Optimal Payment Policy for Deteriorating Items with Hybrid Type Demand and Non-instantaneous Deterioration under Effect of Trade Credit

Jyoti Mishra, Dept, of Computer Application, Manipal University, Jaipur (Raj.), jyoti.slc15@gmail.com
Sushil Bhawaria, Dept. of mathematics & statistics, Manipal University Jaipur, sushilbhawaria01@gmail.com
Dr. Shailendra Shukla, Professor, Dept. of Mathematics, Arya PG College, Jaipur (Raj.), shailjpr41184@gmail.com

Abstract:

In this present article we have developed an optimal payment policy for deteriorating items. The nature of deterioration rate is non-instantaneous and preservation technology is used to control the deterioration. Demand rate depends on stock level and selling price as hybrid type function. Shortages are permitted and partially backlogged with constant rate. A trade credit policy is considered to establish an optimal payment policy. As global changes cannot be ignored hence effect of inflation is also considered to settle a perfect inventory control system. The calculation and sensitivity analysis is performed with the help of Mathematical software mathematica-7.0.

Keywords: Inventory, hybrid type demand, partially backlogging, deterioration, preservation technology

Introduction

In real life inventory system, deterioration is major issue. So we can't ignore the deterioration factor in the inventory system. we know that deterioration is natural process. Deterioration means spoilage, vaporize, decay, loss of utility etc. there are two types of the deterioration first one is instantaneous deterioration and second is non-instantaneous deterioration. So we worked on second type deterioration because our demand function is selling price and stock dependent. Many authors and researchers worked on generally single variable demand like time dependent, price dependent, stock dependent etc. so in this order many researchers worked out.

Agarwal et al. (2017) have elaborated a model for commodities like vegetables and medicines etc. In this paper, demand depends on the time and shortage is permitted. Sharma and Singh (2017) have studied developing replenishment for imperfect quality goods with increasing type demand function under the inflation effect. The whole study carried out under the effect of a fuzzy environment. Rastogi et al. (2018) have described the model for deteriorating items. In this research, demand depends on selling price under the inflation effect. And they allowed shortages.

Khurana et al. (2018) founded an economic production model for decaying products. In this article, they decreased (total average cost) TAC. They consider shortages and partially backlogged. Tripathi and Tomar (2018) have examined an economic order quantity (EOQ) model for decaying items. In this study, they consider quadratic demand function of time. Sekar and Uthayakumar (2018) have proposed the model to determine the two delivery policies and optimum production setups. They are not permitted shortages.

Singhal and Singh (2018) have discussed integrate seller-buyer decaying products with various market demands. In this article, they don't involve the shortage factor. Soni and Chaouhan (2018) have generalized a model for a joint price and an inventory for deteriorating products. And demand function depends on selling price. Yadev et al. (2018) have examined deterministic inventory model for decaying products. They permitted complete backlogged shortages and demand is increasing function of the time.

Dem et al. (2019) have determined inventory model for the manufacturing process. In this study, they sort out the optimal policy for fabric system which maximizes the entire benefits. And included demand function in two ways first one is demand is depends on stock for complete things and for incomplete items depends on decreasing rate of selling price. Shah and Monika (2019) have expressed model for defective products. In this research they have included demand function which depends on price and time. Sheikh et al. (2019) have introduced the model for deteriorating items. In this paper, they reduced the deterioration. And also include trade credit policy. Shen et al. (2019) have developed an inventory system under the carbon tax policy. In this study, they have included a single buyer-vendor policy and single commodity. This study, shortages are not permitted. Ullah et al. (2019) have described two-echelon supply chain model. This study optimized the preservation investment and load quantity of products. And demand is a constant function per unit time.

Yang (2019) has developed a two-warehouse model for defective products with limited storage capacity in chain supply. Shortages are not permitted and the decaying rate is constant under the impact of inflation. Das et al. (2020) analyzed inventory model applying partial credit and reliability effect. And demand function depends on the items price. Feng et al. (2020) have expressed model for the vendor's profit under the payment conditions like- case, advance, and credit. In this research, they included decision variables price, lot size, and payment term.

