REPLENISHMENT POLICY FOR TIME DEPENDENT DETERIORATING ITEMS UNDER CREDIT FINANCING

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ABSTRACT
A time dependent deteriorating inventory model is developed for a deterministic inventory system with constant demand in the presence of trade credit. The discounted cash flows (DCF) approach is used for the problem analysis, which allows a proper recognition of the financial implication of the opportunity cost and out – of – pocket costs. It also permits an explicit algo
rithm of the exact timing of cash – flows associated with an inventory system. A numerical example is considered to a give comprehensive sensitivity analysis of the developed model.

Key words: Time dependent deterioration of units, Discounted cash flows (DCF), Trade credit.

MSC: 90B05

RESUMEN
Un modelo de inventario con deterioro dependiente del tiempo es desarrollado para un sistema de inventario determinístico con demanda constante en presencia de crédito de comercio. El enfoque del flujo de descuento del dinero en efectivo (discounted cash flows: DCF) es usado para el análisis del problema que permite un reconocimiento apropiado de la implicación financiera del costo de oportunidad costado y fuera–del bolsillo (the opportunity cost and out – of – pocket costs). Esto también permite asociar un algoritmo explícito de cronometraje exacto del flujo de dinero en efectivo que se asociaron con un sistema del inventario. Un ejemplo numérico es considerado para brindar un análisis comprensible de sensibilidad del modelo desarrollado.

1. INTRODUCTION

During last three decades, the problem of deteriorating inventory has received considerable attention. This is a realistic situation since most of the products like chemicals, fruits and vegetables, photographic film, radioactive substances, etc. are subject to deterioration. Ghare and Schrader (1963) were the first to study inventory problems considering deterioration of items. Since then a number of studies are undertaken on deteriorating items. Raafat (1991), Shah and Shah (2000) and Goyal and Giri (2001) gave up – to – date survey of literature for inventory models when units in inventory are subject to deterioration. Covert and Philip (1973) assumed a two-parameter weibull distribution to consider varying rate of deterioration of units. Wee (1997) developed a replenishment policy for items with a price dependent demand and a varying rate of deterioration.

All the above models were developed under the assumption that the payments are made to wholesaler as soon as the items are received. However, in practice, the supplier announces some credit period in settling the account, so that no interest charges are payable on the outstanding amount if the account is settled within the allowable delay period. The supplier will obviously charge higher interest if the account is not settled by the end of the delay period. This brings some economic advantage to the system, as it would try to earn some interest from the revenue realized during the period of permissible delay. Davis and Gaither (1985) studied an EOQ model when supplier offers one time opportunity to delay the payments of order in case an order for additional units is placed. Goyal (1985) studied an EOQ model under conditions of permissible delay in payments. Shah, Patel and Shah (1988) extended the above model by allowing shortages. Mandal and Phaujdar (1989) developed mathematical model by including interest earned from the sales revenue on the stock remaining beyond the settlement period. Shah and Shah (1992) and Shah (1993) developed inventory model by taking uncertain demand (i.e. probabilistic demand). Haley and Higgins (1973), Kingsman (1983), Chapman et al (1985), Daellenbach (1986), Ward and Chapman (1987), Daellenbach (1988), Chapman and Ward (1988) examined the effects of the trade credit on the optimal inventory policy. These studies provided useful insights into the importance of the credit period in inventory control decisions, but it fails to visualize the

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effect of the delayed payment in determining the optimal order quantity. Shah (1993) developed a lot size model for exponentially decaying inventory when delay in payments is permissible. Shah (1993) extended above model when demand is probabilistic. The mathematical model with lead – time is developed by Shah (1997). Jamal, Sarker and Wang (2000) developed the problem in which the retailer can pay the wholesaler either at the end of the credit period or later incurring interest charges on the unpaid balance for the overdue period. They developed a retailer's model for optimal cycle time and payment terms for a retailer in a deteriorating item inventory model where a wholesaler allows a specified credit period to the retailer for payment without penalty. Hwang and Shinn (1997) determined the retailer's optimal price and lot – size when the supplier permits delay in payment for an order of a product whose demand rate is given by a constant price elasticity function.

