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A Production Inventory Model for Deteriorating Products with Multiple Market and Selling Price dependent demand

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GJSFR-F Classification: *MSC 2010: 91B26*

APRODUCTIONINVENTORYMODELFORDETERIORATINGPRODUCTSWITHMULTIPLEMARKETANDSELLINGPRICEDEPENDENTDEMAND

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A Production Inventory Model for Deteriorating Products with Multiple Market and Selling Price dependent demand

Pinky Saxena [α], S. R Singh [σ] & Isha Sangal [ρ]

Abstract- This paper presents an inventory model for deteriorating items that have a single manufacturer but multiple market demands for a finite planning horizon. For the market, different selling seasons are considered. It is a production inventory model, which has a demand rate dependent on the selling price. Here, we have presented a solution-search procedure to find the optimal replenishment policy for raw material and optimal production time. The model is illustrated using a numerical example. Further; sensitivity analysis is also performed to check the stability of the model.

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I. Introduction

To consider the effect of deterioration in the development of inventory models is an essential need of inventory modeling. Ignoring the effect of deterioration misleads the results. Ghare and Schrader (1963) were the first to introduce the deterioration in inventory modelling. They developed this model with constant rate of demand and deterioration. Mishra (1975) presented production lot-size model for a system having deteriorating inventory. Kang and Kim (1983) came forward with a study on the price and production level of the deteriorating inventory system. Wee (1993) defined the deterioration of products as “decay, damage, spoilage, evaporation, obsolescence, pilferage, loss of utility or loss of marginal value of a commodity that results in decreasing usefulness”. The deterioration occurs in most of the physical products such as medicines, food products, dairy products and volatile products, etc. Goyal and Giri (2001) proposed an inventory model for recent trends in deteriorating inventory modeling.

In today’s global market, there are so many opportunities for a vendor or manufacturer. It is not necessary that it will deal with a single market. It can deal in many markets for a single production run. Khouja (2001) presented the effect of large order quantities on expected profit in the single-period model. This model is developed with multiple market demand. In this model, he gave the example of a garment industry which sells its product in different markets. It is profitable for the manufacturer but very complicated also. This is because in different markets the demand rate will also be different. An Economic Order Quantity (EOQ) model was

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presented by Covert and Philip (1973) for items that have time-dependent demand and deterioration as per Wei-bull distribution. Giri *et al.* (1996) put forward an inventory model for deteriorating items that have a demand rate dependent on the stock. Yang and Wee (2002) presented a production inventory model with multiple-buyer for a deteriorating item. Wu *et al.* (2006) proposed, for non-instantaneous deteriorating items that have stock-dependent demand and partial backlogging, an optimal-replenishment policy.

In this paper, we propose and develop a production inventory model for deteriorating items that have multiple markets and a demand rate dependent on the selling price. This model is illustrated using a numerical example and sensitivity analysis is also performed to show the model's stability.

Notes

II. Assumptions and Notations

a) Assumptions

1. A single product is from a single manufacturer.
2. The model is for multiple market demand.
3. Demand rate is a function of the selling price.
4. Production rate is constant and is greater than the demand of all the markets.
5. The products being considered are deteriorating in nature.
6. The rate of deterioration is assumed to be a linear function of time.
7. No, shortages are allowed.
8. Planning horizon is considered finite.
9. No replacement or repair of deteriorated units is done during a given cycle.
10. It is assumed that the manufacturer arranges the fix quantity of raw material at a fix interval of time. The quantity of finished products produced by the manufacturer is enough to meet the occurring demand and deterioration in all the markets.

b) Notations

A : Production rate.
θ : Deterioration parameter.
α_k : Demand parameter in k^{th} time interval.
β : Demand parameter.
p : selling price per unit time.
T : production period.
K_0: setup cost
h_f : Holding cost per unit for finished products.
$I_i(t)$: Inventory level at any time t in i^{th} interval where (i=1,2,3……n).
d_f: Deterioration cost per unit for finished products.
d_r: Deterioration cost per unit for raw material inventory.
h_r: Holding cost per unit for raw material.
μ: Ordering cost per order.
q_r: Delivery lot size of raw material.
n_r: Number of deliveries of raw material in time T.

