



Carbon Emission Inventory Model for Deteriorating Goods with Price Dependent Demand and Payment Delay

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Abstract: In today's corporate management environment, environmental awareness is a worldwide concern, and there has been a lot of study on the subject. Since greenhouse gas pollutants are one of the main causes of global warming, it is critical to become worried about limiting carbon dioxide productivity. In light of social and environmental changes, organizations are dealing with the carbon emission. System design is extensively facilitated by environmental reviews, which reduce undesirable ecological effects while improving good financial and social outcomes. In this paper we have developed an EOQ model that incorporates the deterioration of products with time dependent deterioration and price dependent demand. The study evaluated the replenishment strategy in light of permissible delay in payment. This study aims to determine the minimum average cost based on two different scenarios. In order to strengthen the proposed structure even further, a mathematical implementation has been developed. Additionally, an analysis of sensitivity has been carried out with the various parameters with the objective of figuring out the model's sustainability.

Keywords: EPQ model, carbon emission, multivariate demand, shortages

1. Introduction

As a result of industrial activities, harmful greenhouse gases are released in addition to carbon dioxide. Global warming and smog are two of the hazards caused by greenhouse gases. Due to the trapping of heat, these structures alter the climate, creating arid conditions that are beneficial to a number of species. The development of extreme weather patterns is also influenced by climate change, which contributes to wildfires, droughts, and food shortages. Adopting sustainable procedures encourages organizations to be more



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cognizant of how they have an effect on our planet and prepare pathways for an equitable and green future. Preference for eco-friendly technology has grown as environmental concerns throughout the world have intensified. Producing an environmentally conscious supply chain improves an entity's responsible business actions since it reduces waste, utilizes fewer raw materials, and incorporates the recuperate, recycling, and waste reduction idea across the infrastructure. Research on renewable network distribution now appears to hold promise for a coordinated system of inventory monitoring. According to Hua et al. (2011), carbon emissions are a major contributor to global warming. Market-based methods of trading carbon dioxide emissions were also investigated. A minimum cost was numerically verified in the study in terms of carbon constraints. In a study conducted by Hu and Zhou (2014), the manufacturers' carbon emission reduction policies and price policies were evaluated. By looking at carbon emissions, they were able to determine what policies would maximize profits. In their study, Taleizadeh et al. (2018) examined the issue of partial backorders and carbon emissions on joint pricing decision making and inventory decisions. We have developed models of production-inventory to be demand-sensitive and to control deterioration rates thanks to our investment in preservation technology. With partially backlogged shortages, demand is assumed to be linear with time. We need to optimize operations in order to reduce costs and timeliness. By delaying payment, retailers earn interest on accumulated revenue, which reduces system costs. Following this, the modeling approach is illustrated numerically and its sensitivity is examined. Goyal (1985) estimates economic order quantities by assuming a reasonable payment delay. The Yang and Wee (2006) propose a collaborative system for inventory management that allows for delayed deterioration payments. An inventory model for decaying items was found to include quadratic demand rates and trade credit inflation in a study by Kumar et al. (2009). As a result of trade credit and imperfect items, Kang and Hen (2010) designed a system for cooperative vendor-buyer relationships. By taking preservation technology into account for decaying Items that have ramped demand rates, Singh and Sharma (2013) examined global optimization in the context of two-level credit financing. To model perishable production inventory, Tayal et al. (2015) developed a model in which trade credit and preservation technologies were incorporated. Bhardwaj et al. (2023) proposed a three-tier environmental distribution approach to inventory that takes into account stock-based demand, retailer-permitted shortages of goods, and emission levels in order to save crucial time and reduce comprehensive costs. Models of inventory are typically constructed based on constant demand rates. In subsequent research, linear trends in demand were incorporated. A production policy based on ramp type demand was advocated by Goyal et al. in 2013. The price of the item was also found to influence its demand, which led to the discovery. Within the context of preservation technology, a model for estimating demand based on pricing was developed according to Shastri et al. (2014). Based on an inventory model for supply chains created by Singh and Vishnoi (2013), which uses items that are improving or degrading and two levels of storage, Singh and Vishnoi developed a new model. Furthermore, Tayal et al. (2014) constructed a multi-item inventory model under price-sensitive demands that included deteriorating items with expiration dates. Inventory control models are significantly affected by demand rate. A classical theory of business considers the demand for inventory to be a constant rate; however, customers' needs for seasonal goods, fashionable items, etc., fluctuate over time. Resh, Friedman, Barbosa and Donaldson first proposed a linear trend in

