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An Inventory Model with Fluctuate Ordering and Holding Cost with Salvage Value for Time Sensitive Demand and Partial Backlogging

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Abstract:

Inventory models are essential in evaluating a wide range of genuine situations that occur in locations, including grocery and vegetable markets, market yards, petroleum exploration businesses, etc. This article introduces an economic order quantity (EOQ) profit optimization for degrading products. It analyzes how variable ordering prices and holding charges affect profit margins within restricted planning horizons. Here demand rate is projected to be time sensitive, and the worsening price is proportional to time. Models of inventories for decaying objects are established. The dilemma is solved when shortages are considered acceptable and partially backordered. The holding and ordering expenses tend to fluctuate. The salvage value is allocated to items in the system that have deteriorated. A numerical example is used to discuss the sensitivity of the models. Further, We exemplify that the significantly reduced cost coefficient is convex if evaluated simultaneously and finds the most efficient solution. The statistical analysis reveals that a suitable policy can benefit the retailer, especially for worsening products.

Keywords: Partial backlogging, Deterioration rate, salvage value, shortages, variable ordering, and holding cost.

1. Introduction

Change, decay, damage, obsolescence, spoilage, and pilferage all contribute to the loss of a stock's usability or marginal value. Medicine, blood, seafood, liquor, gas, food, and radioactive substances all have a limited shelf life and begin to degrade immediately after they are received. As a result, the deterioration of the product cannot be overlooked. During stockouts, most inventory models incorrectly assume that all demand is lost or backlogged. In reality, some customers wait for replenishment, particularly if the delay is brief, while others become agitated and leave because of these stockouts, Backlogging, in part has been implemented in this investigation. Most academics believe that scarcity is entirely accumulated. Some clients choose to wait patiently for delays amid a scarcity, while others do not. The financial burden of missing out on sales should be taken into consideration in the modelling methodologies.

Decaying models of stocks have received significant attention in the last couple of decades. For a constant demand, Ghare and Schrader [1] became the first to acquire a continuously depleting inventory. Through rectifying and altering the error in Shah and Jaiswal's analysis [3], in determining The mean quantity of inventory storage cost, Aggarwal [2], created an Order-specific stock model.

Goyal and Giri [4], have recently released a comprehensive review of research on deteriorating inventories. They asserted that due to the fact that numerous inventory items, such as technological goods and trendy clothing, experience demand rate swings, applying the concept of a consistent rate of demand to them is not invariably suitable. Many items experience increased necessitate throughout the expansion phase during which the item they produce endures. Alamri and Balkhi [5], investigated the appropriate measure of a production order for perishable goods with cyclical demand and also deterioration rates in connection to memory loss and learning. Dye et al. [6], estimated the optimal lot size and selling price given an exponential partial backlog and a variable rate of deterioration. According to them, the proportion of client backlogs in their purchases augments as the time between replenishments decreases. This investigation predicts a conceptual framework for EOQ inventories that accounts for decaying objects and demand that decreases exponentially. V. K. Mishra [7] developed an A stock approach that incorporates time-dependent variables storage costs, deterioration, salvage value, and scarcity. Vinod Kumar et al.[8], regarded as an inventory framework for degrading goods under a partial stockpile with holding costs that fluctuate with time and demand. The concept of quadratic demand, time-dependent deterioration without shortages, and salvage value was proposed by Mohan and R. Venkateswarlu [9]. Kavitha Priya and K. Senbagam [10] proposed a method for time-dependently deteriorating goods with quadratic time-varying demand and a partial backlog. Numerous academics developed alternative inventory models based on different patterns of demand. Pervin et al. [11] created an inventory model with time-based demand and a stochastic deterioration rate. Singh and Mishra [12] proposed a green inventory model for non-instantaneous substitutable degrading products that employ a combined ordering strategy and carbon emissions. S. Fatma, V. K. Mishra, and R. Singh [13], Model of Inventory for Immediate Deterioration Goods with Time Sensitive Demand for Post COVID-19 Recovery.

This paper contains, it is anticipated that the demand rate will be time sensitive and that the rate of worsening will be proportionate to time, a model of stock for items that are degrading will be created. When shortages are acceptable and partially backordered, the problem is resolved. Costs of holding and ordering are variables. Items in the system that have deteriorated are given the salvage value. An example utilizing numbers is used to discuss the models' sensitivity. The goal of this modelling is to examine the influence of variable ordering and holding costs with salvage values on the partially backlogged problem's overall inventory cost.

