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EOQ Model for Weibull Deteriorating Items with Imperfect Quality, Shortages and Time Varying Holding Cost Under Permissable Delay in Payments

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Abstract

In this paper a deterministic inventory model with imperfect quality have been developed for deteriorating items with two parameters Weibull distribution deterioration and time dependent holding cost. Shortages are allowed and are completely backlogged. The model has been framed to study the items whose deterioration rate increase with time under permissible delay in payments with imperfect quality. Numerical example and sensitivity analysis is taken to support the model.

Keywords: Inventory, Deterioration, Shortages, EOQ, Time varying holding cost, Permissible delay in payment

1. INTRODUCTION:

Deterioration of physical items during storage is a common phenomenon. Most of the products in real life are subject to significant rate of deterioration. For example, the commonly used goods like fruits, vegetables, electronic components, etc. where deterioration is usually observed during their normal storage period. Therefore, if the rate of deterioration is not sufficiently low, its impact on modeling of such an inventory system cannot be ignored.

Inventory models for deteriorating item was first studies by Whitin [14]. Ghare and Schrader [3] studied inventory model with constant rate of deterioration. An order level inventory model for items deteriorating at a constant rate was presented by Shah and Jaiswal [11], Aggarwal [1]. Wee et al. (2007) developed an optimal inventory model for ites with imperfect quality and shortage backordering. Tripathy et al. [13] considered an inventory model with constant demand and linear deterioration rate.

Raafat [10], Goyal and Giri [5] made a literature review of deteriorating inventory items.

Many times the supplier offers a permissible credit period to the retailer if the outstanding amount is paid within the allowable fixed period and the order quantity is large. The credit period is treated as a promotional tool to attract more customers. An EOQ model under the conditions of permissible delay in payments was considered by Goyal [4]. The model was extended by considering the interest earned from the sales revenue by Mandal and Phaujdar [9]. Teng [12] amended Goyal's [4] model by identifying the difference between unit price and unit cost. Chang et al. [2] established EOQ model with deteriorating items under supplier trade credits linked to order quantity. Shah [11] derived an inventory model by assuming constant rate of deterioration of units in an inventory, time value of money under the conditions of permissible delay in payments. Recently, Huang [6] developed EOQ model in which the supplier offers a partially permissible delay in payments when the order quantity is smaller than the predetermined quantity. Jaggi et al. [7] developed an inventory model for deteriorating items with imperfect quality under permissible delay in payment.

In this paper we have developed EOQ model with imperfect quality for deteriorating items with two parameters Weibull distribution deterioration and time dependent holding cost. Shortages are allowed and are completely backlogged. The model has been framed to study the items whose deterioration rate increase with time under permissible delay in payments with imperfect quality. Numerical example and sensitivity analysis is also done.

2. NOTATIONS AND ASSUMPTIONS:

To develop the proposed model, following notations and assumptions are used:

NOTATIONS:

D	: Rate of demand
d	: defective items (%)
1-d	: good items (%)
λ	: Screening rate
I(t)	: Inventory level at time t
Q_1	: Inventory level initially
Q_2	: Shortage of inventory
Q	: Order quantity
$\alpha\beta t^{\beta-1}$	: Deterioration rate, $0<\alpha<1$ and $\beta>0$.
SR	: Sales revenue
OC	: Ordering cost
SrC	: Screening cost
SC	: Shortage cost
DC	: Deterioration cost
Z	: Screening cost per unit
p	: Selling price per unit
p_d	: Price of defective items per unit

c	: Purchasing cost per unit
I_p	: Interest paid per unit
I_e	: Interest earned per unit
t_1	: Screening time
t_2	: Zero level inventory time
T	: Inventory cycle length
M	: Permissible delay in settling the accounts
h(t)	: Variable Holding cost (x + yt)
$\pi_1(T)$	: Total profit for case I, ($t_1 \leq M \leq t_2$)
$\pi_2(T)$	: Total profit for case II, ($t_1 \leq t_2 \leq M$)

ASSUMPTIONS:

The following are the assumptions applied in the development of the model:

