An Inventory Model for Deteriorating Item with Reliability Consideration and Trade Credit

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Abstract

In todays global market every body want to buy products of high level quality and to achieve a high level product quality supplier have to invest in improving reliability of production process. In present article we have studies reliable production process with stock dependent unit production and holding cost. Demand is exponential function of time and infinite production process with non- instantaneous deterioration rate are considered in this paper. Whole study has been done under the effect of trade credit. The main objective of this paper is to optimize the total relevant cost for reliable production process. Numerical example and sensitivity analysis is given at the end of this paper.

Keywords: Infinite production, Deterioration, Trade credit, Reliability, Inflation.

Literature Review

In classical inventory models quality of produced items are assumed to be good. Whereas it is not always true. The quality of items directly or indirectly related to the production process. So now a day many organizations have started to invest in improving the reliability of production process. Recently researchers have started to concentrate on this concept. For the review we can go through the work of Cheng (1989), Leung (2007), Panda and Maiti (2009).

The unit production cost is directly or indirectly related to the order quantity. Cheng (1989, 1991), Kotb (1998), Panda and Maiti (2009) have focused on demand dependent unit cost. The concept of variable holding cost is not discussed in classical inventory. In reality holding cost varies with the amount produced. Hariri and Abou-el-ata (1997), Abou-el-ata and Kotb (1997), Abou-el-ata, Fergany, El-Wakeel (2003), Singh, Singh and Bhaitia (2010) have considered variable inventory costs.

Deterioration means decay, damage out off trend, spoilage, evaporation. Deteriorating items like fruits and vegetables, volatile liquids, blood, fashion goods etc. Deteriorating inventory systems have first introduced by Ghare and Scharder (1967). They have developed an inventory model with constant rate of deterioration. In real life there are different types of items which start to deteriorate after their maximum life time i.e. non-instantaneous deterioration. Manna and Chaudhuri (2006), Skouri, Konstantaras, Papachristos, Ganas (2009) and Wu, Ouyang and Yang (2009), Singh, kumari and Kumar (2010) have focused on non- instantaneous deterioration rate etc.

Demand rate is an important factor in modeling of deteriorating inventory model. There are different types of demand functions like constant, time dependent, stock dependent, price dependent all these are of deterministic type. It is often seen that demand rate vary with time. Hence one can say that this type of demand rate is more practical then constant rate of demand. Linear trend in demand has been considered first by Resh et al. (1976) and Donaldson (1977). As the time progressed sufficient work has been done on trended demand. Giri, Chakrabarty, Chaudhuri (2000), Chang, Hung, Dye (2001), Chu and Chen (2001), Balkhi (2003), Teng and Yang (2007), Singh and Singh (2010), have studied time varying demand rate.

In today's business it is seen that supplier provides a permissible delay period to their customer in settling the account, to decrease total cost and increase their profit. During this period there is no interest charged but after that period interest will be charged on unsold item. Recently Teng, Chang, Goyal (2005) have considered the effect of trade credit and developed an optimal pricing and ordering policies. Kumar, Tripathi, Singh (2008) have developed a model with variable demand rate and trade credit. Many authors have focused on trade credit like Chang, Wu, Chen (2009), Singh and Jain (2009), Chen and Kang (2010), Chen and Cheng (2011), Jaggi, Goel, Mittal (2011), Singh, Kumari and Kumar (2011), Zhou, Zhong, Li (2012), etc.

Before 1970's inflation is not considered by researchers. After that effect of inflation is seen in many countries. Effect of inflation has been introduced first by Buzacot (1975). After that several researchers have extended the work of Buzacot in different ways. For further review we can go through the work of Dye, Mandal, Maiti (2008), Singh Kumar and Kumari (2010), Singh and Singh (2011) etc.

In this paper we have developed a production inventory model for non- instantaneous deteriorating items under consideration of reliability production process in an inflationary environment. The demand is exponential function of time with permissible delay in payment. In the next section assumptions and notations are given for mathematical model formulation which is next to it. At the end numerical illustration and sensitivity analysis is performed.

