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The Inventory Control Model for Deteriorating Items with Hybrid Type Demand under the Inflationary Environment

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ABSTRACT

The current research work presents inventory model for deteriorating items and demand function is dependent on stock levels and selling price of the items. To reduce impact of deterioration, a customized preservation technology is unified in the present work. This study generally investigate the impact of inflation on inventory system, with a focus on optimizing ordering quantities and replenishment cycles to reduce total cost under different payment conditions. The main factors of this research is to analysis of delay in payment and partially advance payments, taking into account the complications of stock-dependent and, inventory level shortages, price-dependent demand function and partial backlogging of deteriorating items. This research article scrupulously calculates the effect of inflation, advanced payments policies and delay in payment on total cost incurred by retailer trader. To validate efficacy of this mathematical model, numerical examples, sensitivity analysis part solved, and graphical part show the optimality of this model using the mathematica software7.0.

1. Introduction

The deterioration is key factor of inventory control system. Deterioration means encompassing decay, waste, spoilage, damage, vaporization etc. In real inventory control system, deterioration assumes thinkable significance. A crowd of factors contribute to deterioration, involving chemical reactions, fire, atmospheric situations, and design. All these factors can exert an assuagement impact on inventory control systems, generally related to complicated ways. For example- the deterioration process may be increased by active impacts of environment pollution. The present research work seeks to establish optimum inventory policy that reduces total cost and effect of inflation on different costs.

Inventory model with deterioration

Recent studies have explored various aspects of inventory management for deteriorating items. A production inventory model was developed by Yadav et al. [2023] to account for the impact of imperfect manufacturing processes and partial backlogging on inventory decisions. In a similar vein, Padiyar et al. [2023] designed a three-echelon supply chain model to optimize inventory management for deteriorating products in environments characterized by inflation. Sharma et al. [2023] proposed an inventory model that addresses the challenges of multivariate demand and time-dependent deterioration, particularly for products of poor quality. Furthermore, Mahdavisharif et al. [2023] introduced a supply chain model for non-instantaneous deteriorating items with uncertain demand, utilizing a game-theoretic approach to inform decision-making. Akhtar et al. [2023] developed an inventory model that incorporates the effects of time and price-dependent demand on inventory levels, allowing for partial backlogging of shortages. Additionally, Senbagam and Kokilamani [2023] investigated an EOQ model for decaying items with quadratic demand and fuzzy holding costs, providing insights into optimal inventory management strategies. Many studies have investigated inventory management strategies for deteriorating items and poor-quality products. Malakar and Sen [2023] developed a model aimed at minimizing the total average cost for low-quality items, incorporating a carbon tax policy. Almakour and Benkherouf [2023] determined an optimal replenishment policy for non-instantaneous deteriorating items with backlogging and time-varying demand. A review of existing literature reveals that numerous researchers have explored inventory models for deteriorating items, including notable contributions from Narag and De [2023], Mondal et al. [2023], Choudhari et al. [2023], Marchi et al. [2023], Kumar et al. [2023], and Fatma et al. [2023]. These studies collectively advance our understanding of inventory management for deteriorating items.

Inventory model with Preservation Technology

Preservation technology plays a significant role in inventory system by deteriorating items from deterioration during storage process. By adopting preservation technology, businesses can effectively reduce the rate of deterioration and minimize losses. Current studies have highlighted the benefits of integrating preservation technology into inventory management systems. For example, Gautam et al. [2023] designed a sustainable retail model that utilizes preservation technology to manage fragmented quality items. Similarly, Saha et al. [2023] explored the impact of green preservation technology on optimal price and replenishment policies under ramp-type demand. In another study, Priyamvda et al. [2022] developed an inventory policy that leverages preservation technology to optimize inventory management for poor-quality items with price-dependent demand.

Many authors and researchers have explored the application of preservation technology in supply chain and inventory management for deteriorating items. Mahata and Debnath [2022] developed a single-item, two-level supply chain model that incorporates preservation techniques in the retailer's warehouse to protect products from deterioration. Singh et al. [2022] investigated a production inventory model for deteriorating items, utilizing preservation technology and complete backlogging. Chang et al. [2022] examined a multistage production model that collaborates with preservation techniques to determine optimal supply, production, delivery, and replenishment policies for maximizing benefits. Other notable contributions to the field of preservation technology include works by Roy et al. [2022], Nita et al. [2022], Jaggi et al. [2022], Ma et al. [2022], Saha et al. [2022], Bhawaria and Rathore [2022], and Jani et al. [2022], among others.