- The rate of demand of the product is known constant and continuous.
- Replenishment rate is instantaneous.
- The lead time is zero.
- Shortages are allowed and are completely backlogged.
- The screening process and demand proceeds simultaneously but screening rate (λ) is greater than the demand rate (D) i.e. λ>D.
- 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 such that screening time (t_1) is always less than the permissible delay period (M) i.e. $t_1 \leq M$. In general, this assumption should be acceptable since the automatic screening machine usually takes only little time to inspect all items produced or purchased.
- During the time, the account is not settled; generated sales revenue is deposited in an interest bearing account. At the end of the credit period, the account is settled as well as the buyer pays off all units sold and starts paying for the interest charges on the items in stocks.

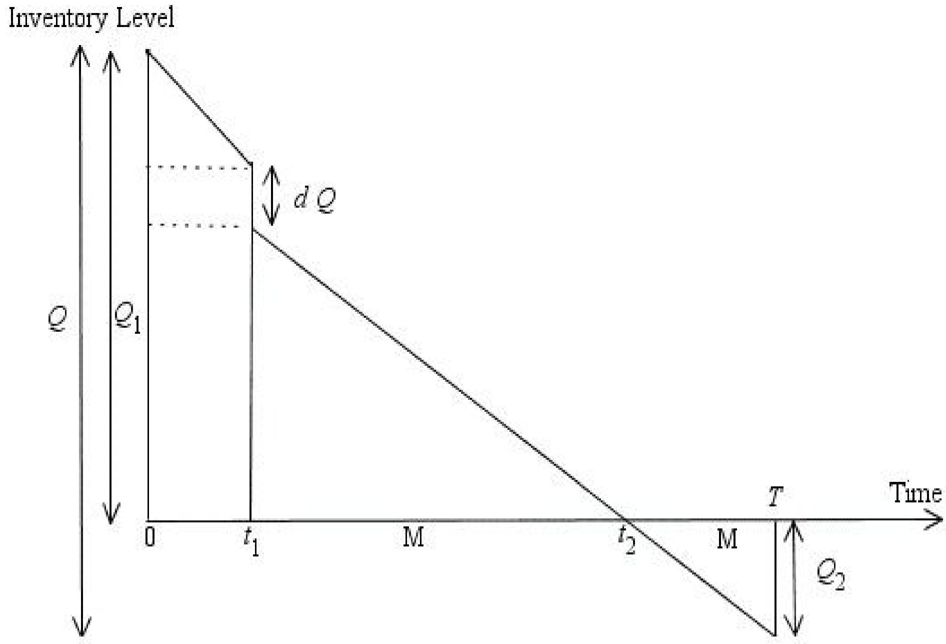
3. THE MODEL ANALYSIS:

At time t=0, a lot size of Q units enters the system. 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 quantity at the rate of λ units per unit time which is greater than demand rate D. After screening, a portion is used to meet the backlogging items towards previous shortages and initial inventory for period is Q_1. During the screening process the demand occurs parallel to the screening process and is fulfilled from goods which are found to be of perfect quality by the 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_2, inventory level will become zero due to demand and partially due to deterioration. Shortages occur during the period t_2 to T and of size Q_2 units at the rate D.

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

and defective percentage (d) is restricted to

$d \le 1 - \dfrac{D}{\lambda}$ (2)



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

The differential equations which describes the instantaneous states of I(t) over the period (0, t_2) is given by

$$\frac{dI(t)}{dt} + \alpha\beta t^{\beta-1} I(t) = -D, \quad 0 \le t \le t_2, \tag{3}$$

with the boundary conditions t = 0, I(0) = Q_1.