demand in 1976. Among the researchers who have developed their models along the same line of research are Giri, Chakrabarty, Chaudhuri (2012), Balkhi (2003), and Teng and Yang (2007). According to Shaikh, (2017), inventory optimization for deteriorating items can be achieved using a model. The model has been developed to include variable demand rates and allowable payment delays. The rate of recovery is thought to be linearly time-sensitive in a framework developed by Handa et al. (2021) in which the end user receives repurchase goods. An approach for degrading supplies was developed by Singh et al. (2022) based on the supposition that the deteriorating things have an optimal lifespan and that learning-forgetting has a direct effect on purchasing expenses. Yadav et al. (2022) examine an integrated model, recognizing that the profit of the centralized system grows due to the influence of learning-forgetting on its initial cost. When the non-reliable factor is taken into account, Das et al. (2021a) propose an economic production inventory model. Trade credit policies have been developed to ensure optimal replenishment. A preservation technology-based inventory model was also developed by Das et al. (2021b) that eliminated the impact of non-instantaneous deterioration products on inventory. As trade credit has been influencing the optimization of the model, swarm optimization has been used. An integrative inventory system incorporating degradation was published by Tyagi et al. (2020) where consumption is regarded as being price-based and production rate as being market-dependent. The model proposed by Zou and Tian (2020) takes into account retailer needs. The pricing strategy of the company is optimal under a reasonable payment delay. Shah, et al. (2021) have proposed a model based on stock on-hand inventories with variable demand. Trade credit has also been described alongside the fixed-time policy. Sepelri (2021) assumes specific strategies to reduce carbon emissions. The customer is responsible for any credit policy that covers decayed products. Sarkar, et al. (2020) have also proposed a decision support tool to address the issue of deteriorating goods under trade credit policies. Their research reveals the existence of a two-echelon model for deteriorating multiproduct portfolios, according to Pervin, et al. (2019). She was instructed on the trade credit policy after the multivariate demand was discussed. An integrated inventory management model has been developed by Pervin et al. (2018). In their analysis, two levels of trade credit policy were used to determine the optimal replenishment policy. Items are assumed to be stored and held. Modeling production was taken into account in recent research by Das et al. (2021). This model was developed using credit capabilities. Zao and Tian, et al. (2020) studied pricing policies using an inventory model under trade credit. Retailers are provided with a supply of products when they implement a reliable replenishment strategy. A policy was presented by Shah et al. (2021) using stock variations as a credit consideration. Singh et al. (2022) analyzed an inventory model with preservation technology investment and order cost reduction under different carbon emission policies, showing that such investments reduce deterioration and improve cost-efficiency under carbon regulations. In a related work, Singh et al. (2022) extended this to price-sensitive demand with partial backlogging in a low-carbon setting, highlighting the importance of preservation and pricing decisions when shortages are allowed. Pundir et al. (2024) systematically reviewed supply chain analytics for targeted ads in e-commerce, demonstrating how predictive analytics enhances marketing efficiency through supply chain data. Finally, Singh et al. (2025) developed a manufacturer-retailer model with two warehouses and reverse logistics under carbon tax, finding that combined warehousing strategy and reverse logistics optimizes both cost and emissions.

Our Inventory model takes into account deterioration and a selling price-related demand rate. We offer two levels of credit financing. To illustrate the model, a number of examples and sensitivity analyses are provided.

2. Notation and assumptions

2.1 Notation

As part of the development of the inventory model, the following notation was used:

Parameters	Description
p	selling price per unit
π	positive constant, $\pi \ll 1$
α, β	demand coefficient, $\alpha - \beta p > 0$
T	Length of the cycle
t_1	Time until inventory is zero
h	Cost per unit of holding
c_θ	deterioration cost per unit
O	ordering cost per order
M	allowable trade credit period
I_e	the amount of interest earned by the retailer
I_p	the amount of interest charged by the supplier
Q	inventory level at the beginning of each cycle
D	total demand
F	Transportation cost
F_c	Carbon emission due to transportation

C	Purchasing cost
H	Holding cost

2.2 Assumptions

The quality of the products deteriorates over time, and the rate of deterioration is time dependent.

1. Price is a determining factor in demand for the products.
2. The retailer is allowed a period of time to settle the account. If the retailer does not pay during this period then the supplier charge an interest to the retailer.
3. Deterioration rate is taken to be time dependent.
4. A major contributor of greenhouse gas emissions to the atmosphere is the manufacturing industry. The researchers are therefore more inclined to look for emissions due to the manufacturing. Carbon emission cost associated with the production cost.

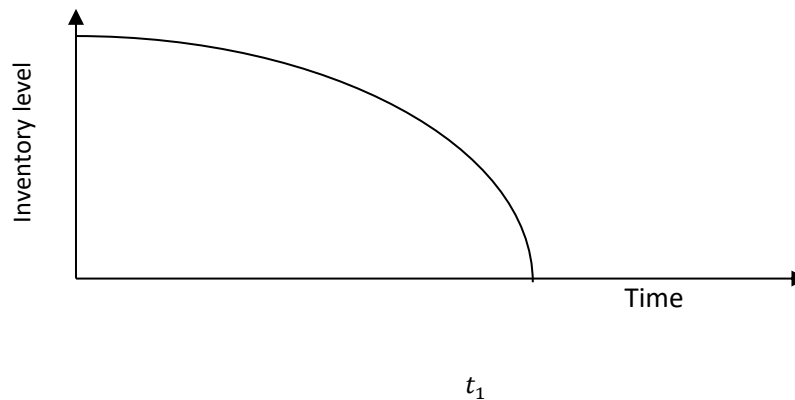


Fig. 1 The inventory level of the buyer.

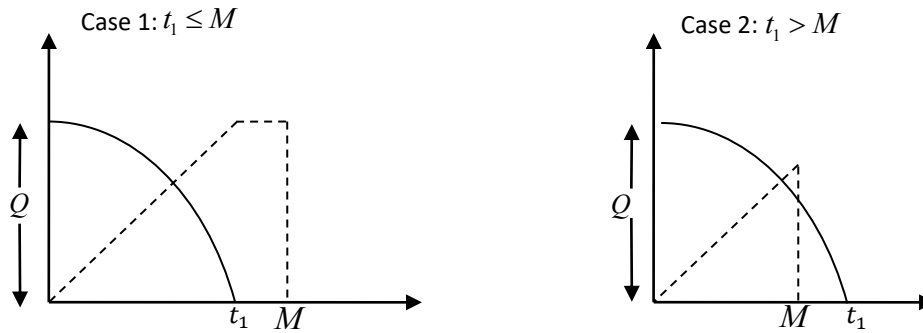


Fig. 2 The inventory level and interest earned for the buyer.

3. Formulated the Model Mathematically

Initially, Q units are in inventory at time $t=0$. A combination of price sensitive demand and time varying deterioration causes the inventory to deplete during the time interval $[0, t_1]$, ultimately reaching zero at $t = t_1$. The level of inventory and the interest earned is depicted in figure 1 and 2 respectively.

