Fuzzy Inventory Model for Deteriorating Items with Shortages under Fully Backlogged Condition

D. Dutta, Pavan Kumar

Abstract— In this paper, a fuzzy inventory model for deteriorating items with shortages under fully backlogged condition is formulated and solved. Deterioration rate and demand are assumed to be constant. Shortages are allowed and assumed to be fully backlogged. Fuzziness is introduced by allowing the cost components (holding cost, shortage cost, etc.), demand rate and the deterioration. In fuzzy environment, all related inventory parameters are assumed to be trapezoidal fuzzy numbers. The purpose of this paper is to minimize the total cost function in fuzzy environment. A numerical example is given in order to show the applicability of the proposed model. The convexity of the cost function is shown graphically. Sensitivity analysis is also carried out to detect the most sensitive parameters of the system. From sensitivity analysis, we show that the total cost function is extremely influenced by the holding cost, demand rate and the shortage cost.

Keywords—Inventory model, Trapezoidal fuzzy number, Fuzzy demand, Fuzzy deterioration.

I. INTRODUCTION


The effect of deterioration is very important in many inventory systems. Deterioration is defined as decay or damage such that the item cannot be used for its original purpose. Most of the physical goods undergo decay or deterioration over time. Commodities such as fruits, vegetables, foodstuffs, etc., suffer from depletion by direct spoilage while kept in store. Highly volatile liquids such as gasoline, alcohol, turpentine, etc., undergo physical depletion over time through the process of evaporation. In the development economic production lot size models, usually researchers consider the deterioration rate, demand rate, unit cost, etc., as fixed, but all of them probably will have some little fluctuations for each cycle in real life situation. So in practical situations, if these quantities are treated as fuzzy variables then it will be more realistic. In 2003, Sujit De Kumar, P. K. Kundu and A. Goswami [16] presented an economic production quantity inventory model involving fuzzy demand rate and fuzzy deterioration rate. In 2007, J. K. Syed and L. A. Aziz [17] applied signed distance method to Fuzzy inventory model without shortages. In 2011, P. K. De and A. Rawat [18] proposed a fuzzy inventory model without shortages using triangular fuzzy number. In 2012, C. K. Jaggi, S. Pareek, A. Sharma and Nidhi [19] presented a fuzzy inventory model for deteriorating items with time-varying demand and shortages. In 2012, Sumana Saha and Tripti Chakraborti [20] proposed a fuzzy EOQ model for time dependent deteriorating items and time dependent demand with shortages. Very recently, D. Dutta and Pavan Kumar published several papers in the area of fuzzy inventory with or with shortages. In 2012, presented a fuzzy inventory model without shortage using trapezoidal fuzzy number with sensitivity analysis [21]. In 2013, the same authors proposed an optimal policy for an inventory model without shortages considering fuzziness in demand, holding cost and ordering cost. In this paper, we first consider a crisp inventory model with constant deteriorating items with constant demand where shortages are allowed with fully backlogged condition.

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Thereafter we develop the corresponding fuzzy inventory model for fuzzy deteriorating items with fuzzy demand rate under fully backlogging. The average total inventory cost in fuzzy sense is derived. All inventory parameters including deterioration rate are fuzzified as the trapezoidal fuzzy numbers. The fuzzy model is defuzzified by using the signed distance method (D. Dutta and Pavan Kumar [21]). The solution for minimizing the fuzzy cost function has been derived.

This paper is organized as follows: In section II, we give some necessary definitions. In section III, we describe in brief the notations and assumptions used in the developed model. In section IV we present the mathematical model and in section V we present the corresponding Fuzzy model & solution procedure. In section VI, a numerical example is given to illustrate the model. In section VII, Sensitivity analysis has been made for different changes in the parameter values and in section VIII we do some observations. Finally, conclusions are given in section IX.

