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INVENTORY MODEL FOR DECAYING ITEMS WITH PARTIAL BACKLOGGING AND INFLATION UNDER TRADE CREDITS

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ABSTRACT

Inventory represents a extremely important division of the company's financial assets, it is very much affected by the market's response to various situations, especially inflation. Inflation is a global phenomenon in present day times. Inflation can be defined as that state of disequilibrium in which an expansion of purchasing power tends to cause or is the effect of an increase in the price level. A period of prolonged, persistent and continuous inflation results in the economic, political, social and moral disruption of society. Inflation can mean either an increase in the money supply or an increase in price levels. Generally, when we hear about inflation, we are hearing about a rise in prices compared to some benchmark. If the money supply has been increased, this will usually manifest itself in higher price levels - it is simply a matter of time. Inflation is the primary reason that companies need to put so much effort into valuing their inventory. In the past most studies in inventory models did not consider the influences of inflation. This was due to the belief that inflation would not influence the inventory policy to any significant degree. This belief is unrealistic since the resource of an enterprise is highly correlated to the return of investment. The concept of the inflation should be considered especially for long-term investment and forecasting.

Key words : Inventory, inflation, increase

INTRODUCTION & REVIEW OF LITERATURE

The recent years there is a state of interest of studying time dependent demand rate. It is observed that the demand rate of newly launched products such as electronics items, mobile phones and fashionable garments increases with time and later it becomes constant. Deterioration of items cannot be avoided in business scenarios. In most of the cases the demand for items increases with time and the items that are stored for future use always loose part of their value with passage of time. In inventory this phenomenon is known as deterioration of items. The rate of deterioration is very small in some items like hardware, glassware, toys and steel. The items such as medicine, vegetables, gasoline alcohol, radioactive chemicals and food grains deteriorate rapidly over time so the effect of deterioration of physical goods cannot be ignored in many inventory systems. The deterioration of goods is a realistic phenomenon in many inventory systems and controlling of deteriorating items becomes a measure problem in any inventory system. Due to deterioration the problem of shortages occurs in any inventory system and shortage is a fraction that is not available to satisfy the demand of the customers in a given period of time. Manjusri Basu and Sudipta Sinha [2007] extended the Yan and Cheng model [1998] for time dependent backlogging rate. Rau et al. [2004] considered an inventory model for determining an economic ordering policy of deteriorating items in a supply chain management system. Teng and Chang [2005] determined an economic production quantity in an inventory model for deteriorating items. Dave and Patel [1983] developed an inventory model together with an instantaneous replenishment policy for deteriorating items with time proportional demand and no shortage. Roy and Chaudhury [1983] considered an order level inventory model with finite rate of replenishment and allowing shortages.

Mishra [1975], Dev and Chaudhuri [1986] assumed time dependent deterioration rate in their models. In this regard an extended summary was given by Raafat[1991]. Berrotoni [1962] discussed the difficulties of fitting empirical data to mathematical distributions. Mandal and Phaujdar [1989] developed a production inventory model for deteriorating items with stock dependent demand and uniform rate of production. In this direction some work also done by Padmanabhan and Vrat [1995]. Chandra and Bahner [1988], Jesse et al. [1983], Mishra [1979] developed their models and show the effect of inflation in inventory models by taking a constant rate of inflation. Liao et al [2000] discuss the effect of permissible delay in payment for an inventory model of deteriorating items under inflation. Bhahmbhatt [1982] developed an EOQ model under price dependent inflation rate. Ray and Chaudhuri [1997] considered an EOQ model with shortages under the effect of inflation and time discount. Goyal [1985] developed an EOQ model under the conditions of permissible delay in payment. Chung et al [2002] and Hung [2003] considered an optimal replenishment policy for EOQ model under permissible delay in payments. Vinod kumar Mishra and Lal sahab singh 2010] developed an inventory model for deteriorating items with time dependent demand and partial backlogging. Further Vinod kumar Mishra [2013] developed an inventory model involving controllable deterioration rate to extend the traditional EOQ model. Mandal [2013] developed an inventory model for random deteriorating items with timedependent demand and partial backlogging. It has been observed that the unsatisfied demand is completely back-logged and during the shortage period either all the customers wait for the arrival of next order (completely backlogged) or all the customers leave the system (completely lost). The length of waiting time for the replenishment is the main factor for determining whether the backlogging is accepted or not.

