Different Deterioration Rates Two Storage Facilities Deteriorating Items Inventory Model under Time and Price Dependent Demand for Single Buyer Single Vendor

R.D. Patel, Jiten Patel

Abstract— An optimal policy for vendor and buyer is developed for items having deterioration and demand is linear function of time and price. One vendor and one buyer system model is constructed as profit maximization to determine the system's optimal cycle time (strategy) under two storage facilities for buyer. We also determine the profit of buyer-vendor jointly. Numerical illustrations show that both buyer and vendor earn significant profit in supply chain inventory system. For parameters, post-optimality analysis is also done.

Index Terms— Two storage facility, Supply chain, Optimal strategy, Different Deterioration, Time dependent demand, price dependent demand, Time varying holding cost .

1 INTRODUCTION

RETAILERS purchase more units than their capacity of Own Warehouse (OW) for getting advantage of price discounts. Additional better storage facility with higher inventory storage cost known as Rented Warehouse (RW) is made for storing excess goods. A two facility location inventory model was first developed by Hartley [1976]. Two facilities location deteriorating items inventory model was obtained by Sarma (1987). A two facilities location deteriorating items inventory model was considered by Benkherouf (1997). Ghosh and Chakrabarty (2007) gave two storage facilities deteriorating items inventory model. Two warehouses inventory model under exponentially decreasing demand was developed by Shah and Munshi (2010). A selling price and advertisement dependent model for two storage location was given by Bhunia et al. (2011). A time dependent demand and variable holding cost inventory model was proposed by Tyagi and Singh (2013). Sheikh and Patel [2017] obtained two facilities location inventory model under varying deterioration. To fulfill customers' (buyers') demand, many stages either directly or indirectly involves in supply chain. It includes suppliers, manufacturers, transporters, warehouses, retailers, customers, etc. To satisfy demand of customers' is the main issue in today's situation. For supply chain, there must be need of significant information sharing between buyer and vendor. Better collaboration between buyer and vendor also reduces total cost of supply chain. In past researchers have developed joint buyer vendor inventory system with different assumptions on demand pattern such as price-dependent, time dependent demand, etc. A combined inventory model when vendor has finite production rate for one buyer one vendor has been derived by Banerjee (1986). By considering items having deterioration characteristics, an inventory model for one item under one vendor, many buyers has been established by Yang and Wee (2001). For reducing the setup cost among allied trading parties, a joint inventory model for one vendor and many buyers via application of information technologies which provides degree of coordination and automation is considered by Woo et al. (2001). An analytical model for one vendor and many buyers for studying interesting industrial case of single vendor and multiple buyers, was considered by Zavanella and Zanoni (2009). A supply chain inventory model for deteriorating items under trade credit policy was established by Lio and Chung (2009). In a supply chain model, collaboration reasons with other members for one-vendor many-buyers joint inventory system was pointed out by Ben-Daya et al. (2010). A one vendor and many buyers quadratic demand inventory model was considered by Shah et al. (2011). A quality improvement in investment for a vendor-buyers supply chain inventory system have been considered by Yang et al. (2013). Ghiami and Williams (2015) delivered a deteriorating item models with multiple buyers and single manufacturer in a supply chain production inventory system with finite production rate. For use of activity based costing approach in supply chain management and cost managing for ordering inventory was given by Momeni and Azizi (2018). Under time and price dependent demand for one vendor one buyer combined two warehouses inventory model for varying deterioration for buyer and changing storage cost for buyer and vendor both is considered in the paper. Under the assumption that vendor has better preservation technology, so preservation technology cost is included for vendor and therefore there is no deterioration cost for vendor.

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2 Notations and assumptions

2.1 Notations:

Here notations considered for developing model are:

$D(t)$: $a + bt - \rho p$, where $a > 0$, $0 < b < 1$, $p > 0$, $\rho > 0$

HC(OW) : OW has time varying holding cost ($x_1 + y_1 t$, $x_1 > 0$, $0 < y_1 < 1$)

HC(RW): RW has time varying holding cost ($x_2+y_2 t$, $x_2>0$, $0<y_2<1$)

$I_{0b}(t)$: OW stock size of buyer

$I_{rb}(t)$: RW stock size of buyer

$I_v(t)$: Vendor's inventory size at time t

A_b : Buyer's per order ordering cost

A_v : Vendor's per order ordering cost

c_b : Per unit cost of purchasing of buyer

θ : OW rate of deterioration during $t_1 < t < t_2$, $0< \theta < 1$

θt : OW rate of deterioration during $t_2 \le t \le T_b$, $0 < \theta < 1$

x_{b1} : Fixed holding cost in OW of buyer

y_{b1} : Buyer's varying holding cost in OW

x_{b2} : RW fixed holding cost of buyer

y_{b2} : Varying holding cost in RW of buyer

x_v : Fixed storage cost of vendor

y_v : Varying storage cost of vendor

p : Unit selling price of buyer (a decision variable)

m : Preservation technology cost for vendor (fixed)

n : Number of time orders placed by buyer during cycle time

t_r : When level of inventory of buyer in RW becomes nil (a decision variable)

W : Capacity of own warehouse of buyer

Assumpltions

The following assumptions are considered for the development of model.