The solution of equation (3) using boundary conditions is:

$$I(t) = -D\left[t - \frac{\alpha\beta t^{\beta+1}}{\beta+1}\right] + \left(1 - \alpha t^{\beta}\right)Q_1. \tag{4}$$

After screening process, the number of defective items at t_1 is dQ. So the effective inventory level during $t_1 \le t \le t_2$ is

$$I(t) = -D\left[t - \frac{\alpha\beta\, t^{\beta+1}}{\beta+1}\right] + \left(1-\alpha\, t^{\beta}\right)Q_1 - dQ,\ t_1 \le t \le t_2. \tag{5}$$

At $t = t_2$, $I(t_2) = 0$, equation (5) gives order quantity as:

$$Q_1 = \frac{D\left[t_2 - \frac{\alpha\beta}{\beta+1} t_2^{\beta+1}\right]}{\left(1 - \alpha t_2^{\beta}\right)} + \frac{dQ}{\left(1 - \alpha t_2^{\beta}\right)}. \tag{6}$$

Similarly during (t_1, t_2), the shortages occurs of size Q_2. $I(t)$ is governed by the following differential equation:

$$\frac{dI(t)}{dt} = -D,\ t_2 \le t \le T, \tag{7}$$

with boundary condition $I(t_2) = 0$.

The solution of equation (7) using boundary conditions is:

$$I(t) = -D(t - t_2),\ t_2 \le t \le T. \tag{8}$$

And the shortage quantity is given by

$$Q_2 = D(T - t_2). \tag{9}$$

The retailer's total profit per unit during a cycle $\pi_j(T)$, j=1, 2 is consisted of the following:

$$\pi_j(T) = \frac{1}{T}\left[\begin{array}{l}\text{Sales revenue + Interest earned - Ordering cost}\\ \text{- Purchasing cost - Screening cost - Holding cost}\\ \text{- Shortage cost - Deterioration cost - Interest paid.}\end{array}\right] \tag{10}$$

Individual costs are now evaluated before they are grouped together as total profit.

1. Total Sales Revenue (SR) = Sum of revenue generated by the demand meet during the time period (0, T) and Sales of imperfect quantity items

$= p(1-d)Q + p_d dQ$ (11)

2. Ordering cost (OC) = A (12)
3. Purchasing cost (PC) = cQ (13)
4. Screening cost (SC) = zQ (14)
5. Holding cost during the period 0 to t_1 and t_1 to t_2 is

$$HC = \left[\int_0^{t_1} h(t)I(t)dt + \int_{t_1}^{t_2} h(t)I(t)dt\right]$$

$$= \left[\int_0^{t_1} (x + yt)I(t)dt + \int_{t_1}^{t_2} (x + yt)I(t)dt\right]$$

$$= \left[\begin{array}{l} \int_0^{t_1}(x+yt)\left[-D\left[t-\frac{\alpha\beta\,t^{\beta+1}}{\beta+1}\right]+\left(1-\alpha\,t^{\beta}\right)Q_1\right]dt \\ +\int_{t_1}^{t_2}(x+yt)\left[-D\left[t-\frac{\alpha\beta\,t^{\beta+1}}{\beta+1}\right]+\left(1-\alpha\,t^{\beta}\right)Q_1-dQ\right]dt \end{array}\right]$$

$$= \left[\begin{array}{l} -D\left[x\left\{\frac{t_2^2}{2}-\frac{\alpha\beta t_2^{\beta+2}}{(\beta+1)(\beta+2)}\right\}+y\left\{\frac{t_2^3}{3}-\frac{\alpha\beta t_2^{\beta+3}}{(\beta+1)(\beta+3)}\right\}\right] \\ +Q_1\left[x\left\{t_2-\frac{\alpha t_2^{\beta+1}}{(\beta+1)}\right\}+y\left\{\frac{t_2^2}{2}-\frac{\alpha t_2^{\beta+2}}{(\beta+2)}\right\}\right] \\ -Q\left[xd(t_2-t_1)+\frac{1}{2}yd(t_2^2-t_1^2)\right] \end{array}\right] \tag{15}$$

