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Optimal Supply Chain Policies for Two - Echelon Players With Credit Time and Price Sensitive Demand when Inventory is Subjected to Time dependent Deterioration

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Abstract

This paper suggests a two echelon integrated supply chain model that involves manufacturer and retailer. Retailer's demand is positively sensitive to credit provided to end customer and it is negatively sensitive to selling price. Ordering cost is lot – size dependent and items in inventory are subjected to time dependent deterioration. A credit is offered by manufacturer to retailer and subsequently credit is given to end customers to boost actual demand. Proposed model suggests joint profit scenario for supply chain that includes both retailer and manufacturer. Cycle time and credit offered by retailer are decision variables to maximize total profit of the supply chain. Maximization of profit is illustrated through numerical example. Further sensitivity of all significant parameter is discussed. Conclusions and results of the paper are useful to retailers and suppliers involved in selling of tinned or processed food, beverages, drugs and other FMCGs.

Key words

Deterioration, supply chain, trade credit, lot-size dependent ordering cost, Weibull distribution

1. Introduction

A supply chain system facilitates smooth flow of goods among all the members of supply chain. Supply chain management basically focuses on efficient integration of manufacturer; wholesaler; retailer and end customers to maximize profit at all levels of chain with ensured quality and appropriate price to customer. This scenario of overall system optimization involves researcher to analyze situation and factors for cost minimization and profit maximization. In order to achieve profit maximization of supply chain, demand is accelerated by offering trade credit and price discounts on the bases of ordered lot etc. Business groups at different levels of supply chain offer trade credits to raise demand and for maintaining long term relationship with the members of supply chain. This was introduced by Goyal (1985) and further Aggrawal and Jaggi (1995) extended the concept with the inclusion of deteriorating item. Khouja and Mehrez (1996) proposed a model with different supplier credit policies. Sarkar et al. (1997) offered deterioration at exponential rate for perishable products. Sarkar et al. (2000) studied inflation for perishable product under permissible delay. Chang et al. (2001) proposed permissible delay for linearly deteriorating items. Abad and Jaggi (2003) computed optimal selling price and credit period for selling price dependent demand. Huyang (2003, 2004) discussed economic order quantity and economic production quantity trade credit policy respectively. Teng et al. (2005) discussed optimal ordering policies with permissible delay. Jaggi et al. (2008) modeled credit dependent demand under permissible delay. Liao (2008) proposed two level of trade credit for exponentially deteriorating items. Teng (2009) offered separate trade credit policy for good and bad customers. Bhowmick and Smantha (2009) discussed time dependent deterioration for stock dependent demand. Shah and Shukla (2009) discussed pricing policies when trade credits are offered by retailer. Later on Shah and Mishra (2010) considered salvage value of the deteriorated stock. Soni et al. (2010) presented an up to date review of trade credit for inventory models. Shah et al. (2011) proposed an integrated supply chain model for price sensitive demand. On the similar line Jaggi et al. (2012) studied two – level trade policy with trade credit dependent demand. Teng (2012) studied importance of trade credit for vendor and buyer under integrated and individual scenarios. Shah et al. (2013) discussed inventory and marketing policies for non –instantaneous deteriorating items. Soni (2013) and Chung et al. (2013) discussed two level trade credit supply chain models with stock dependent demand under different constraints. Lou and Wang (2013) proposed inventory policies when trade credit is demand and default risk dependent. Ouyang et al. (2013) gave a comprehensive extension of ordering policies under scenario of two level trade credit when credit policy is lot size dependent. Chen (2014) proposed conditional trade credits from retailer's perspective. Chung (2014) discussed two level trade credit for non – instantaneous receipt and exponentially deteriorating inventory. Sarkar (2014) considered variable lead time with permissible delay. Wu et al. (2014) also considered permissible delay for deteriorating items with expiry dates. Shah et al. (2014) optimized an integrated model for price sensitive demand. Shah et al. (2015 a) proposed an integrated model with trade credit with constant deterioration. Shah et al. (2015

b) discussed ordering policies and investment on technologies for integrated system with constant deterioration. It is further extended with time dependent deterioration and price sensitive demand by Shah et al (2016).

In this paper a supply chain model with single retailer and single manufacturer is analyzed for the inventory subjected to time dependent deterioration that follows weibull distribution. In this model retailer's demand is sensitive towards selling price and credit period offered. Ordering cost for retailer is lot size dependent. Credit offered by supplier and further by retailer to its end customers to accelerate demand. Two level trade credits helps in boosting demand and further price sensitive demand makes demand more stable and credible. Joint profit of supplier and retailer has been focused in place of individual as it develops a long term business relationship among members of supply chain. Total profit of the supply chain is obtained and further sensitivity of inventory parameters is analyzed through sensitivity analysis. Table 1 shows literature review on the basis of certain parameters to show contribution of proposed model clearly.