Inventory model with inflation

Various studies have examined the impact of inflation on inventory management for deteriorating items. Ahmad et al. [2023] analyzed an economic order quantity model for decaying items, incorporating the learning effect under inflationary conditions. Garg et al. [2022] proposed a two-warehouse inventory model for perishable items, accounting for the effects of inflation. Yadav et al. [2022] developed a deterministic inventory model for poor-quality items with increasing demand, considering the impact of inflation. Kumar and Yadav [2022] investigated an economic order quantity model that integrates greenness level and time-dependent demand under inflation. Thilagavathi et al. [2022] studied the impact of inflation on a single item in a two-warehouse setting, allowing for shortages with stock-level-dependent demand. Alamri et al. [2022] formulated an EOQ model that considers carbon emissions and learning effects in an inflationary environment. Shaikh and Gite [2022] established a production model under a fuzzy approach, accounting for inflation's impact with the time value of money. Jayaswal and Mittal [2022] determined an inventory model for deteriorating items with learning effects under inflation. Other notable researchers who have contributed to the study of inflation include Rizwanullah and Junnaidi [2022], Rana et al. [2022], Rao et al. [2022], Pervin and Roy [2022], and Agarwal and Badole [2022], Bhawaria and Rathore [2023], Bhawaria and Rathore [2025], Rathore et al. [2024], Bhawaria et al. [2023] among others.

2. Assumptions and Notations

2.1 Assumptions

- Horizon planning is infinite
- Lead time is constant
- Replenishment rate behave as infinite as infinite
- The rate of deterioration$\tau_{\theta} = (\theta - m(\xi))$, where $m(\xi) = e^{-c\xi}$ is constant in the interval $[0, t_1]$.
- The demand functions $D = \frac{b+\gamma I(t)}{S^{\beta}}$ in the no shortage phase. and $D = \frac{b}{S^{\beta}}$ is demand function during shortage phase. Where $b > 0,\ \gamma > 0,\ \beta > 0$.
- The demand functions that have not fulfilled are contemplated to be partial backlogged. The percent of backorder arise as customers waiting time (T, t) decreases. $e^{\mu(T-t)}$ Is the partially backorder, where μ is backlogging parameter.
- The supplier requested for n installments for prepayment. Retailer next receive loan from an organization at the special rate. The prepayments total costs (per cycle) calculated applying the lashgari et al. [2018] approach.

2.2 Notations

Notations	**descriptions**
A	Ordering Cost
D	Annual demand
b	Basic demand
HC	Holding Cost
PC	Purchasing cost
LSC	Lost sale Cost
BC	Backorder Cost
ξ	Preservation technology cost
CCC	Cycle capital cost
L	Lead time
n	Prepayment installment number
M	Delay in payment
ρ	Purchase cost fraction that paid before delivery
Q	Quantity order
$I_i(t)$	Inventory level at time t, where i=1, 2.
IE_i	Earned interest

IC_i	Charged interest
I_C	Charged interest rate (per year)
I_{CC}	Interest rate on loan (per year)
I_e	Earned interest rate (per year)
S	Selling Price
Z	Maximum stock
R	Shortage per cycle
T	Replenishment cycle
t_1	Time at which stock level becomes zero
ω	Backlogging variable where $\omega > 0$
TC	Total Cost

