CHAPTER 2

INVENTORY TURNOVER RATIO MODELS WITH INSTANTANEOUS PRODUCTION
2. CHAPTER 2: INVENTORY TURNOVER RATIO MODELS WITH INSTANTANEOUS PRODUCTION

2.1. Introduction:

Inventory turnover is one of the important aspects of the financial analysis. The Finance Management of the firm in most of the case depends on the inventory turnover. It indicates how fast inventory is sold.

In Financial Management, high ratio is good and it indicates efficient liquidity and vice versa, a low ratio indicates that inventory does not sell.

In chapter 1 we discussed the importance of inventory turnover ratio in financial management. Lower ITOR indicates west of inventories where as higher ITOR indicates efficient management of inventories in the firm, some time it indicates shortages of an item. Here, in this chapter, the relation of ITOR for different demand pattern has been established.


The inventory turnover ratio discussed below under a stock dependent consumption rate. The inventory turnover ratio model was proposed by S.B.Srivastav(1978) and supported by Kanti Swaroop-Gupta & Man Mohan(1994).

2.2.1. Notations:-

\[ C_1 = \text{Inventory Carrying / Holding Cost per Rs. Per Unit per Year} \]
\[ C_3 = \text{Ordering Cost / Setup Cost per Rs. per Order / Production} \]
\[ D = \text{Demand per Unit per Year} \]
\[ Q = \text{Lot Size / Contract quantity} \]
\[ P = \text{Purchase Price per Unit} \]
2.2.2. Assumptions:-
(i) Demand is uniform and known stock dependent.
(ii) Shortages are not allowed.
(iii) Lead-time is zero.
(iv) Replenishment Rate is infinite.

2.2.3. Problem Formulation:-
The Inventory Turnover Ratio is defined as
\[ i(Q) = \frac{DP}{C(Q)} \]
\[ \frac{DP}{\left(\frac{QC_1}{2} + \frac{DC_3}{Q}\right)} \]

In order to find the optimum values for \( Q \) so as to maximize Inventory Turnover Ratio, we have,
\[
\frac{\partial i(Q)}{\partial Q} = \frac{\partial}{\partial Q} \left[ DP \left( \frac{QC_1}{2} + \frac{DC_3}{Q} \right)^{-1} \right]
\]
\[ = -DP \left( \frac{QC_1}{2} + \frac{DC_3}{Q} \right)^{-2} \left( C_1 \frac{1}{2} - \frac{DC_3}{Q^2} \right) \]

but \[ \frac{\partial i(Q)}{\partial Q} = 0 \]

\[
\therefore -DP \left( \frac{QC_1}{2} + \frac{DC_3}{Q} \right)^{-2} \left( C_1 \frac{1}{2} - \frac{DC_3}{Q^2} \right) = 0
\]

\[
\therefore \frac{C_1}{2} \frac{DC_3}{Q^2} = 0
\]

\[
\therefore Q = \sqrt{\frac{2DC_3}{C_1}}
\]

The Inventory Turnover Ratio is maximum only if \[ \frac{\partial^2 i(Q)}{\partial Q^2} < 0 \]. Therefore,
\[
\frac{\partial^2 i(Q)}{\partial Q^2} = \frac{\partial}{\partial Q} \left( \frac{\partial i(Q)}{\partial Q} \right)
\]
\[
\frac{\partial}{\partial Q} \left\{ -DP \left( \frac{QC_1 + DC_3}{2} \right)^2 \left( \frac{C_1 - DC_3}{Q} \right) \left( \frac{Q}{2} - \frac{DC_3}{Q^2} \right) \right\} = \frac{-2DP}{Q} \left( \frac{QC_1 + DC_3}{2} \right)^2 \left( \frac{C_1 - DC_3}{Q^2} \right)^2 \left( \frac{Q}{2} - \frac{DC_3}{Q^2} \right) \]

\[
= -\left\{ \frac{2D^2PC_1}{Q} \left( \frac{QC_1 + DC_3}{2} \right)^2 \left( \frac{C_1 - DC_3}{Q^2} \right)^3 \right\} < 0
\]