Authors	Year of publication	Single level trade - credit policy	Two level trade - credit policy	Permissible delay	variable demand	time dependent deterioration	Integrated Supply chain approach
Goyal	1985			✓			
Aggarwal and Jaggi	1995			✓			
Khouja and Mehrez	1996	✓		✓			
Sarkar et al.	1997					✓	
Sarkar et al.	2000	✓		✓			
Chang et al.	2001	✓		✓	✓		
Abad and Jaggi	2003	✓		✓	✓		
Huang and yang-Fu	2003	✓		✓	✓		
Huang and yang-Fu	2004	✓		✓	✓		
Teng Chang & Goyal	2005	✓	✓	✓	✓		
Jaggi et al.	2008	✓		✓	✓		
Liao and Jui-Jung	2008	✓		✓	✓	✓	
Teng	2009		✓	✓		✓	
Shah and Shukla	2009	✓			✓	✓	
Bhowmick and Samantha	2009	✓	✓		✓	✓	
Soni et al.	2010	Review paper					
Shah and Mishra	2010	✓	✓		✓	✓	
Shah et al.	2011	✓	✓	✓		✓	
Teng et al.	2012		✓	✓		✓	✓
Jaggi Kapur et al.	2012		✓	✓		✓	✓
Chung et al.	2013		✓		✓		
Soni	2013		✓			✓	

Lou and Wang	2013			✓			
Shah at al.	2013					✓	
Ouyang et. al	2013		✓				
Chen et al.	2014	✓		✓			
Chung et al.	2014		✓	✓		✓	
Wu et. al	2014		✓				
Sarkar et al.	2014		✓	✓		✓	
Shah et al.	2014	✓		✓		✓	✓
Shah	2015		✓	✓	✓		✓
Shah et al.	2015		✓	✓	✓		✓
Shah et al.	2016		✓	✓	✓	✓	✓
Proposed Model			✓	✓	✓	✓	✓

Table 1: Literature Review

2. Notations and Assumptions

The proposed model is formulated with below mention notations and assumptions.

2.1 Notations

Inventory parameters for manufacturer

A_m Setup Cost / Setup ($)

h_m holding cost/unit/annum ($)

C_m Purchase cost of raw material/unit ($)

P Production rate (constant) (units)

T_m Time delay at which manufacturer starts production (month)

M Fixed credit period offered by manufacturer to the retailer (month)

I_m Loss of interest due to offer of credit period M ($0 < I_m < 1$)

δ Fraction of profit shared by the manufacturer from the retailer during the credit period M ($0 < I_m < 1$)

π_m Manufacturer's Profit / time ($)

Inventory parameters for retailer

A_r Ordering Cost/order ($)

H_r	holding cost/unit/annum ($)
C_r	Purchase cost /unit ($)
S	Selling price /unit time ($)
N	Credit period offered by retailer to end customers (months)
I_b	Interest rate on the loan borrowed from the bank (%)
I_e	Interest earned /unit/annum (%)
τ	Fraction of customer's that avail of credit period N ($0 < \tau < 1$)
$\theta(t)$	Time dependent deterioration of Inventory follows Weibull distribution (units)
D(S, N)	Retailer's demand dependent on selling price and credit offered by retailer. (units)
T	Replenishment time (a decision variable)
π_r	Profit /time unit for retailer

Necessary conditions for different inventory parameters

$0 \leq \tau \leq 1$, $0 \leq \delta \leq 1$, $I_b > I_e$, $N \leq M$,

$S > C_r > C_m$, $t_m = \gamma T$, where $0 < \gamma < 1$

2.2 Assumptions

1. In this model of supply chain a single – manufacturer and retailer under single item is in consideration.
2. Demand rate D(S, N) for retailer is dependent on selling price and credit offered; Demand is negatively related to selling price whereas positively related to credit period; thus demand rate is defined as $D(S, N) = a - cS + bN$

   For convenience simply D is used in place of D(S, N)
3. Production rate P (> R) is constant.
4. Replenishment rate is instantaneous and no shortages allowed.
5. Items in inventory are subject to time dependent deterioration. Deterioration follow Weibull distribution; $\theta(t) = \alpha\beta\ t^{\beta - 1}$, where $0 < \alpha < 1$is shape parameter and β ($\beta \geq 1$) is scale parameter. Deteriorated items can neither be repaired nor be replaced during the cycle time.
6. Retailer's ordering cost is lot size dependent; $A_r = AQ^{\mu}$
7. The manufacturer allows a delay period M to settle the accounts under the condition that a fraction (δ) of profit earned during this period is shared with manufacturer.