All above mathematical development is modeled as a cost minimization problem under various system parameters. Trippi and Lewin (1974) presented an alternative framework for the analysis of the effect of the trade credit on inventory decisions based upon the principles of financial management. They used DCF approach for analysis of the basic EOQ model. Kim, Philippatos and Chung (1986) studied various inventory systems using DCF approach. Chung (1989) used DCF approach for the analysis of the optimal inventory policy in the presence of the trade credit. The DCF approach gives a proper recognition of the financial implication of the opportunity cost and out – of – pocket costs in inventory analysis. It gives the exact timing of cash flows associated with an inventory system, and hence, the effect of the delayed payment is reflected appropriately in determining the optimal order size. Jaggi and Aggarwal (1994) extended the above model for deteriorating items. Wee and Law (2001) developed deterministic inventory model for deteriorating items taking into account the time value of money and price dependent demand. They used DCF approach to derive near optimal solution for maximizing the total net present value of profit.

In this article, an attempt has been made to develop an inventory model for obtaining optimum order quantity of time dependent deteriorating items in the presence of trade credit using the DCF approach.

2. ASSUMPTIONS AND NOTATIONS

The mathematical model is developed under the following assumptions and notations.

1. The demand rate is R units per time unit.
2. The replenishment size Q is a decision variable.
3. The length of inventory cycle is T (a decision variable).
4. C denotes unit purchase cost of item.
5. A denotes ordering cost per order.
6. h = C i denotes inventory holding cost per unit per time unit where i is the carrying charge factor per unit per time unit.
7. r denotes discount rate (opportunity cost) per time unit.
8. Lead time is zero and shortages are not allowed.
9. Replenishment is instantaneous.
10. The deterioration rate is given by the Weibull distribution:

$$\theta(t) = \alpha \beta t^{\beta - 1}, \qquad 0 \le t \le T$$

where α - scale parameter, $0 \le \alpha < 1$, β - shape parameter, $\beta \ge 1$, t - time to deterioration, $t > 0$.

11. There is no repair or replacement of deteriorated units during a given cycle.
12. M denotes allowable credit period.

3. MATHEMATICAL FORMULATION

Let Q (t) be the on-hand inventory at any instant of time t ($0 \le t \le T$). It is assumed that depletion due to deterioration and due to demand will occur simultaneously. The differential equation governing the instantaneous state of Q (t) in the cycle time [0, T] is given by

$$\frac{dQ(t)}{dt} + \theta(t)Q(t) = -R, \quad 0 \le t \le T \tag{1}$$

with initial conditions Q(0) = Q and Q(T) = 0. Then the solution of (1) is

$$Q(t) = R\left[T - t + \frac{\alpha T}{\beta+1}\left(T^{\beta} - (1+\beta)\, t^{\beta}\right) + \frac{\alpha\beta t^{\beta+1}}{\beta+1}\right] \tag{2}$$

using Q(0) = Q; we get

$$Q = R\left[T + \frac{\alpha T^{\beta+1}}{\beta+1}\right] \tag{3}$$

The total demand during one cycle is RT. Hence the number of units that deteriorated during one cycle D (T) is given by

$$D(T) = Q - RT = \frac{R\alpha T^{\beta+1}}{\beta+1} \tag{4}$$

Since credit period is allowed we have following two cases.

Case (I): - Credit only on units in stock:

In the presence of credit period M, customer makes payment to the supplier immediately after the use of the materials. On the last day of the credit period, the customer pays the remaining balance. Hence, the present value of all cash out flows for the first cycle is

PV(T) = – [Ordering Cost + Procurement Cost +

Deterioration Cost (T < M) for Interest Paid (T > M) + Inventory Holding Cost]

$$PV(T) = -\begin{cases} A + CR\int_0^T e^{-rt}\,dt + CD(T)\,e^{-rM} + h\int_0^T Q(t)\,e^{-rt}\,dt, & T < M \\ A + CR\int_0^M e^{-rt}\,dt + C(Q - RM)e^{-rM} + h\int_0^T Q(t)\,e^{-rt}\,dt, & T > M \end{cases}$$

