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INVENTORY MODEL FOR TIME VARYING HOLDING COST UNDER TRADE CREDIT AND QUADRATIC DEMAND FOR DETERIORATING GOODS

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ABSTRACT

Operation research's role in both, the public and the private sectors is increasing rapidly. Inventory modeling is an important part of Operation Research, which may be used in large numbers of problems. To make it applicable in real life situations researchers are busy in modifying the existing models on different parameters under various circumstances. In this present paper we study a deterministic inventory model for quadratic demand with time varying holding cost and trade credit under deteriorating environment, supplier offers a credit limit to the customer during whom there is no interest charged, upon the expiry of the prescribed time limit, the supplier will charge some interest. However, the customer has the reserve capital to make the payment at the beginning, but decides to take the benefits of the credit limit. The objective of the model is to develop an optimal policy that minimizes the total average cost. Numerical examples are used to illustrate the developed models. Sensitivity analysis of the optimal solution with respect to major parameters is carried out.

Keywords: *Deterioration, quadratic demand, trade credit, time varying holding cost.*

INTRODUCTION

Deterioration is defined as decay, spoilage, evaporation, and loss of utility of the product. Deterioration in inventory is a realistic feature and need to consideration it. Often we encounter products such as fruits, milk, drugs, vegetables, and photographic films etc that have a defined period of life time. Such items are referred as deterioration items or deterioration goods.

The loss due to deterioration cannot be avoided. Due to deterioration, inventory system faces the problem of shortage and loss of good will or loss of profit. Shortage is a fraction of those customers whose demand is not satisfied in the current period reacts to this by not returning the next period. The basic well known EOQ model was first introduced by Harris. The model was based on constant demand without any deterioration function. However, in real life situation the demand may increase or decrease in the course of time. In the EOQ model, we assumed that the supplier must be paid for the items as soon as the items are received. However, in practice, this may not true. In today's business transactions, it is more and more to see that a supplier will allow a certain fixed period for setting the amount owed to him for the items supplied. Usually there is no charge if the outstanding amount is settled within the permitted fixed settlement period. Beyond this period, interest is charged. Wee HM, Law ST (2001) developed inventory models with deteriorating items taking into account the time value of money. Chung, K-J. & Tsai, S-F. (2001) developed inventory models with linear trends in demands. Hedjar, R., Bounkhel, M. & Tadj, L. (2004) developed Predictive control of periodic-review of production inventory systems with deteriorating items. Chern, M.S., Chan, Y.L., Teng, J.T., (2005) compare deteriorating items with shortages. Hou, K.L., (2006) developed an inventory model for deteriorating items with stock- dependent consumption rate and shortages under inflation and time discounting. Dye, C.Y., Ouyang, L.Y., Hsieh, T.P., (2007) developed inventory model for deteriorating items with capacity constraint and time proportional backlogging rate. Liao, J.J. (2007) developed an EPQ model for deteriorating items under permissible delay in payments. Kumar M, Tripathi R.P. and Singh S.R. (2009) developed an inventory model with quadratic demand rate for decaying items with trade credits and inflation. Sharma, M. M., Goel, V. C. and Yadav, R. K. (2009) developed inventory model for decaying items with ramp type demand, and partial backlogging. Yang, H.L., Teng, J.T. and Chern, M.S. (2010) developed an inventory model under inflation for deteriorating items with stock-dependent consumption rate and partial backlogging shortages. Abdul, I. & Murata, A. (2011). An inventory model for deteriorating items with varying demand pattern and unknown time horizon. Jaggi, C. K., Goel, S. K. & Mittal, M. (2011) developed an inventory model for deteriorating items with imperfect quality and permissible delay on payment.

