Complexity Analysis and Applications

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Comp. Anal. Appl. . Vol. 1, No. 1 (2024) 14–24.

Paper Type: Original Article

Inventory Modeling for Deteriorating Items with Stock Dependent Demand, Shortages and Inflation Under Two-Warehouse Storage Management System in a Fuzzy Environment

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Citation:

Received: 4 March 2023 *Revised: 10 May 2023* *Accepted: 25 June 2023*	Kaur, P.,Chand, M., Kaur, D., &Rakshit, M. (2024).Inventory modeling for deteriorating items with stock dependent demand, shortages and inflation under two-warehouse storage management system in a fuzzy environment.*Complexity analysis and applications*, *1* (1), 14-24.

Abstract

This article aims to evaluate the value of integrating warehouse and inventory decisions. So, in this paper, a two-warehouse inventory model for deteriorating items is considered under the assumption that the inventory cost (including holding cost and deterioration cost) inRented Warehouse(RW) is higher than that inOwned Warehouse(OW) due to better preservation facilities in RW. The demand is taken as a variable dependent on the stock level. Shortages are allowed in the OW partially backlogged at the next replenishment cycle. This paper mainly deals with deteriorating items where the deterioration rate is linearly dependent on time, and the concept of triangular fuzzy numbers is used for this purpose. A numerical example is presented to illustrate and validate the model.

Keywords: Two warehouses, Instantaneous deterioration, Linear demand, Constant holding cost, Advertisementcost and shortages.

1 | Introduction

For many decades, researchers have conducted research in the field of inventory management, which is a part of supply chain management. Inventory management and supply chain systems deal with demand and supply problems of goods in the business area. In the traditional models, demand and holding costs have been considered constant, and goods are supplied instantly under an infinite replenishment policy when an order is placed. Still, as time passed, many researchers considered that demand might vary due to various factors depending on market requirements, and based on these factors, holding costs may also vary. Many

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models have been developed considering various time-dependent demands with and without shortages. All those models consider demand variation in response to inventory level. During the study of inventory models, it was observed that many researchers considered warehouses to have an unlimited storage capacity. But in real life, it is not like that; in busy marketplaces, supermarkets, corporation markets, etc., the storage areas available are limited. In practice, when there is large procurement due to the production of products during a seasonal period or purchases due to discount offers during the festival season on bulk purchases, a large storage area is needed to stock goods. In a significant procurement situation, goods cannot be accommodated in the existing storehouse (the Own Warehouse, abbreviated as OW). Hence, an additional warehouse is required to accommodate goods in store and excess items, and people may be hired near the business place to reduce transportation costs. This hired space is termed a Rented Warehouse (RW). Ronald[1]developedan inventory model with two storage facilities. Misra [12] worked in this field and extended Harri's (1915)EOQ model with deterioration and shortages. Goyal and Giri [13] produce a survey on recent trends in the inventory modeling of deteriorating items. Lee and Wu [14] es2tablished a note on the EOQ model for items with mixtures of exponential distribution deterioration, shortages, and time-varying demand. In general, it is assumed that the holding cost in the RWis higher than that incurred in the Own warehouse due to the additional cost of material handling and maintenance charges, etc. Thus, it is always considered that to reduce inventory costs, priority should be given to consuming the goods stored in the RW. Deterioration is one of the most critical inventory management phenomena with significant cost effects. Deterioration may occur due to the storage environment, which may occur in both warehouses. Since rented RW has better facilities for storing goods, it is assumed there will be less deterioration. Assuming deterioration in both warehouses, Sarma[2] extended his earlier model to the infinite replenishment rate with shortages. Pakkala and Achary[3]extended the two-warehouse inventory model for deteriorating items with finite replenishment rates and shortages, taking time as a discrete and continuous variable, respectively. In the above-discussed models, the demand rate is considered constant. Subsequently, the ideas of time-varying demand and stock-dependent demand are regarded by some authors, such as Goswami and Chaudhuri[4], Bhunia and Maiti[5], Kar et al.[6]and others. Mandal, Bhunia and Maiti [15] extended the model of Goswami and Chaudhary [16] ; in that model, they did not consider the deterioration and developed the model by allowing shortages backlogging conditions. Goel and Giri (2001) suggested reviewing deteriorating inventory literature, in which all the inventory models for deteriorating items are assumed to fall into deterioration immediately after goods are received and stocked.

