Journal of Scientific & Industrial Research
Vol. 66, September 2007, pp. 716-723

Ordering decision-making under two-level trade credit policy for a retailer with a powerful position

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Received 25 August 2006; revised 09 April 2007; accepted 10 April 2007

This paper investigates retailer's inventory policy under two-level trade credit to reflect the supply chain management situation. It is assumed that retailer maintains a powerful position and can obtain full trade credit offered by supplier yet retailer just offers the partial trade credit to customers. Under these conditions, retailer can obtain the most benefits. Study also investigates retailer's inventory system as a cost minimization problem to determine retailer's optimal inventory policy under supply chain management. One ease-to-use theorem is developed to efficiently determine optimal inventory policy for retailer. Study demonstrates results of previous studies that can be treated as special cases.

Keywords: EOQ, Inventory, Supply chain, Two-level trade credit

Introduction

Traditional economic order quantity (EOQ) model assumes that retailer's capitals are adequate and must pay for the items as soon as the items are received. In practice, supplier will offer retailer a delay period, which is the trade credit period, in paying for the amount of purchase. Before end of the trade credit period, retailer can sell goods and accumulate revenue and earn interest. A higher interest is charged if the payment is not settled by end of the trade credit period. In the real world, supplier often makes use of this policy to promote commodities.

Goyal[1] established a single-item inventory model under trade credit. Chung[2] developed an alternative approach to determine EOQ under condition of trade credit. Aggarwal & Jaggi[3] considered the inventory model with an exponential deterioration rate under the condition of trade credit. This line of research was extended to the varying rate of deterioration[4], with inflation[5,6], allowable shortage[7,8] and linear demand[9]. Buyer's inventory policy[10] was investigated under trade credit by the concept of discounted cash flow. Hwang & Shinn[11] modeled an inventory system for retailer's pricing and lot sizing policy for exponentially deteriorating products under the condition of permissible delay in payment. Optimal payment time [12,13] was addressed under permissible delay in payment with commodity deterioration. Teng[14] assumed that the selling price is not equal to the purchasing price to modify Goyal's model[1]. Chung *et al*[15] discussed that the selling price is not equal to purchasing price and different payment rules are allowed. Shinn & Hwang[16] determined retailer's optimal price and order size simultaneously under the condition of order-size-dependent delay in payments. Chung & Huang[17] extended this type of problem solving within EPQ framework and developed an efficient procedure to determine the retailer's optimal ordering policy. Huang & Chung[18] extended Goyal's model[1] to allow for cash discount for early payment. Salameh *et al*[19] extended this issue to inventory decision under continuous review. EOQ[20,21] has been determined for exponentially deteriorating items under permissible delay in payments depending on the ordering quantity. Chang[22] extended this issue to inflation and finite time horizon. Huang[23] considered the case in which the unit selling price and the unit purchasing price are not necessarily equal within EPQ framework under supplier's trade credit policy. Huang[24] assumed that retailer would adopt a similar trade credit policy to stimulate demand from customer to develop retailer's replenishment model.

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Present study extends Huang's model[24] to investigate that retailer can obtain full trade credit offered by suppliers and the retailer just offers partial trade credit to customers. New model presents retailer's inventory decision-making as a cost minimization problem to determine the retailer's optimal ordering policies.

Model Formulation and Convexity

Annual total relevant cost consists of the following elements:

I Annual ordering cost = $\frac{A}{T}$

II Annual stock holding cost (excluding interest charges) = $\frac{DTh}{2}$

III According to assumption (6), there are two cases to consider in costs of annual interest payable (AIP) for the items kept in stock. When $T \geq M$, the account is settled at M and retailer starts paying for the interest charges on the items in stock with rate I_k. When $T \leq M$, all items are sold at T and retailer can pay the amount of purchasing cost to supplier at M. Hence retailer does not need to pay any interest charge when $T \leq M$.