III. Model Description and Analysis

The model is developed with a piecewise constant function in demand. It is assumed that the optimal production run time T lies in the interval $[T_{m-1}, T_m]$. Let us divide the interval $[T_{m-1}, T_m]$ into two parts. Here $I_m^-(t)$ represents the inventory level during $t \in [T_{m-1}, T]$ and $I_m^+(t)$ represents inventory during $t \in [T, T_m]$.

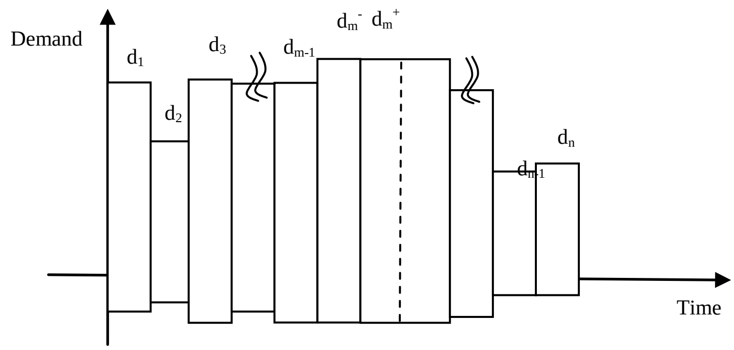

Fig. 1: Manufacture's time v/s demand

The inventory time behavior of the finished products at any time t is given by the following differential equations:

$$\frac{dI_k(t)}{dt} + \theta t I_k(t) = A - \frac{\alpha_k}{p^\beta} \; ; T_{k-1} \le t \le T_k \tag{1}$$

$$\frac{dI_m^-(t)}{dt} + \theta t I_m^-(t) = A - \frac{\alpha_m}{p^\beta} \; ; T_{m-1} \le t \le T \tag{2}$$

$$\frac{dI_m^+(t)}{dt} + \theta t I_m^+(t) = -\frac{\alpha_m}{p^\beta} \; ; T \le t \le T_m \tag{3}$$

$$\frac{dI_j(t)}{dt} + \theta t I_j(t) = -\frac{\alpha_j}{p^\beta} \; ; T_{j-1} \le t \le T_j \tag{4}$$

With boundary conditions:

$$I_1(0)=0,\ I_k(T_{k-1})=I_{k-1}(T_{k-1}), I_m^-(T_{m-1})=I_{m-1}(T_{m-1}),$$

$$I_n(T_n)=0,\ I_{j-1}(T_{j-1})=I_j(T_j \tag{5}$$

The solution of these equations is given by (see appendix A):

$$I_k(t) = (A - \frac{\alpha_k}{p^\beta})(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \sum_{i=1}^{k} \frac{(\alpha_i - \alpha_{i-1})}{p^\beta}(T_{i-1} + \frac{\theta}{6}T_{i-1}^3)e^{-\frac{\theta t^2}{2}}$$

$$T_{k-1} \le t \le T_k \qquad \text{for k=1,2,3...........(m-1)} \tag{6}$$

$$I_m^-(t) = (A - \frac{\alpha_m}{p^\beta})(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \sum_{i=1}^{m} \frac{(\alpha_i - \alpha_{i-1})}{p^\beta}(T_{i-1} + \frac{\theta}{6}T_{i-1}^3)e^{-\frac{\theta t^2}{2}}$$

$$T_{m-1} \le t \le T \tag{7}$$

$$I_m^+(t) = -\frac{\alpha_m}{p^\beta}(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \frac{\alpha_n}{p^\beta}(T_n + \frac{\theta}{6}T_n^3)e^{-\frac{\theta t^2}{2}} - \sum_{i=m+1}^{n} \frac{(\alpha_i - \alpha_{i-1})}{p^\beta}(T_{i-1} + \frac{\theta}{6}T_{i-1}^3)e^{-\frac{\theta t^2}{2}}$$