II. DEFINITIONS AND PRELIMINARIES [2, 3, 7]
A fuzzy set A on the given universal set X is a set of ordered pairs

\[ A = \{(x, \mu_A(x)) : x \in X\} \]

where \( \mu_A : X \rightarrow [0,1] \) is called membership function. The \( \alpha \)-cut of \( A \), is defined as 
\[ A_\alpha = \{x : \mu_A(x) = \alpha, \alpha \geq 0\} \]
If R is the real line, then a fuzzy number is a fuzzy set \( A \) with membership function \( \mu_A : X \rightarrow [0,1] \), with the following properties:

(i) \( A \) is normal, i.e., there exists \( x \in R \) such that \( \mu_A(x) = 1 \).
(ii) \( A \) is piece-wise continuous.
(iii) \( \text{supp}(A) = \text{cl}\{x \in R : \mu_A(x) > 0\} \), where cl represents the closure of a set.
(iv) \( A \) is a convex fuzzy set.

Definition 2.1: A trapezoidal fuzzy number \( A = (a, b, c, d) \) is represented with membership function \( \mu_A(x) \) as:

\[ \mu_A(x) = \begin{cases} \frac{x-a}{b-a}, & \text{when } a \leq x \leq b \\ 1, & \text{when } b \leq x \leq c \\ \frac{d-x}{d-c}, & \text{when } c \leq x \leq d \\ 0, & \text{otherwise} \end{cases} \]

Definition 2.2: A fuzzy set is called in LR-Form, if there exist reference functions \( L \) (for left), \( R \) (for right), and scalars \( m > 0 \) and \( n > 0 \) with membership function

\[ \mu_A(x) = \begin{cases} L \left( \frac{x}{m} \right), & \text{for } x \leq \sigma \\ 1, & \text{for } \sigma \leq x \leq \gamma \\ R \left( \frac{x}{n} \right), & \text{for } x \geq \gamma \end{cases} \]

Where \( \sigma \) is a real number called the mean value of \( A \), \( m \) and \( n \) are called the left and right spreads, respectively. The functions \( L \) and \( R \) map \( \mathbb{R}^+ \rightarrow [0,1] \), and are decreasing. A LR-Type fuzzy number can be represented as \( A = (\sigma, \gamma, m, n)_{LR} \).

Definition 2.3: Suppose \( A = (a_1, a_2, a_3, a_4) \) and \( B = (b_1, b_2, b_3, b_4) \) are two trapezoidal fuzzy numbers, then arithmetical operations are defined as:

\[ A \oplus B = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \]
\[ A \ominus B = (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4) \]
\[ a \otimes B = (a_1 b_1, a_2 b_2, a_3 b_3, a_4 b_4) \]

The status of inventory is shown in Figure 1.

Inventory It(t)

Time

Q

T

t = 0

t = t_1

T

III. NOTATIONS AND ASSUMPTIONS
The proposed inventory model is developed under the following notations and assumptions:

**Notations**

- \( C_o \): Ordering cost per order.
- \( C_h \): Holding cost per unit per unit time.
- \( C_s \): Shortage cost per unit time.
- \( R \): Order quantity per unit.
- \( d \): Demand rate per unit time.
- \( \theta \): Deterioration rate function = \( \theta(t) \), \( t \geq 0 \).
- \( T \): Length of each ordering cycle.
- \( \tilde{C} \): Total shortage cost per unit time.
- \( \tilde{C}_T \): Fuzzy total shortage cost per unit time.
- \( \tilde{C}_{TS} \): Defuzzified value of fuzzy number \( \tilde{C} \) by using Signed distance method.
- \( \tilde{C}(t) \): Fuzzy total inventory cost per unit time.
- \( \tilde{C}(t) \): Defuzzified value of fuzzy number \( \tilde{C}(t) \) by using Signed distance method.
- \( \tilde{U} \): Fuzzy valued (fuzzy number) of \( U \), where \( U \) is any crisp number.

