

Joint Optimal Policy for Variable Deteriorating Inventory System of Vendor-Buyer Ordering With Trapezoidal Demand

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ABSTRACT

A joint optimal policy for the vendor and the buyer is analyzed when units in inventory are subject to deterioration and demand is trapezoidal. It is shown numerically that the joint venture reduces the total joint cost significantly when compared with the independent decision of both the players. To entice the buyer to place orders of larger size, a permissible credit period is offered by the vendor to the buyer. A negotiation factor is incorporated to share the benefits of cost savings.

Keywords: Vendor-Buyer Joint Decision, Deterioration, Credit Period, Trapezoidal Demand

1. INTRODUCTION

Silver and Meal [1], Silver [2], Xu and Wang [3], Chung and Ting [4,5], Bose et al. [6], Hariga [7], Giri and Chaudhari [8], Lin et al. [9] etc. discussed optimal ordering policy when demand is linearly changing with respect to time which is superficial in the market of fashion goods, air seats, smart phones etc. Mehta and Shah [10] assumed the demand to be exponential time varying which is again unrealistic for a newly launched product. Shah et al. [11] introduced the quadratic demand which is again not observed in the market for an indefinite period. In order to have an alternative demand pattern, the trapezoidal demand is considered. This type of demand increases for some time, then gets constant up to some time and afterwards decreases exponentially with time.

Most of the models available in the literature assumed that the buyer is the dominant player to make the decision for procurement. This strategy may not be economical for the vendor. An integrated vendor-buyer policy should be analyzed which is beneficial to the players in the supply chain. Clark and Scarf [12] and thereafter, Goyal [13] proposed a mathematical model for vendor-buyer integration. Banerjee [14] discussed an economic lot-size model when production is finite. Goyal [15] extended Banerjee's model by relaxing the assumption of the lot-for-lot production. Cárdenas-Barrón et al. [16] derived vendor-buyer integrated inventory system with arithmetic-geometric inequality. Teng et al. [17] derived vendor-buyer integrated system without derivatives.

Deterioration is defined as the decay, spoilage, evaporation and loss of utility of a product from the original one. Fruit and vegetables, cosmetics and medicines, electronic items, blood components, radioactive chemicals, agriculture products are some of the examples of

deteriorating commodities. For articles on deteriorating inventory one can refer to Raafat [18], Shah and Shah [19], Shah et al. [20] and Goyal and Giri [21]. Yang and Wee [22] derived a win – win strategy for an integrated system of vendor-buyer when units in inventory are subject to a constant rate of deterioration and deterministic constant demand. Shah et al. [23] extended above model by incorporating salvage value to the deteriorated units.

In this study, a joint vendor – buyer inventory system is analyzed when demand is trapezoidal and units in inventory are subject to deterioration. A negotiation factor is incorporated to share the savings. The credit period is offered to the buyer to attract the buyer for placing a larger order. A numerical example is illustrated to support the proposed model. Sensitivity analysis is carried out to visualize the changes in cost savings.

2. METHODOLOGY

2.1 Notations

The proposed study uses following notations.

A_b	Buyer's ordering cost per order
A_v	Vendor's ordering cost per order
C_b	Buyer's purchase cost per unit
C_v	Vendor's purchase cost per unit
I_b	Inventory carrying charge fraction per unit per annum for the buyer
I_v	Inventory carrying charge fraction per unit per annum for the vendor
θ_b	Deterioration of items in buyer's inventory system
θ_v	Deterioration of items in vendor's inventory system; $0 < \theta_b < \theta_v < 1$
$I_b(t)$	Buyer's inventory level at any instant of time t
$I_v(t)$	Vendor's inventory level at any instant of time t
n	Number of orders during cycle time for the buyer (a decision variable)
K_b	Buyer's total cost per unit time
K_v	Vendor's total cost per unit time
K_{NJ}	Total cost of vendor-buyer inventory System when they take independent decision
K_J	Total cost of vendor-buyer inventory System when they take joint decision
T	Vendor's cycle time (a decision variable)
T_b	($= T / n$) , Buyer's cycle time (a decision variable)
M	Credit period offered by the vendor to the buyer (a decision variable)
r	Continuous discounting rate

2.2 Assumptions

The proposed study uses following assumptions.

