CHAPTER 9

DEVELOPMENT OF TWO-STAGE SUPPLY CHAIN WITH ORDER COST REDUCTION AND CREDIT PERIOD

9.1 INTRODUCTION

In the previous Chapter, a stochastic inventory model involving investments to reduce lead time, setup cost and yield variability was developed. In that model the relationships between the lead time, setup cost and yield variability with their capital investments were represented by logarithmic functions. Most of the inventory models only aimed at the determination of the optimum solutions that minimized cost or maximized profit from the buyer’s or vendor’s side. However, in the modern global competitive market, the buyer and the vendor should be treated as strategic patterns in the supply chain with a long-term cooperative relationship. For this reason, we consider a supply chain in which the vendor and buyer decides to invest in reducing ordering cost to streamline and speed up transactions via the application of information technology. Chang et al., [11] studied a single vendor - single buyer integrated inventory models with controllable lead time and ordering cost reduction.

The efficiency of a supply chain management depends on active cooperation and close coordination between the vendor and the buyer. Graves, Jacker and Rosenblatt, Lee et. al., Monahan, Weng [38, 47, 60, 69, 119] suggested that quantity discount is a coordination mechanism. Luo [52] proved that credit period is an effective mechanism for the buyer-vendor coordination. Many researchers consider deteriorating items in simple EOQ
models. Perishable items, deteriorating items are considered by Sarkar et al., Yu et al., respectively [97, 127] in supply chains also. There is no single vendor, single buyer supply chain model which involves deteriorating items, order cost reduction and credit period incentives. This chapter is organized as follows. In section 2, problem description, assumptions and notations are listed. In section 3, a model to find the joint total cost is formulated. In section 4, numerical examples with an exponential ordering cost function are presented to evaluate these benefits. Section 5 concludes this chapter.

9.2 PROBLEM DESCRIPTION

Here, we propose a two stage supply chain model with single vendor, single buyer for deteriorating items. The vendor and the buyer decide upon an investment in ordering cost reduction and coordinate their inventory policies to minimize their joint average annual cost. The vendor requests the buyer to alter his current order size such that the vendor can benefit from lower ordering and inventory holding costs. To encourage the buyer to accept this strategy, the vendor must compensate the buyer for his increased inventory cost by offering an order size dependent credit period. Initially the buyer’s behaviour is assumed to be captured by simple EOQ and the vendor’s order size is an integer multiple of the buyer’s such that his own inventory cost is minimized. If the buyer accepts to coordinate with the vendor, then the vendor’s order size will be another integer multiple of the buyer’s. Joint total cost for the supply chain is analyzed.

9.2.1 ASSUMPTIONS

1. The supply chain involves only one item, single vendor and single buyer.
2. The replenishment occurs instantaneously at an infinite rate for both vendor and the buyer. i.e., the lead time is zero.
3. There is no repair or replacement of deteriorated units.
4. Demand rate of the buyer is a known constant.
5. Shortages are not allowed.
6. The planned ordering cost for the buyer is a decreasing function of the expenditure incurred per unit time on operating the new ordering system, which is given by 
   \[ PO(G) = K_2 e^{-dG} \]
7. The vendor makes a decision on inventory for the buyer and on the investment amount in ordering cost reduction. That is the buyer adopts the VMI (Vendor managed inventory) policy.
8. The vendor’s credit period begins at the time when the ordered quantity is delivered.
9. There is enough capacity in buyer’s warehouse to store more products.
10. We explicitly split the holding cost into two components namely financing cost and variable holding cost.

9.2.2 NOTATIONS

\[ i_1, i_2 \] The vendor and the buyer’s cost of capital respectively.

\[ h_1', h_2' \] The vendor and the buyer’s unit variable holding cost excluding the cost of capital respectively.

\[ h_1, h_2 \] The vendor and the buyer’s unit variable holding cost including the cost of capital respectively. i.e., 
   \[ h_1 = h_1' + P_1 i_1 \]
   \[ h_2 = h_2' + P_2 i_2 \]

\[ T_v, T_b \] Length of the replenishment cycle for the vendor and the buyer respectively.
\( T_{C_v}, T_{C_b} \)  Total average annual cost of the vendor and the buyer respectively.

