is obtained by differentiating C(T) with respect to t and equating it to zero. Then the optimal cycle time T* is obtained and expressed as

$$T^*=\sqrt{\frac{2A+\pi D\mu^2}{(\pi+H)D}} \qquad \text{------------------ (3)}$$

The optimal economic order quantity Q* is obtained by putting value of T* in equation

$$Q^*=\sqrt{\frac{D(2A+\pi D\mu^2)}{(\pi+H)}} \qquad \text{-------------------- (4)}$$

From the above expressions, it is clear that if there is no perishables (i.e.) $\pi=0$,then these two expression become same as that of the non-perishable lot size model.

Case II (When exponential penalty cost function is used)

An exponential penalty cost function P(t) = $\alpha\left(e^{\beta(t-\mu)}-1\right), t\geq\mu$ which gives the cost of keeping one unit of product in stock until age t where μ be the time period at which deterioration of product starts α and β are constants.

The cost due to the deterioration of the product delivered during the time interval (μ ,T) is given by

$$\int_{\mu}^{T} D\alpha\left(e^{\beta(t-\mu)}-1\right)dt=\frac{\alpha D}{\beta}\left[\left(e^{\beta(t-\mu)}-1\right)-\beta(T-\mu)\right]$$

Therefore, total variable cost per unit time is given by

$$C(T)=\frac{A}{T}+\frac{1}{2}HDT+\frac{\alpha D}{\beta T}\left[\left(e^{\beta(t-\mu)}-1\right)-\beta(T-\mu)\right]$$

By using second order approximation of the exponential

We get, $C(T)=\frac{A}{T}+\frac{1}{2}HDT+\frac{1}{2}\alpha D\beta T+\frac{1}{2T}\alpha D\mu^2\beta-\alpha D\mu\beta$

The optimal solution is obtained by differentiating C(T) with respect to T and equating it to zero.
Then, the optimal cycle T* is obtained and expressed as,

$$T^*=\sqrt{\frac{2A+\alpha D\beta\mu^2}{D(H+\alpha\beta)}} \qquad \text{---------------- (5)}$$

The optimal economic order quantity Q* is obtained by putting value of T* in equation (4.1)

$$Q^*=\sqrt{\frac{D\left(2A+\alpha D\beta\mu^2\right)}{(H+\alpha\beta)}} \qquad \text{--------------- (6)}$$

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From the expression (5) and (6) it is clear that if μ =0 and $\alpha\beta = TT$ then these two expressions are same as (3) and (4).

V. FUZZY MODEL

Case I (When linear penalty cost function is used)

Due to uncertainty in the environment, it is not easy to define all the parameters precisely. Accordingly we assume some of these parameters $\tilde{H}$, $\tilde{A}$ and $\tilde{D}$ may change with some limit.

Let $\tilde{H} = \left(H_1, H_2, H_3, H_4, H_5, H_6\right)$, $\tilde{A} = \left(A_1, A_2, A_3, A_4, A_5, A_6\right)$ and $\tilde{D} = \left(D_1, D_2, D_3, D_4, D_5, D_6\right)$ are hexagonal fuzzy numbers. The total variable cost per unit time in fuzzy sense is given by

$$\tilde{C}(T) = \frac{1}{T}\left[\tilde{A} + \frac{\pi \tilde{D}\mu^2}{2}\right] + \left[\frac{\tilde{H}\tilde{D}}{2} + \frac{\pi \tilde{D}}{2}\right]T - \pi \tilde{D}\mu$$

We defuzzify the fuzzy total cost $\tilde{C}(T)$ by using signed distance method.

