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Inventory Model with Different Deterioration Rates for Imperfect Quality Items under Price and Time Dependent Demand

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Abstract

Many times it happens that units produced or ordered are not of 100% good quality. A deterministic inventory model with imperfect quality is developed when deterioration rate is different during a cycle. Here it is assumed that demand is a function of price and time. Numerical example is taken to support the model. Sensitivity analysis is also carried out for parameters.

Keywords: Inventory model, Varying Deterioration, Time dependent demand, Price dependent demand, Defective items

1. INTRODUCTION:

Most of the time it is assumed that items can be stored indefinitely to meet the future demand. But many items are such that they 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. An inventory model with constant rate of deterioration was considered by Ghare and Schrader [4]. Covert and Philip [3] extended the model by considering variable rate of deterioration. Aggarwal and Goel [1] discussed an inventory model with weibull rate of decay with selling price dependent demand. Patra et al. [12] developed a deterministic inventory model when deterioration rate was time proportional. Demand rate was taken as a nonlinear function of selling price, deterioration rate, inventory holding cost and ordering cost were all functions of time. The related works are found in (Nahmias [8], Raffat [13], Ruxian, et al [14]).

In classical inventory model it is assumed that all received items are of good quality. But in actual practice some of the items received are not of good quality i.e. they are said to be defective items. Considering this fact, many models have been developed for defective items. An optimal ordering policy for defective items was developed by Lee and Rosenblatt [7]. Cheng [2] developed a model of imperfect production quantity by establishing relationship between demand dependent unit production cost and imperfect production process. An inventory model in which items received are of defective quality and after 100% screening, imperfect items are withdrawn from the inventory and sold at a discounted price was developed by Salameh and Jaber [15]. A simple approach for determining economic production quantity model for imperfect quality items was developed by Goyal and Barron [5]. Papachristos. and Konstantaras [9] have examined models without shortages, probabilistic proportional imperfect quality and withdrawing at the end of planning horizon. Jaber et al. [6] considered an EPQ model for items with imperfect quality subject to learning effects. An EPQ model with disaggregation and consolidation of imperfect quality shipments was developed by Yassine et al. [17]. Patel and Patel [10] developed an EOQ model for deteriorating items with imperfect quantity items. Vishkaei et al. [16] obtained the model for optimum order quantity of product batches that contains defective items with percentage nonconforming following a known probability density function. Patel and Sheikh [11] developed an inventory model with different deterioration rates under stock and price dependent demand.

Generally the products are such that initially there is no deterioration. Deterioration starts after certain time 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 models.

In this paper we have developed an inventory model for imperfect quality items with different deterioration rates under price and time dependent demand. Shortages are not allowed. To illustrate the model, numerical example is provided. Sensitivity analysis for major parameters is also carried out.

2. ASSUMPTIONS AND NOTATIONS:

NOTATIONS:

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

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

c : Purchasing cost per unit

p : Selling price per unit

d : defective items (%)

1-d : good items (%)

λ : Screening rate

SR : Sales revenue

A : Replenishment cost per order for

z : Screening cost per unit

p_d : Price of defective items per unit

h(t) : Variable Holding cost ($x + yt$)

t_1 : Screening time

T : Length of inventory cycle

I(t) : Inventory level at any instant of time t, $0 \leq t \leq T$

Q : Order quantity

θ : Deterioration rate during $\mu_1 \leq t \leq \mu_2$, $0< \theta<1$

θt : Deterioration rate during , $\mu_2 \leq t \leq T$, $0< \theta<1$

π : Total relevant profit per unit time.

ASSUMPTIONS:

The following assumptions are considered for the development of the 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.

3. THE MATHEMATICAL MODEL AND ANALYSIS:

In the following situation, Q items are received at the beginning of the period. Each lot having a d % 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 . 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. 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 $I(t_1)$ and at time T, inventory level will become zero due to demand and partially due to deterioration.