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2. NOTATIONS AND ASSUMPTIONS

A. Some basis notations for developing the model is as below

- $\alpha(t) = \alpha t \; is$ inventory deterioration rate.
- C_1 is the inventory shortage cost per unit time .
- C_2 is the unit cost of an item.
- A is the ordering cost of an order.
- T is the length of the cycle.
- q is the order quantity per cycle.
- $t_1$is the length of the period with positive stock of the item.
- I_e is the interest earned per Rs./unit time.
- I_p is the interest paid per Rs. / unit time, $I_P > I_e$
- M is the permissible delay in the account.les.

B. Some basis assumptations used in inventory model is as follow.

- The deterioration rate is time varying. $\alpha(t) = \alpha t$ inventory deterioration rate.
- Shortages are allowed and fully backlogged.
- The demand rate is a quadratic. F(t) = a+bt+ct^2.
- The holding cost is linear with time dependent, h(t) = (h+βt), where $\beta > 0, h > o$ is the inventory holding cost per unit time.
- Replenishment is instantaneous.
- Lead time is zero.
- Delay in payement is allowed.
- During time t_1 , inventory is depleted due to deterioration and demand of the item. At time t_1 the inventory becomes zero and shortages start occurring.

C. MATHEMATICAL FORMULATION AND SOLUTION

If the inventory model with above described assumption and notation is depicted in fig 1. The variation of inventory level Q(t) with respect to time t due to combine effect of demand and deterioration. At time t_1 inventory level goes to zero and shortage occurs. During the period (0, T) can be described by differential equation (1) and (2) with boundary condition

Q$(t_1) = 0$

$$\frac{dQ(t)}{dt} + \alpha t \, . Q(t) = -(a + bt + ct^2), \; 0 \le t \le t_1 \tag{1}$$

$$\frac{dQ(t)}{dt} = -(a + bt + ct^2), \; t_1 \le t \le T \tag{2}$$

The solutions of above differential equation are affected from the relation between t_1 and M, through the quaradtic demand rate.

$$\text{Q(t)} = \begin{bmatrix} \left[a(t_1 - t) + b\left(\frac{t_1^2}{2} - \frac{t^2}{2}\right) + c\left(\frac{t_1^3}{3} - \frac{t^3}{3}\right)\right] + \alpha \begin{bmatrix} a\left(\frac{t_1^3}{6} - \frac{t^2 t_1}{2} + \frac{t^3}{3}\right) + b\left(\frac{t_1^4}{8} - \frac{t^2 t_1^2}{2} + \frac{t^4}{8}\right) \\ +c\left(\frac{t_1^5}{10} - \frac{t^2 t_1^3}{6} + \frac{t^5}{15}\right) \end{bmatrix} \\ +\alpha^2\left[a\left(\frac{t_1^5}{40} - \frac{t_1^3 t^2}{12} + \frac{t_1 t^4}{8} - \frac{t^5}{15}\right) + b\left(\frac{t_1^6}{48} - \frac{t_1^4 t^2}{16} + \frac{t_1^2 t^4}{16} - \frac{t^6}{48}\right) + c\left(\frac{t_1^7}{56} - \frac{t_1^5 t^2}{20} + \frac{t_1^3 t^4}{24} - \frac{t^7}{105}\right)\right] \end{bmatrix} \quad 0 \le t \le t_1 \tag{3}$$

and

$$\text{Q(t)} = -\left[a(t_1 - t) + b\left(\frac{t_1^2}{2} - \frac{t^2}{2}\right) + c\left(\frac{t_1^3}{3} - \frac{t^3}{3}\right)\right] \qquad t_1 \le t \le T \;\; (\text{ Stock loss due to deterioration}) \tag{4}$$

$$\begin{aligned} \text{D} &= \int_0^{t_1}(a + bt + ct^2)e^{\frac{\alpha t^2}{2}}\,dt - \int_0^{t_1}(a + bt + ct^2)dt \\ &= \frac{\alpha}{2}\left[\frac{at_1^3}{3} + \frac{bt_1^4}{4} + \frac{ct_1^5}{5}\right] + \frac{\alpha^2}{8}\left[\frac{at_1^5}{5} + \frac{bt_1^6}{6} + \frac{ct_1^7}{7}\right] \end{aligned} \tag{5}$$