- Demand of item is function of price and time.
- One vendor one buyer are considered.
- Stock out is not permitted.
- Lead time is zero.
- During the cycle time, no repairing or replacement of deteriorated units and deterioration is dependent on time for buyer's inventory.
- For buyer and vendor both, time varying holding cost is considered.
- W units fixed capacity in OW and unlimited capacity in RW are considered.
- First RW goods are consumed and then goods in OW are consumed.
- Unit inventory cost in OW is less than unit inventory cost in RW.

3 THE MODELING AND ANALYSIS

Figure below shows inventory level $I_b(t)$ of buyer at time t ($0 \le t \le T_b$).

Buyer's Inventory

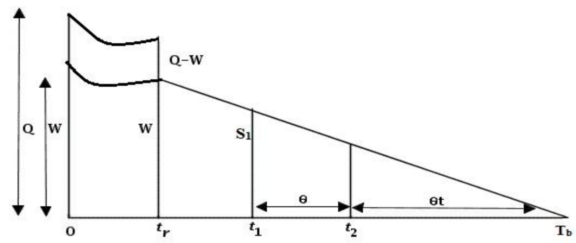

Figure 1

Differential equations in RW and OW of inventory level at time t are expressed as:

$$\frac{dI_{rb}(t)}{dt} = -(a + bt - \rho p), \quad 0 \le t \le t_r \qquad (1)$$

$$\frac{dI_{0b}(t)}{dt} = 0, \quad 0 \le t \le t_r \qquad (2)$$

$$\frac{dI_{0b}(t)}{dt} = -(a + bt - \rho p), \quad t_r \le t \le t_1 \qquad (3)$$

$$\frac{dI_{0b}(t)}{dt} + \theta I_{0b}(t) = -(a + bt - \rho p), \quad t_1 \le t \le t_2 \qquad (4)$$

$$\frac{dI_{0b}(t)}{dt} + \rho t I_{0b}(t) = -(a+bt-\rho p), \quad t_2 \le t \le T_b \qquad (5)$$

$$\frac{dI_v(t)}{dt} = -(a + bt - \rho p), \quad 0 \le t \le T \qquad (6)$$

initial conditions taken are $I_{0b}(0) = W$, $I_{0b}(t_1) = S_1$, $I_{0b}(t_r) = W$, $I_r(0) = Q-W$, $I_{rb}(t_r) = 0$, $I_{0b}(T_b)=0$ and $I_v(T)=0$.

Their solutions are given by

$$I_{rb}(t) = (Q - W) - (at - \rho pt + \frac{1}{2}bt^2) \qquad (7)$$

$$I_{0b}(t) = W \qquad (8)$$

$$I_{0b}(t) = S_1 + a(t_1 - t) - \rho p(t_1 - t) + \frac{1}{2}b(t_1^2 - t^2) \qquad (9)$$

$$I_{0b}(t) = \begin{bmatrix} a(t_1 - t) - \rho p(t_1 - t) + \frac{1}{2}b(t_1^2 - t^2) \\ + \frac{1}{2}a\theta(t_1^2 - t^2) - \frac{1}{2}\rho p\theta(t_1^2 - t^2) + \frac{1}{3}b\theta(t_1^3 - t^3) \\ - a\theta t(t_1 - t) + \rho p\theta t(t_1 - t) - \frac{1}{2}b\theta t(t_1^2 - t^2) \end{bmatrix} \qquad (10)$$

$$+ S_1(1 + \theta(t_1 - t))$$

$$I_{0b}(t) = \begin{bmatrix} a(T_b - t) - \rho p(T_b - t) + \frac{1}{2}b(T_b^2 - t^2) \\ + \frac{1}{6}a\theta(T_b^3 - t^3) - \frac{1}{6}\rho p\theta(T_b^3 - t^3) + \frac{1}{8}b\theta(T_b^4 - t^4) \\ - \frac{1}{2}a\theta t^2(T_b - t) + \frac{1}{2}\rho p\theta t^2(T_b - t) - \frac{1}{4}b\theta t^2(T_b^2 - t^2) \end{bmatrix} \qquad (11)$$

$$I_v(t) = \left[a(T - t) - \rho p(T - t) + \frac{1}{2}b(T^2 - t^2)\right]. \qquad (12)$$