6. Shortage cost is

$$SC = -c_2\int_{t_2}^{T} I(t)dt = -c_2\int_{t_2}^{T} -D(t-t_2)dt$$

$$= c_2D[\frac{1}{2}T^2+\frac{1}{2}t_2^2-t_2T] \tag{16}$$

7. Deterioration cost is given by

$$DC = c\left[Q_1-\int_0^{t_2} Ddt\right]$$

$$= c\left[\frac{D\left[t_2-\frac{\alpha\beta t_2^{\beta+1}}{\beta+1}\right]}{(1-\alpha t_2^{\beta})}+\frac{dQ}{(1-\alpha t_2^{\beta})}-Dt_2\right]$$

$$= c\left[\frac{D\left[t_2-\frac{\alpha\beta t_2^{\beta+1}}{\beta+1}\right]}{(1-\alpha t_2^{\beta})}+\frac{d\left[D\left[t_2-\frac{\alpha\beta t_2^{\beta+1}}{\beta+1}\right]+D(T-t_2)(1-\alpha t_2^{\beta})\right]}{(1-\alpha t_2^{\beta})(1-\alpha t_2^{\beta}-d)}-Dt_2\right] \tag{17}$$

To determine the interest payable and interest earned per unit, there will be two cases that is case I: ($t_1\leq M\leq t_2$) and case II: ($t_1\leq M\leq t_2$).

Case I: ($t_1\leq M\leq t_2$):

In this case the retailer can earn interest on revenue generated from the sales up to M. Although, he has to settle the accounts at M, for that he has to arrange money at some specified rate of interest in order to get his remaining stocks financed for the period M to t_2.

8. Interest earned has got two parts:

Part-I: In the first part, one can earn interest till the time period (M),

$$= pI_e \int_0^M Dtdt = pI_e \left[\frac{1}{2} DM^2 \right]. \tag{18}$$

Part-II: Second part includes the interest earned on defective items for the time period $(M - t_1)$

$$= [p_d I_e dQ(M - t_1)]. \tag{19}$$

Hence from (18) and (19)

$$\text{Total interest earned } (IE_1) = pI_e \left[\frac{1}{2} DM^2 \right] + [p_d I_e dQ(M - t_1)]. \tag{20}$$

9. Interest payable for the inventory not sold after the due period M is

$$\text{Interest paid } (IP_1) = cI_p \int_M^{t_2} I(t)dt$$

$$\begin{aligned} &= cI_p \int_M^{t_2} \left[-D\left[t - \frac{\alpha\beta\, t^{\beta+1}}{\beta+1} \right] + \left(1 - \alpha\, t^{\beta}\right) Q_1 - dQ \right] dt \\ &= cI_p \left[-D\left[\frac{1}{2} t_2^2 - \frac{\alpha\beta t_2^{\beta+2}}{(\beta+1)(\beta+2)} \right] + Q_1\left[t_2 - \frac{\alpha t_2^{\beta+1}}{(\beta+1)} \right] - dQt_2 \right] \\ &\quad - cI_p \left[-D\left[\frac{1}{2} M^2 - \frac{\alpha\beta M^{\beta+2}}{(\beta+1)(\beta+2)} \right] + Q_1\left[M - \frac{\alpha M^{\beta+1}}{(\beta+1)} \right] - dQM \right]. \end{aligned} \tag{21}$$

Substituting values from equations (11) to (17), (20), (21) in equation (10) the total profit per unit becomes:

$$\pi_1(T) = \frac{1}{T}\left[SR + IE_1 - OC - PC - HC - SC - DC - IP_1\right] \tag{22}$$

Differentiating equation (22) with respect to t_2 and T and equate it to zero, we have

$$\frac{\partial \pi_1(t_2, T)}{\partial T} = 0, \; \frac{\partial \pi_1(t_2, T)}{\partial t_2} = 0. \tag{23}$$

By solving equation (23) for t_2 and T, we obtain the optimal cycle length $t_2 = t_2^*$ and $T = T^*$ provided it satisfies equation

$$\frac{\partial^2 \pi_1(t_2,T)}{\partial T^2} < 0, \ \frac{\partial^2 \pi_1(t_2,T)}{\partial t_2^2} < 0 \ \text{and}$$

$$\left[\frac{\partial^2 \pi_1(t_2,T)}{\partial T^2}\right]\left[\frac{\partial^2 \pi_1(t_2,T)}{\partial t_2^2}\right] - \left[\frac{\partial^2 \pi_1(t_2,T)}{\partial T \partial t_2}\right]^2 > 0. \tag{24}$$