- A supply chain of a single vendor and single buyer is considered.
- An inventory system deals with a single item.

- The deterioration rates of items in the vendor's and buyer's inventory are different and proportional to on hand stock in inventory. There is no repair or replacement of deteriorated units during a cycle time.
- The demand rate is trapezoidal. Its functional form is

$$R(t) = \begin{cases} f(t) & ; 0 \leq t \leq u_1 \\ D_0 & ; u_1 \leq t \leq u_2 \\ g(t) & ; u_2 \leq t \leq T \end{cases}$$

where; $f(t)$ is linear in t , $D_0 = f(u_1) = g(u_2)$ and $g(t)$ is exponentially decreasing in t (say)

$$R(t) = \begin{cases} a(1 + b_1 t) & ; 0 \leq t \leq u_1 \\ a(1 + b_1 u_1) & ; u_1 \leq t \leq u_2 \\ a(1 + b_1 u_1)e^{-b_2(-u_2+t)} & ; u_2 \leq t \leq T \end{cases}$$

where; a denotes scale demand, $0 < b_1, b_2 < 1$ denotes rates of change of demand. (See Fig. 1)

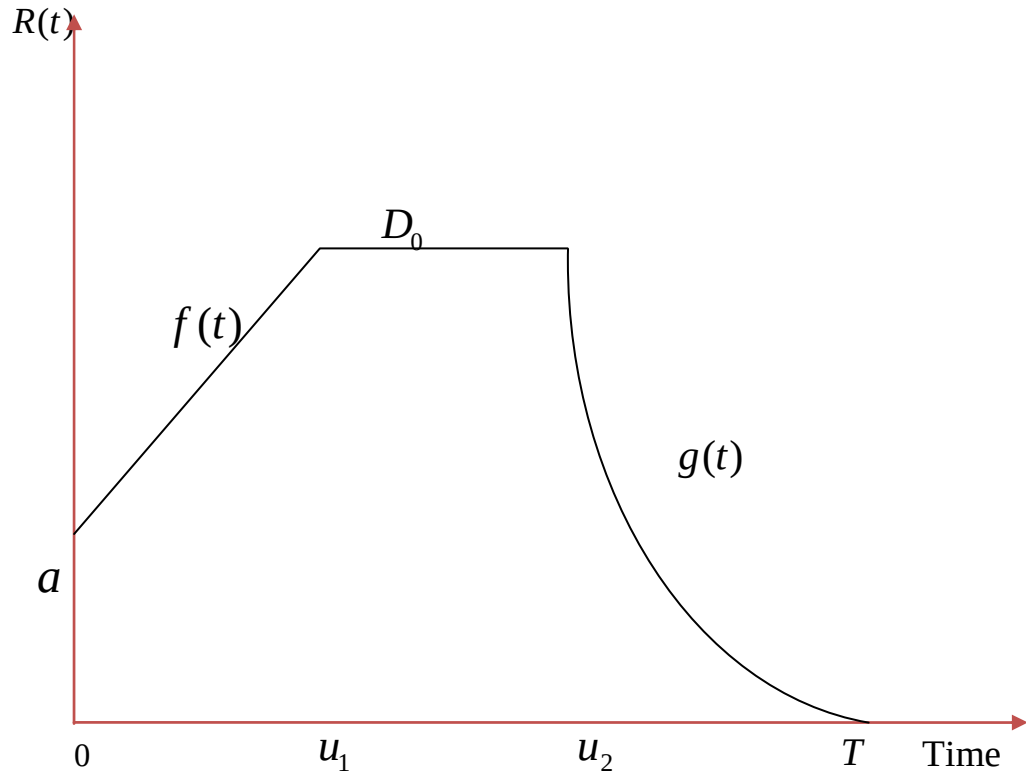


Fig. 1 Trapezoidal Demand

- The lead time is zero and shortages are not allowed.
- The credit period is offered for settling the accounts due against purchases to attract the buyer to opt a joint decision policy.