(higher powers of θ are not considered)

From equation (7), substituting $t = t_r$, we get

$$Q = \left[W + at_r - \rho pt_r + \frac{1}{2}bt_r^2\right] \qquad (13)$$

From equations (8) and (9), putting $t = t_r$, we get

$$I_{0b}(t_r) = W \qquad (14)$$

$$I_{0b}(t_r) = S_1 + a(t_1 - t_r) - \rho p(t_1 - t_r) + \frac{1}{2}b\left(t_1^2 - t_r^2\right) \quad (15)$$

So from equations (14) and (15), we have

$$S_1 = W - a(t_1 - t_r) + \rho p(t_1 - t_r) - \frac{1}{2}b\left(t_1^2 - t_r^2\right) \quad (16)$$

From equations (10) and (11), putting $t = t_2$, we get

$$I_{0b}(t_2) = \begin{bmatrix} a(t_1 - t_2) - \rho p(t_1 - t_2) + \frac{1}{2}a\theta\left(t_1^2 - t_2^2\right) \\ -\frac{1}{2}\rho p\theta\left(t_1^2 - t_2^2\right) + \frac{1}{2}b\left(t_1^2 - t_2^2\right) \\ +\frac{1}{3}b\theta\left(t_1^3 - t_2^3\right) - a\theta t_2(t_1 - t_2) \\ +\rho p\theta t_2(t_1 - t_2) - \frac{1}{2}b\theta t_2\left(t_1^2 - t_2^2\right) \end{bmatrix} + S_1\left[1 + \theta(t_1 - t_2)\right] \quad (17)$$

$$I_{0b}(t_2) = \begin{bmatrix} a(T_b - t_2) - \rho p(T_b - t_2) + \frac{1}{2}b\left(T_b^2 - t_2^2\right) \\ +\frac{1}{6}a\theta\left(T_b^3 - t_2^3\right) - \frac{1}{6}\rho p\theta\left(T_b^3 - t_2^3\right) \\ +\frac{1}{8}b\theta\left(T_b^4 - t_2^4\right) - \frac{1}{2}a\theta t_2^2(T_b - t_2) \\ +\frac{1}{2}\rho p\theta t_2^2(T_b - t_2) - \frac{1}{4}b\theta t_2^2\left(T_b^2 - t_2^2\right) \end{bmatrix}. \quad (18)$$

So from equations (17) and (18), we have

$$T_b = \frac{1}{b\left(\theta\mu_2^2 - 2\right)}\left(2a - a\theta\mu_2^2 + \sqrt{\begin{matrix} 4b\theta t_2^2 a t_1 - 8ab\theta t_r t_2 \\ + 8ab\theta t_r t_1 - 4b\theta^2 t_2^2 a t_r t_1 - 4b\theta t_2^2 a t_r \\ - 4b\theta^2 t_2^2 W t_1 + 4b\theta^2 t_2^2 a t_1^2 - 4b\theta^2 t_2^3 a t_1 \\ + 4b\theta^2 t_2^3 a t_r - 4a^2\theta t t_2^2 + a^2\theta^2 t_2^4 \\ - 8abt_1 + 8abt_r + 8abt_2 - 2b^2\theta t_2^4 \\ + 8ab\theta t_1 t_2 + 4b^2 t_2^2 + 4a^2 + 8bW \\ - 4b^2 t_r^2 + 8bW\theta t_1 - 8bW\theta t_2 - 8ab\theta t_1^2 \\ + 4b^2\theta t_2 t_1^2 - 4b^2\theta t_2 t_r^2 - 4bW\theta t_2^2 \\ + 2b^2\theta t_2^3 t_1^2 - 2b^2\theta t_2^2 t_r^2 \\ + 4bW\theta^2 t_2^3 - 2b^2\theta^2 t_2^3 t_1^2 \\ + 2b^2\theta^2 t_2^3 t_r^2 - 4ab\theta t_2^3 \end{matrix}} \right) \quad (19)$$

Equation (19) states that W and t_r expresses T_b and hence T_b is not a decision variable.