2. Presumptions and annotations

2.1 Presumptions

This mathematical model is described by considering the subsequent presumptions
and notations. Assumptions are,

1. The demand rate $f(t)$ at times it is assumed as $f(t) = \omega_1 + \omega_2 t$; ω_1, ω_2 are constants.
2. Replenishment occurs.
3. Shortages are allowed.
4. $\theta(t) = \theta t$ is the deterioration rate.
5. Both the storage cost and purchasing cost are variable
6. Here, holding cost is time sensitive i.e., where $\alpha > 0,\ \beta > 0$
7. Here Ordering cost is $C_o = q^{\gamma-1}$ where $q > 0, \gamma > 0$.

Units that have deteriorated over the period of a cycle are related with the salvage value δ, $0 \leq \delta < 1$. Unmet demand fulfilled have been described as partially backlogged. As consumers' waiting period, $(T - t)$ reduces, the percentage of backorders increases. The partial reserve rate is equals to $e^{-\mu(T-t)}$. where μ is the parameter for positive backlogging.

2.2 Notations

Notation	Description
C_S	Shortage Cost per unit of time.
C_o	Ordering cost per order.
C_D	Deterioration cost
W	The maximal storage amount for every procurement period.
S	The highest quantity of inventory
Q	The amount of the order $(Q = W + S)$.
$I(t)$	Inventory level at time t.
t_1	Time when shortage start.
T	Total length of each ordering cycle.
TC	The total price of the stock for each purchase period $(0, T)$.
α	Holding cost parameter.
β	Holding cost parameter.
δ	Salvage Value

3. Model Formulation

This study makes the assumption that a depreciating product will need to be replenished with variable holding and ordering costs. We provide the appropriate order quantity, Q, and the ideal total cost of inventory.

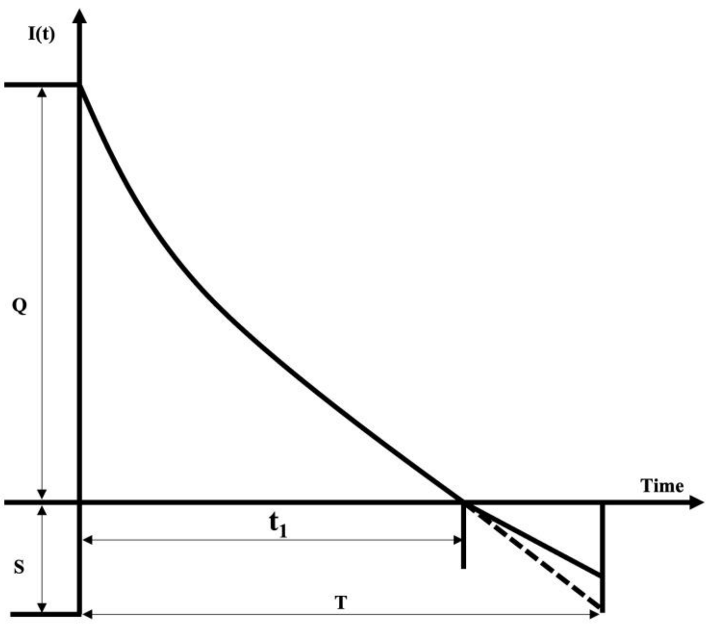

Fig. 1 Inventory level I(t) vs. time

The inventory level $I(t)$ falls to zero at $t = t_1$ due to both demand and deterioration throughout the period $[0, t_1]$, whilst shortages occur during the period $[t_1, T]$ due to demand and a portion of requirements are backlogged.

$$\frac{dI_1(t)}{dt} + \theta t I_1(t) = -(\omega_1 + \omega_2 t);\ 0 \leq t \leq t_1 \tag{1}$$

And during the interval $[t_1, T]$ the shortage occurs, so the differential equation is given by:

$$\frac{dI_2(t)}{dt} == -(\omega_1 + \omega_2 t)e^{-\mu(T-t_1)};\ t_1 \leq t \leq T \tag{2}$$

With the boundary conditions: $t = 0, I(0) = W$,

$$t = t_1; I(t_1) = 0$$

$$t = T;\ \mathrm{I}(T) = S$$

Now by solving equation (1), we get,

$$I_1(t) = \left(\frac{\omega_1+\omega_2 t}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta(t_1-t)} - \left(\frac{\omega_1+\omega_2 t}{\theta} - \frac{\omega_2}{\theta^2}\right) \tag{3}$$

