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Research Paper

An Inventory Model for Perishable Goods with Controllable Deterioration, Partially Backlogged Shortage and Advanced Payment

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Abstract—The purpose of the paper is to develop an optimal strategy for the inventory system for perishable goods. Discount facility is adopted here for advanced payment. Demand is partially backlogged. Preservation technology is applied in the proposed model to reduce the rate of deterioration. An inventory model has been developed and the optimum order quantity as well as the time at which shortage occurs are determined which maximizes the total profit. To observe the practical utility of the proposed model, three numerical illustrations are provided which are solved by Mathematica 5.1 software. Concavity of the average profit is examined graphically. Finally a post optimality analysis is performed to show the effects of inventory parameters on optimal policy. The proposed model can be used for decaying items like fruits, vegetables, food grains and medicines that are subject to preservation technology to maximize the total profit.

Keywords—Inventory, Decaying Items, Preservation Technology, Partial Backlogging, Advance Payment

1. Introduction

To survive in the current business environment, competitive marketing strategies are very much essential. Day by day new challenges are arrived in the field of business and the managers have to adopt new strategies to maximize their profit. In this regard the advance payment facility is adopted in many business farms. It attracts the customers to gain the discount facility in many forms like quantity discount, trade discount and seasonal discount. The discount offered by the seller motivates the customers to become the regular buyers. In the last few decades the academicians, researchers and strategy makers have done commendable works in the field of inventory models with discount facilities.

Maiti et al. [1] introduced discount facility in multi-item inventory model. Bag &Tripathy [2] considered multi-level discount facilities in their models. Khan et al. [3] brought an inventory model for deteriorating products with an advanced payment discount offer. Thangam, A. [4] constructed an optimal price discounting and lot sizing inventory model for perishable goods under advance payment scheme. Khan et al. [5], De [6], Zhang et al. [7], Patro et al. [8] are some other researchers who have developed many inventory models with price discount facilities.

In all the inventory models, the demand is a key parameter. It depends on many factors in the inventory management system. Among all of these, the selling price dependent demand, stock dependent demand, time dependent demand and advertisement frequency dependent demand are common in use. A concise list of researchers in recent times who have considered different types of demands is deliberated below.
Sana and Chaudhuri [9] worked on inventory model assuming demand to be both stock and frequency of advertisement dependent whereas Balkhi and Tadj [10] analysed the model for perishable items considering demand to be time dependent. Maihami and Kamalabadi [11] analysed the inventory model for perishable items considering demand as price and time dependent. Later, Shaikh et al. [12] derived an inventory model where demand depends on both price and inventory level.

Deterioration plays a momentous role in formulating inventory models for perishable goods. Food items, vegetables, grains, milk, medicines etc. became spoiled when stored for long time. To maximize the total profit while dealing with such type of items need appropriate modelling strategies. To reduce the deterioration and increase the usefulness of the items, preservation technology is of great use. By usage of preservation technology, the economic loss is reduced and customer service level in business competitiveness is improved. In developing the inventory models, the preservation technology was first introduced by Hsu et al. [13]. Later Lee and Dye [14] applied preservation technology in developing the inventory model where demand depends on the on-hand products amount in the market. Zhang et al. [15] worked on supply chain model in consideration to preservation facility for deteriorating items. Several researchers like Mishra et al. [16], Das et al. [20] contributed their works on developing mathematical models by using preservation technology.

In this piece of research work a mathematical model is developed for time and selling price dependent demand with partially backlogged shortage. Preservation technology is incorporated in to the model to reduce deterioration rate. The profit is maximized by managing the inventory of perishable items which is beneficial to the environment and community as well.

The rest of the paper has been organized as follows. Section 2 contains the related work of the researchers in various time periods. Section 3 contains notations and assumptions with theory and calculations of the proposed model. Section 4 contains experimental methods. The results and discussion on empirical investigation are narrated in section 5. Sensitivity analysis has been carried out in section 6 to observe the effect of variation in system parameters on the decision variables. Finally section 7 concludes the research work emphasizing on future research work.