By signed distance method, total cost is given by

$$C_{ds}(T) = \frac{1}{6}\left[C_{ds_1}(T), C_{ds_2}(T), C_{ds_3}(T), C_{ds_4}(T), C_{ds_5}(T), C_{ds_6}(T)\right]$$

where

$$C_{ds_1}(T) = \frac{1}{T}\left[A_1 + \frac{\pi D_1 \mu^2}{2}\right] + \left[\frac{H_1 D_1}{2} + \frac{\pi D_1}{2}\right]T - \pi D_1 \mu$$

$$C_{ds_2}(T) = \frac{1}{T}\left[A_2 + \frac{\pi D_2 \mu^2}{2}\right] + \left[\frac{H_2 D_2}{2} + \frac{\pi D_2}{2}\right]T - \pi D_2 \mu$$

$$C_{ds_3}(T) = \frac{1}{T}\left[A_3 + \frac{\pi D_3 \mu^2}{2}\right] + \left[\frac{H_3 D_3}{2} + \frac{\pi D_3}{2}\right]T - \pi D_3 \mu$$

$$C_{ds_4}(T) = \frac{1}{T}\left[A_4 + \frac{\pi D_4 \mu^2}{2}\right] + \left[\frac{H_4 D_4}{2} + \frac{\pi D_4}{2}\right]T - \pi D_4 \mu$$

$$C_{ds_5}(T) = \frac{1}{T}\left[A_5 + \frac{\pi D_5 \mu^2}{2}\right] + \left[\frac{H_5 D_5}{2} + \frac{\pi D_5}{2}\right]T - \pi D_5 \mu$$

$$C_{ds_6}(T) = \frac{1}{T}\left[A_6 + \frac{\pi D_6 \mu^2}{2}\right] + \left[\frac{H_6 D_6}{2} + \frac{\pi D_6}{2}\right]T - \pi D_6 \mu$$

$$C_{ds}(T) = \frac{1}{6}\left[C_{ds_1}(T) + C_{ds_2}(T) + C_{ds_3}(T) + C_{ds_4}(T) + C_{ds_5}(T) + C_{ds_6}(T)\right]$$

To minimize total cost function per unit time $C_{ds}(T)$;the optimal value of T can be obtained by solving the following equation

$$\frac{dc_{ds}(T)}{dT} = 0 \qquad \text{-------------------- (7)} \quad \text{provided}$$

$$\frac{d^2 c_{ds}(T)}{d^2(T)} > 0 \qquad \text{---------------- (8)}$$

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Equation (7) is equivalent to
$$\Rightarrow \frac{1}{6}\begin{bmatrix} -\frac{1}{T^2}\left(A_1+\frac{\pi D_1\mu^2}{2}\right)+\frac{H_1D_1}{2}+\frac{\pi D_1}{2} \\ -\frac{1}{T^2}\left(A_2+\frac{\pi D_2\mu^2}{2}\right)+\frac{H_2D_2}{2}+\frac{\pi D_2}{2} \\ -\frac{1}{T^2}\left(A_3+\frac{\pi D_3\mu^2}{2}\right)+\frac{H_3D_3}{2}+\frac{\pi D_3}{2} \\ -\frac{1}{T^2}\left(A_4+\frac{\pi D_4\mu^2}{2}\right)+\frac{H_4D_4}{2}+\frac{\pi D_4}{2} \\ -\frac{1}{T^2}\left(A_5+\frac{\pi D_5\mu^2}{2}\right)+\frac{H_5D_5}{2}+\frac{\pi D_5}{2} \\ -\frac{1}{T^2}\left(A_6+\frac{\pi D_6\mu^2}{2}\right)+\frac{H_6D_6}{2}+\frac{\pi D_6}{2} \end{bmatrix}=0$$

After simplification we get the optimal cycle time T* is obtained and expressed as

$$T^*=\sqrt{\frac{2\left(A_1+A_2+A_3+A_4+A_5+A_6\right)+\pi\mu^2\left(D_1+D_2+D_3+D_4+D_5+D_6\right)}{\left(H_1D_1+H_2D_2+H_3D_3+H_4D_4+H_5D_5+H_6D_6\right)+\pi\left(D_1+D_2+D_3+D_4+D_5+D_6\right)}}$$

The optimal economic order quantity Q* is

$$Q^*=\tilde{D}T^*=\left(D_1T^*,D_2T^*,D_3T^*,D_4T^*,D_5T^*,D_6T^*\right)$$

Case II (When exponential penalty cost of function is used)

Due to uncertainty in the environment, it is not easy to define all the parameters precisely. Accordingly, we assume some of these parameters $\tilde{H}$, $\tilde{A}$ and $\tilde{D}$ may change with some limit.

