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Two Warehouse Production Inventory Model with Different Deterioration Rates under Linear Demand and Time Varying Holding Cost

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ABSTRACT: A two warehouse production inventory model with different deterioration rates under linear demand is developed. Holding cost is considered as linear function of time. Shortages are not allowed. Numerical case is given to represent the model. Affectability investigation is likewise done for parameters.

Keywords: Two warehouse, Production, deterioration, Linear demand, Time varying holding costs.

I. INTRODUCTION

An item may be stocked in an inventory system at only a single physical location, or it may be stocked at many locations. In real life situation many time retailers decides to buy goods exceeding their Own Warehouse (OW) capacity to take advantage of price discounts. Therefore an additional stock is arranged and managed in Rented Warehouse (RW) which has better storage facilities with higher inventory carrying cost and low rate of deterioration. Bhunia and Maiti [3] gave two warehouse inventory model for deteriorating items with linear demand and shortages. Balkhi [1] studied on finite horizon production lot size model. Goyal and Giri [6] provide solution for production inventory of a product with time varying demand, production and deterioration rates. Samanta and Roy [13] gave production inventory model for deteriorating items with shortages. Teng and Chang [14] developed production inventory model with price and stock dependent demand. Roy and Chaudhary [11] considered Weibull deterioration in the production model suggested by them. Khanra and Chaudhuri [8] studied production inventory model for deteriorating with time dependent demand and shortages. Production model was given by Bansal [2] was based on assumption of price dependent demand and deterioration. Parekh and Patel [9] gave deteriorating items production inventory model with two warehouses with linear demand time varying holding cost , inflation and permissible delay in payments Ghasemi [4] developed EPQ models for non-instanteneous deteriorationg items. Ghiami [5] suggested two echelon production model for deteriorating items with multiple buyers. Jaggi *et al*. [7] gave replenishment policy for non-instantaneous deteriorating items in two storage facilities under inflationary conditions. Raafat [10] and Ruxian [12] and gave review on deteriorating items inventory models.

Generally the products are such that there is no deterioration initially. After certain time deterioration starts and again after certain time the rate of deterioration increases with time. Here we have used such a concept and developed two warehouses deteriorating items inventory model.

In this paper we have developed a two warehouse production inventory model with different deterioration rates. Demand function is linear, holding cost is time varying, Shortages are allowed and completely backlogged. Numerical case is given to represent the model. Affectability investigation is likewise done for parameters.

ASSUMPTIONS AND NOTATIONS

Notations: The following notations are used for the development of the model:

P(t) : Production rate is function of demand at time t, ($\eta D(t)$, $\eta>0$).

D(t) : Demand rate is a linear function of price and inventory level (a + bt, a>0, 0<b<1)

HC(OW): Holding cost is linear function of time $t(x_1+y_1t$, $x1>0$, $0<y_1<1)$ in OW.

HC(RW): Holding cost is linear function of time $t(x_2+y_2t$, $x2>0$, $0<y_2<1)$ in RW.

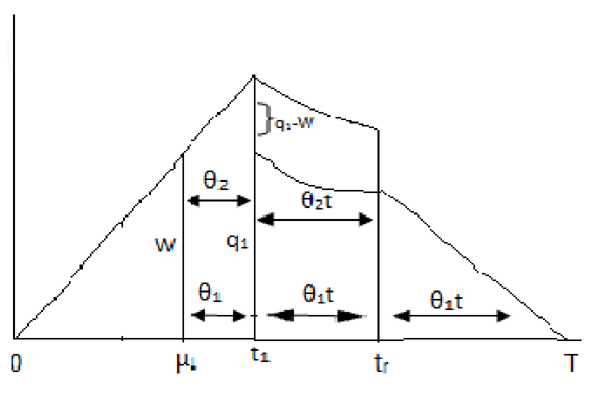
B	: Setup cost per order
SeC	: Setup cost
c	: Purchasing cost per unit
p	: Selling price per unit
T	: Length of inventory cycle
$I_0(t)$	: Inventory level in OW at time t.
$I_r(t)$	: Inventory level in RW at time t.
Q	: Order quantity
q_1	: Inventory level at t_1
t_r	: time at which inventory level becomes zero in RW.
W	: capacity of own warehouse
θ_1	: Deterioration rate in OW, $0< \theta_1<1$ during $\mu_1<t<t_1$
θ_2	: Deterioration rate in RW, $0< \theta_2<1$ during $\mu_1<t<t_1$
θ_1 t	: Deterioration rate during , $t_1 \le t \le T$, $0< \theta_1<1$ in OW
θ_2 t	: Deterioration rate during , $t_1 \le t \le t_r$, $0< \theta_2<1$ in RW.
π	: Total relevant profit per unit time.