Notes

$$T \le t \le T_m \tag{8}$$

$$I_j(t) = -\frac{\alpha_j}{p^\beta}(t+\frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \frac{\alpha_n}{p^\beta}(T_n+\frac{\theta}{6}T_n^{\ 3})e^{-\frac{\theta t^2}{2}} - \sum_{i=j+1}^{m}\frac{(\alpha_i-\alpha_{i-1})}{p^\beta}(T_{i-1}+\frac{\theta}{6}T_{i-1}^{\ 3})e^{-\frac{\theta t^2}{2}}$$

$$T_{j-1} \le t \le T_j \qquad \text{for j=(m+1), (m+2)……….n} \tag{9}$$

Now the total inventory during $[T_{k-1}, T_k]$ will be calculated as follows:

$$I_k = \int_{T_{k-1}}^{T_k} I_k(t)\,dt$$

$$I_k = (A-\frac{\alpha_k}{p^\beta})(\frac{T_k^{\ 2}-T_{k-1}^{\ 2}}{2}-\frac{\theta}{12}(T_k^{\ 4}-T_{k-1}^{\ 4}))$$

$$+\sum_{i=1}^{k}\frac{(\alpha_i-\alpha_{i-1})}{p^\beta}(T_{i-1}+\frac{\theta}{6}T_{i-1}^{\ 3})((T_k-T_{k-1})-\frac{\theta}{6}(T_k^{\ 3}-T_{k-1}^{\ 3})) \tag{10}$$

The total inventory during $[T_{m-1}, T]$ will be:

$$I_m^{\ -} = \int_{T_{m-1}}^{T} I_m^{\ -}(t)\,dt$$

$$I_m^{\ -} = (A-\frac{\alpha_m}{p^\beta})(\frac{T_m^{\ 2}-T_{m-1}^{\ 2}}{2}-\frac{\theta}{12}(T_m^{\ 4}-T_{m-1}^{\ 4}))$$

$$+\sum_{i=1}^{m}\frac{(\alpha_i-\alpha_{i-1})}{p^\beta}(T_{i-1}+\frac{\theta}{6}T_{i-1}^{\ 3})((T_m-T_{m-1})-\frac{\theta}{6}(T_m^{\ 3}-T_{m-1}^{\ 3})) \tag{11}$$

The total inventory during $[T, T_m]$ will be:

$$I_m^{\ +} = \int_{T}^{T_m} I_m^{\ +}(t)\,dt$$

$$I_m^{\ +} = [-\frac{\alpha_m}{p^\beta}(\frac{T_m^{\ 2}-T^2}{2}-\frac{\theta}{12}(T_m^{\ 4}-T^4))$$

$$+\frac{\alpha_n}{p^\beta}(T_n+\frac{\theta}{6}T_n^{\ 3})((T_m-T)-\frac{\theta}{6}(T_m^{\ 3}-T^3))$$

$$-\sum_{i=m+1}^{n}\frac{(\alpha_i-\alpha_{i-1})}{p^\beta}(T_{i-1}+\frac{\theta}{6}T_{i-1}^{\ 3})((T_m-T)-\frac{\theta}{6}(T_m^{\ 3}-T^3))] \tag{12}$$

Similarly, the total inventory during $[T_{j-1}, T_j]$ for all j=(m+1)………n:

$$I_j = [-\frac{\alpha_j}{p^\beta}(\frac{T_j^{\ 2}-T_{j-1}^{\ 2}}{2}-\frac{\theta}{12}(T_j^{\ 4}-T_{j-1}^{\ 4}))$$

$$+\frac{\alpha_n}{p^\beta}(T_n+\frac{\theta}{6}T_n^{\ 3})((T_j-T_{j-1})-\frac{\theta}{6}(T_j^{\ 3}-T_{j-1}^{\ 3}))$$

Notes

$$-\sum_{i=j+1}^{n}\frac{(\alpha_i-\alpha_{i-1})}{p^{\beta}}(T_{i-1}+\frac{\theta}{6}T_{i-1}{}^{3})((T_j-T_{j-1})-\frac{\theta}{6}(T_j^{3}-T_{j-1}{}^{3}))] \quad (13)$$

The holding cost of the system for finished products is calculated as follows:

$$H.C_f=h_f(\sum_{k=1}^{m-1}I_k+I_m{}^{-}+I_m{}^{+}+\sum_{j=m+1}^{n}I_j) \quad (14)$$

Notes

The deterioration cost for the system of finished products is given by:

$$D.C_f=d_f(AT-\sum_{k=1}^{n}\frac{\alpha_k}{p^{\beta}}(T_k-T_{k-1})) \quad (15)$$