The mathematical model developed in this chapter is based on the following assumptions:

Assumptions:

- Single vendor, single buyer with one item is assumed.
- Single item with constant deteriorating rate of the on hand inventory in considered.
- The holding cost is varying as an increasing step function of time in storage.
- Shortages are allowed with partial backlogging.
- A stationary policy where the same lot size is assumed.
- Demand rate is depending on time.
- Inflation is considered.
- Permissible delay on payment is considered.

Notations:

I. The parameters related to vendor are:

$I_{v1}(t)$ Inventory level for vendor when t is between 0 and T_1
$I_{v2}(t)$ Inventory level for vendor when t is between 0 and T_2
I_{mv} Maximum inventory for vendor
P_v The unit production cost for vendor
F_{vj} Holding cost of the item in period j for vendor.
$F_v(t)$ Holding cost of the item at time t, $F_v(t) = F_{vj}$ if $t_{j-1} < t < t_j$.
C_{sv} The set up cost per production cycle for vendor.
VC Total vendor's cost per unit item.

II. The parameters related to buyer are:

$I_b(t)$ Inventory level for buyer.
I_{mb} Maximum inventory for buyer
P_b The unit price cost for buyer.
F_{bj} Holding cost of the item in period j for buyer.
$F_b(t)$ Holding cost of the item at time t, $F_b(t)=F_{bj}$ if $t_{j-1} < t < t_j$.
C_{sb} The set up cost per order for buyer.
C_2 Shortage cost per item for backlogged items.
C_3 The unit cost of lost sales.

B(t) Denote the fraction where t is the waiting time up to the next replenishment. We take B(t) =1/(1+δ t), where the backlogging parameter is a positive constant.

BC Total buyer's cost per unit item.

The other related parameters are as follows:

a+ct Demand rate where a and c are positive constants and I(t) is the inventory level at time t.

T Time length of each cycle, where $T = T_1+T_2$

θ Deterioration rate

T_1 The length of production time in each production cycle.

T_2 The length of non production time

P The production rate per year

n Number of distinct time periods with different holding cost rates.

r Inflation rate

TC The integrate cost of vendor and all buyer per unit item.

M The period of permissible delay in setting account.

t_1' The time at which shortage occur.

MATHEMATICAL MODEL

A. Vendor's Inventory System:

In this model the production starts at time zero for vendor with constant rate P from the starting of each cycle i.e. at t=0. Inventory level increases due to production and decreases due to demand and deterioration upto time T_1 and reaches at maximum value I_{mv} as shown in the Fig.1

$$I_{V1}'(t)+\theta I_{V1}(t)=P-[a+ct],\quad 0\le t\le T_1 \qquad \ldots(1)$$

After time T_1 the inventory level decreases due to demand and deterioration up to time T_2 and reaches at the zero level at time T_2 .

$$I_{V2}'(t)+\theta I_{V2}(t)=-[a+ct],\quad 0\le t\le T_2 \qquad \ldots(2)$$

We have boundary conditions

$$I_{v1}(0)=0, I_{v2}(T_2)=0$$

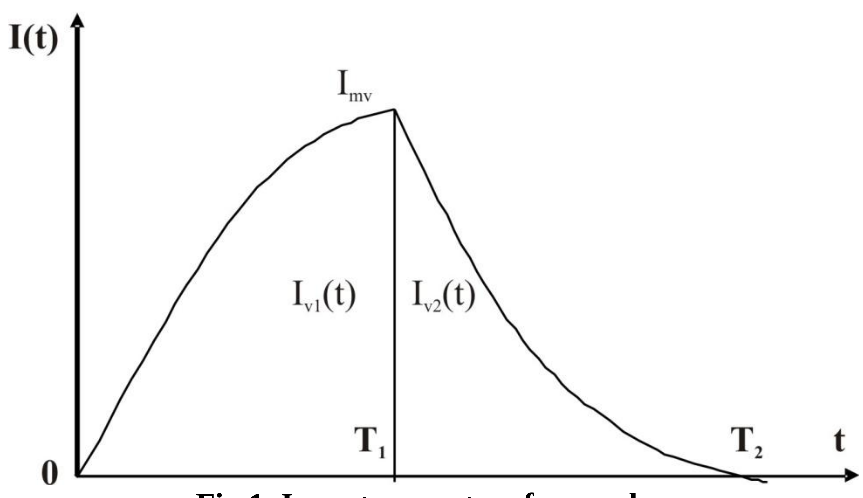

Fig 1. Inventory system for vendor

Now the solutions of the above differential equations are

$$I_{V1}(t)=(1-e^{-(\theta)t})\left(\frac{P-a}{\theta}+\frac{c}{(\theta)^2}\right)-\frac{ct}{\theta} \qquad 0\le t\le T_1 \qquad \ldots(3)$$

$$I_{V2}(t)=\left[\frac{a}{\theta}-\frac{c}{(\theta)^2}\right]\left(e^{(\theta)(T_2-t)}-1\right)+\frac{c}{(\theta)}(T_2e^{(\theta)(T_2-t)}-t) \qquad 0\le t\le T_2 \qquad \ldots(4)$$