Let $\tilde{H}=\left(H_1,H_2,H_3,H_4,H_5,H_6\right)$, $\tilde{A}=\left(A_1,A_2,A_3,A_4,A_5,A_6\right)$ and $\tilde{D}=\left(D_1,D_2,D_3,D_4,D_5,D_6\right)$ be hexagonal fuzzy numbers.

The total variable cost per unit time in fuzzy sense is given by

$$\tilde{C}(T)=\frac{\tilde{A}}{T}+\frac{1}{2}\tilde{H}\tilde{D}T+\frac{1}{2}\alpha\tilde{D}\beta T+\frac{1}{2T}+\alpha\tilde{D}\mu^2\beta-\alpha\tilde{D}\mu\beta$$

We defuzzify the fuzzy total cost $\tilde{C}$(T) by signed distance method.

By signed distance method, total cost is given by

$$C_{ds}\left(T\right)=\frac{1}{6}\left[C_{ds_1}\left(T\right),C_{ds_2}\left(T\right),C_{ds_3}\left(T\right),C_{ds_4}\left(T\right),C_{ds_5}\left(T\right),C_{ds_6}\left(T\right)\right]$$

where

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$$C_{ds}(T) = \begin{cases} Cds_1(T) = \frac{A_1}{T} + \frac{1}{2}H_1D_1T + \frac{1}{2}\alpha D_1\beta T + \frac{1}{2T}\alpha D_1\mu^2\beta - \alpha D_1\mu\beta \\ Cds_2(T) = \frac{A_2}{T} + \frac{1}{2}H_2D_2T + \frac{1}{2}\alpha D_2\beta T + \frac{1}{2T}\alpha D_2\mu^2\beta - \alpha D_2\mu\beta \\ Cds_3(T) = \frac{A_3}{T} + \frac{1}{2}H_3D_3T + \frac{1}{2}\alpha D_3\beta T + \frac{1}{2T}\alpha D_3\mu^2\beta - \alpha D_3\mu\beta \\ Cds_4(T) = \frac{A_4}{T} + \frac{1}{2}H_4D_4T + \frac{1}{2}\alpha D_4\beta T + \frac{1}{2T}\alpha D_4\mu^2\beta - \alpha D_4\mu\beta \\ Cds_5(T) = \frac{A_5}{T} + \frac{1}{2}H_5D_5T + \frac{1}{2}\alpha D_5\beta T + \frac{1}{2T}\alpha D_5\mu^2\beta - \alpha D_5\mu\beta \\ Cds_6(T) = \frac{A_6}{T} + \frac{1}{2}H_6D_6T + \frac{1}{2}\alpha D_6\beta T + \frac{1}{2T}\alpha D_6\mu^2\beta - \alpha D_6\mu\beta \end{cases}$$

$$C_{ds}(T) = \frac{1}{6}\left[C_{ds_1}(T) + C_{ds_2}(T) + C_{ds_3}(T) + C_{ds_4}(T) + C_{ds_5}(T) + C_{ds_6}(T)\right]$$