Assumption

- Production rate is infinite with zero lead time and Infinite time horizon.
- Demand rate is time dependent as $D(t) = \alpha\, e^{\beta t}$ where α and $\beta > 0$.
- Shortages are not allowed
- Deterioration rate θ is non – instantaneous as follows

$$Deterioration\ rate = \begin{cases} 0, & 0 \le t \le t_d \\ \theta, & t_d \le t \le T \end{cases}$$

  where $0 < \theta << 1$ and t_d is maximum life time of an item.
- The unit production cost C_o is order level (Q) dependent i. e. $C_p = a\, Q^{-b}$ where $a > 0$, $0 < b < 1$.
- Holding cost C_h per unit per unit time is unit cost dependent as follows $C_h = F\, C_p$ where $0 < F < 1$.

- The inflation rate R is difference between time discounting and inflation such that 0< R< 1.
- Total cost of interest and depreciation per production cycle is inversely related to the set up cost and directly related to process reliability[1] i. e. IDP=f($C_{o,}$ r) = c C_o^{-d} r^e where c, d, e are all positive constants. The process reliability means only r items are of good quality and are used to satisfy the demand.
- During the permissible delay time M, purchaser will deposit sales revenue in interest- bearing account. There are two choices for purchaser at the end of delay period. Purchaser can pay at the end of trade period M or between M and T. The purchaser pay off for all ordered items and starts paying for the interest charges on the items in stocks when purchaser pays the amount at time M. Supplier charges high interest for unsold items when purchaser choose the payment time between M and T.

Notations

- C_o is set-up cost.
- C_p is unit production cost.
- C_h is the unit holding cost per unit per unit time.
- T is total cycle length.
- I_e: interest earned per $ per year.
- I_p: Interest paid by purchaser per $ in stock per year, which is charged by supplier.
- M: Permissible delay in payment (i. e. trade credit for purchaser to settle the account).
- $I_1(t)$ is inventory level during time period $0 \leq t \leq t_d$.
- $I_2(t)$ is inventory level during time period $t_d \leq t \leq T$.
- $TC_2(Q, C_0, r)$: Present worth of Total relevant cost per time unit, when M ≤ T.
- $TC_1(Q, C_0, r)$: Present worth of Total relevant cost per time unit, when T < M.

Note: The Present worth of total relevant cost includes following costs

- SC is the set-up cost.
- PC is present worth of purchase cost.
- HC is present worth of holding cost.
- IP: Present worth of Interest paid for unsold times at initial time or after the permissible delay M.
- IE: Present worth Interest earned from sales revenue during permissible delay in payment.
- IDP: Cost of interest and depreciation per production cycle.

Mathematical Model Formulation

The inventory depletion during time period [0, t_d] is due to demand only and after t_d life time of an item expires and deterioration starts. Hence inventory depletion during time period [t_d, T] is due to combine effect of demand and deterioration. The whole inventory function is represented by differential equations as follows

$$\frac{dI_1(t)}{dt} = -(\alpha e^{\beta t}) \qquad 0 \le t \le t_d \tag{1}$$

$$\frac{dI_2(t)}{dt} + \theta I_2(t) = -(\alpha e^{\beta t}) \qquad t_d \le t \le T \tag{2}$$

Under following boundary conditions $I_1(t = 0) = rQ$, $I_1(t = t_d) = I_2(t = t_d)$ and $I_2(t = T) = 0$. Now solving (1) and (2) we get

$$I_1(t) = \frac{\alpha}{\beta}(1 - e^{\beta t}) + rQ \tag{3}$$

$$I_2(t) = \frac{\alpha}{(\beta+\theta)}(e^{(\beta+\theta)T} - e^{(\beta+\theta)t})e^{-t\theta} \tag{4}$$

Now from continuity at t= t_d, $I_1(t_d)$= $I_2(t_d)$ we get $T = \frac{1}{\alpha(1-t_d\theta)}(rQ - \alpha(\beta+\theta)t_d^2)$ (5)