Hasan et al. (2020) have derived the model for an optimal price and replenishment decision for vegetables and fruits. Iqbal and Sarkar (2020) have suggested a model for lifetimes of production were raised significantly by using PT. in this research they reduced the rate of deterioration and assumed the demand increased with time. Khan et al. (2020) have presented the model for decaying items including prepayment and discount facilities. In this research, demand function based on stock level and price.

Kumar et al. (2020) have proposed a manufacturer model in which they annexed lead time is trivial or negligible. And the entire study carried out under the effect of inflation, PT, and trade-credit. Kumar and Promila (2020) have formulated a model unfinished manufacturing procedure. In this paper, produce and collection rated are depends on demand and the demand is an exponential function of time. Magfura et al. (2020) have established an EPQ model for decaying products. They applied PT and demand depends on price and stock under the effect of inflation.

Roy et al.(2020) have established a model for a supplier to determine an optimum ordering policy. In this research, they increased the entire benefit for retailers by decreasing total inventory cost. Roy (2020) has investigated two three stage supply chain model for various products. This study decreased setup cost, ordering cost and the total mode cost. And this paper compared between without transportation discount and with transportation discount. Utami (2020) have investigated a single seller-buyer policy for the decaying products under the effect of inflation and carbon emission and they are not assent shortages. We worked on hybrid type demand function including stock and price. Our whole study carried out under the effect of inflation and trade credit policy. Trade credit is (B2B) business to business contract in which a purchaser purchase items without paying the supplier at a letter proposed date. And we analyzed the effect of inflation and trade in the given tables. And graphically representation shows the optimality this model. Bhawaria and Rathore (2022) developed a production inventory model for deteriorating items involving preservation technology.

I. Assumptions and Notations

1. Demand rate is hybrid type as given below function: f(p, I(t)) = (D(p) + aI_i(t)), where a>0 and D (p) = $\tau(x_1 - yp) + (1-\tau)x_2p^{-\gamma}$
   Where; $0 \leq t \leq 1, x_1 > 0, x_2 > 0, y > 0, \frac{x_1}{y} \geq p \; and \; y > 1$ and in fractional form
   $D(p) = \frac{1}{1+\delta(T-t)}$ and $\tau_\Theta = (\Theta - \mathrm{m}(\xi))$
2. The shortages are partially backlogged.
3. The backlogging rate is as follows-
4. The deterioration rate is constant.
5. There is no replacement of the deteriorated items.
6. The inflation rate r is difference between inflation and time discounting.
7. The horizon time is infinite.
8. The replenishment is infinit

Notations

A : The ordering cost
C_{DC1}: The Deterioration cost
C_{HC2}: The holding cost per unit time
C_{BC3}: The backordering cost
C_{LSC4}: The lost sale cost
C_{PC5}: The purchasing cost
PTC: The preservation technology
p: The selling price
ξ: The preservation technology
τ_Θ: The deterioration rate stock items
r: The inflation rate
S: The maximum inventory
T: The total time
t_d: The time length in which production shows the no deterioration
t_1: The time length in which time no shortages
$\bar{Q}^*$: The optimum ordering quantity
Q^*_2: The maximal quantity of demand backlogged
T^*: The replenishment cycle period
$I_1(t)$: Inventory level at the time $t \in [0, t_d]$
$I_2(t)$: Inventory level at the time $t \in [\,t_d, t_1]$
$I_3(t)$: Inventory level at the time $t \in [\,t_1, T]$
I_e: Earned interest per year
I_p: Interest paid by buyer per year
M: permissible delay in payment
IE: Interest earned from sales received during permissible delay in payment
IP: Equivalent to the interest paid at the initial time for unsold time or after the permissible delay M.

