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Two Storage Facilities Single Vendor Single Buyer Supply Chain Different Deterioration Rates Inventory Model under Linear Demand

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ABSTRACT: For a single vendor and single buyer, items having deterioration nature is considered when demand is linear function of time. An inventory system for single vendor-buyer is developed as profit maximization to determine the system's optimal cycle time (strategy) under two storage faculties for vendor and 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.

Keywords: Two storage facilities, Supply chain, Optimal strategy, Different Deterioration, Linear demand, Time varying holding cost

I. INTRODUCTION

Many time retailers decide to buy goods exceeding their Own Warehouse (OW) capacity for getting price discounts. Therefore an additional stock is arranged as Rented Warehouse (RW) which has better storage facilities with higher inventory holding cost. Hartley [4] considered an inventory model under two facilities location. Sarma [13] proposed inventory model with replenishment rate finite under two facility locations. Pakkala and Achary [9] developed two warehouse finite replenishment rate inventory model. Two warehouses inventory model under time dependent demand was developed by Lee and Hsu [6]. Yu [22] gave two warehouses deteriorating items inventory model with decreasing rental over time. Tyagi [18] considered two warehouses inventory model under time dependent demand and variable holding cost. For imperfect quality items, a two warehouses inventory model was developed by Jaggi *et al*. [5]. Raikwar, et al. [11] considered an EOQ inventory model under shortages when deterioration rate follows generalized Weibull distribution and demand is ramp type function of time. A two warehouses inventory model under time dependent demand and variable holding cost was constructed by Sheikh and Patel [15]. Ravithammal *et al*. [12] considered an optimal replenishment policy for two warehouse deteriorating items inventory model to minimize total inventory cost. Patel [10] considered a time and price dependent inventory model when inflation and delay in payment is allowed for two facilities location inventory problem. A two warehouse production inventory model for deteriorating items under linear demand was developed by Sheikh and Patel [16].

Many stages are involved directly or indirectly to fulfill customers' (buyers') demand in a supply chain. It includes suppliers, manufacturers, transporters, warehouses, retailers, customers, etc. In today's situation fulfilling demand of customers is the main issue. 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 finite production rate for vendor, a combined lot size model for one buyer one vendor has been derived by Banerjee [1]. By considering items having deterioration characteristics, an inventory model for one item under one vendor, many buyers has been established by Yang and Wee [20]. Woo et al. [19] proposed a joint supply chain inventory model for one vendor and many buyers via application of information technologies which provides degree of coordination and automation and reduces the setup cost among allied trading parties. Zavanella and Zanoni [23] developed an analytical model for studying industrial case among many buyers and single vendor. Under trade credit policy, Lio and Chung [7] proposed a supply chain deteriorating items inventory model. 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.* [2]. When shortages are permitted for buyers, one vendor and many buyers' production inventory model was considered by Singh and Chandramouli [17]. A quality improvement in investment for a vendor-buyers supply chain inventory system have been considered by Yang et al. [21]. Ghiami and Williams [3] delivered a deteriorating item models with multiple buyers and single manufacturer with finite production rate in a supply chain. For use of activity based costing approach in supply chain management and cost managing for ordering inventory was given by Momeni and Azizi [8]. Sharmila and Uthayakumar [14] developed supply chain inventory model under power demand and trade credit for two facility location problems.

A one vendor one buyer combined two warehouses inventory model for varying deterioration for buyer and changing holding cost for vendor and buyer both under time dependent demand is considered within 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.

II. NOTATIONS AND ASSUMPTIONS

The first objective of this section is to list all the used notations in the subsequent sections for easy reference.

