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ANALYSIS OF INVENTORY MODEL WITH PRICE DEPENDENT DEMAND INCLUDING CONSTANT DETERIORATION RATE WITH SALVAGE VALUE, HOLDING COST IS TIME-DEPENDENT AND SHORTAGE IS PARTIALLY BACKLOGGED

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A B S T R A C T

In this study, we examine a model of inventory for things that are deteriorating along with the price dependent demand. The deterioration rate is constant and Salvage value is related to goods that are deteriorating, and holding cost is time-dependent. The suggested approach allows for some backlog in the shortage. Based on the length of time it will be before the next replenishment, the backlog rate is determined. This framework is solved to reduce the overall cost of given inventory to showing some numerical examples with sensitivity analysis to find the optimal solution for various parameters.

1. INTRODUCTION

A company's inventory is any item it maintains on hand, whether it be a tangible good or a service, for use in producing other things. The investment money of a company is being wasted by idle resources that may be used in more profitable ways, such as inventories. But maintaining inventory is necessary due to the manufacturing system's lack of synchronization. The fact that many managers view inventories as a necessary evil is therefore not surprising. Inventories are utilized for a number of purposes, the most important of which being (i) coordinating operations. They make up an important proportion of a company's overall assets. (ii) Smoothing out output (iii) Gaining economies of scale (iv) enhancing client relations Any inventory model must consider two key factors. When to place orders and how much to order and the latter is known as the economic order quantity. However, product quality is not always perfect and is typically dependent on the reliability of the manufacturing process. When the manufacturing process is in good shape, the products produced may be high-quality or even perfect. However, as time goes off, the manufacturing process deteriorates and the products produced may contain defects or be of poor quality.

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Therefore, the relationship between manufacturing lot size and product quality may be significant. A bigger lot size means a longer manufacturing process and therefore is more likely to have more defective products. Inventory in a manufacturing production system refers to all completed work, including raw materials products that have been partially finished, finished goods that have not yet been sold, and finished goods that have left the manufacturing system. Inventories are essential components of the supply chain, as they serve as a link between the manufacturing process and the final sale to consumers. They enable businesses to meet customer needs by providing products when they are needed, thus avoiding stock outs and meeting customer expectations for product availability and delivery. All work completed prior to sale, including partially processed information, is referred to as inventory in the context of services. The development of business activities and the growth of manufacturing industries have led to the development of inventory management to fulfill customer orders. Maintenance and replenishment of inventory requires an in-depth analysis of when to restock and how much to replenish. Mathematical models or optimization techniques can help answer these questions as they help in the management of inventory systems.

The demand rate has been considered to be steady in the majority of common inventory models. However, in reality, market demand is always rising and falling. Since the inventory manager has the least influence over demand, it is the most impulsive of all market factors. It is widely seen that a variety of factors, including price, time, new technologies, and product availability, may have an impact on consumer demand for a certain product Additionally because deterioration of the actual items in stores is a widespread occurrence and cannot be ignored. Some goods, such as fruits, food grains, fish, vegetables etc., degrade quickly whereas others, such as toys, glassware, clothing, etc., degrade more slowly. In the real-life situation, it is quite difficult to maintain the deteriorating item inventory. In the review many inventory models with deteriorating items were studied by many researchers first Giri et al. presented an EOQ model in 1996 for degrading commodities with time-varying costs and demand. Chang and Dye, (1999) We've come up with a model that can be used to figure out if items are deteriorating, if demand is changing over time, and if there's a backlog of items., further

Sahoo and Tripathy published in 2018. They were both examined using the economic quantity Model for Quadratic Demand Rate, Parabolic Deerioration, and Time Dependent Holding Cost with Partial Backlogging. Shah and Shukla (2009) also came up with an inventory model for creating a waiting time partial backlog of deteriorating items. In 2011, Mishra and Singh figured out how to handle a slow-growing inventory model that had to do with time-sensitive demand and cost of holding inventory. They came up with a solution called partial backlogging. In 2013, the authors of the paper (Amutha & Chandrasekaran, 2013) developed an inventory model in which the demand for products is a constant, with shortages occurring when payment is allowed to be delayed In order to implement an If you're looking for a way to get the most bang for your buck when it comes to non-obviously damaged items, you'll want to make sure you're following the best pricing and ordering policy. A team of experts, including Mr. Kumar V, Mr. Sharma A, and Mr. Gupta CB (2019), collaborated to take into account the demand for the product in terms of price and stock-dependency, as well as the potential for partial backlogging. Rahman (2020), the author proposed the concept of an inventory model that utilizes a time-determining four-dimensional demand function with a variable rate of deterioration over time without the presence of a shortage.

