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An EPQ Model with Trade Credit for Imperfect Items

Vipin Kumar[1]
Dept. of Mathematics,
BKBIET,
Pilani – India

Gopal Pathak[2]
Research Scholar,
Mewar University,
Chittorgarh – India

C. B. Gupta[3]
Dept. of Mathematics,
BITS,
Pilani – India

Abstract: An EPQ model is developed here for defective items on an infinite planning horizon. We have presented an inventory model with trade credit. To make the study realistic the holding cost is taken to be time dependent. The demand rate is considered as time varying. Here the mathematical expression has been developed for the system. Numerical example is given to illustrate the problem. Finally a sensitivity analysis is reported to study the effect of parameters.

Keywords: Inventory, Trade credit, Deterioration, Imperfect items.

I. INTRODUCTION

The demand has been taken constant in most of the classical inventory models. In present marketing environment, products follow either constant demand or variable time-varying demand. The modern trend of the marketing system is to give more buy opportunities to the retailer by the supplier by giving different discounts. In order to get the discount opportunity, retailers want to buy extra products beyond their limit of buying. As a good result, the supplier wants to sell extra products for better earning. This is the profit of the supplier. The classical inventory model does not consider the delay time idea or variable demand. In the present model we have considered delay in payments with finite replenishment rate and time dependent demand.

The Formula for the EOQ of the items which is known as basic well-known square root formula was formulated by Harris F.W. (1913) based on constant demand. The constant demand was extended to linear time-dependent demand model systematically with finite time horizon by Donaldson W. A. (1977). Later on, an important role in this track came out from researchers like Goyal S. K. (1986), Goswami A. and Chaudhuri K. S. (1991), Goyal et al.(1992)and others. Hariga M. A. and Benkherouf L. (1994) discussed an optimal and heuristic replenishment model for deteriorating items with an exponentially time dependent demand. Wee H. M. (1995) calculated a deterministic lot size inventory model for deteriorating objects with shortage and decline market. Khanra S. and Chaudhuri K. S. (2003) extended an inventory model with quadratic strictly increasing demand over shortages and a finite time horizon. Sana S. and Chaudhuri K.S. (2004) discussed an inventory model for linear movement demand incorporating shortages. Cardenas-Barron L. E. (2009) studying the origin of inventory models with the help of analytic geometry and algebra. Sarkar B., Sana S. S. and Chaudhuri K. (2011) discussed an inventory model with quadratic time dependent demand in which Euler-Lagrange method is used. It is generally for all the customers who want to purchase extra products at cheap price.

The traditional quantity model was formulated by Abad P. L. (1988), Kim K. H. and Hwang H. (1988). In the traditional EOQ model, it was assumed that the retailer pays the purchasing charge when he obtains the objects from the supplier. In trade-credit policy, a certain fixed period which is permitted by the supplier to the retailer to pay the purchasing charge is called the credit period to the retailer. In the credit period time, the supplier sells objects to the retailer to gain extra profit with several kinds of offer for the interval of the credit period. Goyal S. K. (1985) first developed an inventory model with permissible delay in payments depending on this plan. Considering permissible delay in payments, Aggarwal S. P. and Jaggi C. K. (1995) developed an inventory model with an exponentially deteriorating charge. Chu P., Chung K.J. and Lan S.P. (1998) extended Goyal (1985) model by assuming the folder of deterioration. Later an inventory model with shortages was discussed by Jamal et al. (2000).

An EOQ model to command small lot size in order to obtain the profit of permissible delay in payments for a retailer was developed by Teng J.T. (2002). Arcelus et al. (2003) explained an inventory model by assuming the retailer's maximizing profit and inventory scheme for vendor's trade promotion offer of price/credit on the buy of fresh items. An inventory model of retailer's inventory system as a price minimization model to find out the retailer's optimum inventory cycle time and optimal order quantity was extended by Huang Y.F. (2007). An economic production quantity (EPQ) model of retailer's inventory system was developed by Huang Y.F. (2007) to examine the optimal retailer's decisions under two different levels of trade credit policy. Cardenas-Barron L. E. (2011) extended optimal ordering policies in activity to a price cut offer. Teng et al.(2011) discussed optimal ordering decisions with overload inventory and profits. Sarkar B. (2012) developed an inventory model with time dependent deterioration rate and delay in payments. An inventory model with cost modification and in the one period inventory system was developed by Forghani et al. (2013). Kumar Vipin, Pathak Gopal and Gupta C.B.(2013) developed a deterministic inventory model for deteriorating items with selling price dependent demand and parabolic time varying holding cost under trade credit.