2.3 Mathematical Model

Fig. 2 depicts the time-varying inventory status for the vendor and the buyer.

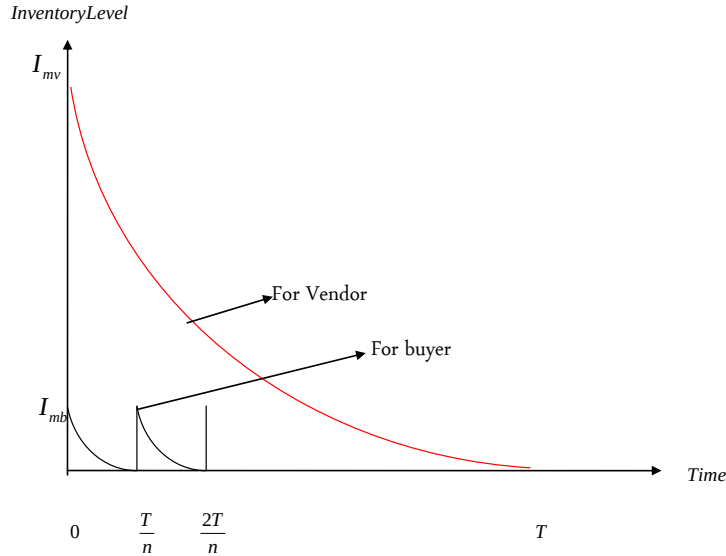


Fig. 2 Vendor –Buyer Inventory Status

The inventory changes due to trapezoidal demand for both vendor and buyer. The rate of change of inventory for both the players is governed by the differential equations:

$$\frac{dI_b(t)}{dt} + \theta_b I_b(t) = -R(t), 0 \leq t \leq T_b \quad (1)$$

$$\frac{dI_v(t)}{dt} + \theta_v I_v(t) = -R(t), 0 \leq t \leq T \quad (2)$$

with the boundary conditions $I_b(T_b) = 0$, $I_v(T) = 0$ and initial conditions $I_b(0) = I_{mb}$, $I_v(0) = I_{mv}$.

The solutions of the differential equations are

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$$I_b(t) = \begin{cases} \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_b - b_2} \right] \left[e^{-\frac{b_2T}{n} + \frac{\theta_b T}{n} - \theta_b t} - e^{-b_2t} \right] & ; 0 \leq t \leq u_1 \\ \frac{a(1+b_1u_1)}{\theta_b} \left[-1 + e^{\theta_b u_2 - \theta_b t} \right] + \\ \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_b - b_2} \right] \left[e^{-\frac{b_2T}{n} + \frac{\theta_b T}{n} - \theta_b t} - e^{-b_2u_2 + \theta_b u_2 - \theta_b t} \right] & ; u_1 \leq t \leq u_2 \\ a \left[-\frac{1+b_1t}{\theta_b} + \frac{b_1}{\theta_b^2} + \frac{1+b_1u_1}{\theta_b} e^{\theta_b u_1 - \theta_b t} - \frac{b_1}{\theta_b^2} e^{\theta_b u_1 - \theta_b t} \right] + \\ \frac{a(1+b_1u_1)}{\theta_b} \left[e^{\theta_b u_2 - \theta_b t} - e^{\theta_b u_1 - \theta_b t} \right] + \\ \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_b - b_2} \right] \left[e^{-\frac{b_2T}{n} + \frac{\theta_b T}{n} - \theta_b t} - e^{-b_2u_2 + \theta_b u_2 - \theta_b t} \right] & ; u_2 \leq t \leq T_b \end{cases} \quad (3)$$

