CHAPTER IV
AN EOQ MODEL UNDER PRICE CHANGE ANTICIPATION OR PRICE DISCOUNT FOR A SYSTEM WITH INSUFFICIENT STORAGE CAPACITY

In the classical EOQ system it is implicitly assumed that the inventory system under consideration has sufficient storage capacity to store the optimum order quantity, and that the unit cost remains unchanged during the period under consideration. Naddor [9] and Tersine [19] have considered a model to determine optimum purchase quantity when the supplier announces a fixed price increase with effect from some given time instant T_0. In this chapter, the problem of determining a special order quantity in the face of known price increase, when the system does not have sufficient capacity to store the one time special order quantity in OW is discussed. Also in this chapter, when price discount is announced for short time period by the dealer and system does not have sufficient capacity to store the one time special order quantity in OW, then two alternative cases are discussed.

ASSUMPTIONS AND NOTATIONS

The following assumptions are made for the development of the mathematical model:
i) The demand rate of D quantity units per time unit is known and constant.

ii) Lead time is zero, and shortages are not allowed.

iii) Replenishment rate is infinite. Replenishment size is the decision variable.

iv) The storage capacity of OW is W, and that of RW is infinite. If order quantity exceeds W, then excess units are kept in RW. Demands are satisfied from OW only.

v) The cost of transportation for K units from RW to OW in one transhipment is U(K).

Following notations are used:

D = Demand rate per time unit
D = Cost per unit at present
\( c \) = Known price increase as of time instant \( T_o \).
\( D_o \) = EOQ before price increase
\( D_o' \) = EOQ after price increase
\( Q' \) = Special order quantity before price increase becomes effective.

W = Storage capacity of OW

\( I_1 \) = Carrying charge fraction for OW.

\( I_2 \) = Carrying charge fraction for RW.

A = Replenishment cost per order.

\( T_o \) = Effective time of price increase

\( T_1 \) = Time when the special order gets depleted.
\[ U(K) = \begin{cases} a & \text{if } K \leq P \\ a + b(K-P) & \text{if } K > P \end{cases} \]

where \( a > b > 0 \) are constants. The cost of transporting \( K \) units from \( RW \) to \( DW \) in one shipment, where \( P \) is the maximum number of units which can be transported under the fixed cost \( 'a' \) and for every additional unit after \( P \) a variable cost \( 'b' \) is to be paid.

**KNOWN PRICE INCREASE**

Note that at present the optimum order quantity is:

\[ Q_o = \left[ \frac{2AD}{d_1} \right]^{1/2} \quad \text{..................(4.1)} \]

After the price change becomes effective the new price will be \( (d+c) \) per unit and the optimum lot-size will then be

\[ Q_o'' = \left[ \frac{2AD}{(d+c)d_1} \right]^{1/2} \quad \text{..................(4.2)} \]

Obviously \( Q_o'' < Q_o \) and less than or equal to \( W \). The problem for the management is to determine the size of the order, before the price change becomes effective. If a quantity \( Q' \) is purchased just before \( T_o \), the next purchase will occur at \( T \) after a lapse \( (Q'/D) \) time units. All subsequent purchases will be made at the new price \( (d + c) \) and then the optimum order quantity is given by \( (4.2) \).
To determine the one time order size \( Q' \), to purchase prior to \( T_0 \). By maximizing the cost difference during the period \((T_0, T_1)\) with and without one time special order.

Assumed that \( Q' > W \), so that \( W \) units are kept in \( QW \), and \( (Q' - W) \) units are kept in \( RW \). Earlier, \( Q < W \), so that, the entire lot-size were kept in \( QW \) only.

To find out the total cost, the following cost were considered.

Ordering cost = \( A \)

Purchase cost = \( dQ' \)

Holding cost at \( RW \) is

\[
(I_2/d/2D)(Q' - W)(Q' - W + K) + \frac{(Q' - W)(W)}{K}U(K)
\]

Holding cost at \( QW \) is

\[
(I_1/d/D)(Q' - W + K)(W - K/2) + \frac{(I_1, d/2D)(W)}{K}^2
\]

Total cost due to the special order quantity during \((T_0, T_1)\)

\[
T(Q', K) = A + dQ' + (I_2/d/2D)(Q' - W)(Q' - W + K) + \frac{(Q' - W)}{K}((a - bP)/K + b) + (I_1/d/D)(Q' - W + K)(W - K/2) + \frac{(I_1, d/2D)(W - K)}{K}^2
\]

\[
= A + dQ' + (I_2/d/2D) Q'^2 + \frac{(I_2 - I)/2D)(W(W - K))}{K} + Q'(K - 2W)) + (Q' - W)((a - bP)/K + b)
\]

\[
\ldots \ldots \ldots (4.3)
\]
Let \( T(0) \) denote the total cost of the system during \((T_o, T_1)\), when no special purchase is made just before \( T_o \), and several purchases of \( Q_o^* \) are made at new price of \((d + c)\), then the total cost during \((T_o, T_1)\) is

\[
T(0) = (d + c)Q' + \left(\frac{Q_o^*}{2}\right)(d + c)(I_1 Q'/D) + A Q'/Q_o^*
\]
\[
= Q'(d + c) + C_o^*/D \] ..........................(4.4)

where

\[
C_o^* = (2AD(d + c)I_1)^{1/2} \] ..........................(4.5)