Also here $t_1 = \frac{Q}{\lambda}$ (1)

and defective percentage (d) is restricted to $d \leq 1 - \frac{(a+bt-\rho p)}{\lambda}$ (2)

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

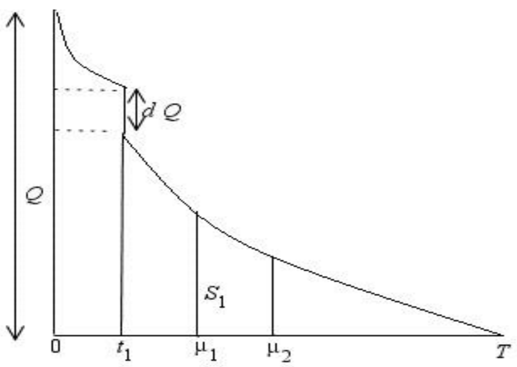


Figure 1

The differential equations which describes the instantaneous states of I(t) over the period (0, T) is given by

$$\frac{dI(t)}{dt} = -(a + bt + \rho p), \qquad 0 \le t \le \mu_1 \qquad (3)$$

$$\frac{dI(t)}{dt} + \theta I(t) = -(a + bt + \rho p), \qquad \mu_1 \le t \le \mu_2 \qquad (4)$$

$$\frac{dI(t)}{dt} + \theta t I(t) = -(a + bt + \rho p), \qquad \mu_2 \le t \le T \qquad (5)$$

with initial conditions I(0) = Q, I(μ_1) = S_1 and I(T) = 0.

Solutions of these equations are given by

$$I(t) = Q - (at - \rho pt + \frac{1}{2}bt^2), \qquad (6)$$

$$I(t) = \left[\begin{array}{l} a(\mu_1 - t) - \rho p(\mu_1 - t) + \frac{1}{2}a\theta(\mu_1^2 - t^2) - \frac{1}{2}\rho p\theta(\mu_1^2 - t^2) + \frac{1}{2}b(\mu_1^2 - t^2) \\ + \frac{1}{3}b\theta(\mu_1^3 - t^3) - a\theta t(\mu_1 - t) + \rho p\theta t(\mu_1 - t) - \frac{1}{2}b\theta t(\mu_1^2 - t^2) \end{array}\right] + S_1\left[1 + \theta(\mu_1 - t)\right] \qquad (7)$$

$$I(t) = \left[\begin{array}{l} a(T - t) - \rho p(T - t) + \frac{1}{2}b(T^2 - t^2) + \frac{1}{6}a\theta(T^3 - t^3) - \frac{1}{6}\rho p\theta(T^3 - t^3) \\ + \frac{1}{8}b\theta(T^4 - t^4) - \frac{1}{2}a\theta t^2(T - t) + \frac{1}{2}\rho p\theta t^2(T - t) - \frac{1}{4}b\theta t^2(T^2 - t^2) \end{array}\right]. \qquad (8)$$

(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

$$I(t) = Q(1 - d) - (at - \rho pt + \frac{1}{2}bt^2). \qquad (9)$$

From equation (6), putting t = μ_1, we have

$$Q = S_1 + \left(a\mu_1 - \rho p\mu_1 + \frac{1}{2}b\mu_1^2\right). \qquad (10)$$

From equations (7) and (8), putting t = μ_2, we have

$$I(\mu_2) = \left[\begin{array}{l} a(\mu_1 - \mu_2) - \rho p(\mu_1 - \mu_2) + \frac{1}{2}a\theta(\mu_1^2 - \mu_2^2) - \frac{1}{2}\rho p\theta(\mu_1^2 - \mu_2^2) + \frac{1}{2}b(\mu_1^2 - \mu_2^2) \\ + \frac{1}{3}b\theta(\mu_1^3 - \mu_2^3) - a\theta\mu_2(\mu_1 - \mu_2) + \rho p\theta\mu_2(\mu_1 - \mu_2) - \frac{1}{2}b\theta\mu_2(\mu_1^2 - \mu_2^2) \end{array}\right] + S_1\left[1 + \theta(\mu_1 - \mu_2)\right] \quad (11)$$

$$I(\mu_2) = \left[\begin{array}{l} a(T - \mu_2) - \rho p(T - \mu_2) + \frac{1}{2}b(T^2 - \mu_2^2) + \frac{1}{6}a\theta(T^3 - \mu_2^3) - \frac{1}{6}\rho p\theta(T^3 - \mu_2^3) \\ + \frac{1}{8}b\theta(T^4 - \mu_2^4) - \frac{1}{2}a\theta\mu_2^2(T - \mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T - \mu_2) - \frac{1}{4}b\theta\mu_2^2(T^2 - \mu_2^2) \end{array}\right]. \quad (12)$$