The differential equation governing the transition of the system is as follows:

$$\frac{dI(t)}{dt} + \pi t I(t) = -(\alpha - \beta p) \quad 0 \leq t \leq t_1 \quad (1)$$

With boundary condition $I(t_1) = 0$

The following is the solution to the previously mentioned differential equations

$$I(t) = (\alpha - \beta p) \left[(t_1 - t) + \frac{\pi}{6} (t_1^3 - t^3) \right] e^{-\frac{\pi t^2}{2}}, \quad 0 \leq t \leq t_1 \quad (2)$$

Initial conditions is given as $I(0) = Q$,

$$\text{thus } Q = (\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} \quad (3)$$

The following is the calculation for different costs associated with proposed frame work:

1. The total purchasing cost = Qc

$$= (\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} c \quad (4)$$

2. The holding cost along with the carbon emission cost occurred due to the emission of carbon of the system is given by

$$\begin{aligned} &= (h + h_c) \int_0^{t_1} I(t) dt \\ &= (h + h_c) \int_0^{t_1} e^{-\frac{\pi t^2}{2}} (\alpha - \beta p) \left\{ -t + t_1 + \frac{1}{6} \pi (-t^3 + t_1^3) \right\} dt \end{aligned} \quad (5)$$

3. Ordering cost per order is given by O

$$\text{Transportation cost with carbon emission occurred due to the transportation} = (F + F_c)Q = (\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} (F + F_c) \quad (6)$$

Taking into account the reasonable credit period the supplier is able to give to the retailer, there are two conditions that arise:

Case 1: When $M \geq t_1$

Case 2: When $M < t_1$

Interest Earned

Case 1: When $M \geq t_1$

As in this case, all the income generated by the retailer is deposited in an interest bearing account, hence, the retailer earned interest in this instance

$$= pI_e \left[\int_0^{t_1} (\alpha - \beta p) t dt + (M - t_1) \int_0^{t_1} (\alpha - \beta p) dt \right] \quad (7)$$

Case 2: When $M < t_1$

In this instance, the retailer earns interest = $pI_e[\int_0^{t_1}(\alpha - \beta p)tdt$ (8)

Interest Charged

Case 1: $M \geq t_1$

In this case the retailer has sold all the inventory so will have enough money to settle the account. Interest charged will be zero in this case.

$$IC_1=0 \quad (9)$$

Case 2: $M < t_1$

Based on the total available capital to the retailer at the time $t=M$, two different cases will arise

$$= \int_0^M (\alpha - \beta p)dt = D[0, M] = (\alpha - \beta p)M \quad (10)$$

Interest charged in this case will be:

$$= I_c(\alpha - \beta p)Mp \quad (11)$$

Thus, the Total Average cost is ascertained for different cases are given as:

Case 1: When $M \geq t_1$

In this case the total average cost for the retailer is given by:

$$TC_1 = \frac{1}{t_1} \left[(\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} c + (h + h_c) \int_0^{t_1} e^{-\frac{\pi t^2}{2}} (\alpha - \beta p) \left\{ -t + t_1 + \frac{1}{6} \pi (-t^3 + t_1^3) \right\} dt + (\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} (F + F_c) + pI_e \left[\int_0^{t_1} (\alpha - \beta p)tdt + (M - t_1) \int_0^{t_1} (\alpha - \beta p)dt \right] \right] \quad (12)$$

Case 2: When $M < t_1$

$$TC_2 = \frac{1}{t_1} \left[(\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} c + (h + h_c) \int_0^{t_1} e^{-\frac{\pi t^2}{2}} (\alpha - p\beta) \left\{ -t + t_1 + \frac{1}{6} \pi (-t^3 + t_1^3) \right\} dt + (\alpha - \beta p) \left\{ t_1 + \frac{\pi}{6} t_1^3 \right\} (F + F_c) + pI_e \left[\int_0^{t_1} (\alpha - \beta p) t dt - I_c (\alpha - \beta p) M p \right] \right] \quad (13)$$

4. Solution procedure

The total cost of the system for both cases is given in the above section. The replenishment cycle is assumed to be the decision variables. Hence, our objective is to find the optimum value of the cycle length in order to minimize the total cost.

Therefore, to find the optimum solution we equate first derivative of the total cost to zero i. e. $\frac{\partial TC_1}{\partial t_1} = 0$ for

case 1 and $\frac{\partial TC_2}{\partial t_1} = 0$ for case 2.

And the sufficient condition for the objective function to be minimum is as follows

$$\frac{\partial^2 TC_1}{\partial t_1^2} > 0 \text{ for case 1 and } \frac{\partial^2 TC_2}{\partial t_1^2} > 0 \text{ for case 2.}$$

To get the minimum cost for the system, first we find the minimum cost for both systems then find the minimum value of both costs.

5. Numerical Example

Example 5.1: The mathematical expression given above are numerically verified by using a numerical example the parametric value of the given parameters are taken as follows

$$\alpha = 1250 \text{ units}, \beta = 0.25, c = 100 \text{ rs/unit}, M = 20 \text{ days}, p = 150 \text{ rs/unit}, h_c = 0.5 \text{ rs/unit}$$

$$h = 2 \text{ rs/unit}, F = 0.75 \text{ rs/unit}, F_c = 0.25 \text{ rs/unit}, \pi = 0.1, I_e = 0.02/\text{rs}, I_c = 0.03/\text{rs}$$

Taking these values into account, the optimal critical time value and total average cost comes out to be 18.5252 days and 6314.02 respectively. An optimal quantity of 1522.4 items would be optimal.