The optimum value of \( Q \) has thus been obtained and is given by,

\[
Q = \sqrt{\frac{2DC_3}{C_1}} \quad \ldots \ldots \quad 2.2
\]

and optimum Inventory Turnover Ratio is given by

\[
I\left( Q_{\text{opt}} \right) = \frac{DP}{\frac{Q_{\text{opt}}C_1 + DC_3}{2}} \left( \frac{C_1 - DC_3}{Q_{\text{opt}}} \right)^2 \left( \frac{Q}{2} - \frac{DC_3}{Q^2} \right) \]

\[
= \frac{DP}{\sqrt{\frac{C_1C_3D}{2} + \sqrt{\frac{C_1C_3D}{2}}} \left( \frac{C_1 - DC_3}{Q_{\text{opt}}} \right)^2} \left( \frac{Q}{2} - \frac{DC_3}{Q^2} \right) \]

\[
= \frac{DP}{2\sqrt{\frac{C_1C_3D}{2}}} \quad \text{or} \quad \frac{\sqrt{\frac{D}{2C_1C_3}}}{P} \quad \ldots \ldots \quad 2.3
\]
2.2.4. Hypothetical Problem:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) D</th>
<th>Holding Cost C₁</th>
<th>Ordering Cost C₃</th>
<th>Purchase Cost P</th>
<th>Optimal Turnover (Units) Qₜₒᵖ</th>
<th>Total Inventory Cost C(Qₒₜₘ)</th>
<th>Optimal Turnover Ratio I(Qₒₜₘ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8,000</td>
<td>Rs. 25</td>
<td>Rs. 70</td>
<td>Rs. 5</td>
<td>212</td>
<td>Rs.5292</td>
<td>7.56</td>
</tr>
<tr>
<td>2</td>
<td>9,500</td>
<td>Rs. 25</td>
<td>Rs. 60</td>
<td>Rs. 6</td>
<td>214</td>
<td>Rs.5339</td>
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<td>3</td>
<td>12,000</td>
<td>Rs. 25</td>
<td>Rs. 50</td>
<td>Rs. 7</td>
<td>219</td>
<td>Rs.5477</td>
<td>15.34</td>
</tr>
<tr>
<td>4</td>
<td>13,500</td>
<td>Rs. 25</td>
<td>Rs. 45</td>
<td>Rs. 7.5</td>
<td>220</td>
<td>Rs.5511</td>
<td>18.37</td>
</tr>
</tbody>
</table>

Note: Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.

2.2.5. Remark:-

It is clear from above example that optimal turnover is depend on consumption rate. The size of turnover increases up to particular level to maintaining optimal ordering cost. For a given demand, optimal turnover increases the turnover ratio increases, it means there are no shortages of inventories and handling of inventory is efficient in the firm. So, it is beneficial for the company.

2.2.6. Case-1: \( D=\alpha+\beta Q \)

Demand \( D \) is a linear function of lot size \( Q \). Let us take \( D=\alpha+\beta Q \), where \( \alpha \) and \( \beta \) are constants and the Inventory Turnover Ratio is given by,

\[
I(Q) = \frac{DP}{C(Q)}
\]

\[
= \frac{DP}{\frac{QC_1}{2} + \frac{DC_3}{Q}}
\]

\[
= P(\alpha + \beta Q) \left( \frac{\alpha C_1}{2} + \frac{(\alpha + \beta Q)C_3}{Q} \right)^{-1}
\]

\[
= (\alpha P + \beta PQ) \left[ \frac{Qu}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right]^{-1}
\]

\[
\cdots \cdots 2.4
\]
To obtain the optimum value of $Q$, necessary and sufficient conditions are $\frac{\partial I(Q)}{\partial Q} = 0$ and $\frac{\partial^2 I(Q)}{\partial Q^2}$, thus,

$$\frac{\partial I(Q)}{\partial Q} = (O + \beta P) \left[ \frac{QC_1}{2} + \frac{\alpha C_1}{Q} + \beta C_3 \right] + (-1)(\alpha P + \beta PQ)$$

$$\left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right]^2 \left[ \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + 0 \right]$$

but $\frac{\partial I(Q)}{\partial Q} = 0$

$$\therefore \beta P \left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right] - (\alpha P + \beta PQ) \left[ \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} \right] = 0$$

$$\therefore \beta P \left[ \frac{Q^2 C_1}{2} + 2\alpha C_3 + 2\beta C_3 Q \right] - (\alpha P + \beta PQ) \left[ \frac{C_1 Q^2}{2} - 2\alpha C_3 \right] = 0$$

$$\therefore \beta P Q \left[ Q^2 C_1 + 2\alpha C_3 + 2\beta C_3 Q \right] - (\alpha P + \beta PQ) \left[ C_1 Q^2 - 2\alpha C_3 \right] = 0$$

$$\therefore \left( 2\beta^2 P C_3 - \alpha P C_1 \right) Q^2 + 4\alpha \beta P C_3 Q + 2\alpha^2 PC_3 = 0$$