Order quantity

$$\begin{aligned} \text{Q} &= \left[D + \int_0^T(a + bt + ct^2)dt\right] \\ &= \frac{\alpha}{2}\left[\frac{at_1^3}{3} + \frac{bt_1^4}{4} + \frac{ct_1^5}{5}\right] + \frac{\alpha^2}{8}\left[\frac{at_1^5}{5} + \frac{bt_1^6}{6} + \frac{ct_1^7}{7}\right] + aT + \frac{bT^2}{2} + \frac{cT^3}{3} \end{aligned} \tag{6}$$

Holding cost

$$HC= \int_0^{t_1}(h+\beta t)\, e^{-\frac{\alpha t^2}{2}} \left\{\int_t^{t_1}\left(1+\frac{\alpha u^2}{2}+\frac{\alpha^2 u^4}{8}\right)du\right\}dt$$

$$= h\left[\frac{t_1^{\,2}}{2}+\alpha\frac{11t_1^{\,4}}{72}+\alpha^2\frac{13t_1^{\,6}}{720}\right]+\beta\left[\frac{t_1^{\,3}}{6}+\alpha\frac{13t_1^{\,5}}{120}+\alpha^2\frac{t_1^{\,7}}{336}\right] \tag{7}$$

Shortage cost

$$SC = -\,c_s\int_{t_1}^{T}[-(a+bt+ct^2)(t-t_1)]\,dt$$

$$= c_s\left[a\left(\frac{T^2}{2}-t_1T+\frac{t_1^{\,2}}{2}\right)+b\left(\frac{T^3}{3}-\frac{T^2t_1}{2}+\frac{t_1^{\,3}}{6}\right)+c\left(\frac{T^4}{4}-\frac{T^3t_1}{3}+\frac{t_1^{\,4}}{12}\right)\right] \tag{8}$$

The total profit of the system consist of the following elements.

Net stock loss due to deterioration

Net annual holding cost HC

Annual shortage cost SC

Interest Charged I_P

Interest Earned I_E

Annual ordering cost A

Unit cost of an item order quantity per cycle q

Total profit per unit time is

$$P(T, t_1) = \frac{1}{T}[A+SC+HC+q+IP_1-IE_1] \tag{9}$$

Now, there are two possibilities regarding the period M of permissible delay in payments.

Case-1: $M \le t_1$(payment at or before total depletion of inventory i.e. the inventory not being sold after the due date and evaluate the interest payable IP_1 and interest earned IE_1 per cycle)

Case-2: $M \ge t_1$ (payment at or after depletion i.e. the interest payable per cycle is zero because the supplier can be paid in full at time M, so only evaluate the interest earned per cycle which is earned during the positive inventory period plus the interest earned from the cash invested during time period (t_1, M) after the inventory is exhausted at time t_1).

In this case, the credit time expires on or before the inventory depleted completely to zero. The interest payable per cycle for the inventory not being sold after the due date M is interest payable in the time horizon when $M < t \le t_1$