The total relevant cost consists following cost parameters

1. The set- up cost (SC)= C_0
2. The Purchase Cost (PC)= C_p *Q
3. The present worth of holding cost (HC) is

$$HC = C_h[\int_0^{t_d} I_1(t)e^{-Rt}dt + \int_{t_d}^{T} I_2(t)e^{-Rt}dt] \tag{6}$$

$$HC = C_h[\frac{\alpha}{(\beta+\theta)}(1-(\beta+\theta)T)(T-t_d) - \frac{\alpha}{(\beta+\theta)}((T-t_d)+(\beta-R)(\frac{T^2-t_d^2}{2}))$$
$$-(t_d + t_d^2 R)(\frac{\alpha}{\beta}+rQ) - \frac{\alpha}{\beta}(t_d + t_d^2(\beta-R))] \tag{7}$$

Now we will find Interest paid and earned by purchaser, for this there are two cases (i) T < M and (ii) M ≤ T. These two cases are graphically represented in Figure-1 & 2.

Case: 1 (T < M)

The permissible delay period M is greater than the total inventory depletion period i.e. T. Therefore there is no interest paid by purchaser to the supplier for the items. However purchaser will uses the sales revenue to earn interest at the rate of I_e during time period [0, T] and interest from cash invested during period [T, M]. Hence the Present worth of interest earned is

$$IE_1 = I_e[\int_0^T tD(t)e^{-Rt}dt + (M-T)\int_0^T D(t)e^{-Rt}dt]$$

$$IE_1 = I_e[\{(\beta - R)\frac{\alpha T^3}{2} + \frac{\alpha T^2}{2}\} + (M - T)\alpha\{T - (\beta - R)T^2\}] \tag{8}$$

Hence the Present worth of total relevant cost per cycle is

$$TC_1(Q, C_0, r) = (1/T)\,[SC + PC + HC + IDP - IE_1]$$

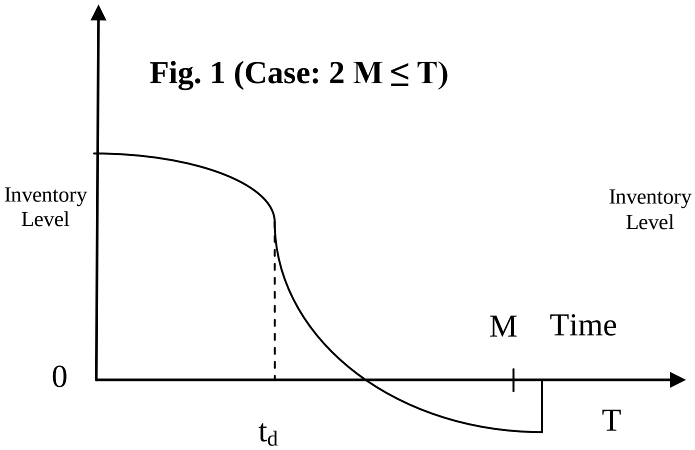

Fig. 1 (Case: 2 M ≤ T)

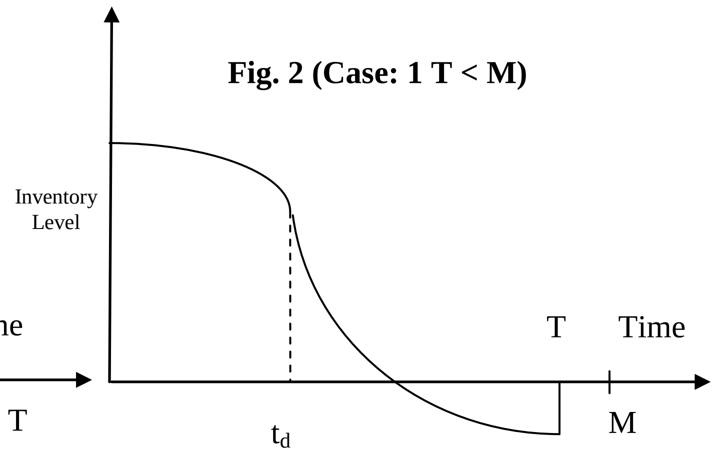

Fig. 2 (Case: 1 T < M)

Case: 2 (M ≤ T)

