International Journal of Engineering, Science and Mathematics
Vol. 7Issue 4, April 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

DIFFERENT DETERIORATION RATES TWO WAREHOUSE DEFECTIVE ITEMS INVENTORY MODEL WITH TIME AND PRICE DEPENDENT DEMAND

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Abstract

Generally it happens that units produced or ordered are not of 100% good quality. A two warehouse inventory model with different deterioration rates is developed. Demand is considered as function of price and time. 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;
Different deterioration;
Time dependent dmand;
Time dependent dmand;
Defective items.

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1. Introduction

Most of the time it is assumed that items can be stored indefinitely to meet the future demand. But some items either deteriorate or become obsolete in the course of time. Therefore, if the rate of deterioration is not sufficiently low, its impact on modeling of such an inventory system cannot be ignored. Within [26] was the first to develop deteriorating items inventory model for fashion goods deteriorating at the end of prescribed storage period. An inventory model with constant rate of deterioration was developed by Ghare and Schrader [4]. The model was extended by Covert and Philip [3] by considering variable rate of deterioration. Shah and Jaiswal [22] further extended the model by considering shortages. An inventory model with weibull rate of decay with selling price dependent demand was discussed by Aggarwal and Goel [1]. Inventory model with stock level dependent demand rate and variable holding cost was developed by Alfares [2]. A deterministic inventory model when deterioration rate was time proportional was discussed by Patra et al. [14]. Demand rate was taken as a nonlinear function of selling price, deterioration rate, inventory holding cost and ordering cost were all functions of time. Patel and Sheikh [13] developed an inventory model with different deterioration rates and time varying holding cost. The related work are found in (Nahmias [10], Raffat [16], Goyal and Giri [5], Ruxian et al. [18]).

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It is generally assumed that products produced/ received are all 100% perfect. But, in reality, it happens that units produced/ received are not of 100% good quality. Inventory model in which due to imperfect quality production process, the product produced are defective product were considered by Rosenblatt and Lee [17], Porteus [15]. Salameh and Jaber [19] developed an inventory model in which items received are of defective quality and after 100% screening, imperfect items are withdrawn from the inventory and sold at a discounted price. Model of Salameh and Jaber [19] was extended by Wee et al. [25] model to consider allowed shortages and the effect of varying backordering cost. Patel and Patel [12] developed an EOQ model for deteriorating items with imperfect quantity items. Jaggi et al. [8] considered a two warehouse inventory model for imperfect quality items.

To take advantages of bulk purchasing many times retailer decides to buy goods exceeding their Own Warehouse (OW) capacity. So an additional stock is arranged as Rented Warehouse (RW) which has better storage facilities with low rate of deterioration and higher inventory holding cost. A two warehouse inventory model was developed by Hartley [6]. Sarma [21] developed an inventory model with finite rate of replenishment with two warehouses. A deterministic inventory model for deteriorating items with two warehouses and finite replenishment rates was developed by Pakkala and Achary [11]. Lee and Hsu [9] discussed a two warehouse inventory model with time dependent demand. A two warehouse inventory model on pricing decision was discussed by Sana et al. [20]. Yu [27] proposed two warehouse inventory model for deteriorating items with decreasing rental over time. Tyagi and Singh [24] proposed two warehouse inventory model with time dependent demand and variable holding cost. Sheikh and Patel [23] developed a two warehouse inventory model under linear demand and time varying holding cost. A two warehouse deteriorating items inventory model under price dependent demand was developed by Jaggi et al. [7].

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 the deteriorating items inventory model.

In this paper we have developed a two warehouse defective items inventory model with different deterioration rates. Demand function is price and time dependent. Holding cost is time varying. Shortages are not allowed. Numerical case is given to represent the model. Affectability investigation is likewise done for parameters.