Various inventory models considering different patterns of holding cost, such as varying and constant, have been developed by some authors. Chang [18] established an inventory model with stock-dependent demand and nonlinear holding costs for deteriorating items. Roy and Samanta [19] has established an inventory model for deteriorating items with time-varying holding costs and price-dependent demand. Sugapriya and Jeyaraman [20] have extended this as an EPQ model for deteriorating items whose holding cost varies with time.Gyan andPal[7]established a two-warehouse inventory model for deteriorating items with a stock-dependent demand rate and holding cost. Kaur, P., and Rakshit [21] considered variable holding costs for developing an optimal ordering and transfer policy for an inventory system. A deterministic inventory model for deteriorating items with price-dependent demand and time-varying holding costs under trade credits was developed by Kumar, Chauhan and Kumar[21]. Yadavand Swami[8]have established a two-warehouse inventory model for deteriorating items with exponential demand and variable holding costs.Rathod and Bhathawala[9]constructed a model with variable holding cost and dependent demand on inventory level.

Tripathi[10]has also constructed an inventory model for varying demand and variable holding costs.Mishra et al. [11]developed an inventory model with variable holding cost and salvage value.. Shah and Pandey [23] have established the deteriorating inventory model when demand depends on advertisement and stock display. In this paper, they have considered the demand rate as a function of advertisement cost and stock inventory level. In this paper, they have taken demand as a function of the selling price, continuous time, and advertisement frequency. A two-warehouse inventory model for deteriorating items with variable demand under an alternative trade credit policy has been developed by Ali Akbar Shaikh [24] considering the demand rate a combination of selling price and frequency of advertisement cost. Sanjai Sharma et al. [25] have developed an optimizing inventory and marketing policy under two warehouse storage systems to evaluate items with generalized type holding cost rates. Shekhawat, Rathore and Sharma, [26] gave the model an inventory model for deteriorating items with advertising and quantity discount policies. An inventory model on preservation technology with trade credits under a demand rate dependent on advertisement, time, and selling price where demand is dependent on the frequency of advertisement is created by Mukesh Kumar et al. [26].

A deterministic fuzzy inventory model is developed for deteriorating items with two levels of the storage system and where stock-dependent demand with partially backlogged shortages is considered. Firstly, a crisp model is established, and a corresponding fuzzy model is developed for this model. The deterioration rates of both the warehouses are time-dependent, as well as the quality of preservation procedures, and holding cost is considered a constant quantity. A numerical example is presented to demonstrate the development and validate the model.

2 | Definition and Preliminaries

For the development of a fuzzy inventory model, we need the following definitions:

I. A fuzzy set $\tilde{S}$ on a given universal set X is denoted and defined by

$$\{(x, \lambda_{\tilde{S}}(x)) : x \,\varepsilon\, X\},$$

where $\lambda_{\tilde{S}}$: X→ $[0,1]$, is called the membership function and $\lambda_{\tilde{S}}(x)$ = degree of x in $\tilde{S}$.

II. A triangular fuzzy number is specified by the triplet (a, b, c) where $a < b < c$ and defined by its continuous membership function $\lambda_{\tilde{S}}$: X→ $[0,1]$ as follows:

$$\lambda_{\tilde{S}}(x) = \begin{cases} \dfrac{x - a_1}{c - a_1}, & \text{if } a_1 \le x \le b_1, \\ \dfrac{b_1 - x}{c_1 - b_1}, & \text{if } c_1 \le x \le c_1, \\ 0, & \text{otherwise.} \end{cases}$$

III. Let $\tilde{S}$ be the fuzzy set defined on the R (set of real numbers), then the signed distance of $\tilde{S}$ is defined as

$$D(\tilde{S}, 0) = \frac{1}{2}\int_0^1 [S_L(\alpha) + S_R(\alpha)] d_\alpha,$$

where $A_\alpha = [S_L(\alpha) + S_R(\alpha)] \alpha \,\varepsilon [0,1]$ is α-cut of a fuzzy set $\tilde{S}$.