3. Mathematical Model Formulation

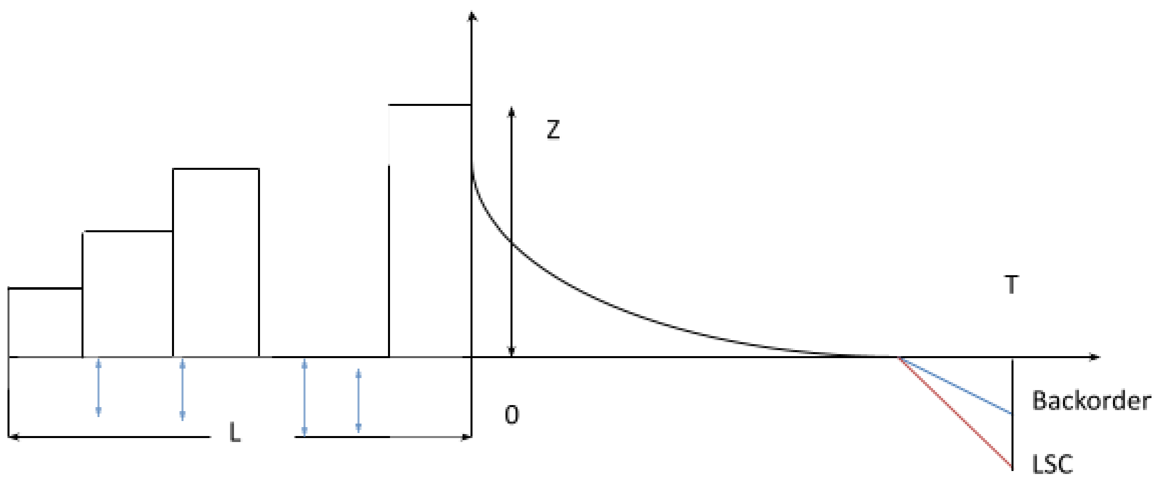

Fig.1 Inventory functioning

This inventory model provides two models for hybrid payment strategy that includes trade credit and advance payment policy. In this situation inventory level becomes at time $t = t_1$ due to deterioration and demand. After that shortages rise during interval $[t_1, T]$ due to part of requirements are backlogged and demand. Figure 1 left side shows the multiple prepayments were formed in equal durations L/n with the lead time L. The big part represents payments made in advance and the small section describe the amount must paid by retailer when items are secured. Then the governing inventory system's differential equations are as

$$\frac{dI_1(t)}{dt} + \tau_\theta I_1(t) = -\frac{b+\gamma I_1(t)}{S^\beta} \qquad 0 < t \le t_1 \qquad (1)$$

With the boundary condition $I_1(t_1) = 0$ equation (1) gives

$$I_1(t) = \frac{b}{S^\beta(\tau_\theta + \frac{\gamma}{S^\beta})}[e^{(t_1 - t)(\tau_\theta + \frac{\gamma}{S^\beta})} - 1] \quad (2)$$

Now, using the condition $I_1(0) = Z.$ then initial stock level is given by

$$Z = \frac{b}{S^\beta(\tau_\theta + \frac{\gamma}{S^\beta})}[e^{(t_1)(\tau_\theta + \frac{\gamma}{S^\beta})} - 1] \quad (3)$$

Inventory level gradually decline below zero at the time $t = t_1$ due to shortages. During the shortage interval $[t_1, T]$, requirements are partially backlogged at rate for (T-t). Then the differential equation is given as

$$\frac{dI_2(t)}{dt} = - \frac{b}{S^\beta} e^{-\omega(T-t)} \quad (4)$$

Applying the boundary condition $I_2(t_2) = 0$

$$I_2(t) = \frac{b}{\omega S^\beta}[e^{-\omega(T-t_2)} - e^{-\omega(T-t)}] \quad (5)$$

The maximum shortage is

$$R = - I_2(T) = [1 - e^{-\omega(T-t_2)}] \quad (6)$$

The retailer's total order mathematical form is

Q=Z+R

$$Q = \frac{b}{S^\beta(\tau_\theta + \frac{\gamma}{S^\beta})}\left[e^{(t_1)(\tau_\theta + \frac{\gamma}{S^\beta})} - 1\right] + \frac{b}{\omega S^\beta}[1 - e^{-\omega(T-t_2)}] \quad (7)$$

Ordering Cost

$$OC = A \quad (8)$$

Holding Cost

$$HC = HC\int_0^{t_1} e^{-rt} I_1(t)dt$$

$$HC = \frac{bHC}{S^\beta(\tau_\theta + \frac{\gamma}{S^\beta})}[\left(\frac{e^{-rt_1} - 1}{r}\right) + \frac{1}{r + \tau_\theta + \frac{\gamma}{S^\beta}}(e^{(t_1)(\tau_\theta + \frac{\gamma}{S^\beta})} - e^{-rt_1})] \quad (9)$$