By solving equation (2), we get:

$$I_2(t) = e^{-\mu(T-t_1)}\left(\frac{\omega_1+\omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right) - e^{-\mu(T-t)}\left(\frac{\omega_1+\omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right) \tag{4}$$

Now, at $t = 0$ the maximal storage amount for every period is given by

$$I_1(0) = W, t = 0$$

$$W = I_1(0) = \left(\frac{\omega_1 + \omega_2 t}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta t_1} - \left(\frac{\omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right)$$

And at $t = T$ The maximum cycle-level quadratic demand is given by

$$t = T, I_2(t) = -S$$

$$S = \left(\frac{\omega_1 + \omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right) - e^{-\mu(T-t_1)}\left(\frac{\omega_1 + \omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right)$$

Now the amount purchased per round is,

$$Q = W + S = \left(\frac{\omega_1+\omega_2 t}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta t_1} - \left(\frac{\omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right) + \left(\frac{\omega_1+\omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right) - e^{-\mu(T-t_1)}\left(\frac{\omega_1+\omega_2 t}{\mu} - \frac{\omega_2}{\mu^2}\right) \tag{5}$$

The price of holding per unit time originates by,

$$H_C = \int_0^{t_1}(\alpha + \beta t)I_1\,(t)$$

$$H_C = \frac{1}{2\theta^4}\left[\{2\theta^2(\beta(2\omega_2 t_1^2 + 2\omega_1 t_1) + \alpha(2\omega_2 t_1 + 2\omega_1)\} + \theta(\beta(-6\omega_2 t_1 - 2\omega_1) - 4\omega_2\alpha) + 6\omega_2\beta)(1 - \theta t_1) + \theta^2(\omega_2\beta t_1^2 + 2\omega_2\alpha t_1) + \theta^3(-\omega_1\beta t_1^2 - 2\omega_1\alpha t_1)\right] - \left\{\frac{\omega_1\alpha\theta^4 + (-\omega_1\beta - 2\omega_2\alpha)\theta + 3\omega_2\beta}{\theta^4}\right\} \tag{6}$$

The cost of ordering per order is calculated by

$$O_C = C_o = q^{\gamma-1} \quad (7)$$

Now, the deteriorating cost is given by,

$$D_C = C_D\left[W - \int_0^{t_1} f(t)dt\right]$$

$$D_C = C_D\left[\left(\frac{\omega_1+\omega_2 t_1}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta t_1} - \left(\frac{\omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right) - \left(\omega_1 t_1 + \frac{\omega_2 {t_1}^2}{2}\right)\right] \quad (8)$$

Shortages incur costs over time is given by

$$S_C = -C_S\int_{t_1}^{T} I_2(t)$$

$$S_C = -C_S\left[\left(\frac{\omega_1+\omega_2 T}{\mu^2} - \frac{2\omega_2}{\mu^3}\right) - \left(\frac{\omega_1+\omega_2 t_1}{\mu^2} - \frac{2\omega_2}{\mu^3}\right) + (T-t_1)\left(\frac{\omega_1+\omega_2 t_1}{\mu^2} - \frac{\omega_2}{\mu^3}\right)e^{-\mu(T-t_1)}\right] \quad (9)$$