To find the optimal value of \( K \) and \( Q' \), we maximize the differences between \( T(0) \) and \( T'(Q', K) \). This difference, denoted by \( G(Q', K) \), is given by

\[
G(Q', K) = G'(c + C_o^*/D - I_2dQ'/2D - d(I_2 - I_1)(W - K/2)/D - ((a - bP)/K + b)J
\]
\[
- Wd(I_2 - I_1)(W - K)/2D - ((a - bP)/K + b)J \]

..........................(4.6)

For the optimum values of \( K \) and \( Q' \)

\[
\frac{\partial G(Q', K)}{\partial K} = 0 \quad \text{and} \quad \frac{\partial G(Q', K)}{\partial Q'} = 0
\]

give

\[
K_o = (2D(a-bP)/d(I_2 - I_1))^{1/2} \] ..........................(4.7)

and

\[
Q_o' = (D/I_2 d)(c + C_o^*/D + d(I_2 - I_1)(W - K_o/2)/D
\]
\[
- ((a-bP)/K_o + b)J \] ..........................(4.8)
The optimum gain $G_o(Q'_o, K_o)$ is

\[
G_o(Q'_o, K_o) = \left[ \frac{D}{2L_2 d} \left( c + \frac{C_o^*}{D} - d(I_o - I_1) \right) (W - K_o/2)/D 
- \left( (e - bP)/K_o + b \right) f^2 - Wd(I_o - I_1)(W - K_o)/2D 
- \left( (e - bP)/K_o + b \right) \right] - A \] .......(4.9)

Note that when $I_o = I_1$, and $U(K) \rightarrow 0$, then the total maximum gain $\{G_o(Q'_o)\}$ equation of the system becomes

\[
G_o(Q'_o) = \left( c/d \right) \left( Dc/2I_1 + A + Q_o(d + c) \right) \] .......(4.10)

and

\[
Q'_o = (Dc + C_o^*)/I_1 d \] .......(4.11)

Equations (4.10) and (4.11) are the same as those given by Naddor [9] for the single storage model.

Under certain circumstances a retailer is unable to hire RW, and he wants to take advantage of anticipated the price change before time $T_o$, then the maximum gain through ordering $Q_o = W$ units is given by $G_o(W)$

\[
G_o(W) = W(c + C_o^*)/D - I_1 dW/2D \] .......(4.12)

This equation also indicates that when $G_o(W) > G_o(Q'_o, K_o)$, then hiring RW is uneconomic.

For the feasibility of the two storage facilities model, we should have $Q_o' > W$ and $K_o \leq W$. This then suggests that the optimal solution of the system under study should be represented by the following steps.
Step - I : Find the value of \( K_1 \) of \( K \) from (4.7). If \( K_1 \leq W \), then (4.8) shows that the \( Q' \) is the optimal solution, and (4.9) becomes the maximum gain equation. Otherwise go to step II.

Step - II : If \( Q' > W \) and \( K_0 = W \), then
\[
Q' = \frac{D}{C_0} \left( c + \frac{C_0^*}{D} + d(I_2 - I_1) W/2D - \frac{(a-bP)}{K_0} + b \right)^2
\]
................................. (4.13)
and the optimal maximum gain of the system is
\[
G_0(Q', W) = \frac{D}{C_0} \left( c + \frac{C_0^*}{D} - d(I_2 - I_1) W/2D - \frac{(a-bP)}{K_0} + b \right)^2 + \frac{(a - bP)}{K_0} + bW - A
\]
................................. (4.14)
otherwise go to step - III.

Step - III : If \( Q' = W \) then \( Q' \) is same as of equation (4.11) and \( G_0(Q', K_0) \) is also same as of equation (4.10), and its classical EOQ system with single storage facilities.

To strengthen the theory of price change anticipation with two storage facilities, we discuss here the results obtained with the help of numerical example.

Numerical Example - 4.1:

Consider an inventory system in which dealer has announced the price change anticipation will take place at time interval \( T_0 \), with following parameter values:

\[ D = 12000 \text{ units per annum}, \]

\[ \]
d = Rs. 10 per unit
\(c = Rs. 0.50(0.25)^3,\)
\(l_1 = 0.2,\)
\(l_2 = 0.4,\)
\(A = Rs. 100,\)
\(a = Rs. 300,\)
\(W = 1100 \text{ units and } P = 900 \text{ units per transshipment.}\)

Find out the maximum gain when the retailer is hiring RW and without RW, and analyze with detailed sensitivity analysis.

Table 4.1 shows that if we are keeping fixed capacity of OW at 1100 units with price increase parameter \(c\), and fixed \(K_o = 0.49\) units per transshipment, the system indicates that if price increase is less than Rs. 1.00, it is better not to take services of RW as shown in column \(g_o(W)\). But if price increase is one rupee and above, it is profitable to hire RW as shown by \(g_o(0',K_o)\) in Table 4.1.