So from equations (11) and (12), we get

$$S_1 = \frac{1}{\left[1 + \theta(\mu_1 - \mu_2)\right]} \left[\begin{array}{l} a(T - \mu_2) - \rho p(T - \mu_2) + \frac{1}{2}b(T^2 - \mu_2^2) + \frac{1}{6}a\theta(T^3 - \mu_2^3) - \frac{1}{6}\rho p\theta(T^3 - \mu_2^3) \\ + \frac{1}{8}b\theta(T^4 - \mu_2^4) - \frac{1}{2}a\theta\mu_2^2(T - \mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T - \mu_2) - \frac{1}{4}b\theta\mu_2^2(T^2 - \mu_2^2) \\ - a(\mu_1 - \mu_2) + \rho p(\mu_1 - \mu_2) - \frac{1}{2}a\theta(\mu_1^2 - \mu_2^2) + \frac{1}{2}\rho p\theta(\mu_1^2 - \mu_2^2) - \frac{1}{2}b(\mu_1^2 - \mu_2^2) \\ - \frac{1}{3}b\theta(\mu_1^3 - \mu_2^3) + a\theta\mu_2(\mu_1 - \mu_2) - \rho p\theta\mu_2(\mu_1 - \mu_2) + \frac{1}{2}b\theta\mu_2(\mu_1^2 - \mu_2^2) \end{array}\right]. \quad (13)$$

Putting value of S_1 from equation (13) into equation (7), we have

$$I(t) = \frac{\left\lfloor 1 + \theta(\mu_1 - t)\right\rfloor}{\left[1 + \theta(\mu_1 - \mu_2)\right]} \left[\begin{array}{l} a(T - \mu_2) - \rho p(T - \mu_2) + \frac{1}{2}b(T^2 - \mu_2^2) + \frac{1}{6}a\theta(T^3 - \mu_2^3) - \frac{1}{6}\rho p\theta(T^3 - \mu_2^3) \\ + \frac{1}{8}b\theta(T^4 - \mu_2^4) - \frac{1}{2}a\theta\mu_2^2(T - \mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T - \mu_2) - \frac{1}{4}b\theta\mu_2^2(T^2 - \mu_2^2) \\ - a(\mu_1 - \mu_2) + \rho p(\mu_1 - \mu_2) - \frac{1}{2}a\theta(\mu_1^2 - \mu_2^2) + \frac{1}{2}\rho p\theta(\mu_1^2 - \mu_2^2) - \frac{1}{2}b(\mu_1^2 - \mu_2^2) \\ - \frac{1}{3}b\theta(\mu_1^3 - \mu_2^3) + a\theta\mu_2(\mu_1 - \mu_2) - \rho p\theta\mu_2(\mu_1 - \mu_2) + \frac{1}{2}b\theta\mu_2(\mu_1^2 - \mu_2^2) \end{array}\right] \quad (14)$$

$$+ \left[\begin{array}{l} a(\mu_1 - t) - \rho p(\mu_1 - t) + \frac{1}{2}a\theta(\mu_1^2 - t^2) - \frac{1}{2}\rho p\theta(\mu_1^2 - t^2) + \frac{1}{2}b(\mu_1^2 - t^2) \\ + \frac{1}{3}b\theta(\mu_1^3 - t^3) - a\theta t(\mu_1 - t) + \rho p\theta t(\mu_1 - t) - \frac{1}{2}b\theta t(\mu_1^2 - t^2) \end{array}\right].$$

Similarly putting value of S1 from equation (13) in equation (10), we have

$$Q = \frac{1}{\left[1+\theta(\mu_1-\mu_2)\right]}\left[\begin{array}{l} a(T-\mu_2) - \rho p(T-\mu_2) + \frac{1}{2}b\left(T^2-\mu_2^2\right) + \frac{1}{6}a\theta\left(T^3-\mu_2^3\right) - \frac{1}{6}\rho p\theta\left(T^3-\mu_2^3\right) \\ + \frac{1}{8}b\theta\left(T^4-\mu_2^4\right) - \frac{1}{2}a\theta\mu_2^2(T-\mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T-\mu_2) - \frac{1}{4}b\theta\mu_2^2\left(T^2-\mu_2^2\right) \\ - a(\mu_1-\mu_2) + \rho p(\mu_1-\mu_2) - \frac{1}{2}a\theta\left(\mu_1^2-\mu_2^2\right) + \frac{1}{2}\rho p\theta\left(\mu_1^2-\mu_2^2\right) - \frac{1}{2}b\left(\mu_1^2-\mu_2^2\right) \\ - \frac{1}{3}b\theta\left(\mu_1^3-\mu_2^3\right) + a\theta\mu_2(\mu_1-\mu_2) - \rho p\theta\mu_2(\mu_1-\mu_2) + \frac{1}{2}b\theta\mu_2\left(\mu_1^2-\mu_2^2\right) \end{array}\right] + \left(a\mu_1 - \rho p\mu_1 + \frac{1}{2}b\mu_1^2\right). \quad (15)$$