Assumptions: The following assumptions are considered for the development of model.

- The demand of the product is declining as a linear function of time.
- Replenishment rate is infinite and instantaneous.
- Lead time is zero.
- Shortages are not allowed.
- OW has fixed capacity W units and RW has unlimited capacity.
- The goods of OW are consumed only after consuming the goods kept in RW.
- The unit inventory cost per unit in the RW is higher than those in the OW.
- Deteriorated units neither be repaired nor replaced during the cycle time.

II. THE MATHEMATICAL MODEL AND ANALYSIS

At time t=0, Production starts at rate η the level of inventory increases to W up to time μ_1 in OW, due to combined effect of production and demand. Then inventory is continued to be stored in RW up to time t_1, production stops at time t_1. During interval $[\mu_1,t_1]$ inventory in RW gradually decreases due to demand and deterioration at rate θ_2, during $[\mu_1,t_1]$ inventory in OW depletes due to deterioration at rate θ_1. during interval $[t_1,t_r]$ inventory in OW depletes due to deterioration at rate θ_1t, inventory in RW depletes due to demand and deterioration at rate θ_2t and reaches to zero at time t_r. during the interval (t_r,T) inventory depletes in OW due to linear demand and deterioration(θ_1t), By time T both the warehouses are empty.
The figure describes the behaviour of inventory system.



Hence, the inventory level at time t at RW and OW and governed by the following differential equations:

$$\frac{dI_0(t)}{dt}=(\eta-1)(a+bt) \qquad 0 \le t \le \mu_1 \qquad ...(1)$$

$$\frac{dI_r(t)}{dt}+\theta_2 I_r(t)=(\eta-1)(a+bt) \qquad \mu_1 \le t \le t_1 \qquad ...(2)$$

$$\frac{dI_0(t)}{dt}+\theta_1 I_0(t)=0 \qquad \mu_1 \le t \le t_1 \qquad ...(3)$$

$$\frac{dI_r(t)}{dt}+\theta_2 tI(t)=-(a+bt) \qquad t_1 \le t \le t_r \qquad ...(4)$$

$$\frac{dI_0(t)}{dt}+\theta_1 tI_0(t)=0 \qquad t_1 \le t \le t_r \qquad ...(5)$$

$$\frac{dI_0(t)}{dt}+\theta_1 tI_0(t)=-(a+bt) \qquad t_r \le t \le T \qquad ...(6)$$

With boundary conditions

$I_0(0)=0,\ I_0(\mu_1)=W,\ I_0(t_1)=W,\ I_0(t_r)=W,\ I_0(T)=0,\ I_r(0)=0,\ I_r(\mu_1)=0,\ I_r(t_1)=q_1-W,\ I_r(t_r)=0$

Solving equations (1) to (6) we have,

$$I_0(t)=\left[(\eta-1)\left(at+\frac{1}{2}bt^2\right)\right] \qquad ...(7)$$

$$I_r(t)=\left[(\eta-1)\begin{pmatrix} a(t-\mu_1)+\frac{1}{2}a\theta_2(t^2-\mu_1^2)+\frac{1}{2}b(t^2-\mu_1^2)+ \\ \frac{1}{3}b\theta_2(t^3-\mu_1^3)-a\theta_2 t(t-\mu_1)-\frac{1}{2}b\theta_2 t(t^2-\mu_1^2) \end{pmatrix}\right] \qquad ...(8)$$

$$I_0(t)=\left[W\left(1+\theta_1(\mu_1-t)\right)\right] \qquad ...(9)$$

$$I_r(t)=\begin{bmatrix} a(t_r-t)+\frac{1}{6}a\theta_2(t_r^3-t^3)+\frac{1}{2}b(t_r^2-t^2)+ \\ \frac{1}{8}b\theta_2(t_r^4-t^4)-\frac{1}{2}a\theta_2 t^2(t_r-t)-\frac{1}{4}b\theta_2 t^2(t_r^2-t^2) \end{bmatrix} \qquad ...(10)$$

$$I_0(t)=\left[W\left(1+\frac{1}{2}\theta_1(t_1^2-t^2)\right)\right] \qquad ...(11)$$

$$I_0(t)=\begin{bmatrix} a(T-t)+\frac{1}{6}a\theta_1(T^3-t^3)+\frac{1}{2}b(T^2-t^2)+ \\ \frac{1}{8}b\theta_1(T^4-t^4)-\frac{1}{2}\theta_1 t^2 a(T-t)-\frac{1}{4}b\theta_1 t^2(T^2-t^2) \end{bmatrix} \qquad ...(12)$$

