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A new model for deteriorating items with inflation under permissible delay in payments

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A B S T R A C T

Inflation is an important factor influencing traditional economic order quality models. Marketing strategy depends on inflation due to public demand and availability of the materials. This paper presents an optimal inventory policy for deteriorating items using exponential demand rate under permissible delay in payments. Mathematical model has been derived under two cases: case I: cycle time is greater than or equal to permissible delay period, case II: cycle time is less than permissible delay period by considering holding cost as a function of time. Numerical examples and sensitivity analysis are given to reflect the numerical results. Mathematica software is used for finding optimal solutions.

1. Introduction

The objective of many inventory management problems is to deal with the minimization of inventory carrying expenditures (Donalson, 1977). Thus, it is necessary to determine the optimal inventory level as well as optimal time of replenishment of inventory to meet any future demand. Among the classical inventory management models, there are many cases on solving the optimal order quantity by ignoring the type of payment. At present scenario, it is observed that supplier offers a certain fixed period to settle the account for stimulating retailers demand. During the credit period when the payment is made, some items can be sold and revenue can be accumulated to earn interest. This paper investigates inventory model for deteriorating items with exponential time dependent demand rate. In recent years, deteriorating inventory models have been widely studied. In real life situations, it is observed that demand for a particular product can be influenced by internal factor such as inflation, price and availability. The change in the demand is responsible for the change in inventory is commonly referred to as demand elasticity. Generally, inventory model considers a case in which depletion of inventory is caused by demand rate and deterioration. Most of the items deteriorate over time and this phenomena plays essential role for decision making in modern organization. During the past few decades, many researchers have developed inventory models for deteriorating items.

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The analysis of deteriorating model is discussed by Ghare and Schrader (1963) with constant rate of deterioration. In the earlier period, researchers have discussed various demand patterns fitting the stage of product lifecycle. Resh et al. (1976) and Donaldson (1977) considered the situation and linearly time varying demand and established an algorithm to determine the optimal number of replenishments and timing. Henery (1976) further generalized the demand rate by considering a concave demand function increasing with time. Harris (1913) first introduced the basic economic order quantity (EOQ) model. Several interesting research papers are associated with deterioration, which are based on constant demand without any deterioration function (e.g. Sachan, 1984; Dave & Patel, 1981; Goyal & Giri, 2001; Liao & Haung, 2010; Sana, 2010; Lin et al., 2010; Sarkar, 2012; etc.). Covert and Phillip (1973) extended Ghare and Schrader's model by considering variable rate of deterioration.

Data and Pal (1988) developed an EOQ model by introducing a variable deterioration rate and power demand pattern. Chung and Tang (1994) determined the replenishment schedules for deteriorating items with time proportional demand. However, in real life, the demand may increase or decrease in the course of time. Many researchers considered the varying demand (e.g. Sana, 2010; Sana & Chaudhuri, 2008; Donaldson, 1977; Goyal, 1986; Kharna & Chaudhuri, 2003; Silver & Meal, 1969; Haringa, 1996; Goyal et al., 1986).

Various researchers have developed the inflanatory effects on the inventory policy. Liao et al. (2001) developed an inventory for initial stock dependent consumption rate when a delay in payment is permissible. Hou (2006) derived an inventory model for deteriorating items with stock dependent consumption rate and shortages under inflation and time discounting over a finite planning horizon. Buzacolt (1975) developed an inventory model with inflation. Vrat and Padmanabhan (1990) developed an inventory model under a constant inflation rate and initial stock dependent consumption rate. Datta and Pal (1991) developed a model with linear time dependent demand rate and shortages to investigate the effects of inflation with time value of money on ordering policy over a finite time horizon.

Recently, Teng et al. (2012) developed an EOQ model with trade credit financing for non–decreasing demand and fundamental theoretical results obtained. Sarkar (2011) developed an EOQ model with delay in payment for time varying deterioration rate and obtained a function for maximization of profit. Pricing and lot sizing policies for deteriorating items with partial backlogging under inflation was presented by Hsieh and Dye (2010) by considering pricing and lot sizing policies for deteriorating items with partial backlogging under inflation.

In this paper, demand rate is exponential time dependent and holding cost is time dependent. The present model is discussed by using truncated Taylor's series. The conditions for convexity of optimality are obtained and numerical examples and sensitivity analysis are given.

The rest of the paper is organized as follows: In the next section assumptions and notations are given. In section 3 mathematical formulations with maximization of total inventory cost is given. In section 4 numerical examples for the cases I and II are given. In section 5 sensitivity analysis with various parameters is given to validate the inventory cost function. Finally conclusion and future research directions are given in the last section 6.