B. Buyer's Inventory System:

Buyer cycle starts with the maximum inventory I_{mb} at $t = 0$ and this inventory gradually depletes to zero at time t_1' due to the simultaneous effect of demand and deterioration, shown by the Fig. 1.2.

$$I_{b1}'(t) + \theta I_{b1}(t) = -[a + ct], \qquad 0 \le t \le t_1' \qquad \ldots(5)$$

After time t_1' partial backlogging occurs and the change in the inventory is directed by the following differential equation.

$$I_{b2}'(t) = -\frac{[a+ct]}{1+\delta\left(\frac{T}{n}-t\right)} \qquad t_1' < t \le T/n \qquad \ldots(6)$$

Boundary condition is $I_{b1}(t_1') = 0 = I_{b2}(t_1')$

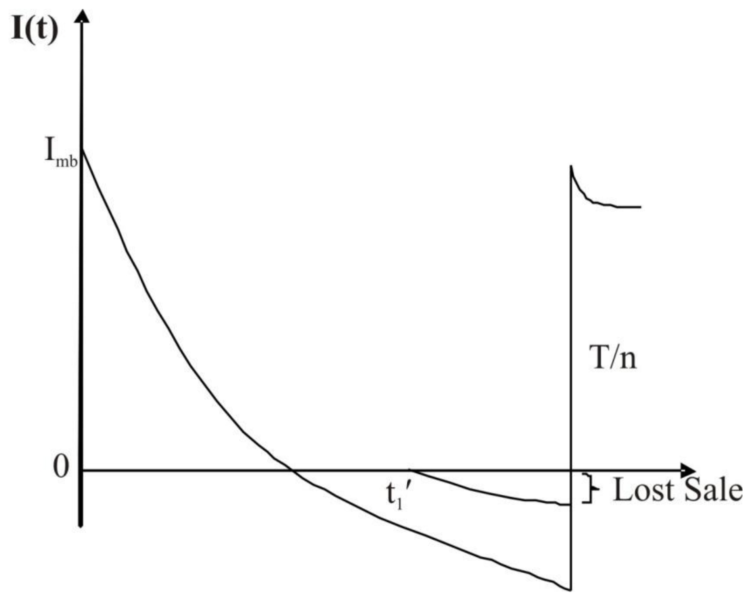

Fig 2 : Inventory system for buyer when shortage is allowed

Now the solutions of the above differential equations are

$$I_{b1}(t) = \left(\frac{a}{\theta} - \frac{c}{(\theta)^2}\right)\left(e^{(\theta)(t_1'-t)} - 1\right) + \frac{c}{(\theta)}\left(t_1' e^{(\theta)(t_1'-t)} - t\right), \quad 0 \le t \le t_1' \qquad \ldots(7)$$

$$I_{b2}(t) = -\frac{1}{\delta}\left[a + \frac{c}{\delta}\left(1+\delta\frac{T}{n}\right)\right]\log\left\{\frac{\left(1+\delta\left(\frac{T}{n}-t_1'\right)\right)}{\left(1+\delta\left(\frac{T}{n}-t\right)\right)}\right\} + \frac{c}{\delta}(t - t_1') \qquad t_1' \le t \le T/n$$

$$\ldots(8)$$

By using the boundary condition $I_{mv} = I_{v2}(0)$ and $I_{mb} = I_{b1}(0)$, we have

$$I_{mv} = T_2(a + cT_2) + \frac{T_2^2}{2}\left[a(\theta) - c + cT_2(\theta)\right] \qquad \ldots(9)$$

$$I_{mb} = t_1'(a + ct_1') + \frac{t_1'^2}{2}\left[a(\theta) - c + ct_1'(\theta)\right] \qquad \ldots(10)$$

By the boundary condition, $I_{v1}(T_1) = I_{v2}(0)$, we can derive the following equation:

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$$(p-a)\left(T_1-\frac{(\theta)T_1^2}{2}\right)-\frac{cT_1^2}{2}=T_2(a+cT_2)+\frac{T_2^{\,2}}{2}\left[a(\theta)-c+cT_2(\theta)\right]$$

By Taylor's series expansion and the assumption $\theta \ll 1$& by neglecting some small terms, we get

$$T_1=\frac{(a+cT_2)T_2}{(p-a)}+\frac{T_2^{\,2}}{2(p-a)}\left[(\theta)(a+cT_2)-c\right] \qquad \ldots(11)$$

Knowing $T=T_1+T_2$

We can derive

$$T=T_2\left[1+\frac{(a+cT_2)}{(p-a)}+\frac{T_2}{2(p-a)}\left((\theta)(a+cT_2)-c\right)\right] \qquad \ldots(12)$$

Case I: Retroactive holding cost increase

The yearly holding cost for all the buyers and vendors are

$$HC_b=\frac{F_{bj}n}{T}\int_0^{t_1'}I_{b1}(t)e^{-rt}dt$$

$$=\frac{F_{bj}n}{T}\left[\frac{(a+ct_1')t_1'^2}{2}-\frac{t_1'^2}{2r}\left\{(\theta)(a+ct_1')-c\right\}\right] \qquad \ldots(13)$$

and

$$HC_v=\frac{F_{vj}}{T}\left[\int_0^{T_1}I_{v1}(t)e^{-rt}dt+e^{-rT_1}\int_0^{T_2}I_{v2}(t)e^{-rt}dt-n\int_0^{t_1'}I_{b1}(t)e^{-rt}dt\right]$$

$$=\frac{F_{vj}}{T}\left[\begin{array}{l}(p-a)\left\{\frac{T_1^2}{2}-\frac{rT_1^3}{2}+\frac{(\theta)rT_1^4}{4}\right\}+\frac{crT_1^4}{4}+e^{-rT_1}\left\{\frac{(a+cT_2)T_2^{\,2}}{2}\right\}\\ -n\left\{(a+ct_1')\frac{t_1'^2}{2}-\left(\frac{(\theta)(a+ct_1')-c}{2}\right)\frac{t_1'^2}{r}\right\}\end{array}\right] \qquad \ldots(14)$$

Case II: Incremental holding cost increase:

$$HC_b=\frac{n}{T}\left[F_{b1}\int_0^{t_1}I_{b1}(t)e^{-rt}dt+F_{b2}\int_{t_1}^{t_2}I_{b1}(t)e^{-rt}dt+\ldots\ldots+F_{bc}\int_{t_{c-1}}^{t_c=t_1'}I_{b1}(t)e^{-rt}dt\right]$$

$$=\frac{n}{T}\sum_{j=1}^{c}F_{bj}\int_{t_{j-1}}^{t_j}I_{b1}(t)e^{-rt}dt$$

$$=\frac{n}{T}\sum_{j=1}^{c}F_{bj}\left[(a+ct_1')\left\{-(t_1'-t_j)\frac{e^{-rt_j}}{r}+\frac{e^{-rt_j}}{r^2}+(t_1'-t_{j-1})\frac{e^{-rt_{j-1}}}{r}-\frac{e^{-rt_{j-1}}}{r^2}\right\}\right.$$
$$+\left\{\frac{a(\theta)-c+ct_1'(\theta)}{2}\right\}\left\{-(t_1'-t_j)^2\frac{e^{-rt_j}}{r}+2(t_1'-t_j)-2\frac{e^{-rt_j}}{r^3}\right.$$
$$\left.\left.+(t_1'-t_{j-1})^2\frac{e^{-rt_{j-1}}}{r}-\frac{2(t_1'-t_{j-1})e^{-rt_{j-1}}}{r^2}+\frac{2e^{-rt_{j-1}}}{r^3}\right\}\right] \qquad \ldots(15)$$

$$HC_v=\frac{1}{T}\left[F_{v1}\int_0^{T_1}I_{v1}(t)e^{-rt}dt+e^{-rT_1}F_{v2}\int_0^{T_2}I_{v2}(t)e^{-rt}dt\right.$$

$$-n\left\{F_{b1}\int_0^{t_1} I_{b1}(t)e^{-rt}dt+F_{b2}\int_{t_1}^{t_2} I_{b1}(t)e^{-rt}dt+.......+F_{bc}\int_{t_{c-1}}^{t_c=t_1'} I_{b1}(t)e^{-rt}dt\right\}\Bigg]$$

