An EOQ Model for Deteriorating Items with Power Demand and Time – Varying Holding Cost

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Abstract: *In this paper, we consider deterministic inventory model with power demand and constant deteriorating in considered. The time – varying holding cost is al linear function of time. Shortage are allowed and fully backlogged. The items (like food grains, fashion apparels and electronic equipments) have fixed shelf-life which decreases with time during the end of the season. Using the differential equations the instantaneous state of inventory is derived. With suitable cost considerations the total cost function is obtained. By minimizing the total cost function the optimal ordering policies are derived. A numerical illustration is presented to demonstrate the model and the sensitivity analysis of various parameters is carried out.*
Keywords: *Constant Deterioration; Power Demand; Inventory; Shortages; Time Dependent Holding Cost*

I. Introduction

The main objective of the proposed model is to develop an inventory model for a deteriorating item having a time-dependent power demand rate and time-varying holding cost. The literature review of the present paper is discussed as follows:

Deterioration is usually defined as the damage, decay, spoilage, evaporation and obsolescence of item. The process of deterioration is happened in two categories of items. The first category refers to the items that become damaged, spoiled, decayed, loss of utility, evaporative or expired through time like fruits, vegetables, food items, seafood's, agricultural products, flowers, films, cement, fertilizers, oils, gas, medicines and so on, while the other category refers to the items that loss their parts or their total values through time because of the introduction of new technology or the alternatives like fashion and seasonal goods, electronic components, computer chips and mobile phones and so on. For the first category, the items have a short natural life cycle whereas in the second category, the items have a short market life. The literature surveys starting from the first inventory models for deteriorating items by Wihitin (1957) much work has been reported regarding inventory problems dealing with deteriorating items. Raafat (1991), Goel and Giri (2001), Ruxien Li, et al. (2010), Pentico and Drake (2011) have reviewed the inventory models for deteriorating items.

Goswami and Chaudhuri(1991) were first researchers whom studied the inventory model for deteriorating with shortages. Bose, et al. (1995) generalized by Gowswami and Chaudhuri' model and with shortages under inflation and time discounting. Then Wee(1995) concluded in their study that deterministic inventory model for deteriorating items with shortages and declining market. They established the classical EOQ model with constant deterioration rate and with shortages. Moncer Hariga (1996) studied firstly the inventory model on deteriorating items with time – varying demand when shortages are allowed. Some of the recent work in this field has been established by Chang and Ting, (1993), Vinod Kumar, et al. (2011), Mishra et al. (2013). Chang and Dye (1999) established an inventory model with time varying demand and partial backlogging. On the basis on demand variations, Giri et al. (1996a) developed an inventory model for deteriorating items time varying demand and costs. Nirmal Kumar Dauri and Tripati Chakraporti (2014) studied single warehouse system with price dependent demand and shortages. Shukla et al. (2013) also studied an inventory model for deteriorating items with exponential demand rate and shortages. Datta and Pal (1988), Singh and Sehgal (2011), Srichandan Mishra et al. (2012) also studied on inventory model on deteriorating items with various pattern of power demand. Usually, inventory holding cost and demand rate are considered to be constant. But sometimes in reality, we may observe that inventory holding cost and demand rate for physical goods may be time dependent. This paper examines an inventory model with linearly varying holding cost. The objective function is to minimize the total cost of an inventory system based on inventory holding cost, ordering cost and deterioration cost. In reality, the demand rate and the inventory holding cost for physical goods may be time dependent. As time is an important factor in the inventory system, we consider that demand rate and inventory holding cost are time dependent. We have developed an EOQ inventory model for deteriorating items with power demand when the deterioration rate follows a constant rate with time dependent linear holding cost and shortages are allowed.

In this paper, an effort has been made to analyze an EOQ model for deteriorating items by considering the time dependent power demand rate and time dependent linear inventory holding cost. Shortages are allowed and fully backlogged. The proposed model is based on the inventory items like fashion and seasonal goods,

electronic equipments, computer chips and mobile phones and so on, as they experience fluctuations in the demand rate. The mathematical model has been derived under power demand rate. Through numerical illustration the sensitivity analysis is carried.