Total profit consists of:

Buyer's relevant costs:

(i) Ordering cost (OC_b) = n A_b (20)

$$\text{(ii) } HC_b(OW) = n\begin{bmatrix} \int_0^{t_r}(x_{1b} + y_{1b}t)I_{0b}(t)\,dt + \int_{t_r}^{t_1}(x_{1b} + y_{1b}t)I_{0b}(t)\,dt \\ + \int_{t_1}^{t_2}(x_{1b} + y_{1b}t)I_{0b}(t)\,dt + \int_{t_2}^{T_b}(x_{1b} + y_{1b}t)I_{0b}(t)\,dt \end{bmatrix} \quad (21)$$

$$\text{(iii) } HC_b(RW) = n\left[\int_0^{t_r}(x_{2b} + y_{2b}t)I_{rb}(t)\,dt\right] \quad (22)$$

$$\text{(iv) } DC_b = n\,c_b\left(\int_{t_1}^{t_2}\theta I_{0b}(t)\,dt + \int_{t_2}^{T_b}\theta t I_{0b}(t)\,dt\right) \quad (23)$$

(v) Sales Revenue:

$$SR_b = np\left(\int_0^{Tb}(a + bt - \rho p)\,dt\right)$$

$$= np\left(aT_b - \rho p T_b + \frac{1}{2}bT_b^2\right) \quad (24)$$

(by not considering higher powers of θ)

(vi) Total Profit

$$TP_b = \frac{1}{T}\left[SR_b - OC_b - HC_b(RW) - HC_b(OW) - DC_b\right] \quad (25)$$

Relevant costs of vendor:

(i) Cost of Ordering (OC_v) = A_v (26)

(ii) Cost of Holding:

$$HC_v = x_v\left[\int_0^{T} I_v(t)\,dt - n\left\{\int_0^{T_b} I_b(t)\,dt\right\}\right] + y_v\left[\int_0^{T} tI_v(t)\,dt - n\left\{\int_0^{T_b} tI_b(t)\,dt\right\}\right]$$

$$= x_v\left[\int_0^{T} I_v(t)\,dt - n\begin{Bmatrix} \int_0^{t_r} I_{rb}(t)\,dt + \int_0^{t_r} I_{0b}(t)\,dt \\ + \int_{t_r}^{t_1} I_{0b}(t)\,dt + \int_{t_1}^{t_2} I_{0b}(t)\,dt \\ + \int_{t_2}^{T_b} I_{0b}(t)\,dt \end{Bmatrix}\right]$$

$$+ y_v\left[\int_0^{T} tI_v(t)\,dt - n\begin{Bmatrix} \int_0^{t_r} tI_{rb}(t)\,dt + \int_0^{t_r} tI_{0b}(t)\,dt \\ + \int_{t_r}^{t_1} tI_{0b}(t)\,dt + \int_{t_1}^{t_2} tI_{0b}(t)\,dt \\ + \int_{t_2}^{T_b} tI_{0b}(t)\,dt \end{Bmatrix}\right] \quad (27)$$

(iii) Preservation Technology Cost (PTC_v) = m (28)

(iv) Sales Revenue:

$$SR_v = c_b\left(\int_0^{T}(a + bt - \rho p)\,dt\right) = c_b\left(aT - \rho p T + \frac{1}{2}bT^2\right) \quad (29)$$

(v) Total Profit:

$$TP_v = \frac{1}{T}\left[SR_v - OC_v - HC_v - PTC_v\right] \quad (30)$$

Situation I: Independent decision of buyer and vendor:

Here the buyer and vendor make decision independently. For given value of n, TP_b can be maximized by solving

$$\frac{\partial TP_b(t_r, p)}{\partial t_r} = 0, \quad \frac{\partial TP_b(t_r, p)}{\partial p} = 0, \qquad (31)$$

where $T_b = \frac{T}{n}$ and T_b is function of t_r,

provided it satisfies the second order condition

$$\begin{bmatrix} \frac{\partial^2 TP_b(t_r,p)}{\partial t^2} & \frac{\partial^2 TP_b(t_r,p)}{\partial p\,\partial T} \\ \frac{\partial^2 TP_b(t_r,p)}{\partial T\,\partial p} & \frac{\partial^2 TP_b(t_r,p)}{\partial p^2} \end{bmatrix} > 0 \qquad (32)$$

This solution (n, T) maximizes TP_v.

Then the total profit without collaboration is given by:

$TP = \max(TP_b + TP_v)$.

