International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06 | Jun 2022 www.irjet.net p-ISSN: 2395-0072

TWO WAREHOUSE INVENTORY MODEL FOR DETERIORATING THINGS WITH SHORTAGES BELOW THE CONDITIONS OF PERMISSIBLE DELAY IN PAYMENTS

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Abstract: *In this paper, a deterministic inventory model for deteriorating items with two warehouses and shortages is developed. The conditions of permissible delay in payments are also taken into consideration. A rented warehouse is used when the ordering quantity exceeds the limited capacity of the owned warehouse, and it is assumed the deterioration rates of items in the two warehouses may be different. In addition, shortages are neither completely backlogged nor completely lost assuming the backlogging rate to the inversely proportional to the waiting time for the next replenishment. We obtain the condition when to rent the warehouse and provide simple solution procedures for finding the minimum total cost per unit time. We presented special cases of this model. In one of the case we considered that the capacity of OW is infinite so there is no need of rented warehouse. In other case we consider that deterioration is not allowed and shortage are allowed and completely backlogged.*

Key-Words **:** Two-warehouse inventory model, shortage, time-dependent demand rate, time-dependent partial backlogging rate, time-dependent deterioration rate, permissible delay in payments.

1. INTRODUCTION

In today's business transactions, it's oftentimes ascertained that a client is allowed some grace amount before subsiding the account with the provider or the producer. The client doesn't need to pay any interest throughout this fastened amount however if the payment gets on the far side the amount interest are going to be charged by the provider. This arrangement comes intent on be terribly advantageous to the client as he might delay the payment until the tip of the permissible delay amount. throughout the amount he might sell the products, accumulate revenues on the sales and earn interest on it revenue. Thus, it makes economic sense for the client to delay the payment of the renewal account upto the Judgment Day of the settlement amount allowed by the provider or the producer. Goyal (1985) 1st developed associate degree economic order amount (EOQ) model below the condition of permissible delay in payments. Chung (1989) given the discounted income approach for the analysis of the best inventory police within the presence of trade credit. Later, Shinn et al. (1996) extended Goyal's (1985) model and thought of amount discounts for freight price. Recently, to accommodate a lot of sensible options of the $64000 inventory systems, Aggarwal and Jaggi (1995) and Hwang and Shinn (1997) extended Goyal's (1985). afterward Jamal et al (1997) extended Aggarwal and Jaggi (1995) model to permit for shortages and create it a lot of applicable in universe.

In classical inventory models is that the organization owns one warehouse while not capability limitation. In follow, whereas an oversized stock is to be command, because of the restricted capability of the in hand warehouse (OW), one extra warehouse is needed. this extra warehouse is also a rented warehouse (RW), that is assumed to be accessible with luxuriant capability. There exist some sensible reasons specified the organizations area unit impelled to order a lot of things then the capability of OW. for instance, the worth discount for bulk purchase is also advantageous to the management; the demand of things is also high enough specified a substantial increase in profit is predicted, and so on. In these things, it's usually assumed that the holding price in RW is above that in OW. to scale back the inventory prices, it'll be economical to consume the products of RW at the earliest.

An early discussion on the impact of two-warehouses was thought of by David Hartley (1976). Recently different authors have thought of this kind of inventory model. Sarma (1983) developed a settled inventory model with finite renewal rate. Dave (1988) any mentioned the cases of bulk unharness pattern for each finite and infinite renewal rates. He corrected the errors in Murdeshwar and Sathe (1985) offer|and provides} an entire answer for the model give by Sarma (1983). within the higher than literature, deterioration development wasn't taken into consideration. Presumptuous the deterioration in each warehouses, Sarma (1987) extended the model to the case of infinite renewal rate with shortages. Pakkala and Achary (1992) extended the two-warehouse inventory model for deteriorating things with finite renewal rate and shortages, taking time as separate and continuous variable, severally. In these models mentioned higher than the demand rate was assumed to be constant. later on, the concepts of your time variable demand and stock-dependent demand thought of by some authors, like Goswami and Chaudhuri (1998) Bhunia and Maiti (1998) Bankherouf (1997), kar et al. (2001) et al.. Dye, Ouyang and Hsich (2006) developed a settled inventory model for deteriorating things with capability constraint and time-proportional back work rate.