In this case the permissible delay period M expires before the total inventory depletion period T; hence purchaser will have to pay interest charged on unsold items during (M, T). Therefore Present worth of interest paid by purchaser is

$$IP_2 = I_P \int_M^T I_2(t) e^{-Rt} dt$$

$$IP_2 = I_P \frac{\alpha}{(\beta + \theta)}[(1 + (\beta + \theta)T)(T - M) - \{(T - M) + \frac{1}{2}(\beta - R)(T^2 - M^2)\}] \tag{9}$$

Now the Present worth of interest earned during positive inventory and interest from invested cost is

$$IE_2 = I_e \int_M^T tD(t) e^{-Rt} dt$$

$$IE_2 = I_e \alpha\{\frac{1}{2}M^2 + (\beta - R)M^3\} \tag{10}$$

Hence the Present worth of total relevant cost per cycle is

$$TC_2(Q, C_0, r) = 1/T[SC + PC + HC + IDP + IP_2 - IE_2]$$

To minimize total relevant cost, we differentiate $TC(Q, C_0, r)$ w. r. t to Q, C_0 *and* r, and for optimal value necessary conditions are

$$\frac{\partial TC(Q, C_0, r)}{\partial Q} = 0, \quad \frac{\partial TC(Q, C_0, r)}{\partial C_0} = 0, \quad \frac{\partial TC(Q, C_0, r)}{\partial r} = 0$$

Provided the determinant of principal minor of hessian matrix are positive definite, i.e. det(H1)>0, det(H2)>0,det(H3)>0 where H1, H2, H3 is the principal minor of the Hessian-matrix.

Hessian Matrix of the total cost function is as follows:

$$\begin{bmatrix} \frac{\partial^2 TC(Q,C_0,r)}{\partial Q^2} & \frac{\partial^2 TC(Q,C_0,r)}{\partial Q \partial C_0} & \frac{\partial^2 TC(Q,C_0,r)}{\partial Q \partial r} \\ \frac{\partial^2 TC(Q,C_0,r)}{\partial C_0 \partial Q} & \frac{\partial^2 TC(Q,C_0,r)}{\partial {C_0}^2} & \frac{\partial^2 TC(Q,C_0,r)}{\partial C_0 \partial r} \\ \frac{\partial^2 TC(Q,C_0,r)}{\partial r \partial Q} & \frac{\partial^2 TC(Q,C_0,r)}{\partial r \partial C_0} & \frac{\partial^2 TC(Q,C_0,r)}{\partial r^2} \end{bmatrix}$$

Numerical Example

For the Illustration of proposed model we consider following inventory system in which values of different parameters in proper units are $\alpha = 90, \beta = 2.2, \theta = 0.05, I_e = 0.18, I_p = 0.2.$ a=15, b= 7, F= 0.011, c = 50, d = 2.5, e_1 = 5, t_d= 0.002, R= 0.02 there are two cases according to the permissible delay period as follows:

Case: 1 for T < M, M= 0.003, Using mathematical software Mathematica7 the output results are as follows

T= 0.002375, C_0^*= 1.54688, r^*= 0.516699, Q^*= 0.286356, $TC_1^*(Q^*, C_0^*, r^*)$ =9715.23

Case: 2 for M≤ T, M= 0.00231, Using mathematical software Mathematica7 the output results are as follows

T= 0.00261, C_0^*=1.54688, r^*= 0.516699, Q^*= 0.286356, $TC_2^*(Q^*, C_0^*, r^*)$ =9724.14

Sensitivity Analysis

To check sensitivity of the model we have performed a sensitivity analysis by changing values of some important parameters like α, β, θ, t_d, M, R, F, a. we have made +10%, +5%, -5%, -10% change in their original value given in numerical example. The effect of slight variations in values of parameters is given below in table 1 &2.