In inventory models, it is suggested that the demand rate is constant. but in reality, demand for tangible products may vary stock-, time-, and price-dependent. Demand rates that depend upon establishing the price are based on the observation that many items' sales tend to grow when selling prices fall. Many researchers work on the price dependent demand. First Whitin (1995), has introduced Inventory control and price theory, after that Burwell et al. (1997) discussed an “EOQ lot size model for price-dependent demand under quantity and freight discounts”. Further study by Mondal et al. (2003) introduced an inventory system for price dependent demand rate of ameliorating items. Roy in (2008) developed a model of inventory for products that depreciate with time-varying holding costs and demand that is based on prices. Sahoo et al. (2010) suggested an inventory model for products that are continually degrading that implements price-related demand and oscillating holding costs. Invented by Venkateswarlu and Mohan (2013), A salvage value has been added to an inventory model that takes price-dependent quadratic demand and time-varying degradation into evaluation. The development of an Inventory and Pricing model based on price-driven demand was conducted by the team of Alfares (H.K.), H.K., and Ghaithean (A.M) in 2016. The team took into account time-variant holding costs and quantity discounts. Sujata and Saha (2017) examined a lack of consistency in the inventory model of a supply chain system with deteriorating items and discovered that the demand for goods was price-driven and there was no requirement for back order. N., Saha, S., and Nath, B. (2017) were carried out research work on the inventory model with price-dependent demand under the allowable delay payment. The characteristics of deterioration tend to involve decay, damage, dryness, and spoiling. It is the process through which a thing stops serving a purpose and becoming worthless. Inventory of degrading goods is a common occurrence in daily life. stuff like fruit, veggies, milk, clothing, and electrical components. Deteriorating products include things like pharmaceuticals, alcohol, and petrol.

Consequently, the depreciation or disintegration of physical assets in Stock is a highly practical component that must be taken advantage of while modelling inventories. Within (1957) conducted the first study on the inventory of deteriorating goods and concentrated on the deterioration of fashion items at the conclusion of the allowed storage time. The traditional EOQ formula was expanded by A mathematical model of inventory of decaying items by Ghare and Schrader (1963) with an exponential decay of inventory due to deterioration. Kumar VM. (2010) took a look at how inventory models are changing and how demand is changing over time, and here he's taken a look at how partial backlogs are happening. Mishra and Singh (2011) provided an inventory model for time-dependently decaying items with salvage value, ramp-type demand, and shortages. Shah (N.H.), Jani (M.Y.), and Chaudhari (U.S.) (2018) wrote a paper on "Optimal Ordering Policy for Deteriorating Items Under Down-Stream Trade Credit Dependent Quadratic Demand with Full Up-Stream Trade Credit and Partial Down-stream Trade Credit".

Holding costs are the expenses associated with the storage of inventory that has not yet been sold. These costs are a part of an organization's total inventory costs, which includes both ordering costs and shortage costs. A company's holding costs include the cost of damaged or spoiled goods, as well as storage costs, labor costs, and insurance costs. One of the most crucial elements in calculating the total profit as well as the cost of planning the inventory is the holding cost. Regarding the time parameter, the holding cost might either be linear or non-linear. Many academics have thought about expanding their work on inventory planning to include time-dependent variable holding costs.