Furthermore, the characteristics of all higher than papers area unit that shortages don't seem to be allowed or assumed to be fully backlogged. Zhou (2003) given a multi-warehouse inventory model for non-perishable things with time-varying demand and partial backlogging. In his model, the backlogging operate was assumed to be addicted to the number of demand backlogged. In several cases customers area unit conditioned to a shipping delay, and will be willing to attend for a brief time so as to urge their 1st selection. usually speaking, the length of the waiting time for succeeding renewal is that the main issue for deciding whether or not the backlogging are going to be accepted or not. The temperament of a client to attend for backlogging throughout a shortage amount declines with the length of the waiting time. Abad (1996, 2001) mentioned a valuation and lot-sizing downside for a product with a variable rate of decay, permitting shortages and partial backlogging.

In this paper, we have a tendency to develop a settled inventory model for deteriorating things with two warehouses. We have a tendency to assume that the inventory prices (including holding price and deterioration price in RW area unit above those in OW). additionally shortages area unit allowed within the in hand warehouse and therefore the backlogging rate of unhappy demand is assumed to be a decreasing operate of the waiting time. Shortages area unit of nice importance particularly in a very model that considers a delay in payment because of the very fact that shortages will impact the amount ordered to learn from the delay in payment. Currently there arises a natural question whether or not the amount of the amount ordered influences the length of the permissible delay amount. Intuition results in the very fact that {the volume/the amount/the amount/the degree} of the ordered quantity ought to have an on the spot impact on the length of this era. The current paper incorporates this reality in a list model permitting shortages and obtains the best ordering policy.

2. NOTATIONS AND ASSUMPTIONS

To develop the planned inventory model with two warehouses, the subsequent notations and assumptions square measure utilized in this paper:

$I_1(t)$ the amount of inventory positive in RW of your time t.

$I_2(t)$ the level of positive inventory in OW of your time t.

$I_3(t)$ the level of negative inventory at time t.

D the demand rate per unit time

A the refilling price per order

C the buying price per unit

S the price per unit, where $S \geq C$

W the capability of the in hand warehouse

H the holding price per unit per unit time in OW

F the holding price per unit per unit time in RW, where $F > H$

C_2 the shortage price per unit per unit time

π the opportunity cost per unit

α the deterioration rate in OW, wherever $0 \leq \alpha < 1$

β the deterioration rate in RW, wherever $0 \leq \beta < 1$

T_w the time at that the inventory level reaches zero in RW

t_1 the time at that the inventory level reaches zero in OW

t_2 the length of amount throughout that shortages square measure allowed

T the length of the inventory cycle, hence $T = t_1 + t_2$

I_e interest which might be attained

I_r interest charges that endowed in inventory, $I_r > I_e$

M permissible delay in subsiding the accounts, $0 < M < T$

$C_M(t_1,T)$ Average total inventory price per unit time, once permissible delay amount in payment is M

Let us write: $$C_M(t_1,T) = \begin{cases} C_M^1(t_1,T) & \text{for } t_1 \geq M \\ C_M^2(t_1,T) & \text{for } t_1 < M \end{cases}$$

The following assumptions are used:

(i) Replenishment rate is infinite, and lead-time is zero.

(ii) The time horizon of the inventory system is infinite.

(iii) The closely-held warehouse (OW) contains a fastened capability of W units, the rented warehouse (RW) has unlimited capability.

(iv) The product of OW square measure consumed solely once intense the products unbroken in RW.

(v) The unit inventory costs (including holding cost and deterioration cost) per unit time in RW are higher than those in OW, that is, $F+\beta C > H+\alpha C$.

(vi) To guarantee the optimal solution exists, we assume that the maximum deteriorating quantity for times in OW, αW, is less than the demand date D, that, $\alpha W<D$.