Hence

$$PV(T) = -\begin{cases} A + \frac{CR}{r}\left(1 - e^{-rT}\right) + \frac{CR\alpha T^{\beta+1}}{\beta+1}e^{-rM} + hR\left[\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^3}{6}\right], & T < M \quad (5.a) \\ A + \frac{CR}{r}\left(1 - e^{-rM}\right) + CR(T - M)\,e^{-rM} + hR\left[\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^3}{6}\right], & T > M \quad (5.b) \end{cases}$$

The present value of all future cash – flows is

$$PV_\infty(T) = \sum_{n=0}^{\infty} PV(T)\, e^{-nrT} = \frac{PV(T)}{1 - e^{-rT}}$$

Hence (5.a) and (5.b) reduces to

$$PV_\infty(T) = \left(\frac{1}{rT} + \frac{1}{2} + \frac{rT}{4} \right) PV(T)$$

$$= -\left[\frac{A}{rT} + CR\left(\frac{1}{r} - \frac{T}{2} + \frac{rT^2}{6} \right) + \frac{Cr\alpha\beta T^{\beta}}{\beta+1}\left(\frac{1}{r} - M \right) \right.$$

$$+ \frac{hR}{r}\left(\frac{T}{2} + \frac{\alpha\beta T^{\beta+1}}{(\beta+1)(\beta+2)} - \frac{rT^2}{6} \right) + \frac{A}{2} + \frac{CRT}{2}\left(1 - \frac{rT}{2} \right) + \frac{CR\alpha\, T^{\beta+1}}{2(\beta+1)}$$

$$\left. + \frac{hR}{2}\left(\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^3}{6} \right) + \frac{ArT}{4} + \frac{CRT^2}{4} + \frac{CRrT^{\beta+2}}{4(\beta+1)} + \frac{hRrT^3}{16} \right]$$

for $(T < M)$. (6.a)

$$= -\left[\frac{A}{rT} + \frac{CR}{T}\left(\frac{M}{r} - \frac{M^2}{2} + \frac{rM^3}{6} \right) + \frac{CR}{T}(T - M)\left(\frac{1}{r} - M + \frac{rM^2}{2} \right) \right.$$

$$+ \frac{hR}{r}\left(\frac{T}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^2}{6} \right) + \frac{A}{2} + \frac{CRM}{2}\left(1 - \frac{rM}{2} \right) + \frac{CR}{2}(T - M)(1 - rM)$$

$$\left. + \frac{hR}{2}\left(\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{\beta+2} - \frac{rT^3}{6} \right) + \frac{ArT}{4} + \frac{CRrTM}{4} + \frac{CRrT(T - M)}{4} + \frac{hRrT^3}{16} \right]$$

for $(T > M)$. (6.b)

Also at $T = M$, both the cost functions in equations (6.a) and (6.b) are equal. The terms involved in (6) are expanded till power one of both αT and rT ignoring the second and higher powers of αT and rT. The optimum value of T, (say) T_1 can be obtained by solving equations (7.a) and (7.b) using Newton Raphson's Method.

$$\frac{dPV_\infty(T)}{dT} = \frac{A}{rT^2} - \frac{CRrT}{3} - \frac{CR\alpha\beta\, T^{\beta-1}}{\beta+1}\left(\frac{1}{r} - M \right) - \frac{hR}{r}\left(\frac{1}{2} + \frac{\alpha\beta\, T^{\beta}}{\beta+2} \right)$$

$$- \frac{hRT}{6} - \frac{CR\alpha\, T^{\beta}}{2} - \frac{hR\alpha\beta\, T^{\beta+1}}{2(\beta+1)} + \frac{hRrT^2}{16} - \frac{Ar}{4}$$

$$- \frac{CRr(\beta+2)\, T^{\beta+1}}{4(\beta+1)} = 0, \quad \text{for } (T < M) \qquad (7.a)$$