Purchasing Cost

$$PC = PCQ$$

$$PC = PC[\frac{b}{S^\beta\left(\tau_\theta + \frac{\gamma}{S^\beta}\right)}(e^{(t_1)(\tau_\theta + \frac{\gamma}{S^\beta})} - 1) + \frac{b}{\omega S^\beta}(1 - e^{-\omega(T-t_2)})] \quad (10)$$

Backorder Cost

$$BC = BC\int_{t_1}^{T} e^{-rt} I_2(t)dt$$

$$BC = \frac{BC.b}{r\omega S^{\beta}}[e^{-rt_1} - e^{-rt_1-\omega(T-t_1)}] \quad (11)$$

Lost Sale Cost

$$LSC = \int_{t_1}^{T} e^{-rt} bS^{-\beta}(1 - e^{-\omega(T-t)})dt$$

$$LSC = LSCbS^{-\beta}[\frac{(e^{-rt_1}-e^{rT})}{r} + \frac{e^{rT}-e^{-rt_1-\omega(T-t_1)}}{r-\omega}] \quad (12)$$

Preservation Technology Cost

$$PTC = \xi\int_{0}^{t_1} e^{-rt}dt$$

$$PTC = \frac{\xi(1-e^{-rt_1})}{r} \quad (13)$$

Cycle Capital Cost

$$CCC = \frac{C\rho I_{CC}QL(n+1)}{2n} \quad (14)$$

We calculate the total inventory level for use in the demand function

$$Total\ Inventory = I_1(t) + I_2(t)$$

$$I_1(t) + I_2(t) = \frac{b}{S^{\beta}\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}\left[e^{\left(t_1-t\right)\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)} - 1\right] + \frac{b}{\omega S^{\beta}}[e^{-\omega\left(T-t_2\right)} - e^{-\omega(T-t)}] \quad (15)$$

Therefore, demand is

$$D = \frac{b(b+\gamma)}{(S^{\beta})^2\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}\left[e^{\left(t_1-t\right)\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)} - 1\right] + \frac{b(b+\gamma)}{(S^{\beta})^2\omega}[e^{-\omega\left(T-t_2\right)} - e^{-\omega(T-t)}] \quad (16)$$

$Case\ 1: 0 < M < t_1$

Before the shortage retailer get compound interest, but in shortage time they receive simple interest. And I_e is related to the IE_1 Then the expression for IE_1 is

$$IE_1 = (1 - \rho)[SI_e\iint_{00}^{t_1 t}\frac{b(b+\gamma)}{\left(S^{\beta}\right)^2\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}\left(e^{\left(t_1-t\right)\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)} - 1\right) + \frac{b}{\omega S^{\beta}}\left(e^{-\omega\left(T-t_2\right)} - e^{-\omega(T-t)}\right) + \frac{SI_e}{\omega}\int_{0}^{t_1}\left(1 - e^{-\omega\left(T-t_1\right)}\right)\Big(-$$

$$IE_1 = (1 - \rho)[SI_e\frac{b(b+\gamma)}{\left(S^{\beta}\right)^2\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}\left(\frac{1-e^{\left(t_1\right)\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}}{\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)^2} - \frac{t_1^2}{2} - \frac{\frac{b(b+\gamma)}{\left(S^{\beta}\right)^2\omega}}{\omega^2}\left(e^{-\omega\left(T-t_1\right)} - e^{-\omega T}\right) + \frac{t_1e^{t_1\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)}}{\left(\tau_{\theta}+\frac{\gamma}{S^{\beta}}\right)} - \frac{\left(\frac{b(b+\gamma)}{\left(S^{\beta}\right)^2\omega}\right)t_1e^{-\omega T}}{\omega}\right) +$$

(17)

This is earned interest on the total inventories up to $(1 - \rho)$. The charged interest IC_1 on whole inventory relative to interest rate I_C

$$IC_1 = - CI_C \int_{t_1}^{M} I_1(t)dt$$

$$IC_1 = \frac{CI_C b}{\left(\tau_\theta + \frac{\gamma}{S^\beta}\right)} [\frac{e^{(t_1 - M)} - 1}{\left(\tau_\theta + \frac{\gamma}{S^\beta}\right)} + M + t_1] \quad (18)$$