2. Assumptions and Notations

The mathematical model of inventory for deteriorating items is based on the following assumptions:

(i) Demand rate is exponential and Inflation is constant

(ii) Shortages are not allowed and lead time is zero

(iii) During the permissible delay period the sales revenue generated is deposited in an interest bearing account. At the end of the trade credit period the customer pays off all units ordered and begins paying for the interest charged on the items in stock.

(iv) There is no repair or replenishment of deteriorated items during the given cycle.

(vii) Holding cost is time dependent i.e. $h(t) = ht, \quad 0 \le t \le T$

The following notations are used throughout the manuscript:

h : Holding cost per unit

$p(t) = p_0 e^{rt}$: Instantaneous selling price per unit

p_0 : Selling price per unit at $t = 0$

C : Purchasing price per unit at $t = 0$

$C(t) = C_0 e^{rt}$: Instantaneous ordering cost per order

C_0 : Ordering cost per order at $t = 0$

H : Length of finite planning horizon

I_c : Interest charged

I_e : Interest earned per annum by the retailer

T : Optimum length of cycle time , $H = nT$

T_1 : Allowable delay period during settlement of the account

Q : Optimum ordering quantity

r : Constant rate of inflation

$I(t)$: Instantaneous level of inventory

$R = Ae^{-\alpha t}$: Demand rate, $0 < \alpha < 1$

A : Demand at $t = 0$

θ : Constant deterioration rate ($\theta < \alpha$)

O_C : Ordering cost

C_D : Cost of deterioration

I_{HC} : Inventory holding cost

Z_1, Z_2 : Total cost for case 1 and 2 respectively

3. Mathematical Formulation

The level of inventory I(t) decreases gradually mainly to meet demands and due to deterioration. Thus, the variation of inventory with respect to time can be described by the following differential equation:

$$\frac{dI(t)}{dt} + \theta I(t) = -Ae^{-\alpha t}, \quad 0 \le t \le T \tag{1}$$

The solution of equation is given by

$$I(t) = \frac{A}{\theta - \alpha}\left[e^{(\theta-\alpha)T-\theta t} - e^{-\alpha t}\right] \tag{2}$$

and order quantity

$$Q = \frac{A}{\theta - \alpha}\left[e^{(\theta-\alpha)T} - 1\right] \tag{3}$$

Since *I(t)* is a periodic function with period *T* hence we have *I(kT + t) = I(t),* therefore,

$$I(kT+t) = \frac{A}{\theta - \alpha}\left[e^{(\theta-\alpha)T-\theta t} - e^{-\alpha t}\right] \tag{4}$$

Ordering Cost: Instantaneous ordering cost per order

$$O_C = \sum_{k=0}^{n-1} C_0 e^{krt} = C_0(e^{rH} - 1)\left(\frac{1}{rT} + \frac{rT}{4} - \frac{1}{2}\right) \tag{5}$$

(6)

The number of deteriorated units = $Q - \int_0^T Ae^{-\alpha t}dt$

The cost of total deteriorated units

$$C_D = C\left[\frac{A}{\theta - \alpha}\left\{e^{(\theta-\alpha)T} - 1\right\} + \frac{1}{\alpha}\left(e^{-\alpha T} - 1\right)\right] = \frac{1}{2}AC\theta T^2 \tag{7}$$

Inventory Holding Cost I_{HC} is given by

$$I_{HC} = \frac{Ah}{\theta - \alpha}\sum_{k=0}^{n-1} C_0 e^{rkT}\int_0^T \left\{e^{\theta T-(\theta+\alpha)t} - e^{-\alpha t}\right\}.tdt = \frac{AhC_0(e^{rH}-1)\theta T}{r(\alpha^2 - \theta^2)} \tag{8}$$

Depending on the customer's choice and the length of cycle time *T* two possible cases are taken into account:

Case I $T \ge T_1$

Optimal cycle time T is greater than the permissible delay time T_1, the interest charged IC_1 during the period [0, H] is given by

$$IC_1 = I_c \sum_{k=0}^{n-1} C(kT)\int_{T_1}^{T} I(kT+t)dt = \frac{AI_cC_0(e^{rH}-1)}{(\theta^2 - \alpha^2)r}\alpha T_1\left(\frac{T_1}{T} - 1\right) \tag{9}$$