8. The retailer borrows from the bank at the rate of I_b to settle the accounts with manufacturer for the purchases made at the end of time T. Loan is repaid to the bank at the end of the cycle time.
9. Manufacturer incurs a loss of interest at the rate of I_m /unit/annum due to credit period offered to retailer.

3. Mathematical Model

3.1 Retailer's inventory system

The retailer's inventory level reduces due to credit period and selling price dependent demand. Inventory also reduces due to time dependent deterioration. Reduction of inventory at any instantaneous of time t $\in$ [0, T] is governed by following differential equation.

$$\frac{dQ_r(t)}{dt} = -D - \theta(t)(Q_r(t)), \qquad 0 \le t \le T \quad \text{with } I_r(T) = 0 \tag{1}$$

The solution of given differential equation is given by

$$Q_r(t) = D\left((T-t) + \frac{\alpha}{\beta+1}(T^{\beta+1} - t^{\beta+1}) - \alpha t^{\beta}(T-t)\right), \qquad 0 \le t \le T\,, \tag{2}$$

Initially retailer starts with $Q_{r1}(t) = Qr(0) = \left(T + \frac{\alpha T^{\beta+1}}{\beta+1}\right),$ (3)

Costs associated with retailer are as follows

- Purchase cost of procuring Q units /unit time ; $PC_r = \frac{Cr}{T}\left((T-t) + \frac{\alpha}{\beta+1}(T^{\beta+1} - t^{\beta+1}) - \alpha t^{\beta}(T-t)\right),$
- Ordering cost per order ; $OC_r = \frac{Ar\,Q^{\mu}}{T}$
- Holding cost /unit time; $HC_r = \int_0^T Q_r(t)\frac{hr\,D}{T}\left(\frac{T^2}{2} + \frac{\alpha T^{\beta+2}}{\beta+2} - \frac{\alpha T^{\beta+2}}{(\beta+1)(\beta+2)}\right)$

On the basis of cycle time and credit periods M and N offered by manufacturer and retailer following cases arise:

(a) $N \le M \le T$, (b) $N \le T \le M$, (c) $T \le N \le M$. Next section these cases are discussed in detail.

Case (a) $N \le M \le T$ (Cycle time ends more than credit offered by retailer (N) and Supplier (M))

In this case retailer generates revenue [0, T], $SR_r = \frac{S}{T}\int_0^T D\,dt$.

Now as per contract manufacturer earns δ% of profit share of generated during [0, M].

So, $FP_{r1} = \frac{\delta(S - Cr)DM}{T}$ is shared and remaining can be used to settle the account.

Retailer takes a loan at the rate of I_b per unit per annum and settle the account at the end of the cycle time.

Thus total interest charged by bank per unit time is $ICBr = \frac{I_b}{T}(C_r DT - SDM + \delta(S - C_r)MD)(T - M)$ and further interest earned by retailer during the cycle time per unit time is $IE_{r1} = \frac{SI_e}{T}\left(\int_0^M Dtdt + \int_0^{T-M} Dtdt\right)$

Retailer faces opportunity loss due to credit period offered to customers as $OL_{r1} = \frac{\tau SI_e}{T}\int_0^N Dtdt$

Hence the retailer's net profit, π_{r1} per unit time is

$$\pi_{r1}(S,N,T) = SR_r - PC_r - FP_{r1} - OC_r - HC_r - ICB_r - OL_{r1} + IE_{r1} \tag{4}$$

Case (b) $N \le T \le M$ (Cycle time goes more than credit offered by retailer (N) but less than credit offered by Supplier (M))

Profit share for manufacturer as per contract is $FP_{r2} = \delta(S - Cr)D$

Interest earned by the retailer during the cycle time T per unit is $IE_{r2} = \frac{SI_e}{T}\left(\int_0^T Dtdt + Q(M - T)\right)$

Retailer faces opportunity loss due to credit period offered to customers as $OL_{r2} = \frac{\tau SI_e}{T}\int_0^N Dtdt$

In this case credit offered goes beyond cycle time so obviously there is sufficient revenue to settle the account without taking any loan from bank.

$$\pi_{r2}(S,N,T) = SR_r - PC_r - FP_{r2} - OC_r - HC_r - OL_{r2} + IE_{r2} \tag{5}$$

Case (c) T ≤ N ≤ M (Cycle time ends before credit offered by retailer (N) and Supplier (M))