Using (14) in (6), we have

$$I(t) = \frac{1}{\left[1+\theta(\mu_1-\mu_2)\right]}\left[\begin{array}{l} a(T-\mu_2) - \rho p(T-\mu_2) + \frac{1}{2}b\left(T^2-\mu_2^2\right) + \frac{1}{6}a\theta\left(T^3-\mu_2^3\right) - \frac{1}{6}\rho p\theta\left(T^3-\mu_2^3\right) \\ + \frac{1}{8}b\theta\left(T^4-\mu_2^4\right) - \frac{1}{2}a\theta\mu_2^2(T-\mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T-\mu_2) - \frac{1}{4}b\theta\mu_2^2\left(T^2-\mu_2^2\right) \\ - a(\mu_1-\mu_2) + \rho p(\mu_1-\mu_2) - \frac{1}{2}a\theta\left(\mu_1^2-\mu_2^2\right) + \frac{1}{2}\rho p\theta\left(\mu_1^2-\mu_2^2\right) - \frac{1}{2}b\left(\mu_1^2-\mu_2^2\right) \\ - \frac{1}{3}b\theta\left(\mu_1^3-\mu_2^3\right) + a\theta\mu_2(\mu_1-\mu_2) - \rho p\theta\mu_2(\mu_1-\mu_2) + \frac{1}{2}b\theta\mu_2\left(\mu_1^2-\mu_2^2\right) \end{array}\right] + \left(a(\mu_1-t) - \rho p(\mu_1-t) + \frac{1}{2}b\left(\mu_1^2-t^2\right)\right). \quad (16)$$

Similarly, using (15) in (9), we have

$$I(t) = \frac{(1-d)}{\left[1+\theta(\mu_1-\mu_2)\right]}\left[\begin{array}{l} a(T-\mu_2) - \rho p(T-\mu_2) + \frac{1}{2}b\left(T^2-\mu_2^2\right) + \frac{1}{6}a\theta\left(T^3-\mu_2^3\right) - \frac{1}{6}\rho p\theta\left(T^3-\mu_2^3\right) \\ + \frac{1}{8}b\theta\left(T^4-\mu_2^4\right) - \frac{1}{2}a\theta\mu_2^2(T-\mu_2) + \frac{1}{2}\rho p\theta\mu_2^2(T-\mu_2) - \frac{1}{4}b\theta\mu_2^2\left(T^2-\mu_2^2\right) \\ - a(\mu_1-\mu_2) + \rho p(\mu_1-\mu_2) - \frac{1}{2}a\theta\left(\mu_1^2-\mu_2^2\right) + \frac{1}{2}\rho p\theta\left(\mu_1^2-\mu_2^2\right) - \frac{1}{2}b\left(\mu_1^2-\mu_2^2\right) \\ - \frac{1}{3}b\theta\left(\mu_1^3-\mu_2^3\right) + a\theta\mu_2(\mu_1-\mu_2) - \rho p\theta\mu_2(\mu_1-\mu_2) + \frac{1}{2}b\theta\mu_2\left(\mu_1^2-\mu_2^2\right) \end{array}\right] + (1-d)\left(a\mu_1 - \rho p\mu_1 + \frac{1}{2}b\mu_1^2\right) - (at - \rho pt + \frac{1}{2}bt^2). \quad (17)$$

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

(i) Ordering cost (OC) = A (18)

(ii) Screening cost (SrC) = zQ (19)

(iii) $HC = \int_0^T (x+yt)I(t)dt$

$$= \int_0^{t_1} (x+yt)I(t)dt + \int_{t_1}^{\mu_1} (x+yt)I(t)dt + \int_{\mu_1}^{\mu_2} (x+yt)I(t)dt + \int_{\mu_2}^{T} (x+yt)I(t)dt \quad (20)$$

(iv) $DC = c\left(\int_{\mu_1}^{\mu_2} \theta I(t)dt + \int_{\mu_2}^{T} \theta t I(t)dt\right)$ (21)

(vi) $SR = \left(p\int_0^T (a + bt - \rho p)dt + p_d dQ \right).$ (22)

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

$$\pi = \frac{1}{T}\left[SR - OC - SrC - HC - DC\right] \quad (23)$$

Substituting values from equations (18) to (22) in equation (23), we get total profit per unit. Putting $\mu_1 = v_1T$ and $\mu_2 = v_2T$ and value of t_1 and Q in equation (23), we get profit in terms of T. Differentiating equation (23) with respect to T and equate it to zero, we have

$$\text{i.e. } \frac{\partial \pi(T,p)}{\partial T} = 0, \ \frac{\partial \pi(T,p)}{\partial p} = 0 \quad (24)$$