Interest earned IE_1 during the period [0, H] is given by

$$IE_1 = I_e \sum_{k=0}^{n-1} P(kT)\int_0^{T_1} Ae^{-\alpha t}.t\,dt = P_0 A I_e \frac{(e^{rH}-1)}{2rT}\left(\frac{T_1^2}{2}-\frac{\alpha}{2}T_1^3\right) \tag{10}$$

Total Inventory Cost $Z_1(T)=\frac{1}{T}\left[O_C + C_D + I_{HC} + IC_1 - IE_1\right]$

$$=\frac{1}{T}\left[C_0(e^{rH}-1)\left(\frac{1}{rT}+\frac{rT}{4}-\frac{1}{2}\right)+\frac{1}{2}AC\theta T^2-\frac{AhC_0(e^{rH}-1)\theta T}{r(\theta^2-\alpha^2)}+\frac{AI_cC_0(e^{rH}-1)\alpha T_1\left(\frac{T_1}{T}-1\right)}{r(\theta^2-\alpha^2)}-\frac{P_0AI_e(e^{rH}-1)\left(\frac{T_1^2}{2}-\frac{\alpha}{2}T_1^3\right)}{rT^2}\right] \tag{11}$$

Differentiating $Z_1(T)$ with respect to 'T' two times we get

$$\frac{\partial Z_1}{\partial T} = C_0(e^{rH}-1)\left(-\frac{2}{rT^3}+\frac{1}{2T^2}\right)+\frac{1}{2}AC\theta+\frac{AI_cC_0(e^{rH}-1)\alpha T_1}{r(\theta^2-\alpha^2)}\left(-\frac{2T_1}{T^3}+\frac{1}{T^2}\right)+\frac{P_0AI_e(e^{rH}-1)}{rT^3}\left(T_1^2-\alpha T_1^3\right) \tag{12}$$

$$\frac{\partial^2 Z_1}{\partial T^2} = C_0(e^{rH}-1)\left(\frac{6}{rT^4}-\frac{1}{T^3}\right)+\frac{AI_cC_0(e^{rH}-1)\alpha T_1}{r(\theta^2-\alpha^2)}\left(\frac{6T_1}{T^4}-\frac{2}{T^3}\right)+\frac{3P_0AI_e(e^{rH}-1)(\alpha T_1^3-T_1^2)}{rT^4}>0 \tag{13}$$

Optimal (minimum) solution is obtained by solving $\frac{\partial Z_1}{\partial T}=0,$ yields

$$\frac{AC\theta}{2}T^3+\left\{2C_0(e^{rH}-1)+\frac{AC_0I_c(e^{rH}-1)\alpha T_1}{(\theta^2-\alpha^2)}\right\}T+\frac{P_0AI_e(e^{rH}-1)(T_1^2-\alpha T_1^3)}{r}-\frac{2C_0(e^{rH}-1)}{r}-\frac{2AI_cC_0(e^{rH}-1)\alpha T_1^2}{(\theta^2-\alpha^2)}=0 \tag{14}$$

Case II $T<T_1$

In this case, the retailer pays the procurement cost to the supplier prior to expiration of the delay period T_1 provided by the supplier. Hence, the interest charged IC_2 will be zero. Since cycle time T is less than permissible delay time T_1, the interest earned IE_2 during [0, H] is given by

$$IE_2 = I_e\sum_{k=0}^{n-1}P(kT)\left[\int_0^T tAe^{-\alpha t}dt+(T_1-T)\int_0^T Ae^{-\alpha t}dt\right]=P_0I_eA\frac{(e^{rH}-1)}{r}\left(T_1-\frac{1}{2}T-\frac{1}{2}\alpha TT_1\right) \tag{15}$$

Total Inventory Cost in this case $Z_2(T)=\frac{1}{T}\left[O_C+C_D+I_{HC}-IE_2\right]$

$$Z_2=\frac{1}{T}\left[C_0(e^{rH}-1)\left(\frac{1}{rT}+\frac{rT}{4}-\frac{1}{2}\right)+\frac{1}{2}AC\theta T^2-\frac{AhC_0(e^{rH}-1)\theta T}{r(\theta^2-\alpha^2)}-\frac{P_0AI_e(e^{rH}-1)}{r}\left(T_1-\frac{1}{2}T-\frac{1}{2}\alpha T_1T\right)\right] \tag{16}$$