\( JTC_0 \)  Joint total cost of the system without any coordination between the vendor and the buyer.

\( JTC \)  Joint total cost of the system in the presence of coordination between the vendor and the buyer.

\( \Delta JTC \)  Relative improvement of the joint total cost.

**9.3 MODEL FORMULATION**

In the absence of any coordination between the vendor and the buyer, the buyer’s behaviour is assumed to be captured by simple EOQ.

The buyer’s optimal ordering quantity is

\[
Q_0 = \sqrt{\frac{2RK_2}{h_2}}
\]

and buyer’s minimized cost is \( \sqrt{2RK_2h_2} \) and the fixed interval is \( \frac{Q_0}{R} \). The vendor’s order size is \( mQ_0 \) where \( m \) is a positive integer. Hence the average inventory held up by the vendor per year is

\[
= \left( \frac{(m - 1)Q_0 + (m - 2)Q_0 + \ldots + 2Q_0 + Q_0}{R} \right) \frac{Q_0}{R}
\]

\[
= \frac{(m - 1)Q_0}{2}.
\]

Holding cost for the vendor \( = \frac{(m - 1)Q_0h_1}{2} \) \hspace{1cm} (80)

Ordering cost for the vendor \( = \frac{K_1}{T_v} \) where \( T_v = \frac{mQ_0}{R} \).
\[
= \frac{RK_1}{mQ_0}
\]

The differential equation that describes the instantaneous states of the inventory level of the vendor, \( I_1(t) \) over \((0, T_v)\) is

\[
\frac{dI_1(t)}{dt} + \theta I_1(t) = -R \quad \text{if} \quad 0 \leq t < T_v
\]

(82)

The solution is

\[
I_1(t)e^{\theta t} = \frac{R}{\theta} e^{\theta t} + c_1,
\]

where \(c_1\) is the constant of integration.

Using the condition \( I_1(T_v) = 0 \), the solution of (82) is

\[
I_1(t) = \frac{R}{\theta} \left[ e^{\theta(T_v-t)} - 1 \right]
\]

(83)

We know that \( t(0) = Q \). In particular, for the vendor \( t(0) = mQ_0 \).

The number of deteriorated units during one cycle in vendor’s place,

\[
= mQ_0 - RT_v
\]

Hence the average deterioration cost for the vendor is

\[
= \left\{ \frac{R}{\theta} \left[ e^{\theta T_v} - 1 \right] - RT_v \right\} \frac{P_1}{T_v}.
\]

Vendor’s total average annual cost is

\[
TC_v = \text{Ordering cost} + \text{Holding cost} + \text{Deterioration cost}
\]

\[
= \frac{RK_1}{mQ_0} + \frac{(m-1)Q_0h_v}{2} + \frac{P_1}{T_v} \left\{ \frac{R}{\theta} \left[ e^{\theta T_v} - 1 \right] - RT_v \right\}, \quad \text{where} \quad T_v = \frac{mQ_0}{R}
\]

(84)

Similarly, we can find the buyer’s total average annual cost as

\[
TC_b = \text{Ordering cost} + \text{Holding cost} + \text{Deterioration cost}
\]

\[
= \frac{RK_2}{Q_0} + \frac{Q_0h_2}{2} + \frac{P_2}{T_b} \left\{ \frac{R}{\theta} \left[ e^{\theta T_b} - 1 \right] - RT_b \right\}, \quad \text{where} \quad T_b = \frac{Q_0}{R}
\]

(85)
Joint total cost of the vendor and the buyer without any coordination  
\[ JTC_0 = TC_v + TC_b \]  
(86)

JTC_0 is convex with respect to \( m \) (Appendix 9.1).

Let \( m^* \) be the optimum solution of  
\[ \min_{m \geq 1} JTC_0(m) \]

\[ m^* = \left\lceil \frac{h_1^2 + \frac{4K_1h_2}{K_2} (h_1 + 2P_1\theta) - h_1}{2(h_1 + 2P_1\theta)} \right\rceil, \]

where \( \lceil x \rceil \) is the least integer greater than or equal to \( x \). (Appendix 9.2)

In order to achieve effective coordination, the vendor requests the buyer to alter his current order size by a factor, say \( F \), \((F>0)\) such that the vendor can benefit from lower setup, ordering and inventory holding costs. The buyer may be unwilling to accept this strategy due to the increase of inventory costs to him. Hence the vendor must compensate the buyer for his increased inventory costs and possibly provide an additional savings. We assume that the vendor offers a credit period \( M \) to the buyer and hence the buyer can earn interest from sales during the period \( M \).