II. Notations And Assumptions

2.1 Notations
The following notations have been used in developing the model
i. A_0: Ordering cost.
ii. Q_0: Initial ordering quantity.
iii. Q: Ordering quantity.
iv.   I (t): The inventory at time t, $0 \leq t \leq T$.

v. $\lambda(t)$: The power demand rate, where $\lambda(t) = \frac{dt^{\frac{1}{n}-1}}{nT^{\frac{1}{n}}}$, where d is the total demand, n is the pattern of index $(0<n<\infty)$.

vi. $\theta(t)$: The constant deteriorating rate of an item, where $\theta(t) = \theta$ $(0<\theta<1)$.
vii. $C_1(t)$: The time – varying holding cost per unit, where $C_1(t) = a + bt$, a, b>0.
viii. C_d : The cost of each deteriorated unit.
ix. C_2: Shortage cost per unit time.
x.   T: The length of ordering cycle.

2.2 Assumptions
The following assumptions are made in developing the model
i.   The inventory system considered as multi items.
ii.   The demand rate is deterministic and is power demand function of time.
iii. The deterioration rate is considered as constant.
iv.   Lead time is zero.
v.   Shortages are allowed and fully backlogged.

III. Mathematical Formulation of The Model
Let Q be the total amount of inventory produced or purchased at the beginning of each period and after fulfilling backorders let us assume we get an amount Q_0 as initial inventory. Let d be the total demand during period T. Inventory level gradually decreases during the period $(0, t_1)$ due to market demand and deterioration of items and reaches to zero at time t $= t_1$. Shortages occur during time period (t_1, T) which is fully backlogged. Let I(t) be the on hand inventory at any time t. The differential equations which the on hand inventory I(t) must satisfy to different parts of the cycle time T are the following

$$\frac{d}{dt}I(t) + \theta(t)I(t) = -\lambda(t), 0 \leq t \leq t_1 \tag{1}$$

$$\frac{d}{dt}I(t) = -\lambda(t), t_1 \leq t \leq T \tag{2}$$

where $\theta(t) = \theta$ and $\lambda(t) = \frac{dt^{\frac{1}{n}-1}}{nT^{\frac{1}{n}}}$, with the initial conditions, $I(t_1) = Q_0$ and $I(t_1) = 0$.

Substituting $\lambda(t)$ in equations (1) and (2) and solving the differential equations and neglecting higher order terms of θ, the on hand inventory at time 't' is obtained as

$$I(t) = Q_0 e^{-\theta t} - \frac{d}{T^{1/n}} e^{-\theta t} \left[t^{1/n} + \frac{\theta}{n+1} t^{\frac{1}{n}+1}\right], \qquad 0 \leq t \leq t_1 \tag{3}$$

$$I(t) = \frac{d}{T^{1/n}}\left[t_1^{1/n} - t^{1/n}\right], t_1 \leq t \leq T \tag{4}$$

Thus, the initial order quantity is obtained by putting the boundary condition $I(t_1) = 0$ in equation (3). Therefore,

$$Q_0 = \frac{d}{T^{1/n}}\left[t_1^{1/n} + \frac{\theta}{n+1} t_1^{\frac{1}{n}+1}\right] \tag{5}$$

The ordering quantity Q is obtained from the equation $Q = Q_0 + d - \frac{dt_1^{1/n}}{T^{1/n}}$

Therefore,

$$Q = d\left[\frac{1}{T^{1/n}}\left(\frac{\theta}{n+1} t_1^{\frac{1}{n}+1}\right) + 1\right] \tag{6}$$

The total demand during the cycle period $[0, t_1]$ is

$$\int_0^{t_1} \lambda(t)dt = \int_0^{t_1} \frac{dt^{\frac{1}{n}-1}}{nT^{\frac{1}{n}}} dt = d\left(\frac{t_1}{T}\right)^{1/n}$$

The number of deteriorated units is

$$Q_0 - \int_0^{t_1} \lambda(t)dt = \frac{d}{T^{1/n}}\left[\frac{\theta}{n+1} t_1^{\frac{1}{n}+1}\right]$$

The deterioration cost (DC) for the cycle $[0, t_1]$ = C_d(the number of deteriorated units)

$$C_d \frac{d}{T^{1/n}}\left[\frac{\theta}{n+1} t_1^{\frac{1}{n}+1}\right] \tag{7}$$

The total in inventory holding cost (IHC) for the cycle $[0, t_1]$ is

$$\int_0^{t_1} C_1(t)I(t)dt = \int_0^{t_1}(a+bt)\left[Q_0 e^{-\theta t} - \frac{d}{T^{1/n}} e^{-\theta t}\left[t^{1/n} + \frac{\theta}{n+1} t^{\frac{1}{n}+1}\right]\right]dt \tag{8}$$