Case II: ($t_1 \le t_2 \le M$):
In this case, the retailer earns interest on the sales revenue up to the permissible delay period and no interest is payable during this period for the items kept in stock. So

10. Interest earned per cycle has two parts:
Part-I: First part, one can earn interest till the time period M.

$$= pI_e\left[\int_0^{t_2} Dtdt + Dt_2(M\text{-}t_2)\right] = pI_e\left[\frac{1}{2}Dt_2^2 + Dt_2(M - t_2)\right]. \tag{25}$$

Part-II: Second part includes the interest earned on defective items till the time period M

$$= [p_d I_e dQ(t_2 - t_1) + p_d I_e dQ(M - t_2)] \tag{26}$$

Total interest earned (IE_2)

$$= pI_e\left[\frac{1}{2}Dt_2^2 + Dt_2(M - t_2)\right] + [p_d I_e dQ(t_2 - t_1) + p_d I_e dQ(M - t_2)]. \tag{27}$$

11. Interest payable (IP_2) = 0 (28)

Substituting values from equations (11) to (17), (27), (28) in equation (10) the total profit per unit becomes:

$$\pi_2(T) = \frac{1}{T}\left[SR + IE_2 - OC - PC - HC - SC - DC - IP_2\right] \tag{29}$$

Differentiating equation (29) with respect to t_2 and T and equate it to zero, we have

$$\frac{\partial \pi_2(t_2,T)}{\partial T} = 0, \ \frac{\partial \pi_2(t_2,T)}{\partial t_2} = 0, \tag{30}$$

By solving equation (30) for t_2 and T, we obtain the optimal cycle length $t_2=t_2^*$ and T = T* provided it satisfies equation

$$\frac{\partial^2 \pi_2(t_2,T)}{\partial T^2} < 0, \ \frac{\partial^2 \pi_2(t_2,T)}{\partial t_2^2} < 0 \ \text{and}$$

$$\left[\frac{\partial^2 \pi_2(t_2,T)}{\partial T^2}\right]\left[\frac{\partial^2 \pi_2(t_2,T)}{\partial t_2^2}\right] - \left[\frac{\partial^2 \pi_2(t_2,T)}{\partial T \partial t_2}\right]^2 > 0. \tag{31}$$

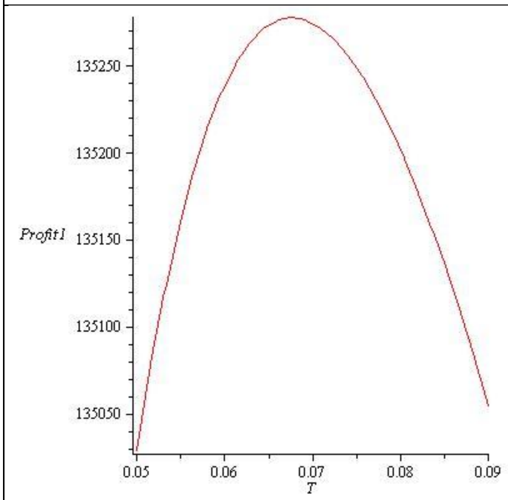
4. NUMERICAL EXAMPLE:

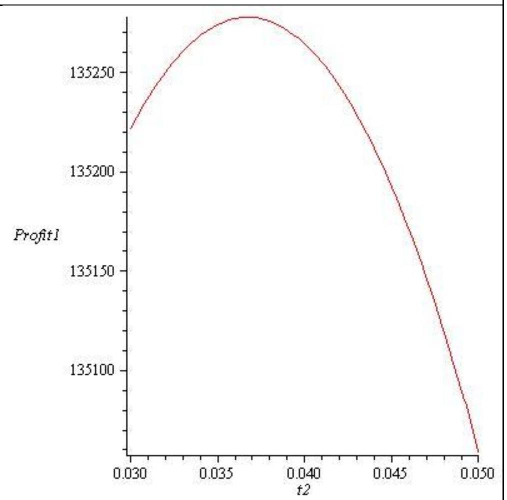
Case I: Considering D = 10000 units per year, A= Rs 100 units per year, c = Rs. 25 per unit, p = Rs 40 per unit, I_p = Rs 0.15 per year, I_e=0.12 per year, M = 0.02 years, α = 0.04, β=2, z= 0.5, d = 0.02, p_d= 15, λ = 1, 75, 200. Then we obtained the optimal value of t_1* = 0.0039, t_2* = 0.0367, T*=0.0676, and the optimal total profit $\pi_1(T^*)$ = Rs. 135277.9751 and the optimum order quantity Q_1* = 380.8034, Q_2* = 309.00, Q*= 689.8034.

Case II: Considering D = 10000 units per year, A= Rs 100 units per year, c = Rs. 25 per unit, p = Rs 40 per unit, I_p = Rs 0.15 per year, I_e=0.12 per year, M = 0.05 years, α = 0.04, β=2, z= 0.5, d = 0.02, p_d= 15, λ = 1, 75, 200. Then we obtained the optimal value of t_1* = 0.0035, t_2* = 0.0413, T*=0.0617, and the optimal total profit $\pi_1(T^*)$ = Rs. 136124.7823 and the optimum order quantity Q_1* = 425.6022, Q_2* = 204.00, Q*= 629.6022.

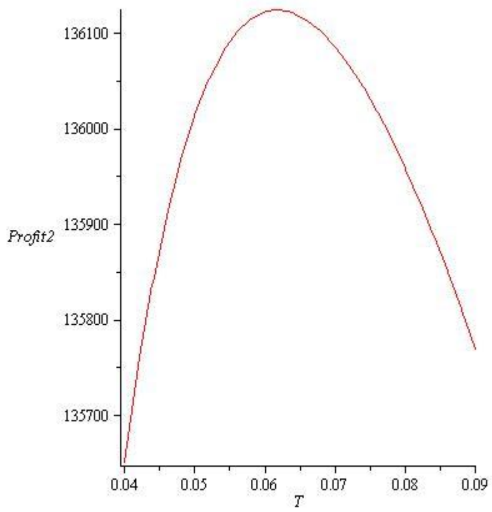
The second order conditions given in equations (24) and (31) are also satisfied. The graphical representation of the concavity of the cost function for the two cases is also given.

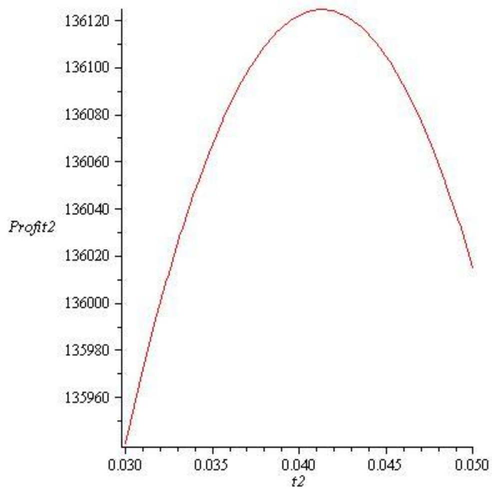
Case I	
T and Profit	t_2 and Profit





Case II	
T and Profit	t_2 and Profit





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.

Sensitivity Analysis Table
Case I: ($t_1 \leq M \leq t_2$)