$$HC_v=\frac{1}{T}\left[(p-a)F_{v1}\left\{\frac{T_1^2}{2}-\frac{rT_1^3}{2}+(\theta+b)\frac{rT_1^4}{4}\right\}+\frac{F_{v1}crT_1^4}{4}+e^{-rT_1}\frac{F_{v2}(a+cT_2)T_2^{\ 2}}{2}\right]$$

$$-n\sum_{j=1}^{c}F_{bj}(a+ct_1')\left\{\left\{-(t_1'-t_j)\frac{e^{-rt_j}}{r}+\frac{e^{-rt_j}}{r^2}+(t_1'-t_{j-1})\frac{e^{-rt_{j-1}}}{r}-\frac{e^{-rt_{j-1}}}{r^2}\right\}\right.$$

$$+\left\{\frac{a(\theta)-c+ct_1'(\theta)}{2}\right\}\left\{-(t_1'-t_j)^2\frac{e^{-rt_j}}{r}+2(t_1'-t_j)-2\frac{e^{-rt_j}}{r^3}\right.$$

$$\left.\left.+(t_1'-t_{j-1})^2\frac{e^{-rt_{j-1}}}{r}-\frac{2(t_1'-t_{j-1})e^{-rt_{j-1}}}{r^2}+\frac{2e^{-rt_{j-1}}}{r^3}\right\}\right\} \qquad \ldots(16)$$

When $t_1'>M$

Interest payable per cycle per unit time is

$$IP=\frac{nP_bI_P}{T}\int_M^{t_1'} I_{b1}(t)e^{-rt}dt$$

$$=\frac{nP_bI_P}{T}\int_M^{t_1'}\left[(t_1'-t)(a+ct_1')+\frac{(t_1'-t)^2}{2}\left\{a(\theta)-c+ct_1'(\theta)\right\}\right]e^{-rt}dt$$

$$=\frac{nP_bI_P}{T}\left[(a+ct_1')(t_1'-M)\left(t_1'-\frac{M}{2}+\frac{rM^2}{2}\right)\right.$$

$$\left.+\left\{\frac{(\theta)(a+ct_1')-c}{2}\right\}(t_1'-M)\left\{-Mt_1'+\frac{M^2}{2}(t_1'-M)\right\}\right] \qquad \ldots(17)$$

Interest earned per cycle per unit time is

$$IE=\frac{nP_bI_e}{T}\int_0^{t_1'} e^{-rt}(a+ct)dt$$

$$=\frac{nP_bI_e}{T}\left[(a+ct_1')(t_1'-\frac{rt_1'^2}{2})\right] \qquad \ldots(18)$$

(ii) When $t_1'\le M$

Interest earned up to time t_1' is

$$IE=P_bI_e\int_0^{t_1'} e^{-rt}(a+ct)dt$$

$$=P_bI_e\left[(a+ct_1')(t_1'-\frac{rt_1'^2}{2})\right]$$

Interest earned during $(M-t_1')$ is $P_bI_e\left[(a+ct_1')(t_1'-\frac{rt_1'^2}{2})\right]\int_{t_1'}^{M} e^{-rt}dt$

$$= P_b I_e \left[(a+ct_1')(t_1' - \frac{rt_1'^2}{2}) \right] \left(\frac{e^{-rt_1'}}{r} - \frac{e^{-rM}}{r} \right)$$

Total Interest earned per unit time is

$$IE = \frac{nP_b I_e}{T} \left[(a+ct_1') \left(t_1' - \frac{rt_1'^2}{2} \right) \right] \left(1 + \frac{e^{-rt_1'}}{r} - \frac{e^{-rM}}{r} \right) \quad \ldots(19)$$

In this case customer pays no interest.

The annual deteriorated costs for all buyer and vendor are:

$$DC_b = \frac{nP_b}{T} \left[I_{Mb} - \int_0^{t_1'} (a+ct) e^{-rt} dt \right]$$

$$= \frac{nP_b}{T} t_1'^2 \left[\left(\frac{a(\theta) - c}{2} \right) + \frac{ar}{2} \right] \quad \ldots(20)$$

$$DC_v = \frac{P_v}{T} [PT_1 - nI_{Mb}]$$

$$= \frac{P_v}{T} \left[PT_1 - n \left\{ t_1'(a+ct_1') + \frac{t_1'^2}{2} ((\theta)(a+ct_1') - c) \right\} \right] \quad \ldots(21)$$