Finally, we study the effect of variations in both price increase \(c\) and OW capacity \(W\) on the values of \(g_o\), \(g_o(0',K_o)\) and \(g(W)\) in Table 4.2. From the Table 4.2 we observe that, if price increase are Rs. 0.5 and Rs. 0.75, then it indicates that not to hire RW with any capacity of OW. But, if \(c = Rs. 1.00\), it indicates that for the smaller capacity of OW, it is better to hire RW to maximize the
Table 4.1: Values of $Q_0^*$, $C_0^*$, $Q'_o$, $G_o(Q'_o, K_o)$ and $G_o(W)$ with increase in price parameter $c$.

<table>
<thead>
<tr>
<th>$c$</th>
<th>$Q_0^*$</th>
<th>$C_0^*$</th>
<th>$Q'_o$</th>
<th>$G_o(Q'_o, K_o)$</th>
<th>$G_o(W)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1069</td>
<td>2245</td>
<td>1287</td>
<td>313.29</td>
<td>554.96</td>
</tr>
<tr>
<td>0.75</td>
<td>1057</td>
<td>2272</td>
<td>2044</td>
<td>733.30</td>
<td>832.39</td>
</tr>
<tr>
<td>1.00</td>
<td>1044</td>
<td>2298</td>
<td>2600</td>
<td>1344.08</td>
<td>1109.30</td>
</tr>
<tr>
<td>1.25</td>
<td>1033</td>
<td>2324</td>
<td>3557</td>
<td>2145.56</td>
<td>1387.18</td>
</tr>
<tr>
<td>1.50</td>
<td>1022</td>
<td>2349</td>
<td>4313</td>
<td>3137.71</td>
<td>1664.53</td>
</tr>
<tr>
<td>1.75</td>
<td>1011</td>
<td>2375</td>
<td>5069</td>
<td>4320.46</td>
<td>1941.86</td>
</tr>
<tr>
<td>2.00</td>
<td>1000</td>
<td>2400</td>
<td>5826</td>
<td>5693.76</td>
<td>2219.17</td>
</tr>
<tr>
<td>2.25</td>
<td>990</td>
<td>2425</td>
<td>6582</td>
<td>7257.58</td>
<td>2496.45</td>
</tr>
<tr>
<td>2.50</td>
<td>980</td>
<td>2449</td>
<td>7338</td>
<td>9011.67</td>
<td>2773.70</td>
</tr>
<tr>
<td>2.75</td>
<td>970</td>
<td>2474</td>
<td>8094</td>
<td>10956.58</td>
<td>3050.94</td>
</tr>
<tr>
<td>3.00</td>
<td>961</td>
<td>2498</td>
<td>8850</td>
<td>13071.68</td>
<td>3328.15</td>
</tr>
</tbody>
</table>

Where $K_o = 649$ units.
Table 4.2: Values of $Q_1^*, G_0^*(Q;\omega,K_0)$ and $G_0^*(W)$ with increases in parameter values $c$ and $W$.

<table>
<thead>
<tr>
<th>$W$</th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
<th>1.75</th>
<th>2.00</th>
<th>2.25</th>
<th>2.50</th>
<th>2.75</th>
<th>3.00</th>
</tr>
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<tbody>
<tr>
<td>$c^*$</td>
<td>1869</td>
<td>1867</td>
<td>1864</td>
<td>1863</td>
<td>1877</td>
<td>1877</td>
<td>1877</td>
<td>1877</td>
<td>1888</td>
<td>1888</td>
<td>1888</td>
</tr>
<tr>
<td>$\omega^*$</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
<td>849</td>
</tr>
<tr>
<td>$K_0^*$</td>
<td>2245</td>
<td>2272</td>
<td>2298</td>
<td>2324</td>
<td>2349</td>
<td>2375</td>
<td>2400</td>
<td>2425</td>
<td>2449</td>
<td>2474</td>
<td>2498</td>
</tr>
</tbody>
</table>

$G_0^*(Q;\omega,K_0)$:

- $G_0^*(Q;\omega,K_0)$ for $W = 1.00$:
  - $G_0^*(Q;\omega,K_0)$ = 313.19 (733.70)
- $G_0^*(Q;\omega,K_0)$ for $W = 1.25$:
  - $G_0^*(Q;\omega,K_0)$ = 554.96 (832.39)

$G_0^*(W)$:

- $G_0^*(W)$ for $W = 1.00$:
  - $G_0^*(W)$ = 1787 (2844)
- $G_0^*(W)$ for $W = 1.25$:
  - $G_0^*(W)$ = 1320 (1377)

Price increase per unit:

- For $W = 1.00$, price increase per unit is 3487 (6807).
- For $W = 1.25$, price increase per unit is 7865 (7865).