2.1 | Assumption and Notations

This mathematical model of two warehouse inventory model for deteriorating items is based on the following notation and assumptions:

I. The replenishment rate is infinite and instantaneous.

II. The storage capacity of RW is considered to be unlimited.

III. The lead time is negligible, and the initial inventory level is zero.

IV. Shortages are allowed and partially backlogged at the next replenishment.

V. In OW and RW, the deterioration rate is time dependent given as $\theta(t) = \alpha\, t$ and $\emptyset(t) = \beta\, t$ respectively.

VI. The holding cost is constant and higher in RW than in OW.

VII. The deteriorated units cannot be repaired or replaced during the storage period.

VIII. Deterioration occurs as soon as items are received and stored.

IX. The inventory system considers a single item, and the demand rate is a function of the on-hand inventory level, i.e., $d = f(I(t))$.

2.2 | Notations

The following notation is used throughout the paper.Demand rate (units/unit time) stock dependent and given as

$$d = \begin{cases} a + b\, I(t) & \text{if } I(t) > 0 \\ a & \text{if } I(t) < 0 \end{cases}.$$

W2: inventory level in RW at t=0.

W1: finite capacity of OW.

$\phi(t)$: variable deterioration rate in OW given as $\theta(t) = \beta t$ where $0 < \beta < 1$.

$\theta(t)$: variable deterioration rate in RW given as $\phi(t) = \alpha t$ where $0 < \alpha < 1$.

B(t): partial back ordering rate, which decreases exponentially for waiting time andDefined as$B(t)=e^{-\sigma t}$.

Bmax: maximum inventory backlogged.

A: ordering cost per order.

Ch1: holding cost per unit time in RW.

Ch2: holding cost per unit per unit time in OWsuch thatCh1> Ch2.

Cs: inventory shortages cost.

CL: inventory lost sales cost.

Qmax: the maximum order quantity for a cycle length.

Ii: maximum inventory level at any time for i=1, 2, 3, etc. in RW and OW.

T: length of the stock ordering cycle.

r: inflation rate.

$V(t_\lambda, t_w, T)$: present the total average inventory cost per unit of time for the crisp model.

$\tilde{V}(\tilde{t}_\lambda, \tilde{t}_w, \tilde{T})$: present the total average inventory cost per unit of time for the fuzzy model.

3 | Crisp Model: Mathematical Formulation of the Model

Upon the arrival of the inventory, a fixed amount of W1 units are kept at OW according to their capacity. The rest of the inventory W2 is kept in the RW. The evolution of stock level in the system is depicted in *Fig. 1*. First, the amount of inventory kept in RW is consumed to minimize the rent of RW and hence inventory cost; after that, customers' demand is fulfilled by supplying inventory from OW. In the RW, the level of inventory depleted due to the combined effect of demand and deterioration, and the differential equation governing this situation is given as

$$\frac{dI_1(t)}{dt} = -d - \alpha\,\{I_1(t)\}, \quad 0 \le t \le t_\lambda, \tag{1}$$

with B.C. $I_1(t) = 0$ at $t = t_\lambda$. The solution of *Eq. (1)* is

$$I_1(t) = \left(a\left\{\left(t_\lambda - \frac{b}{2}t_\lambda^2 + \frac{\alpha}{6}t_\lambda^3\right) - \left(t - \frac{b}{6}t^2 + \frac{\alpha}{6}t^3\right)\right\}\right)e^{\left(bt - \frac{\alpha t^2}{2}\right)}. \tag{2}$$

When inventory vanishes at RW, the demand of customers is fulfilled by supplying goods from OW and inventory of OW in the interval $[0 \;\; t_1]$ reduces due to varying deterioration rates only and during the interval $[t_1 t_2]$, the inventory reduces due to the combined effect of both variable deterioration rate and demand. The following differential equations govern the situations.