(vii) Shortages are allowed. Unsatisfied demand is backlogged, and the fraction of shortages back ordered is $\frac{1}{1+\delta x}$, where x is the waiting time up to the next replenishment and δ is a positive constant.

No payment to the supplier is outstanding at the time of placing an order i.e. M < T.

3. MATHEMATICAL FORMULATION

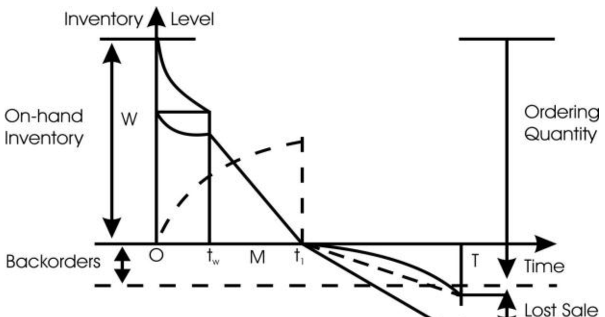

Figure-1

As shown in Fig. 1, we consider the following time intervals separately, $[0, t_w]$, $[t_w, t_1]$ and $[t_1, T]$. During the interval $[0, t_w]$, the inventory levels are positive at RW and OW. At RW, the inventory is depleted due to the combined effects of demand and deterioration. At OW, the inventory is only depleted by the effect of deterioration. Hence the inventory level at RW and OW are governed by the following differential equations;

$$\frac{dI_1(t)}{dt} = -D - \beta I_1(T), \qquad 0 < t < t_w \qquad ...(1)$$

with the boundary condition $I_1(t_w) = 0$ and

$$\frac{dI_2(t)}{dt} = -\alpha I_2(t), \qquad 0 < t < t_w \qquad ...(2)$$

with the initial condition $I_2(0) = W$, respectively. Solving equations (1) and (2), we get the inventory level as follows:

$$I_1(t) = \frac{D}{\beta}\left[e^{\beta(t_w - t)} - 1\right], \qquad 0 \le t \le t_w \qquad ...(3)$$

and $$I_2(t) = We^{-\alpha t}, \qquad 0 \le t \le t_w \qquad ...(4)$$

During the interval $[t_w, t_1]$, the inventory in OW is depleted due to the combined effects of demand and deterioration. Hence, the inventory level at OW is governed by the following differential equation:

$$\frac{dI_2(t)}{dt} = -D - \alpha I_2(t), \qquad t_w < t < t_1 \qquad ...(5)$$

with the boundary condition $I_2(t_1) = 0$. Solving the differential equation (5), We get the inventory level as:

$$I_2(t) = \frac{D}{\alpha}\left[e^{\alpha(t_1 - t)} - 1\right], \qquad t_w \le t \le t_1 \qquad ...(6)$$

Due to continuity of $I_2(t)$ of point $t = t_w$, from equation (4) and (6), we have

$$We^{-\alpha t_w} = \frac{D}{\alpha}\left[e^{\alpha(t_1 - t_w)} - 1\right] \qquad ...(7)$$

This implies that

$$t_1 = t_w + \frac{1}{\alpha}\text{In}\left(1 + \frac{\alpha We^{-\alpha t_w}}{D}\right) \qquad ...(8)$$

which shows that t_1 is a function of t_w

Furthermore, at time t1, the inventory level reaches zero in OW and lack happens. During [t1, T], the inventory level solely depend upon demand, and a few demand is lost whereas a fraction $\frac{1}{1+\delta(T-t)}$ of the demand is backlogged, where $t \in [t_1, T]$. The inventory level is governed by the following differential equation:

$$\frac{dI_3(t)}{dt} = -\frac{D}{1+\delta(T-t)}, \qquad t_1 < t < T \qquad ...(9)$$

with the boundary condition $I_3(t_1) = 0$. Solving the differential equation (10), we get the inventory level as:

$$I_3(t) = -\frac{D}{\delta}\left\{\text{In}\left[1+\delta(T-t_1)\right] - \text{In}\left[1+\delta(T-t)\right]\right\}, \qquad t_1 \le t \le T \qquad ...(10)$$