Case 1 ($M \leq T$)

$$\text{AIP} = cI_k D(T-M)^2/2T$$

Case 2 ($T \leq M$)

$$\text{AIP} = 0$$

IV According to assumption (7), there are three cases to consider in annual interest earned (AIE). Retailer can accumulate interest from customer partial payment on [0, N] and from the total amount of payment on [N, M] with rate I_e.

Case 1 ($M \leq T$, Fig. 1a)

$$\text{AIE} = cI_e\left[\frac{\alpha DN^2}{2} + \frac{(DN+DM)(M-N)}{2}\right]/T$$

$$= cI_e D[M^2 - (1-\alpha)N^2]/2T$$

Case 2 ($N \leq T \leq M$, Fig. 1b)

$$\text{AIE} = cI_e\left[\frac{\alpha DN^2}{2} + \frac{(DN+DT)(T-N)}{2} + DT(M-T)\right]/T$$

$$= cI_e D[2MT - (1-\alpha)N^2 - T^2]/2T$$

Case 3 ($T \leq N$, Fig. 1c)

$$\text{AIE} = cI_e\left[\frac{\alpha DT^2}{2} + \alpha DT(N-T) + DT(M-N)\right]/T$$

$$= cI_e DT\left[M - (1-\alpha)N - \frac{\alpha T}{2}\right]/T$$

From the above arguments, annual total relevant cost for retailer can be expressed as

TRC(T) = ordering cost + stock-holding cost + interest payable − interest earned.

where

$$TRC(T) = \begin{cases} TRC_1(T) & \text{if} \quad T \geq M & \cdots (1a) \\ TRC_2(T) & \text{if} \quad N \leq T \leq M & \cdots (1b) \\ TRC_3(T) & \text{if} \quad 0 < T \leq N & \cdots (1c) \end{cases}$$

$$TRC_1(T) = \frac{A}{T} + \frac{DTh}{2} + cI_k D(T-M)^2/2T - cI_e D[M^2 - (1-\alpha)N^2]/2T \quad \text{...(2)}$$

$$TRC_2(T) = \frac{A}{T} + \frac{DTh}{2} - cI_e D[2MT - (1-\alpha)N^2 - T^2]/2T \quad \text{...(3)}$$

and

$$TRC_3(T) = \frac{A}{T} + \frac{DTh}{2} - cI_e D\left[M - (1-\alpha)N - \frac{\alpha T}{2}\right] \quad \text{...(4)}$$

$TRC_1(M) = TRC_2(M)$ and $TRC_2(N) = TRC_3(N)$, *TRC(T)* is continuous and well-defined. $TRC_1(T)$, $TRC_2(T)$, $TRC_3(T)$ and *TRC(T)* are defined on T>0. Eqs (2), (3) and (4) yield

$$TRC_1'(T) = -\left[\frac{2A + cDM^2(I_k - I_e) + cD(1-\alpha)N^2 I_e}{2T^2}\right] + D\left(\frac{h + cI_k}{2}\right), \quad \text{...(5)}$$

$$TRC_1''(T) = \frac{2A + cD[M^2(I_k - I_e) + (1-\alpha)N^2 I_e]}{T^3} > 0, \quad \text{...(6)}$$

$$TRC_2^{'}(T) = -\left[\frac{2A + cD(1-\alpha)N^2 I_e}{2T^2}\right] + D(\frac{h + cI_e}{2}), \quad \text{...(7)}$$

$$TRC_2^{''}(T) = \frac{2A + cD(1-\alpha)N^2 I_e}{T^3} > 0, \quad \text{...(8)}$$

and

$$TRC_3^{'}(T) = \frac{-A}{T^2} + D(\frac{h + c\alpha I_e}{2}) \quad \text{...(9)}$$

$$TRC_3^{''}(T) = \frac{2A}{T^3} > 0 \,. \quad \text{...(10)}$$

Eqs (6), (8) and (10) imply that $TRC_1(T)$, $TRC_2(T)$ and $TRC_3(T)$ are convex on $T>0$. Furthermore, $TRC_1^{'}(M) = TRC_2^{'}(M)$ and

Therefore, Eqs 1(a, b, c) imply that $TRC(T)$ is convex on $T > 0$.