Profit share for manufacturer as per contract is $FP_{r3} = \delta(Sr - Cr)D$ and interest earned by the retailer during the cycle time T per unit time is $IE_{r3} = \frac{SI_e}{T}\left(\int_0^T Ddt + Q(M-T)\right)$. Retailer faces opportunity loss due to credit period offered to customers as

$$OL_{r3} = \frac{\tau SI_e}{T}\left(\int_0^N Ddt + Q(N-T)\right)$$

There is no interest charged or profit sharing with the manufacturer in this case as cycle time ends before cycle time.

$$\pi_{r3}(S,N,T) = SR_r - PC_r - FP_{r3} - OC_r - HC_r - OL_{r2} + IE_{r3} \tag{6}$$

3.2 Manufacturer's inventory system

Manufacturer's inventory level at any point of time t [0, T] is governed by following differential equation

$$\frac{dQ_m(t)}{dt} = P - \theta Q_m(t) \qquad t_m \le t \le T \quad \text{with} \; Q_m(t_m) = 0 \tag{7}$$

Solution of equation (7) with given conditions is $Q_m(t) = P\left[(t - t_m) + \frac{\alpha}{\beta+1}\left(t^{\beta+1} - t_m^{\beta+1}\right) - \alpha t^{\beta+1} + \alpha\, t_m t^{\beta+1}\right]$ (8)

Holding cost; $HC_m = \frac{h_m}{T}\int_{t_m}^{T} Q_m(t)\, d$

- Loss occurred due to loss of credit offered; $OL_m = \frac{C_r P I_m (T - t_m) M}{P}$
- Set up cost per time unit; $SC_m = \frac{A_m}{T}$

- Fraction of profit gained by the manufacturer per unit time is

$$FP_m = \begin{cases} FP_{m1} = \dfrac{\delta(P-Cr)DM}{T}, & \text{M} \le \text{T} \\ FP_{m2} = \delta(P-Cr)D, & \text{M} > \text{T} \end{cases}$$

Hence the manufacture's net profit per unit time is

$$\pi_{m1}(\text{T}) = (\text{C}_\text{r} - \text{C}_\text{m})\text{D} - \text{SC}_\text{m} - \text{HC}_\text{m} - \text{OL}_\text{m} + \text{FP}_{\text{m}1}, \quad \text{M} \le \text{T} \tag{9}$$

$$\pi_{m2}(\text{T}) = (\text{C}_\text{r} - \text{C}_\text{m})\text{D} - \text{SC}_\text{m} - \text{HC}_\text{m} - \text{OL}_\text{m} + \text{FP}_{\text{m}2}, \quad \text{M} > \text{T} \tag{10}$$

3.3 Joint profit of manufacturer and retailer

This paper is proposed to maximize joint profit of manufacturer and retailer in order to optimize total supply chain. Integrated profit of supply chain is mentioned below:

$$\pi(N,S,T) = \begin{cases} \pi_1(N,S,T) = \pi_{r1}(N,S,T) + \pi_{m1}(T), & \text{N} \le \text{M} \le \text{T} \\ \pi_2(N,S,T) = \pi_{r2}(N,S,T) + \pi_{m2}(T), & \text{N} \le \text{T} \le \text{M} \\ \pi_3(N,S,T) = \pi_{r3}(N,S,T) + \pi_{m2}(T), & \text{T} \le \text{N} \le \text{M} \end{cases} \tag{11}$$

4. Algorithm

Step 1: Set values of all the inventory parameters.

Step 2: Compute

$$\frac{\partial \pi_i}{\partial N} = 0 \; \frac{\partial \pi_i}{\partial S} = 0 \; \frac{\partial \pi_i}{\partial T} = 0$$

Step 3: Solve above equations simultaneously for optimal N, S & T.

Step 4: For case N ≤ M ≤ T, π_1 will give the optimal profit. Simialrly, for case N ≤ T ≤ M, π_2 will give the optimal profit and or case T ≤ N ≤ M, π_3 will give the optimal profit.

5. Numerical example

Example 1: Consider a numerical example for case I ($N \leq M \leq T$)

$a = 1200$, $c = 15$, $b = 5$, $\tau = 0.75$, $\delta = 0.4$, $\gamma = 0.03$, A_r =\$ 150, A_m = \$ 300, $h_r = 0.3$, $h_m = 0.15$, C_r = \$ 40, C_m = \$1, I_e = 9 %, I_b = 15 %, I_m =18 %, M = 5 months, $\alpha = 0.15$, $\beta = 1.5$, P =1000 units, $\mu = 0.5$ in appropriate units.