Situation-II: Joint decision of vendor and buyer:

Here buyer and vendor jointly make decision:

For maximum total profit (TP) when buyer and vendor take joint decision, it must fulfil the condition

$$\frac{\partial TP(t_r, p)}{\partial t_r} = 0, \quad \frac{\partial TP(t_r, p)}{\partial p} = 0, \qquad (33)$$

for ($T_b = \frac{T}{n}$) is a function of t_r,

provided it satisfies the second order condition

$$\begin{bmatrix} \frac{\partial^2 TP(t_r,p)}{\partial t^2} & \frac{\partial^2 TP(t_r,p)}{\partial p\,\partial T} \\ \frac{\partial^2 TP(t_r,p)}{\partial T\,\partial p} & \frac{\partial^2 TP(t_r,p)}{\partial p^2} \end{bmatrix} > 0 \qquad (34)$$

where total profit (TP) with collaboration is given by:

$TP = TP_b + TP_v$ (35)

4 NUMERICAL EXAMPLE

Various parameter values in appropriate units are taken for numerical illustration, A_b= 150, W = 135, a = 1200, b=0.05, c_b= 40, θ=0.05, x_{b1} = Rs. 4, y_{b1}=0.04, x_{b2} = Rs. 6, y_{b2}=0.08, A_v = 2000, x_v = 3, y_v=0.03, m = 5, v_1=0.30, v_2 = 0.50. Table provides the independent and joint optimal values of t_r, T and profits for buyer and vendor.

Table-1 The optimal solution for without collaboration and with collaboration

	Independent Decision	Joint Decision
n	5	4
t_r	0.0746	0.1582
P	75.4108	56.2746
T	1.4997	1.3484
Buyer's Profit	44076.6760	41111.8702
Vendor's Profit	21453.2693	27363.0836
Total Profit	65529.9453	68474.9539

5 POST-OPTIMALITY ANALYSIS

Study of one parameter at a time, post-optimality results of above illustration is done here.

Table 2 Post-optimality Analysis Independent Decision

Para-meter	%	n	TP
a	+20%	5	89809.4008
	+10%	5	77216.3050
	-10%	5	54751.1516
	-20%	5	44881.0876
A_b	+20%	5	65431.8318
	+10%	5	65530.8082
	-10%	5	65575.6696
	-20%	5	65617.7097
x_{b1}	+20%	5	65448.6846
	+10%	5	65489.6419
	-10%	5	65569.7283
	-20%	5	65608.9841
x_{b2}	+20%	5	65509.7058
	+10%	5	65519.5922
	-10%	5	65540.8691
	-20%	5	65552.2187
θ	+20%	5	65515.8671
	+10%	5	65522.8671
	-10%	5	65537.0286
	-20%	5	65543.9867
ρ	+20%	5	58005.1922
	+10%	5	61426.6462
	-10%	5	70542.3849
	-20%	5	80376.9508
A_v	+20%	5	65263.2225
	+10%	5	65396.5839
	-10%	5	65663.3067
	-20%	4	65799.7329
x_v	+20%	5	65315.3000
	+10%	5	65422.6226
	-10%	5	65637.2680
	-20%	5	65744.5906

Table 3 Post-optimality Analysis Joint Decision

Para-meter	%	n	Profit(bv)
a	+20%	4	92780.3091
	+10%	4	80174.9787
	-10%	4	57680.8692
	-20%	4	57680.8692
A_b	+20%	4	68386.9340
	+10%	4	68430.7060
	-10%	4	68519.6936
	-20%	4	68564.9418
x_{b1}	+20%	4	68395.8960
	+10%	4	68435.3995
	-10%	4	68514.5587
	-20%	4	68554.2132
x_{b2}	+20%	4	68442.9712
	+10%	4	68458.6134
	-10%	4	68492.0446
	-20%	3	68520.0668
θ	+20%	4	68459.6716
	+10%	4	68467.3045
	-10%	4	68482.6199
	-20%	4	68490.3026
P	+20%	4	61536.6320
	+10%	4	64664.6986
	-10%	4	73194.6842
	-20%	4	79164.8142
A_v	+20%	4	68188.5325
	+10%	4	68329.2854
	-10%	4	68626.0949
	-20%	3	68788.1198
x_v	+20%	3	68271.8522
	+10%	4	68362.8636
	-10%	4	68590.2464
	-20%	4	68709.0261

From Table 2 and 3 computations we observe about variations of optimal cycle time T* and maximum total profits for independent as well as joint decisions. For independent as well as jointly, there will be increase or decrease in value of parameter 'a' when parameter 'a' increase/ decrease, however, when A_b, x_b, x_v, A_v, and θ increase/decrease then total profit decrease/increase in independent and joint decision case.

6 CONCLUSION

The result shows that the optimal cycle time is significantly decreased and total profit significantly increased when buyers and vendor take joint decision as compared to independent decision taken by buyers and vendor. We can also observe that the vendor's profit is increased and number of times order placed by buyer during cycle time is decreased when buyers and vendor take joint decision.

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