The salvage value $\partial,\ 0 \leq \partial < 1$

$$S_V = \delta(C_D) \quad (10)$$

Therefore, The entire cost per unit time per unit cycle is provided by,

$$TC = \frac{1}{T}\left(H_C + S_C + O_C + D_C - S_V\right)$$

$$=\frac{1}{T}\left[\frac{1}{2\theta^4}\left[\{2\theta^2(\beta(2\omega_2 t_1^2 + 2\omega_1 t_1) + \alpha(2\omega_2 t_1 + 2\omega_1)\} + \theta(\beta(-6\omega_2 t_1 - 2\omega_1) - 4\omega_2\alpha) + 6\omega_2\beta)(1-\theta t_1) + \theta^2(\omega_2\beta t_1^2 + 2\omega_2\alpha t_1) + \theta^3(-\omega_1\beta t_1^2 - 2\omega_1\alpha t_1)\right] - \left\{\frac{\omega_1\alpha\theta^4 + (-\omega_1\beta - 2\omega_2\alpha)\theta + 3\omega_2\beta}{\theta^4}\right\} - C_S\left[\left(\frac{\omega_1+\omega_2 T}{\mu^2} - \frac{2\omega_2}{\mu^3}\right) - \left(\frac{\omega_1+\omega_2 t_1}{\mu^2} - \frac{2\omega_2}{\mu^3}\right) + (T-t_1)\left(\frac{\omega_1+\omega_2 t_1}{\mu^2} - \frac{\omega_2}{\mu^3}\right)e^{-\mu(T-t_1)}\right] + q^{\gamma-1} + C_D\left[\left(\frac{\omega_1+\omega_2 t_1}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta t_1} - \left(\frac{\omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right) - \left(\omega_1 t_1 + \frac{\omega_2 {t_1}^2}{2}\right)\right] - \delta C_D\left[\left(\frac{\omega_1+\omega_2 t_1}{\theta} - \frac{\omega_2}{\theta^2}\right)e^{\theta t_1} - \left(\frac{\omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right) - \left(\omega_1 t_1 + \frac{\omega_2 {t_1}^2}{2}\right)\right]\right] \quad (11)$$

The model's objective is to locate the best values of t_1 and T to decrease the mean total expenditure per unit time TC. For the optimal value, we have to get a partial derivative of t_1 and T and equating to zero.

$$\frac{\partial(TC)}{\partial T} = -\frac{1}{T^2}\left[\left\{\frac{1}{2}\frac{1}{\theta^4}\left\{\left(\theta^2\left(\beta(2\omega_2 {t_1}^2 + 2\omega_1 t_1) + \alpha(2\omega_2 t_1 + 2\omega_1)\right) + \theta(\beta(-6\omega_2 t_1 - 2\omega_1) - 4\omega_2\alpha) + 6\omega_2\beta\right)(-t_1\theta + 1) + \theta^2(\omega_2\beta {t_1}^2 + 2\alpha\omega_2 t_1) + \theta^3(-\omega_1\beta {t_1}^2 - 2\omega_1\alpha t_1)\right\} - \frac{\omega_1\alpha\theta^4 + (-\omega_1\beta - 2\alpha\omega_2)\theta + 3\omega_2\beta}{\theta^4}\right\} + C_S\left(\frac{\omega_2 T + \omega_1}{\mu^2} - \frac{2\omega_2}{\mu^3}\right) - \frac{\omega_2 t + \omega_1}{\mu^2} + \frac{2\omega_2}{\mu^3} + (T-t_1)\left(\frac{\omega_2 t_1 + \omega_1}{\mu^2} - \frac{\omega_2}{\mu^3}\right)\{1 - \mu(T-t_1)\} + q^{\gamma-1} + C_D\left\{\left(\frac{\omega_2 t_1 + \omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right)(-t_1\theta + 1) - \frac{\omega_1}{\theta} + \frac{\omega_2}{\theta^2} - \omega_1 t_1 - \frac{1}{2}\omega_2 {t_1}^2\right\} - \delta C_D\left\{\left(\frac{\omega_2 t_1 + \omega_1}{\theta} - \frac{\omega_2}{\theta^2}\right)(-t_1\theta + 1) - \frac{\omega_1}{\theta} + \frac{\omega_2}{\theta^2} - \omega_1 t_1 - \frac{1}{2}\omega_2 {t_1}^2\right\} + \frac{1}{T}\left\{\frac{C_S\omega_2}{\mu^2} + \left(\frac{\omega_2 t_1 + \omega_1}{\mu^2} - \frac{\omega_2}{\mu^3}\right)\{1 - \mu(T-t_1)\} - (T-t_1) + \left(\frac{\omega_2 t_1 + \omega_1}{\mu^2} - \frac{\omega_2}{\mu^3}\right)\mu\right\}\right] \quad (12)$$