Now, $Q = \frac{-b \pm \sqrt{\Delta}}{2a}$ where $\Delta = b^2 - 4ac$

$$\therefore \Delta = 16\beta^2 C_3^2 P \alpha^2 - 4 \left( 2\beta^2 P C_3 - \alpha P C_1 \right) \alpha^2 PC_3$$

$$= 16 \alpha^2 \beta^2 P^2 C_3^2 - 16 \alpha^2 \beta^3 P^3 C_3^2 + 8 \alpha^3 P^2 C_3 C_3$$

$$= 8 \alpha^3 P^2 C_3 C_3$$

$$\therefore Q = \frac{-b \pm \sqrt{\Delta}}{2a}$$

$$= \frac{-4\alpha \beta P C_3 \pm \sqrt{8\alpha^3 P^2 C_3 C_3}}{2(2\beta^2 P C_3 - \alpha P C_1)}$$
and \[
\frac{d^2 I(Q)}{dQ^2} = 0 - \beta P \left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right] - \frac{1}{Q^2} \left[ \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} \right] + (-1)(\alpha P + \beta PQ)\left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} \right) \\
\left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right]^2 - \frac{1}{Q^2} \left[ \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} \right] + \beta P \left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \beta C_3 \right] \left( \frac{2\alpha C_3}{Q^2} \right) < 0
\]

\[
Q_{\text{opt}} = \frac{-4\alpha \beta PC_3 \pm \sqrt{8\alpha^2 \beta^2 C_3^2 C_1}}{4\beta^2 C_3 - 2\alpha PC_3}
\] ...... 2.6

Which maximize the inventory turnover ratio \( I(Q) \).

Therefore,
\[
I\left( Q_{\text{opt}} \right) = \frac{DP}{C_1 Q_{\text{opt}} + DC_3 Q_{\text{opt}}^2} 
\] ...... 2.7

### 2.2.7. Hypothetical Problem:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) ( D = \alpha + \beta Q )</th>
<th>Holding Cost (( C_1 ))</th>
<th>Ordering Cost (( C_3 ))</th>
<th>Purchase Cost (( p ))</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>Optimal Turnover (Units) ( Q_{\text{opt}} )</th>
<th>Total Inventory Cost ( C(Q_{\text{opt}}) )</th>
<th>ITOR ( I(Q_{\text{opt}}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1493</td>
<td>Rs. 20</td>
<td>Rs. 60</td>
<td>Rs. 5</td>
<td>200</td>
<td>5</td>
<td>259</td>
<td>Rs.2932</td>
<td>2.55</td>
</tr>
<tr>
<td>2</td>
<td>2544</td>
<td>Rs. 20</td>
<td>Rs. 51</td>
<td>Rs. 6</td>
<td>220</td>
<td>6</td>
<td>387</td>
<td>Rs.4209</td>
<td>3.63</td>
</tr>
<tr>
<td>3</td>
<td>3018</td>
<td>Rs. 20</td>
<td>Rs. 41.5</td>
<td>Rs. 7</td>
<td>240</td>
<td>7</td>
<td>397</td>
<td>Rs.4285</td>
<td>4.93</td>
</tr>
<tr>
<td>4</td>
<td>3621</td>
<td>Rs. 20</td>
<td>Rs. 35</td>
<td>Rs. 8</td>
<td>260</td>
<td>8</td>
<td>420</td>
<td>Rs.4503</td>
<td>6.43</td>
</tr>
<tr>
<td>5</td>
<td>4093</td>
<td>Rs. 20</td>
<td>Rs. 30</td>
<td>Rs. 9</td>
<td>280</td>
<td>9</td>
<td>424</td>
<td>Rs.4526</td>
<td>8.14</td>
</tr>
</tbody>
</table>