The table shows how the values of $Q_1^*$, $G_0^*(Q;\omega,K_0)$, and $G_0^*(W)$ change with increases in parameter values $c$ and $W$. The price increase per unit also increases with $W$.
<table>
<thead>
<tr>
<th></th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
<th>1.75</th>
<th>2.00</th>
<th>2.25</th>
<th>2.50</th>
<th>2.75</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_o)</td>
<td>25000</td>
<td>1987</td>
<td>2744</td>
<td>3500</td>
<td>4257</td>
<td>5013</td>
<td>5769</td>
<td>6524</td>
<td>7282</td>
<td>8033</td>
<td>8794</td>
</tr>
<tr>
<td>(D_o^p)</td>
<td>578.24</td>
<td>1174.88</td>
<td>1967.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_o^q)</td>
<td>1896.67</td>
<td>1727.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_o^r)</td>
<td>3000</td>
<td>2227</td>
<td>3758</td>
<td>4250</td>
<td>5263</td>
<td>6017</td>
<td>6775</td>
<td>7532</td>
<td>8288</td>
<td>9044</td>
<td>9800</td>
</tr>
<tr>
<td>(D_o^q^p)</td>
<td>633.20</td>
<td>1262.78</td>
<td>2143.25</td>
<td>3104.30</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_o^q^q)</td>
<td>1211.25</td>
<td>1967.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_o^q^r)</td>
<td>2774.46</td>
<td>3400.36</td>
<td>4237.37</td>
<td>4993.32</td>
<td>5750.30</td>
<td>6506.22</td>
<td>7262.21</td>
<td>8018.24</td>
<td>8774.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
gain. As size of DW increases beyond 1500 and above units, it is not economical to take RW services. Therefore, any given W capacity of DW, $Q_o'$ and $G_o(Q', K_o)$ increases with increase in c. However, for any given c, the values of $Q_o'$ increase with increase in W, but the optimum gain increase is only very marginal, and at latter stage it shows the lower returns of $G_o(Q', K_o)$ in comparison to $G(W)$.

AN EGG MODEL WHEN TEMPORARY PRICE DECREASE FOR A SYSTEM WITH INSUFFICIENT STORAGE CAPACITY

Whenever a supplier gives an advance notice of the special discount periods for a product, the buyers can very often take advantage of the opportunities of buying the product at a lower unit price. The decision problem facing the buyer is to determine the economic ordering policy during the special discount period. This problem is akin to the problem of determining the economic ordering policy when an increase in the purchase price of the product is announced by the supplier.

ASSUMPTIONS AND NOTATIONS

Following assumptions are made;

i) The demand rate of D quantity units per time unit is known and constant.

ii) Lead time is zero. Shortages are not allowed.
iii) Replenishment rate is infinite; replenishment size is the decision variable.

iv) Storage capacity of OW is $W$, and that of RW is infinite. If order quantity exceeds $W$ then excess units are kept in RW. Demands are satisfied from OW only.

v) The cost of transportation of $K$ units from RW to OW in one transshipment is $U(K)$.

In addition following notations are used:

$D$ = Demand rate per time unit

d = Cost per unit at present

c = Known price increase as of time instant $T_o$

$Q_o$ = EOQ before price decrease

$Q_o^*$ = EOQ after price decrease

$Q^*$ = Special order quantity after price decrease becomes effective.

$W$ = Storage capacity of OW

$I_1$ = Carrying charge fraction for OW.

$I_2$ = Carrying charge fraction for RW.

$A$ = Replenishment cost per order.

$T_e$ = Effective time of price decrease.

$T_1$ = Time when the special order gets depleted.

$U(K) = a$

$= a + b(K - P)$, if $K > P$

where $a > b > 0$ are constants. The cost of transporting $K$ units from RW to OW in one lot, where $P$ is the maximum number of units which can be
transported under the fixed cost 'a' and for every additional unit after 'P' a variable cost 'b' is to be paid.

PRICE DISCOUNT OR PRICE DECREASE

Since current cost per unit is d, the EOQ at present is:

\[ Q_o = \left( \frac{2AD}{d} \right)^{\frac{1}{2}} \] ........................ (4.15)

with optimal cost \( C_o \)

\[ C_o = \left( 2ADD_1 \right)^{\frac{1}{2}} \] ........................ (4.16)

We assume that \( d_1 \leq W \), so that at present it is not necessary to keep the units in RW. Suppose that the supplier announces a special sale price of \( (d - c) \) during a shortlived interval \( (T_0, T_0') \) i.e. units purchased during \( (T_0, T_0') \) will cost \( (d - c) \) per unit and those purchased after this time will cost \( d \) per unit. In such a situation one must determine the size \( Q' \) of the purchase quantity so as to take advantage of the reduced price. We obtain the optimum special order quantity \( Q' \) so as to maximize the cost difference during the period \( Q'/D \) with and without the special order.

If \( Q'> W \), then \( W \) units are kept in RW and \( Z = (Q' - W) \) in RW. Then, as shown by Sarma [11], the total cost of the system is
\[ T(Q', K) = (d - c)Q' + (d - c)I_1 Q'^2 / 2D + (d - c)(I_2 - I_1)(Q' - W)(Q' - W + K) / 2D + (O' - W) U(K) / K + A \quad \cdots \cdots \cdots \quad (4.17) \]

Let \( T_o + Q'/Q = T'_1 \), i.e., the \( Q' \) units will satisfy the demands of the system up to time \( T'_1 \).

Now suppose that no special order is placed during the shortlived interval \( (T_o, T'_1) \). Two cases may arise:

**Case I**: current on-hand inventory is sufficient to meet the demands up to \( T'_1 \) i.e., no unit is purchased at the discount price.

**Case II**: One order of \( Q_o \) units is required to be placed during \( (T_o, T'_1) \). In this case, \( Q \) units are purchased at the discounted price and rest are purchased at normal price.