II. Mathematical Modeling

The differential equations are representing during the time interval [0, t_d] ,[t_1,t_d] in this interval the inventory level decreases due to deterioration and demand, and third interval is [t_1, T] in this interval shortage occurred and demand is partially backlogged.

$$\frac{dI_1(t)}{dt} = -D(p); \qquad 0 \le t \le t_d \qquad (1)$$

$$\frac{dI_2(t)}{dt} = -\tau_\Theta I_2(t) - D(p); \qquad t_d \le t \le t_1 \qquad (2)$$

$$\frac{dI_3(t)}{dt} = \frac{-D(p)}{1+\delta(T-t)}; \qquad t_1 \le t \le T \qquad (3)$$

Solving (1), (2) & (3) respectively using the boundary conditions $I_1(t=0)=S$, $I_1(t) = I_2(t)$ at $t=t_d$, $I_2($ t=0 $)=t_1= I_3(t=0)$ we yield.

$$I_1 = D(p)(S-t) \qquad (4)$$

$$I_2 = \frac{D(p)}{\tau_\Theta}(e^{\Theta(t_1-t)} - 1) \qquad (5)$$

$$I_3 = \frac{D(p)}{\delta}[\log\frac{1+\delta(T-t)}{1+\delta(T-t_1)}] \qquad (6)$$

$$S = \frac{e^{(t_1-t)-1)}}{\tau_\Theta} + t \qquad (7)$$

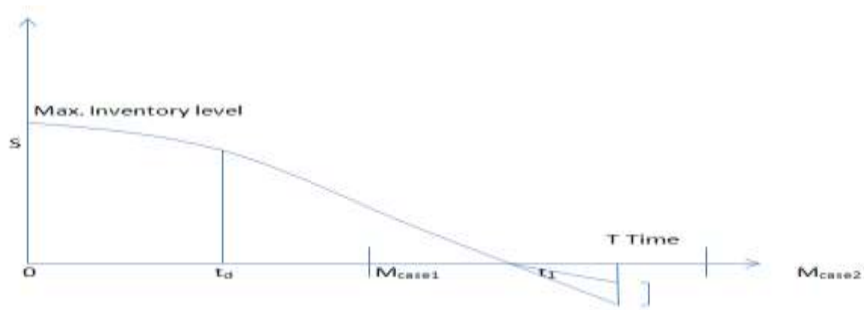


Figure 1. Inventory Functioning

We replace equation (7) in equation (1) we yield

$$I_1(t) = D(p)[\frac{e^{(t_1-t)}-1}{\tau_\Theta}] \qquad (8)$$

We put t= T in $I_3(t)$ we get

$$Q_2 = \frac{D(p)}{\delta}[\log\left(\frac{1}{1+\delta(T-t_1)}\right)] \qquad (9)$$

Quantity order per cycle is i.e.

$$Q = S + Q_2$$

$$Q = \frac{e^{(t_1-t)}-1}{\tau_\Theta} + t\ \frac{D(p)}{\delta}\log\left(\frac{1}{1+\delta(T-t_1)}\right) \qquad (10)$$

III. Cost Calculation

The ordering cost:

$$OC = A \qquad (11)$$

The deterioration cost:

$$C_{DC1} = -C_{DC1}D(p)[\frac{e^{\tau_\Theta(t_1-t)}}{\tau_\Theta} + t] \qquad (12)$$

The Holding cost:

$$C_{HC2} = -C_{HC2}\frac{D(p)}{\tau_\Theta}[e^{(t_1-t_d)} - \frac{e^{\tau_\Theta(t_1-t_d)}}{\tau_\Theta} + e^{t_1} + \frac{1}{\tau_\Theta} + t_1] \qquad (13)$$

The Shortage cost:

$$C_{SC3} = C_{SC3}\frac{D(p)}{\tau_\Theta}[e^{(t_1-T)} + T + t_1 - 1] \qquad (14)$$