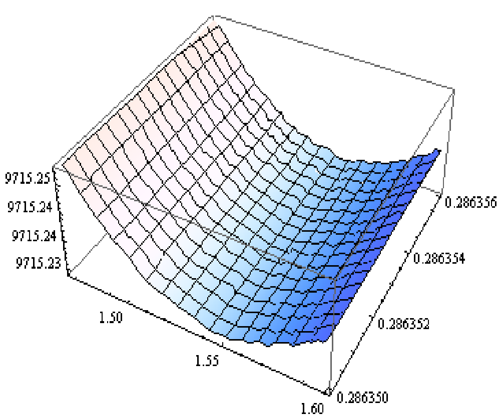

Fig.3 (Case: T < M) Convexity of TC_1^* w. r. t. Q^* and C_0^*

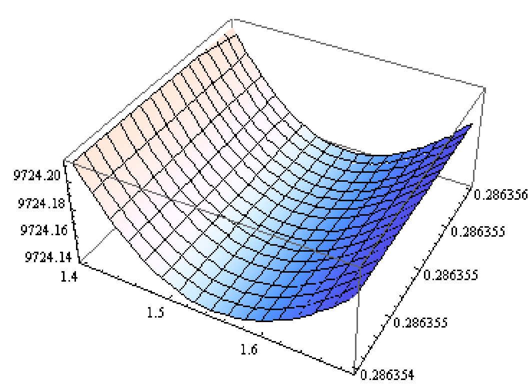

Fig.4 (Case: M ≤ T Convexity of TC_2^* w. r. t. Q^* and C_0^*

Table: 1 (Case : T < M)

change in α	r	C_0	Q	TC_1	T
10%	0.136223	0.23032	0.314965	2192.86	0.002002
5%	0.261174	0.58366	0.300657	2899.57	0.002148
_5%	1.05775	4.30478	0.272071	5286.07	0.002469
_10%	2.24661	10.627	0.257819	7308.56	0.002626
change in β					
10%	0.560271	1.73654	0.284705	4023.18	0.002379
5%	0.539055	1.64337	0.285491	3957.22	0.002377
_5%	0.493132	1.44708	0.287313	3809.16	0.002372
_10%	0.468278	1.34403	0.288376	3725.72	0.002369
change in θ					
10%	0.52172	1.5684	0.286158	3902.25	0.002376
5%	0.519206	1.55761	0.286257	389417	0.002375
_5%	0.5142	1.5362	0.286455	3878.01	0.002374
_10%	0.511709	1.52558	0.28655	3869.93	0.002373
change in t_d					
10%	0.607686	1.95024	0.287592	3787.41	0.002385
5%	0.561838	1.74349	0.286973	3836.43	0.00238
_5%	0.472415	1.36102	0.285741	3936.39	0.002369
_10%	0.429135	1.18645	0.285127	39874.34	0.002363
change in M					
10%	0.516699	1.54688	0.286356	3886.09	0.002374
5%	0.516699	1.54688	0.286356	3886.09	0.002374
_5%	0.516699	1.54688	0.286356	3886.09	0.002374
_10%	0.516699	1.54688	0.286356	3886.09	0.002374
change in R					
10%	0.518819	1.55595	0.286274	3892.77	0.002374
5%	0.517758	1.55141	0.286315	3889.43	0.002375
_5%	0.515643	1.54237	0.286397	3882.76	0.002376
_10%	0.514589	1.53787	0.286438	3879.42	0.002377
change in F					
10%	0.170124	0.31638	0.314969	2193.02	0.002303
5%	0.292624	0.686598	0.30066	2899.61	0.002308
_5%	0.938917	3.63089	0.272061	5286.38	0.00274
_10%	1.76054	8.91334	0.257781	7310.6	0.002915
change in a					
10%	0.645133	2.12416	0.286364	4274.66	0.002912
5%	0.578891	1.81957	0.28636	4080.38	0.002443
_5%	0.458498	1.30411	0.286352	3691.78	0.002356
_10%	0.404113	1.0893	0.286349	3497.45	0.002386