The both cases are discussed below:

**Case I**: When no unit is purchased at discount price during \( (T_o, T'_1) \), the total minimum cost per cycle is

\[ T(Q_o) = dQ_o + [(2ADdI_1)^{1/2} Q_o / D \quad \cdots \cdots \cdots \quad (4.18) \]

Note that during \( (T_0, T'_1) \) there will be \( n = Q'/Q_o \) such cycles. Hence, total cost of the system during \( (T_o, T'_1) \) is

\[ T_2(Q') = T(Q_o) Q'/Q_o \]

\[ = dQ' + [(2dI_1 AD)^{1/2} Q_o / D \quad \cdots \cdots \quad (4.19) \]
From (4.16) and (4.18), the maximum gain $G_1(Q', K)$ is

$$G_1(Q', K) = T_1(Q') - T(Q', K)$$

$$= cQ' + C_o Q'/D - (d-c)I_z Q'/2D$$

$$- (d-c)(I_z - I_z)(Q' - W)(Q' - W + K)/2D$$

$$- (Q' - W)U(K)/K - A \quad \quad \quad \quad \quad (4.20)$$

For the optimum values of $K_o$ and $Q_{o1}$, $\partial G(Q', K)/\partial K = 0$ and $\partial G(Q', K)/\partial Q' = 0$, give

$$K_{o1} = \frac{2D(a - bP)}{(d-c)(I_z - I_z)1/2} \quad \quad \quad (4.21)$$

and

$$Q_{o1} = \left( \frac{D}{(d-c)I_z} \right) \left[ c + C_o/D - (d-c)(I_z - I_z)(W - K_{o1}/2)/D - \{(a - bP)/K_{o1} + b\} \right] \quad (4.22)$$

The optimum gain is

$$G_{o1}(Q_{o1}, K_{o1}) = \left( \frac{D}{2I_z(d-c)} \right) \left[ c + C_o/D - (d-c)(I_z - I_z)(W - K_{o1}/2)/D - \{(a - bP)/K_{o1} + b\} \right] \quad (4.23)$$

Now again for the feasibility of this price discount model, $Q_{o1} > W$ are necessary. This then suggest that the optimal solution of the system under this study should be represented by the following steps.

Step I: If $K_{o1}$ from (4.20) is less than $W$, and $Q_{o1}$ of (4.21) is greater than $W$, then (4.21) is the optimal lotsize
quantity and (4.22) gives the maximum gain, otherwise go to step - II.

Step - II : If $Q_a' > W$ and $K_b = W$, then $Q_{o1} = Q_{11} \prime$

$$Q_{11} \prime = \frac{(D/d-c)I_2}{c + C/D - (d - c)(I_2 - I_1)W/2D}$$

$$- ((a - bP)/W + b)$$

.......................... (4.28)

and the maximum gain from the system is

$$G_{o1}(Q_{o1}, W) = \frac{(D/2I_2(d-c))(c + C_o/D - (d-c)I_2}{W/2D}$$

$$- 1, I_2W/2D - ((a - bP)/W + b)I_2^2 - ((a - bP) + bW) - A$$

............ (4.29)

otherwise go to step - III.

Step - III : If $Q_{o1} = W$, then $Q_{o1} \prime$ is same as $Q_o$ of single storage classical EOD models, and maximum gain will be equivalent to single storage price discount model.

To cross examine the results of step - III, if we take $I_2 = I_1$, $W$(K) --- $Q$, then $Q_{o1} \prime = Q'$ of (4.21) reduces to

$$Q_o' = \frac{(c + C_o/D)I_1}{(d - c)I_1}$$

$$= \frac{cD + C_o}{(d - c)I_1}$$

.................. (4.30)

and the maximum $G_{o1}(Q_{o1}', K_o) = G_o(Q_o')$ of (4.22) reduces to

$$G_o(Q_o') = cQ_o' + C_o'd/D - (d - c)I_1Q_o' - A$$

.................. (4.31)

Results of case - I, (4.30) and (4.31) are similar to

Tersine [17] single storage model without taking advantage
of price discount.

Suppose the management under certain circumstances is unable to hire RW, but wish to take advantage of the price change, then the ordered quantity $Q'_o = W$. The maximum gain he opts through the system is

$$G_c(W) = cW + C_w W/D - (d - c)I_1, W^2 - A \quad \ldots \ldots (4.32)$$

Further, by this development it indicates that how much quantity should be ordered to hire RW services. A numerical example is given for this to understand the theoretical results.

**Example 4.2:** Consider an inventory system, in which price decrease is announced by the dealer in advance for short period. But, the on-hand inventory is sufficient up to $T$, so no unit is purchased. Find out the optimum gain by keeping the parameter values of example 4.1.

Table 4.3 shows that, price decrease is announced by the dealer with fixed capacity of OW, ($W = 1100$ units). The system indicate that it is better to hire rented warehouse even at Rs. 0.5 decrease per unit. Also it suggest that more units should be stored, when high decrease per unit is
Table 4.3: Values of $Q_o^*$, $K_o$, $Q_o'$, $G_o(Q_o',K_o)$ and $G_o(W)$ with increases in price parameter $c$.