Para-meter	%	t_1	t_2	T	Profit	Q_1	Q_2	Q
D	+50%	0.0048	0.0306	0.0546	203730.6468	475.7207	360.00	835.7207
	+20%	0.0043	0.0338	0.0615	162641.9335	420.6682	332.40	753.0682
	-20%	0.0035	0.0407	0.0759	107944.8756	338.0000	281.60	619.6000
	-50%	0.0028	0.0505	0.0967	67032.1941	262.3771	231.00	493.3771
α	+50%	0.0039	0.0367	0.0676	135277.3605	380.8071	309.00	689.8071
	+20%	0.0039	0.0367	0.0677	135277.7258	380.8116	309.00	689.8116
	-20%	0.0039	0.0367	0.0677	135278.2172	380.8201	310.00	690.8201
	-50%	0.0039	0.0367	0.0677	135278.5851	380.8223	310.00	690.8223
x	+50%	0.0037	0.0305	0.0641	135063.3071	318.0859	336.00	654.0859
	+20%	0.0038	0.0339	0.0660	135183.8365	352.4753	321.00	673.4753
	-20%	0.0041	0.0401	0.0697	135386.1245	145.2342	296.00	711.2342
	-50%	0.0043	0.0466	0.0737	135582.7868	481.0559	271.00	752.0559

M	t_1	t_2	T	Profit	Q_1	Q_2	Q
0.010	0.0040	0.0349	0.0686	135053.8244	363.0268	338.00	701.0268
0.015	0.0039	0.0359	0.0682	135162.3731	372.9253	323.00	695.9253
0.025	0.0038	0.0375	0.0669	135400.8354	388.6610	294.00	682.6610

Sensitivity Analysis Table
Case II: ($t_1 \leq t_2 \leq M$)

Para-meter	%	t_1	t_2	T	Profit	Q_1	Q_2	Q
D	+50%	0.0042	0.0351	0.0479	205095.8759	541.1728	192.000	733.1728
	+20%	0.0039	0.0384	0.0553	163690.4314	474.3529	202.80	677.1529
	-20%	0.0033	0.0452	0.0704	108597.9777	373.1049	201.60	574.7048
	-50%	0.0037	0.0547	0.0915	67411.4446	283.2164	368.00	651.2164
α	+50%	0.0036	0.0413	0.0617	136123.8412	425.6073	204.00	629.6075
	+20%	0.0036	0.0413	0.0617	136124.4059	425.6044	204.00	629.6044
	-20%	0.0036	0.0413	0.0617	136125.1592	425.6002	204.00	629.6002
	-50%	0.0036	0.0413	0.0617	136125.7236	425.5970	204.00	629.5971
x	+50%	0.0035	0.0354	0.0595	135821.8945	366.1495	241.00	607.1495
	+20%	0.0035	0.0386	0.0607	135993.5620	398.3963	221.00	619.3963
	-20%	0.0036	0.0443	0.0629	136272.4134	455.8495	186.00	641.8495
	-50%	0.0038	0.0449	0.0654	136502.4321	462.3604	205.00	667.3604

M	t_1	t_2	T	Profit	Q_1	Q_2	Q
0.0525	0.0035	0.0417	0.0611	136205.8855	429.4801	194.00	623.4501
0.055	0.0035	0.0420	0.0604	136288.5914	432.3374	184.00	616.3374
0.060	0.0034	0.0428	0.0591	136459.0619	440.0728	163.00	603.0778
0.075	0.0031	0.0445	0.0538	137015.8839	455.9925	93.00	548.9924

From the table we observe that as parameter D (demand) increases/ decreases, order quantity and average total profit increases/ decreases in both case I and case II.

We observe that with increase/ decrease in parameter α, there is very slight decrease/ increase in total profit and in quantity for case I, but for case II, there is decrease/ increase in profit but increase/ decrease in quantity with increase and decrease in the value of parameter α.

Also we observe that with increase/ decrease in parameters x, there is corresponding very slight decrease/ increase in total profit and total quantity in both case I and case II.

We observe that with the increase/ decrease in the value of M, there is decrease/ increase in total profit but increase/ decrease in total quantity for case I. Also with increase in the value of M, there is increase in total profit, but (decrease in shortages and thereby) decrease in quantity.

There is almost no change in profit and total quantity if we make sensitivity for remaining parameters.

6. CONCLUSION:

In this chapter we have proposed an EOQ model with imperfect quality for deteriorating items with linear demand, shortages and time varying holding cost under permissible delay in payments. Sensitivity with respect to parameters have been carried out. The results show that with the increase/ decrease in the parameter values for demand and holding cost there is corresponding increase/ decrease in the value of total profit.

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