A shortage is a condition or situation where the required items are not available in sufficient quantities or are not available at all. To give you an idea of what a shortage is, let’s say A business manufactures specific necessities whose demand is increasing quickly or abruptly. Due to certain unavoidable circumstances, the company can’t deliver the product to its customers. At that point, it becomes a shortage for that particular product. What is the importance of a shortage for many models? When you think about it, a shortage is very important for many models. Especially when you think about it in terms of delay in payment. If you have a shortage but you offer delay in payment to your customers, you can get more orders. That’s why a company that offers a delay in payment can enjoy a lot of profit. In inventory models where there are shortages, It's frequently believed that the unmet demand is either lost or in the line. But there are few of possibilities that this can happen: Some customers walk away others are content to wait until their demand is met.

Sharma (A.K.), Kumar (M.), and Ramani (N.) (2012) have come up with an inventory model that looks at how weibull distribution affects the demand for certain items. It looks at how shortages and time-dependency on holding costs affect the supply of those items. An order level inventory model developed for an item with quadratic time-varying demand and scarcity, and also partial backlog was developed by Manna, S.K., and Chaudhuri, K. (2014). In 2013, Sarkar, S., and Chakrabarti (T) conducted a study on an EPQ model that presented evidence of Weibull distribution degradation with an exponential increase in demand and production, as well as shortages, under the assumption that payments would be subject to a permissible delay. The research was conducted by Pervin et al. (2018) and focused on the development of an inventory control model which is based on a shortage model with a time dependent demand and here they considered time varying holding cost, which included stochastic deterioration. A collaborative study has been conducted by Handa et al.'s (2020) “study on a trade credit policy in an equilibrium observation quality (EOQ) model with stock-sensitive demand and shortages of deteriorating” goods. The estimated resale value is the salvage value. When something has outlasted its usefulness, the portion of an asset's cost that will be paid off over time is calculated by deducting it from the asset's cost. The computation of depreciation includes salvage value as one of its factors. Mishra (P), & Shah (H.N.), 2008, “were studied on Inventory Management of Time Dependent Deteriorating Items with Salvage Value”. The authors of Tripathi and Tomar (2018) looked at the use of an EOQ model whose demand has a parabolic-time linked holding cost with a savings value and a quadratic time sensitivity. In (2022) by the Sathish and Iswarya.” An inventory model with price-dependent demand, partially backlogged shortages, and salvage cost has been proposed”.

A solution methodology is created to address this model, which typically involves mathematical optimization techniques to identify the most cost-effective order quantity and reorder points to optimize inventory levels. The model's use is exhibited by way of concluding the problem, and a sensitivity analysis is carried out to determine how different factors affect the best possible outcome. This type of comprehensive inventory model is intended to provide more precise and practical insights into inventory level management. In the proposed work, we developed a model for items that degrade with price-dependent demand, and in this case, we consider deficits to be partial backlog and hosting to be time-dependent. In this present work we take the salvage value associated with deterioration items. A mathematical model is created that conforms with the provided assumptions in order to identify the ideal determination, and a technique is created in order to maximize overall profit. In this paper we also given a numerical example with sensitivity analysis and also shown graphical representation for variation of total average cost by different parameters.

2. ASSUMPTIONS AND NOTATIONS

2.1 Assumptions

The mathematical framework is constructed based on certain generalizations.

- Demand is price dependent.
- Deterioration rate is taken constant.
- Holding cost is time dependent.
- Shortage allowed with partially backlogging.
- Replenishment rate is infinite.
- deterioration items associated with Salvage value.

2.2 Notation

Demand rate is price dependent and assumed as: R(t) = ap^{-b},where a, b>0 and p is the selling price.

θ *is* the deterioration rate which is assumed constant.
Cost of holding HC(t) per object per unit of time depends on time and is assumed as. h(t) = $h_1 + h_2 t$, $h_1 > 0, 0 < h_2 < 1$
A is the cost to order for the each order.
$B_1$is the cost of inventory per unit.
B_2 is the shortage cost per unit.
B_3 is the opportunity cost of lost.
t_1 is the point at which the shortage begins.
T is the length of each ordering cycle.
I_A is inventory level for find the maximum every order cycle.
I_B is the maximum quantity of backlogged demand for a single ordering cycle.
E is the appropriate amount to order economically for each cycle.
Inventory level at time (t) is represented by I(t).
γ is the salvage value and assumed as Sv:0 ≤γ< 1 with deteriorated units during the cycle time.