$$\frac{dI_2(t)}{dt} = -\theta(t)\{I_2(t)\}, \;\; 0 \le t \le t_\lambda. \tag{3}$$

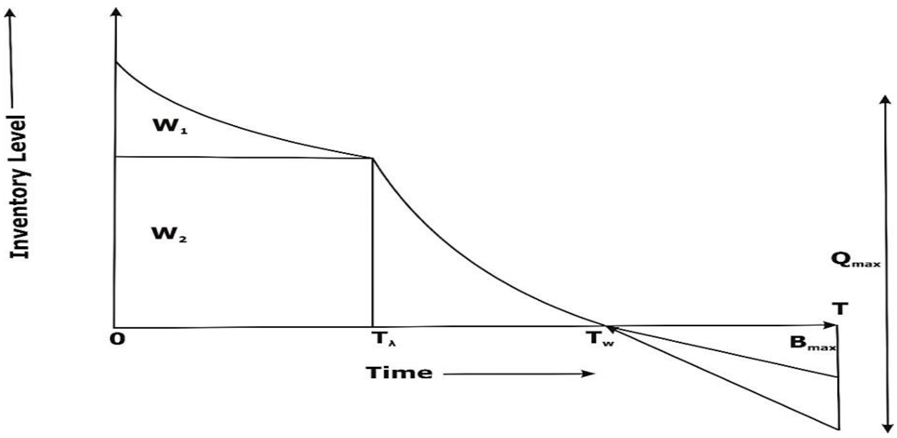

Fig. 1. Representing the level of inventory in both warehouses.

$$\frac{dI_3(t)}{dt} = -D - \phi(t)\{I_3(t)\}, \qquad t_\lambda \le t \le t_w. \tag{4}$$

With B. C. $I_2(0) = W_2$ at $t = 0$ and $I_3(t_w) = 0$ at $t = t_w$. The *Solutions* of *(3)* and *(4)* are resp.

$$I_2(t) = W_2 e^{-\frac{\beta t^2}{2}}. \tag{5}$$

$$I_3(t) = \left(a\left\{\left(t_w - \frac{b}{2}t_w^2 + \frac{\beta}{6}t_w^3\right) - \left(t - \frac{b}{6}t^2 + \frac{\beta}{6}t^3\right)\right\}\right)e^{\left(bt - \frac{\beta t^2}{2}\right)}. \tag{6}$$

Since at time epoch $t = t_2$ the level of inventory vanishes, and due to continuous demand, shortages occur till the next replenishment, and shortages back ordered partially the differential equation governs this

$$\frac{dI_s(t)}{dt} = -B(T - t), \qquad = -e^{-\sigma(T-t)}, \qquad t_w \le t \le T. \tag{7}$$

Solution of the above equation with B.C. $I_s(t_w) = 0$ at $t = t_w$ is given as

$$I_s(t) = \frac{a}{2}\left(e^{-\sigma(T-t_2)} - e^{-\sigma(T-t)}\right). \tag{8}$$

Maximum inventory backlogged at $t = T$ is

$$B_{max} = \frac{a}{2}\left(e^{-\sigma(T-t_w)} - 1\right). \tag{9}$$

Since, initially, the inventory level in RW is$W_1 = I_1(0)$, therefore, we obtain from *Eq. (2)*

$$W_1 = \left(a\left\{\left(t_\lambda - \frac{b}{2}t_\lambda^2 + \frac{\alpha}{6}t_\lambda^3\right)\right\}\right). \quad \textbf{(10)}$$

Continuity in OW at $t = t_1$gives$I_2(t_1) = I_3(t_1)$ therefore

$$W_2 = \left(a\left\{\left(t_w - \frac{b}{2}t_w^2 + \frac{\beta}{6}t_\lambda^3\right) - \left(t_\lambda - \frac{b}{2}t_\lambda^2 + \frac{\beta}{6}t_\lambda^3\right)e^{bt_\lambda}\right\}\right). \quad \textbf{(11)}$$

Now, the maximum ordered quantity per cycle is obtained as

$$Q = W_1 + W_2 + B_{max}$$

Thus, the total present worth inventory cost during the cycle length consists of the following cost elements.