2. ASSUMPTIONS AND NOTATIONS:

NOTATIONS:

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

D(t,p) : Demand is a function of time and price ($a + bt - \rho p$, $a>0$, $0<b<1$, $\rho>0$)

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

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

A : Ordering cost per order

c : Purchasing cost per unit

p : Selling price per unit

d : defective items (%)

1-d : good items (%)

λ : Screening rate

SR : Sales revenue

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z : Screening cost per unit
p_d : Price of defective items per unit
t_1 : Screening time
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
t_r : Time at which inventory level becomes zero in RW.
W : Capacity of own warehouse
θ : Deterioration rate in OW during $\mu_1<t<\mu_2$, $0<\theta<1$
θt : Deterioration rate in OW during $\mu_2 \le t \le T$, $0<\theta<1$
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 function of time and price.
- Replenishment rate is infinite and instantaneous.
- Lead time is zero.
- Shortages are not allowed.
- The screening process and demand proceeds simultaneously but screening rate (λ) is greater than the demand rate i.e. $\lambda > (a+bt-\rho p)$.
- The defective items are independent of deterioration.
- Deteriorated units can neither be repaired nor replaced during the cycle time.
- A single product is considered.
- Holding cost is time dependent.
- The screening rate (λ) is sufficiently large. In general, this assumption should be acceptable since the automatic screening machine usually takes only little time to inspect all items produced or purchased.
- 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.

3. THE MATHEMATICAL MODEL AND ANALYSIS:

In the following situation, Q items are received at the beginning of the period. Each lot having d% of defective items. The nature of the inventory level is shown in the given figure, where screening process is done for all the received items at the rate of λ units per unit time which is greater than demand rate for the time period 0 to t_1. d% of defective items are separated and from remaining Q – dQ = Q(1-d) good items, W units are stored in own warehouse (OW) and remaining Q(1-d)-W units are stored in rented warehouse(RW). During the screening process the demand occurs parallel to the screening process and is fulfilled from the goods which are found to be of perfect quality by screening process in rented warehouse. The defective items are sold immediately after the screening process at time t_1 as a single batch at a discounted price. After the screening process at time t_1 the inventory level will be $I(t_1)$. 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,μ_1) inventory depletes in OW due to demand, during interval (μ_1, μ_2) inventory depletes in OW due to deterioration

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at rate θ and demand. During interval (μ_2, T) inventory in OW depletes due to joint effect of deterioration at rate θt and demand. By time T both the warehouses are empty.

Also here $t_1 = \frac{Q}{\lambda}$

(1)

and defective percentage (d) is restricted to $d \le 1 - \frac{(a+bt-\rho p)}{\lambda}$

(2)

Let I(t) be the inventory at time t ($0 \le t \le T$) as shown in figure.

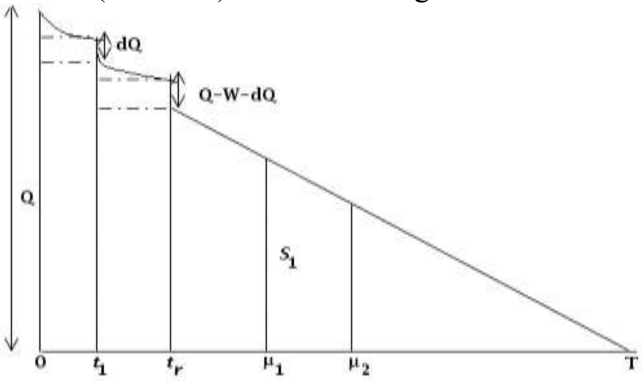

Figure 1

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

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

$$\frac{dI_0(t)}{dt} = 0, \qquad 0 \le t \le t_r \qquad (4)$$

$$\frac{dI_0(t)}{dt} = -(a + bt - \rho p), \qquad t_r \le t \le \mu_1 \qquad (5)$$

$$\frac{dI_0(t)}{dt} + \theta I_0(t) = -(a+bt - \rho p), \qquad \mu_1 \le t \le \mu_2 \qquad (6)$$

$$\frac{dI_0(t)}{dt} + \theta t I_0(t) = -(a+bt - \rho p), \qquad \mu_2 \le t \le T \qquad (7)$$

with initial conditions $I_0(0) = W$, $I_0(\mu_1) = S_1$, $I_0(t_r) = W$, $I_r(0) = Q(1-d)-W$, $I_r(t_r) = 0$ and $I_0(T)=0$.