$$IP_1 = C_2 I_P \int_M^{t_1} Q(t)\,dt$$

$$= c_2\, I_P\left[\begin{array}{l} \left(a\frac{t_1^{\,2}}{2}+b\frac{2t_1^{\,3}}{3}+c\frac{3t_1^{\,4}}{4}+\alpha\left(a\frac{t_1^{\,4}}{12}-b\frac{t_1^{\,5}}{60}+c\frac{t_1^{\,6}}{18}\right)+\alpha^2\left(a\frac{t_1^{\,6}}{120}-b\frac{11t_1^{\,7}}{720}+c\frac{7t_1^{\,8}}{960}\right)\right) \\ -\left(\left(a\left(t_1M-\frac{M^2}{2}\right)+b\left(\frac{Mt_1^{\,2}}{2}-\frac{M^3}{6}\right)+c\left(\frac{Mt_1^{\,3}}{3}-\frac{M^4}{12}\right)\right)+\alpha\left(\begin{array}{c} a\left(\frac{Mt_1^{\,3}}{6}-\frac{M^3t_1}{6}+\frac{M^4}{12}\right) \\ +b\left(\frac{Mt_1^{\,4}}{8}-\frac{M^3t_1^{\,2}}{6}+\frac{M^5}{40}\right)+c\left(\frac{Mt_1^{\,5}}{10}-\frac{M^3t_1^{\,3}}{18}+\frac{M^6}{90}\right)\end{array}\right)\right. \\ \left.+\alpha^2\left(a\left(\frac{Mt_1^{\,5}}{40}-\frac{M^3t_1^{\,3}}{36}-\frac{M^5t_1}{40}-\frac{M^6}{72}\right)+b\left(\frac{Mt_1^{\,6}}{48}-\frac{M^3t_1^{\,4}}{48}+\frac{M^5t_1^{\,2}}{80}-\frac{M^7}{336}\right)+c\left(\frac{Mt_1^{\,7}}{56}-\frac{M^3t_1^{\,5}}{60}+\frac{M^5t_1^{\,3}}{120}-\frac{M^8}{448}\right)\right)\right) \end{array}\right] \tag{10}$$

In addition, the interest earned per cycle I E_1 is the interest earned during the positive inventory level, and is given by interest earned in the time horizon when $t_1 < t \le 0$

$$IE_1 = C_2 I_e \int_0^{t_1}(a+bt+ct^2)t\,dt$$

$$= c_2 I_e\left[\frac{at_1^{\,2}}{2}+\frac{bt_1^{\,3}}{3}+\frac{ct_1^{\,4}}{4}\right] \tag{11}$$

Total profit per unit time is

$P(T, t_1) = \frac{1}{T}[A + SC + HC + q + IP_1 - IE_1]$

$$= \frac{1}{T}\left[\begin{array}{c} A + c_s\left[a\left(\frac{T^2}{2} - t_1 T + \frac{t_1^2}{2}\right) + b\left(\frac{T^3}{3} - \frac{T^2 t_1}{2} + \frac{t_1^3}{6}\right) + c\left(\frac{T^4}{4} - \frac{T^3 t_1}{3} + \frac{t_1^4}{12}\right)\right] \text{h}\left[\frac{t_1^2}{2} + \alpha\frac{11t_1^4}{72} + \alpha^2\frac{13t_1^6}{720}\right] \\ +\beta\left[\frac{t_1^3}{6} + \alpha\frac{13t_1^5}{120} + \alpha^2\frac{t_1^7}{336}\right] + \frac{\alpha}{2}\left[\frac{at_1^3}{3} + \frac{bt_1^4}{4} + \frac{ct_1^5}{5}\right] + \frac{\alpha^2}{8}\left[\frac{at_1^5}{5} + \frac{bt_1^6}{6} + \frac{ct_1^7}{7}\right] + aT + \frac{bT^2}{2} + \frac{cT^3}{3} \end{array}\right]$$

$$+c_2$$

$$I_P\left[\begin{array}{c} \left(a\frac{t_1^2}{2} + b\frac{2t_1^3}{3} + c\frac{3t_1^4}{4} + \alpha\left(a\frac{t_1^4}{12} - b\frac{t_1^5}{60} + c\frac{t_1^6}{18}\right) + \alpha^2\left(a\frac{t_1^6}{120} - b\frac{11t_1^7}{720} + c\frac{7t_1^8}{960}\right)\right) \\ -\left(\begin{array}{c} \left(a\left(t_1 M - \frac{M^2}{2}\right) + b\left(\frac{Mt_1^2}{2} - \frac{M^3}{6}\right) + c\left(\frac{Mt_1^3}{3} - \frac{M^4}{12}\right)\right) + \alpha\left(\begin{array}{c} a\left(\frac{Mt_1^3}{6} - \frac{M^3 t_1}{6} + \frac{M^4}{12}\right) + b\left(\frac{Mt_1^4}{8} - \frac{M^3 t_1^2}{6} + \frac{M^5}{40}\right) \\ +c\left(\frac{Mt_1^5}{10} - \frac{M^3 t_1^3}{18} + \frac{M^6}{90}\right) \end{array}\right) \\ +\alpha^2\left(a\left(\frac{Mt_1^5}{40} - \frac{M^3 t_1^3}{36} - \frac{M^5 t_1}{40} - \frac{M^6}{72}\right) + b\left(\frac{Mt_1^6}{48} - \frac{M^3 t_1^4}{48} + \frac{M^5 t_1^2}{80} - \frac{M^7}{336}\right) + c\left(\frac{Mt_1^7}{56} - \frac{M^3 t_1^5}{60} + \frac{M^5 t_1^3}{120} - \frac{M^8}{448}\right)\right) \end{array}\right) \end{array}\right]$$