Substituting the value of Q_0 from (5), the total inventory holding cost (8), we obtain

$$\frac{d}{T^{1/n}}\left[\frac{a}{n+1} t_1^{\frac{1}{n}+1} + \frac{b+a\theta}{2(2n+1)} t_1^{\frac{1}{n}+2} + \frac{b\theta - 3a\theta^2}{6(3n+1)} t_1^{\frac{1}{n}+3} - \frac{b\theta^2}{3(4n+1)} t_1^{\frac{1}{n}+4}\right] \tag{9}$$

The shortage cost for the cycle (t_1, T) is

$$\int_{t_1}^{T} -I(t)C_2 dt = -C_2 \int_{t_1}^{T} \frac{d}{T^{1/n}}\left[t_1^{1/n} - t^{1/n}\right]dt$$

On simplification

$$\frac{-C_2 d}{T^{1/n}}\left[t_1^{1/n}(T-t_1) + \frac{n}{n+1}\left(t_1^{\frac{1}{n}+1} - T^{\frac{1}{n}+1}\right)\right] \tag{10}$$

Let K (t_1, T) be total cost per unit time. Since the total cost is the sum of ordering cost (OC), deteriorating cost (DC), inventory holding cost (IHC) and shortage cost (SC), the total cost per unit time becomes

$$K(t_1, T) = \frac{A_0}{T} + \frac{C_d d\theta}{T^{\frac{1}{n}+1}(n+1)} t_1^{\frac{1}{n}+1}$$
$$+ \frac{d}{T^{\frac{1}{n}+1}}\left[\frac{a}{n+1} t_1^{\frac{1}{n}+1} + \frac{b+a\theta}{2(2n+1)} t_1^{\frac{1}{n}+2} + \frac{b\theta - 3a\theta^2}{6(3n+1)} t_1^{\frac{1}{n}+3} - \frac{b\theta^2}{3(4n+1)} t_1^{\frac{1}{n}+4}\right]$$
$$- \frac{C_2 d}{T^{\frac{1}{n}+1}}\left[t_1^{1/n}(T-t_1) + \frac{n}{n+1}\left(t_1^{\frac{1}{n}+1} - T^{\frac{1}{n}+1}\right)\right] \tag{11}$$

IV. Optimal Pricing And Ordering Policies of The Model

In this section we obtain the optimal policies of the inventory system under study. To find the optimal values of t_1 and T, we obtain the first order partial derivatives of $K(t_1, T)$ given in equation (11) with respect to t_1 and T and equate them to zero. The condition for minimization of $K(t_1, T)$ is

$$D = \begin{vmatrix} \dfrac{\partial^2 K(t_1, t_3)}{\partial t_1^2} & \dfrac{\partial^2 K(t_1, t_3)}{\partial t_1 \partial t_3} \\ \dfrac{\partial^2 K(t_1, t_3)}{\partial t_1 \partial t_3} & \dfrac{\partial^2 K(t_1, t_3)}{\partial t_3^2} \end{vmatrix} > 0$$

Differentiating $K(t_1, T)$ given in equation (11) with respect to t_1 and equating to zero, one can get

$$\left(C_d\theta + \frac{a}{n}\right) t_1^{1/n} + \frac{b+a\theta}{2n} t_1^{\frac{1}{n}+1} + \frac{b\theta - 3a\theta^2}{6n} t_1^{\frac{1}{n}+2} - \frac{b\theta^2}{3n} t_1^{\frac{1}{n}+3} - C_2\left(\frac{T}{n} t_1^{\frac{1}{n}-1} - \frac{1}{n} t_1^{\frac{1}{n}}\right) = 0 \tag{12}$$

Differentiating $K(t_1, T)$ given in equation (11) with respect to T and equating to zero, one can get

$$\frac{A_0}{T^2} + \frac{C_d\theta d}{nT^{-\left(\frac{1}{n}+2\right)}} t_1^{\frac{1}{n}+1} + \frac{d(n+1)}{nT^{-\left(\frac{1}{n}+2\right)}}\left[\frac{a}{n+1} t_1^{\frac{1}{n}+1} + \frac{b+a\theta}{2(2n+1)} t_1^{\frac{1}{n}+2} + \frac{b\theta - 3a\theta^2}{6(3n+1)} t_1^{\frac{1}{n}+3} - \frac{b\theta^2}{3(4n+1)} t_1^{\frac{1}{n}+4}\right]$$
$$+ C_2 d\left[\frac{n+1}{nT^{-\left(\frac{1}{n}+2\right)}} t_1 - \frac{1}{nT^{-\left(\frac{1}{n}+1\right)}} t_1^{\frac{1}{n}} - T^{\frac{1}{n}}\right] = 0 \tag{13}$$