2. Related Work

Table:1 Comparative study of review of literature

Literature	Payment	Rate of demand	Preservation technology	Shortage	Discount
Maiti et al.	Advanced payment	Price dependent	No	Fully backlogged	No
Mishra & Singh	No	Constant	Present	Partially backlogged	No
Lee & Dye	No	Stock dependent	Present	Fully backlogged	No
Mishra	No	Time dependent	Present	No	No
Teng et al.	Advanced payment	Constant	No	Partially backlogged	No
Zang et al.	Advanced payment	Constant	No	No	No
Khan et al.	Advanced payment	Price dependent	No	Partially backlogged	No
Shaikh et al.	Advanced payment	Price dependent	No	Partially backlogged	No
Das et al.	No	Depends on availability of product	No	No	No
Shaikh et al.	No	Ramp type	Yes	Partially backlogged	No
Present paper	Advanced payment	Selling price dependent	Yes	Partially backlogged	Yes

3. Theory/Calculation

3.1 Notations

$D(t)$: The rate of demand at any instant of time.

A : Ordering cost

θ: Rate of deterioration, $0 < \theta \leq 1$

k: Backlogging rate

t: The time at which shortage occurs

T: Cycle time

Q: Order quantity

h: Holding cost per unit/ unit time

S: Shortage cost per unit / unit time

P: Purchase cost per unit/ unit time

$m(\xi)$: Reduced deterioration rate by using preservation technology

$K(t_1, T)$: Total inventory cost / unit time

s: Selling price per unit

Z: Total profit

3. 2 Assumptions

1. Demand $D(t) = \alpha(1+\beta t)s^{-1}$ $(\alpha > 0, 0 < \beta < 1)$
2. There is instantaneous replacement with zero lead time.
3. The shortage is allowed in this model and it is partially backlogged.
4. The deterioration rate reduced by using preservation technology.

3.3 Mathematical Model

The on hand inventory $I(t)$ depletes during the period $[0, t_1]$ due to the combined effect of demand and deterioration and exhausted at time t_1. During the period $[t_1, T]$ the shortage occurs and is fully backlogged.

The resultant deterioration rate by using preservation technology, will be $[\theta - Z(\xi)]$

where $Z(\xi) = \theta(1 - e^{-0.5m})$ $(0 \leq \text{m} \leq 1)$

So resultant rate of deterioration becomes

$[\theta - \theta(1 - e^{-0.5m})] = \theta e^{-0.5m}$

The inventory level $I(t)$ at any instant of time 't' is given by the following differential equations.

$$\frac{dI(t)}{dt} + \theta e^{-0.5m} I(t) = -D(t) \qquad 0 \leq t \leq t_1 \tag{1}$$

$$\frac{dI(t)}{dt} = -kD(t) \qquad t_1 \leq t \leq T \tag{2}$$

With $I(0) = Q$ and $I(t_1) = 0$ the solutions of equations (1) and (2) are given by

$$I(t) = Qe^{-\theta e^{-0.5m} t} + \left(\frac{\alpha}{\theta e^{-0.5m} s} - \frac{\alpha\beta}{(\theta e^{-0.5m})^2 s}\right) e^{-\theta e^{-0.5m} t} + \frac{\alpha\beta}{(\theta e^{-0.5m})^2 s} - \frac{\alpha}{\theta e^{-0.5m} s}(1 + \beta t) \tag{3}$$

and $$I(t) = k\frac{\alpha}{s}(t_1 - t) + \frac{\alpha\beta}{2s}\left(t_1^2 - t^2\right) \tag{4}$$

With initial condition $I(t_1)=0$

$$Q=\left(\frac{\alpha}{\theta e^{-0.5m}s}(1+\beta t_1)-\frac{\alpha\beta}{(\theta e^{-0.5m})^2 s}\right)e^{\theta t_1}-\left(\frac{\alpha}{\theta e^{-0.5m}s}-\frac{\alpha\beta}{(\theta e^{-0.5m})^2 s}\right) \tag{5}$$

Using this value of Q, equation (3) becomes

$$I(t)=\frac{\alpha\beta}{(\theta e^{-0.5m})^2 s}-\frac{\alpha}{\theta e^{-0.5m}s}(1+\beta t) \tag{6}$$

The average number of holding units I_H in the time interval $[0,T]$ is given by

$$I_H=\int_0^{t_1} I(t)dt=\frac{\alpha}{s}\left(\frac{t_1^{\,2}}{2}+\frac{\theta e^{-0.5m}}{6}t_1^{\,3}\right)+\frac{\alpha\beta}{s}\left(\frac{t_1^{\,3}}{3}+\frac{\theta e^{-0.5m}}{6}t_1^{\,4}\right) \tag{7}$$