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$$I_v(t) = \begin{cases} \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_v - b_2} \right] \left[e^{-b_2T + \theta_v T - \theta_v t} - e^{-b_2t} \right] & ; 0 \leq t \leq u_1 \\ \frac{a(1+b_1u_1)}{\theta_v} \left[-1 + e^{\theta_v u_2 - \theta_v t} \right] + \\ \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_v - b_2} \right] \left[e^{-b_2T + \theta_v T - \theta_v t} - e^{-b_2u_2 + \theta_v u_2 - \theta_v t} \right] & ; u_1 \leq t \leq u_2 \\ a \left[-\frac{1+b_1t}{\theta_v} + \frac{b_1}{\theta_v^2} + \frac{1+b_1u_1}{\theta_v} e^{\theta_v u_1 - \theta_v t} - \frac{b_1}{\theta_v^2} e^{\theta_v u_1 - \theta_v t} \right] + \\ \frac{a(1+b_1u_1)}{\theta_v} \left[e^{\theta_v u_2 - \theta_v t} - e^{\theta_v u_1 - \theta_v t} \right] + \\ \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_v - b_2} \right] \left[e^{-b_2T + \theta_v T - \theta_v t} - e^{-b_2u_2 + \theta_v u_2 - \theta_v t} \right] & ; u_2 \leq t \leq T \end{cases} \quad (4)$$

Using $I_b(0) = I_{mb}$, $I_v(0) = I_{mv}$, the maximum procurement quantities for the buyer and the vendor are

$$I_{mb} = \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_b - b_2} \right] \left[e^{\frac{b_2T + \theta_b T}{n}} - 1 \right]$$

$$I_{mv} = \left[\frac{a(1+b_1u_1)e^{b_2u_2}}{\theta_v - b_2} \right] \left[e^{-b_2T + \theta_v T} - 1 \right]$$

respectively.

During the cycle time $[0, T]$, for n -shipments, the buyer's

• Purchase Cost; $PC_b = nC_b I_{mb}$

• Holding Cost; $HC_b = nC_b I_b \int_0^{T_b} I_b(t) dt = nC_b I_b \left[\int_0^{u_1} I_b(t) dt + \int_{u_1}^{u_2} I_b(t) dt + \int_{u_2}^{T_b} I_b(t) dt \right]$

• Ordering Cost; $OC_b = nA_b$

Hence, the buyer's total cost; K_b per unit time is

$$K_b = \frac{1}{T} [PC_b + HC_b + OC_b] \quad (5)$$

The vendor's inventory is the difference between the vendor-buyer combined inventory and the buyer's inventory during n -orders. This is known as the joint two-echelon inventory model. The vendor's

• Purchase Cost; $PC_v = C_v I_{mv}$

• Holding Cost; $HC_v = C_v I_v \left[\int_0^T I_v(t) dt - n \int_0^{T_b} I_b(t) dt \right]$

• Ordering Cost; $OC_v = A_v$

Hence, the buyer's total cost; K_v per unit time is

$$K_v = \frac{1}{T} [PC_v + HC_v + OC_v] \quad (6)$$

The joint total cost K is the sum of K_b and K_v where $T_b = \frac{T}{n}$.

Thus, K is the function of discrete variable n and continuous variable T .

2.4 Computational Procedure

There are two cases to be analyzed.

Case 1: When the vendor and the buyer take decision independently.

For given value of n , differentiate K_b with respect to T_b (equivalently, T) and solve

$\frac{\partial K_b}{\partial T_b} = 0$. This n and T_b minimizes K_v provided

$$K_v(n-1) \geq K_v(n) \leq K_v(n+1) \quad (7)$$

satisfies.

Here, the total cost per unit time with independent decision; K_{NJ} is given by

$$K_{NJ} = \left[\min_n K_b + K_v \right] \quad (8)$$

Case 2: When vendor and buyer make decision jointly.