Solving equations (12) and (13) simultaneously, we obtain the optimal times t_1^* of t_1 and T^* of T are obtained. The optimum ordering quantity Q^* of Q in the cycle of length T is obtained by substituting the optimal values of t_1^*, T^* in equation (6)

V. Numerical Illustrations

In this section we discuss the solution procedure of the model through a numerical illustration by obtaining the optimal times, optimum ordering quantity and the total cost of an inventory system. For the numerical illustrations of the model, the values of various parameters in proper units can be taken as follows:

$A_0 = 500$, $C_d = 2$, $C_2 = 4$, $a = 12$, $b = 10$, $\theta = 0.4$, $n = 2$ and $d = 50$

Substituting these values the optimal times, optimal ordering quantity and total cost are computed and presented in Table 1.

From Table1 it is observed that the cost parameters, deteriorating parameters and demand parameters have a tremendous influence on the optimal values of times, ordering quantity and total cost.

Table 1: Optimal values of t_1^*, T^*, Q^* and K^* for different values of parameters

A_0	C_d	C_2	a	b	θ	n	d	t_1	T	Q	K
500	2	4	12	10	0.4	2	50	1.453	7.657	54.219	142.422
525								1.396	7.794	53.940	144.189
550								1.351	7.941	53.715	145.988
575								1.305	8.096	53.491	147.768
	2.1							1.455	7.647	54.232	142.587
	2.2							1.457	7.636	54.244	142.751
	2.3							1.460	7.626	54.257	142.916
		4.2						1.426	7.891	54.040	142.972
		4.4						1.412	8.175	53.913	143.578
		4.6						1.400	8.520	53.784	144.189
			12.6					1.474	7.535	54.346	144.635
			13.2					1.493	7.429	54.464	146.842
			13.8					1.512	7.336	54.574	149.044
				10.5				1.470	7.581	54.315	143.541
				11.0				1.486	7.511	54.408	144.66
				11.5				1.502	7.447	54.497	145.779
					0.42			1.304	6.238	54.173	157.139
					0.44			1.354	7.827	54.128	140.667
					0.46			1.074	8.542	52.921	136.835
						2.1		1.424	7.695	54.115	140.736
						2.2		1.396	7.729	54.009	139.111
						2.3		1.369	7.759	53.903	137.548
							52.5	1.473	7.642	57.029	146.555
							55.0	1.492	7.628	59.838	150.684
							57.5	1.509	7.616	62.647	154.811

VI. Sensitivity Analysis

We now study the effect of changes in the values of the system parameters A_0, C_d, C_2, a, b, θ, n and d on the optimal cost and number of reorder. The sensitivity analysis is performed by changing each of the parameters by -15%, -10%, -5% ,0%, 5%, 10% and 15% taking one parameter at a time and keeping the remaining parameters unchanged. The relationship between the parameters and the optimal values of the schedule is shown in Figure 1.

The analysis is based on the Numerical illustration and the results are shown in the Table 2. The following points are observed.

1) T^*, K^* increases while t_1^*, Q^* decreases with decrease and increase in value of the parameter A_0. Here t_1^*, T^*, Q^* and K^* are moderately sensitive to change in A_0.
2) T^*, Q^*, K^* increase while t_1^* decrease with decrease and increase in value of the parameter C_d. Here t_1^*, T^*, Q^* and K^* are low sensitive to change in C_d.
3) T^*, K^* increases while t_1^*, Q^* decreases with decrease and increase in value of the parameter C_2. Here t_1^*, T^*, Q^* and K^* are low sensitive to change in C_2.
4) t_1^*, Q^*, K^* increase while T^* decrease with decrease and increase in value of the parameter a. Here t_1^*, T^*, Q^* and K^* are moderate sensitive to change in a.
5) t_1^*, Q^*, K^* increase while T^* decrease with decrease and increase in value of the parameter b. Here t_1^*, T^*, Q^* and K^* are low sensitive to change in b.
6) T^* increase while t_1^*, Q^*, K^* decreases with decrease and increase in value of the parameter θ. Here t_1^*, T^*, Q^* and K^* are high sensitive to change in θ.
7) T^* increase while t_1^*, Q^*, K^* decreases with decrease and increase in value of the parameter n. Here t_1^*, T^*, Q^* and K^* are moderately sensitive to change in n.
8) t_1^*, Q^*, K^* increase while T^* decrease with decrease and increase in value of the parameter d. Here t_1^*, T^*, Q^* and K^* are high sensitive to change in d.