Buyer’s new order size is fixed at \( FQ_o \) and the vendor’s new order size is \( nFQ_o \) where \( n \) is a positive integer.

The cost incurred to the vendor in offering a credit period \( M \) is \( P_2RM_l_i \).

Hence, in coordination, vendor’s annual cost is  
\[ \frac{RK_1}{nFQ_0} + \frac{(n-1)FQ_0h_1}{2} + \frac{P_1}{T_v} \left\{ R \left[ e^{\frac{\theta}{R}} - 1 \right] - RT_v \right\} + P_2RM_l_i \]

\[ = \frac{RK_1}{nFQ_0} + \frac{(n-1)FQ_0h_1}{2} + \frac{P_1R}{nFQ_0} \left\{ R \left[ e^{\frac{nFQ_0}{R}} - 1 \right] - nFQ_0 \right\} + P_2RM_l_i \]  
(87)

where \( T_v = \frac{nFQ_0}{R} \).
Buyer’s total interest earned from sales during the credit period is $P_2RM_{t_2}$. We assume that the vendor and the buyer also decide to reduce the ordering cost of the buyer through an investment. $K_2$ is the original ordering cost of the buyer.

$PO(G)$ is the planned ordering cost per order, which is a decreasing function of investment $G$ and it is given by

$PO(G) = K_2 e^{-dG}$ where $0 < d < 1$ with

$PO(0) = K_2$ and $PO(G_0) = 0$.

Even with a great investment in ordering cost reduction, there must be some sort of operational cost for ordering. However it does not alter the conclusions in this chapter, therefore we assume that ordering cost can be reduced to zero with a maximum investment.

By considering the credit period and order cost reduction, the buyer’s cost becomes

$$\frac{RK_2 e^{-dG}}{FQ_0} + \frac{FQ_0 h_2}{2} + \frac{P_2 R}{FQ_0} \left\{ \frac{R}{\theta} \left[ \frac{6FQ_0}{e^{FR}} \right] - FQ_0 \right\}, \text{ where } T_b = \frac{FQ_0}{R}$$

Joint total cost of the system with coordination is

$$JTC(F, G, M, n) = \frac{RK_1}{nFQ_0} + \frac{(n - 1)FQ_0 h_1}{2} + \frac{P_1 R}{nFQ_0} \left\{ \frac{R}{\theta} \left[ \frac{nFQ_0}{e^{FR}} \right] - nFQ_0 \right\} + P_2 RM_{t_1}$$

$$+ \frac{RK_2 e^{-dG}}{FQ_0} + \frac{FQ_0 h_2}{2} + \frac{P_2 R}{FQ_0} \left\{ \frac{R}{\theta} \left[ \frac{6FQ_0}{e^{FR}} \right] - FQ_0 \right\} + G \quad (88)$$

We have to minimize the joint total cost for the system which is a function of 4 variables $F$, $G$, $M$ and $n$. First we can minimize the joint total
cost (JTC) of the system for fixed n. JTC is a function of three variables F, G and M.

The buyer will accept the new strategy if his increased cost is less than or equal to the interest earned in the credit period. Buyer’s total inventory cost without any co-ordination, deterioration and order cost reduction is 

\[ \sqrt{2RK_2h_2} \]

The buyer will accept the new strategy if

\[ \frac{RK_2e^{-dG}}{FQ_0} + \frac{FQ_0h_2}{2} + \frac{P_2R}{FQ_0} \left( \frac{\frac{\theta FQ_0}{\theta e^R} - 1}{R} - FQ_0 \right) - \sqrt{2RK_2h_2} \leq P_2RM \]