The optimum value of T and n must satisfy the following conditions simultaneously:

$$\frac{\partial K}{\partial T} = 0 \quad (\text{here; } K = K_J) \quad \text{and} \quad K(n-1) \geq K(n) \leq K(n+1) \quad (9)$$

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Thus, the total joint cost is

$$K_J = \min_{n,T} [K_b + K_v] \quad (10)$$

It is obvious that $K_J \leq K_{NJ}$. Hence, total cost savings Sav_J is defined

as $Sav_J = K_{NJ} - K_J$. Now define buyer's cost saving, Sav_b as $Sav_b = \alpha Sav_J$, where

$0 \leq \alpha \leq 1$ is the negotiation factor. When negotiation factor equals to 0.5, saving gets equally distributed between two players; when it is equal to zero, all saving is in the vendor's pocket and when it is equal to 1, it is in favor of the buyer.

The present value of the unit after a time interval M is ,where r is discounting rate. Solving the following equation

$$R(t)C_b(1 - e^{-rM}) = Sav_b \quad (11)$$

the buyer's credit period is given by

$$M = \frac{1}{r} \ln \left[\frac{C_b R(t)}{C_b R(t) - Sav_b} \right] \quad (12)$$

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3. RESULTS AND DISCUSSION

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3.1 Numerical Example

Consider following inventory parameters values in proper units:

$$[a \quad b_1 \quad b_2 \quad A_b \quad A_v \quad C_b \quad C_v \quad I_b \quad I_v \quad \theta_b \quad \theta_v \quad r] \\ = [40000 \quad 0.04 \quad 0.02 \quad 600 \quad 3000 \quad 10 \quad 6 \quad 0.11 \quad 0.10 \quad .05 \quad .08 \quad 0.06]$$

Let $\alpha = 0.5$.

The optimal solution is listed in Table 1 for independent and joint decisions.

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Table 1: Optimal Solution for Independent and Joint Decisions

	Case 1	Case 2
	Independent Decision	Joint Decision
n	3	2
T	0.146304333	0.1959635
T_b	0.438913	0.391927
K_b	409194	409546
K_v	254141	253457
$K(=K_{NJ} \text{ OR } K_J)$	$K_{NJ} = 663335$	$K_J = 663003$
$PJCR$	-	0.050075188
$M(\text{days})$		6.455621012

191 (where; $PJCR$ = Percentage change in Joint Cost Reduction)

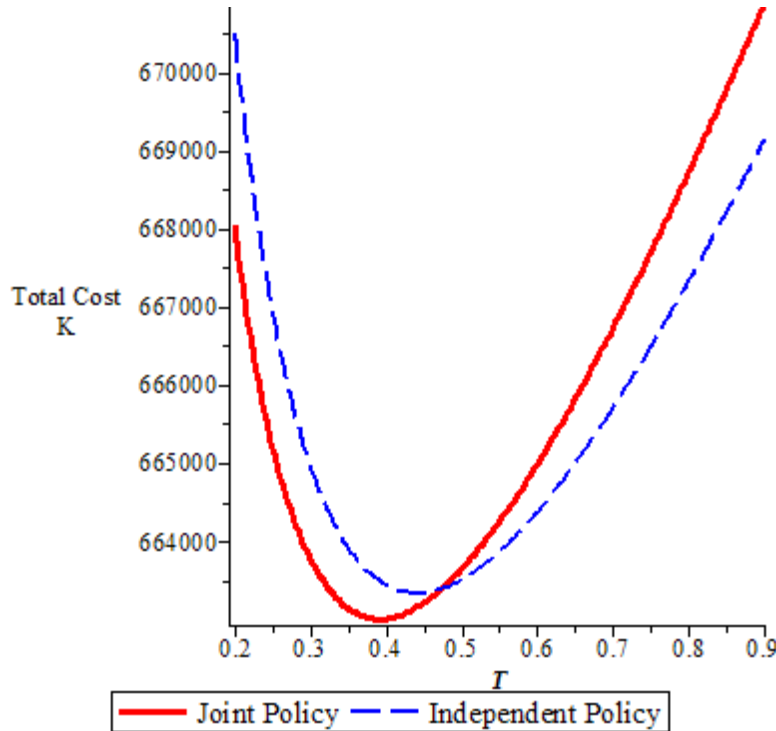
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193 The buyer's cost and cycle time increase in joint decisions. The vendor gains \$684 and the
 194 buyer loses \$352. This hinders the buyer to agree for joint decision. To entice the buyer to
 195 joint decision, the vendor offers the buyer a credit period of 6.45 days with equal sharing of
 196 cost savings. This reduces the joint total cost PJCR by 0.050075188 %, where PJCR is