Based on equations (3), (4), (6) and (11), the total cost per cycle consists of the following elements:

1. Ordering cost per cycle = A
2. Holding cost per cycle in RW

$$HC_{RW}=F\int_0^{t_w} I_1(t)dt = FD\left(e^{\beta t_w}-\beta t_w-1\right)/\beta^2$$

3. Holding cost per cycle in OW

$$HC_{OW}=H\left(\int_0^{t_w} I_2(t)dt+\int_{t_w}^{t_1} I_2(t)dt\right)$$

$$=H\left[W-D\left(t_1-t_w\right)\right]/\alpha$$

4. Shortage cost per cycle:

$$SC=C_2\int_{t_1}^{T}-I_3(t)dt=C_2D\left\{\delta\left(T-t_1\right)-In\left[1+\delta\left(T-t_1\right)\right]\right\}/\delta^2$$

5. Opportunity cost due to lost sales per cycle:

$$OC=\pi D\int_{t_1}^{T}\left\{1-\frac{1}{\left[1+\delta\left(T-t\right)\right]}\right\}dt$$

$$=\pi D\left\{\delta\left(T-t_1\right)-In\left[1+\delta\left(T-t_1\right)\right]\right\}/\delta$$

The number of deteriorated items in RW in $[0, t_w]$ is

$$I(0)-\int_0^{t_w} Ddt=\frac{D}{\beta}\left[e^{\beta t_w}-1\right]-Dt_w$$

and the number of deteriorated items in OW in $[0,t_1]$ is

$$I_2(0)-\int_0^{t_1} D(t)=W-D\left(t_1-t_w\right)$$

6. Deterioration cost per cycle:

$$DC=P\left\{\frac{D}{\beta}\left[e^{\beta t_w}-1\right]-Dt_1+W\right\}$$

Case I: $M \le t_1$

In this state of affairs, since the length of amount with positive stock is larger than the credit amount, the client will use the sale revenue to earn interest at an annual rate I_e that is in $(0, t_1)$

The interest earned IE_1 is

$$IE_1=CI_e\; IE_1=CI_e\int_0^{t_1} D\left(t_1-t\right)dt=DCI_e\frac{t_1^2}{2} \quad ...(11)$$

However beyond credit period, the unsold stock is supposed to be financial with an annual rate I_r and the interest payable IP is given by:

$$IP=CI_r\int_M^{t_1} D\left(t_1-t\right)dt=\frac{DCI_r}{2}\left(t_1-M\right)^2 \quad ...(12)$$

Therefore the total average cost per unit time is:

$$C_M^1\left(t_1,T\right)=\frac{OC+HC_{RW}+HO_{OW}+SC+OC+DC+IP-IE_1}{T}$$

$$=\frac{1}{T}\left\{A+\frac{FD}{\beta^2}\left(e^{\beta t_w}-\beta t_w-1\right)+\frac{H}{\alpha}\left[W-D\left(t_1-t_w\right)\right]\right.$$

$$+\frac{C_2D}{\delta^2}\left[\delta t_2-In\left(1+\delta t_2\right)\right]+\frac{\pi D}{\delta}\left[\delta t_2-In\left(1+\delta t_2\right)\right]$$

$$\left.+P\left[\frac{D}{\beta}\left(e^{\beta t_w}-1\right)-Dt_1+W\right]+\frac{DCI_r}{2}\left(t_1-M\right)^2-DCI_e\frac{t_1^2}{2}\right\}$$

...(13)

Optimal values of t_1 and T, which minimize $C_M^1(t_1T)$ are obtained by solving the equations.

$$\frac{\partial C_M^1\left(t_1,T\right)}{dt_1}= \text{ and } \frac{\partial C_M^1\left(t_1,T\right)}{dT}=0 \text{ Which give}$$