**Note:** Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.

### 2.2.8. Remark:-

It is clear from above example that optimal turnover is depend on \( \alpha \) & \( \beta \). The size of turnover increases maintaining the lower ordering cost. For a linear demand, optimal turnover increases the turnover ratio increases. So, it is beneficial for the company.
2.2.9. Case-II: \( D = \beta Q^x \)

Let us take demand \( D \) as given below:-

\[
D = \beta Q^x
\]

Where \( x \) is a variable, \( 0 < x < 1; \)

\( \beta \) is a Constant

\( Q \) is a Contract Quantity

The inventory turnover ratio is given by

\[
I(Q) = DP \left[ \frac{QC_1}{2} + \frac{DC_3}{Q} \right]
\]

\[
= \beta Q^x \left[ \frac{QC_1}{2} + C_3 \beta Q^x \right]
\]

\[
= \beta Q^x \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-1}
\]  \( \cdots \)  \( 2.8 \)

The turnover ratio is maximum if (i) \( \frac{\partial I(Q)}{\partial Q} = 0 \) and \( \frac{\partial^2 I(Q)}{\partial Q^2} < 0 \). Thus,

\[
\frac{\partial I(Q)}{\partial Q} = x\beta PQ^{x-1} \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-1} - \beta PQ \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-2} \left[ \frac{C_1}{2} + (x-1)C_3 \beta Q^{x-2} \right]
\]  \( \cdots \)  \( 2.9 \)

but \( \frac{\partial I(Q)}{\partial Q} = 0 \)

\[
\therefore x\beta PQ^{x-1} \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-1} - \beta PQ \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-2} \left[ \frac{C_1}{2} + (x-1)C_3 \beta Q^{x-2} \right] = 0
\]

\[
\therefore xQ^{x-1} \left[ \frac{QC_1}{2} + C_3 \beta Q^{x-1} \right]^{-1} \left[ \frac{C_1}{2} + (x-1)C_3 \beta Q^{x-2} \right] = 0
\]

\[
\therefore \frac{xC_1}{2} + xC_3 \beta Q^{x-2} - \frac{C_1}{2} - xC_3 \beta Q^{x-2} + C_3 \beta Q^{x-2} = 0
\]

\[
\therefore -\frac{C_1}{2} (1-x) + C_3 \beta Q^{x-2} = 0
\]
\[ C_3 \beta Q^{x-2} = \frac{C_1}{2} (1-x) \]
\[ Q^{x-2} = \frac{C_1 (1-x)}{2C_3 \beta} \]
\[ Q = \frac{(1-x)C_1 Q^2}{2C_3 \beta} \]
\[ \therefore Q = \left[ \frac{(1-x)C_1 Q^2}{2C_3 \beta} \right]^{1/2} \]

or
\[ Q = \sqrt{\frac{(1-x)C_1 Q^2}{2C_3 \beta}} \]  \[ \text{..... 2.10} \]

and
\[ \frac{\partial^2 I(Q)}{\partial Q^2} = \frac{x^2 \beta PC_1 Q^{x-1}}{2} - \frac{x \beta PC_1 Q^{x-1}}{2} + (2x-2) \beta^2 PC_3 Q^{2x-3} \left[ \frac{QC_1}{2} + \beta C_3 Q^{1-1} \right] \]
\[ - 2 \left[ \left( \frac{C_1}{2} + (x-1) \beta C_3 Q^{x-2} \right) \left( \frac{x \beta C_1 Q^{x-2}}{2} - \frac{\beta PC_1 Q^3}{2} + \beta^2 PC_3 Q^{2x-3} \right) \right] \]
\[ \left[ \frac{QC_1}{2} + \beta C_3 Q^{1-1} \right]^{-3} < 0 \]

Thus 2.10 becomes,
\[ \therefore Q_{\text{opt}} = \sqrt{\frac{(1-x)C_1 Q^2}{2C_3 \beta}} \]  \[ \text{..... 2.11} \]

Which maximize the inventory turnover ratio \( I(Q) \).