Table: 2(Case M ≤ T)

change in α	r	C_0	Q	TC_1	T
10%	0.136223	0.23032	0.314965	5491.96	0.002602
5%	0.261174	0.58366	0.300657	7258.27	0.002443
_5%	1.05775	4.30478	0.272071	13223.7	0.002125
_10%	2.24661	12.627	0.257819	18279.4	0.001967
change in β					
10%	0.560271	1.73654	0.284705	10067.7	0.002266
5%	0.539055	1.64337	0.285491	9902.39	0.002274
_5%	0.493131	1.44708	0.287313	9531.4	0.002295
_10%	0.468278	1.34403	0.288376	9322.37	0.002306
change in θ					
10%	0.52172	1.5684	0.286158	9764.56	0.002282
5%	0.519206	1.55761	0.286257	9744.35	0.002283
_5%	0.5142	1.5362	0.286455	9703.94	0.002285
_10%	0.511709	1.52558	0.286555	9683.74	0.002286
change in t_d					
10%	0.607686	1.95024	0.287592	9477.44	0.002298
5%	0.561838	1.74349	0.286973	9600	0.002291
_5%	0.472415	1.361045	0.285741	9849.89	0.002277
_10%	0.429135	1.18645	0.285127	9977.26	0.00227
change in M					
10%	0.516699	1.546699	1.286356	9724.14	0.002284
5%	0.516699	1.546699	1.286356	9724.141	0.002284
_5%	0.516699	1.546699	1.286356	9724.143	0.002284
_10%	0.516699	1.546699	1.286356	9724.15	0.002284
change in R					
10%	0.518819	1.55595	0.286274	9707.48	0.002282
5%	0.517758	1.55141	0.286315	9715.8	0.002283
_5%	0.515643	1.54237	0.286397	9732.49	0.002284
_10%	0.514589	1.53787	0.286438	9740.89	0.002285
change in F					
10%	0.170124	0.31638	0.314969	5491.46	0.002602
5%	0.292624	0.686598	0.30066	7257.94	0.002443
_5%	0.938917	3.63089	0.272061	13224.9	0.002125
_10%	1.76054	8.91334	0.257781	18285.4	0.001966
change in a					
10%	0.645133	2.12416	0.286364	10695.6	0.002284
5%	0.578891	1.81957	0.28636	10209.9	0.002284
_5%	0.458498	1.30411	0.286352	9238.37	0.002284
_10%	0.404223	1.0893	0.286349	8752.55	0.002284

Through keen observation of Table 1 & 2 we found following variations:

Case: 1 (T < M)

1. increment in α results in decrement r^*, C_0^*, TC_1^*, T^*, & increment in Q^*
2. increment in β results in increment r^*, C_0^*, TC_1^*, T^*, & decrement in Q^*
3. increment in θ results in increment r^*, C_0^*, TC_1^*, T^*, & decrement in Q^*
4. increment in t_d results in increment r^*, C_0^*, Q^*, T^*, & decrement in $TC1^*$
5. increment in M results in slight change in r^*, C_0^*, Q^*, T^*, $TC1^*$
6. increment in R results in increment r^*, C_0^*, TC_1^*, & decrement in T^*, Q^*
7. increment in F results in decrement r^*, C_0^*, TC_1^*, T^*, & increment in Q^*
8. increment in 'a' results in increment r^*, C_0^*, TC_1^*, T^*, Q^*

Case: 2 (M ≤ T)

1. increment in α results in decrement r^*, C_0^*, TC_1^* & increment in T^*, Q^*
2. increment in β results in increment r^*, C_0^*, TC_1^* & decrement in T^*, Q^*
3. increment in θ results in increment r^*, C_0^*, TC_1^* & decrement in T^*, Q^*
4. increment in t_d results in increment r^*, C_0^*, Q^*, T^*, & decrement in $TC1^*$
5. increment in M results in decrement in $TC1^*$
6. increment in R results in increment r^*, C_0^* & decrement in Q^*, T^*, $TC1^*$
7. increment in F results in decrement r^*, C_0^*, $TC1^*$, & increment in Q^*, T^*
8. increment in 'a' results in increment r^*, C_0^*, TC_1^*, T^*, Q^*

Conclusion

In this paper we have studied the reliability production process. Through which quality of produced amount is improved. We have developed and production inventory model for non- instantaneous deteriorating items with time dependent demand under the effect of trade credit in an inflationary environment. At the end the model is numerically illustrated and a sensitivity analysis is performed using mathematical software Mathematica7 and results are shown through graphical representation. This study is useful for the items like fruits, vegetables etc and can be extended by incorporating other inventory control parameters.

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