The maximum profit is π_1= \$ 7010.5911 at N = 3.0252 months, S = \$147.4832 , T = 7.3306 months

Concavity of total profit of supply chain at selling price, S=\$147.4832 is shown in the figure 1.

Concavity of total profit of supply chain at credit period, N=3.0252 months is shown in the figure 2.

Concavity of total profit of supply chain at cycle time, T=7.3306 months is shown in the figure 3.

Example 2: Consider another example for case II ($N \leq T \leq M$)

$a = 1000$, $c = 15$, $b = 5$, $\tau = 0.75$, $\delta = 0.4$, $\gamma = 0.03$, A_r =\$ 150, A_m = \$ 300, hr = 0.3, $h_m = 0.15$, Cr = \$ 40, C_m = \$1, I_e = 9 %, I_b = 15 %, I_m =18 %, M = 5 months, $\alpha = 0.15$, β =1.5, P =1000 units, $\mu = 0.5$.

The maximum profit is π_2= \$ 26457.49 at N = 0.4566 months, S = \$106.6017 , T = 0.7704 months

Example 3: Consider another example for case III ($T \leq N \leq M$)

$a = 800$, $c = 15$, $b = 5$, $\tau = 0.75$, $\delta = 0.4$, $\gamma = 0.03$, A_r =\$ 150, A_m = \$ 300, hr = 0.3, $h_m = 0.15$, C_r = \$ 40, C_m = \$1, I_e = 9 %, I_b = 15 %, I_m =18 %, M = 5 months, $\alpha = 0.15$, β =1.5, P =1000 units, $\mu = 0.5$. The maximum profit is π_3= \$ 56417.49 at N = 1.4566 months, S = 204.6017, T = 0.4655 months