The number of deteriorated units I_D in the time interval $[0,T]$ is given by

$$I_D = Q - \text{Total Demand} = Q-\int_0^{t_1}\alpha(1+\beta t)dt$$

$$I_D=\frac{1}{2s}\alpha\theta e^{-0.5m}t_1^{\,2}+\frac{1}{3s}\alpha\beta\theta e^{-0.5m}t_1^{\,3} \tag{8}$$

The average number of shortage units I_S due to partial backlogging in the time interval $[0,T]$ is given by

$$I_s=-\int_{t_1}^{T} I(t)dt=k\frac{\alpha}{2s}(t_1-T)^2-\frac{\alpha\beta}{2s}k\left(t_1^{\,2}T-\frac{T^3}{3}-\frac{2}{3}t_1^{\,3}\right) \tag{9}$$

The retailer pays the cash in advance and avail cash discount,

The cash discount earned due to advanced payment = $\dfrac{rsQ}{T}$ (10)

The total cost of the inventory system per unit time is

$$K(t_1,T)=\frac{1}{T}(A+hI_H+PI_D+SI_S)$$

$$=\frac{1}{Ts}\left[\begin{array}{l}As+h\alpha\left(\frac{t_1^{\,2}}{2}+\frac{\theta e^{-0.5k}}{6}t_1^{\,3}\right)+h\alpha\beta\left(\frac{t_1^{\,3}}{3}+\frac{\theta e^{-0.5k}}{6}t_1^{\,4}\right)+P\frac{1}{2}\alpha\theta e^{-0.5k}t_1^{\,2}\\+P\frac{1}{3}\alpha\beta\theta e^{-0.5k}t_1^{\,3}+Sk\frac{\alpha}{2}(t_1-T)^2-Sk\frac{\alpha\beta}{2}\left(t_1^{\,2}T-\frac{T^3}{3}-\frac{2}{3}t_1^{\,3}\right)\end{array}\right] \tag{11}$$

Sales Revenue (SR) = $s\int_0^{t_1}\alpha(1+\beta t)dt=s\left[\alpha\beta\frac{t_1^{\,2}}{2}\right]$ (12)

Total Profit (Z) = Sales revenue – Total cost+ Cash discount (13)

The optimal values of t_1 and T that will maximize the system total profit can be obtained by solving the following equations.

$$\frac{\partial Z}{\partial t_1}=0 \text{ and } \frac{\partial Z}{\partial T}=0$$

The following concavity conditions will be verified with suitable examples

$$\frac{\partial^2 Z}{\partial t_1^{\,2}}<0,\ \frac{\partial^2 Z}{\partial T^2}<0 \text{ and } \left(\frac{\partial^2 Z}{\partial t_1^{\,2}}\right)\left(\frac{\partial^2 Z}{\partial T^2}\right)-\frac{\partial^2 Z}{\partial t_1\partial T}<0$$

4. Experimental Method/Procedure

MATHEMATICA 5.1 software is used to solve the equations and find the relevant results by assigning values to the system parameters. Sensitivity analysis has been drawn to get managerial implications.

5. Results and Discussion

Numerical illustration-1:

An inventory system is considered with the following values of the parameters.
A= Rs 900/order, P = Rs 15/unit, h=Rs 5/unit/year, α = 90 units/year, β = 3 units/year, θ = 1.5/year, $r=0.018$, s = Rs 90/unit , S= 120 and k = 8

Solution: $t_1=2.6296$, $T=8.57795$, $Z(t_1,T)=19651$

Numerical illustration-2:

An inventory system is considered with the following values of the parameters.
A= Rs 5000/order, C= Rs 20/unit, h=Rs 25/unit/year, α = 50 units/year, β = 5 units/year, θ = 1.5/year, $r=0.020$, s = Rs 60/unit , S= 110 and k = 6