Differentiating partially (16) w.r.t. 'T' two times yields

$$\frac{\partial Z_2}{\partial T}=C_0(e^{rH}-1)\left(-\frac{2}{rT^3}+\frac{1}{2T^2}\right)+\frac{1}{2}AC\theta+\frac{P_0AI_e(e^{rH}-1)}{r}\frac{T_1}{T^2}$$

$$\frac{\partial^2 Z_2}{\partial T^2}=C_0(e^{rH}-1)\left(\frac{6}{rT^4}-\frac{1}{T^3}\right)-\frac{2P_0AI_e(e^{rH}-1)}{r}\frac{T_1}{T^3}>0$$

Optimal (minimum) solution is obtained by solving $\frac{\partial Z_2}{\partial T}=0$, yields the following

$$\frac{AC\theta}{2}T^3+\left\{\frac{C_0(e^{rH}-1)}{2}+\frac{P_0AI_e(e^{rH}-1)}{r}T_1\right\}T-\frac{2C_0(e^{rH}-1)}{r}=0 \tag{17}$$

Note: Truncated Taylor's series in exponential terms i.e $e^{\alpha T}\approx 1+\alpha T+\frac{1}{2}\alpha^2T^2+$ ...etc. is used from Eqs. (5-17) for finding closed form solution.

4. Numerical Example 1

Let

$A=100,\quad \theta=0.01\quad r=0.01\ to\ 0.05,\quad \alpha=0.1,\quad H=1,\quad h=0.02,\quad C_0=10$
$I_e=0.12,\ C=15,\quad I_c=0.15,\quad P_0=20,\ T_1=15,30,45,60,75\ and\ 90\ days$

Optimal solution for different values of parameters associated with model for $T\geq T_1$ is given in Table 1 as follows,

Table 1
The results of optimal solution for different values of $T > T_1$

		T_1 *(Days)*					
r	*Parameters*	15	30	45	60	75	90
0.01	*T(years)*	1.37847	1.34582	1.28789	1.19730	1.05657	0.807657
	Q(units)	129.639	126.751	121.605	113.505	100.789	77.90000
	Z($)	79.8319	122.78	175.643	209.926	271.264	353.7040
0.02	*T(years)*	1.37967	1.34311	1.2774	1.17236	1.00147	0.641322
	Q(units)	130.626	127.347	121.430	111.906	96.2403	62.51480
	Z($)	80.1079	123.476	168.433	218.617	282.468	394.3190
0.03	*T(years)*	1.38100	1.34080	1.26790	1.14934	0.947806	0.329037
	Q(units)	131.635	127.980	121.326	110.432	91.7048	32.52770
	Z($)	80.3821	124.153	170.096	222.682	294.314	338.4250

Numerical Example 2

Let $A=100,\quad \theta=0.01,\quad r=0.01\ to\ 0.05,\quad \alpha=0.1,\quad H=1,\quad h=0.02,\quad I_e=0.02,$
$T_1=225, 240,\ 255,\ 270, 285\ \text{and}\ 300\ days$

Optimal solution for different values of parameters associated with model for $T<T_1$

Table 2
The results of optimal solution for different values of $T < T_1$

		T_1(Days)					
r	*Parameters*	225	240	255	270	285	300
0.01	*T(years)*	0.60691	0.58707	0.56792	0.54947	0.53173	0.51470
	Q(units)	59.4199	57.5173	55.6782	53.9042	52.1960	50.5538
	Z(Dollars)	87.6304	84.9451	82.1664	79.2914	76.3174	73.2419
0.02	*T(years)*	0.60680	0.58694	0.56776	0.54930	0.53154	0.51449
	Q(units)	59.4095	57.5042	55.6630	53.8870	52.1773	50.5340
	Z(Dollars)	87.9197	85.2203	82.4269	79.5366	76.5466	73.5443
0.03	*T(years)*	87.9197	85.2203	82.4269	79.5366	76.5466	73.5443
	Q(units)	59.3990	57.4911	55.6475	53.8696	52.1584	50.5138
	Z(Dollars)	88.2111	85.4976	82.6894	79.7836	76.7775	73.6684
0.04	*T(years)*	0.60658	0.58666	0.56744	0.54893	0.53115	0.51407
	Q(units)	59.3883	57.4776	55.6318	53.8521	52.1394	50.4936
	Z(Dollars)	88.5047	85.7770	82.9538	80.0324	77.0101	73.8841
0.05	*T(years)*	0.60647	0.58652	0.56728	0.54875	0.53095	0.51386
	Q(units)	59.3774	57.4641	55.6161	53.8345	52.1202	50.4733
	Z(Dollars)	88.8006	86.0584	83.2202	80.2831	77.2444	74.1014

5. Sensitivity Analysis: Case I

When θ and α are allowed to vary by using $T_1 = 15, 30, 45, 60, 75 \, and \, 90$ days. We get different values of parameters as shown in Table 3 as follows,