$$\frac{dPV_\infty(T)}{dT} = \frac{A}{rT^2} + \frac{CRM}{T^2}\left(\frac{M}{2} - \frac{rM^2}{3}\right) - \frac{hR}{r}\left(\frac{1}{2} + \frac{\alpha\beta T^\beta}{\beta+2}\right) - \frac{5hRT}{6}$$

$$- \frac{CR}{2} - \frac{CRr}{2}(T - M) - \frac{hR\alpha\beta T^{\beta+1}}{2(\beta+1)} - \frac{Ar}{4} = 0, \text{ for } (T > M) \qquad (7.b)$$

The value of T = T_1 obtained using equation (7.a) will be optimum if T1 < M and satisfies the sufficient condition $\frac{d^2PV_\infty{}^2(T)}{dT^2} < 0$ for equation (8.a); otherwise equation (7.b) will determine the optimum cycle time provided the same condition is satisfied by equation (8.b).

$$\frac{d^2PV_\infty(T)}{dT^2} = -\left[\frac{2A}{rT^3} + \frac{CRr}{3} + \frac{CR\alpha\beta(\beta-1)T^{\beta-2}}{\beta+1}\left(\frac{1}{r} - M\right) + \frac{hR}{r}\frac{\alpha\beta^2T^{\beta-1}}{(\beta+2)}\right.$$

$$+ \frac{hR}{6} + \frac{CR\alpha\beta T^{\beta-1}}{2} + \frac{hR\alpha\beta T^\beta}{2} - \frac{hRrT}{8}$$

$$\left. + \frac{CRr(\beta+2)T^\beta}{4}\right], \quad \text{for } (T < M) \qquad (8.a)$$

$$= -\left[\frac{2A}{rT^3} + \frac{2CRM}{T^3}\left(\frac{M}{2} - \frac{rM^2}{3}\right) + \frac{hR\alpha\beta^2T^{\beta-1}}{r(\beta+2)} + \frac{5hR}{6}\right.$$

$$\left. + \frac{CRr}{2} + \frac{hR\alpha\beta T^\beta}{2}\right], \quad \text{for } (T > M) \qquad (8.b)$$

Once the optimum cycle time is determined, optimum order quantity and the corresponding optimum present value of all future cash flows can be obtained from equations (3), (6.a) and (6.b). It is observed that the payments to the supplier immediately follows the use of material and if the credit period is longer than the cycle time then only out – of – pocket cost and the discounted cost of deterioration should be taken to calculate optimum cycle time. The opportunity cost has no role to play because in this case, the firm finances the inventory investment with trade credit offered by the supplier.

When the credit period is less than cycle time, i.e. T > M, the DCF approach gives a different solution from the usual cost minimizing analysis for deteriorating items. When β = 1, the results are identical to the results of Jaggi and Aggarwal (1994). When equation .3 INCRUSTAR Equation.3 µ uaequation.3 µ § = 1, results correspond tcorrespond to those of Chung (1989).hung (198rametric values are given in Tables 1 – 6.

Case (II): - Fixed credit period:

Here customer pays the full purchase amount on the last day of the credit period. Thus, the present value of all cash out flows for the first cycle is PV (T) given by

PV(T) = – [Ordering Cost + Procurement Cost + Inventory Holding Cost]

$$PV(T) = -\left[A + CQ e^{-rM} + h\int_0^T Q(t)\,dt \right]$$

$$= -\left[A + CR\left(T + \frac{\alpha T^{\beta+1}}{\beta+1}\right) e^{-rM} + hR\left(\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^3}{6}\right)\right]$$

$$\therefore \quad PV_\infty(T) = \left(\frac{1}{rT} + \frac{1}{2} + \frac{rT}{4}\right) PV(T)$$

$$PV_\infty(T) = -\left[\frac{A}{rT} + CR\left(\frac{1}{r} - M + \frac{rM^2}{2}\right) + \frac{CR\alpha T^{\beta}}{r(\beta+1)}\right.$$