Therefore,
\[ I \left( Q_{\text{opt}} \right) = \frac{DP}{\left[ \frac{QC_1}{2} + DC_3 \right]} \]
\[ Q_{\text{opt}} \]

2.2.10. Hypothetical Problem:-

To understand this ITOR Model, we use some hypothetical value of \( C_1, C_3, x \) and \( \beta \) and substituting in equation 2.11, we have,
<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units)</th>
<th>Holding Cost (C₁)</th>
<th>Ordering Cost (C₃)</th>
<th>Purchase Cost (P)</th>
<th>x</th>
<th>Optimal Turnover (Units)</th>
<th>Total Inventory Cost C(Q)</th>
<th>I(Q_{opt})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3919</td>
<td>Rs.20</td>
<td>Rs.60</td>
<td>Rs.5</td>
<td>0.9</td>
<td>15</td>
<td>Rs.5334.18</td>
<td>3.67</td>
</tr>
<tr>
<td>2</td>
<td>2476</td>
<td>Rs.20</td>
<td>Rs.50</td>
<td>Rs.6</td>
<td>0.8</td>
<td>30</td>
<td>Rs.2985.83</td>
<td>4.98</td>
</tr>
<tr>
<td>3</td>
<td>1658</td>
<td>Rs.20</td>
<td>Rs.40</td>
<td>Rs.7</td>
<td>0.7</td>
<td>50</td>
<td>Rs.1932.77</td>
<td>6.00</td>
</tr>
</tbody>
</table>

**Note:** Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.

**2.2.11. Remark:**

As $\beta$ increases and $x$ ($0 < x < 1$) decreases, there is a decrease in optimal turnover and ITOR increases hence handling of inventory is at satisfactory level in the firm.

**2.2.12. Case III: $D=\beta_1 Q - \beta_2 Q^2$**

The Inventory turnover ratio is given by,

$$I(Q) = \frac{DP}{C(Q)}$$

$$= \frac{DP}{\left[ \frac{QC_1}{2} + \frac{DC_3}{Q} \right]}$$

Let us take demand as $D=\beta_1 Q - \beta_2 Q^2$

Where $\beta_1$ and $\beta_2$ are constants and $Q$ is a contract quantity.

$$I(Q) = P(\beta_1 Q - \beta_2 Q^2) \left[ \frac{QC_1}{2} + \frac{C_3}{Q} (\beta_1 Q - \beta_2 Q^2) \right]$$

$$= \left( P\beta_1 Q^2 - P\beta_2 Q^3 \right) \left[ \frac{QC_1}{2} + C_3\beta_1 - C_3\beta_2 Q \right]$$

The turnover ratio is maximum if (i) $\frac{dI(Q)}{dQ} = 0$ and (ii) $\frac{d^2I(Q)}{dQ^2} < 0$.

Thus.
\[ \frac{\partial f(Q)}{\partial Q} = (Pq - 2Pq) \left( \frac{OC}{2} + Cq + Cq \right) - \left( Pq - Pq \right) \left( \frac{OC}{2} + Cq + Cq \right)^2 \left( \frac{C}{2} - Cq \right) \]

but \[ \frac{\partial f(Q)}{\partial Q} = 0 \]

\[ \therefore (Pq - 2Pq) = \left( Pq - Pq \right) \left( \frac{OC}{2} + Cq + Cq \right)^2 \left( \frac{C}{2} - Cq \right) = 0 \]

\[ \therefore 2(Pq - 2Pq) \left( \frac{OC}{2} + Cq + Cq \right) - \left( Pq - Pq \right) \left( \frac{OC}{2} + Cq + Cq \right)^2 \left( \frac{C}{2} - Cq \right) = 0 \]

\[ \therefore 2PqPq - 2PqPqCq^2 - 2PqPqCq^2 = 0 \]

\[ \therefore -PqPqCq^2 - 2PqPqCq^2 - 4PqPqCq^2 + 2PqPqCq^2 = 0 \]

\[ \therefore (2PqPqCq^2 - PqPqCq^2)^2 - 4PqPqCq^2 + 2PqPqCq^2 = 0 \]

now \[ \Delta = b^2 - 4ac \]

\[ = 16Pq^2Pq^2Cq^2 - 4(2PqPqCq^2 - PqPqCq^2)PqPqCq^2 \]