Table 3
The results of optimal solution for different values of θ

		θ					
α	*Parameters*	0.01	0.02	0.03	0.04	0.05	0.06
	T_1 *(Days)*	15	30	45	60	75	90
0.2	*T(years)*	1.25623	0.97230	0.81087	0.68160	0.55175	0.37573
	Q(units)	111.756	89.1972	75.7469	64.5750	52.9536	36.6021
	Z(Dollars)	44.8472	94.0812	146.748	201.516	254.443	260.742
0.3	*T(years)*	1.25676	0.97432	0.81564	0.69134	0.57162	0.42688
	Q(units)	105.320	85.2724	73.2114	85.0612	53.2657	40.5738
	Z(Dollars)	33.9366	68.2219	103.366	138.058	169.279	180.020
0.4	*T(years)*	1.25704	0.97544	0.81833	0.69687	0.58266	0.45193
	Q(units)	99.3651	81.5068	70.6055	61.6334	52.7090	41.8925
	Z(Dollars)	28.9211	56.3023	83.5749	109.697	132.318	141.359
0.5	*T(years)*	1.25723	0.97620	0.82023	0.70085	0.59061	0.46915
	Q(units)	93.8617	77.9389	68.0628	59.9099	51.8637	42.3895
	Z(Dollars)	26.0511	49.4608	72.2592	93.6252	111.656	119.040

Case II: When θ and r are allowed to vary by using T_1 = 225, 240, 255, 270, 285 and 300 days. We get different values of parameters as shown in Table 4 as follows,

Table 4
The results of optimal solution for different values of θ

		θ					
r	*Parameters*	0.03	0.04	0.05	0.06	0.07	0.08
	T_1 *(Days)*	225	240	255	270	285	300
0.01	*T(years)*	0.60691	0.56002	0.52335	0.49336	0.46807	0.44626
	Q(units)	59.4199	55.0715	51.6565	48.8530	46.4806	44.4280
	Z(Dollars)	87.6304	118.694	158.066	213.142	300.834	471.514
0.02	*T(years)*	0.60680	0.55999	0.52336	0.49340	0.46813	0.44633
	Q(units)	59.4095	55.0683	51.6575	48.8565	46.4857	44.4342
	Z(Dollars)	87.9107	119.116	158.665	214.000	302.115	473.637
0.03	*T(years)*	0.60669	0.55995	0.52337	0.49344	0.46818	0.44638
	Q(units)	59.3990	55.0050	51.6582	48.8598	46.4906	44.4401
	Z(Dollars)	88.2111	119.542	159.270	214.864	303.405	475.774
0.04	*T(years)*	0.66658	0.55991	0.52338	0.49347	0.46823	0.44645
	Q(units)	59.3883	55.0614	51.6589	48.8631	46.4955	44.4461
	Z(Dollars)	88.5047	119.971	159.878	215.734	304.704	477.925
0.05	*T(years)*	0.60647	0.55988	0.52338	0.49350	0.46827	0.44651
	Q(units)	59.3774	55.0578	51.6594	48.8662	46.5002	44.4518
	Z(Dollars)	88.8006	120.402	160.322	216.609	306.011	480.091

From the above tables we conclude the following results:

From Table 1, we observe that:

Increase in T_1 results decrease in T, Q and increase in Z, keeping θ, α and r constant and increase in r results increase in T, Q and Z keeping T_1 constant.

From Table 2, we observe that:
Increase in T_1 results decrease in T, Q and Z keeping r constant and increase in r results increase in T, Q and Z keeping T_1 constant.

From Table 3, we observe that:
Increase in deterioration rate θ results decrease in T, Q and increase in Z keeping α constant. An increase in α results increase in T and decrease in Q and Z keeping θ and T_1 constant.

From Table 4, we observe that:
Increase in θ results decrease in T, Q and increase in Z keeping r constant. An increase in r results increase in T, Q and Z.

6. Conclusion

In this paper, an inventory model has been developed for deteriorating items under permissible delay in payments. Optimal solutions were obtained for both cases i.e. case I and II. Numerical examples and sensitivity analysis have been presented to obtain optimal cycle time and optimal total average cost per unit time. The sensitivity analysis is quite sensitive to the managerial point of view.

The proposed model can be extended in several ways for instance we may consider the demand rate as quadratic time dependent or stock dependent patterns as well as discount demand. We could extend the model for non – deteriorating demand function to stock dependent demand function. In addition, we could generate the model to allow shortages, finite capacity and others.

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