From (11) and (12) when $t=t_r$ we have,

$$I_0(t_r)=\left[W\left(1+\frac{1}{2}\theta_1(t_1^2-t_r^2)\right)\right] \qquad ...(13)$$

$$I_0(t_r)=\begin{bmatrix} a(T-t_r)+\frac{1}{6}a\theta_1(T^3-t_r^3)+\frac{1}{2}b(T^2-t_r^2)+ \\ \frac{1}{8}b\theta_1(T^4-t_r^4)-\frac{1}{2}\theta_1 t^2 a(T-t_r)-\frac{1}{4}b\theta_1 t_r^2(T^2-t_r^2) \end{bmatrix} \qquad ...(14)$$

Solving (13) and (14) for T we have,

$$T=\frac{-a+\sqrt{a^2+2bW+bW\theta_1 t_1^2-bW\theta_1 t_r^2+2abt_r+b^2t_r^2}}{b} \quad ...(15)$$

Based on the assumptions and descriptions of the model, the total annual relevant profit (π), include the following elements:

(i) Setup cost (SeC) = B ...(16)

(ii) $$HC(OW)=\int_0^{\mu_1} I_0(t)(x_1+y_1t)\,dt+\int_{\mu_1}^{t_1} I_0(t)(x_1+y_1t)\,dt+\int_{t_1}^{t_r} I_0(t)(x_1+y_1t)\,dt+\int_{t_r}^{T} I_0(t)(x_1+y_1t)\,dt$$

$$=\left[\begin{array}{l}\frac{1}{8}(\eta-1)by_1\mu_1^4+\frac{1}{3}\left((\eta-1)ay_1+\frac{1}{2}(\eta-1)bx_1\right)\mu_1^3+\frac{1}{2}(\eta-1)ax_1\mu_1^2-\frac{1}{3}W\theta_1y_1\left(t_1^3-\mu_1^3\right)\\ +\frac{1}{2}\left(W(1+\theta_1\mu_1)y_1-W\theta_1x_1\right)\left(t_1^2-\mu_1^2\right)+W(1+\theta_1\mu_1)x_1(t_1-\mu_1)-\frac{1}{8}W\theta_1y_1\left(t_r^4-t_1^4\right)-\\ \frac{1}{6}W\theta_1x_1\left(t_r^3-t_1^3\right)+\frac{1}{2}W\left(1+\frac{1}{2}\theta_1t_1^2\right)y_1\left(t_r^2-t_1^2\right)+W\left(1+\frac{1}{2}\theta_1t_1^2\right)x_1(t_r-t_1)\end{array}\right]$$

$$+\left[\begin{array}{l}\frac{1}{48}b\theta_1y_1\left(T^6-t_r^6\right)+\frac{1}{5}\left(\frac{1}{3}a\theta_1y_1+\frac{1}{8}b\theta_1x_1\right)\left(T^5-t_r^5\right)+\\ \frac{1}{4}\left(\left(-\frac{1}{2}b-\frac{1}{2}a\theta_1T-\frac{1}{4}b\theta_1T^2\right)y_1+\frac{1}{3}a\theta_1x_1\right)\left(T^4-t_r^4\right)+\\ \frac{1}{3}\left(-ay_1+\left(-\frac{1}{2}b-\frac{1}{2}a\theta_1T-\frac{1}{4}b\theta_1T^2\right)x_1\right)\left(T^3-t^3\right)+\\ \frac{1}{2}\left(\left(aT+\frac{1}{6}a\theta_1T^3+\frac{1}{2}bT^2+\frac{1}{8}b\theta_1T^4\right)y_1-ax_1\right)\left(T^2-t_r^2\right)\\ +\left(aT+\frac{1}{6}a\theta_1T^3+\frac{1}{2}bT^2+\frac{1}{8}b\theta_1T^4\right)x_1(T-t_r)\end{array}\right] \quad ...(17)$$