Determination of Optimal Cycle Time *T**

Let for all i= 1, 2, 3. One gets

, ...(11)

$$T_2^* = \sqrt{\frac{2A + cD(1-\alpha)N^2 I_e}{D(h + cI_e)}} \quad \text{...(12)}$$

and

$$T_3^* = \sqrt{\frac{2A}{D(h + c\alpha I_e)}} \quad \text{...(13)}$$

By the convexity of $TRC_i(T)$ (i = 1, 2, 3), one gets

$$TRC_i^{'}(T) \begin{cases} < 0 & \text{if } \; T < T_i^* & \text{...(14a)} \\ = 0 & \text{if } \; T = T_i^* & \text{...(14b)} \\ > 0 & \text{if } \; T > T_i^*. & \text{...(14c)} \end{cases}$$

Eqs (5), (7) and (9) yield that

$$TRC_1^{'}(M) = TRC_2^{'}(M) = \frac{-2A + DM^2(h + cI_e) - cD(1-\alpha)N^2 I_e}{2M^2} \quad \text{...(15)}$$

and

$$TRC_2^{'}(N) = TRC_3^{'}(N) = \frac{-2A + DN^2(h + c\alpha I_e)}{2N^2}. \quad \text{...(16)}$$

Furthermore,

$$\Delta_1 = -2A + DM^2(h + cI_e) - cD(1-\alpha)N^2 I_e \quad \text{...(17)}$$

and

$$\Delta_2 = -2A + DN^2(h + c\alpha I_e)\,. \quad \text{...(18)}$$

Then, $\Delta_1 \geq \Delta_2$ and can obtain the following results:

Theorem 1

(A) If $\Delta_1 > 0$ and $\Delta_2 \geq 0$, then $TRC(T^*) = TRC(T_3^*)$ and $T^* = T_3^*$

(B) If $\Delta_1 > 0$ and $\Delta_2 < 0$, then $TRC(T^*) = TRC(T_2^*)$ and $T^* = T_2^*$

(C) If $\Delta_1 \leq 0$ and $\Delta_2 < 0$, then $TRC(T^*) = TRC(T_1^*)$ and $T^* = T_1^*$

Proof

(A) If $\Delta_1 > 0$ and $\Delta_2 \geq 0$, then

$TRC_1^{'}(M) = TRC_2^{'}(M) > 0$ and

≥ 0. Eqs 14(a, b, c) imply that

i) $TRC_1(T)$ is increasing on $[M, \infty)$.
ii) $TRC_2(T)$ is increasing on $[N, M]$.
iii) $TRC_3(T)$ is decreasing on $(0, T_3^*]$ and increasing on $[T_3^*, N]$.

Combining i), ii), iii) and Eqs 1(a, b, c), it is observed that $TRC(T)$ is decreasing on $(0, T_3^*]$ and increasing on $[T_3^*, \infty)$. Consequently, $T^* = T_3^*$.

(B) If $\Delta_1 > 0$ and $\Delta_2 < 0$, then

> 0 and

< 0. Eqs 14(a, b, c)

imply that

i) $TRC_1(T)$ is increasing on $[M, \infty)$.
ii) $TRC_2(T)$ is decreasing on $[N, T_2^*]$ and increasing on $[T_2^*, M]$.
iii) $TRC_3(T)$ is decreasing on $(0, N]$.

Combining i), ii), iii) and Eqs 1(a, b, c), it is observed that $TRC(T)$ is decreasing on $(0, T_2^*]$ and increasing on $[T_2^*, \infty)$. Consequently, $T^* = T_2^*$.