$$\frac{\partial(TC)}{\partial t_1}=\frac{1}{T}\Big[\frac{1}{2}\frac{1}{\theta^4}\{(\theta^2(\beta 4\omega_2+2\beta\omega_1)+2\omega_2\alpha)-6\theta\omega_2\beta\}-(-t_1\theta+1)-\big(\theta^2\big(\beta(2\omega_2 t_1{}^2+2\omega_1 t_1)+\alpha(2\omega_2 t_1+2\omega_1)\big)+\theta(\beta(-6\omega_2 t_1-2\omega_1)-4\omega_1\alpha)+6\omega_2\beta\big)\theta+\theta^2(2\omega_2\beta t_1+2\alpha\omega_2)+\theta^3(-2\omega_1\beta t_1-2\omega_1\alpha)-\frac{\omega_2}{\mu^2}-\left(\frac{\omega_2 t_1+\omega_1}{\mu^2}-\frac{\omega_2}{\mu^3}\right)\big(1-\mu(T-t_1)\big)+\left(\frac{\omega_2 t_1+\omega_1}{\mu^2}-\frac{\omega_2}{\mu^3}\right)\mu+C_D\left(\left(\frac{\omega_2(-t_1\theta+1)}{\theta}-\left(\frac{\omega_2 t_1+\omega_1}{\theta}-\frac{\omega_2}{\theta^2}\right)\theta\right)-\omega_1-\omega_2 t_1\right)-\delta C_D\left(\left(\frac{\omega_2(-t_1\theta+1)}{\theta}-\left(\frac{\omega_2 t_1+\omega_1}{\theta}-\frac{\omega_2}{\theta^2}\right)\theta\right)-\omega_1-\omega_2 t_1\right)\Big] \qquad (13)$$

We get the optimal value of t_1 and T by solving the equation (12) and (13) by using MAPLE18.

4. Numerical Example

A hypothetical system with the following values of multiple considerations have been investigated

$$\omega_1=4,\omega_2=8,C_S=10,q=7,\gamma=3,C_D=3,\theta=0.9,\delta=110,\mu=0.1,\qquad \alpha=10,\beta=25$$

We utilised MAPLE 18 to solve the problem at hand the optimum rarity value, the optimal duration of the ordering cycle is $T=32.48365353$ unit time and $t_1=32.48365353$per unit time. The total inventory cost is $TC=8994.779218$.

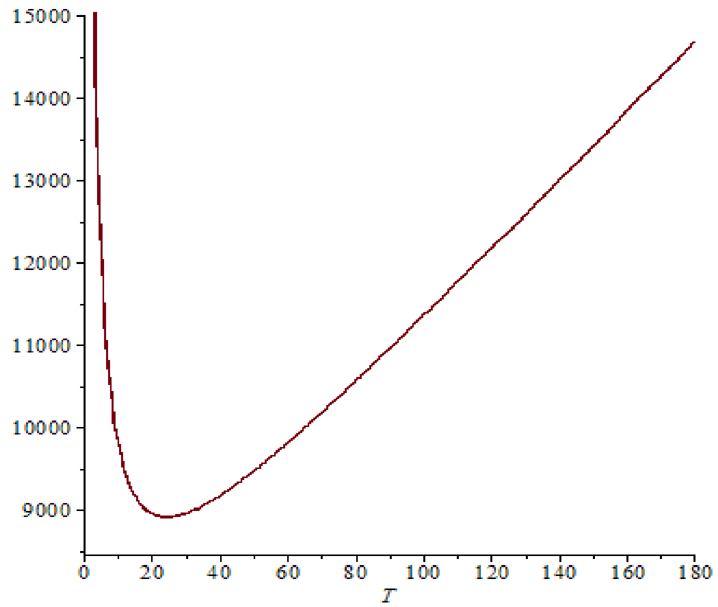

Fig. 2 Total inventory cost TC vs. time

5. Sensitive Analysis

To investigate the impact of under and overestimating demand, deterioration, shortage cost, ordering cost, and holding cost variable on maximising system profit, sensitivity analysis was conducted on the previously described numerical example. To conduct this analysis, we varied the value of a single parameter (from -20% to +20%) while keeping all others constant. You can see the outcomes of these studies in Table 1.