Solving equations (3) to (7) we have,

$$I_r(t) = Q - W - (a - \rho p)t - \frac{1}{2}bt^2 \qquad (8)$$

$$I_0(t) = W \qquad (9)$$

$$I_0(t) = S_1 + (a - \rho p)(\mu_1 - t) + \frac{1}{2}b(\mu_1^2 - t^2) \qquad (10)$$

$$I_0(t) = \begin{bmatrix} a(\mu_1 - t) - \rho p(\mu_1 - t) + \frac{1}{2}a\theta(\mu_1^2 - t^2) - \frac{1}{2}\rho p\theta(\mu_1^2 - t^2) + \frac{1}{2}b(\mu_1^2 - t^2) \\ + \frac{1}{3}b\theta(\mu_1^3 - t^3) - a\theta t(\mu_1 - t) + \rho p t(\mu_1 - t) - \frac{1}{2}b\theta t(\mu_1^2 - t^2) \end{bmatrix} + S_1(1 + \theta(\mu_1 - t))$$

(11)

$$I_0(t) = \begin{bmatrix} a(T - t) - \rho p(T - t) + \frac{1}{6}a\theta(T^3 - t^3) - \frac{1}{6}\rho p\theta(T^3 - t^3) + \frac{1}{2}b(T^2 - t^2) \\ + \frac{1}{8}b\theta(T^4 - t^4) - \frac{1}{2}a\theta t^2(T - t) + \frac{1}{2}\rho p\theta t^2(T - t) - \frac{1}{4}b\theta t^2(T^2 - t^2) \end{bmatrix} \quad (12)$$

(by neglecting higher powers of θ)

After screening process, the number of defective items at time t_1 is dQ.
So effective inventory level during $t_1 \le t \le T$ is given by

$$I_r(t) = Q(1-d) - W - (a - \rho p)t - \frac{1}{2}bt^2. \quad (13)$$

Putting t = tr in equation (13), we get

$$Q = \frac{1}{(1-d)}\left[W + (a - \rho p)t_r + \frac{1}{2}bt_r^2\right] \quad (14)$$

Putting t = tr in equations (9) and (10), we get

$$I_0(t_r) = W \quad (15)$$

$$I_0(t_r) = S_1 + (a - \rho p)(\mu_1 - t_r) + \frac{1}{2}b(\mu_1^2 - t_r^2) \quad (16)$$

So from equations (15) and (16), we have

$$S_1 = W - (a - \rho p)(\mu_1 - t_r) - \frac{1}{2}b(\mu_1^2 - t_r^2) \quad (17)$$

Putting t = μ_2 in equations (11) and (12), we get

$$I_0(\mu_2) = \begin{bmatrix} a(\mu_1 - \mu_2) - \rho p(\mu_1 - \mu_2) + \frac{1}{2}a\theta(\mu_1^2 - \mu_2^2) - \frac{1}{2}\rho p\theta(\mu_1^2 - \mu_2^2) + \frac{1}{2}b(\mu_1^2 - \mu_2^2) \\ + \frac{1}{3}b\theta(\mu_1^3 - \mu_2^3) - a\theta t(\mu_1 - \mu_2) + \rho p t(\mu_1 - \mu_2) - \frac{1}{2}b\theta t(\mu_1^2 - \mu_2^2) \end{bmatrix} + S_1(1 + \theta(\mu_1 - \mu_2)) \quad (18)$$

$$I_0(\mu_2) = \begin{bmatrix} a(T - \mu_2) - \rho p(T - \mu_2) + \frac{1}{6}a\theta(T^3 - \mu_2^3) - \frac{1}{6}\rho p\theta(T^3 - \mu_2^3) + \frac{1}{2}b(T^2 - \mu_2^2) \\ + \frac{1}{8}b\theta(T^4 - \mu_2^4) - \frac{1}{2}a\theta\mu_2^2(T - \mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T - \mu_2) - \frac{1}{4}b\theta t^2(T^2 - \mu_2^2) \end{bmatrix} \quad (19)$$

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So from equations (18) and (19), we have