In this paper, an EPQ model is developed for defective items on an infinite planning horizon. We have presented an inventory model with trade credit. To make the study realistic, the holding cost is taken to be time dependent and demand rate is considered as time varying. Here the mathematical expression has been developed for the system. We have divided this paper in seven different sections. In the second, assumptions and notation are given for mathematical model formulations which are elaborated in the third section. Numerical illustration is mentioned in fourth sections and sensitivity analysis is mentioned in fifth sections of this paper. Observations are mentioned in the sixth section. In the seventh section, we have concluded our model.

II. Assumptions and Notations

We consider the following notation to develop the model.

T^* : The optimal length of inventory cycle (decision variable).

t_1^* : The optimal duration of replenishment (decision variable).

$q_1(t)$: On-hand inventory at time $t(0 \le t \le t_1)$

$q_2(t)$: On-hand inventory at time $t(t_1 \le t \le T)$

$D(t)$: Time-varying demand rate.

K : Constant replenishment/supply rate.

R : Delay period.

R_w : Rework cost per unit

C_1 : Ordering cost per order.

C_2 : Unit holding cost per unit time, excluding interest charge.

C_3 : Purchasing cost per unit.

M : Scale parameter of holding cost.

H : Shape parameter for holding cost.

α : Fraction of imperfect rate.

C_4 : Maximum retail price per unit.

P : Selling price per unit.

I_c : Rate of interest gaining due to the credit balance.

I_f : Rate of interest due to financing inventory.

T : Length of the inventory cycle.

t_1 : Duration of the replenishment.

Z_1 : Average profit of the system when $T \geq R$

Z_2 : Average profit of the system when $T \leq R$

The following assumptions are taken to develop the model.

(a) The inventory system involves only single kind of product.

(b) The demand rate is taken time dependent.

(c) Replenishment rate is instantaneously infinite, but its size is taken finite.

(d) Time horizon is taken as infinite.

(e) In this model the Lead time is almost negligible.

(f) We have not allowed shortage as well as backlogging.

(g) Imperfect is taken into account.

(h) Holding cost is time dependent.

III. Mathematical Model

The cycle starts with zero inventory level at supply rate K and filling or supply continues up to time t_1. The inventory loads up to the time period $[0, t_1]$ by adjusting the requirement in the market. This collected inventory level at time t_1 consume regularly to convene require demand and it moves to zero level at time $t = T\,(T > t_1)$. Generally, the supplier offers delay period $R\,(R > t_1)$ to the retailer to give the whole purchasing charge $(C_3 K t_1)$ of objects.

Case 1 $(T \geq R)$**.** In this case the inventory cycle length T is larger than or equal to the credit period R (see Figure 1).When $T \geq R$, there is some interest charged due to financing inventory during $[R, T]$ and some profits based on credit balance during the delay period.