(C) If $\Delta_1 \leq 0$ and $\Delta_2 < 0$, then

≤ 0 and

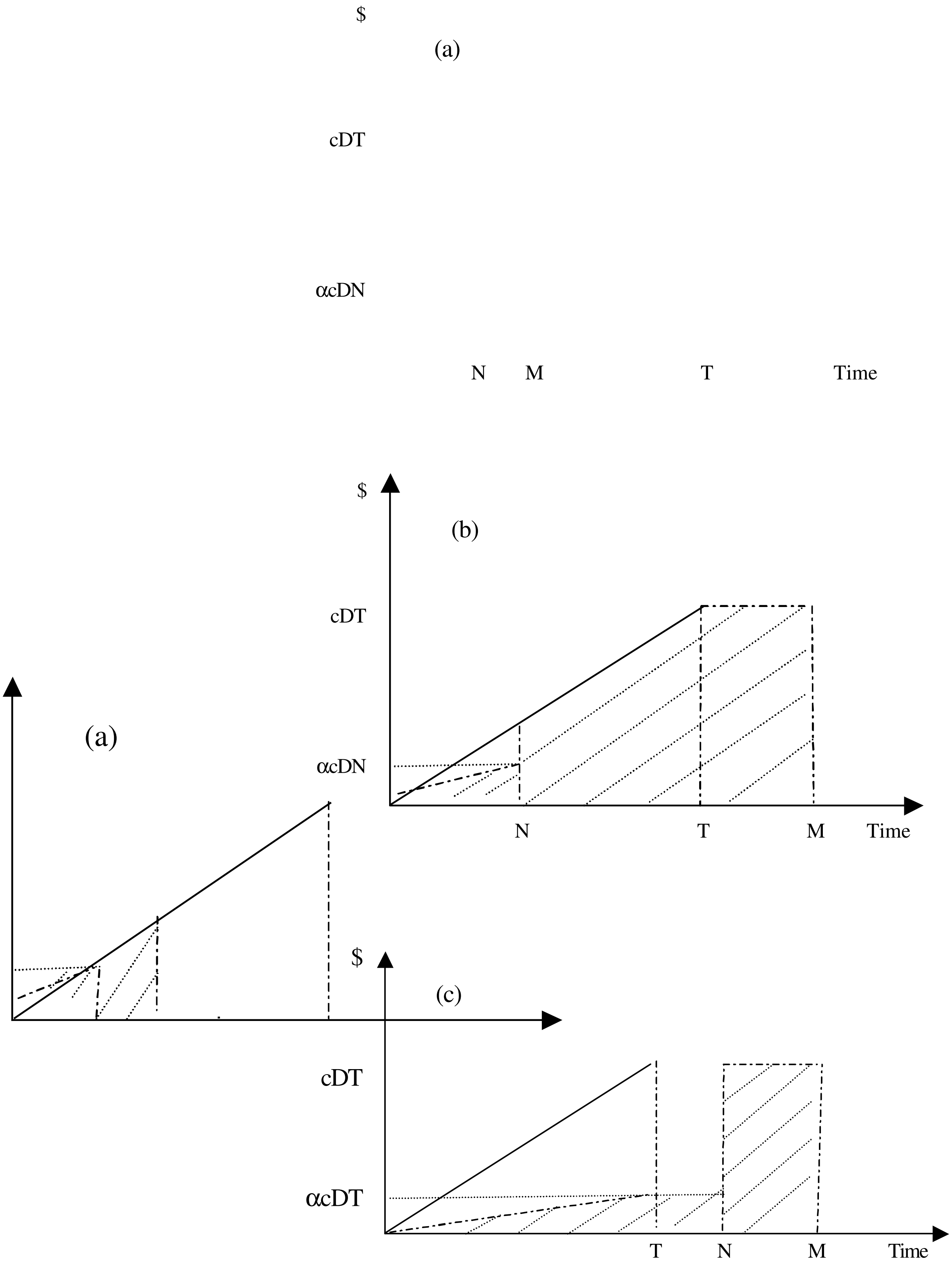

Fig. 1—Total amount of interest earned when: a) M ≤ T; b) N ≤T ≤ M; and c) T ≤ N

$TRC_2'(N) = TRC_3'(N) < 0$. Eqs 14(a, b, c) imply that

i) $TRC_1(T)$ is decreasing on $[M, T_1^*]$ and increasing on $[T_1^*, \infty]$.

ii) $TRC_2(T)$ is decreasing on $[N, M]$.

iii) $TRC_3(T)$ is decreasing on $(0, N]$.