(iii) $$HC(RW)=\int_{\mu_1}^{t_1} I_r(t)(x_2+y_2t)\,dt+\int_{t_1}^{t_r} I_r(t)(x_2+y_2t)\,dt$$

$$=\left[\begin{array}{l}-\frac{1}{24}(\eta-1)b\theta_2x_2\left(t_1^4-\mu_1^4\right)+\frac{1}{3}(\eta-1)\left(-\frac{1}{2}a\theta_2+\frac{1}{2}b\right)x_2\left(t_1^3-\mu_1^3\right)+\\ \frac{1}{2}(\eta-1)\left(a+a\theta_2\mu_1+\frac{1}{2}b\theta_2\mu_1^2\right)x_2\left(t_1^2-\mu_1^2\right)+(\eta-1)\left(-a\mu_1-\frac{1}{2}a\theta_2\mu_1^2-\frac{1}{2}b\mu_1^2-\frac{1}{2}b\theta_2\mu_1^3\right)x_2(t_1-\mu_1)\\ -\frac{1}{30}(\eta-1)b\theta_2y_2\left(t_1^5-\mu_1^5\right)+\frac{1}{4}(\eta-1)\left(-\frac{1}{2}a\theta_2+\frac{1}{2}b\right)y_2\left(t_1^4-\mu_1^4\right)\\ +\frac{1}{3}(\eta-1)\left(a+a\theta_2\mu_1+\frac{1}{2}b\theta_2\mu_1^2\right)y_2\left(t_1^3-\mu_1^3\right)+\frac{1}{2}(\eta-1)\left(-a\mu_1-\frac{1}{2}a\theta_2\mu_1^2-\frac{1}{2}b\mu_1^2-\frac{1}{3}b\theta_2\mu_1^3\right)y_2\left(t_1^2-\mu_1^2\right)\end{array}\right]$$

$$+\left[\left[\begin{array}{l}\frac{1}{40}b\theta_2x_2\left(t_r^5-t_1^5\right)+\frac{1}{12}a\theta_2x_2\left(t_r^4-t_1^4\right)+\frac{1}{3}\left(-\frac{1}{2}b-\frac{1}{2}a\theta_2t_r-\frac{1}{4}b\theta_2t_r^2\right)x_2\left(t_r^3-t_1^3\right)-\\ \frac{1}{2}ax_2\left(t_r^2-t_1^2\right)+\left(at_r+\frac{1}{6}a\theta_2t_r^3+\frac{1}{2}bt_r^2+\frac{1}{8}b\theta_2t_r^4\right)x_2\left(t_r-t_1\right)+\frac{1}{48}b\theta_2y_2\left(t_r^6-t_1^6\right)\\ +\frac{1}{15}a\theta_2y_2\left(t_r^5-t_1^5\right)+\frac{1}{4}\left(-\frac{1}{2}b-\frac{1}{2}a\theta_2t_r-\frac{1}{4}b\theta_2t_r^2\right)y_2\left(t_r^4-t_1^4\right)-\frac{1}{3}ay_2\left(t_r^3-t_1^3\right)+\\ \frac{1}{2}\left(at_r+\frac{1}{6}a\theta_2\tau_r^3+\frac{1}{2}bt_r^2+\frac{1}{8}b\theta_2t_r^4\right)y_2\left(t_r^2-t_1^2\right)\end{array}\right]\right] \quad ...(18)$$

$$DC=c\theta_1\left(\int_{\mu_1}^{t_1}I_0(t)\,dt+\int_{t_1}^{t_r}tI_0(t)\,dt+\int_{t_r}^{T}tI_0(t)\,dt\right)+c\theta_2\left(\int_{\mu_1}^{t_1}I_r(t)\,dt+\int_{t_1}^{t_r}tI_r(t)\,dt\right)$$