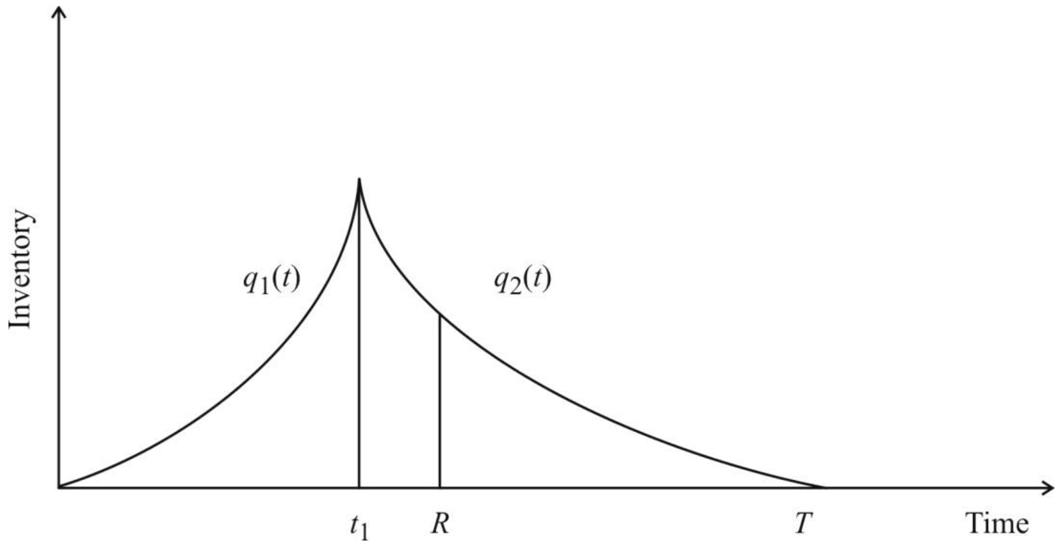

Fig. 1: Inventory versus time (Case 1 $T \geq R$)

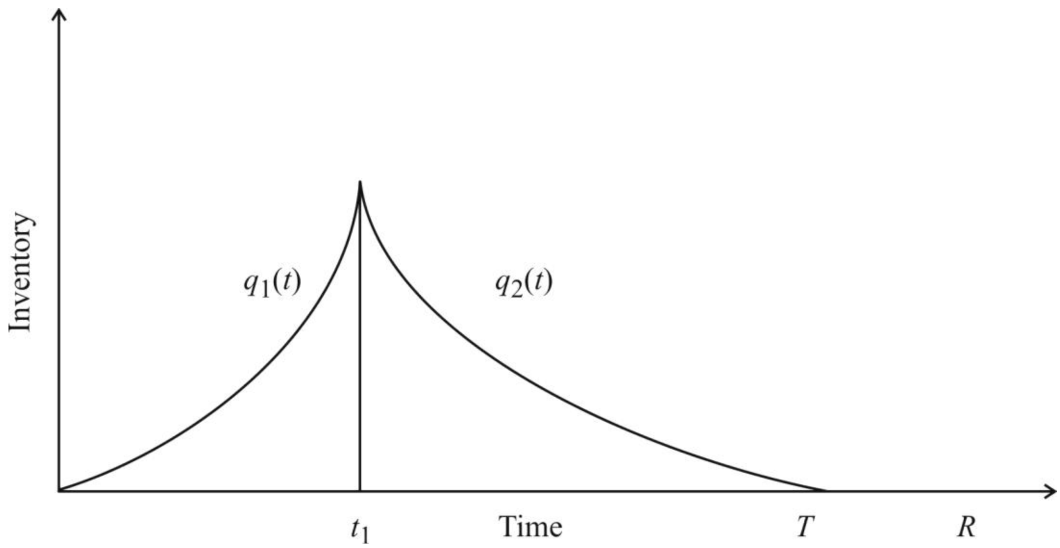

Fig. 2: Inventory versus time (Case 2 $R \geq T$)

Case 2 $(T \leq R)$**.** In this case the inventory cycle length T is smaller than or equal to the credit period R (see Figure 2). When $T \leq R$, there is no interest charged due to financing inventory and some profits based on credit balance during the delay period.

The governing differential equations of the presented model are

$$\frac{dq_1}{dt} = \alpha K - D(t) \text{ with } q_1(0) = 0, \qquad 0 \leq t \leq t_1, \qquad ...(1)$$

$$\frac{dq_2}{dt} = -D(t) \text{ with } q_2(T) = 0, \qquad t_1 \leq t \leq T, \qquad ...(2)$$

From (1), we get

$$q_1(t) = \alpha K t - \int_0^t D(t)dt \qquad 0 \leq t \leq t_1, \qquad ....(3)$$

From (2), we get

$$q_2(t)=\int_t^T D(t)dt \qquad t_1 \le t \le T, \qquad ...(4)$$

By applying the continuity at t_1, $q_1(t_1)=q_2(t_2)$, we get

$$\alpha K t_1 - \int_0^{t_1} D(t)dt = \int_{t_1}^T D(t)dt$$

$$t_1 = \frac{1}{\alpha K}\int_0^T D(t)dt \qquad ...(5)$$

Now we consider Cases 1 and 2 using (3) to (5).