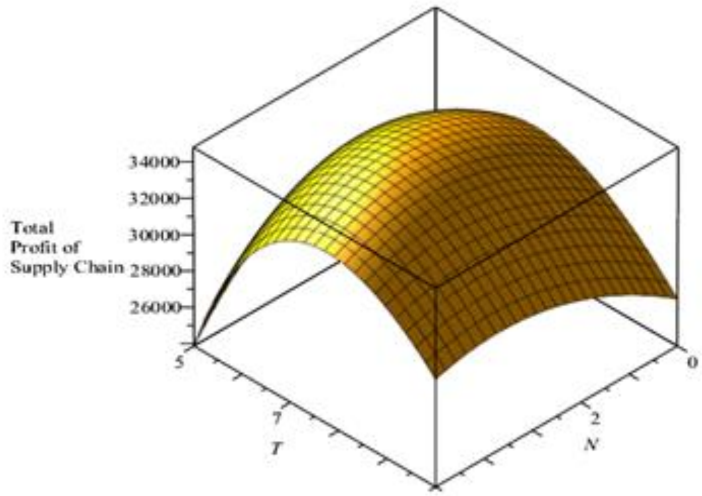

Figure 1- Concavity of total profit of Supply chain at S = \$ 147.4832

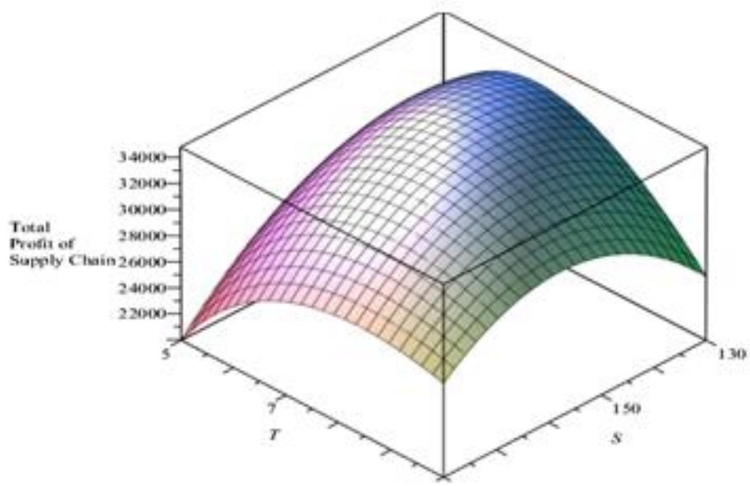

Figure 2 – Concavity of total profit of supply chain at N = 3.025 months

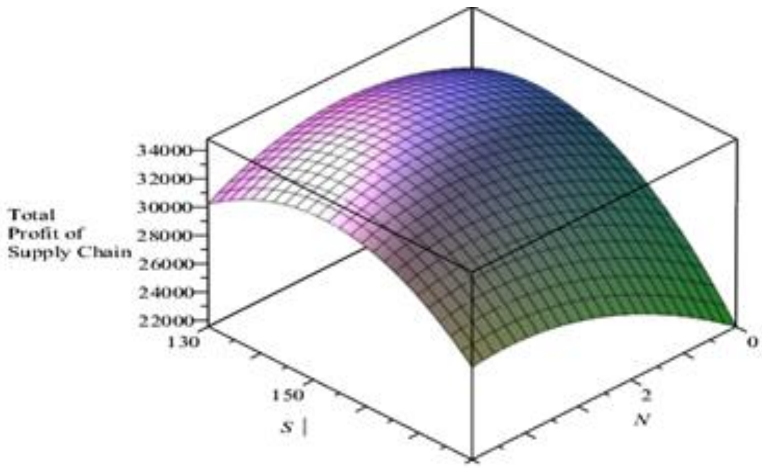

Figure 3 – Concavity of total profit of supply chain at T = 7.3306 months

6. Sensitivity analysis

As in the proposed model demand is selling price dependent so it become an important decision variable for the discussed model. Hence, its sensitivity towards all the inventory parameters is studied accordingly. As shown in the above figure 4 the selling price of retailer is highly sensitive towards parameter b i.e multiplicity factor to credit period N. Selling price increases as cost price of manufacturer increases whereas b decreases. Selling price increases significantly as with fixed demand (a), multiplicity factor of selling price (c), Production rate (P) and credit offered by manufacturer (M) increases. A very small increment in parameters like retailer's fixed ordering cost (A_r), manufacturer ordering cost (A_m) and manufacturer's cost price (C_m) can be seen with substantial increment in selling price. Parameters like profit sharing fraction (δ), fraction of customer's (τ) that avail credit, deterioration shape parameter (β) decreases significantly with increase in selling price. Production delay factor (γ), retailer's holding cost (h_r) and retailer's cost price shows very less negative change with respect to selling price.

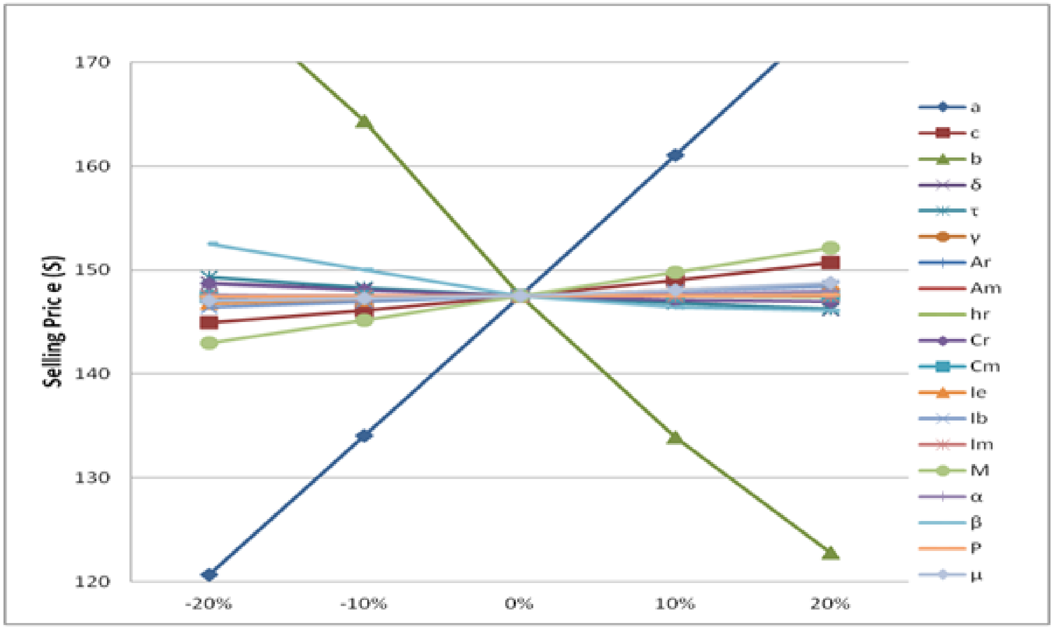

Figure 4 - Variations in selling price w.r.t different inventory parameters

Figure 5 shows that manufacturer's ordering cost (A_m), interest rate on borrowed amount (I_b), credit period offered by manufacturer (M) and production rate (P) increases as credit period offered by retailer (N) increases. It is also observed from the sensitivity analysis that inventory parameters like fixed demand (a), profit sharing fraction (δ), fraction of customer's that avail credit(τ), deterioration shape parameter (β), scale parameter of deterioration (α), fixed part of retailer's ordering cost (A_r), retailer's holding cost (h_r) and retailer's cost price (C_r) decreases significantly with increase in credit period offered by retailer (N).