The lost sale cost:

$$C_{LSC4} = C_{LSC4}D(p)[(T-t_1) - \frac{1}{\delta}\log(1+\delta(T-t_1))] \qquad (15)$$

The purchasing cost:

$$C_{PC5} = C_{PC5}((\frac{e^{(t_1-t)}-1}{\tau_\Theta} + t\frac{D(p)}{\delta}\log\left(\frac{1}{1+\delta(T-t_1)}\right)) \qquad (16)$$

The preservation technology:

$$PTC = \xi t_d \qquad (17)$$

The total average cost is:

$$TAC_1 = \frac{1}{T}[OC + C_{DC} + C_{HC} + C_{BC} + C_{LSC} + C_{PC} + PTC] \quad (18)$$

According to length of trade credit period there are two cases as follows: Case-1: $0 < \mathrm{M} \le \mathrm{t}_1 \le \mathrm{T}$ and Case-2: $0 < \mathrm{T} < \mathrm{t}_1 \le \mathrm{M}$. (19)

Case-1: $0 < \mathrm{M} \le \mathrm{t}_1 \le \mathrm{T}$

The trade credit period M is less than time t_1 therefore there is no interest paid by purchaser to supplier for the goods. Purchaser will use the sales revenue to earn interest at the I_e during time [0, T].

$$IE_1 = I_e[\int_0^T tD(p)e^{-rt}dt + (M-T)\int_0^T D(p)e^{-rt}dt \quad (20)$$

$$IE_1 = I_eD(p)[\frac{Te^{-rT}}{-r} - \frac{e^{-rT}}{r^2} + \frac{1}{r^2} + (M-T)\left(\frac{1}{r} - \frac{e^{-rT}}{r}\right)] \quad (21)$$

$$TAC_2 = \frac{1}{T}[OC + C_{DC1} + C_{HC2} + C_{BC3} + C_{LSC4} + C_{PC5} + PTC - IE_1] \quad (22)$$

Case-2: $0 < \mathrm{T} < \mathrm{t}_1 \le \mathrm{M}$

In case permissible delay period M expire before total inventory period T, in which the purchaser will pay interest charged on unsold goods during (M,T). present worth of interest paid by purchaser is-

$$IP_2 = I_P\int_T^M I_2(t)e^{-rt}dt \quad (23)$$

$$IP_2 = \frac{I_pD(p)}{\tau_\Theta}[-\frac{e^{\tau_\Theta(t_1-M)-rM}}{(\tau_\Theta+r)} + \frac{e^{\tau_\Theta(t_1-T)-rT}}{(\tau_\Theta+r)} + \frac{e^{-rM}}{r} - \frac{e^{-rT}}{r}] \quad (24)$$

Now the earned during positive inventory and Interest from invested cost is-

$$IE_2 = I_eD(p)\int_T^M t\,e^{-rt}dt \quad (25)$$

$$IE_2 = I_eD(p)[\frac{e^{-rT}}{r}\left(\frac{1}{r} + T\right) - \frac{e^{-rM}}{r}\left(M + \frac{1}{r}\right)] \quad (26)$$

$$TAC_3 = \frac{1}{T}[OC + C_{DC1} + C_{HC2} + C_{BC3} + C_{LSC4} + C_{PC5} + PTC + IP_2 - IE_2] \quad (27)$$

IV. Optimality of the model

To minimize the total cost we differentiate TAC (p, t_1, ξ) with respect to p, ξ, and t_1. And for optimum value necessary conditions are-

$$\frac{\partial TAC(p,t_1,\xi)}{\partial p} = 0, \frac{\partial TAC(p,t_1,\xi)}{\partial \xi} = 0, \frac{\partial TAC(p,t_1,\xi)}{\partial t_1} = 0$$

det.(H1)> 0, det.(H2) > 0, det.(H3)) > 0; where H1, H2, and H3, are the principle minor of the Hessian matrix. Hessian Matrix of the total cost function is as follows.