The variable backlogging rate, which is determined when the shortage period starts, is based on how much time will pass until the next replenishment. The waiting period grew longer. Because of the wait time, the number of customers. Who would be willing to take up the backlog at time t is diminishing. (T - t) till next replenishment. To avoid this circumstance, we have defined $\frac{1}{1+\alpha(T-t)}$ as the quantity of backlog when the inventory is negative with constant positive backlogging parameter α for the time period (t_1 , T).

3. MATHEMATICAL MODEL

Here, we make the deteriorating inventory model with price-dependent demand and time-dependent replenishment our starting point. t = 0 then the maximum level of inventory is I_A. Then the differential equation describing the state of inventory is given by.

$$\frac{dI(t)}{dt} + \theta I(t) = -R(t), 0 \le t \le t_1 \ldots \quad (1)$$

With initial condition $I(t_1) = 0$, and boundary condition $I(0) = I_A$. (Figure 1).

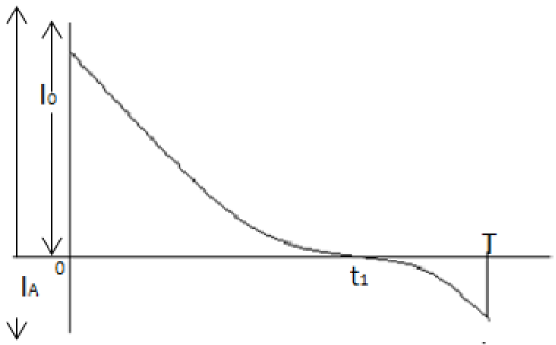

Figure 1. Mathematical Model

$$\frac{dI(t)}{dt} + \theta I(t) = -ap^{-b}, \ 0 \le t \le t_1 \ \ldots \ (2)$$

$(t_1) = 0$, and $I(0) = I_A$. Solution of equeation (2) is

$$I(t) = \frac{ap^{-b}}{\theta}\left[e^{\theta(t_1-t)} - 1\right] \quad \ldots \quad (3)$$

To establish a boundary condition, the maximum inventory level for each cycle is obtained. $I(0) = I_A$ in equeation (3) therefor

$$I(0) = I_A = \frac{ap^{-b}}{\theta}\left[e^{\theta t_1} - 1\right] \ \ldots \quad (4)$$

Through the shortage period$[t_1, T]$, demand is partial backlog at time t for the friction $\frac{1}{1+\alpha(T-t)}$, so that
The differential equation that determines how much backlog demand exists is

$$\frac{dI(t)}{dt} = -\frac{ap^{-b}}{1+\alpha(T-t)}, t_1 < t < T \ \ldots \quad (5)$$

With boundary condition $I(t_1) = 0.$ the solution of equation (5)

$$I(t) = -\int \frac{ap^{-b}}{1+\alpha(T-t)} dt$$

$$I(t) = \frac{ap^{-b}}{\alpha}[\log(1+\alpha(T-t)) - \log(1+\alpha(T-t_1))] \ (6)$$

Maximum backlog in demand orders per cycle as determined by accumulating t = T in equation (6)

$$I_B = -I(T) = \frac{ap^{-b}}{\alpha}\log(1+\alpha(T-t_1))$$

Now, the economic order quantity per cycle is:

$$E = I_A + I_B = \frac{ap^{-b}}{\alpha}\left[e^{\theta t_1} - 1 + \log(1 + \alpha(T - t_1))\right]$$
(7)

The holding cost of inventory per cycle is:

$$H_c = \int_0^{t_1} h(t)\, I(t)dt$$

$$H_c = \frac{ap^{-b}}{2\theta^3}\left[2\theta h_1\left(e^{\theta t_1} - \theta t_1 - 1\right) + h_2(2e^{\theta t_1} - \theta^2 t_1^2 - 2\theta t_1 - 2)\right]$$
(8)

The cost of deterioration rate per cycle is:

$$D_c = B_1(I_A - \int_0^{t_1} R(t)dt)$$

$$D_c = \frac{B_1 ap^{-b}}{\theta}\left[\left(e^{\theta t_1} - \theta t_1 - 1\right)\right] \ldots \quad (9)$$