$$-c_2 I_e\left[\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4}\right]] \tag{12}$$

Now, our objective is to maximize the profit function $P(T, t_1)$. The necessary conditions for maximizing the profit are

$$\frac{\partial P(T,t_1)}{\partial T} = 0 \tag{13}$$

and

$$\frac{\partial P(T,t_1)}{\partial t_1} = 0 \tag{14}$$

Case-2: M > t_1 (payment at or after depletion)

In this case, the interest payable per cycle is zero, i.e., IP_2=0, when $t_1 < M \leq T$ because the supplier can be paid in full at time M, the permissible delay. Thus, the interest earned per cycle is the interest earned during the positive inventory period plus the interest earned from the cash invested during time period (t_1, M) after the inventory is exhausted at time t_1, and it is given by

$$IE_2 = C_2 I_e \int_0^{t_1}(a + bt + ct^2)dt + C_2 I_e(M - t_1)\int_0^{t_1}(a + bt + ct^2)dt$$

$$= C_2 I_e(\text{M}(\text{a}t_1 + \frac{bt_1^2}{2} + \frac{ct_1^3}{3}) - (\frac{at_1^2}{2} + \frac{bt_1^3}{6} + \frac{ct_1^4}{12})) \tag{15}$$

Total profit per unit time is

$P(T, t_1) = \frac{1}{T}[A + SC + HC + q + IP_1 - IE_2]$

$$= \frac{1}{T}\left[\begin{array}{c} A + c_s\left[a\left(\frac{T^2}{2} - t_1 T + \frac{t_1^2}{2}\right) + b\left(\frac{T^3}{3} - \frac{T^2 t_1}{2} + \frac{t_1^3}{6}\right) + c\left(\frac{T^4}{4} - \frac{T^3 t_1}{3} + \frac{t_1^4}{12}\right)\right] \text{h}\left[\frac{t_1^2}{2} + \alpha\frac{11t_1^4}{72} + \alpha^2\frac{13t_1^6}{720}\right] \\ +\beta\left[\frac{t_1^3}{6} + \alpha\frac{13t_1^5}{120} + \alpha^2\frac{t_1^7}{336}\right] + \frac{\alpha}{2}\left[\frac{at_1^3}{3} + \frac{bt_1^4}{4} + \frac{ct_1^5}{5}\right] + \frac{\alpha^2}{8}\left[\frac{at_1^5}{5} + \frac{bt_1^6}{6} + \frac{ct_1^7}{7}\right] + aT + \frac{bT^2}{2} + \frac{cT^3}{3} \end{array}\right]$$

$$- C_2 I_e(\text{M}(\text{a}t_1 + \frac{bt_1^2}{2} + \frac{ct_1^3}{3}) - (\frac{at_1^2}{2} + \frac{bt_1^3}{6} + \frac{ct_1^4}{12}))] \tag{16}$$

Our objective is to maximize the profit function P(T,t_1)