$$\begin{bmatrix} \frac{\partial^2(TAC)}{\partial \xi^2} & \frac{\partial^2(TAC)}{\partial \xi \partial t_1} & \frac{\partial^2(TAC)}{\partial \xi \partial p} \\ \frac{\partial^2(TAC)}{\partial t_1 \partial \xi} & \frac{\partial^2(TAC)}{\partial t_1^2} & \frac{\partial^2(TAC)}{\partial t_1 \partial p} \\ \frac{\partial^2(TAC)}{\partial p \partial \xi} & \frac{\partial^2(TAC)}{\partial p \partial t_1} & \frac{\partial^2(TAC)}{\partial p^2} \end{bmatrix}$$

V. Numerical Illustrations

Numerical Example-1:

We are taking appropriate numerical values of various parameters in the proper unites, are given, below for calculating values of TAC_1, ξ, p and t_1:

$C_{DC1} = 3$, $C_{HC2} = 16$, $C_{SC3} = 14$, $C_{LSC4} = 15$, $C_{PC5} = 10$, $t_d = 2$, $T = 18$, $\Theta = 0.05$, $\tau = 0.05$, x_1=1, x_2=1, y=1.5, $\mu = 1$, $\gamma = 1.5$, t=1, $\delta = 0.05$ the optimum values ξ^*,p, t_1, and TAC_1 has been calculated, then the optimum values.

p^*= 4.01693 $\xi^* = 2.051860$ t^*_1 = 4.38170 TAC_1^*= 9.963480×10^{-7}

Numerical Example-2: Case 1

We are taking appropriate numerical values of different parameters in proper unites, which are given, below for calculating values of TAC_2, ξ, p and t_1:

$C_{DC1} = 3$, $C_{HC2} = 18$, $C_{SC3} = 14$, $C_{LSC4} = 15$, $C_{PC5} = 10$, $t_d = 2$, $T = 18$, $\Theta = 0.05$, $\tau = 0.05$, x_1=1, x_2=1, y=1.5, $\mu = 1$, $\gamma = 1.5$, t=1, $\delta = 0.05$, M=0.002, I_e=0.15, I_p=0.001 the optimum values ξ^*,p, t_1, and TAC_2 has been calculated, then the optimum values.

P^*= 3.95241 $\xi^* = 2.13407$, t^*_1 = 4.26094 TAC_2^*= 1.12784×10^{-6}

Numerical Example-3: Case 2

We are taking appropriate numerical values of different parameters in proper unites, which are given, below for calculating values of TAC_3, ξ, P and t_1:

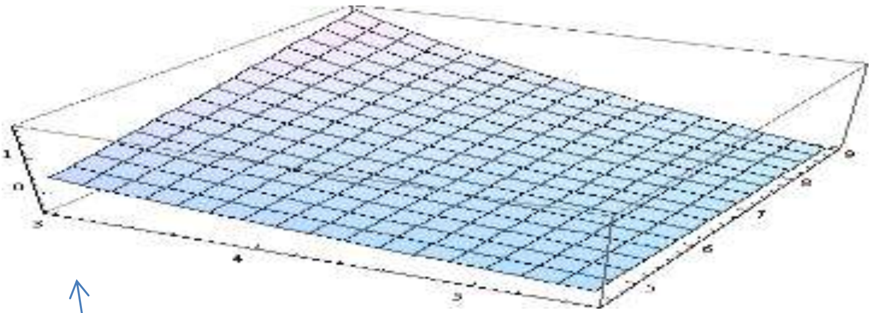
$C_{DC1} = 3$, $C_{HC2} = 18$, $C_{SC3} = 14$, $C_{LSC4} = 15$, $C_{PC5} = 10$, $t_d = 2$, $T = 18$, $\Theta = 0.05$, $\tau = 0.05$, x_1=1, x_2=1, y=1.5, $\mu = 1$, $\gamma = 1.5$, t=1, $\delta = 0.05$, M=0.002, I_e=0.001, I_p=0.001 the optimum values ξ^*,P, t_1, and TAC_3 has been calculated, then the optimum values.