Case 1. $(T \ge R)$. In this case the inventory cycle T is larger than or equal to the credit period R, the holding cost excluding the interest charges is

$$\left\{\int_0^{t_1}(R+Ht)q_1(t)dt+\int_{t_1}^T (R+Ht)q_2(t)dt\right\}.$$

The profit gains during the time $[0,R]$ due to credit balance are $I_c P\int_0^R (R-t)D(t)dt$.

The interest charges for financing inventory during $[R,T]$ is $I_f C_3\int_R^T q_2(t)dt$.

The Rework cost is $R_\omega(\alpha-1)Kt_1$.

Therefore the total profit is (see figure 1)

$$P_1=\Big[(P-C_3)\alpha K t_1 + I_c P\left\{\int_0^{R_i}(R_i-t)D(t)dt\right\}-\left\{\int_0^{t_1}(M+Ht)q_1(t)dt+\int_{t_1}^T(M+Ht)q_2(t)dt\right\}$$

$$-R_\omega(\alpha-1)Kt_1 - I_f C_3\int_{R_i}^T q_2(t)dt - C_1\Big] \qquad ...(6)$$

Hence, the average profit is

$$Z_1=\frac{P_1}{T}$$

$$=\frac{1}{T}\Big[(P-C_3)\alpha K t_1 + I_c P\left\{\int_0^{R_i}(R_i-t)D(t)dt\right\}-\left\{\int_0^{t_1}(M+Ht)q_1(t)dt+\int_{t_1}^T(M+Ht)q_2(t)dt\right\}$$

$$-R_\omega(\alpha-1)Kt_1 - I_f C_3\int_{R_i}^T q_2(t)dt - C_1\Big] \text{ for } i=\{1,2,3\} \qquad ...(7)$$

Case 2. $(T \le R)$. In this case the inventory cycle T is smaller than or equal to the credit period R, the holding cost excluding the interest charges is

$$\left\{\int_0^{t_1}(M+Ht)q_1(t)dt+\int_{t_1}^T (M+Ht)q_2(t)dt\right\}.$$

The profit gains due to credit balance during the time $\left[0,R\right]$ are $I_cP\left[\int_0^T \left(T-t\right)D(t)dt+\alpha Kt_1\left(R-T\right)\right]$.

The Rework cost is $R_\omega\left(\alpha-1\right)Kt_1$.

Therefore the total profit is (see figure 2)

$$P_2=\Big[\left(P-C_3\right)\alpha Kt_1+I_cP\left\{\int_0^T\left(T-t\right)D(t)dt+\alpha Kt_1\left(R_i-T\right)\right\}-R_\omega\left(\alpha-1\right)Kt_1$$
$$-\left\{\int_0^{t_1}\left(M+Ht\right)q_1(t)dt+\int_{t_1}^{T}\left(M+Ht\right)q_2(t)dt\right\}-C_1\Big] \quad ...(8)$$

Hence, the average profit is

$$Z_2=\frac{P_2}{T}$$
$$=\frac{1}{T}\Big[\left(P-C_3\right)\alpha Kt_1+I_cP\left\{\int_0^T\left(T-t\right)D(t)dt+\alpha Kt_1\left(R_i-T\right)\right\}-R_\omega\left(\alpha-1\right)Kt_1$$
$$-\left\{\int_0^{t_1}\left(M+Ht\right)q_1(t)dt+\int_{t_1}^{T}\left(M+Ht\right)q_2(t)dt\right\}-C_1\Big] \quad ...(9)$$

Now we want to maximize Z and obtain the optimal replenishment period t_1^* and inventory cycle length T^*. Now we explain various time dependent and constant demands by applying the general formula. Let the demand is taken as linearly time-dependent that is $D(t)=a+bt$, where $a>0,b>0$ are arbitrary constants.