Combining i), ii), iii) and Eqs 1(a, b, c), it is observed that $TRC(T)$ is decreasing on $(0, T_1^*]$ and increasing on $[T_1^*, \infty)$. Consequently, $T^* = T_1^*$.

Linking together above arguments, the proof of Theorem 1 is completed. Theorem 1 immediately determines the optimal cycle time T^* after computing for the numbers Δ_1 and Δ_2. Theorem 1 is an efficient solution procedure.

Previous Research Results as Special Cases

(I) Huang's Model

When $\alpha = 0$, it means that the retailer also offers the full trade credit to customers. Let

...(19)

$$TRC_5(T) = \frac{A}{T} + \frac{DTh}{2} - cI_e D(2MT - N^2 - T^2)/2T \quad ...(20)$$

$$TRC_6(T) = \frac{A}{T} + \frac{DTh}{2} - cI_e D(M - N) \quad ...(21)$$

$$T_4^* = \sqrt{\frac{2A + cD[M^2(I_k - I_e) + N^2 I_e]}{D(h + cI_k)}} \quad ...(22)$$

$$T_5^* = \sqrt{\frac{2A + cDN^2 I_e}{D(h + cI_e)}} \quad ...(23)$$

and

$$T_6^* = \sqrt{\frac{2A}{Dh}}\,. \quad ...(24)$$

Then $TRC_i'(T_i^*) = 0$ for i= 4, 5, 6.

Eqs 1(a, b, c) can be modified accordingly as:

$$TRC(T) = \begin{cases} TRC_4(T) & \text{if} \quad T \ge M & \cdots \text{(25a)} \\ TRC_5(T) & \text{if} \quad N \le T \le M & \cdots \text{(25b)} \\ TRC_6(T) & \text{if} \quad 0 < T \le N & \cdots \text{(25c)} \end{cases}$$

Eqs 25(a, b, c) are consistent with Eqs 1(a, b, c) in Huang[24], respectively. Eqs (17) and (18) can be modified as

$\Delta_1 =$ and $\Delta_2 = -2A + DN^2 h$, respectively. If $\bar{\Delta}_1 = -2A + DM^2(h + cI_e) - cDN^2 I_e$ and $\bar{\Delta}_2 = -2A + DN^2 h$, Theorem 1 can be modified as:

Theorem 2

(A) If $\bar{\Delta}_1 > 0$ and $\bar{\Delta}_2 \ge 0$, then $TRC(T^*) = TRC(T_6^*)$ and $T^* = T_6^*$

(B) If $\bar{\Delta}_1 > 0$ and $\bar{\Delta}_2 < 0$, then $TRC(T^*) = TRC(T_5^*)$ and $T^* = T_5^*$

(C) If $\bar{\Delta}_1 \le 0$ and $\bar{\Delta}_2 < 0$, then $TRC(T^*) = TRC(T_4^*)$ and $T^* = T_4^*$

Theorem 2 has been proposed as Theorem 1 of Huang[24]. Hence, Huang's[24] results are seen to be a special case of this paper.