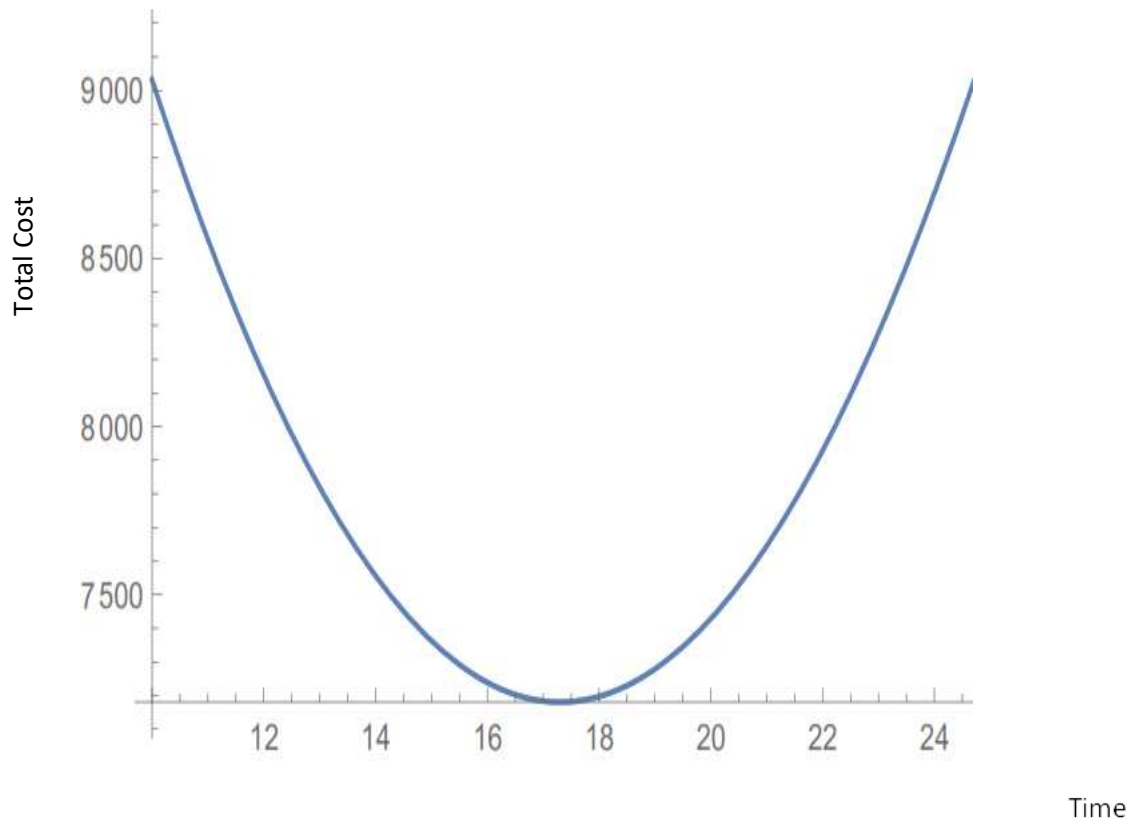


Fig. 3 Represent the convexity of above model

6. Sensitivity analysis

A sensitivity analysis is performed to look into the effects of altering a handful of factors with respect to the optimal result generated by the previously outlined approach. Below is a table summarizing the results.

Table 1. Sensitivity Analysis regarding Different Parameters:

Parameter	Change in Parameter	T*	TC*
β	-10%	21.18216	6935.429
	-5%	19.94034	6646.721
	5%	16.40876	5915.375
	10%	17.57332	6115.61
M	-10%	22.88398	8502.848
	-5%	20.25662	7374.003
	5%	17.89601	5389.965
	10%	17.4684	4422.716
p	-10%	16.0968	5002.074
	-5%	17.48475	5818.911
	5%	19.9124	6865.877
	10%	21.01404	7538.948
h	-10%	17.75983	5862.056
	-5%	18.22891	6103.566

	5%	19.30783	6631.244
	10%	19.92257	6980.285
F	-10%	18.7122	6291.737
	-5%	18.72731	6330.177
	5%	18.76167	6407.478
	10%	18.78091	6446.36
I_c	-10%	19.20109	6275.031
	-5%	18.95474	6320.696
	5%	18.56123	6418.619
	10%	18.40171	6469.796
I_e	-10%	17.90996	7303.947
	-5%	18.11924	6972.42
	5%	19.70501	5520.879
	10%	20.92265	4471.488
A	-10%	18.75165	6360.722
	-5%	18.74774	6363.998
	5%	18.73993	6370.613
	10%	18.73603	6373.931
	-10%	18.78281	6328.697

π	-5%	18.76337	6345.066
	5%	18.72431	6378.047
	10%	18.70469	6394.574
c	-10%	18.75425	6358.055
	-5%	18.74905	6362.465
	5%	18.73863	6371.253
	10%	18.73342	6375.632
h_c	-10%	18.76677	6319.824
	-5%	18.75526	6333.422
	5%	18.73232	6392.411
	10%	18.72081	6422.105
F_c	-10%	18.65579	6298.929
	-5%	18.69959	6326.964
	5%	18.78833	6384.263
	10%	18.83315	6413.463