Putting \( Q_0 = \sqrt{\frac{2RK_2}{h_2}} \) in the above equation,

\[ M \geq \frac{e^{-dG}}{FP_{t_2}} \sqrt{\frac{K_2h_2}{2R}} + \frac{F}{P_{t_2}} \sqrt{\frac{K_2h_2}{2R}} + \frac{1}{P_{t_2}} \sqrt{\frac{h_2}{2RK_2}} \left[ \frac{\theta FQ_0}{\theta e^R} - 1 \right] - \frac{1}{P_{t_2}} \sqrt{\frac{2K_2}{h_2}} \]

\[ M \geq \frac{1}{P_{t_2}} \sqrt{\frac{K_2h_2}{2R}} \left[ F + \frac{e^{-dG}}{F} \right] + \frac{1}{P_{t_2}} \sqrt{\frac{R}{2K_2}} \left[ \frac{\theta FQ_0}{\theta e^R} - 1 \right] - \frac{1}{i_2} \]

\[ M \geq \frac{1}{P_{t_2}} \sqrt{\frac{K_2h_2}{2R}} \left[ F + \frac{e^{-dG}}{F} - 2 \right] + \frac{1}{P_{t_2}} \sqrt{\frac{R}{2K_2}} \left[ \frac{\theta FQ_0}{\theta e^R} - 1 \right] - \frac{1}{i_2} \]  \hspace{1cm} (89)

Consider the equality sign in result (89) and use M in equation (88) we get

\[ JTC(F, G) = \frac{RK_1}{nFQ_0} + \frac{(n-1)FQ_0h_1}{2} + \frac{P_1R}{nFQ_0} \left( \frac{\theta FQ_0}{\theta e^R} \right) - nFQ_0 \]

\[ + P_2R \left\{ \frac{1}{P_{t_2}} \sqrt{\frac{K_2h_2}{2R}} \left[ F + \frac{e^{-dG}}{F} - 2 \right] + \frac{1}{P_{t_2}} \sqrt{\frac{R}{2K_2}} \left[ \frac{\theta FQ_0}{\theta e^R} - 1 \right] - \frac{1}{i_2} \right\} \]

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\[ \frac{RK_2 e^{-dG}}{FQ_0} + \frac{FQ_0 h_2}{2} + \frac{P_2 R}{FQ_0} \left\{ \frac{\theta FQ_0}{e^R - 1} - FQ_0 \right\} + G \]

Here also putting \( Q_0 = \sqrt{\frac{2RK_2}{h_2}} \).

\[ JTC(F, G) = \frac{K_1}{nF} \sqrt{\frac{Rh_2}{2K_2}} + (n-1)Fh_1 \sqrt{\frac{RK_2}{2h_2}} \]

\[ + \frac{P_2}{nF} \sqrt{\frac{Rh_2}{2K_2}} \left\{ \frac{R}{\theta} \left[ e^{\frac{2K}{Rh_2}} - 1 \right] \right\} \]

\[ + \frac{i_1}{i_2} \sqrt{\frac{RK_2 h_2}{2}} \left[ F + e^{-dG} \right] + \frac{P_2 (i_1 + i_2)}{F i_2} \sqrt{\frac{Rh_2}{2K_2}} \left[ \frac{R}{\theta} e^{\frac{2K}{Rh_2}} - 1 \right] \]

\[ + \sqrt{\frac{RK_2 h_2}{2}} \left[ F + e^{-dG} \right] - R \left( P_1 + P_2 \left( \frac{i_1 + i_2}{i_2} \right) \right) + G \]

(90)

\[ JTC(F, G) \] is convex with respect to \( F \) and \( G \) for any given positive integer \( n \) (Appendix 9.3).

The optimal values of \( F \) and \( G \) can be found by solving the equations \( \frac{\partial JTC(F, G)}{\partial F} = 0 \) and \( \frac{\partial JTC(F, G)}{\partial G} = 0 \) simultaneously.