Solution: The solution of the crisp model is

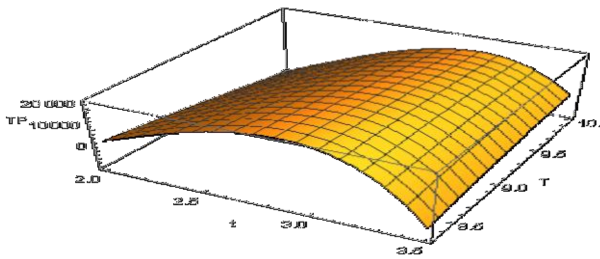
$$t_1=4.0207,\ T=9.73883,\ Z(t_1,T)=66005$$

Numerical illustration-3:

An inventory system is considered with the following values of the parameters.
A= Rs 10000/order, C= Rs 25/unit, h=Rs 10/unit/year, α = 100 units/year, β = 2 units/year, θ = 2.5/year, $r=0.028$, s = Rs 50/unit , S= 100 and k = 5

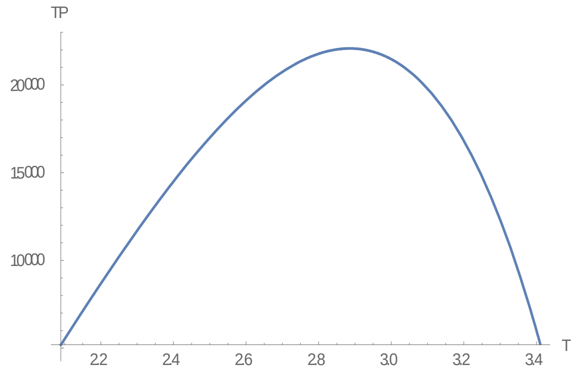
Solution: The solution of the crisp model is

$t_1=3.07495$, $T=9.0705$, $Z(t_1,T)=17916.9$

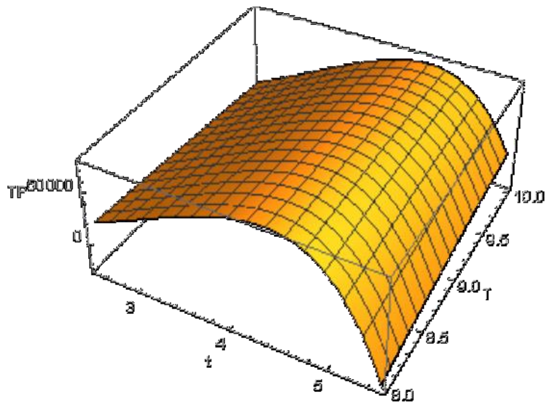


[Fig. 1. TP vs. t and T] Numerical illustration 1

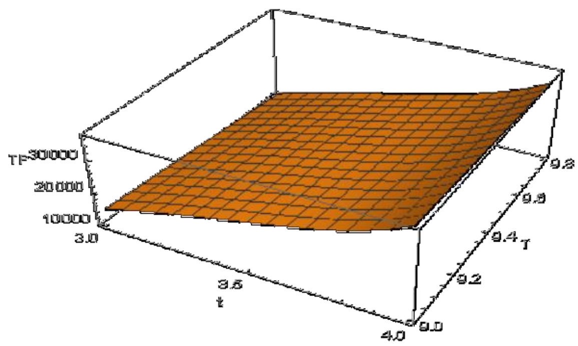
[Fig. 2. TP vs t at T = 8.57795] Numerical illustration 1