Set up cost for the finished product is computed as follows:

$$S.C_f=K_0 \quad (16)$$

Now, the total cost for the finished product can be calculated as follows:

$$T.C_f=H.C_f+D.C_f+S.C_f \quad (17)$$

a) Manufacturer's raw material inventory model

In this model, the inventory is replenished at t=0. During $[0,\ T/n_r]$, the inventory depletes as a result of the combined effect of demand and deterioration. At $t=T/n_r$, the inventory level becomes zero and is again replenished. The differential equation that governs the transition of the system is represented as follows:

$$\frac{dI_r(t)}{dt}+\theta_r tI_r(t)=-f_r\ ;0\le t\le T/n_r \quad (18)$$

With boundary condition $I_r(T/n_r)=0$.
The solution of equation (18) will be:

$$I_r(t)=f_r\{(\frac{T}{n_r}-t)+(\frac{\theta r}{6}(\frac{T}{n_r})^3-t^3)\}e^{-\theta_r\frac{t^2}{2}};0\le t\le T/n_r \quad (19)$$

We know that $I_r(0)=q$

$$q=f_r\{(\frac{T}{n_r})+\frac{\theta_r}{6}(\frac{T}{n_r})^3\} \quad (20)$$

Now, the holding cost of the system for carrying the raw material will be:

$$H.C_r=n_rh_r\int_0^{T/n_r}I_r(t)\,dt$$

$$H.C_r=nh_r[f_r\{\frac{T^2}{2n_r{}^2}+\frac{\theta_r}{8}(\frac{T}{n_r})^4-f_r\frac{\theta_r}{24}(\frac{T}{n_r})^4\}] \quad (21)$$

The cost of deteriorated units of raw material:

$$D.C_r=d_r(n_rq-f_rT) \quad (22)$$

Now, the total cost of raw material inventory can be calculated as follows:

$$T.C_r=H.C_r+D.C_r+O.C_r \quad (23)$$

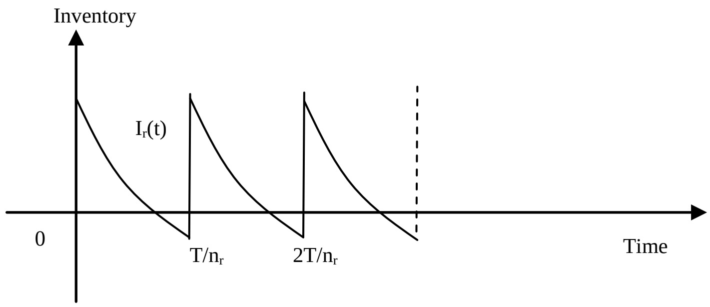

Fig. 2: Raw material inventory system

Then, the integrated total cost for whole the system will be as follows:

$$T.C. = T.C_f + T.C_r \tag{24}$$

After putting the values in equation (24), we observe that T.C. for whole the system is a function of n_r and T, where n_r is a discrete variable and T is a continuous variable.

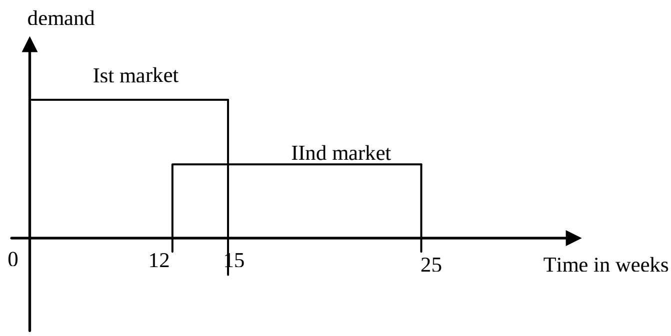

Fig. 3: Time v/s demand in each the market

IV. Solution Procedure

Step 1: Here n_r is a discrete variable.

Step 2: Solve the equation $\frac{\partial TC}{\partial T} = 0$ for all possible values of n_r starting from n_r=1.

Step 3: Put all these values of T and n_r in equation (24) and find the value of T.C.

Step 4: Repeat the step 2-3 until the optimal value of T.C. is found.