P^*= 3.93086 $\xi^* = 1.91702$, t^*_1 = 4.77785 TAC_3^*= 2.47611× 10^{-7}

Note: The superscript * denotes the optimum values of the respective parameters.

VI. Convexity Analysis

The convexity of the TAC in different cases is well presented in 3D graphs in figure 2, 3, 4, 5, 6 and figure 7.



TAC₁

Figure 2. Optimum nature of TAC_1 w. r. t. p and t_1

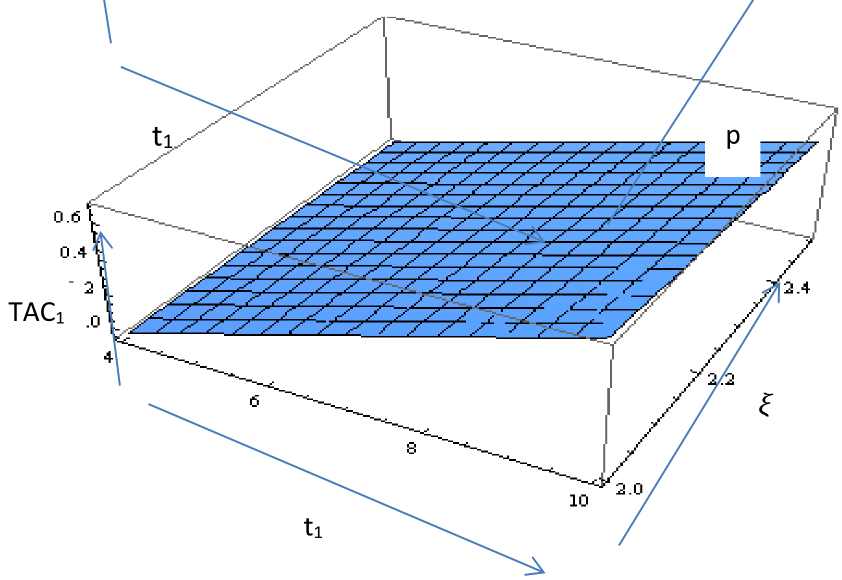


Figure 3. Optimum nature of TAC_1 w. r. t. ξ and t_1

VII. Sensitivity Analysis

The sensitivity test of TAC is performed by varying values of some important parameters. The analysis is well described in table 1, 3, 5 and the output is presented in table 2, 4 and table 6.

Table 1. Sensitivity Analysis

Parameters	Variations	P	ξ	t_1	TAC_1× 10^{-7}
x_1	0.50	3.99599	2.05186	4.38171	4.6647
	1.00	4.01693	2.05186	4.38170	9.96348
	1.50	4.03798	2.05186	4.38171	1.62197
x_2	0.95	3.96673	2.05186	4.38171	14.9983
	1.00	4.01693	2.05186	4.38170	9.96348
	1.05	4.06587	2.05186	4.38171	4.02774
c_{dc1}	2.95	4.01577	2.04886	4.37027	133804
	3.00	4.01693	2.05186	4.38170	9.96348
	3.05	4.01811	2.05488	4.39322	133932

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Y	1.0	5.24648	2.05186	4.38171	896936
	1.5	4.01693	2.05186	4.38170	9.96348
	2.0	3.36899	2.05186	4.38171	1743220

Table 2. Output of sensitivity Analysis

No.	Parameters	Changes	$TAC_1 \times 10^{-7}$
1	x_1	↓	↓
		↑	↓
2	x_2	↓	↑
		↑	↓
3	c_{dc1}	↓	↑
		↑	↑
4	Y	↓	↓
		↑	↓

In this table arrow ↓ shows the decrement and the arrow ↑ shows increment in the parameters and TAC_1.