**Assumptions**

1. The inventory system involves only one item.
2. Demand rate \( \theta(t) = \tau \), constant.
3. The replenishment rate is infinite, and lead time is zero.
4. Shortages are allowed and fully backlogged. Thereby, the lost sale cost per cycle is zero.
5. The deterioration rate function, \( \theta(t) \), denotes the on-hand inventory deteriorates per unit time and there is no replacement or repair of deteriorated units during the period \( T \).
6. There is no repair or replacement of the deteriorated items during the production cycle.
7. The goal of this model is to search for the optimal values of the parameters: \( \tilde{C}(t_1, T) \), \( T \) and \( t_1 \).

IV. MATHEMATICAL MODEL

The status of inventory is shown in Figure 1.
Let $Q$ be the total amount of inventory purchased or produced at the beginning of each period and after fulfilling backorders. Due to reasons of market demand and deterioration of the items, the inventory level gradually diminishes during the period $[0, t_1]$, and ultimately falls to zero at $t = t_1$. Now, during time period, shortages occur which are completely backlogged.

Let $I(t)$ be the on-hand inventory level at any time $t$, which is governed by the following two differential equations:

$$\frac{dI(t)}{dt} = 0 \quad \text{for} \quad 0 \leq t \leq t_1$$

$$\frac{dI(t)}{dt} = -r, \quad \text{for} \quad t_1 \leq t \leq T$$

with $I(0) = Q$ and $I(t_1) = 0$.

Now, solve (1) and (2) using given conditions in (3). The final solution is given by

$$I(t) = \frac{r}{\theta} \left[ t^\theta \left( 1 - t_1^\theta \right) \right], \quad \text{for} \quad 0 \leq t \leq t_1$$

and

$$I(t) = r \left[ (T - t)^\theta \right], \quad \text{for} \quad t_1 \leq t \leq T$$

Using exponential expansion in (4), and since $0 < \theta \ll 1$, the higher power term of 0, we obtain

$$I(t) = \frac{r}{\theta} \left[ 1 + (t_1 - t)^\theta \right], \quad \text{for} \quad 0 \leq t \leq t_1$$

$$I(t) = r \left[ (T - t)^\theta \right], \quad \text{for} \quad t_1 \leq t \leq T$$

Using the initial condition: $I(0) = Q$, in (6), we obtain

$$Q = r \left( t_1 + \theta t_1^\theta + \frac{1}{2} \theta^2 t_1^{2\theta} - \frac{1}{2} \theta^2 t_1^{2\theta} \right)$$

Total average no. of holding units ($I_H$) during the period $[0, T]$ is given by

$$I_H = \int_0^T I(t) \, dt = \frac{r}{\theta} \left( \frac{t_1^\theta}{\theta} + 1 + \frac{1}{2} \theta t_1^\theta + \frac{1}{2} \theta^2 t_1^{2\theta} \right)$$

Total no. of deteriorated units ($I_D$) during the period $[0, T]$ is given by

$$I_D = Q - I_H = \frac{r}{\theta} \left( \frac{t_1^\theta}{\theta} + 1 + \frac{1}{2} \theta t_1^\theta + \frac{1}{2} \theta^2 t_1^{2\theta} \right)$$

Total average no. of shortage units ($I_S$) during the period $[0, T]$ is given by

$$I_S = \int_0^T I(t) \, dt = \frac{r}{\theta} \left( \frac{t_1^\theta}{\theta} - 2(T - t_1)^\theta \right)$$

Total shortage cost per unit time

$$C_{TS} = \frac{1}{\theta} \left[ C_{D} \right]$$

Total cost of the system per unit time is given by

$$C(t_1, T) = \frac{1}{\theta} \left[ C_o + C_h I_H + C_D I_D + C_S I_S \right]$$

To minimize total cost $C(t_1, T)$, the optimal value of $t_1$ and $T$ can be obtained by solving the following equations:

$$\frac{dC(t_1, T)}{dt_1} = 0, \quad \text{and} \quad \frac{dC(t_1, T)}{dT} = 0$$

Now, solving (12), we get

$$C_o + C_h \left[ t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right] + 2 C_D t_1 \left( T - t_1^\theta \right) + C_S \left( T - t_1^\theta \right) = 0$$

We solve the non linear equations (13) and (14) by using computer software MATHEMATICA 8.0. With the help of graph, we can easily prove the convexity of total cost function $C(t_1, T)$, (see Figure 2 in section VI).