\[ = 16Pq^2Pq^2Cq^2 - 16Pq^2Pq^2Cq^2 + 8Pq^2Pq^2Cq^2 \]

\[ = 8Pq^2Pq^2Cq^2 \]

\[ \therefore Q = \frac{-b \pm \sqrt{\Delta}}{2a} \]

\[ = \frac{4PqPqCq^2 \pm \sqrt{8Pq^2Pq^2Cq^2Cq^2}}{2(2PqPqCq^2 - PqPqCq^2)} \]

\[ = \frac{4PqPqCq^2 \pm \sqrt{8Pq^2Pq^2Cq^2Cq^2}}{4Pq^2Cq^2 - 2PqPqCq^2} \]

under certain conditions, it is observed that the turnover ratio is maximum only if \[ \frac{\partial^2 f(Q)}{\partial Q^2} < 0 \]
\[
\frac{\partial^2 I(Q)}{\partial Q^2} = -2 \left[ \frac{C_1}{2} - \beta_2 C_3 \right] + \frac{\beta_2 C_3 Q^2}{2} - 2P\beta_1 \beta_2 C_3 Q \left[ \frac{QC_1}{2} + \beta_1 C_3 - \beta_2 C_3 Q \right]^3 \\
+ [2P\beta_2^2 C_3 Q - P\beta_2 C_3 Q - 2P\beta_1 \beta_2 C_3 \left[ \frac{QC_1}{2} + \beta_1 C_3 - \beta_2 C_3 Q \right]^2 < 0
\]

\[
Q = \frac{4P\beta_1 \beta_2 C_3 \pm \sqrt{8P^2 \beta_2^2 C_3 C_1}}{4P\beta_2^2 C_3 - 2P\beta_2 C_1}
\]

Which maximize the inventory turnover ratio \(I(Q)\).

Therefore,

\[
I \left( Q_{\text{opt}} \right) = \frac{DP}{\left[ \frac{QC_1}{2} + DC_3 \right]^2}
\]

### 2.2.13. Hypothetical Problem:-

Using hypothetical values, we solve this type of ITOR Model as below:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand</th>
<th>Holding Cost (C₁)</th>
<th>Ordering Cost (C₃)</th>
<th>Purchase Cost (P)</th>
<th>(\beta_1)</th>
<th>(\beta_2)</th>
<th>Optimal Turnover (units) (Q_{\text{opt}})</th>
<th>Total Inventory Cost (C(Q_{\text{opt}}))</th>
<th>Optimal Turnover Ratio (I(Q_{\text{opt}}))</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2274</td>
<td>Rs. 20</td>
<td>Rs. 60</td>
<td>Rs. 5</td>
<td>70</td>
<td>0.5</td>
<td>89</td>
<td>Rs.2425</td>
<td>4.69</td>
</tr>
<tr>
<td>2</td>
<td>3882</td>
<td>Rs. 20</td>
<td>Rs. 50</td>
<td>Rs. 6</td>
<td>80</td>
<td>0.4</td>
<td>117</td>
<td>Rs.2828</td>
<td>8.24</td>
</tr>
<tr>
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<td>Rs. 40</td>
<td>Rs. 7</td>
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<td>0.3</td>
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<td>Rs.3651</td>
<td>15.94</td>
</tr>
</tbody>
</table>

Note: Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.

### 2.2.14. Remark:-

Here, \(\beta_1\) increase and \(\beta_2\) decreases with increase in demand. Here the order quantity is maintained with minimum total inventory cost. Also ITOR increases which shows that the goodwill of the customer is taken care off.
2.3. Model – II: Inventory Turnover Ratio Model Using Stock Dependent Consumption Rate When Setup Cost Varies.

2.3.1. Introduction:-

In ITOR concept, if we can take setup cost as $C_3 + bQ$ instead of being fixed, where $b$ is setup cost per unit item produced, then there is no change in the optimum inventory turnover produced due to change in the setup cost. The inventory turnovers are discussed here under a stock dependent consumption rate. The model proposed by S.B.Srivastav (1978) is clubbed with the model by Kanti Swarup, Gupta and Manomohan (1994).