197 defined as $\frac{K_{NJ} - K_J}{K_J} \times 100$.

198 The convexity of total integrated cost and independent costs are shown in Fig. 3.

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Fig. 3 Total Cost for Independent Vs Joint Vendor-Buyer Inventory System

3.2 Sensitivity Analysis

Table 2: Sensitivity Analysis of Demand Rate

a	24000	32000	40000	48000	56000
K_{NJ}	401803	532724	663335	793726	923950
K_j	401544	532426	663003	793363	923558
$PJCR$	0.064501026	0.055970219	0.050075188	0.045754592	0.042444546
$M(days)$	6.510393077	6.481558237	6.455621012	6.440704274	6.437320861

Observations

- Increase in fixed demand a , decreases percentage of cost reduction and delay period.

Table 3: Sensitivity Analysis of Linear Rate of Change of Demand

b_1	0.024	0.032	0.04	0.048	0.056
K_{NJ}	663060	663198	663335	663473	663611
K_j	662727	662864	663003	663141	663280
$PJCR$	0.050246934	0.05038741	0.050075188	0.050064768	0.04990351
$M(days)$	6.48253545	6.498269843	6.455621012	6.451908917	6.428358053

Observations

- Increase in linear rate of change of demand b_1 , does not reflect the monotonous change in PJCR and delay period.

Table 4: Sensitivity Analysis of Exponential Rate of Change of Demand

b_2	0.012	0.016	0.02	0.024	0.028
K_{NJ}	663653	663497	663335	663168	662996
K_j	663347	663178	663003	662822	662634
$PJCR$	0.046129703	0.048101716	0.050075188	0.052201043	0.05463046
$M(days)$	6.142206701	6.303860301	6.455621012	6.615915098	6.80271129

Observations

- Increase in exponential rate of change of demand b_2 , increases percentage of cost reduction and delay period.

Table 5: Sensitivity Analysis of Buyer's Ordering Cost

A_b	360	480	600	720	840
K_{NJ}	661960	662566	663335	664165	665014
K_j	661741	662382	663003	663607	664195
$PJCR$	0.033094519	0.027778533	0.050075188	0.084085912	0.123307161
$M(days)$	4.522686628	3.683132288	6.455621012	10.55763341	15.10091537

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Observations

- Increase in Buyer's Ordering cost A_b , does not reflect the monotonous change in percentage of cost reduction and delay period.

Table 6: Sensitivity Analysis of Vendor's Ordering Cost

A_v	1800	2400	3000	3600	4200
K_{NJ}	660601	661968	663335	664702	666069
K_J	659684	661413	663003	664482	665873
$PJCR$	0.139005948	0.083911263	0.050075188	0.033108497	0.029435042
$M(days)$	21.10788028	11.65741969	6.455621012	4.001834111	3.362265634

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Observations

- Increase in Vendor's Ordering Cost A_v , decreases the percentage of cost reduction and delay period.

Table 7: Sensitivity Analysis of Buyer's Purchase Cost

C_b	6	8	10	12	14
K_{NJ}	501511	582345	663335	744382	825445
K_J	500284	581677	663003	744273	825495
$PJCR$	0.245260692	0.11484037	0.050075188	0.014645164	-0.00605697
$M(days)$	35.56472559	15.3972342	6.455621012	1.853298522	-0.76152659

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Observations

- Increase in Buyer's purchase cost C_b , decreases the percentage of cost reduction and delay period significantly.