Table 1 Sensitive analysis concerning different parameters

Parameter	% Change	Change In			
		T	t1	Q	TC
	20	32.44435934	8.860404894	1195.347733	9604.449743
	10	32.46402837	8.911875947	1189.898073	9597.337511
	-10	32.5032319	9.014936609	1179.003918	9582.785599
w_1	-20	32.52276059	9.066524693	1173.55884	9575.351379
	20	32.51635628	9.049409871	1410.469628	11493.10771
	10	32.50150881	9.010295229	1297.459474	10541.65116
	-10	32.46177675	8.906098139	1071.442485	8638.47087
w_2	-20	32.43435353	8.83455679	958.4372594	7686.673133
	20	-7.18351398	8.386866499	-1703.510229	5936.38726
	10	32.67056652	9.125484922	1217.91362	9911.266027
	-10	32.28341066	8.799451309	1150.266525	9271.826164
C_S	-20	32.06914071	8.633266262	1115.325694	8956.639099
	20	32.48338612	8.963161565	1184.403494	9590.778939
	10	32.48352591	8.963279287	1184.427926	9590.431993
	-10	32.48376899	8.96348402	1184.470414	9589.828614
q	-20	32.4838723	8.963571031	1184.488472	9589.572181
	20	35.81636369	8.602033267	1384.613584	11191.63675
	10	34.25891999	8.759876309	1292.017818	10427.49246
	-10	30.33682651	9.247697539	1050.485579	8649.492292
C_D	-20	27.29715106	9.729613477	850.1471854	7425.210406
	20	-13.00795588	5.889472258	-1345.473025	-422.23059
	10	32.24998362	7.911044345	1159.991768	8568.936419
	-10	32.42011627	10.36323689	1159.381322	10603.69929
μ	-20	22.38175361	14.217159	44.4843059	11651.00788
	20	35.84340917	8.599448461	1386.209366	11205.09329
	10	34.27405401	8.75825374	1292.9248	10434.8029
	-10	30.31444565	9.250899012	1049.061371	8640.231256
δ	-20	16.27301748	11.63030261	-74.9144711	8121.780064
	20	33.90269066	8.855904645	1251.776572	10065.92668
	10	-10.22258989	7.315248156	-1691.350087	121.66668
	-10	31.56554	9.035790259	1140.777255	9301.996899
θ	-20	30.45273246	9.127406793	1087.892922	8973.232869
	20	32.48230768	8.962253483	1184.215025	9593.455147
γ	10	32.4831717	8.962980991	1184.366017	9591.311112

	-10	32.48392225	8.963613108	1184.497204	9589.44817
	-20	32.48407213	8.963739355	1184.523404	9589.076098
	20	32.40692585	8.970135186	1179.431191	9563.041069
	10	32.44535279	8.966750509	1181.945297	9576.592845
	-10	32.52182941	8.96004373	1186.946098	9603.608408
α	-20	32.55988174	8.956721143	1189.432992	9617.072611
	20	29.83616174	9.121449156	999.2641367	8951.810835
	10	31.24618305	9.034264799	1098.401849	9282.591388
	-10	33.59965309	8.903679015	1261.381806	9879.219623
β	-20	-11.17740669	7.293205014	-1734.118399	-287.172516

- With an increase or decrease in $\omega_1 and\ \omega_2, TC$ increases or decreases, respectively, and Q varies.
- In C_S (shortage cost) and μ are small increases then TC increase but after more increase it will be decreases and if C_S decreases then TC decreases.
- If q (Ordering variable) increases or decreases, TC not much very.
- If holding parameters α and β are increase TC decreases and if holding parameter decreases then TC increases but β is sensitive and Q changes.
- If γ increases, TC increases, but when γ decreases then TC not changed and Q not very.
- In the small increment of θ, TC and Q decreases (10%) and after that with θ. TC and Q increases and if θ is decreases both are increases
- TC is increase and decreases when δ and C_d increases and decrease respectively.

6. Conclusions

In this study, it is hypothesized that the demand rate would be time sensitive and that the rate of degradation will be proportional to time; hence, an inventory representation of things experiencing depreciation is established. The issue is remedied when shortages are tolerable and partial backorders are placed. The costs of keeping and ordering vary. The salvage value is assigned to items in the system that have degraded. The sensitivity of the models is discussed using a numerical example.

7. Application

The suggested deterministic inventory model takes into consideration dynamic demand and stock, partial supply backlogs, and the expiration of perishable commodities. This strategy can be used to reduce overall inventory costs for companies in the chemical industry, where supply and demand are tightly tied and some shortages have been postponed. The model employed in this study includes a general architecture that allows variable setup costs to be accounted for while keeping stock levels constant. The cost function's convexity condition ensures the existence of a unique minimum. Inventory management is useful for non-perishable commodities such as food, gadgets, and apparel accessories. The demand function can be extended to include stochastically shifting demand patterns or stock-dependent demand rates.

8. Future Scope

The proposed model can be developed to accommodate more types of demand, such as uncertain demand, stock-dependent demand, probabilistic demand, and many others. Furthermore, in order to facilitate additional study, the model can be developed to include more realistic components such as quantity count, two-level trade credit policy, multi-item with constraint, and so on. This can be done in order to improve the model's accuracy. Furthermore, the current scope of this approach can be expanded to include less precise settings such as fuzzy, rough, random, fuzzy-random, bifuzzy, type-2 fuzzy, and so on.

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