I. Ordering cost.
II. Inventory holding cost in RW.
III. Inventory holding cost in OW.
IV. Deterioration cost in RW.
V. Deterioration cost in OW.
VI. Shortages cost.
VII. Lost sales cost.

The above costs are given under.

Orderingcost is

$$OC = Ae^{-rt}.$$

Inventory holding cost in RW is

$$HC_{rw} = C_{h_1}\left(\int_0^{t_\lambda} e^{-rt}I_1(t)dt\right).$$

Inventory holding cost in OW is

$$HC_{rw} = C_{h_2}\left(\int_0^{t_\lambda} e^{-rt}I_2(t)dt + \int_{t_w}^{T} e^{-rt}I_3(t)dt\right).$$

The total cost of inventory deteriorated in RW during the storage period

$$DC_{rw} = C_{d_1}\left\{e^{-rt}\,W_1 - \int_0^{t_\lambda} e^{-rt}D\,dt\right\}.$$

The total cost of inventory deteriorated in OW during the storage period

$$DC_{ow} = C_{d_2}\left\{e^{-rt}W_2 - \int_{t_\lambda}^{t_2} e^{-rt}D\,dt\right\}.$$

Total cost of inventory shortages during $[t_w\ T]$ is

$$SC = \int_{t_w}^{T} e^{-rt}\{I_s(t)\}dt$$

$$= \frac{C_s\, a}{\sigma}\left\{\left(\frac{e^{-rt} - e^{-\sigma(T-t_2)-rt_2}}{\sigma - r}\right) + \left(\frac{e^{-(\sigma+r)T+\sigma t_w} - e^{(\sigma-r)t_w-\sigma T}}{r}\right)\right\} \text{if } \sigma \neq r.$$

Total cost of inventory lost sales during $[t_2\ T]$ is

$$LC = \int_{t_w}^{T} e^{-rt}(1 - B(T-t))dt$$

$$= a\, C_L \left\{\left(\frac{e^{-rt_w} - e^{-rT}}{r}\right) + \left(\frac{e^{-(r+\sigma)T} - e^{(\sigma-r)t_w-\sigma T}}{\sigma - r}\right)\right\} \text{ if } \sigma \neq r.$$

Hence, the totalrelevant inventory cost per unit of time during cycle length is given by

$$V(t_\lambda^*, t_w^*, T^*) = \frac{1}{T}\Big[Ae^{-rt} + C_{h_1}\left(\int_0^{t_\lambda} e^{-rt} I_1(t)dt\right) + C_{h_2}\left(\int_0^{t_\lambda} e^{-rt} I_2(t)dt + \int_{t_w}^{T} e^{-rt} I_3(t)dt\right) + C_{d_1}\left\{e^{-rt}\, W_1 - \int_0^{t_\lambda} e^{-rt} d\, dt\right\} + C_{d_2}\left\{e^{-rt} W_2 - \int_{t_\lambda}^{t_w} e^{-rt} d\, dt\right\} + C_s \int_{t_w}^{T} e^{-rt}\{I_s(t)\}dt + C_L \int_{t_w}^{T} e^{-rt}(1 - B(T-t))dt\Big]. \quad (12)$$

The optimal problem can be formulated as

$\text{Minimize}\Pi(t_\lambda, t_w, T)$

Subject to: $(t_\lambda > 0, t_w > 0, T > 0)$.

To find the optimal solution to the equation, the following conditions must be satisfied

$$\frac{\partial V(t_\lambda^*, t_w^*, T^*)}{\partial t_\lambda} = 0, \quad \frac{\partial V(t_\lambda^*, t_w^*, T^*)}{\partial t_w} = 0, \quad \frac{\partial V(t_\lambda^*, t_w^*, T^*)}{\partial T} = 0. \quad (13)$$

Solving *Eq. (13)* for t_λ, t_w and T, the optimal value of decision variables can be obtained as t_λ^*, t_w^* and T^*. We can find the model's total minimum inventory cost with these values from *Eq. (12)*.