Table 8: Sensitivity Analysis of Vendor's Purchase Cost

C_v	3.6	4.8	6	7.2	8.4
K_{NJ}	564413	613874	663335	712797	762258
K_J	564569	613816	663003	712139	761231
$PJCR$	-0.0276317	0.009449086	0.050075188	0.092397692	0.134913055
$M(days)$	-2.72030458	1.07110368	6.455621012	13.40843984	21.85033584

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Observations

- Increase in Vendor's purchase cost C_v , increases the percentage of cost reduction and delay period significantly.

Table 9: Sensitivity Analysis of Inventory Carrying Charge Fraction of Buyer					
I_b	0.066	0.088	0.11	0.132	0.154
K_{NJ}	662148	662704	663335	664000	664679
K_j	661201	662122	663003	663850	664665
$PJCR$	0.143224224	0.087899209	0.050075188	0.022595466	0.002106324
$M(days)$	16.89189119	10.85880018	6.455621012	3.030101841	0.293038529

Observations

- Increase in buyer's inventory Carrying Charge Fraction I_b , decreases the percentage of cost reduction and delay period significantly.

Table 10: Sensitivity Analysis of Inventory Carrying Charge Fraction of Vendor					
I_v	0.06	0.08	0.1	0.12	0.14
K_{NJ}	661928	662632	663335	664039	664743
K_j	662038	662526	663003	663470	663927
$PJCR$	-0.01661536	0.015999372	0.050075188	0.085761225	0.122905078
$M(days)$	-2.04166732	2.01480826	6.455621012	11.30755438	16.56036679

Observations

- Increase in Vendor's Inventory Carrying Charge Fraction I_v , increases the percentage of cost reduction and delay period significantly.