The necessary conditions for maximizing the profit are

$$\frac{\partial P(T,t_1)}{\partial T} = 0 \tag{17}$$

and

$$\frac{\partial P(T,t_1)}{\partial t_1} = 0 \tag{18}$$

The solutions of (13), (14),(17) and (18) will give T^* & t_1^*. The optimal value p^*(T,t_1) of the average net profit is determined provided the sufficient conditions for maximizing P(T , t_1) are

$$\frac{\partial^2 P(T,t_1)}{\partial T^2} < 0, \qquad \frac{\partial^2 P(T,t_1)}{\partial t_1^2} < 0 \quad And$$

$$\frac{\partial^2 P(T,t_1)}{\partial T^2}.\frac{\partial^2 P(T,t_1)}{\partial t_1^2} - \frac{\partial^2 P(T,t_1)}{\partial T \partial t_1} > 0 \quad At$$

T = T^* & t_1 = t_1^*

2.1 Numerical example

To illustrate the above model described, we applied our procedure to a reliance store. In which product include sunscreen, shampoo, lipstick, baby items, these products was promoted by TV/ interest advertisements, but the sales of the products decreasing at the same rate. the related parameter can be determined by regression analysis using historical transication data.

Example: The parameters of the product are: A=2000, a=25, b=20, c=15, M=0.35, $C_2 = 20$, h=0.4, $C_1 = 1.2$, $\beta = 0.1, \alpha = 0.1, I_P = 0.15$, I_e=0.12.

Solution: based on following inputs of case 1 and case 2 output are as follows:

Case-1: Profit = 984.83, $t_1 = 0.94, t_2 = 3.15$

Case-2: Profit = 957.29, $t_1 = 1.78, t_2 = 3.35$

Change in parameters $(\boldsymbol{\beta}, \boldsymbol{h}, \boldsymbol{A}, \boldsymbol{\alpha})$ $\boldsymbol{in\ case-1}$

$parameter$	value	profit	t_1	t_2
α	.05	953.91	1.93	3.35
	.1	957.27	1.78	3.32
	.15	959.76	1.68	3.29
	.2	961.72	1.60	3.28
h	.35	957.25	1.78	3.32
	.4	957.27	1.78	3.32
	.45	957.30	1.78	3.32
	.5	957.33	1.78	3.32
A	1000	623.32	1.23	2.63
	1500	799.78	1.56	3.02
	2000	957.27	1.78	3.32
	2500	1102.43	1.95	3.56
β	0.05	957.27	1.78	3.32
	.1	957.27	1.78	3.32
	.15	957.28	1.78	3.32
	.20	957.29	1.78	3.32

As we change increase the parameter α, A the profit will increase. And if we change h, β there is slightly increase in profit.

Change in parameters $(\boldsymbol{\beta}, \boldsymbol{h}, \boldsymbol{A}, \boldsymbol{\alpha})$ in case-2

$parameter$	value	profit	t_1	t_2
α	.05	984.72	0.95	3.15
	.1	984.83	0.94	3.15
	.15	984.94	0.93	3.15
	.2	984.04	0.93	3.15
h	.35	984.82	0.94	3.15
	.4	984.83	0.94	3.15
	.45	984.84	0.94	3.15
	.5	984.84	0.94	3.15
A	1000	633.70	0.50	2.51
	1500	819.12	0.75	2.87
	2000	984.83	0.94	3.15
	2500	1137.44	1.10	3.39
β	0.05	984.83	0.94	3.15
	.1	984.83	0.94	3.15
	.15	984.83	0.94	3.15
	.20	984.83	0.94	3.15

If we change the parameter (α, β, h) there is slightly increase in profit. If we change A profit will increase.

CONCLUSIONS

The main purpose of this study is to formulate a deterministic inventory model for deteriorating items under demand rate is quadratic and holding cost is time varying and when the supplier offer a trade credit period. The supplier offers credit period to the retailer who has the reserve money to make the payments, but decides to available the benefits of credit limit. Shortages are allowed and are completely backlogged. Finally, numerical example provides to illustrate and inference the theoretical result.

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