4 | Fuzzy Model

$$\tilde{V}(t_\lambda^*, t_w^*, T^*) = \frac{1}{T}\Big[Ae^{-rt} + \tilde{C}_{h_1}\left(\int_0^{t_\lambda} e^{-rt} I_1(t)dt\right) + \tilde{C}_{h_2}\left(\int_0^{t_\lambda} e^{-rt} I_2(t)dt + \int_{t_w}^{T} e^{-rt} I_3(t)dt\right) + \tilde{C}_{d_1}\left\{e^{-rt}\, W_1 - \int_0^{t_\lambda} e^{-rt} d\, dt\right\} + \tilde{C}_{d_2}\left\{e^{-rt} W_2 - \int_{t_\lambda}^{t_w} e^{-rt} d\, dt\right\} + C_s \int_{t_w}^{T} e^{-rt}\{I_s(t)\}dt + C_L \int_{t_w}^{T} e^{-rt}(1 - B(T-t))dt\Big]. \quad (14)$$

The optimal problem can be formulated as

$\text{Minimize}\Pi(\tilde{t}_\lambda, \tilde{t}_w, \tilde{T})$, Subject to: $(\tilde{t}_\lambda > 0, \tilde{t}_w > 0, \tilde{T} > 0)$.

To find the optimal solution to the equation, the following conditions must be satisfied

$$\frac{\partial V\left(\tilde{t}_\lambda^*, \tilde{t}_w^*, \tilde{T}^*\right)}{\partial t_\lambda} = 0, \quad \frac{\partial V\left(\tilde{t}_\lambda^*, \tilde{t}_w^*, \tilde{T}^*\right)}{\partial t_w} = 0, \quad \frac{\partial V\left(\tilde{t}_\lambda^*, \tilde{t}_w^*, \tilde{T}^*\right)}{\partial T} = 0. \tag{15}$$

Solving *Eq. (15)* for $\tilde{t}_\lambda, \tilde{t}_w$ and $\tilde{T}$, the optimal value of decision variables can be obtained as $\tilde{t}_\lambda^*, t_w^*$and $\tilde{T}^*$and with these values we can find the total minimum inventory cost from *Eq. (14)*for the model.

5 | Numerical Examples

For analyzing this model, four sets of parameters corresponding to the situations are considered, and the optimality of the system is satisfied.

Example 1. Consider the following set of parameter values: $a = 60. b = 0.30, A = 1200, r = 0.05, C_{h_1} = 8.0, C_{h_2} = 5.0, C_{d_1} = 16, C_{d_2} = 20, C_s = 3, C_L = 16, \alpha = 0.004, \beta = 0.005, \sigma = 0.7, W_2 = 150$ for the crisp model, and fuzzy model values are taken as $a = (50\ 60\ 70), C_{h_1} = (6.0,\ 8.0,\ 10), C_{h_2} = (4.0\ \ 5.0\ \ 6.0), C_{d_1} = (14\ \ 16\ \ 18)$, and $C_{d_2} = (18\ \ 20\ \ 22)$ are considered triangular fuzzy numbers, and then the total average inventory cost is obtained and given in *Table 1*. The optimal results obtained from *Eqs.(13)*and*(15)* from Section 5 and for the other cases discussed in the model are shown in *Table 1*. Sensitivity analysis can be performed by changing the value of one parameter at a time and keeping the values of other parameters unchanged.