By substituting these optimal values in equation (90), the joint total cost for the system becomes a function of \( n \).

\[ JTC(n) = \frac{k_1}{nF} \sqrt{\frac{Rh_2}{2k_2}} + (n-1)Fh_1 \sqrt{\frac{RK_2}{2h_2}} + \frac{P_1}{nF} \sqrt{\frac{Rh_2}{2K_2}} \left\{ \frac{\theta Fh_1}{e^R - 1} \right\} \]

\[ + \frac{i_1}{i_2} \sqrt{\frac{RK_2 h_2}{2}} \left[ F + e^{-dG} \right] + \frac{P_2 (i_1 + i_2)}{F i_2} \sqrt{\frac{Rh_2}{2K_2}} \left[ \frac{R}{\theta} e^{\frac{2K}{Rh_2}} - 1 \right] \]

\[ + \sqrt{\frac{RK_2 h_2}{2}} \left[ F + e^{-dG} \right] - R \left( P_1 + P_2 \left( \frac{i_1 + i_2}{i_2} \right) \right) + G \]

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Thus our problem is concluded as the following optimization problem.

\[
\text{Minimize} \\
\quad n \geq 1 \quad \text{JTC}(n)
\]  

(91)

The optimum value of \( n \) can be obtained as

\[
n^* = \begin{cases} 
\frac{1}{F} \sqrt{\frac{k_1}{k_2} \left( \frac{h_2}{h_1 + P_1\theta} \right) - \frac{1}{2}} & \text{if } \frac{k_1 h_2}{k_2 F^2 (h_1 + P_1\theta)} \geq 2 \\
1 & \text{otherwise}
\end{cases}
\]

(92)

where \( \lceil x \rceil \) is the least integer greater than or equal to \( x \). (Appendix 9.4)

We propose the following algorithm to find the solution for the above optimization problem.

**Algorithm**

**Step 1.** Put \( G = 0 \) in the equation \( \frac{\partial \text{JTC}(F, G)}{\partial F} = 0 \) and find \( F \).

**Step 2.** Substitute \( F \) in the equation \( \frac{\partial \text{JTC}(F, G)}{\partial G} = 0 \) and find \( G \).

**Step 3.** Put \( G \) in the equation \( \frac{\partial \text{JTC}(F, G)}{\partial F} = 0 \) to find \( F \).

**Step 4.** Repeat steps 2 and 3 until there is no change in the successive values of \( F \) and \( G \).

**Step 5.** If \( \frac{k_1 h_2}{k_2 F^2 (h_1 + P_1\theta)} \geq 2 \) then \( n^* = \left\lceil \frac{1}{F} \sqrt{\frac{k_1}{k_2} \left( \frac{h_2}{h_1 + P_1\theta} \right) - \frac{1}{2}} \right\rceil \) otherwise \( n^* = 1 \).

**Step 6.** Find \( m^* \).

**Step 7.** Compute

\[
M = \frac{1}{P_2 i_2} \sqrt{\frac{K_2 h_2}{2R} \left[ F + e^{-G} \right] - 2} + \frac{1}{\theta_2 i_2} \sqrt{\frac{R h_2}{2K_2} e^{-\frac{2K_2}{Rh_2}} - 1} - \frac{1}{i_2}
\]

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Step 8. Compute JTC (n*) and JTC_0(m*).

Step 9. Compute ΔJTC where \( ΔJTC = \left( \frac{JTC_0 - JTC}{JTC_0} \right) \times 100\% \)

9.4 NUMERICAL EXAMPLES

Numerical examples are given to mention the workability of the proposed theory, model and to discuss the effects of the cost of capital of the buyer, ordering cost of the vendor and that of the buyer on the relative improvement of the joint total cost. Computational works are carried out using MATLAB 7.0.

9.4.1 WORKABILITY OF THE THEORY AND MODEL

Example 1

Consider the following data \( R = 1000 \) units/year, \( P_1 =$300 / unit, 
\( P_2 =$400 / unit, \( h_1' =$100 /unit/year, h_2' =$150 /unit/year, \( \theta = 0.07, \( d = 0.002, 
K_1 = $300 /order, K_2 = $200 /order, i_1 = 0.1, i_2 = 0.1. \) By applying the above proposed algorithm we find the optimum values. JTC_0 =$16381, JTC = 
$13411, ΔJTC = 18.1308\%. Thus by the effective coordination between the vendor and the buyer in a supply chain, the joint total cost of the system can be reduced. Hence the relative improvement of the joint total cost (ΔJTC) by the investment in reducing ordering cost is also high.

Example 2

First seven data in example 1 are kept fixed while the remaining data are changed. The results are shown in Table 9.i. From this table we observe that when \( i_2 \) increases joint total cost also increases and hence the relative
improvement of the joint total cost decreases. The investment in reducing the ordering cost of the buyer also decreases when \( i_2 \) increases.