V. Numerical Example

Here we have discussed only the two market situation. The demand rate is taken as a function of selling price. The value of demand parameter α_k for market one and market two is 1500 units and 1200 units respectively. The selling rate is Rs 8 per unit. The value for the deterioration parameter for finished products and raw material are 0.01 and 0.015 respectively. The season for selling items in market one is considered from 1-15 weeks and for second market it is 12-25 weeks. The setup cost and ordering cost for production and ordering the raw material is given by Rs 750 and Rs 500 respectively. The production cost and purchasing cost of raw material is Rs 5 and Rs 2 per unit respectively. The holding cost h_f and h_r are 0.25 and 0.2 per unit per time. The production rate is 500 units/ week.

Here n=3, T_1=5, T_2=17, T_3=25

By applying the above mentioned solution procedure, we find the following values:

T*=21 weeks, nr=5.008, T.C. = Rs 852.012

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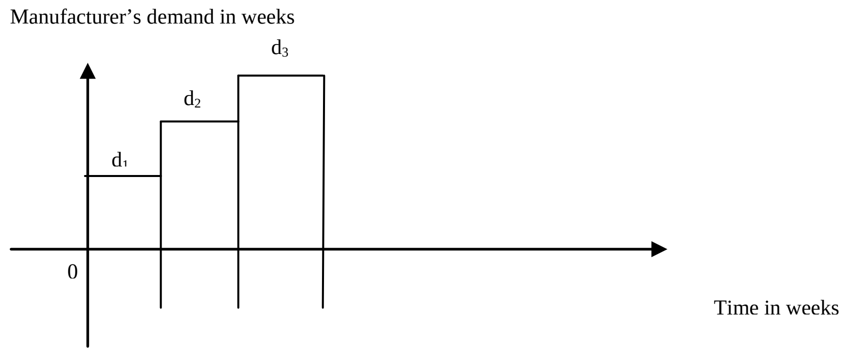

Fig. 4: Time v/s demand in each the market

VI. Sensitivity Analysis

For the given numerical illustration, investigations have been performed to study the impact of changes of different parameters on the number of deliveries of raw material, production period along with the total cost of the system.

Table 1: Sensitivity analysis for production rate A

% variation in A	A	nr	T	T.C.
-20%	400	5.2	16.5	720.85
-15%	425	5.168	17.32	745.72
-10%	450	5.16	18.45	775.81
-5%	475	5.09	19.2	822.01
0%	500	5.008	21	852.012
5%	525	4.89	21.8	878.92
10%	550	4.72	22.71	912.65
15%	575	4.61	23.5	934.37
20%	600	4.45	24	961.41

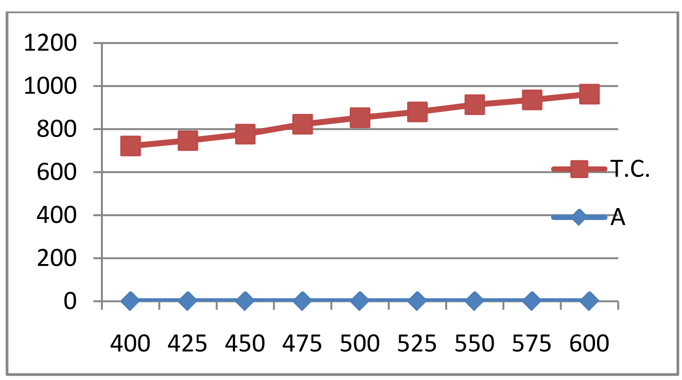

Fig. 5: Variation of total cost T.C. with respect to production rate A

Table 2: Sensitivity analysis for deterioration parameter θ

% variation in θ	θ	nr	T	T.C.
-20%	0.012	5.008	13.67	828.52
-15%	0.01275	5.008	15.52	839.716
-10%	0.0135	5.008	17.81	843.82
-5%	0.01425	5.008	19.2	847.79
0%	0.015	5.008	21	852.012

5%	0.01575	5.008	23.03	856.92
10%	0.0165	5.008	25.57	861.13
15%	0.01725	5.008	27.73	864.99
20%	0.018	5.008	29.89	867.321

Table 3: Sensitivity analysis for holding cost of finished products h_f

% variation in h_f	h_f	n_r	T	T.C.
-20%	0.2	6.712	25.7172	751.816
-15%	0.2125	6.381	24.875	782.71
-10%	0.225	5.862	23.981	813.48
-5%	0.2375	5.418	22.112	831.18
0%	0.25	5.008	21	852.012
5%	0.2625	4.67	19.987	878.93
10%	0.275	4.219	18.753	891.25
15%	0.2875	3.892	17.625	913.21
20%	0.3	3.416	16.512	934.48