$$+ \frac{hR}{r}\left(\frac{T}{2} + \frac{\alpha\beta T^{\beta+1}}{(\beta+1)(\beta+2)} - \frac{rT^2}{6}\right) + \frac{A}{2} + \frac{CRT}{2}\left(1 - rM\right) + \frac{CR\alpha T^{\beta+1}}{2(\beta+1)}$$

$$\left. + \frac{hR}{2}\left(\frac{T^2}{2} + \frac{\alpha\beta T^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{rT^3}{6}\right) + \frac{ArT}{4} + \frac{CRrT^2}{4} + \frac{hRrT^3}{8}\right] \qquad (9)$$

The optimum value of $T = T_2$ can be obtained by solving equation (10) using Newton Raphson's method.

$$\frac{dPV_\infty(T)}{dT} = \frac{A}{rT^2} - \frac{CR\alpha\beta T^{\beta-1}}{r(\beta+1)} - \frac{hR}{r}\left(\frac{1}{2} + \frac{\alpha\beta T^{\beta}}{\beta+2}\right) - \frac{hRT}{6} - \frac{CR}{2}$$

$$+ \frac{CRr}{2}\left(M - T\right) - \frac{CR\alpha T^{\beta}}{2} - \frac{hR\alpha\beta T^{\beta+1}}{2(\beta+1)} - \frac{Ar}{4} - \frac{hRrT^2}{8} = 0 \qquad (10)$$

Hence, optimum purchase quantity and present value of future cash flows can be obtained. The obtained present value of future cash flows is minimum because

$$\frac{d^2PV_\infty(T)}{dT^2} = -\left[\frac{2A}{rT^3} + \frac{CR\alpha\beta(\beta-1)T^{\beta-2}}{r(\beta+1)} + \frac{hR\alpha\beta^2 T^{\beta-1}}{r(\beta+2)} + \frac{hR}{6} + \frac{CRr}{2} + \frac{CR\alpha\beta T^{\beta-1}}{2}\right.$$

$$\left. + \frac{hR\alpha\beta T^{\beta}}{2} + \frac{hRrT}{4}\right] \text{ which is } < 0 \text{ for } T = T_2 \qquad (11)$$

Hence, cycle time is optimum at $T = T_2$.

When $\beta = 1$, we get results of Jaggi and Aggarwal (1994) and $\alpha = 0$, $\beta = 1$, the derived model reduces to that of Chung (1989).

3. NUMERICAL EXAMPLE

Consider an inventory system with following parametric values in appropriate units.

R = 2000	A = 200	C = 20	i = 0.15	h = Ci = 3
α = 0.02, 0.03, 0.04	β = 1.5, 2.0, 2.5	r = 0.03, 0.04, 0.05	M = 15 / 365, 30 / 365, 45 / 365	

In the table values, T_1 = Optimum Cycle Time; Q = Optimum Procurement Quantity and P = $PV_\infty(T)$ = Optimum Present Value.

Table 1. Variations in α and r for given value of β = 1.5 and M = 15 / 365.

α↓		r →		
		0.03	**0.04**	**0.05**
0.02	T_1	0.2479	0.2475	0.2473
	Q	496.29	495.49	495.09
	P	1360167	1019815	815593
0.03	T_1	0.2434	0.2431	0.2429
	Q	487.50	486.90	486.50
	P	1361262	1020627	816242
0.04	T_1	0.2392	0.2391	0.2389
	Q	479.30	479.09	478.69
	P	1362312	1021398	816858

Table 2. Variations in β and r for given value of α = 0.02 and M = 15 / 365.

β↓		r →		
		0.03	**0.04**	**0.05**
1.5	T_1	0.2479	0.2476	0.2473
	Q	496.29	495.69	495.07
	P	1360167	1019807	815593
2.0	T_1	0.2519	0.2518	0.2517
	Q	504.01	503.51	503.61
	P	1358992	1018913	814867
2.5	T_1	0.2545	0.2543	0.2542
	Q	509.09	508.69	508.49
	P	1358410	1018485	814526

Table 3. Variations in α and β for given value of r = 0.04 and M = 15 / 365.