2.3.2. Notations:-

- $Q$ = Contract Quantity (in Units)
- $D$ = Annual Demand (in Units)
- $P$ = Purchase Cost Rs./Unit
- $C_1$ = Inventory Holding Cost Rs./Unit/Year
- $C_3$ = Inventory Setup Cost Rs. Per Order
- $b$ = Setup Cost per Unit item produced.

2.3.3. Assumptions:-

(i) Demand is Uniform and Known/Stock Dependent
(ii) Shortages are not allowed
(iii) Lead time is zero
(iv) Rate of replenishment is not instantaneous.

2.3.4. Problem Formulation:-

The Inventory Turnover Ratio is given by:

$$I(Q) = \frac{DP}{C(Q)}$$  \hspace{1cm} 2.16

where

$$C(Q) = \frac{QC_1}{2} + \frac{DC_3}{Q}$$
Let us take $C_3$ as $C_3+bQ$, we have,

$$C(Q) = \frac{QC_1}{2} + \frac{D}{Q}(C_3+bQ)$$

$$= \frac{QC_1}{2} + \frac{DC_3}{Q} + Db$$

$$\therefore I(Q) = \frac{DP}{\frac{QC_1}{2} + \frac{DC_3}{Q} + Db}$$

$$= DP \left[ \frac{QC_1}{2} + \frac{DC_3}{Q} + Db \right]^{-1} \quad \ldots \ldots \text{2.17}$$

To obtain the optimal contract value, differentiate equation no 2.17 with respect to $Q$ and equate it with equal to zero. Also, ITOR is maximum if $\frac{\partial^2 I(Q)}{\partial Q^2} < 0$, Therefore,

$$\frac{\partial I(Q)}{\partial Q} = -DP \left[ \frac{QC_1}{2} + \frac{DC_3}{Q} + Db \right]^{-2} \left[ \frac{C_1}{2} - \frac{DC_3}{Q^2} \right] = 0$$

$$\therefore \frac{C_1}{2} - \frac{DC_3}{Q^2} = 0$$

$$\therefore Q^2 = \frac{2DC_3}{C_1}$$

$$\therefore Q = \sqrt{\frac{2DC_3}{C_1}}$$

and

$$\frac{\partial^2 I(Q)}{\partial Q^2} = \left( 2DP \left[ \frac{QC_1}{2} + \frac{DC_3}{Q} + Db \right]^{-3} \left[ \frac{C_1}{2} - \frac{DC_3}{Q^2} \right] \left[ \frac{(C_3 + bQ_{opt})}{Q_{opt}} \right] \right) < 0$$

$$\therefore Q_{opt} = \sqrt{\frac{2DC_3}{C_1}} \quad \ldots \ldots \text{2.18}$$

$$C(Q_{opt}) = \frac{C_1}{2} Q_{opt} + \frac{D(C_3 + bQ_{opt})}{Q_{opt}} \quad \ldots \ldots \text{2.19}$$
2.3.5. Hypothetical Problem:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) (D)</th>
<th>Holding Cost (C₁) (Rs.)</th>
<th>Setup Cost (C₃ + bQ) (Rs.)</th>
<th>Purchase Cost (P) (Rs.)</th>
<th>Optimal Turnover (Units) Q_{opt}</th>
<th>Total Inventory Cost C(Q_{opt}) (Rs.)</th>
<th>Optimal Turnover Ratio I(Q_{opt})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8000</td>
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<td>72</td>
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<td>214</td>
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</tr>
<tr>
<td>3</td>
<td>12000</td>
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<td>52</td>
<td>7</td>
<td>219</td>
<td>5597</td>
<td>15.01</td>
</tr>
<tr>
<td>4</td>
<td>13500</td>
<td>25</td>
<td>47</td>
<td>7.5</td>
<td>220</td>
<td>5646</td>
<td>17.94</td>
</tr>
</tbody>
</table>

Note: Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.

2.3.6. Remark:-

From the hypothetical problem stated above, clearly indicates that the contract quantity increases with increase in demand considering lower total inventory cost. It also seen that even if setup cost varies there is hardly any change in optimal turnover Q_{opt} and I(Q_{opt}). This indicates efficient handling of inventory by the firm.