$D(t)$: $a + b\,t$, is demand, where $a > 0$, $0 < b < 1$
$I_{0b}(t)$: At time t buyer's inventory size in OW
$I_{rb}(t)$: At time t buyer's inventory size in RW
$I_v(t)$: At time t vendor's inventory size
A_b: Per order buyer's ordering cost
A_v: Per order vendor's ordering cost
c_b: Unit cost of purchasing of buyer
θ: Deterioration rate in OW during $t_1<t<t_2$, $0<\theta<1$
θt: Deterioration rate in OW during $t_2 \le t \le T_b$, $0<\theta<1$
x_{b1}: Fixed holding cost in OW of buyer
y_{b1}: Varying holding cost in OW of buyer
x_{b2}: Fixed holding cost in RW of buyer
y_{b2}: Varying holding cost in RW of buyer
x_v: Vendor's fixed holding cost
y_v: Vendor's varying holding cost
p: Selling price of buyer per unit
m: Preservation technology cost for vendor (fixed)
n: Number of time orders placed by buyer during cycle time
t_r: Inventory level of buyer becomes zero in RW (a decision variable)
W: Capacity of own warehouse of buyer

Further we present the assumptions related to the work.

- Demand is decreasing function of time.
- One vendor one buyer is considered.
- Stock out is not permitted.
- Lead time is zero.
- During the cycle time, no repairing or replacement of deteriorated items and deterioration is dependent on time for buyer's inventory.
- For buyer and vendor both time varying holding cost is considered.
- Unlimited capacity in RW and finite capacity W in OW.
- RW goods are consumed first and then OW goods are consumed.
- RW has higher holding cost per unit of inventory than OW holding cost per unit of inventory.

III. MODELING AND ANALYSIS

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

Fig. 1 represents the buyer's inventory situation for one cycle. At time t=0, Q units enters into the system of which W are stored in OW and rest (Q-W) are stored in RW. At time t_r level of inventory in RW reaches to zero because of demand and OW inventory remains W. During the interval (t_r,t_1) inventory depletes in OW due to demand, during interval (t_1, t_2) inventory depletes in OW due to deterioration at rate θ and demand. During interval (t_2, T_b) inventory in OW depletes due to joint effect of deterioration at rate θt and demand.

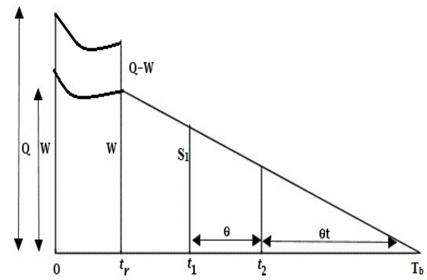

Fig. 1. Buyer's Inventory.

By time T_b both the warehouses are empty.
Considering linear demand, inventory size is given for buyer and vendor. Change in inventory sizes are given by following differential equations for vendor and buyer:

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

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

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

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

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

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

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

$$I_{rb}(t) = (Q-W) - \left(at + \frac{1}{2}bt^2\right) \quad (7)$$

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

$$I_{0b}(t) = S_1 + a(t_1 - t) + \frac{1}{2}b\left(t_1^2 - t^2\right) \quad (9)$$

$$I_{0b}(t) = \begin{bmatrix} a(t_1-t) + \frac{1}{2}b\left(t_1^2-t^2\right) + \frac{1}{2}a\theta\left(t_1^2-t^2\right) \\ + \frac{1}{3}b\theta\left(t_1^3-t^3\right) - a\theta t(t_1-t) - \frac{1}{2}b\theta t\left(t_1^2-t^2\right) \end{bmatrix} + S_1(1+\theta(t_1-t)) \quad (10)$$

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

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

(by not considering higher powers of θ)

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

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

Using equations (8) and (9) for $t = t_r$, we get

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

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

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

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

Using equations (10) and (11) for t = t_2, we get

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

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

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

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

Above equation (19), shows that T_b is expressed in terms of W and t_r, hence T_b is not a decision variable. Various cost components are:

Buyer's relevant costs:

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

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

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

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

(v) Sales Revenue:

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

$$= np\left(aT_b + \frac{1}{2}bT_b^2\right) \tag{24}$$

(by not considering higher powers of θ)

(vi) Total Profit of Buyer

$$TP_b = \frac{1}{T}\begin{bmatrix} SR_b - OC_b - HC_b(RW) \\ - HC_b(OW) - DC_b \end{bmatrix} \tag{25}$$

Relevant costs of vendor:

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

(ii) Cost of Holding:

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

$$= x_v\left[\int_0^T I_v(t)\,dt - n\left\{\begin{aligned} &\int_0^{t_r} I_{rb}(t)\,dt + \int_0^{t_r} I_{0b}(t)\,dt \\ &+ \int_{t_r}^{t_1} I_{0b}(t)\,dt + \int_{t_1}^{t_2} I_{0b}(t)\,dt \\ &+ \int_{t_2}^{T_b} I_{0b}(t)\,dt \end{aligned}\right\}\right]$$
$$+ y_v\left[\int_0^T tI_v(t)\,dt - n\left\{\begin{aligned} &\int_0^{t_r} tI_{rb}(t)\,dt + \int_0^{t_r} tI_{0b}(t)\,dt \\ &+ \int_{t_r}^{t_1} tI_{0b}(t)\,dt + \int_{t_1}^{t_2} tI_{0b}(t)\,dt \\ &+ \int_{t_2}^{T_b} tI_{0b}(t)\,dt \end{aligned}\right\}\right] \tag{27}$$

(iii) Preservation Technology Cost:

(PTC_v) = m (28)

(iv) Sales Revenue:

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

(v) Total Profit of Vendor:

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

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

$\frac{dTP_b}{dt_r} = 0$, where $T_b = \frac{T}{n}$ and T_b is function of t_r,

provided it satisfies the second order condition

$\frac{d^2TP_b}{dt_r^2} < 0.$

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

$\frac{dTP}{dt_r} = 0$ where $T_b = \frac{T}{n}$ ad T_b is a function of t_r, provided it satisfies the second order condition

$$\frac{d^2TP}{dt_r^2} < 0,$$

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

$$TP = TP_b + TP_v.$$

IV. NUMERICAL EXAMPLE

Various parameter values in appropriate units are taken for numerical illustration, $A_b = 150$, $W = 135$, $a = 1200$, $b = 0.05$, $c_b = 40$, $p = 75$, $\theta = 0.05$, $x_{b1} =$ 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	3
t_r	0.0914	0.2179
T	1.0175	0.9879
Buyer's Profit	88657.3102	88461.3147
Vendor's Profit	44559.2330	44780.3232
Total Profit	133216.5433	133241.6379

V. 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	160345.1504
	+10%	5	146775.5847
	-10%	5	119669.5049
	-20%	5	106136.4270
A_b	+20%	5	133104.0997
	+10%	5	133162.3171
	-10%	5	133264.8877
	-20%	6	133334.1008
x_{b1}	+20%	5	133129.0673
	+10%	5	133172.7734
	-10%	5	133259.8801
	-20%	5	133303.0478
x_{b2}	+20%	5	133156.8562
	+10%	5	133186.5647
	-10%	5	133246.6628
	-20%	5	133275.9277
θ	+20%	5	133198.0657
	+10%	5	133207.4594
	-10%	5	133225.5786
	-20%	5	133234.7909
A_v	+20%	6	132848.5369
	+10%	5	133091.9687
	-10%	5	133413.1178
	-20%	5	133609.6924
x_v	+20%	5	132923.6497
	+10%	5	133070.0965
	-10%	5	133362.9900
	-20%	5	133362.9900

Table 3: Post-optimality Analysis Joint Decision.

Para-meter	%	n	TP
a	+20%	4	160406.2115
	+10%	4	146833.5524
	-10%	4	119720.8917
	-20%	4	106184.4498
A_b	+20%	4	133159.4057
	+10%	4	133215.0273
	-10%	4	133328.1203
	-20%	4	133385.6343
x_{b1}	+20%	4	133186.2895
	+10%	4	133228.7615
	-10%	4	133313.7806
	-20%	4	133356.3272
xb_2	+20%	4	133209.6802
	+10%	4	133239.8913
	-10%	4	133303.8610
	-20%	4	133337.7861
θ	+20%	4	133252.8282
	+10%	4	133262.0342
	-10%	4	133280.5016
	-20%	4	133289.7633
A_v	+20%	4	132907.3509
	+10%	4	133086.1583
	-10%	4	133463.3745
	-20%	3	133663.9379
x_v	+20%	3	133010.1034
	+10%	4	133130.0775
	-10%	4	133416.4765
	-20%	4	133566.0946

Based on the results of Table 2 and 3 we can observe about the optimal length of order cycle 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 profit '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.

VI. 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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