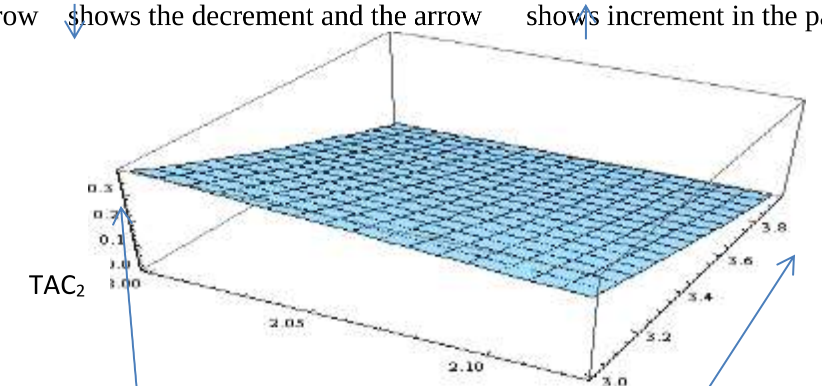

Figure 4. Optimum nature TAC_2 w. r. t. p & ξ

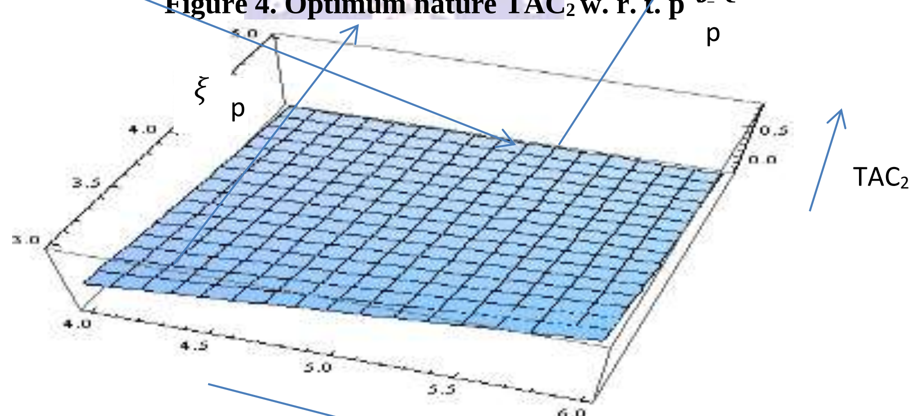

Figure 5. Optimum Nature of TAC_2 w. r. t. p & t_1

Table 3 (Case 1). Sensitivity Analysis

Parameters	Variations	P	t_1	ξ	$TAC_2 \times 10^{-6}$
x_1	0.95	3.93178	4.26094	2.13407	1.23258
	1.00	3.95241	4.26094	2.13407	1.12784
	1.05	3.3802	4.26094	2.13407	161286
x_2	0.95	3.90174	4.26094	2.13407	0.723113
	1.00	3.95241	4.26094	2.13407	1.12784
	1.05	3.38323	4.26094	2.13407	171083
c_{dc1}	2.95	3.33726	4.25014	4.25014	168487
	3.00	3.95241	4.26094	2.13407	1.12784
	3.05	3.95349	4.27181	4.27181	1.13301
y	1.0	5.14071	4.26094	2.13407	0.786659
	1.5	3.95241	4.26094	2.13407	1.12784
	2.0	3.32335	4.26094	2.13407	0.0819898

Table 4 (case 1). Output sensitivity Analysis

No.	Parameters	Changes	$TAC_2 \times 10^{-6}$
1	x_1	↓	↑
		↑	↑
2	x_2	↓	↓
		↑	↑
3	C_{DC1}	↓	↑
		↑	↑
4	y	↓	↓
		↑	↓

In this table arrow ↓ shows the decrement and the arrow ↑ shows increment in the parameters and TAC_2.