(II) Goyal's Model

When $N = 0$, supplier would offer retailer a delay period but retailer would not offer delay period to customers. That is one level of trade credit, as specified by $\alpha = 0$ and $N = 0$. Let

$$TRC_7(T) = \frac{A}{T} + \frac{DTh}{2} + cI_k\left[\frac{D(T-M)^2}{2}\right]/T - cI_e\left(\frac{DM^2}{2}\right)/T \quad ...(26)$$

$$TRC_8(T) = \frac{A}{T} + \frac{DTh}{2} - cI_e\left[\frac{DT^2}{2} + DT(M - T)\right]/T \quad ..(27)$$

$$T_7^* = \sqrt{\frac{2A + DM^2 c(I_k - I_e)}{D(h + cI_k)}} \quad ...(28)$$

and

$$T_8^* = \sqrt{\frac{2A}{D(h + cI_e)}}\,. \quad ...(29)$$

Then $TRC_i'(T_i^*) = 0$ for i= 7, 8. Eqs 1(a, b, c) will be reduced as:

$$TRC(T) = \begin{cases} TRC_7(T) & \text{if} \quad M \le T & \cdots \text{(30a)} \\ TRC_8(T) & \text{if} \quad 0 < T \le M & \cdots \text{(30b)} \end{cases}$$

Eqs 30(a, b) are consistent with Eqs (1) and (4) in Goyal[1], respectively. Eq. (17) can be modified as $\Delta_1 = -2A + DM^2(h + cI_e)$. If $\Delta = -2A + DM^2(h + cI_e)$, Theorem 1 can be modified as:

Table 1 — Optimal solutions under various parametric values

Let A=\$80/order, D=2000units/year, h=\$7/unit/year, Ik=\$0.15/\$/year, Ie=\$0.13/\$/year and M=0.1year

α	N	c	Δ_1	Δ_2	*Theorem*	T^*	Q^*	$TRC(T^*)$
0.1	0.02	10	> 0	< 0	1-(B)	T_2^*=0.09846	196.9	1374.48
		30	> 0	< 0	1-(B)	T_2^*=0.08642	172.8	1103.94
		50	> 0	< 0	1-(B)	T_2^*=0.0781	156.2	808.64
	0.05	10	> 0	< 0	1-(B)	T_2^*=0.09995	199.9	1399.25
		30	> 0	< 0	1-(B)	T_2^*=0.09025	180.5	1187.4
		50	> 0	< 0	1-(B)	T_2^*=0.08372	167.4	960.48
	0.08	10	< 0	< 0	1-(A)	T_1^*=0.10261	205.2	1444.3
		30	> 0	< 0	1-(B)	T_2^*=0.09696	193.9	1333.63
		50	> 0	< 0	1-(B)	T_2^*=0.09327	186.5	1218.29
0.5	0.02	10	> 0	< 0	1-(B)	T_2^*=0.09834	196.7	1372.37
		30	> 0	< 0	1-(B)	T_2^*=0.08609	172.2	1096.7
		50	> 0	< 0	1-(B)	T_2^*=0.0776	155.2	795.28
	0.05	10	> 0	< 0	1-(B)	T_2^*=0.09917	198.3	1386.19
		30	> 0	< 0	1-(B)	T_2^*=0.08824	176.5	1143.68
		50	> 0	< 0	1-(B)	T_2^*=0.08079	161.6	881.46
	0.08	10	< 0	< 0	1-(A)	T_1^*=0.10068	201.4	1411.56
		30	> 0	< 0	1-(B)	T_2^*=0.09211	184.2	1228.02
		50	> 0	< 0	1-(B)	T_2^*=0.08641	172.8	1033.07
0.9	0.02	10	> 0	< 0	1-(B)	T_2^*=0.09821	196.4	1370.25
		30	> 0	< 0	1-(B)	T_2^*=0.08575	171.5	1089.44
		50	> 0	< 0	1-(B)	T_2^*=0.07711	154.2	781.84
	0.05	10	> 0	< 0	1-(B)	T_2^*=0.09838	196.8	1373.03
		30	> 0	< 0	1-(B)	T_2^*=0.08619	172.4	1098.97
		50	> 0	< 0	1-(B)	T_2^*=0.07776	155.5	799.46
	0.08	10	> 0	< 0	1-(B)	T_2^*=0.09869	197.4	1378.18
		30	> 0	< 0	1-(B)	T_2^*=0.087	174	1116.53
		50	> 0	> 0	1-(C)	T_3^*=0.0789	157.8	831.81

Theorem 3

(A) If $\Delta > 0$, then $T^*=T_8^*$.