Total Cost

$$TC = \frac{1}{T}[OC + HC + PTC + BC + LSC + IC_1 + PC + CCC - IE_1]$$

(19)

$Case\ 2$: $t_1 < M < T$

In this situation

$$IE_2 = IE_1 \quad (20)$$

After M there is no positive stock. Hence the charged interest is zero i.e.

$$IC_2 = 0$$

$$TC = \frac{1}{T}[OC + HC + PTC + BC + LSC + PC + CCC - IE_2]$$

(21)

4. Optimality of the Model

To get the optimum value for total cost $TC_i\left(t_1, \xi, T\right)$, $i = 1, 2, 3.$ partially differentiate total cost with respect to t_1, T and ξ and equating

Step-1 $\frac{\partial TP(\xi, t_1, T)}{\partial \xi} = 0,\quad \frac{\partial TP(\xi, t_1, T)}{\partial t_1} = 0,\quad \frac{\partial TP(\xi, t_1, T)}{\partial T} = 0.$

Step-2 $\frac{\partial TP(\xi, t_1, T)}{\partial \xi} > 0, \frac{\partial TP(\xi, t_1, T)}{\partial t_1} > 0, \frac{\partial TP(\xi, t_1, T)}{\partial T} > 0.$

Step-3 $\frac{\partial^2 TP(\xi, t_1, T)}{\partial \xi^2} = \left(\frac{\partial^2 TP}{\partial T^2}\right)\left(\frac{\partial^2 TP}{\partial t_1^2}\right)$

$$\frac{\partial^2 TP(\xi, t_1, T)}{\partial \xi \partial T} = \left(\frac{\partial^2 TP}{\partial T \partial \xi}\right)\left(\frac{\partial^2 TP}{\partial t_1^2}\right) - \left(\frac{\partial^2 TP}{\partial T \partial t_1}\right)\left(\frac{\partial^2 TP}{\partial \xi \partial t_1}\right)$$

Step-4 optimum solution YES/No

Step-5 if not then repeat step-3

Step-6 if yes then optimum solution

Solving above equations for T, ξ andt_1, we get the value of t_1, T and ξ. To show sufficient condition for total cost t_1 , T, and ξ.

$$\frac{\partial^2 TC_i(t_1, \xi, T)}{\partial t_1^2} > 0, \quad \frac{\partial^2 TC_i(t_1, \xi, T)}{\partial T^2} > 0, \quad \frac{\partial^2 TC_i(t_1, \xi, T)}{\partial \xi^2} > 0.$$

The Hessian Matrix of total cost is as follows.

$$TC\left(t_1, \xi, T\right) = \begin{bmatrix} \frac{\partial^2(t_1,\xi,T)}{\partial\xi^2} & \frac{\partial^2(t_1,\xi,T)}{\partial\xi\partial t_1} & \frac{\partial^2(t_1,\xi,T)}{\partial\xi\partial T} & \frac{\partial^2(t_1,\xi,T)}{\partial t_1\partial\xi} & \frac{\partial^2(t_1,\xi,T)}{\partial t_1^2} & \frac{\partial^2(t_1,\xi,T)}{\partial t_1\partial T} & \frac{\partial^2(t_1,\xi,T)}{\partial T\partial\xi} & \frac{\partial^2(t_1,\xi,T)}{\partial T\partial t_1} & \frac{\partial^2(t_1,\xi,T)}{\partial T^2} \end{bmatrix}$$

DET.[H1]> 0, DET.[H2]> 0, DET.[H3]> 0; where H1, H2, and H3, are minor of the above matrix.

5. Numerical example

Case -1.