$$=\left[c\theta_1\left(\begin{array}{l}-\frac{1}{2}W\theta_1\left(t_1^2-\mu_1^2\right)+W\left(1+\theta_1\mu_1\right)\left(t_1-\mu_1\right)-\frac{1}{8}W\theta_1\left(t_r^4-t_1^4\right)+\\ \frac{1}{2}W\left(1+\frac{1}{2}\theta_1t_1^2\right)\left(t_r^2-t_1^2\right)+\frac{1}{48}b\theta_1\left(T^6-t_r^6\right)+\\ \frac{1}{15}a\theta_1\left(T^5-t_r^5\right)+\frac{1}{4}\left(-\frac{1}{2}b-\frac{1}{2}a\theta_1T-\frac{1}{4}b\theta_1T^2\right)\left(T^4-t_r^4\right)-\frac{1}{3}a\left(T^3-t_r^3\right)\\ +\frac{1}{2}T\left(a+\frac{1}{6}a\theta_1(T)^2+\frac{1}{2}bT+\frac{1}{8}b\theta_1T^3\right)\left(T^2-t_r^2\right)\end{array}\right)\right]$$

$$+\left[\begin{array}{l}c\theta_2\left(\begin{array}{l}-\frac{1}{24}(\eta-1)b\theta_2\left(t_1^4-\mu_1^4\right)+\frac{1}{3}(\eta-1)\left(-\frac{1}{2}a\theta_2+\frac{1}{2}b\right)\left(t_1^3-\mu_1^3\right)+\\ \frac{1}{2}(\eta-1)\left(a+a\theta_2\mu_1+\frac{1}{2}b\theta_2\mu_1^2\right)\left(t_1^2-\mu_1^2\right)+(\eta-1)\left(-a\mu_1-\frac{1}{2}a\theta_2\mu_1^2-\frac{1}{2}b\mu_1^2-\frac{1}{2}b\theta_2\mu_1^3\right)\left(t_1-\mu_1\right)\end{array}\right)+\\ c\theta_2\left(\begin{array}{l}\frac{1}{48}b\theta_2\left(t_r^6-t_1^6\right)+\frac{1}{15}a\theta_2\left(t_r^5-t_1^5\right)+\frac{1}{4}\left(-\frac{1}{2}b-\frac{1}{2}a\theta_2t_r-\frac{1}{4}b\theta_2t_r^2\right)\left(t_r^4-t_1^4\right)-\\ \frac{1}{3}a\left(t_r^3-t_1^3\right)+\frac{1}{2}\left(at_r+\frac{1}{6}a\theta_2t_r^3+\frac{1}{2}bt_r^2+\frac{1}{8}b\theta_2t_r^4\right)\left(t_r^2-t_1^2\right)\end{array}\right)\end{array}\right] \quad ...(19)$$

$$SR=p\left(\int_0^T(a+bt)\,dt\right)$$

$$=\left[p\left(aT+\frac{1}{2}bT^2\right)\right] \quad ...(20)$$

The total profit (π) during a cycle, T consisted of the following:

$$\pi = \frac{1}{T}\left[SR - SeC - HC\,(RW) - HC(OW) - DC\right] \quad ...(21)$$

Substituting values from equations (16) to (20) in equation (21), we get total profit per unit. Putting $\mu_1 = v_1 T$ in equation (21), we get profit in terms of t_r and t_1. Differentiating equation (21) with respect to t_r and t_1 and equating it to zero, we have

$$\text{i.e. } \frac{\partial \pi(t_r, t_1)}{\partial t_r} = 0, \ \frac{\partial \pi(t_r, t_1)}{\partial t_1} = 0 \quad ...(22)$$

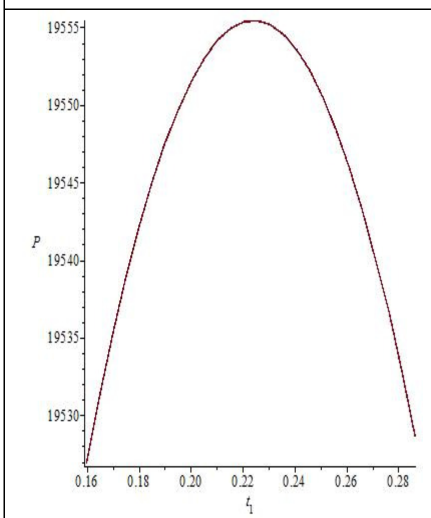
provided it satisfies the condition

$$\begin{vmatrix} \dfrac{\partial^2 \pi(t_1, t_r)}{\partial t_1^2} & \dfrac{\partial^2 \pi(t_1, t_r)}{\partial t_1 \partial t_r} \\ \dfrac{\partial^2 \pi(t_1, t_r)}{\partial t_r \partial t_1} & \dfrac{\partial^2 \pi(t_1, t_r)}{\partial t_r^2} \end{vmatrix} > 0. \quad ...(23)$$