From (3), we get

$$q_1(t)=\alpha Kt-at-\frac{bt^2}{2} ,$$

From (4), we get

$$q_2(t)=a(T-t)+\frac{b}{2}(T^2-t^2) ,$$

Using these values of $q_1(t)$ and $q_2(t)$ in (7) and (9), we get

$$Z_1=\frac{1}{T}\Big[\left(P-C_3\right)\alpha Kt_1+I_cP\left(\frac{aR_i^2}{2}+\frac{bR_i^3}{6}\right)-M\left(\frac{\alpha Kt_1^2}{2}+\frac{aT^2}{2}+\frac{bT^3}{3}-aTt_1-\frac{bT^2t_1}{2}\right)$$
$$-H\left(\frac{\alpha Kt_1^3}{3}+\frac{aT^3}{6}-\frac{aTt_1^2}{2}+\frac{bT^4}{8}-\frac{bT^2t_1^2}{4}\right)-I_fC_3\left(\frac{aT^2}{2}-aTR_i+\frac{bT^3}{3}-\frac{bT^2R_i}{2}+\frac{aR_i^2}{2}+\frac{bR_i^3}{6}\right)$$
$$-R_\omega\left(\alpha-1\right)Kt_1-C_1\Big] \quad ...(10)$$

$$Z_2=\frac{1}{T}\Big[\left(P-C_3\right)\alpha Kt_1+I_cP\left(\frac{aT^2}{2}+\frac{bT^3}{6}+\alpha Kt_1\left(R_i-T\right)\right)-M\left(\frac{\alpha Kt_1^2}{2}+\frac{aT^2}{2}+\frac{bT^3}{3}-aTt_1$$

$$-\frac{bT^2t_1}{2}\Bigg)-H\left(\frac{\alpha Kt_1^3}{3}+\frac{aT^3}{6}-\frac{aTt_1^2}{2}+\frac{bT^4}{8}-\frac{bT^2t_1^2}{4}\right)-R_\omega(\alpha-1)Kt_1-C_1\Big] \qquad ...(11)$$

Using (5) in (10) and (11), we get

$$Z_1=\Big[(P-C_3)\left(a+\frac{bT}{2}\right)+\frac{I_cP}{T}\left(\frac{aR_i^2}{2}+\frac{bR_i^3}{6}\right)-M\left(\frac{-1}{2\alpha K}\left(a^2T+\frac{b^2T^3}{4}\right)+\frac{aT}{2}-\frac{abT^2}{2\alpha K}+\frac{bT^2}{3}\right)$$

$$-H\left(-\frac{a^3T^2}{6\alpha^2K^2}-\frac{b^3T^5}{48\alpha^2K^2}-\frac{ab^2T^4}{8\alpha^2K^2}+\frac{aT^2}{6}+\frac{bT^3}{8}-\frac{a^2bT^3}{4\alpha^2K^2}\right)-I_fC_3\left(\frac{aT}{2}+\frac{bT^2}{3}-aR_i-\frac{bTR_i}{2}\right.$$

$$\left.+\frac{aR_i^2}{2T}+\frac{bR_i^3}{6T}\right)-R_\omega\left(\frac{\alpha-1}{\alpha}\right)\left(a+\frac{bT}{2}\right)-\frac{C_1}{T}\Big] \qquad ...(12)$$

$$Z_2=\Big[(P-C_3)\left(a+\frac{bT}{2}\right)+I_cP\left(aR_i+\frac{bTR_i}{2}-\frac{aT}{2}-\frac{bT^2}{3}\right)-M\left(\frac{-1}{2\alpha K}\left(a^2T+\frac{b^2T^3}{4}\right)+\frac{aT}{2}\right.$$

$$\left.-\frac{abT^2}{2\alpha K}+\frac{bT^2}{3}\right)-H\left(-\frac{a^3T^2}{6\alpha^2K^2}-\frac{b^3T^5}{48\alpha^2K^2}-\frac{ab^2T^4}{8\alpha^2K^2}+\frac{aT^2}{6}+\frac{bT^3}{8}-\frac{a^2bT^3}{4\alpha^2K^2}\right)$$

$$-R_\omega\left(\frac{\alpha-1}{\alpha}\right)\left(a+\frac{bT}{2}\right)-\frac{C_1}{T}\Big] \qquad ...(13)$$

IV. Numerical Example

Example 1: To illustrate the proposed model, we have Consider the following data in appropriate units.