The Salvage value associated with deterioration rate is:

$$S_v = \frac{B_1 \gamma ap^{-b}}{\theta}\left[\left(e^{\theta t_1} - \theta t_1 - 1\right)\right] \ldots \quad (10)$$

The Shortage cost of each per cycle is:

$$S_c = B_2\left[-\int_{t_1}^{T} I(t)dt\right] = \frac{B_2 ap^{-b}}{\alpha}\left[(T - t_1) - \frac{1}{\alpha}\log(1 + \alpha(T - t_1))\right]\ldots$$
(11)

The opportunity cost associated with each cycle of lost sales is:

$$O_c = B_3\left[\int_{t_1}^{T} ap^{-b}(1 + \frac{1}{1 + \alpha(T - t)})dt\right]$$
$$= B_3 ap^{-b}\left[(T - t_1) - \frac{1}{\alpha}\log(1 + \alpha(T - t_1))\right] \ldots \quad (12)$$

Therefore, total average cost per unit time per cycle TC is given by

$$TC\,(t_1, T) = \frac{1}{T}(A + H_c + D_c + S_c + O_c - S_v)$$

$$= \frac{1}{T}\left[A + \frac{ap^{-b}}{2\theta^3}\left[2\theta h_1\left(e^{\theta t_1} - \theta t_1 - 1\right) + h_2\left(2e^{\theta t_1} - \theta^2 t_1^2 - 2\theta t_1 - 2\right)\right] + \frac{B_1 ap^{-b}}{\theta}\left[\left(e^{\theta t_1} - \theta t_1 - 1\right)\right] + \frac{(B_2 + \alpha B_3)ap^{-b}(T - t_1)}{\alpha} - \frac{(B_2 + \alpha B_3)ap^{-b}\log\left(1 + \alpha(T - t_1)\right)}{\alpha^2} - \frac{B_1 \gamma ap^{-b}}{\theta}\left[\left(e^{\theta t_1} - \theta t_1 - 1\right)\right]\right] \ldots$$
(13)

Our goal is to use the mathematical Software to determine the ideal values of $t_1$and T to reduce the overall cost of inventory per unit of time.

$$\frac{\partial TC(\,t_1, T)}{\partial t_1} = 0 \text{ and } \frac{\partial^2 TC(t_1 T)}{\partial t_1^2} > 0$$

By satisfy the sufficient conditions. From equation 13 can be written as

$$= \frac{1}{T}\left[\frac{ap^{-b}}{\theta^2}\left[h_1\left(\theta e^{\theta t_1} - \theta\right) + h_2\left(e^{\theta t_1} - \theta t_1 - 1\right)\right] + B_1 ap^{-b}\left[\left(e^{\theta t_1} - 1\right)\right] - \frac{(B_2 + \alpha B_3)ap^{-b}(T - t_1)}{1 + \alpha(T - t_1)} - B_1 \gamma ap^{-b}\left[\left(e^{\theta t_1} - 1\right)\right]\right] = 0 \ \ldots$$
(14)

Again, Differentiating Equation (14) with respect to t_1

$$\frac{\partial^2 TC(t_1, T)}{\partial t_1^2} = \frac{1}{T}\left[\frac{ap^{-b}}{\theta}\left[h_1\left(\theta e^{\theta t_1}\right) + h_2\left(e^{\theta t_1} - 1\right)\right] + B_1 ap^{-b}\left(\theta e^{\theta t_1}\right) + \frac{(B_2 + \alpha B_3)ap^{-b}}{(1 + \alpha(T - t_1))^2} - B_1 \gamma ap^{-b}\left(\theta e^{\theta t_1}\right)\right] = 0 \ \ldots \quad .(15)$$

4. NUMERICAL ILLUSTRATION

Example: Let A=200, a= 10, b= 0.5 p=10, h_1= 4, h_2= 0.2, θ= 0.4, B1= 1.5, B2= 2.5, B3= 2, $\alpha = 0.4$ and $\gamma = 0.2$ By applying Mathematics software we find the outputs (Table 1, Table 2, figure 2 and figure 3).