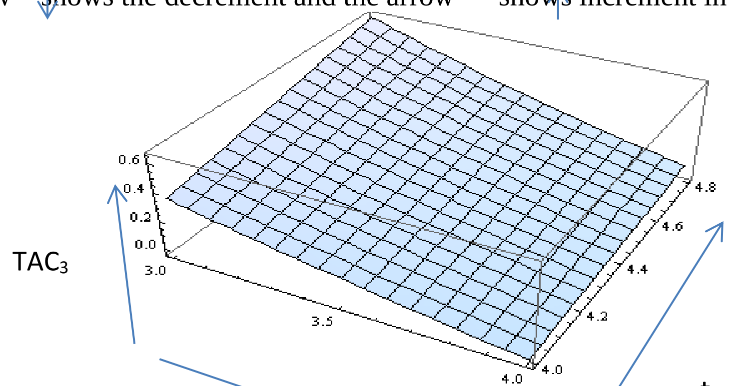

Figure 6. Optimum nature of TAC_3 w. r. t_1 and t_1

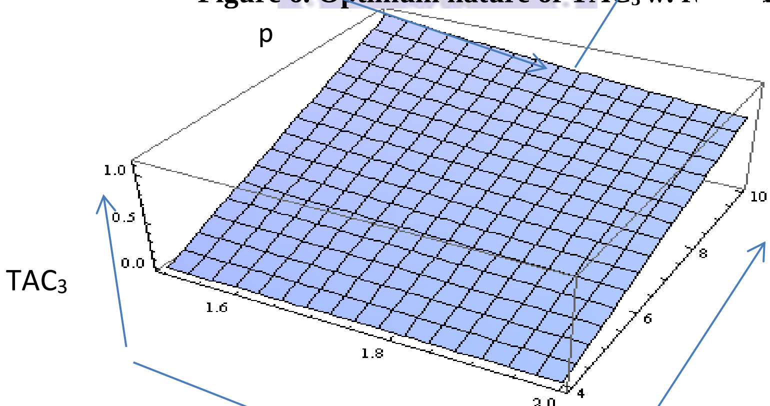

Figure 7. Optimum nature of TAC_3 w. r. t_1 and t_1

Table 5 (case 2). Sensitivity Analysis

Parameters	Variations		ξ	t_1	$TAC_3 \times 10^{-7}$
x_1	0.95	3.91034	1.91702	4.77785	915155
	1.00	3.93086	1.91702	4.77785	2.47611
	1.05	3.95149	1.91702	4.77785	8883600
x_2	0.95	3.88003	1.91702	4.77785	8826860
	1.00	3.93086	1.91702	4.77785	2.47611
	1.05	3.98038	1.91702	4.77785	9197360
c_{dc1}	2.95	3.92998	1.91452	4.76701	9028710
	3.00	3.93086	1.91702	4.77785	2.47611
	3.05	3.93174	1.91953	4.78876	9005180
Y	1.0	5.10541	1.91702	4.77785	4106410
	1.5	3.93086	1.91702	4.77785	2.47611
	2.0	3.30809	1.91702	4.77785	1453400

Table No. 6 (case 2). Output of Sensitivity Analysis

No.	Parameters	Changes	$TAC_3 \times 10^{-7}$
1	X_1	↓	↑
		↑	↑

2	X_2	↓	↑
		↑	↑
3	C_{DC1}	↓	↑
		↑	↑
4	y	↓	↑
		↑	↑

In this table arrow ↓ shows the decrement and the arrow ↑ shows increment in the parameters and TAC_3.

VIII. Conclusion

We developed a model for non-instantaneous deteriorating with stock level and selling price dependent demand as hybrid type function.to find out the optimum selling price and optimum quantity under the effect of inflation. And we described the trade credit policy to determine an optimum policy in payment. Here the deterioration is constant. We permitted the shortages and opine that occurring shortages are partially backlogged. Numerical examples and graphs shown in this model referred that was usual and tolerable. In future, this model can be expended in many ways like- stochastic demand, stock level and time dependent deterioration.

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