<table>
<thead>
<tr>
<th>$c$</th>
<th>$Q_o^*$</th>
<th>$K_o$</th>
<th>$Q_o'$</th>
<th>$G_o(Q_o',K_o)$</th>
<th>$G_o(W)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1124</td>
<td>871</td>
<td>1323</td>
<td>562.90</td>
<td>555.04</td>
</tr>
<tr>
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<td>1005.93</td>
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</tr>
<tr>
<td>1.00</td>
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<td>894</td>
<td>3045</td>
<td>1677.36</td>
<td>1110.00</td>
</tr>
<tr>
<td>1.25</td>
<td>1171</td>
<td>907</td>
<td>3580</td>
<td>2596.83</td>
<td>1387.60</td>
</tr>
<tr>
<td>1.50</td>
<td>1188</td>
<td>920</td>
<td>4769</td>
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<td>1665.12</td>
</tr>
<tr>
<td>1.75</td>
<td>1206</td>
<td>934</td>
<td>6020</td>
<td>5270.39</td>
<td>1942.64</td>
</tr>
<tr>
<td>2.00</td>
<td>1225</td>
<td>949</td>
<td>7135</td>
<td>7076.83</td>
<td>2220.16</td>
</tr>
<tr>
<td>2.25</td>
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<td>2497.69</td>
</tr>
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<td>980</td>
<td>9590</td>
<td>11786.07</td>
<td>2775.21</td>
</tr>
<tr>
<td>2.75</td>
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<td>997</td>
<td>10945</td>
<td>14764.71</td>
<td>3052.73</td>
</tr>
<tr>
<td>3.00</td>
<td>1309</td>
<td>1014</td>
<td>12397</td>
<td>18218.97</td>
<td>3330.25</td>
</tr>
</tbody>
</table>

Where $C_o = 2191$, $W = 1100$ units, and $Q_o = 1095$ units
Table 4.4: Values of $Q_a', G_x(O', K_d)$ and $G_x(W)$ with decreases in price parameter value $c_x$ and increases in parameter values $W$.  

<table>
<thead>
<tr>
<th>$\frac{W}{c_x}$</th>
<th>0.58</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
<th>1.75</th>
<th>2.00</th>
<th>2.25</th>
<th>2.50</th>
<th>2.75</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1174</td>
<td>1139</td>
<td>1166</td>
<td>1171</td>
<td>1160</td>
<td>1225</td>
<td>1244</td>
<td>1265</td>
<td>1297</td>
<td>1309</td>
<td></td>
</tr>
<tr>
<td>$K_d$</td>
<td>671</td>
<td>622</td>
<td>594</td>
<td>597</td>
<td>628</td>
<td>934</td>
<td>949</td>
<td>964</td>
<td>988</td>
<td>997</td>
<td>1014</td>
</tr>
<tr>
<td>$G_x(W)$</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
<td>0.1026</td>
</tr>
<tr>
<td>$G_x(O', K_d)$</td>
<td>1109</td>
<td>1329</td>
<td>3695</td>
<td>3098</td>
<td>4969</td>
<td>6028</td>
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<td>12397</td>
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<td>$G_x(W)$</td>
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<td>3261.99</td>
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<td>1912.64</td>
<td>2220.16</td>
<td>2487.19</td>
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<tr>
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<td>$G_x(W)$</td>
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<td>1536.39</td>
<td>1965.02</td>
<td>2393.65</td>
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<td>898.89</td>
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<td>2178.93</td>
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<td>$G_x(W)$</td>
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<td>1473</td>
<td>2318</td>
<td>3163</td>
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<td>$G_x(W)$</td>
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<td>2418</td>
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<td>1.50</td>
<td>1.75</td>
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<td>-----</td>
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<tr>
<td>$c_1 \cdot 2586$</td>
<td>1773</td>
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<td>2592</td>
<td>5419</td>
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<tr>
<td>$c_2 \cdot (2 + 10 \cdot q) \cdot W$</td>
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<tr>
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<td>2944</td>
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<tr>
<td>$c_5 \cdot (2 + 10 \cdot q) \cdot W$</td>
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<td>4398.34</td>
<td>5572.81</td>
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<td>14530.19</td>
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<td>$c_6 \cdot (W)$</td>
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<td>2387.69</td>
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<td>4301.75</td>
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<td>4638</td>
<td>5511</td>
<td>4520</td>
<td>7925</td>
<td>9923</td>
<td>10548</td>
<td>11895</td>
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<td>$c_8 \cdot (2 + 10 \cdot q) \cdot W$</td>
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<td>7362.92</td>
<td>8153.97</td>
<td>8922.72</td>
</tr>
</tbody>
</table>
announced. Table 4.3 give optimal order quantity and optimal gain with and without hiring RW.

Table 4.4 shows impact on warehouse capacity by increasing warehouse capacity with more price decrease per unit. When price decreased is Rs. 0.50 per unit the system suggest that buy more number of units and store in RW upto OW capacity is 1500 units. But for Rs.0.5 price discount unit and OW capacity is to store 2000 units, then also system indicate to store only 1773 units. As price discount per unit is more then the optimal order size quantity and maximum gain with and without RW are given in the Table 4.4.