$C_1 =$ Rs. 250/order, $R = 0.5$ year, $H =$ Rs. 0.1/unit, $R_1 =$ 120/365 year, $a =$ 100 units, $b = 0.5$ units, $D(t) = a + bt$, $C_4 =$ Rs. 120/units, $P =$ Rs. 200/units, $I_f = 0.16$/Rs./year, $I_c =$ 0.13/Rs./year, $K =$ 500 units, $\alpha =$ 0.8 and $R_\omega =$ 100 Rs./units.

Then the optimal solutions are { $Z_1 =$ Rs. 179888.90, $T =$ 1.252 year, $t_1^* =$ 0.411 year}

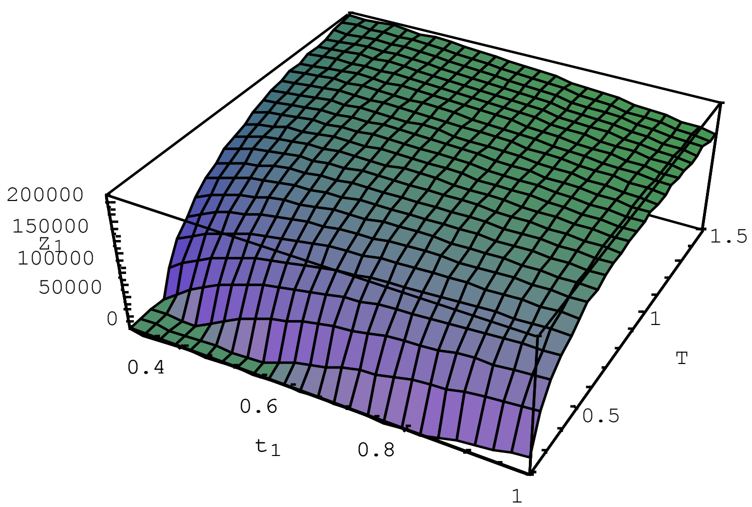

Fig. 3: Concavity of the Average Profit function Z_1

and { Z_2 = Rs. 140909.52, T = 1.329 year, t_1^* = 0.089 year}.

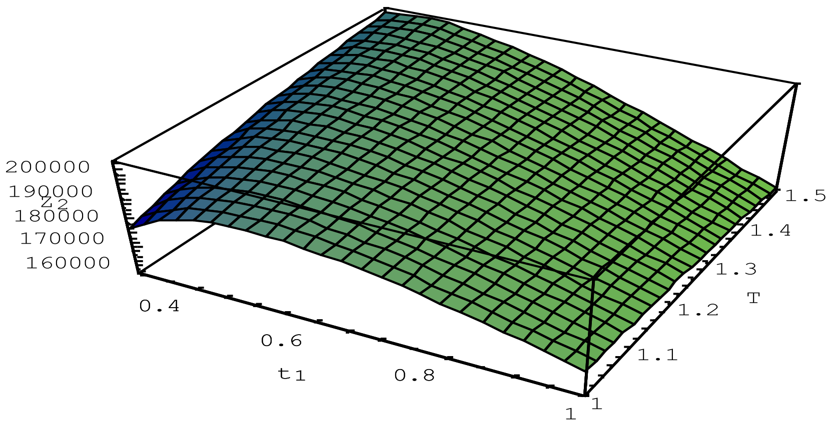

Fig. 4: Concavity of the Average Profit function Z_2

V. Sensitivity Analysis

Now we will check the sensitivity of various parameters as follows:

Table 1: Optimal results for the same set of values as in example 1 for the different production rates