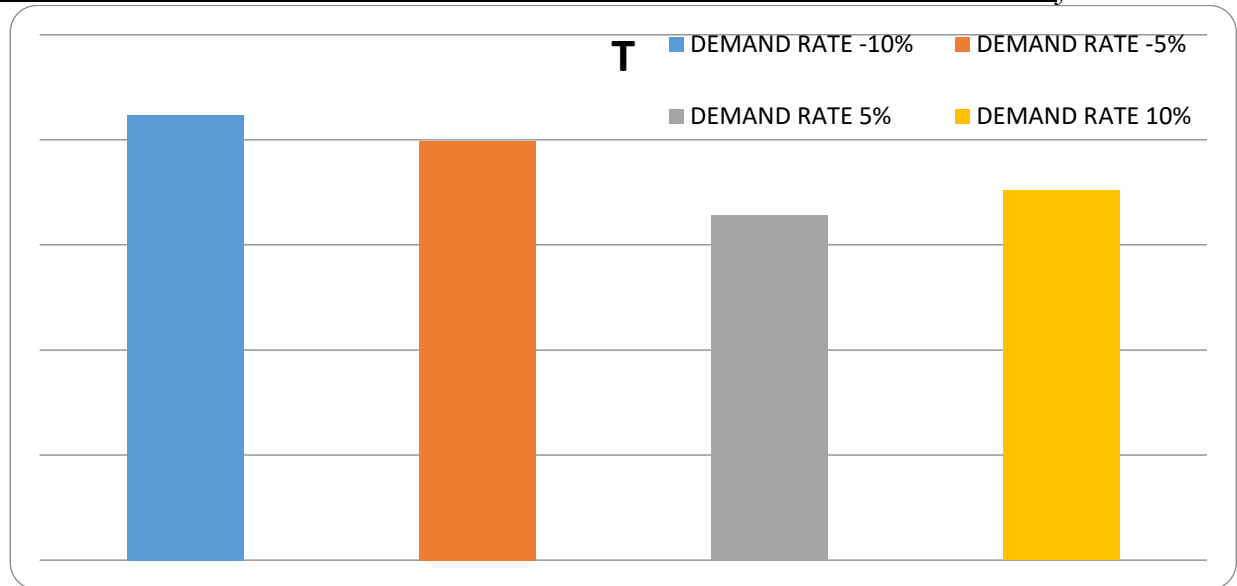


Fig 4: Sensitivity Analysis of cycle length with respect to demand rate

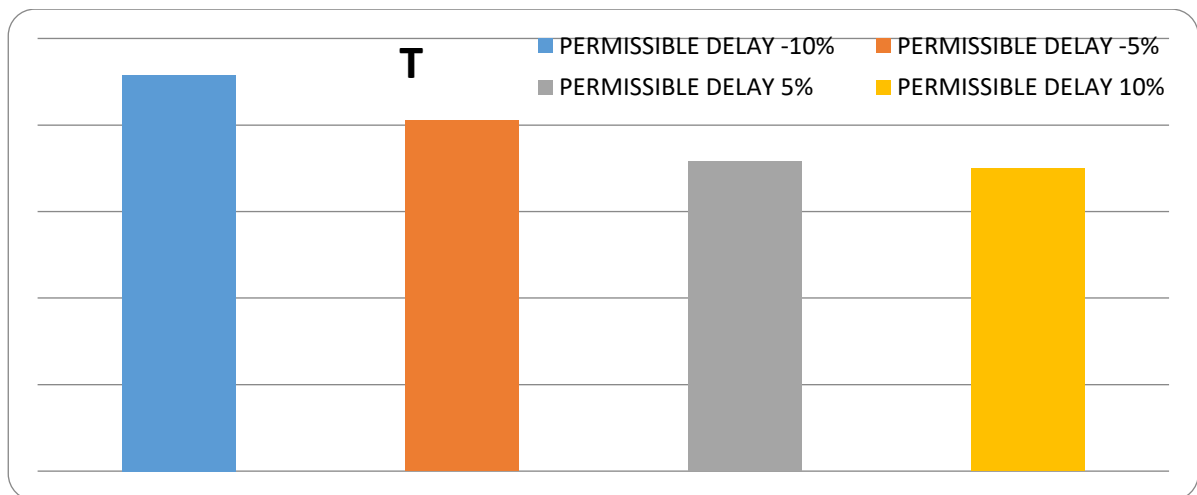


Fig 5: Sensitivity Analysis of cycle length with respect to permissible delay



Fig 6: Sensitivity Analysis of cycle length with respect to price

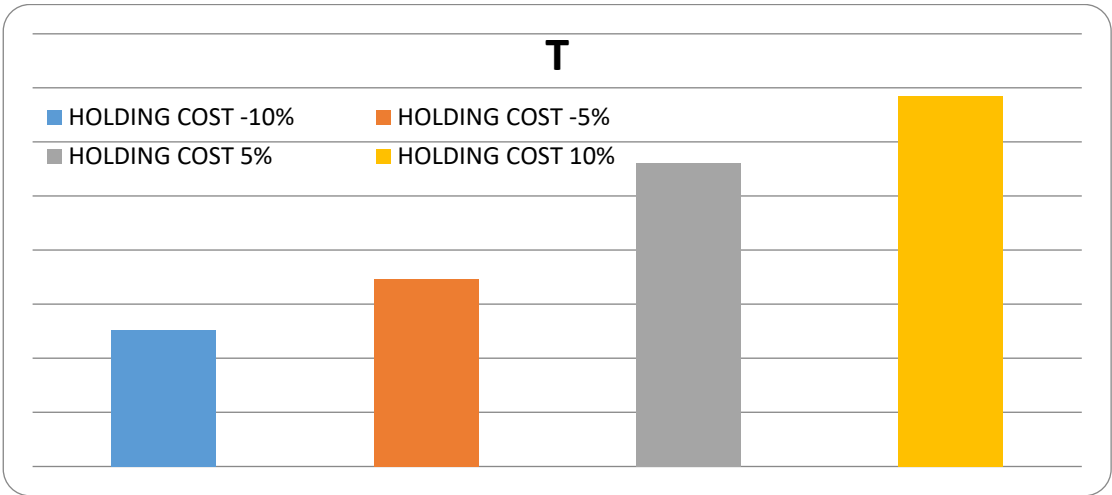


Fig 7: Sensitivity Analysis of cycle length with respect to holding cost

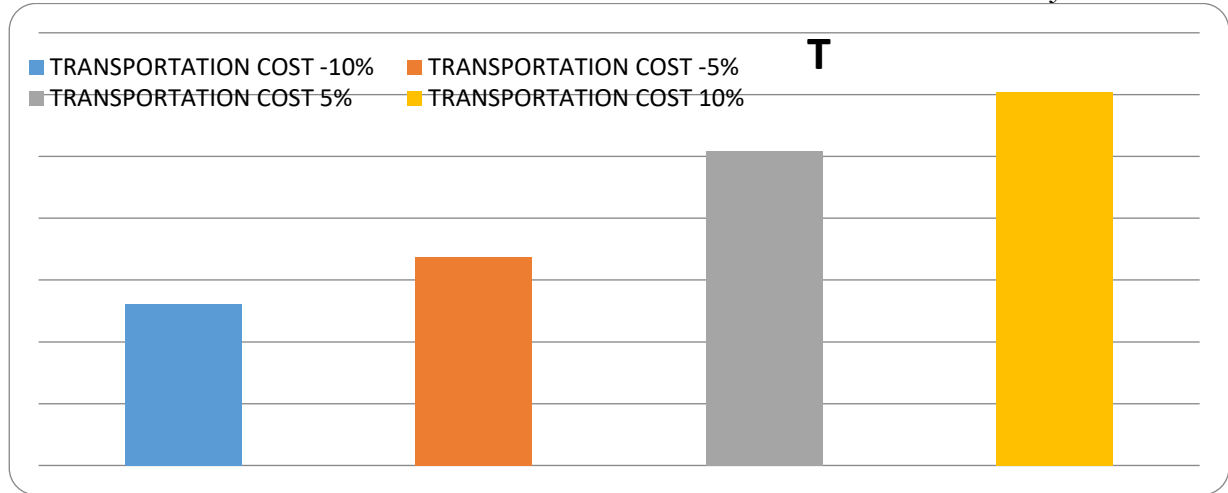


Fig 8: Sensitivity Analysis of cycle length with respect to transportation cost

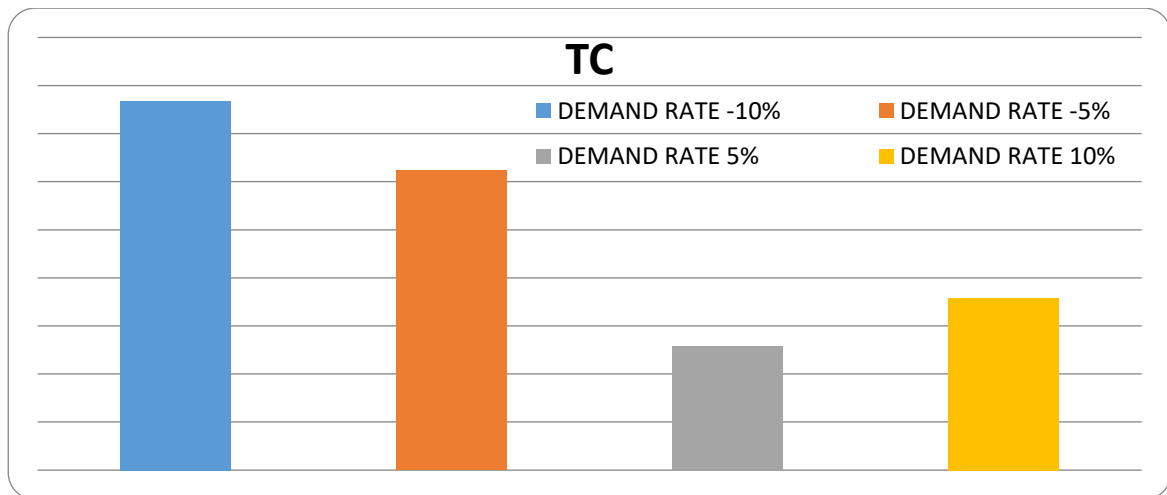


Fig 9: Sensitivity Analysis of total cost with respect to demand rate

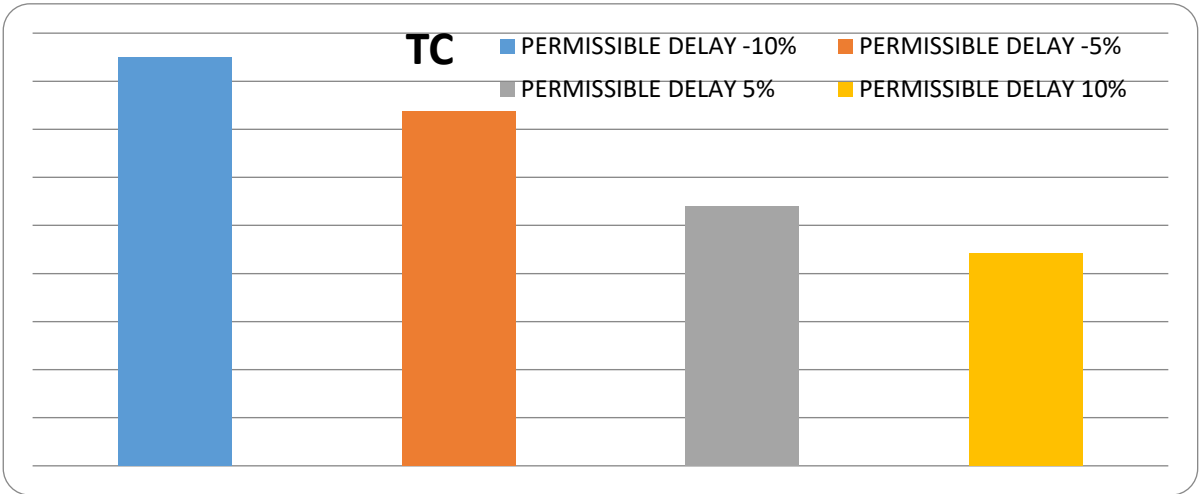


Fig 10: Sensitivity Analysis of total cost with respect to permissible delay

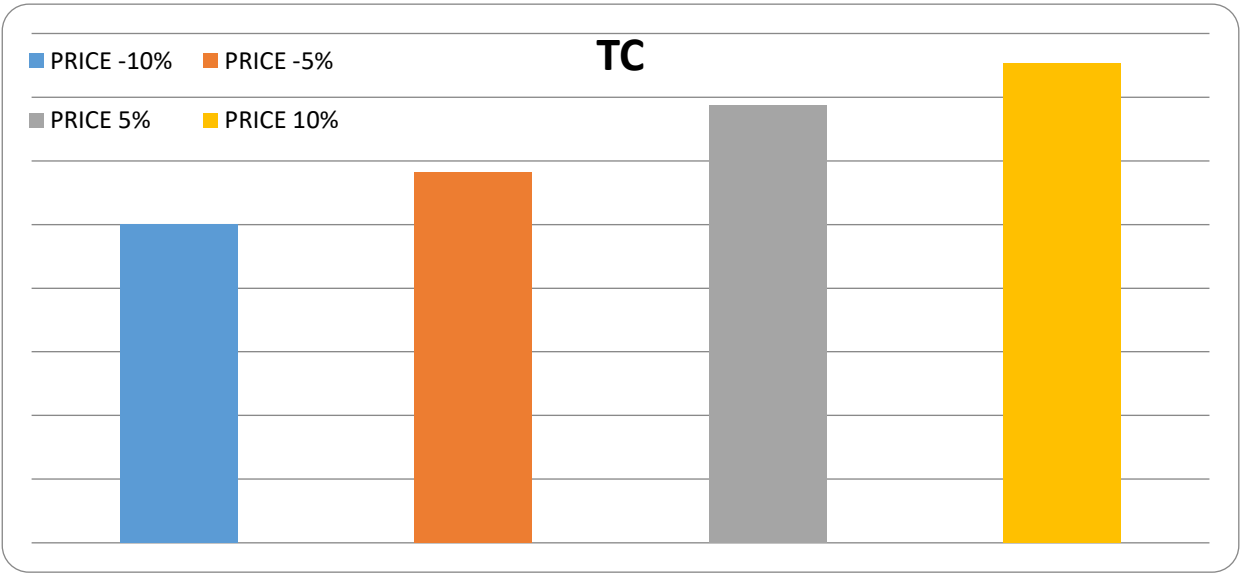


Fig 11: Sensitivity Analysis of total cost with respect to price

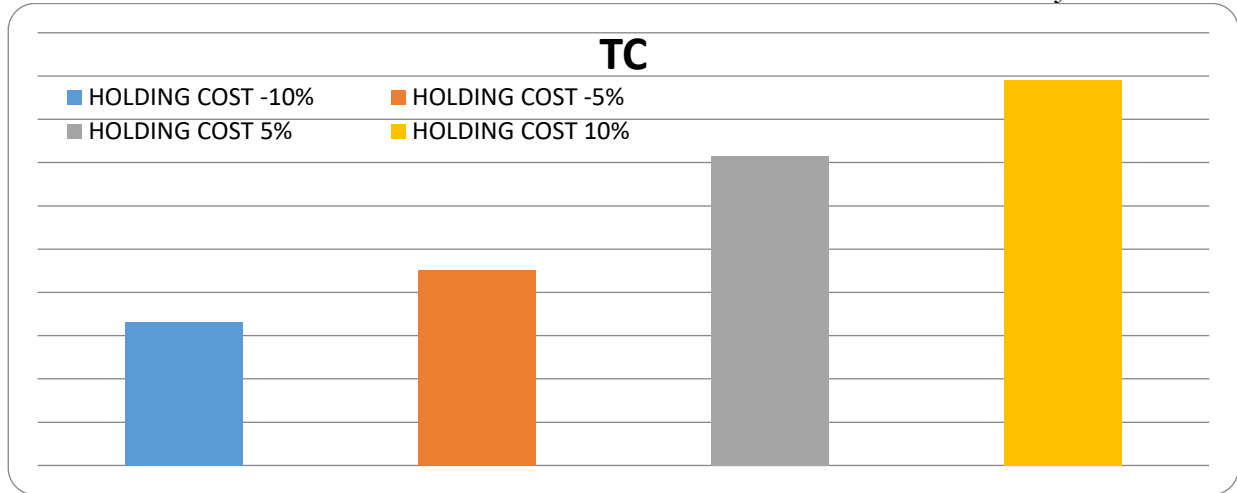