V. FUZZY MODEL AND SOLUTION PROCEDURE

We consider the model in fuzzy environment. Due to fuzziness, it is not easy to define all the parameters precisely. Let $C_o = (C_{o1}, C_{o2}, C_{o3}, C_{o4})$, $C_{D} = (C_{D1}, C_{D2}, C_{D3})$, $C_{S} = (C_{S1}, C_{S2}, C_{S3}, C_{S4})$, $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$, be trapezoidal fuzzy numbers in LR form. Then, the total cost of the system per unit time in fuzzy sense is given by

$$C(t_1, T) = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$$

We consider the model in fuzzy environment. Due to fuzziness, it is not easy to define all the parameters precisely. Let $C_o = (C_{o1}, C_{o2}, C_{o3}, C_{o4})$, $C_{D} = (C_{D1}, C_{D2}, C_{D3})$, $C_{S} = (C_{S1}, C_{S2}, C_{S3}, C_{S4})$, $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$, be trapezoidal fuzzy numbers in LR form. Then, the total cost of the system per unit time in fuzzy sense is given by

$$C(t_1, T) = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$$

We consider the model in fuzzy environment. Due to fuzziness, it is not easy to define all the parameters precisely. Let $C_o = (C_{o1}, C_{o2}, C_{o3}, C_{o4})$, $C_{D} = (C_{D1}, C_{D2}, C_{D3})$, $C_{S} = (C_{S1}, C_{S2}, C_{S3}, C_{S4})$, $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$, be trapezoidal fuzzy numbers in LR form. Then, the total cost of the system per unit time in fuzzy sense is given by

$$C(t_1, T) = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$$

The $\alpha$ - cuts, $C_\alpha(a)$ and $C_{\alpha}(a)$, of trapezoidal fuzzy number $C(t_1, T)$, are given

$$C_\alpha(a) = W + (X - W) a = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$$

$$C_{\alpha}(a) = W + (X - W) a = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$$

And $C_D(a) = Z - (X - Y) a = \frac{1}{\theta} \left[ C_o + C_h \left( t_1^\theta + \frac{2}{\theta} t_1^{2\theta} \right) + C_D \left( T - t_1^\theta \right) \right]$

By using signed distance method, the defuzzified value of fuzzy number $C(t_1, T)$, is given by

$$C_{DF}(t_1, T) = \frac{1}{2} \int_{0}^{1} [C_\alpha(a) + C_{\alpha}(a)] da$$
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To minimize total cost function per unit time \( C_{d}(t_1, T) \), the optimal value of \( t_1 \) and \( T \) can be obtained by solving the following equations:

\[
\frac{\partial C_{d}(t_1, T)}{\partial t_1} = 0, \quad \frac{\partial C_{d}(t_1, T)}{\partial T} = 0.
\]

Using the values of both \( t_1 \) and \( T \), we can obtain:

\[
\Rightarrow 4C_o + 2[\frac{1}{2}C_p + \frac{2}{3}C_d + \frac{4}{3}C_s] + 2[\frac{1}{2}C_p + \frac{2}{3}C_d + \frac{4}{3}C_s] + 2[\frac{1}{2}C_p + \frac{2}{3}C_d + \frac{4}{3}C_s] = 0.
\]

We solve the non-linear equations (17) and (18) by using computer software MATHEMATICA 8.0. To find out the second derivatives of the total cost function is very difficult and lengthy. However, with the help of graph, we can easily demonstrate the convexity of total fuzzy cost function \( C_{d}(t_1, T) \), (see Figure 3). Similarly, the total shortage per unit time in fuzzy sense is given by

\[
C_{T_{35}} = \frac{T}{2}C_s(T - t_1)^{3} = \frac{T}{2}C_s(T - t_1)^{3} + \frac{T}{2}C_s(T - t_1)^{3} + \frac{T}{2}C_s(T - t_1)^{3} + \frac{T}{2}C_s(T - t_1)^{3} = 0.
\]