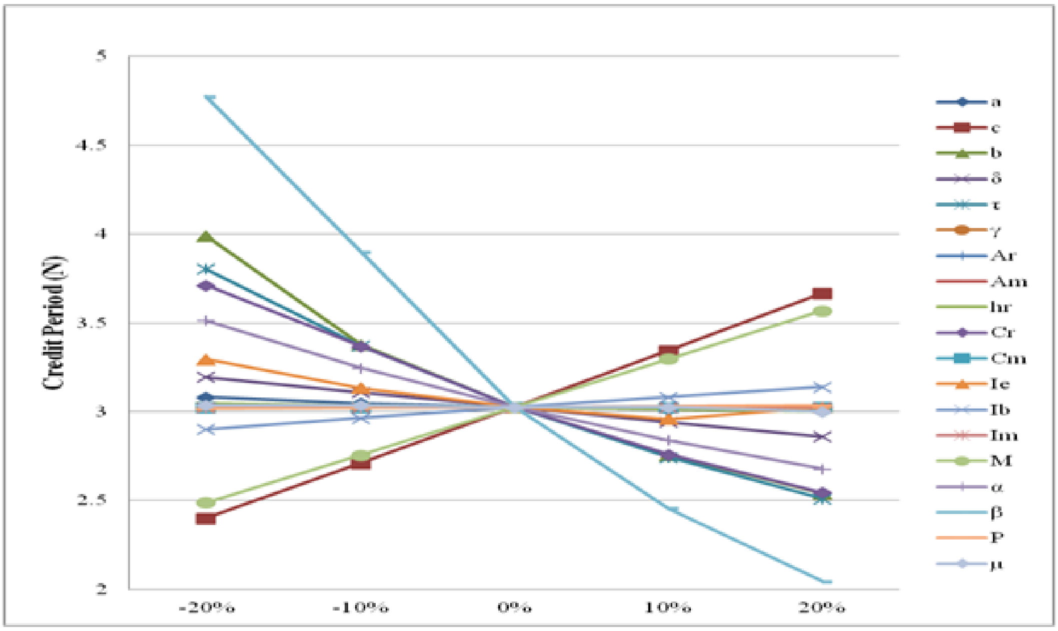

Figure 5 - Variations in credit period profit w.r.t different inventory parameters

Sensitivity analysis of cycle time (T) is shown in Figure 6, where fixed demand (a), selling price scale (c), fixed part of retailer's ordering cost (A_r), manufacturer's ordering cost (A_m), interest on borrowed amount (I_b), credit period offered by manufacturer (M) and rate of production (P) is increases with respect to time. Parameters like credit scale of demand (b), profit sharing fraction (δ), fraction of customer's that avail credit (τ), production delay factor (γ), deterioration shape parameter (β), scale parameter of deterioration (α), manufacturer's production cost and lot size dependent parameter (μ) decreases with cycle time.