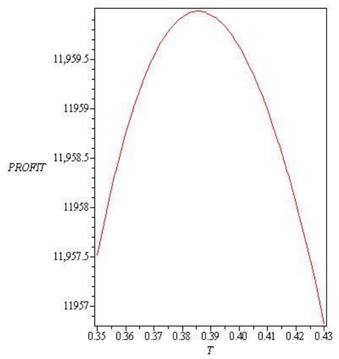
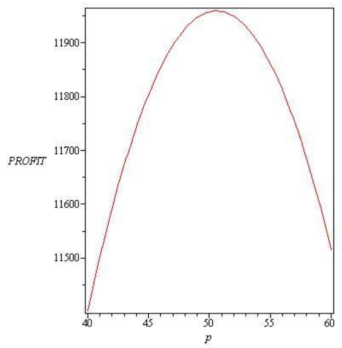
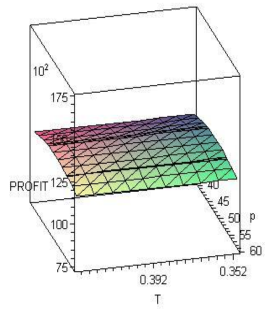
provided it satisfies the condition

$$\begin{vmatrix} \frac{\partial^2 \pi(T,p)}{\partial T^2} & \frac{\partial^2 \pi(T,p)}{\partial p \partial T} \\ \frac{\partial^2 \pi(T,p)}{\partial T \partial p} & \frac{\partial^2 \pi(T,p)}{\partial p^2} \end{vmatrix} > 0. \quad (25)$$

4. NUMERICAL EXAMPLE:

Considering A= Rs.100, a = 500, b=0.05, c=Rs. 25, p_d = 15, d= 0.02, z = 0.40, λ= 10000, θ=0.05, x = Rs. 5, y=0.05, v_1=0.30, v_2 = 0.50, in appropriate units. The optimal value of T*=0.3855, p* = 50.5668, Profit*= Rs. 11959.9902 and optimum order quantity Q*=94.5667.

The second order conditions given in equation (25) are also satisfied. The graphical representation of the concavity of the profit function is also given.

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

5. 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	p	Profit	Q
a	+20%	0.3520	60.5213	17405.8696	104.9617
	+10%	0.3676	55.5425	14557.3647	100.3744
	-10%	0.4063	45.5952	9613.9243	89.8919
	-20%	0.4310	40.6289	7519.3985	85.1357
θ	+20%	0.3821	50.5697	11956.2255	94.7705
	+10%	0.3838	50.5683	11958.1031	95.1687
	-10%	0.3872	50.5653	11961.8870	95.9641
	-20%	0.3890	50.5639	11963.7937	96.3857

x	+20%	0.3551	50.6135	11914.7047	87.9226
	+10%	0.3694	50.5907	11936.8764	91.5175
	-10%	0.4039	50.5419	11984.1744	100.1959
	-20%	0.4252	50.5156	12009.5893	105.5575
A	+20%	0.4217	50.6164	11910.4427	104.4718
	+10%	0.4040	50.5922	11934.6613	100.1189
	-10%	0.3660	50.5402	11986.6007	90.7650
	-20%	0.3454	50.5120	12014.7135	85.6891
ρ	+20%	0.3859	42.2339	9876.8970	95.4458
	+10%	0.3857	46.0215	10823.7429	95.5065
	-10%	0.3853	56.1223	13348.7725	95.6265
	-20%	0.3851	63.0666	15084.7906	95.6864
λ	+20%	0.3855	50.5667	11960.0297	95.5669
	+10%	0.3855	50.5668	11960.0117	95.5667
	-10%	0.3855	50.5669	11959.9638	95.5665
	-20%	0.3855	50.5670	11959.9309	95.5663

From the table we observe that as parameter a increases/ decreases average total profit and optimum order quantity also increases/ decreases.

Also, we observe that with increase and decrease in the value of θ, x and ρ, there is corresponding decrease/ increase in total profit and optimum order quantity.

From the table we observe that as parameter A increases/ decreases average total profit decreases/ increases and optimum 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 optimum order quantity.

6. CONCLUSION

In this paper, we have developed an inventory model for deteriorating items with price and time dependent demand with different deterioration rates. Sensitivity with respect to parameters have 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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