III. NUMERICAL EXAMPLE

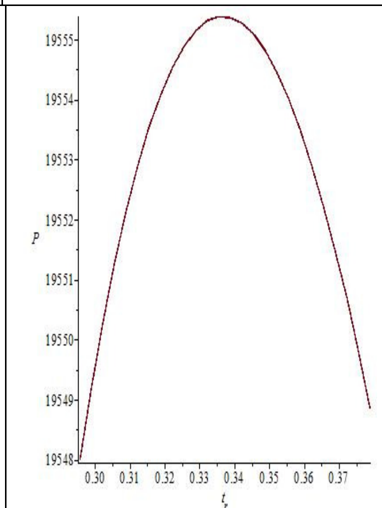
Considering A= Rs.100, a = 500, W=56, b=0.05,c=Rs. 25, p=Rs 40, θ_1=0.05, θ_2 =0.02, x_1 = Rs. 3, y_1=0.05, x_2 = Rs. 6, y_2=0.06, v_1=0.30, in appropriate units. Optimal values of t_1^* = 0.2241, t_r^* = 0.3365, and Profit*=19555.5490. The second order conditions given in equation (23) are also satisfied. The graphical representation of the concavity of the profit function is also given.

t_1 and Profit



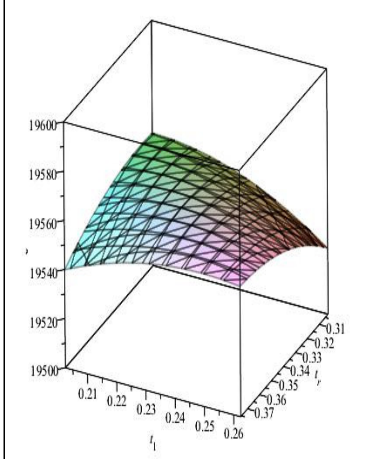
Graph 1

t_r and Profit



Graph 2

t_1, t_r and Profit



Graph 3

Sensitivity Analysis. On the basis of the data given in example above we have studied the sensitivity analysis by changing the following parameters one at a time and keeping the rest fixed.

Table sensitivity analysis

Parameter	%	t_1	t_r	Profit
a	+20%	0.2112	0.3190	23514.8147
	+10%	0.2174	0.3275	21534.7095
	-10%	0.2313	0.3461	17577.4837
	-20%	0.2392	0.3563	15600.7088
θ_1	+20%	0.2197	0.3325	19551.1589
	+10%	0.2219	0.3345	19553.3442
	-10%	0.2262	0.3385	19557.7732
	-20%	0.2283	0.3405	19560.0164
θ_2	+20%	0.2224	0.3348	19554.9240
	+10%	0.2232	0.3357	19555.2353
	-10%	0.2249	0.3374	19555.8654
	-20%	0.2257	0.3383	19556.1843
x_1	+20%	0.2173	0.3262	19530.3091
	+10%	0.2207	0.3313	19542.8994
	-10%	0.2275	0.3418	19568.2584
	-20%	0.2310	0.3472	19581.0278
x_2	+20%	0.2087	0.3100	19542.6184
	+10%	0.2160	0.3226	19548.8677
	-10%	0.2330	0.3522	19562.7202
	-20%	0.2431	0.3700	19570.4518
B	+20%	0.2526	0.3803	19513.0197
	+10%	0.2386	0.3589	19533.7904
	-10%	0.2087	0.3129	19578.4544
	-20%	0.1924	0.2878	19602.7128

From the table we observe that as parameter a increases/ decreases average total profit increases/ decreases.
Also, we observe that with increase and decrease in the value of θ_1, θ_2, x_1, and x_2 there is corresponding decrease/ increase in total profit.
From the table we observe that as parameter B increases/ decreases average total profit decreases/ increases.

IV. CONCLUSION

In this paper, we have developed a two warehouse Production inventory model for deteriorating items with different deterioration rates, linear demand and time varying holding cost. Sensitivity with respect to parameters has been carried out. The results show that with the increase/ decrease in the parameter values there is corresponding increase/ decrease in the value of profit.

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