Provided they satisfy the sufficient conditions

$$\left.\frac{\partial^2 C_M^1\left(t_1,T\right)}{\partial t_1^2}\right|_{\left(t_1^*,T^*\right)}>0,\left.\frac{\partial^2 C_M^1\left(t_1,T\right)}{\partial T^2}\right|_{\left(t_1^*,T^*\right)}>0$$

and

$$\left.\left(\frac{\partial^2 C_M^1\left(t_1,T\right)}{\partial t_1^2}\right)\left(\frac{\partial^2 C_M^1\left(t_1,T\right)}{\partial T^2}\right)-\left(\frac{\partial^2 C_M^1\left(t_1,T\right)}{\partial t_1\partial T}\right)\right|_{\left(t_1^*,T^*\right)}>0$$

...(14)

Case 2: $M > t_1$:

Since $M > T_1$, the buyer pays no interest but earns interest at an annual rate I_e during the period (0,M) interest earned in this case, denoted by IE_2, is given by:

$$IE_2=CI_e\left(\int_0^{t_1}\left(t_1-t\right)Ddt+\left(M-t_1\right)\int_0^{t_1}Ddt\right)$$

$$=CI_eDt_1\left(M-\frac{t_1}{2}\right) \quad ...(15)$$

Then the total average cost per unit time is

$$C_M^2\left(t_1,T\right)=\frac{1}{T}\left[OC+HC_{RW}+HC_{OW}+SC+OC+DC-IE_2\right]$$

$$=\frac{1}{T}\left\{A+\frac{FD}{\beta^2}\left(e^{\beta t_w}-\beta t_w-1\right)+\frac{H}{\alpha}\left[W-D\left(t_1-t_w\right)\right]+\frac{C_2D}{\delta^2}\right.$$

$$\left[\delta(T-t_1)-\ln(1+\delta(T-t_1)\right]+\frac{\pi D}{\delta}\left[\delta(T-t_1)-\ln(1+\delta(T-t_1))\right]$$

$$+P\left[\frac{D}{\beta}\left(e^{\beta t_w}-1\right)-Dt_1+W\right]-CI_eDt_1\left(M-\frac{t_1}{2}\right)\Bigg\} \quad ...(16)$$

Optimal values of t_1 and T which minimize $C_M^2(t_1,T)$ are obtained by solving the equations:

$$\frac{\partial C_M^2(t_1,T)}{dt_1}=0 \text{ and } \frac{\partial C_M^2(t_1,T)}{dT}=0 \text{ which give}$$

provided they satisfy the sufficient conditions:

$$\left.\frac{\partial^2 C_M^2(t_1,T)}{\partial t_1^2}\right|_{(t_1^*,T^*)}>0, \left.\frac{\partial^2 C_M^2(t_1,T)}{\partial T^2}\right|_{(t_1^*,T^*)}>0$$

$$\left.\left(\frac{\partial^2 C_M^2(t_1,T)}{\partial t_1^2}\right)\left(\frac{\partial^2 C_M^2(t_1,T)}{\partial T^2}\right)-\left(\frac{\partial^2 C_M^2(t_1,T)}{\partial t_1\partial T}\right)\right|_{(t_1^*T^*)}>0$$

. ..(17)

3.1. Particular Case A

Inventory problem without capacity constraint in OW: When the space of OW is so abundant then there is no need to use RW; In this situation the previous model reduces to the single warehouse inventory problem. We remove the capacity constraint of the OW