α↓		β →		
		1.5	2.0	2.5
0.02	T_1	0.2476	0.2517	0.2544
	Q	495.69	503.61	508.90
	P	1019807	1018920	1018478
0.03	T_1	0.2432	0.2491	0.2529
	Q	487.10	498.51	505.94
	P	1020620	1019322	1018681
0.04	T_1	0.2391	0.2467	0.2514
	Q	479.09	493.80	502.98
	P	1021398	1019705	1018883

Table 4. Variations in α and M for given value of β = 1.5 and r = 0.04.

$\alpha\downarrow$		M →		
		15 / 365	30 / 365	45 / 365
0.02	T_1	0.2476	0.2476	0.2476
	Q	495.69	495.69	495.69
	P	1019807	1018133	1016461
0.03	T_1	0.2432	0.2432	0.2432
	Q	487.10	487.10	487.10
	P	1020620	1018944	1017271
0.04	T_1	0.2391	0.2391	0.2391
	Q	479.09	479.09	479.09
	P	1021398	1019721	1018046

Table 5. Variations in β and M for given value of $\alpha = 0.2$ and $r = 0.04$.

$\beta\downarrow$		M →		
		15 / 365	30 / 365	45 / 365
1.5	T_1	0.2476	0.2476	0.2476
	Q	495.69	495.69	495.69
	P	1019807	1018133	1016461
2.0	T_1	0.2518	0.2518	0.2518
	Q	503.81	503.81	503.81
	P	1018913	1017240	1015569
2.5	T_1	0.2544	0.2544	0.2544
	Q	508.89	508.89	508.89
	P	1018478	1016805	1015135

Table 6. Variations in r and M for given value of $\alpha = 0.2$ and $\beta = 1.5$

$r\downarrow$		M →		
		15 / 365	30 / 365	45 / 365
0.03	T_1	0.2478	0.2478	0.2478
	Q	496.08	496.08	496.08
	P	1360176	1358501	1356827
0.04	T_1	0.2476	0.2476	0.2476
	Q	495.69	495.69	495.69
	P	1019807	1018133	1016461
0.05	T_1	0.2474	0.2474	0.2474
	Q	495.29	495.29	495.29
	P	815587	813914	812243

It can be seen from Table (1) that for fixed rate of deterioration, as r increases, T_1 and Q decreases and PV decreases very significantly. Similarly for the fixed value of discounting factor r, as α increases, T_1 and Q decreases, but PV increases. It is evident from Table (2) that as α increases for fixed value of r, T_1 and Q increases very significantly but PV decreases. However, for the fixed value of β, as r increases there is no significant difference in the values of T_1 and Q but very sharp decrease in PV is observed. From Table (3) it is observed that for fixed value of α, as β increases, there is an increase in T_1 and Q and at the same point of time PV decreases. For fixed value of β, as α increases, T_1 and Q decreases and PV increases. From Table (4) it can be seen that for fixed value of α, as credit period M increases, there is no change in T_1 and Q but PV decreases. However, for fixed credit period M, as α increases, T_1 and Q decreases and PV increases at the same point of time. Similarly from Table (5) it can be seen that for fixed value of β, as credit period M increases, there is no change in T_1 and Q, but PV decreases to a great extent. As β increases for fixed value of M, T_1 and Q increases and PV decreases. It is evident from Table (6) that as M increases for fixed value of r, there is no change in T_1 and Q but PV decreases and as r increases for fixed value of M, T_1 and Q decreases and PV also decreases very significantly. Thus it is very clear that optimum cycle time, optimum procurement quantity and optimum present value are very sensitive to small changes in credit period and discount factor.

5. CONCLUSIONS

In this article, the optimum inventory policies for time dependent deteriorating items when permissible delay period is allowed, is developed using the discounted cash flows approach. As a result, the effect of credit period is appropriately reflected in determining the optimal inventory policies. From the tables, it is observed that optimum present value and optimum procurement quantity are very sensitive to small changes in credit period and opportunity cost.

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