[Fig. 3. TP vs T at t = 2.6296] Numerical illustration 1



[Fig. 4. TP vs. t and T] Numerical illustration 2



[Fig. 5. TP vs. t and T] Numerical illustration 3

6. Sensitivity Analysis

SENSITIVITY ANALYSIS OF NUMERICAL ILLUSTRATION 1

Parameters	**% change**	t	T	**Total Profit (TP)**	**% change in TP**
A =900	+10	2.6296	8.57795	19640.6	-0.05%
	+5	2.6296	8.57795	19645.8	-0.03%
	-5	2.6296	8.57795	19655.3	0.02%
	-10	2.6296	8.57795	19661.5	0.05%
P =15	+10	2.6296	8.57794	19652.3	0.01%
	+5	2.6296	8.57794	19652.3	0.01%
	-5	2.6296	8.57795	19652.4	0.01%
	-10	2.6296	8.57796	19652.4	0.01%
h=5	+10	2.62957	8.5778	19651.2	0.00
	+5	2.62958	8.57787	19651.7	0.00
	-5	2.62962	8.57802	19653	0.01%
	-10	2.62964	8.5781	19653.7	0.01%
a= 90	+10	2.6296	8.57795	21628.1	10.06%
	+5	2.6296	8.57795	20640.2	5.03%
	-5	2.6296	8.57795	18664.5	-5.02%
	-10	2.6296	8.57795	17676.6	-10.05%
b = 3	+10	2.62962	8.5929	21720.7	10.53%
	+5	2.62961	8.58577	20686.5	5.27%
	-5	2.62959	8.56932	18618.4	-5.25%
	-10	2.62959	8.55976	17584.9	-10.51%
$\theta = 1.5$	+10	2.34676	8.10616	11351.1	-42.24%
	+5	2.48094	8.33328	15105.5	-23.13%
	-5	2.79515	8.84254	25195	28.21%
	-10	2.98054	9.12991	26694.8	35.84%
s = 90	+10	2.92064	9.9299	31147.2	58.5%
	+5	2.7805	9.25553	25255.2	28.52%
	-5	2.46551	7.89378	14376.8	-26.89%
	-10	2.28452	7.19729	9433.08	-52%
S= 120	+10	2.47741	7.94164	16910.1	-13.95%
	+5	2.55237	8.24936	18285.6	-6.95%
	-5	2.70945	8.93048	20996	6.84%
	-10	2.79231	9.31065	22297	13.46%
k =8	+10	1.26126	5.28165	-9839.87	-150.07%
	+5	2.08857	7.32586	2136.73	-89.13%
	-5	3.11763	9.7245	41561.6	111.5%
	-10	3.58972	10.893	67778	244.91%
r= 0.018	+10	2.52029	8.37478	15408.6	-21.59%
	+5	2.57405	8.47525	17455.6	-11.17%
	-5	2.68716	8.6832	22016	12.04%
	-10	2.74698	8.79138	24566.3	25.01%

Obserations Drawn From Sensitivity Analysis

From the above sensitivity analysis we observed the followings:

1. An increasing value in order quantity A do not have any effect on the values of *t* (the time at which shortage occurs) and *T*(cycle time) but have a negative impact on the Total Profit (*TP*). When the value of *A* increases, the total profit decreases and when the value of A decreases the total profit increases.

2. An increasing value in holding cost (h), results an inclination in the values of t, T and TP where as an decreasing value in the parameter h results an increment in the values of t, T and TP.

4. An increment in the values of the parameters a, r, k and S, do not have any effect on the values of t and T. On the other hand the Total Profit (TP) increases and by declining the values of the parameters a, r and k it is observed that Total

Profit(TP) decreases though there is no change in the values of t and T .

5. An increment in the values of the parameters b and s results an increment in the values of t, T and TP where as by declining the values of the parameters b and s, results a declination in the values of t, T and TP.

6. An increment in the values of the parameters θ, r, k and S, results a declination in the values of the values of t, T and TP where as a declination in the values of the parameters θ, r, k and S results an increment in the values of t, T and TP.

7. Conclusion and Future Scope

This paper presents an optimal strategy for the inventory system for decaying items. In the present paper we have discussed discount facility that is adopted for advanced payment where demand is assumed to be partially backlogged and preservation technology is implemented to maximize the total profit. Numerical illustrations are provided to determine the cycle time and the time at which shortage occurs and total profit is maximized by using Mathematica 5.1 software. Sensitivity analysis is conducted for the model to know the impact of changes on total profit by percentage change in the different parameters. It has been observed that the total profit can be increased by making the order size considerably high. The holding cost can be decreased to obtain maximum profit. Rate of cash discount can also be fixed to a minimum one to check the decline in profit. The selling price can be fixed high to gain maximum profit. Moreover the deterioration in the inventory system can be reduced by applying suitable controllable deterioration facilities.

This proposed model can be useful in the business organizations dealing with decaying items like fruits, vegetables, food grains, medicines, pharmaceuticals etc. that are subject to preservation technology to maximize the total profit.

This proposed model can be extended by applying fuzzy theory due to uncertainty in the environment. Inflation can also be implemented in the model.

Data Availability

None

Conflict of Interest

The authors do not have any conflict of interest.

Funding Source

None

Authors' Contributions

Author-1 researched literature and conceived the study. She involved in model development, gaining ethical approval and wrote the first draft of the manuscript. Author-2 carried the data analysis with suitable figure construction. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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