Table 2: Sensitivity analysis of the model

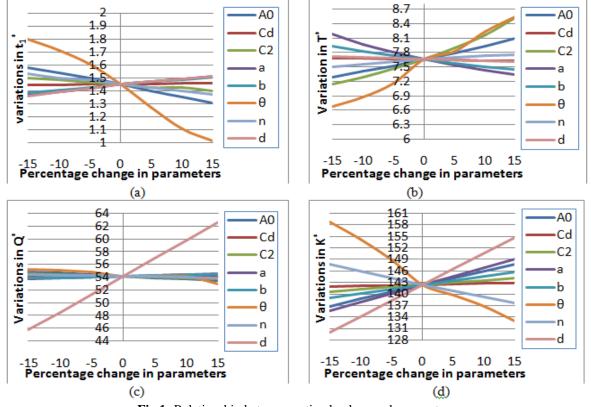| Variation Parameters	optimal policies	Change in parameters						
		-15%	-10%	-5%	0%	5%	10%	15%
A_0	t_1^*	1.576	1.536	1.495	1.453	1.396	1.351	1.305
	T^*	7.289	7.406	7.528	7.657	7.794	7.941	8.096
	Q^*	54.884	54.662	54.44	54.219	53.94	53.715	53.491
	K^*	136.824	138.714	140.58	142.422	144.189	145.988	147.768
C_d	t_1^*	1.446	1.448	1.451	1.453	1.455	1.457	1.46
	T^*	7.69	7.679	7.668	7.657	7.647	7.636	7.626
	Q^*	54.18	54.193	54.206	54.219	54.232	54.244	54.257
	K^*	141.928	142.093	142.257	142.422	142.587	142.751	142.916
C_2	t_1^*	1.499	1.483	1.468	1.453	1.426	1.412	1.4
	T^*	7.145	7.291	7.46	7.657	7.891	8.175	8.52
	Q^*	54.579	54.461	54.341	54.219	54.04	53.913	53.784
	K^*	140.65	141.235	141.826	142.422	142.972	143.578	144.189
a	t_1^*	1.365	1.392	1.417	1.453	1.474	1.493	1.512
	T^*	8.181	7.974	7.801	7.657	7.535	7.429	7.336
	Q^*	53.719	53.879	54.027	54.219	54.346	54.464	54.574
	K^*	135.692	137.926	140.152	142.422	144.635	146.842	149.044
b	t_1^*	1.382	1.403	1.422	1.453	1.47	1.486	1.502
	T^*	7.939	7.834	7.74	7.657	7.581	7.511	7.447
	Q^*	53.845	53.956	54.063	54.219	54.315	54.408	54.497
	K^*	139.011	140.131	141.252	142.422	143.541	144.66	145.779
θ	t_1^*	1.795	1.714	1.604	1.453	1.274	1.104	1.012
	T^*	6.681	6.871	7.166	7.657	7.827	8.238	8.542
	Q^*	55.273	55.136	54.806	54.219	54.173	54.128	52.921
	K^*	158.689	154.248	148.808	142.422	140.667	136.835	132.835
n	t_1^*	1.532	1.5	1.482	1.453	1.424	1.396	1.369
	T^*	7.511	7.564	7.616	7.657	7.695	7.729	7.759
	Q^*	54.453	54.362	54.32	54.219	54.115	54.009	53.903
	K^*	147.776	145.92	144.169	142.422	140.736	139.111	137.548
d	t_1^*	1.36	1.39	1.417	1.453	1.473	1.492	1.509
	T^*	7.72	7.695	7.674	7.657	7.642	7.628	7.616
	Q^*	45.734	48.545	51.355	54.219	57.029	59.838	62.647
	K^*	129.96	134.099	138.237	142.422	146.555	150.684	154.811

Fig 1: Relationship between optimal values and parameters

VII. Conclusions

In this paper, an inventory model is developed which investigates the optimal order quantity of the on – hand inventory due to power demand rate. The items like food grains, fashion apparels and electronic equipments etc., have fixed shelf – life which decreases with time during the end of the season and the storage period in which the demand, deterioration, and holding cost depend upon time. This model is closed analytically by minimizing the total inventory cost. Finally, the model has been verified by the numerical illustration along with sensitivity analysis. In the future study, it is hoped to extended the proposal model into several situations having linear increasing demand, stock dependent, price dependent demand. This model further extended to three – parameter Weibull distribution or Gamma distribution deterioration. Further – more, it may also take practical backlogging into account when determining the optimal replenishment policy.

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