$t_1 = 181.75$ days and the Total cost = ₹403.72

Table 1. Effect of θ and ϒ

θ / γ	0.2	0.3	0.4	0.5	0.6
0.1	TC=390.28	TC=398.37	TC=405.94	TC=413.02	TC=419.62
0.15	TC=389.64	TC=397.48	TC=404.84	TC=411.73	TC=418.19
0.2	TC=389.00	TC=396.47	TC=403.72	TC=410.43	TC=416.73
0.25	TC=388.35	TC=395.67	TC=402.59	TC=409.10	TC=415.24
0.3	TC=387.70	TC=394.76	TC=401.44	TC=407.75	TC=413.72

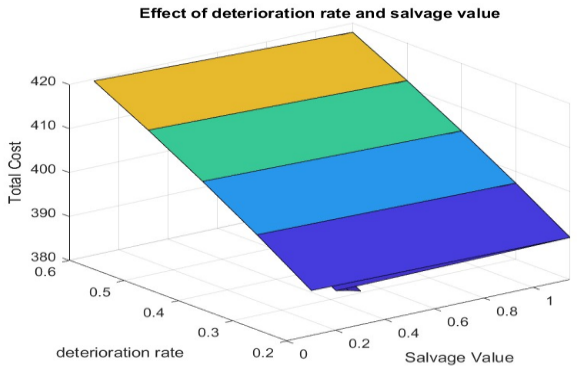

Figure 2. Effect of deterioration rate and salvage value

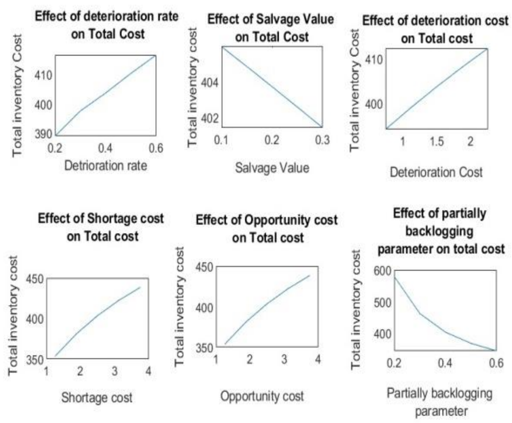

Figure 3. Sensitive Analysis of Table 2

Table 2. Sensitivity Analysis

Parameters	%change in parameters	t_1	TC
θ	+50	168.70	416.73
	+25	175.04	410.43
	-25	188.84	397.58
	-50	196.33	389.00
B_1	+50	173.17	412.28
	+25	177.36	408.11
	-25	186.35	399.10
	-50	191.19	394.22
B_2	+50	211.64	438.60
	+25	197.98	422.62
	-25	162.16	381.04
	-50	138.10	353.41
B_3	+50	192.47	416.19
	+25	187.26	410.13
	-25	175.89	396.92
	-50	169.66	389.71
γ	+50	184.02	401.44
	+25	182.88	402.59
	-25	180.63	404.84
	-50	179.53	405.94

5. CONCLUSION

This research paper seeks to create a model for the inventory of deterioration items that can be used to determine price-dependent demand. We have taken into account the fact that holding cost is time-dependent, and that shortages can be accommodated with part of the backlog. The primary objective of the model is to determine the impact of cost-per-unit-time on the variation of various parameters. Numerical examples are used to illustrate the results. It is discussed how the solution is responds to changes in the parameters associated with the model.

- When the salvage value (γ) and deterioration rate (θ) increase. Then the total cost increased significantly.
- When the deterioration rate (θ) will increase, the total cost shows the effect increase significantly.
- When the deterioration cost (B_1) increase, (then total cost increase significantly).
- When the shortage cost (B_2) will increase, the total cost increase significantly accordingly.
- When the opportunity cost (B_3) will increase, the total cost increase significantly.
- According to the table we can say when salvage value (γ) will increase, the total cost decrease marginally.
- The overall cost decreases significantly when the partly backlogging parameter is increased.

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