Fig 12: Sensitivity Analysis of total cost with respect to holding cost

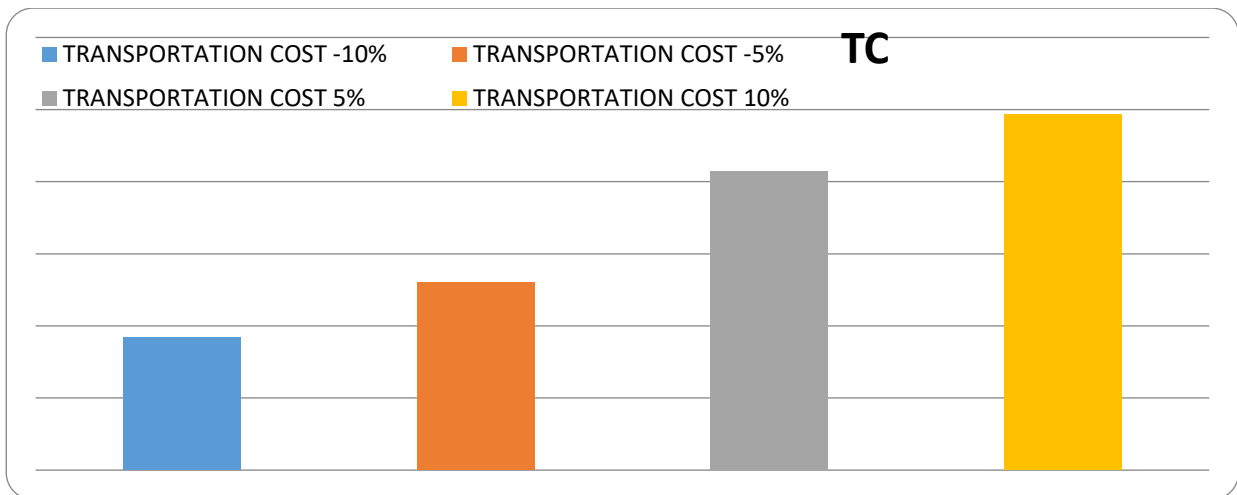


Fig 13: Sensitivity Analysis of total cost with respect to transportation cost

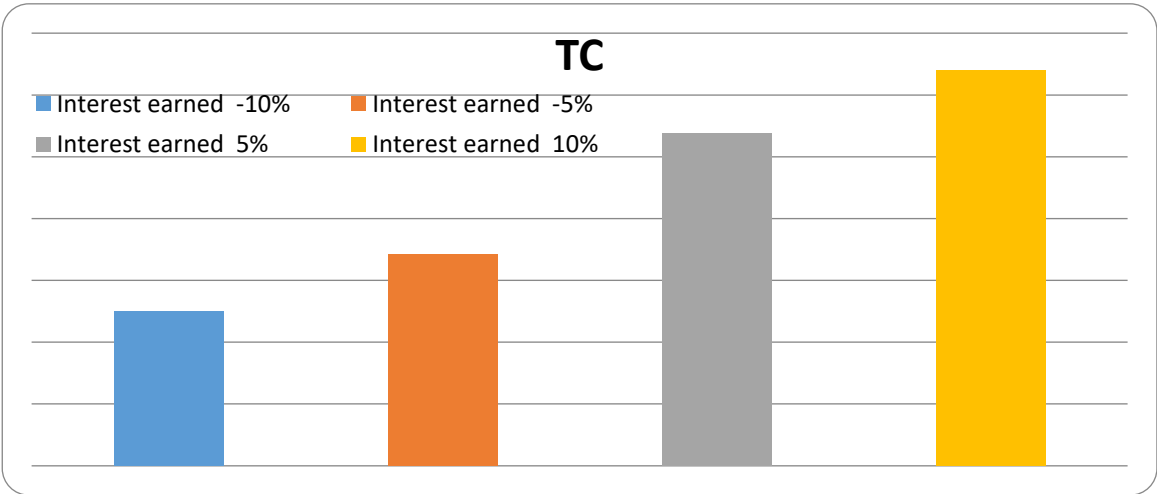


Fig 14: Sensitivity Analysis of total cost with respect to interest earned

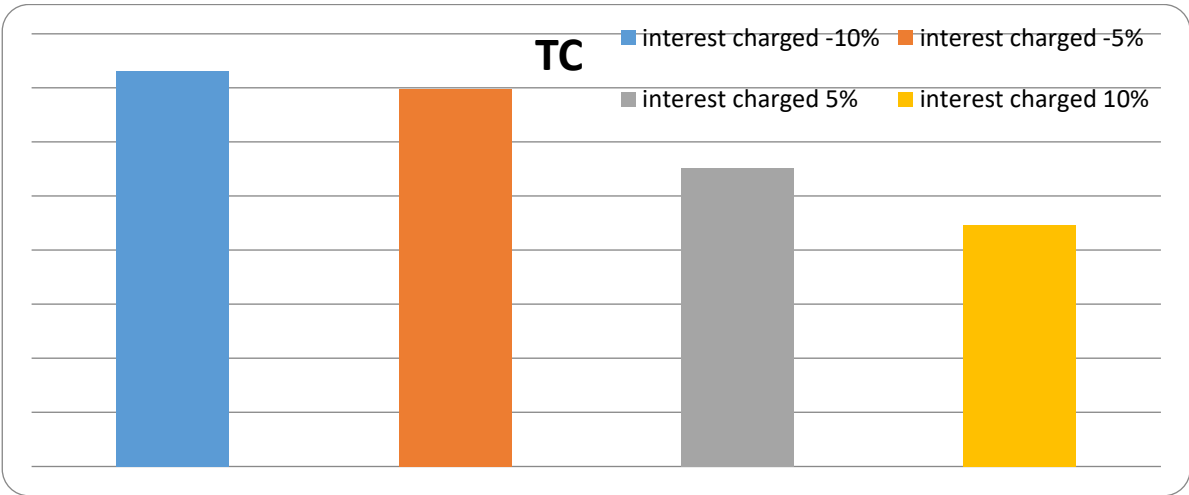


Fig 15: Sensitivity Analysis of total cost with respect to interest charged

7. Observations

The sensitivity analysis with respect to various parameters is shown in above mentioned table 1. The results revealed some useful insights such as:

1. In table 1, one can see how the profit function changes as the value of demand parameter α and β varies, one can see that as the value of demand parameter α and β increases, the cost also increases.
2. It is noticed that an increase in the permissible delay M generates a reduction in costing, which is not surprising.
3. Tables also showed the variation in holding costs and the increment in cost function is attributed to the increment in h .
4. With the increment of transportation cost or carbon emission cost, the cost of the system increases.

Accordingly, results display the variation in deterioration rate and interest rate and it may be observed that the system's costing increases as the parametric value increases.

Conclusions

We present an efficient system in this paper for obtaining the optimal solution for the inventory model with deteriorating items having a price-dependent demand rate under trade credit financing conditions with inflation. Carbon emission cost has been incorporated and investigated. Two different possible conditions depending on allowable trade credit are discussed and numerically explained. Results display the variation in demand rate, holding cost carbon emission cost, deterioration rate and interest rate. It may be observed that the system's costing increases as the parametric value increases. Furthermore, the costing has been found to be negatively sensitive to the permissible delay and the interest earned. To be used for future extensions. The study suggests that this model is applicable to seasonal products, fashion products, and bakery products. It also suggests that the phenomenon of stock out leads to partially backlogged shortages. This model and its benefits are illustrated numerically and by way of a sensitivity analysis. . This model has the potential of further extension with an allowed delay period.

Declaration of Competing Interest: The authors declare that they have no known competing financial interests

or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability: No additional data has been used in the proposed research.

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