K	t_r	*T*	Z_1	t_1	*T*	Z_2
300	0.0449079	1.421969	189132.35	0.1259701	1.59954	154023.52
400	0.0434039	1.318516	181501.54	0.118288	1.40638	146539.34
500	0.0411192	1.258831	179888.90	0.0897728	1.329831	140909.52
600	0.0401242	1.197748	176595.24	0.0707677	1.207677	133775.20
700	0.0386894	1.08698	175052.35	0.0558098	1.103747	128253.12

Table 2: Optimal results for the same set of values as in example 1 for different permissible delay in payment

R	t_r	*T*	Z_1	t_1	*T*	Z_2
0.3	0.0419079	1.423269	169132.35	0.1259701	1.59954	124023.53
0.4	0.0414039	1.315354	171501.54	0.118288	1.40638	136539.84
0.5	0.0411192	1.258354	179888.90	0.0897728	1.329831	140909.52
0.6	0.0401242	1.197354	186595.24	0.0707677	1.207677	153775.24
0.7	0.0396894	1.086354	189052.35	0.0558098	1.103747	168253.65

Table 3: Optimal results for different value of demand parameter 'a'

a	t_r	*T*	Z_1	t_1	*T*	Z_2
80	0.0541079	1.425469	129132.35	0.1259701	1.59954	114023.52
90	0.0454039	1.312516	151501.54	0.118288	1.40638	136539.34
100	0.0411192	1.267831	179888.90	0.0897728	1.329831	140909.52
110	0.03501242	1.192448	196595.24	0.0707677	1.207677	153775.20
120	0.0326894	1.08028	215052.35	0.0558098	1.103747	168253.12

Table 4: Optimal results for different value of demand parameter 'b'

b	t_r	*T*	Z_1	t_1	*T*	Z_2
0.3	0.0449079	1.421969	189132.35	0.1259701	1.59954	154023.52
0.4	0.0434039	1.318516	181501.54	0.118288	1.40638	146539.34
0.5	0.0411192	1.258831	179888.90	0.0897728	1.329831	140909.52
0.6	0.0401242	1.197748	176595.24	0.0707677	1.207677	133775.20
0.7	0.0386894	1.08698	175052.35	0.0558098	1.103747	128253.12

Table 5: Optimal results for different selling price P

P	t_r	T	Z_1	t_1	T	Z_2
100	0.0449079	1.421969	112532.35	0.1259701	1.59954	104023.51
150	0.0434039	1.318516	115201.54	0.118288	1.40638	126539.54
200	0.0411192	1.258831	179888.90	0.0897728	1.329831	140909.52
250	0.0401242	1.197748	191495.24	0.0707677	1.207677	173775.34
300	0.0386894	1.08698	225452.35	0.0558098	1.103747	218253.97

VI. Observations

(a) From Table-1 we can say that the optimal value of Z_1 and Z_2 decreases when parameter K is increases.

(b) From Table-2 we can say that the optimal value of Z_1 and Z_2 increases when parameter R is increases.

(c) From Table-3 we can say that the optimal value of Z_1 and Z_2 both increases with the increase of the value of the parameter a.

(d) From Table-4 we can say that the optimal value of Z_1 and Z_2 decreases when parameter b is increases.

(e) From Table-5 we can say that the optimal value of Z_1 and Z_2 both increases with the increase of the value of the parameter P.

VII. Conclusion

Generally in EOQ models, the retailer pays the purchasing charge of items as soon as he received the objects by the supplier. In the economical marketing situation, the offer of delay period that is given by supplier to the retailer is called the trade credit period to motivate the retailer to purchase extra objects. During the trade credit period, the retailer can sell his products, collect profits, and receive interest.

In this paper an EPQ model is developed here for defective items on an infinite planning horizon. We have presented an inventory model with trade credit. In the present models we have consider the demand of the products is a strictly increasing function of time. To make the study realistic and effective the holding cost is considered to be time dependent. We illustrate the numerical results. The sensitivity analysis with respect to different associated parameters is also presented to check the stability of the model and conclusion is made that the model is quite stable and applicable in a different field of inventory models where these assumptions are valid. Further extension of the model may be generalized by taking into account shortages, deterioration, and stochastic demand.

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