$A = 130,\ b = 2,\ BC = 13,\ S^{\beta} = 12,\ \gamma = 1,\ S = 400,\ \theta = 0.02,\ \omega = 1,\ I_{CC} = 0.1,\ I_e = 0.4,\ LSC = 3$

$T = 2.33161$ $\quad\xi = 0.093886$ $\quad t_1 = 4.34416$

$TC = 375.797$

6. Table -1. Sensitive Analysis

S. No.	Parameters	Changes	T	ξ	t_1	TC
1	**r**	0.019	2.34830	0.0940764	4.35364	371.701
		0.020	2.33161	0.0938860	4.34416	375.797
		0.021	2.31783	0.0937188	4.33613	379.448
2	θ	0.019	2.33161	0.0939769	4.34416	375.797
		0.020	2.33161	0.0938860	4.34416	375.797
		0.021	2.33161	0.0937951	4.34416	375.797
3	γ	0.90	2.29272	0.0943723	4.37580	377.678
		1.00	2.33161	0.0938860	4.34416	375.797
		1.10	2.36599	0.0933889	4.31329	374.465
4	**S**	390	2.30182	0.0936892	4.36588	377.313
		400	2.33161	0.0938860	4.34416	375.797
		410	2.35896	0.0940764	4.32294	374.460
5	t_2	39	2.33122	0.0936865	4.37847	382.946
		40	2.33161	0.0938860	4.34416	375.797
		41	2.33148	0.0940933	4.30915	368.649

Table -2. Analysis

S. No.	Parameters	Changes	T	ξ	t_1	TC
1	**r**	↓ ↑	↑	↑	↑	↓ ↑
			↓	↓	↓	
2	θ	↓	*	↑	*	*
		↑	*	↓	*	*
3	γ	↓	↓	↑	↑	↑
		↑	↑	↑	↓	↓
4	**S**	↓	↓	↓	↑	↑
		↑	↑	↑	↓	↓

5	t_2	↓	↓	↓	↑	↑
↑		↓ ↑	↓	↑	↓	↓

Here Shows the increment, shows the decrement and * shows no changes in the parameters.