Table 4: Sensitivity analysis for holding cost of raw material h_r

% variation in h_r	h_r	n_r	T	T.C.
-20%	0.16	5.008	21	839.78
-15%	0.17	5.008	21	842.14
-10%	0.18	5.008	21	845.32
-5%	0.19	5.008	21	849.516
0%	0.2	5.008	21	852.012
5%	0.21	5.008	21	855.221
10%	0.22	5.008	21	858.31
15%	0.23	5.008	21	861.54
20%	0.24	5.008	21	864.715

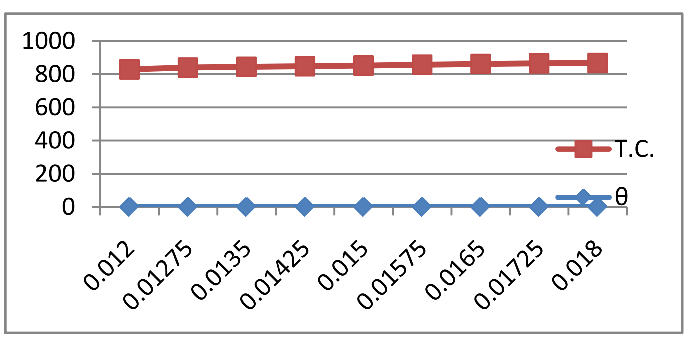

Fig. 6: Variation in total cost T.C. w.r.t deterioration parameter θ

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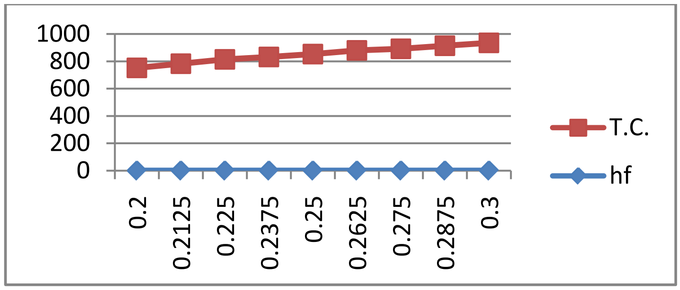

Fig. 7: Variation in total cost. T.C with respect to holding cost h_f

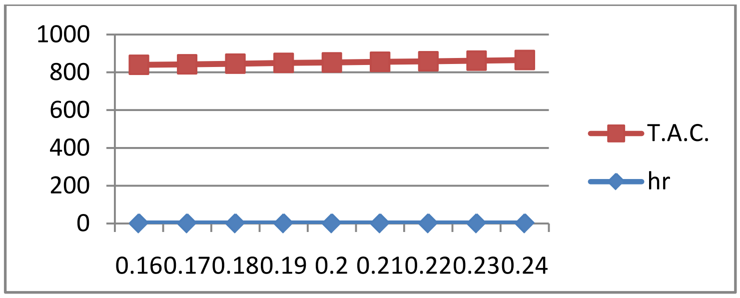

Fig. 8: Variation in total cost T.C. with respect to holding cost hr

VII. Concluding Remarks

A sensitivity analysis is performed with respect to different system parameters to check the stability of the model.

1. From table1, it is observed that as the value of the production parameter 'A' increases, it also results in increase in the total cost of the system.
2. Table 2 shows the variation in deterioration parameter 'θ'. It is shown in this table that an increment in deterioration parameter 'θ' results also in an increment in T.C. of the system.
3. In table 3 and table 4, the variation in holding cost h_f and h_r are shown. It is observed from these tables that with the increment in holding parameters, the T.C. of the system increases in both the cases.

VIII. Conclusion

In this chapter we have presented an inventory model for deteriorating products. In this model, the manufacturer produces the items at a single location and sells it in different markets having different demands and selling seasons. With the help of a mathematical model, we calculate the different associated costs and provide a method to reduce the total cost of the system. This is done by deriving the optimal production time and replenishes time for the raw material. Further; performing a sensitivity analysis helps to check the stability of the model. With the sensitivity analysis, the model is found to be quite stable. For further research, time value of money and different permissible conditions can be applied for the extension of this model.