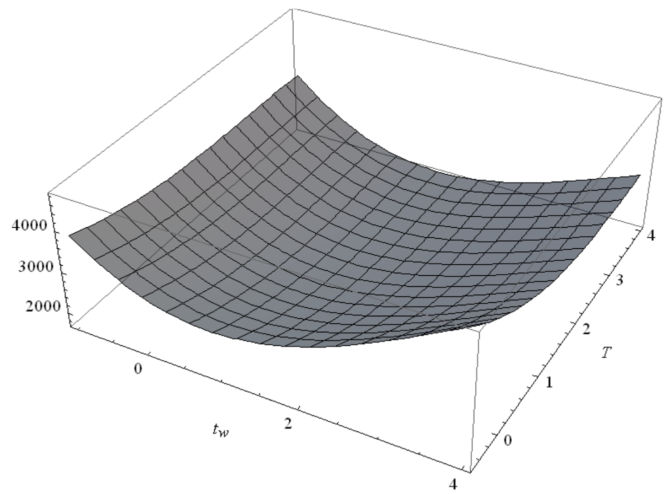

Fig. 2. Representing convexity of the two warehouse crisp model

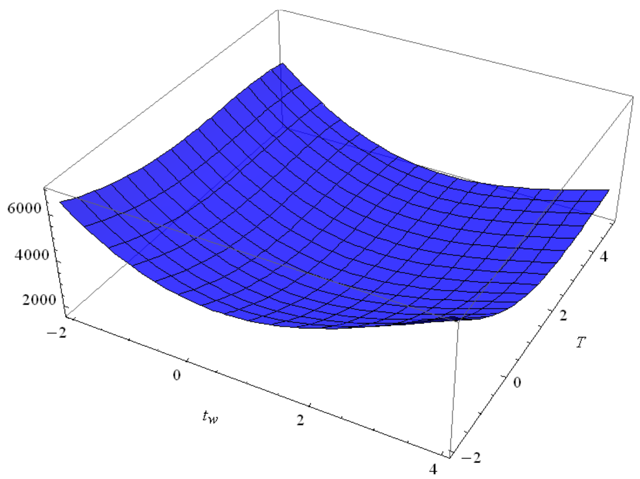

Fig. 3. Representing convexity of the two warehouse fuzzy model.

Table 1. Representing value of decision variables and inventory cost.

Decision Variables	Crisp Model	Fuzzy Model
	$V(t_\lambda^*, t_w^*, T^*)$	$\tilde{V}(\tilde{t}_\lambda^*, \tilde{t}_w^*, \tilde{T}^*)$
t_λ^*	1.2153	1.2537
t_w^*	2.9770	2.9541
T^*	3.4763	3.4570
Total relevant inventory cost	1718.52	1714.83

*Table 1*shows that the fuzzy model is more effective than the crisp model because when we have t_λ^*=1.2153,t_w^* = 2.9770,T^* =3.4763 then the total relevant inventory cost for the crisp model is 1718.52, and when we havet_λ^*=1.2537,t_w^* = 2.9541,T^* =3.4570, then the total relevant inventory cost for the fuzzy model is 1714.83. *Fig. 2* and *Fig. 3* show the convexity of the crisp and fuzzy model for two warehouse inventory models, as convexity shows the total cost minimization. In this convex optimization problem, we find a point that minimizes the objective function.

6 | Conclusion

In this paper, inflation has been established to minimize the average inventory cost in a deterministic fuzzy inventory model under two warehouse management and time-dependent deterioration rate. It is assumed that the capacity of OW is limited. The optimization technique is used to derive the optimum replenishment policy, i.e., to minimize the total relevant cost of the inventory system. A numerical example is presented to illustrate this model. The average inventory cost has been calculated using crisp values (random values) of parameters, as mentioned in Section 6. Then, some triangular fuzzy numbers are used as parameters to calculate the average inventory cost. *Table 1* shows that the fuzzy model is more efficient and suitable for minimizing costs while dealing with uncertain parameter values than the crisp model because the fuzzy model provides minimum costs compared to the crisp model.

This model is most useful for the instant deteriorating items under varying deterioration rates. Further, this paper can be enriched by incorporating other types of probabilistic demand, and another extension of this model can be made for a bulk release pattern. In practice, displaying the stock and advertising of the product also affects the demand rate and must be considered while extending the model.

Author Contribution

Conceptualization and Methodology, P. K., Software, Validation, formal analysis, M. Ch., investigation, D. K.; writing-creating the initial design, M. R.; writing-reviewing and editing, M. Ch. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data Availability

All the data are available in this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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