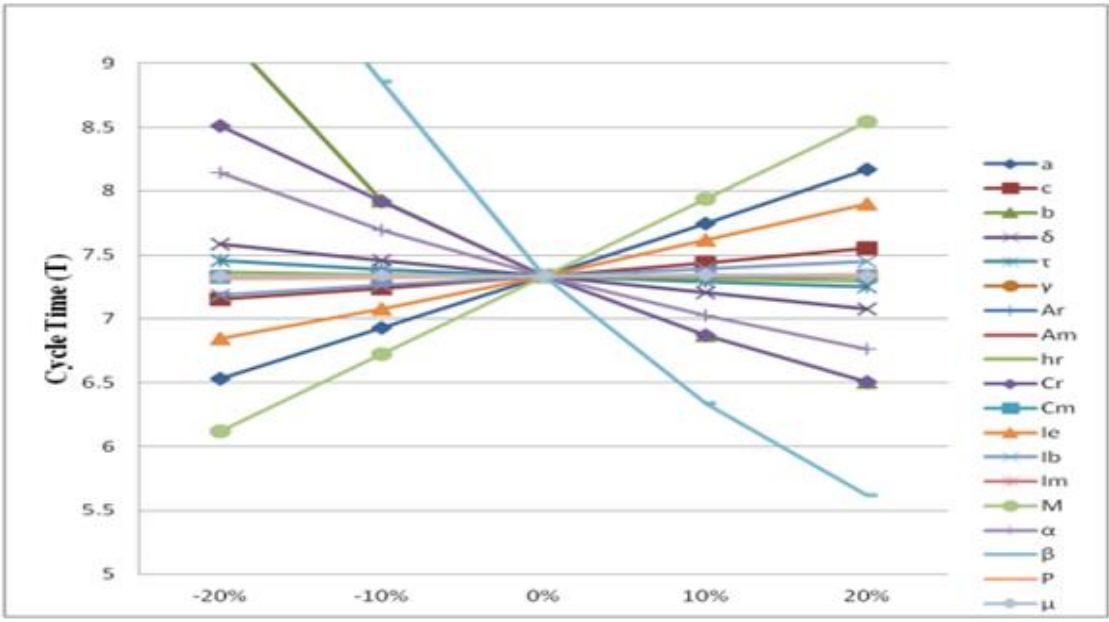

Figure 6 - Variations in cycle time profit w.r.t different inventory parameters

Figure 7 shows sensitivity of all parameters towards total supply chain profit. Figure clearly shows that manufacturer's cost price i.e manufacturing cost (C_m) and credit period's scale (b) are highly sensitive towards total profit. Cm is positively whereas b is negatively correlated with total profit. Other than this total profit increases moderately with demand (a), selling price scale (c), production delay factor (γ) and interest earned rate (I_e). Total profit decreases significantly with increment in credit's scale of demand (b), profit sharing fraction (δ), fraction of customer's that avail credit (τ), deterioration shape parameter (β), scale parameter of deterioration (α), manufacturer's production cost and lot size dependent parameter (μ) decreases with cycle time, fixed part of retailer's ordering cost (A_r), retailer's holding cost (h_r) and retailer's cost price (C_r).

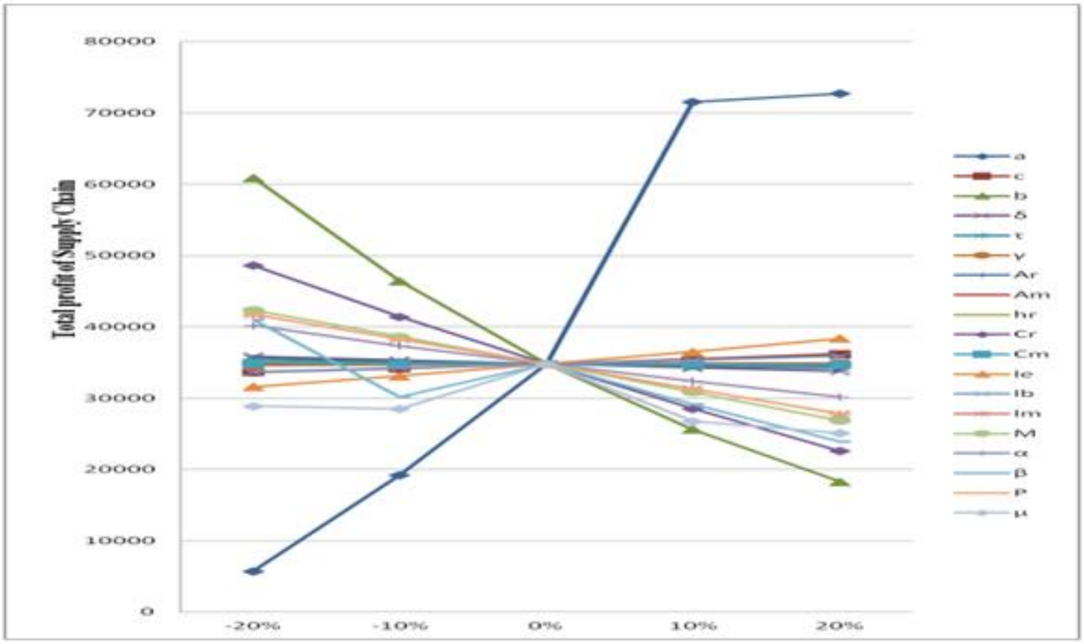

Figure 7 - Variations in supply chain profit w.r.t different inventory parameters

Conclusion

This study deals with joint profit optimization of manufacturer – retailer trade in supply chain when demand is price and credit linked. Proposed model offers credit to retailer and consequently to end customers with a contract of profit sharing, this increases actual demand and hence enhances profit of the supply chain. Items in inventory are subjected to time dependent deterioration that make model more relevant to many perishable goods. Ordering cost is also lot size dependent which makes it more authentic and usable in many cases. This two level trade credit model clearly help in boosting demand which increases overall profit of the supply chain. As a future scope of research this model can be studied under stochastic demand for the items with fixed life-time. To make it more relevant to today's scenario certain constraints on space and budget can be implemented.

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