**Case II:** Here one order of \( Q_0 \) units is placed at the special discount price of \( (d - c) \). The total cost of this \( Q_0 \) units at \( (d - c) \) discount price is \( T_{21}(Q) \).

\[
T_{21}(Q_0') = (d - c)Q_0' + (d - c)I_1, Q_0'^2/2D + A
= (d - c)[Q_0 + A/d] + A \quad \text{............... (4.33)}
\]

The cost for the rest of units purchased at normal price \( d \) per unit, so the total cost for purchasing \( (Q' - Q_0) \) units is given by \( T_{22}(Q') \).

\[
T_{22}(Q') = l_d + C_2/D3(Q' - Q_0) \quad \text{............. (4.34)}
\]

So, the total cost \( T_2(Q') \) from (4.33) and (4.34) is

\[
T_2(Q') = T_{21}(Q') + T_{22}(Q')
= dQ' - cQ_0 + A \quad \text{............... (4.35)}
\]
To find the optimal one-time order lot-size $Q_o$ and the optimal units of transportation $K_o$, are the differences between $T_o(Q')$ and $T(Q',K)$ should be maximized is given by $G_o(Q',K)$.

$$G_o(Q',K) = T_o(Q') - T(Q',K)$$
$$= c(Q' - Q_o) + (Q' - Q_o)C_o/D + (d - c)A/d$$
$$- (d - c)(I_e^2 / 2D - (I_e - I_1)(Q' - W)(Q' - W)$$
$$+ K_o) / 2D - (Q' - W)U(K) / K$$ ................................ (4.36)

The optimum values of $K_o$ and $Q_o$, $dG(Q',K)/dK = 0$ and $dG(Q',K)/dQ' = 0$, give

$$K_o = \left[ 2D(a - bP) / (d - c)(I_e - I_1) \right]^{1/2}$$ ................................ (4.37)

and

$$Q_o = (D / (d - c)I_e) \left( C_o + C_e / D \right)$$
$$+ (d - c)(I_e - I_1)(W - K_o / 2) / D - ((a - bP) / K_o + b)^3$$ ................................ (4.38)

Substituting the value of $Q_o$ and $K_o$ in $G_o(Q',K)$ the optimal gain $G_o(Q_o',K_o)$ can be obtained.

$$G_o(Q_o',K_o) = (D / 2I_e) \left( (d - c)C_o + C_e / D \right)$$
$$- (d - c)(I_e - I_1)(W - K_o / 2) / D$$
$$- ((a - bP) / K_o + b)^2 - C_o / (C_e + C_e / D)$$
$$+ (d - c)A/d - W(d - c)(I_e - I_1)(W$$
$$- K_o / 2D)$$ ................................ (4.39)

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For the feasibility of this case \( Q_{o2} \geq W \) and \( K_{o2} \leq W \) are necessary. So the optimal solution under study can be represented by the following steps.

**Step - I**: If \( K_{o2} \) from (4.36) is less than \( W \), and \( Q_{o2} \geq W \) of (4.37), then \( Q_{o2} \) is the optimal lot-size quantity and optimal gain will remain same as of (4.39). Otherwise, go to step - II.

**Step - II**: If \( Q_{o2} = Q_{o2} \geq W \) and \( K_{o2} = W \) then

\[
Q_{o2} = \frac{(d/(d-c))I_2}{C_c/C_d - (d-c)(I_2 - I_1)W/2D - ((a-bP)/W + b)}
\]

\[\text{..........................(4.40)}\]

and the maximum gain of the system is

\[
G_{o2}(Q_{o2},W) = \frac{(d/2)(d-c)I_2}{C_c/C_d - (d-c)(I_2 - I_1)W/2D - ((a-bP)/W + b)^2 - C_c/C_d}
\]

\[\text{..........................(4.41)}\]

Otherwise go to step III.

**Step - III**: If \( Q_{o2} = W \), then \( Q_{o2} \) is same as \( Q_{o2} \) single storage price decreased EOQ model with one order of \( Q_{o2} \) units placed at \( (d-c) \) price and rest of the purchased at normal price. So, the maximum gain will also be equivalent to single storage model with the above conditions.

To examine the results of step - III, if we consider \( I_2 = I_2 \), and \( U(K) \rightarrow 0 \), in (4.37) and (4.38),

\[
Q_{o2} = \frac{(d/(d-c))I_2}{C_c/C_d}
\]

\[\text{..........................(4.42)}\]
and maximum gain $G_o(Q_o')$ is

$$G_o(Q_o') = c(Q_o' - Q_o) + C_j Q_o' - Q_o) / D$$

$$+ (d - c)(A/d - Q_o')^2 I_1 / 2D \quad \ldots \ldots \ldots \ldots (4.43)$$

Results of this case (4.42) and (4.43) are similar to Goyal [4].

If somebody do not wish to hire RW, and also wants to take advantage of same in that case $Q_o' = W$, and maximum gain is

$$G_o(W) = (c + C_o / D)(W - Q_o)) + (d - c)A/d - (d - c)I_1 W^2 / 2D \quad \ldots \ldots \ldots \ldots (4.44)$$

Sensitivity analysis of this case is carried out in detail to understand and support the model.