Graphical representation

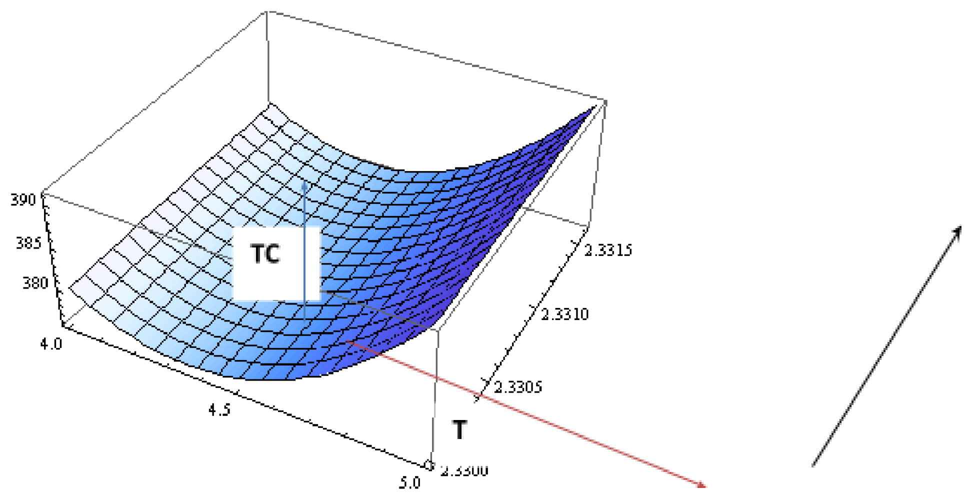

Fig. 2 Graph between T & t_1

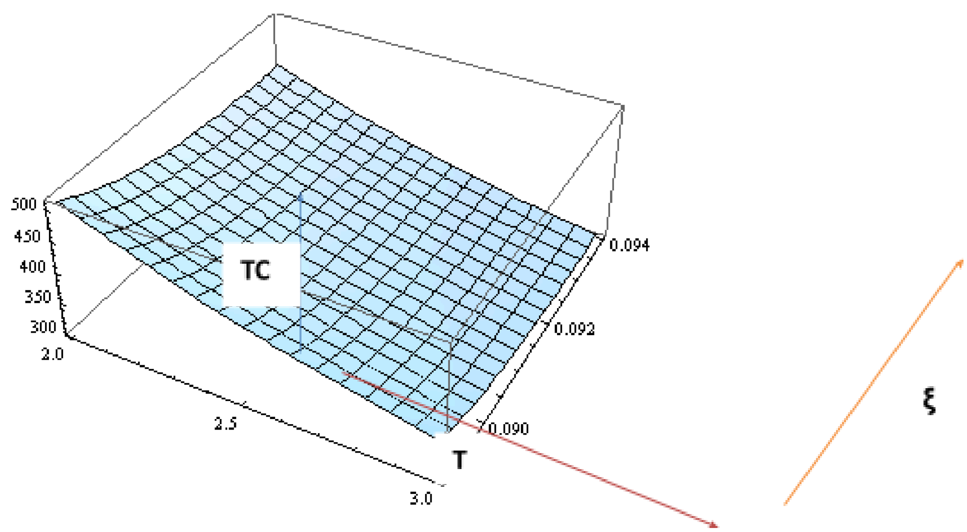

Fig. 3 Graph T vs ξ

Case -2

Numerical Example

$A = 130,\ b = 2,\ BC = 13,\ S^{\beta} = 12,\ \gamma = 1,\ S = 400,\ \theta = 0.02,\ \omega = 1,\ I_e = 0.4,\ LSC = 30,\ PC = 15$

$T = 2.06801$ $\xi = 0.105802$ $t_1 = 3.07875$

$TC = 190.117$

Table -3. Sensitive Analysis

S. No.	Parameters	Changes	T	ξ	t_1	TC
1.	r	0.019	2.09086	0.106407	3.09082	187.509
		0.020	2.06801	0.105802	3.07875	190.117
		0.021	2.04819	0.105273	3.06861	192.504
2.	ω	0.900	1.86636	0.104143	2.87133	203.552
		1.000	2.06801	0.105802	3.07875	190.117
		1.100	2.25952	0.107389	3.27844	179.289
3.	s^{β}	11.99	2.06559	0.105869	3.07329	189.807
		12.00	2.06801	0.105802	3.07875	190.117
		12.01	2.07043	0.105737	3.08421	190.426
4.	b	1.900	2.14072	0.101900	3.38632	209.569
		2.000	2.06801	0.105802	3.07875	190.117
		2.100	1.95694	0.111243	2.75332	169.536
5.	BC	12	2.02881	0.104962	3.05826	194.267
		13	2.06801	0.105802	3.07875	190.117
		14	2.10780	0.106684	3.10043	186.119
6.	PC	145	2.12107	0.103844	3.23064	203.938
		150	2.06801	0.105802	3.07875	190.117
		155	2.00391	0.108308	2.91108	175.811

Table -4 Analysis

S. No.	Parameters	Changes	T	ξ	t_1	TC
1	r	↓	↑	↑	↑	↓
		↑	↓	↓	↓	↑
2	ω	↓	↓	↓	↓	↑
		↑	↑	↑	↑	↓
3	s^{β}	↓	↓	↑	↓	↓
		↑	↑	↓	↑	↑
4	b	↓	↑	↓	↑	↑
		↑	↓	↑	↓	↓
5	BC	↓	↓	↓	↓	↑
		↑	↑	↑	↑	↓
6	PC	↓	↑	↓	↑	↑
		↑	↓	↑	↓	↓