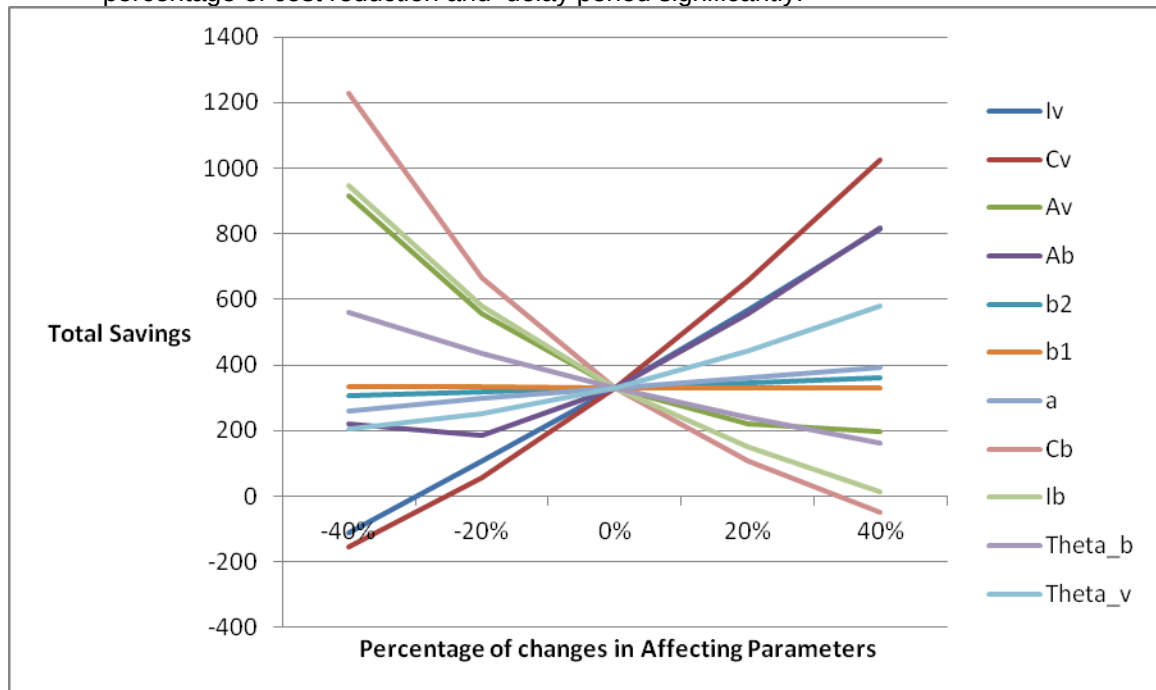


Fig. 4 Total Savings Vs. Percentage of Changes in Affecting Parameters

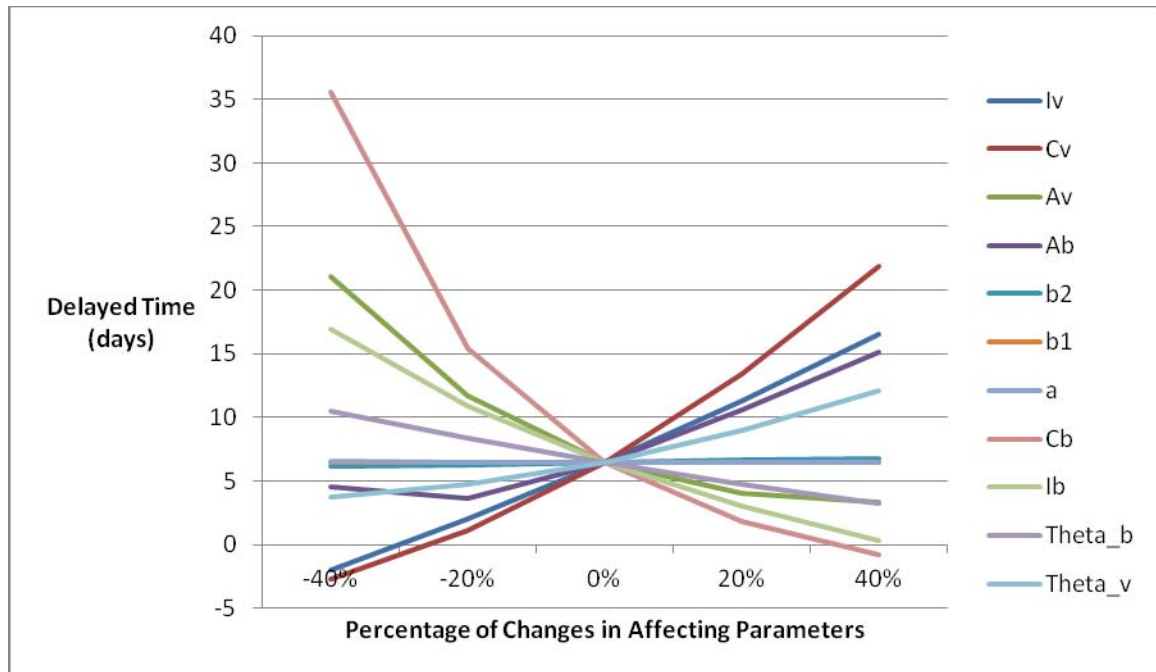


Fig. 5 Delayed Time in Days Vs. Percentage of Changes in Affecting Parameters

4. CONCLUSION

In this paper, a mathematical model is developed to analyze an optimal ordering policy for a supply chain comprising of vendor-buyer inventory system when demand is trapezoidal. The deterioration rate of units in vendor-buyer inventory system is considered to be different. It is established that the joint decision lowers the total cost of an inventory system, even though the buyer's cost increases significantly. To attract the buyer for a joint decision, a credit period is offered by the vendor to the buyer to settle the account. The problem can be studied for time-dependent deterioration. One can apply the DCF approach to visualize financial perspectives of the goals.

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