**Table 9.i Changes in the relative improvement of the joint total cost with the cost of capital of the buyer**

<table>
<thead>
<tr>
<th>( K_1 )</th>
<th>( K_2 )</th>
<th>( i_1 )</th>
<th>( i_2 )</th>
<th>( JTC_0 )</th>
<th>( JTC )</th>
<th>( \Delta JTC )</th>
<th>( G )</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>200</td>
<td>0.05</td>
<td>0.15</td>
<td>16642</td>
<td>14033</td>
<td>15.6772</td>
<td>208.2</td>
</tr>
<tr>
<td>300</td>
<td>200</td>
<td>0.05</td>
<td>0.2</td>
<td>17048</td>
<td>14598</td>
<td>14.3712</td>
<td>208.08</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
<td>0.05</td>
<td>0.1</td>
<td>17394</td>
<td>12749</td>
<td>26.7046</td>
<td>213.75</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
<td>0.05</td>
<td>0.15</td>
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<td>15382</td>
<td>15.246</td>
<td>182.8</td>
</tr>
<tr>
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<td>200</td>
<td>0.05</td>
<td>0.15</td>
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<td>24.3279</td>
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<td>0.05</td>
<td>0.2</td>
<td>19446</td>
<td>17280</td>
<td>11.1385</td>
<td>550.85</td>
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</table>

**Table 9.ii Analysis on relative improvement of the joint total cost with the ordering cost of the vendor**

<table>
<thead>
<tr>
<th>( K_1 )</th>
<th>( K_2 )</th>
<th>( i_1 )</th>
<th>( i_2 )</th>
<th>( JTC_0 )</th>
<th>( JTC )</th>
<th>( \Delta JTC )</th>
</tr>
</thead>
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<td>0.1</td>
<td>16234</td>
<td>13176</td>
<td>18.837</td>
</tr>
<tr>
<td>400</td>
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<td>0.1</td>
<td>17324</td>
<td>15296</td>
<td>11.7063</td>
</tr>
<tr>
<td>460</td>
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<td>0.1</td>
<td>17977</td>
<td>15991</td>
<td>11.0474</td>
</tr>
<tr>
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<td>0.1</td>
<td>18413</td>
<td>16854</td>
<td>8.4668</td>
</tr>
</tbody>
</table>

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Table 9.iii Analysis on relative improvement of the joint total cost with the ordering cost of the buyer

<table>
<thead>
<tr>
<th>K₁</th>
<th>K₂</th>
<th>i₁</th>
<th>i₂</th>
<th>JTC₀</th>
<th>JTC</th>
<th>ΔJTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>200</td>
<td>0.05</td>
<td>0.15</td>
<td>16642</td>
<td>14033</td>
<td>15.6772</td>
</tr>
<tr>
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<td>0.15</td>
<td>17592</td>
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<td>15.3934</td>
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<td>0.05</td>
<td>0.15</td>
<td>18149</td>
<td>15382</td>
<td>15.246</td>
</tr>
</tbody>
</table>

**Example 3**

We change the values of the parameters K₁, K₂, i₁, and i₂ while the other parameters are kept fixed. The computational values are presented in Table 9.ii. From Table 9.ii we come to know that when K₁ increases the joint total cost of the system increases. Consequently the relative improvement of the joint total cost decreases.

**Example 4**

Here we analyze the joint total cost with the increase of the ordering cost of the buyer (K₂). We consider the same data as in example 1 except K₁, K₂, i₁ and i₂. The results are shown in Table 9.iii. From this Table we see that joint total cost of the system (with or without coordination) increases with the increase of K₂ and hence the relative improvement of the joint total cost decreases.
9.5 CONCLUSION

The scenario of a supply chain with a single vendor, a single buyer for a single product was considered. The effects of deterioration and credit period incentives were also taken into account. We assume that the vendor and the buyer decide upon an investment in reducing the ordering cost of the buyer and coordinate their inventory policies to minimize their joint total cost. The benefits of order cost reduction and credit period incentives are studied and analyzed. The numerical examples elucidate these benefits. In all these examples the joint total cost with coordination is less than that of the system without coordination. This model may be extended to multi items.