**Example 4.3:** Consider an inventory system in which price decrease per unit is announced by the dealer in advance for short period. But due to financial constraints and untimely announcement the retailer is unable to hire RW, so could not place the order for the special order lot-size. However, he was able to place order for $W$ units during the announced period; find out the maximum profit gained by him if he was able to hire RW, and without RW. The parameters values are same as given in example 4.1.
Table 4.5: Values \( Q'_o \), \( K_o \), \( O'_o \), \( B_o (Q'_o , K_o) \)

and \( B_o (W) \) with decreases in price

<table>
<thead>
<tr>
<th>( c )</th>
<th>( Q'_o )</th>
<th>( K_o )</th>
<th>( O'_o )</th>
<th>( B_o (Q'_o , K_o) )</th>
<th>( B_o (W) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1124</td>
<td>871</td>
<td>1323</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>0.75</td>
<td>1139</td>
<td>882</td>
<td>2160</td>
<td>177</td>
<td>3</td>
</tr>
<tr>
<td>1.00</td>
<td>1155</td>
<td>894</td>
<td>3045</td>
<td>572</td>
<td>5</td>
</tr>
<tr>
<td>1.25</td>
<td>1171</td>
<td>907</td>
<td>3980</td>
<td>1215</td>
<td>6</td>
</tr>
<tr>
<td>1.50</td>
<td>1186</td>
<td>920</td>
<td>4969</td>
<td>2128</td>
<td>7</td>
</tr>
<tr>
<td>1.75</td>
<td>1206</td>
<td>934</td>
<td>6020</td>
<td>3336</td>
<td>8</td>
</tr>
<tr>
<td>2.00</td>
<td>1225</td>
<td>949</td>
<td>7135</td>
<td>4866</td>
<td>9</td>
</tr>
<tr>
<td>2.25</td>
<td>1244</td>
<td>964</td>
<td>8323</td>
<td>6750</td>
<td>10</td>
</tr>
<tr>
<td>2.50</td>
<td>1265</td>
<td>980</td>
<td>9590</td>
<td>9022</td>
<td>12</td>
</tr>
<tr>
<td>2.75</td>
<td>1287</td>
<td>997</td>
<td>10945</td>
<td>11725</td>
<td>13</td>
</tr>
<tr>
<td>3.00</td>
<td>1309</td>
<td>1014</td>
<td>12397</td>
<td>14903</td>
<td>14</td>
</tr>
</tbody>
</table>

\( C_o/B = 0.1826 \) and \( Q_o = 1075 \) units.
Table 4.6: Values of $Q_o$, $G_o(Q_o')$, $K_d$ and $G_o(W)$ with decreases in price parameter value $c$ and increases in parameter value of $W$.

<table>
<thead>
<tr>
<th>$W$</th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
<th>1.75</th>
<th>2.00</th>
<th>2.25</th>
<th>2.50</th>
<th>2.75</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_o$</td>
<td>1124</td>
<td>1139</td>
<td>1155</td>
<td>1171</td>
<td>1188</td>
<td>1205</td>
<td>1225</td>
<td>1244</td>
<td>1265</td>
<td>1287</td>
<td>1309</td>
</tr>
<tr>
<td>$G_o(Q_o')$</td>
<td>9862</td>
<td>987</td>
<td>989</td>
<td>987</td>
<td>984</td>
<td>982</td>
<td>980</td>
<td>978</td>
<td>976</td>
<td>974</td>
<td>973</td>
</tr>
<tr>
<td>$K_d$</td>
<td>1089</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
<td>1095</td>
</tr>
<tr>
<td>$G_o(W)$</td>
<td>1199</td>
<td>1223</td>
<td>1273</td>
<td>2223</td>
<td>2273</td>
<td>2323</td>
<td>2373</td>
<td>2423</td>
<td>2473</td>
<td>2523</td>
<td>2573</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Table 4.6: (continue)....</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price decrease per unit</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.2</td>
</tr>
<tr>
<td>0.4</td>
</tr>
<tr>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
</tr>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>1.2</td>
</tr>
<tr>
<td>1.4</td>
</tr>
<tr>
<td>1.6</td>
</tr>
<tr>
<td>1.8</td>
</tr>
<tr>
<td>2.0</td>
</tr>
<tr>
<td>2.2</td>
</tr>
<tr>
<td>2.4</td>
</tr>
<tr>
<td>2.6</td>
</tr>
<tr>
<td>2.8</td>
</tr>
<tr>
<td>3.0</td>
</tr>
</tbody>
</table>

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Table 4.5 shows that when prices are decreased from Rs.0.50 to Rs.3.00, the maximum gain increases with fixed warehouse capacity. Also, it indicates that when RW was not hired, and per unit price decrease Rs.0.50 is announced, then the retailer gains only 2 rupees, if he was able hire RW then he might have earned Rs.10. In this case OW can store maximum 1100 units. Which is 5 units more than Q_a, so very marginal gain is there with OW. But, when price decrease per unit announced is Rs.3.00 by the dealer and system was able to hire RW. This model suggest to store more units then a yearly demand in RW.

Table 4.6 shows the impact of price decreasing with increase in OW capacity. Decrease in price of Rs.0.50 per unit, indicates that RW can hire OW capacity to store upto 1500 units. Even if the capacity OW increases then also it could accomodate the optimal order quantity in OW. If price decreased per unit is more than Rs.1.50 then its order quantity is stagnating with increase in OW capacity. However, hiring RW in this case is very much economical than without RW.