Defuzzified fuzzy number \( C_{T_{35}} \) by using Signed Distance method, is given by

\[
(C_{T_{35}})_{d} = \frac{(T - t_1)^{3}}{\sqrt{t_1}}C_{T_{35}} + C_{T_{35}} + C_{T_{35}} + C_{T_{35}}
\]

VI. NUMERICAL EXAMPLE

To illustrate the proposed method, let us consider the following input data:

**Crisp Model**

**Input data:**
- \( C_o = Rs \ 200 \) per order.
- \( C_p = Rs \ 5 \) per unit per year.
- \( C_d = Rs \ 15 \) per order per year.
- \( C_s = Rs \ 418.642.\)
- \( \theta = 0.01 \) per year, \( r = 110 \) per year.
- Solution of crisp model is: \( t_1 = 0.7002 \) year, \( T = 0.9539 \) year, \( C_{T_{35}} = 55.6663, \) and \( C(t_1, T) = Rs \ 418.642.\)

To show the convexity of cost function \( C(t_1, T) \), we plot a 3D graph among \( t_1 \) and \( T \), where values of both \( t_1 \) and \( T \) ranging from 0.5000 to 1.000. A three-dimensional graph is shown in the following Figure 2.

**Fuzzy Model**

Let \( v_1 = (2, 4, 6, 8), \ (v_2 = (14, 18, 22, 26), \ (v_3 = (12, 14, 16, 18), \ \hat{\sigma} = (80, 100, 120, 140), \ \hat{\theta} = (0.004, 0.008, 0.012, 0.016). \) Then, by using Signed Distance Method, we obtain:

CASE-I: When \( \hat{v}_1, \hat{v}_2, \hat{v}_3, \hat{\sigma}, \hat{\theta} \), and \( \hat{\theta} \) are fuzzy trapezoidal numbers.
The solution of fuzzy model is: \( t_1 = 0.6605 \) year, \( T = 0.9167 \) year, \( (C_{T5})_{d_5} = 60.8625 \), and \( C_{d_5}(t_1, T) = Rs 435.313 \).

**CASE–II:** When \( C_p, C_m, \tilde{\tau}, \) and \( \tilde{\theta} \) are fuzzy trapezoidal numbers.

The solution of fuzzy model is: \( t_1 = 0.6951 \) year, \( T = 0.9476 \) year, \( (C_{T5})_{d_5} = 55.7434 \), and \( C_{d_5}(t_1, T) = Rs 422.866 \).

**CASE–III:** When \( \tilde{C}_z, \tilde{\tau}, \) and \( \tilde{\theta} \) are fuzzy trapezoidal numbers.

The solution of fuzzy model is: \( t_1 = 0.6997 \) year, \( T = 0.9439 \) year, \( (C_{T5})_{d_5} = 55.1248 \), and \( C_{d_5}(t_1, T) = Rs 422.866 \).

**CASE–IV:** When \( \tilde{\tau} \) and \( \tilde{\theta} \) are fuzzy trapezoidal numbers.

The solution of fuzzy model is: \( t_1 = 0.6970 \) year, \( T = 0.9513 \) year, \( (C_{T5})_{d_5} = 56.0827 \), and \( C_{d_5}(t_1, T) = Rs 419.560 \).

**CASE–V:** When \( \tilde{\tau} \) is a fuzzy trapezoidal number.

The solution of fuzzy model is: \( t_1 = 0.7002 \) year, \( T = 0.9539 \) year, \( (C_{T5})_{d_5} = 56.6663 \), and \( C_{d_5}(t_1, T) = Rs 418.726 \).

**CASE–VI:** When none of \( \tilde{C}_h, \tilde{C}_p, \tilde{\tau}, \) and \( \tilde{\theta} \) is a fuzzy trapezoidal numbers.

The solution of fuzzy model is: \( t_1 = 0.7002 \) year, \( T = 0.9539 \) year, \( (C_{T5})_{d_5} = 55.6663 \), and \( C_{d_5}(t_1, T) = Rs 418.642 \).