Here ↑ show the increment and ↓ showing the decrement in the parameters

Graphical Analysis

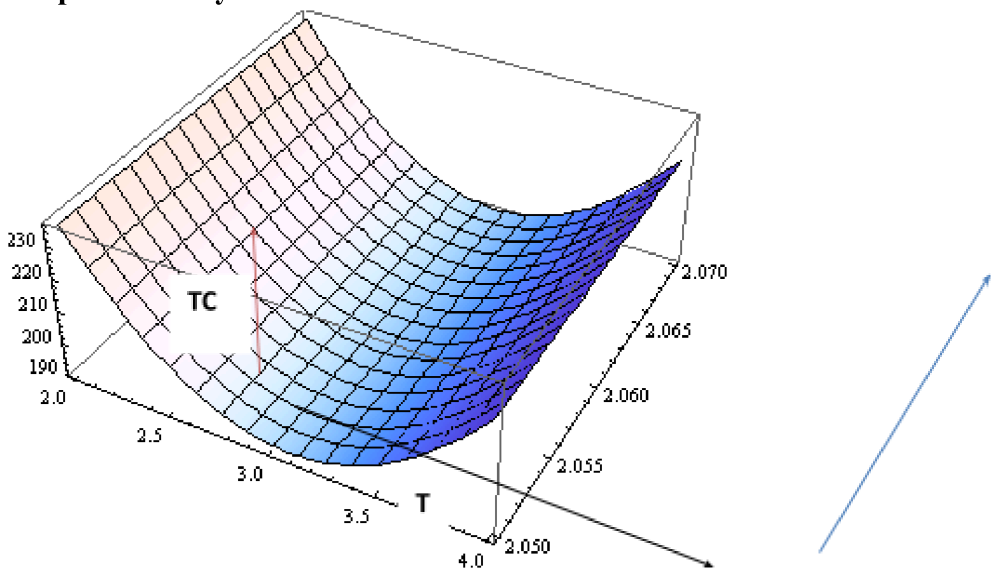

Fig. 4 convexity Between T & t_1

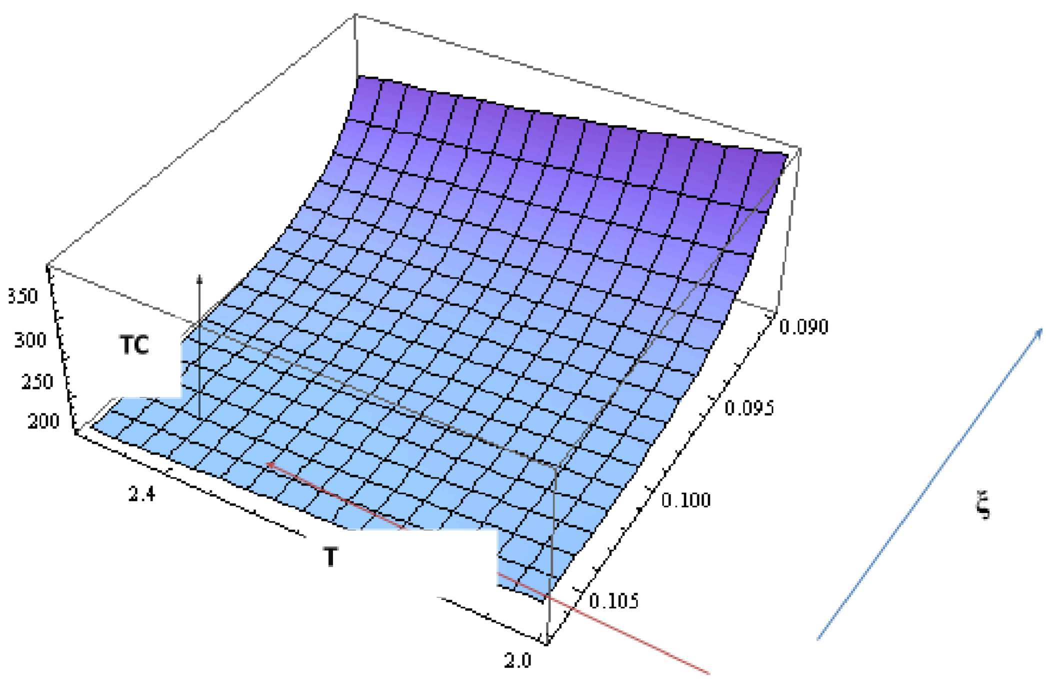

Fig 5 Concavity between T & ξ

7. Conclusion

This study develops an inventory model for deteriorating items with hybrid demand, characterized by instantaneous deterioration and partial backlogging. Preservation technology is utilized to control the deterioration, and its impact is graphically illustrated. The analysis is conducted under the influence of inflation, where the supplier requests prepayment in n installments, and financial institutions provide loans at a fixed interest rate. The proposed strategy aims to enhance the economic recovery of the supply chain. Numerical examples are provided to demonstrate the model's applicability under varying trade credit periods, and the results show that effective implementation of delayed payment strategies and trade credit can significantly reduce total costs. The graphical analysis confirms the convexity of the total cost function. Future research directions could include exploring different demand patterns, such as time-dependent and selling price-dependent demand, as well as investigating the implications of carbon cap policies in a fuzzy environment.

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