Appendix A:

The solution of equation (1) is given by:

$$I_k(t) = (A - \frac{\alpha_k}{p^\beta})(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + c_k e^{-\frac{\theta t^2}{2}} \qquad \text{for k=1,2.............(m-1)}$$

if k=1, from $I_1(0)=0$,We get $c_1=0$

Now from the boundary condition,
we get ,$I_k(T_{k-1}) = I_{k-1}(T_{k-1})$

$$(c_k - c_{k-1}) = \frac{1}{p^{\beta}}(T_{k-1} + \frac{\theta}{6}T_{k-1}^{\ 3})(\alpha_k - \alpha_{k-1})$$

From this equation we get:

$$c_2 - c_1 = \frac{1}{p^{\beta}}(\alpha_2 - \alpha_1)(T_1 + \frac{\theta}{6}T_1^3)$$

$$c_3 - c_2 = \frac{1}{p^{\beta}}(\alpha_3 - \alpha_2)(T_2 + \frac{\theta}{6}T_2^3)$$

$$c_4 - c_3 = \frac{1}{p^{\beta}}(\alpha_4 - \alpha_3)(T_3 + \frac{\theta}{6}T_3^3)$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$c_k - c_{k-1} = \frac{1}{p^{\beta}}(\alpha_k - \alpha_{k-1})(T_{k-1} + \frac{\theta}{6}T_{k-1}^{\ 3})$$

Summing up all these equations gives us:

$$c_k - c_1 = \sum_{i=2}^{k}\frac{1}{p^{\beta}}(\alpha_i - \alpha_{i-1})(T_{i-1} + \frac{\theta}{6}T_{i-1}^{\ 3})$$

Since c_1 is zero so:

$$c_k = \sum_{i=1}^{k}\frac{1}{p^{\beta}}(\alpha_i - \alpha_{i-1})(T_{i-1} + \frac{\theta}{6}T_{i-1}^{\ 3})$$

Then the solution of equation (1) will be:

$$I_k(t) = (A - \frac{\alpha_k}{p^{\beta}})(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \sum_{i=1}^{k}\frac{1}{p^{\beta}}(\alpha_i - \alpha_{i-1})(T_{i-1} + \frac{\theta}{6}T_{i-1}^{\ 3})e^{-\frac{\theta t^2}{2}}$$

$$T_{k-1} \le t \le T_k$$

for k=1,2,...............(m-1)
Let k=m, then solution of equation (2) will be:

$$I_m^{\ -}(t) = (A - \frac{\alpha_m}{p^{\beta}})(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \sum_{i=1}^{m}\frac{1}{p^{\beta}}(\alpha_i - \alpha_{i-1})(T_{i-1} + \frac{\theta}{6}T_{i-1}^{\ 3})e^{-\frac{\theta t^2}{2}}$$

$$T_{m-1} \le t \le T$$

$$I_j(t) = -\frac{\alpha_j}{p^{\beta}}(t + \frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \frac{\alpha_n}{p^{\beta}}(T_n + \frac{\theta}{6}T_n^{\ 3})e^{-\theta\frac{t^2}{2}}$$

$$-\sum_{i=j+1}^{n}\frac{1}{p^{\beta}}(\alpha_i - \alpha_{i-1})(T_{i-1} + \frac{\theta}{6}T_{i-1}^{\ 3})e^{-\frac{\theta t^2}{2}}$$

for j=m+1,m+2......n $\qquad T_{j-1} \le t \le T_j$

Notes

$$I_m^{+}(t) = -\frac{\alpha_m}{p^{\beta}}(t+\frac{\theta}{6}t^3)e^{-\frac{\theta t^2}{2}} + \frac{\alpha_n}{p^{\beta}}(T_n+\frac{\theta}{6}T_n^{3})e^{-\theta\frac{t^2}{2}}$$

$$-\sum_{i=m+1}^{n}\frac{1}{p^{\beta}}(\alpha_i-\alpha_{i-1})(T_{i-1}+\frac{\theta}{6}T_{i-1}^{3})e^{-\frac{\theta t^2}{2}}$$

$$T \le t \le T_m$$

Notes

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