The set up cost per year for all buyer and vendor are:

$$SC_b = \frac{nC_{sb}}{T} \quad \ldots(22)$$

$$SC_v = \frac{C_{sv}}{T} \quad \ldots(23)$$

Shortage cost per cycle for the buyer

$$AS_b = \frac{nC_2}{T} \int_{t_1'}^{T/n} -I_{b2}(t) e^{-rt} dt$$

$$= -\frac{nC_2}{\delta T} \left[\left\{ a + \frac{c}{\delta}(1 + \delta \frac{T}{n}) \right\} \log \left\{ 1 + \delta \left(\frac{T}{n} - t_1' \right) \right\} \left\{ \frac{T}{n} - t_1' - \frac{1}{\delta} \left(1 - \frac{r}{2\delta} \left(1 + \delta \frac{T}{n} \right) \right) \right.\right.$$

$$\left.\left(1 + \delta \frac{T}{n} \right) + \left(t_1' - \frac{rt_1'^2}{2} \right) \right\} + \frac{c}{\delta r} \left(\frac{T}{n} - t_1' \right) \left(1 - e^{-r\frac{T}{n}} \right) - \left\{ a + \frac{c}{\delta}(1 + \delta \frac{T}{n}) \right\}$$

$$\left.\left(\frac{T}{n} - t_1' \right) \left\{ \frac{r}{4} \left(\frac{T}{n} + t_1' \right) - \left(1 - \frac{r}{2\delta} \left(1 + \delta \frac{T}{n} \right) \right) \right\} \right] \quad \ldots(24)$$

Opportunity cost per cycle due to lost sales

$$OC = \frac{nC_3}{T} \int_{t_1'}^{T/n} \left[1 - \frac{1}{1 + \delta \left(\frac{T}{n} - t \right)} \right] (a+ct) e^{-rt} dt$$

$$= \frac{nC_3}{T} \left[\left(e^{-rT/n} - e^{-rt_1'} \right) \left\{ -\frac{c}{r^3} - \frac{c}{r^2} - \frac{2\delta c}{r^4} - \frac{\delta a}{r^3} \right\} - \frac{\delta cT}{r^3 n} e^{-rT/n} \right.$$

$$\left. + \frac{\delta c t_1'}{r^3} e^{-rt_1'} - \frac{c\delta}{r^3} \left(\frac{T}{n} - t_1' \right) e^{-rt_1'} \right] \quad \ldots(25)$$

Case I: Retroactive holding cost increase:

(i) When $t_1' > M$

Total Cost (TC_{1a}) = VC + BC

= $HC_b + DC_b + SC_b + AS_b + OC + HC_v + DC_v + SC_v$ + Interest payable – Interest earned

Where HC_b, DC_b, SC_b, AS_b, OC, HC_v, DC_v, SC_v, Interest payable and Interest earned are (13), (20), (22), (24), (25), (14), (21), (23), (17) and (18) respectively. The necessary and sufficient conditions for the total relevant cost per unit time to be minimize are

$$\frac{\partial TC_{1a}(T_2, t_1')}{\partial T_2} = 0 \quad \frac{\partial TC_{1a}(T_2, t_1')}{\partial t_1'} = 0$$

$$\frac{\partial^2 TC_{1a}(T_2, t_1')}{\partial T_2^{\,2}} > 0, \qquad \frac{\partial^2 TC_{1a}(T_2, t_1')}{\partial t_1'^2} > 0$$

and $$\left(\frac{\partial^2 TC_{1a}(T_2, t_1')}{\partial T_2^{\,2}}\right)\left(\frac{\partial^2 TC_{1a}(T_2, t_1')}{\partial t_1'^2}\right) - \left(\frac{\partial^2 TC_{1a}(T_2, t_1')}{\partial t_1' \partial T_2}\right) > 0$$

(ii) When $t_1' \le M$

Total Cost (TC_{1b}) = VC + BC

= $HC_b + DC_b + SC_b + AS_b + HC_v + DC_v + SC_v$ - Interest earned

Where HC_b, DC_b, SC_b, AS_b, OC, HC_v, DC_v, SC_v and Interest earned are (13), (20), (22), (24), (25), (14), (21), (23) and (19) respectively.

CONCLUSION

An inventory model was developed for deteriorating items with supply chain, permitting shortage under inflation and time-value of money. In particular, the backlogging rate considered to be a decreasing function in the waiting time until the next replenishment is more realistic. It is true that the stock-out is very difficult to measure. The proposed model can be extended in numerous ways. For example, the demand can be taken as a more generalized pattern that fluctuates with stock or price or stochastic.

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