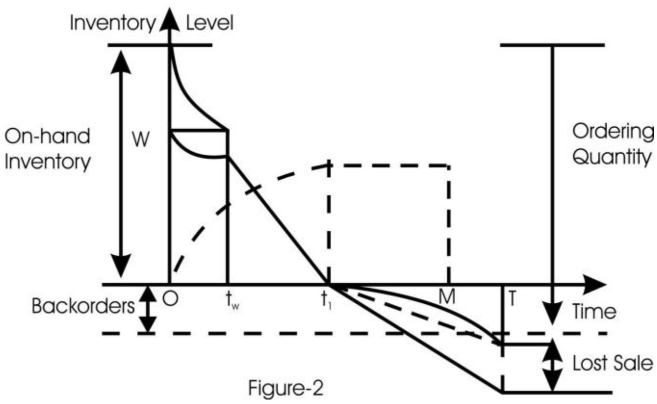

Figure-2

Case 1: M ≤ t₁: In this the total average cost per unit time

$$C_M^1(t_1,T)=\frac{OC+HC+SC+OC+DC+IP-IE_1}{T}$$

$$=\frac{1}{T}\left\{A+\frac{HD}{\alpha^2}\left(e^{\alpha t_1}-\alpha t_1-1\right)\right.$$

$$+\frac{C_2D}{\delta^2}\left[\delta t_2-\ln(1+\delta t_2)\right]+\frac{\pi D}{\delta}\left[\delta t_2-\ln(1+\delta t_2)\right]$$

$$+C\frac{D}{\alpha}\left[\left(e^{\alpha t_1}-1\right)-\alpha t_1\right]$$

$$\left.+\frac{DCI_r}{2}(t_1-M)^2-DCI_e\frac{t_1^2}{2}\right\} \quad ...(18)$$

Case 2: M > t₁: In this the total average cost per unit time

$$C_M^2(t_1,T)=\frac{1}{T}\left[OC+HC+SC+OC+DC-IE_2\right]$$

$$=\frac{1}{T}\left\{A+\frac{HD}{\alpha^2}\left(e^{\alpha t_1}-\alpha t_1-1\right)+\frac{C_2D}{\delta^2}\right.\backslash$$

$$\left[\delta(T-t_1)-\ln(1+\delta(T-t_1)\right]+\frac{\pi D}{\delta}\left[\delta(T-t_1)-\ln(1+\delta(T-t_1))\right]$$

$$+C\left[\frac{D}{\beta}\left(e^{\alpha t_1}-1\right)-\alpha t_1\right]-CI_eDt_1\left(M-\frac{t_1}{2}\right)\Bigg\} \quad ...(19)$$

These results are same as those obtain by **Chung-Yuan Dye (2002).**

3.2. Particular Case B

Now we consider the deterioration rate is zero and shortages are allowed and completely backlogged. **Case 1: M ≤ t₁** : In this the total average cost per unit time

$$C_M^1(t_1,T)=\frac{OC+HC+SC+IP-IE_1}{T}$$

$$=\frac{1}{T}\left\{A+\frac{DHt_1^2}{2}+\frac{DC_2}{2}\left(T-t_1^2\right)+\frac{DCI_r}{2}(t_1-M)^2\right.$$

$$\left.-DCI_e\frac{t_1^2}{2}\right\} \quad ...(20)$$

Case 2: M > t₁: In this the total average cost per unit time

$$C_M^2(t_1,T)=\frac{1}{T}\left[OC+HC+SC-IE_2\right]$$

$$=\frac{1}{T}\left\{A+\frac{HD}{2}t_1^2+\frac{DC_2}{2}(T-t_1)^2-DCI_rt_1(M-\frac{t_1}{2})\right.$$

...(21)

These results are same as those obtain by **M. Pal** and **S. K. Ghosh (Online).**

4. CONCLUSION

In this paper, a list model is developed for deteriorating things with two-warehouses, allowing shortage and time-proportional backlogging rate below the conditions of permissible delay in payments. Holding prices and deterioration prices area unit totally {different/ completely different} in OW and RW because of different preservation environments. The inventory prices (including holding price and deterioration cost) in RW area unit assumed to be above those in OW. to cut back the inventory prices, it'll be economical for corporations to product in OW before RW, however clear the stocks in RW before OW. Particularly, the backlogging rate thought-about to be a decreasing operation of the waiting time for ensuing filling is a lot of realistic. In follow, we will observe sporadically the proportion of demand, which might settle for backlogging, and therefore the corresponding waiting time for ensuing filling. we have a tendency to additionally notice that the optimum average inventory price.

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