To minimize total cost function per unit time $C_{ds}(T)$the optimal value of T can be obtained by solving the following equation

$$\frac{dc_{ds}(T)}{dT} = 0 \qquad \text{--------------- (9)}$$

provided

$$\frac{d^2c_{ds}(T)}{d^2(T)} > 0 \qquad \text{--------------- (10)}$$

Equation (9) is equalent to

$$\Rightarrow \frac{1}{6}\begin{bmatrix} \left[-\frac{A_1}{T^2} + \frac{1}{2}H_1D_1 + \frac{1}{2}\alpha D_1\beta - \frac{1}{2T^2}\alpha D_1\mu^2\beta\right] + \\ \left[-\frac{A_2}{T^2} + \frac{1}{2}H_2D_2 + \frac{1}{2}\alpha D_2\beta - \frac{1}{2T^2}\alpha D_2\mu^2\beta\right] + \\ \left[-\frac{A_3}{T^2} + \frac{1}{2}H_3D_3 + \frac{1}{2}\alpha D_3\beta - \frac{1}{2T^2}\alpha D_3\mu^2\beta\right] + \\ \left[-\frac{A_4}{T^2} + \frac{1}{2}H_4D_4 + \frac{1}{2}\alpha D_4\beta - \frac{1}{2T^2}\alpha D_4\mu^2\beta\right] + \\ \left[-\frac{A_5}{T^2} + \frac{1}{2}H_5D_5 + \frac{1}{2}\alpha D_5\beta - \frac{1}{2T^2}\alpha D_5\mu^2\beta\right] + \\ \left[-\frac{A_6}{T^2} + \frac{1}{2}H_6D_6 + \frac{1}{2}\alpha D_6\beta - \frac{1}{2T^2}\alpha D_6\mu^2\beta\right] \end{bmatrix} = 0$$

After simplification we get the optimal cycle time T* is obtained and expressed as

$$T^* = \sqrt{\frac{2(A_1 + A_2 + A_3 + A_4 + A_5 + A_6) + \alpha\mu^2\beta(D_1 + D_2 + D_3 + D_4 + D_5 + D_6)}{(H_1D_1 + H_2D_2 + H_3D_3 + H_4D_4 + H_5D_5 + H_6D_6) + \alpha\beta(D_1 + D_2 + D_3 + D_4 + D_5 + D_6)}}$$

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The optimal economic order quantity Q* is

$Q^* = \tilde{D} * \tilde{T} = (D_1T^*, D_2T^*, D_3T^*, D_4T^*, D_5T^*, D_6T^*)$

Numerical example

Crisp model

Let P=50 units per day, D=32 units per day, H=Rs.0.03 per day, μ =6 days, α =12, β =1, A =110.

Case I

When linear penalty cost function is used, then

- Optimum cycle time T*=6.14 days.
- Optimum order quantity Q*=196.8 units.

Case II

When exponential penalty cost function is used, then

- Optimum cycle time T*=6.04 days.
- Optimum order quantity Q*=193.2 units

Fuzzy model

Let P=50 units per day. μ =6 days, α =12, β =1

$\tilde{H}$ = (0.01, 0.02, 0.03, 0.04, 0.05, 0.06)

$\tilde{A}$ = (90, 95, 100, 105, 110, 115)

$\tilde{D}$ = (23, 26, 29, 32, 35, 38)

Case I

When linear penalty cost function is used, then

- Optimum cycle time T*= 6.14 days.
- Optimum order quantity Q*= (14119, 159.61, 178.02, 196.44, 214.86, 233.27) units.

Case II

When exponential penalty cost function is used, then

- Optimum cycle time T*=6.04 days.
- Optimum order quantity Q* = (138.85, 156.96, 175.07, 193.18, 211.29, 229.40) units.

VI. CONCLUSION

In this paper, a fuzzy EOQ model for time-degenerating items using penalty cost is studied. The demand rate, holding cost and set up cost are represented by hexagonal fuzzy numbers. It has been also fuzzified by using signed distance method. With the increased value of parameter μ will also result in increase of optimal cycle time and optimal order quantity. Similarly, with the decreased value of parameter μ will also result in decrease of optimal cycle time and optimal order quantity. It is concluded that the value of the optimal cycle time and optimal order quantity are not much sensitive to change in the value of the parameter μ implying that fuzzy model permits flexibility in the system inputs. The outcome of this research can be extended in future to the case of discount models.

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