(B) If $\Delta < 0$, then $T^*=T_7^*$.

(C) If $\Delta = 0$, then $T^*= T_7^*= T_8^* =M$.

Theorem 3 has been proposed as Theorem 1 of Chung[2]. Hence, Goyal's[1] results are seen to be a special case of this paper.

Numerical Examples with Managerial Insights

To illustrate the results developed in this paper, proposed method has been applied to solve the numerical examples (Table 1). For convenience, numerical values of parameters (α, N, c) are selected randomly. Based on the results (Table 1), following inferences can be made: 1) For fixed N and c, the larger value of α, the shorter the optimal cycle time and lower the annual total relevant cost; 2) For fixed α and c, the larger the value of N, the lengthier the optimal cycle time and the higher the annual total relevant cost; and 3) For fixed α and N, the larger the value of c, the shorter the optimal cycle time and the smaller the optimal order quantity.

Conclusions

This paper further relaxes the assumption of two-level trade credit policy in the previously published works to investigate inventory problem, in which retailer maintains a powerful position. Theorem 1 helps retailer accurately and speedily determining the optimal ordering policy after computing for the numbers Δ_1 and Δ_2. If the customer's fraction of the total amount due at the time of placing an order within the delay period offered by retailer equals zero, the proposed inventory model is reduced to Huang[24]. If the suppliers offer retailer a delay period, yet retailer offers no delay period to customers, the proposed inventory model is reduced to Goyal[1]. Finally, numerical examples are given to illustrate the results developed in this paper. There are several managerial insights as follows: 1) When customer's fraction of the total amount due at the time of placing an order to the retailer is increasing, the retailer will order a smaller quantity and increase its order frequency. The retailer can save a larger amount of interest earned under higher order frenquency and receiving a larger customer's fraction of the total amount due at the time of placing an order within the delay period offered by retailer; 2) When a longer trade credit period offered to customer, the retailer will order a larger quantity to save interest payments paid to suppliers to compensate the loss of interest earned paid by customers; and 3) When the unit purchasing price is increasing, retailer will order a smaller quantity to enjoy benefits of trade credit more frequently.

Acknowledgements

Authors thank referees for their valuable and constructive comments and suggestions that have led to a significant improvement on an earlier version of this paper. The NSC in Taiwan and CYUT partially financed this research, and the project no. was NSC 95-2416-H-324-006.

Notations

D = demand rate per year
A = ordering cost per order
c = unit purchasing price
h = unit stock holding cost per year excluding interest charges
α = customer's fraction of the total amount payable at the time of placing an order within the delay period to retailer, $0 \leq á \leq 1$
I_e = interest earned per \$ per year
I_k = interest charged per \$ in stocks per year by supplier
M = retailer's trade credit period as measured by years offered by supplier
N = customer's trade credit period as measured by years offered by retailer
T = cycle time in years
$TRC(T)$= annual total relevant cost, which is a function of T
T^* = optimal cycle time of $TRC(T)$
Q^*= optimal order quantity, also defined by DT^*

Assumptions

(1) Demand rate, D, is known and constant
(2) Shortages are not allowed
(3) Time horizon is infinite
(4) Replenishments are instantaneous
(5) $I_k \geq I_e$, $M \geq N$
(6) Since supplier offers the full trade credit to retailer. When $T \geq M$, the account is settled at M and retailer starts paying for the interest charges on items in stock with rate I_k. When $T \leq M$, all items are sold at T and retailer can pay amount of purchasing cost to supplier at M. Hence retailer need to pay any interest charge when $T \leq M$.
(7) Since retailer just offers the partial trade credit to customers. Hence, customers must make a partial payment to retailer when the item is received. Then customers must pay off the remaining balance at the end of the trade credit period offered by retailer. That is, retailer can accumulate interest from customer partial payment on $(0, N]$ and from the total amount of payment on $[N, M]$ with rate I_e.

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