$$T = \frac{1}{b\left(\theta\mu_2^2-2\right)}\left(\begin{array}{l} -2\rho p + \rho p\theta\mu_2^2 + 2a - a\theta\mu_2^2 \\ + \sqrt{\begin{array}{l} 8a\rho p\theta\mu_2^2 + 8b\rho p\theta t_r\mu_2 + 4b\theta^2\mu_2^3 at_r + 2b\theta^2\mu_2^4\rho p - 4b\theta^2\mu_2^2 at_r\mu_1 + 4b\theta\mu_2^2\rho pt_r - 4b\theta\mu_2^2 at_r \\ - 4b\theta^2\mu_2^2 W\mu_1 - 2b\theta^2\mu_2^2\rho p\mu_1^2 + 4b\theta^2\mu_2^2\rho pt_r\mu_1 - 4b\theta^2\mu_2^3\rho pt_r - 4\rho^2p^2\theta\mu_2^2 + 4\rho^2p^2 \\ + 4a^2 + 4b^2t_r^2 + 8bW + a^2\theta^2\mu_2^4 - 8a\rho p + 8abt_r - 4ab\theta\mu_1^2 + 2b\theta^2\mu_2^2 a\mu_1^2 + 4b\theta\rho p\mu_1^2 \\ - 8b\theta\rho pt_r\mu_1 + \rho^2p^2\theta^2\mu_2^4 - 4a^2\theta\mu_2^2 - 2a\rho p\theta^2\mu_2^4 - 8b\rho pt_r + 8ab\theta t_r\mu_1 - 8bW\theta\mu_2 \\ + 8bW\theta\mu_1 + 4ab\theta\mu_2^2 - 4b^2\theta\mu_2\mu_1^2 - 2b^2\theta\mu_2^2t_r^2 + 4b\theta^2\mu_2^3 W - 2ab\theta^2\mu_2^2 + 2b^2\theta^2\mu_2^3\mu_1^2 \\ - 4b\theta\mu_2^2 W - 8ab\theta t_r\mu_2 - 4b\rho p\theta\mu_2^2 \end{array}} \end{array} \right) \quad (20)$$

From equation (20), we see that T is a function of W and t_r, so T is not a decision variable.
Based on the assumptions and descriptions of the model, the total annual relevant profit (π), include the following elements:

(i) Ordering cost (OC) = A

(21)

(ii) Screening cost (SrC) = zQ

(22)

(iii) $HC(RW) = \int_0^{t_1}(x_2+y_2t)I_r(t)dt + \int_{t_1}^{t_r}(x_2+y_2t)I_r(t)dt$

(23)

(iv) $$HC(OW) = \int_0^{t_r}(x_1+y_1t)I_0(t)dt + \int_{t_r}^{\mu_1}(x_1+y_1t)I_0(t)dt + \int_{\mu_1}^{\mu_2}(x_1+y_1t)I_0(t)\,dt + \int_{\mu_2}^{T}(x_1+y_1t)I_0(t)\,dt \quad (24)$$

(v) $$DC = c\left(\int_{\mu_1}^{\mu_2}\theta I_0(t)dt + \int_{\mu_2}^{T}\theta tI_0(t)dt\right) \quad (25)$$

(v) SR = Sum of sales revenue generated by demand meet during the period (0,T)
+ Sales of imperfect quality items

$$= \left(p\int_0^T(a + bt - \rho p)\,dt + p_d dQ\right) = p\left(aT - \rho pT + \frac{1}{2}bT^2\right) + p_d dQ$$

(26)

(by neglecting higher powers of θ)

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

$$\pi = \frac{1}{T}\left[SR - OC - SrC - HC(RW) - HC(OW) - DC\right] \quad (27)$$

Substituting values from equations (21) to (26) in equation (27), we get total profit per unit. Putting $\mu_1 = v_1T$, $\mu_2 = v_2T$ and value of S_1 and T from equation (17) and (20) in equation (26), we get profit in terms of tr and p.
The optimal value of t_r* and p* (say), which maximizes profit (π) can be obtained by solving equation (27) by differentiating it with respect to t_r and p and equate it to zero

$$\text{i.e. } \frac{\partial\pi(t_r,p)}{\partial t_r} = 0, \quad \frac{\partial\pi(t_r,p)}{\partial p} = 0, \quad (28)$$