### Table 1. Comparison of Optimal Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Optimal value of ( t_1 ) (year)</th>
<th>Optimal value of ( T ) (year)</th>
<th>Optimal value of ( C_{T5} ) (Rs.)</th>
<th>Optimal value of ( C(t_1,T) ) (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crisp Model</td>
<td>0.7002</td>
<td>0.9539</td>
<td>55.6663</td>
<td>418.642</td>
</tr>
<tr>
<td>Fuzzy Model</td>
<td>0.6605</td>
<td>0.9167</td>
<td>60.8625</td>
<td>435.313</td>
</tr>
</tbody>
</table>

**VII. SENSITIVITY ANALYSIS**

To study the effects of changes in the system parameters, the sensitivity is analyzed. The results are shown in below tables.

### Table 2. Sensitivity Analysis on parameter \( r \)

<table>
<thead>
<tr>
<th>Defuzzify value of ( r ) (units/year)</th>
<th>Fuzzy value of parameter ( \tau )</th>
<th>( t_1 ) (year)</th>
<th>( T ) (year)</th>
<th>( C_{d_5}(t_1, T) ) (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.014</td>
<td>0.008</td>
<td>0.6745</td>
<td>0.9283</td>
<td>430.603</td>
</tr>
<tr>
<td>0.012</td>
<td>0.010</td>
<td>0.6678</td>
<td>0.9230</td>
<td>432.976</td>
</tr>
<tr>
<td>0.006</td>
<td>0.012</td>
<td>0.6605</td>
<td>0.9167</td>
<td>435.313</td>
</tr>
<tr>
<td>0.009</td>
<td>0.014</td>
<td>0.6541</td>
<td>0.9116</td>
<td>437.617</td>
</tr>
</tbody>
</table>

**VIII. OBSERVATIONS**

1) From Table 2, as we increase the demand rate \( r \), the optimum values of \( t_1 \) and \( T \) decreases. By this effect, the total cost increases.

2) From Table 3, as we increase the deterioration rate \( \theta \), the optimum values of \( t_1 \) and \( T \) decrease. By this effect, the total cost increases.

3) From Table 4, as we increase the shortage cost \( C_p \), the optimum value of \( t_1 \) increases, and optimum value of \( T \) decreases, and finally the total cost increases.
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4) From Table 5, as we increase the purchasing cost $C_p$, the optimum values of $t_s$ and $T$ decrease. By this effect, the total cost increases.

5) From Table 6, as we increase the holding cost $C_h$, the optimum values of $t_s$ and $T$ decrease. By this effect, the total cost increases.

6) Total cost function is more sensitive to the changes in holding cost, and in demand rate (Table 6&2), while it is less sensitive to the changes in purchasing cost, and in deterioration (Table 5&3).

7) In comparing the optimal results obtained in crisp model and in fuzzy model, we observe that the optimal values of shortages cost and total cost increase in fuzzy model (Table 1).

8) In CASE-VI, when none of $C_h$, $C_p$, $C_t$, $\theta$, and $\beta$ is a fuzzy trapezoidal number, the solution of fuzzy model is the same as that of crisp model. So, when we change the nature of all the parameters - $C_h$, $C_p$, $C_t$, $\theta$, and $\beta$ from fuzziness to crispness, the concerned fuzzy model immediately becomes the crisp model.

IX. CONCLUSIONS

This paper presented a fuzzy inventory model for deteriorating items with shortages under fully backlogged condition. Shortages and deterioration are natural in any inventory control system. Demand rate and deterioration rate were both assumed to be constant. The proposed model is developed in both the crisp and fuzzy environments. In fuzzy environment, all related inventory parameters were assumed to be trapezoidal fuzzy numbers. The optimum results of fuzzy model are defuzzified by Signed distance method. Sensitivity analysis indicates that the total cost function is more sensitive to the changes in the holding cost. So, the decision maker, after analyzing the result, can plan for the optimal value for total cost, and for other related parameters.

REFERENCES


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