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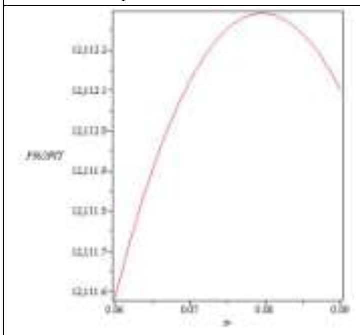
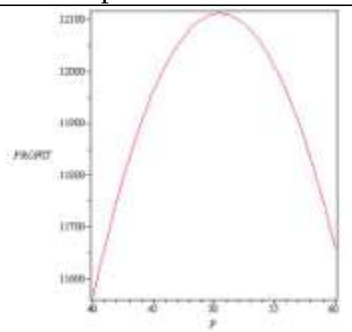
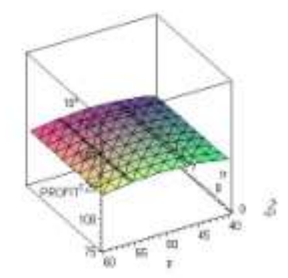
provided it satisfies the condition

$$\begin{vmatrix} \frac{\partial \pi^2 (t_r,p)}{\partial t_r^2} & \frac{\partial \pi^2 (t_r,p)}{\partial t_r \partial p} \\ \frac{\partial \pi^2 (t_r,p)}{\partial p \partial t_r} & \frac{\partial \pi^2 (t_r,p)}{\partial p^2} \end{vmatrix} > 0. \tag{29}$$

4. NUMERICAL EXAMPLE:

Considering A= Rs.100, W = 95, a = 500, b=0.05, c=Rs. 25, ρ= 5, d=0.05, p_d= Rs. 15, λ=10000, θ=0.05, z=Rs. 0.40, x_1=Rs. 2, y_1=0.04, x_2 = Rs. 6, y_2=0.08, v_1=0.30, v_2=0.50, in appropriate units. The optimal value of t_r*=0.0795, p = 50.4781, Profit*=Rs.12112.2914 and Q*=117.0256.

The second order condition given in equation (29) is also satisfied. The graphical representation of the concavity of the profit function is also given.

t_r and Profit	p and Profit	t_r, p and Profit
 Graph 1	 Graph 2	 Graph 3

4. 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 1
Sensitivity Analysis

Parameter	%	t_r	p	Profit	Q
a	+20%	0.0888	60.4563	17565.8073	123.9159
	+10%	0.0848	55.4669	14713.7807	120.5329
	-10%	0.0726	45.4902	9761.3784	113.4257
	-20%	0.0633	40.5032	7661.0821	109.6947
θ	+20%	0.0761	50.4794	12107.5550	116.1660
	+10%	0.0778	50.4788	12109.9179	116.5958
	-10%	0.0813	50.4775	12114.6766	117.4806
	-20%	0.0831	50.4769	12117.0733	117.9357

x_1	+20%	0.0699	50.4879	12090.2029	114.5965
	+10%	0.0747	50.4829	12101.2052	115.8110
	-10%	0.0843	50.4735	12123.4588	118.2402
	-20%	0.0890	50.4689	12134.7049	119.4301
x_2	+20%	0.0682	50.4898	12110.4522	114.1664
	+10%	0.0734	50.4843	12111.3088	115.4820
	-10%	0.0868	50.4710	12113.4315	118.8732
	-20%	0.0955	50.4627	12114.7718	121.0758
A	+20%	0.01050	50.5369	12070.0923	123.4371
	+10%	0.0925	50.5081	12090.9059	120.2961
	-10%	0.0662	50.4467	12134.2997	113.6757
	-20%	0.0525	50.4137	12156.9896	110.2209
ρ	+20%	0.0794	42.1447	10029.0895	116.9616
	+10%	0.0794	45.9326	10975.9891	116.9810
	-10%	0.0796	56.0338	13501.1306	117.0702
	-20%	0.0797	62.9784	15237.2079	117.1149
λ	+20%	0.0796	50.4780	12112.3508	117.0509
	+10%	0.0795	50.4780	12112.3238	117.0509
	-10%	0.0795	50.4782	12112.2518	117.0256
	-20%	0.0795	50.4784	12112.2023	117.0255

From the table we observe that as parameter a increases/ decreases average total profit and order quantity increases/ decreases.
From the table we observe that as parameter θ increases/ decreases there is very minor change in average total profit and order quantity.
From the table we observe that as parameter x_1, x_2, and ρ increases/ decreases average total profit and order quantity decreases/ increases.
From the table we observe that as parameters A increases/ decreases average total profit decreases/ increases and order quantity increases/ decreases.
From the table we observe that as parameter λ increases/ decreases there is almost no change in average total profit and order quantity

6. CONCLUSION:

In this paper, we have developed a two warehouse inventory model for deteriorating items with different deterioration rates under time and price dependent 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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