2.3.7. Case-I: D=\alpha + \beta Q, C₃=C₃+bQ

The Inventory Turnover ratio is defined as

\[ I(Q) = \frac{DP}{C(Q)} \]

\[ \text{where } C(Q) = \frac{QC_1}{2} + \frac{D}{Q} (C_3 + bQ) \]

Let us take demand as D=\alpha + \beta Q. Where \alpha & \beta are Constants.

Equation (2.21) is rewritten as

\[ I(Q) = P(\alpha + \beta Q) \left[ \frac{QC_1}{2} + \frac{\alpha + \beta Q (C_3 + bQ)}{Q} \right] \]
\[ t_a = (\alpha P + \beta QP) \left[ \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right] \] 

The turnover ratio is maximum only if the second derivative
\[ \frac{\partial^2 I(Q)}{\partial Q^2} < 0. \]
This implies that,

\[
\left[ -1 \beta P \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \right] \\
\left[ \beta P \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \right] \\
-2(\alpha P + \beta QP) \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^3 \\
+ (\alpha P + \beta QP) \left( \frac{OC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \left( \frac{2\alpha C_3}{Q^3} \right) \\
= -2 \beta P \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \\
-2\alpha^2 PC_3 \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \\
-2\alpha^2 PC_3 \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q^2} + \alpha p + \beta C_3 + \beta bQ \right)^2 \\
+ 2(\alpha P + \beta QP) \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^3 \\
= - \left[ 2 \beta P \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) + 2\alpha^2 PC_3 \frac{QC_1}{Q^3} + 2\alpha^2 PC_3 \frac{QC_1}{Q^3} \right] \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^2 \\
-2(\alpha P + \beta QP) \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha p + \beta C_3 + \beta bQ \right)^3 \left. \right] < 0 \\
Which implies that,

\[ \frac{\partial I(Q)}{\partial Q} = 0 \]

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\[
\beta P \left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha b + \beta c_3 + \beta b Q \right)^{-1} - (\alpha P + \beta Q P)
\]
\[
\left( \frac{QC_1}{2} + \frac{\alpha C_3}{Q} + \alpha b + \beta c_3 + \beta b Q \right)^2 \left( \frac{C_1}{2} - \frac{\alpha C_3}{Q^2} + \beta b \right) = 0
\]
\[
: (2\beta^2 c_3 - \alpha c_1) Q^2 + 4\alpha \beta c_3 Q + 2\alpha^2 c_3 = 0 \quad \ldots \quad 2.23
\]

Now, \( Q = \frac{-b \pm \sqrt{\Delta}}{2a} \) where \( \Delta = b^2 - 4ac \)

\[
: \Delta = 16\beta^2 c_3^2 \alpha^2 - 4(2\beta^2 c_3 - \alpha c_1)2\alpha^2 c_3
\]
\[
= 16\alpha^2 \beta^2 c_3^2 - 16\alpha^2 \beta^2 c_3^2 + 8\alpha^2 c_1 c_3
\]
\[
= 8\alpha^2 c_1 c_3
\]
\[
: Q = \frac{-b \pm \sqrt{\Delta}}{2a}
\]

Therefore,
\[
Q_{opt} = \frac{-4\alpha \beta c_3 \pm \sqrt{8\alpha^2 c_1 c_3}}{2(2\beta^2 c_3 - \alpha c_1)} \quad \ldots \quad 2.24
\]
\[
C\left( Q_{opt} \right) = \frac{C_1}{2} Q_{opt} + \frac{D(C_3 + b Q_{opt})}{Q_{opt}}
\]
\[
I\left( Q_{opt} \right) = \frac{DP}{C(Q_{opt})}
\]

### 2.3.8. Hypothetical Problem:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) ((D=\alpha+\beta Q))</th>
<th>Holding Cost ((C_1)) (\text{Rs.})</th>
<th>Setup Cost ((C_3+bQ)) (b=0.01) (\text{Rs.})</th>
<th>(\alpha)</th>
<th>(\beta)</th>
<th>Purchase Cost per Unit ((P)) (\text{Rs.})</th>
<th>Optimal Turnover (Units) (Q_{opt})</th>
<th>Total Inventory Cost (C(Q_{opt})) (\text{Rs.})</th>
<th>Optimal Turnover Ratio (I(Q_{opt}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1493</td>
<td>20</td>
<td>62.59</td>
<td>200</td>
<td>5</td>
<td>5</td>
<td>259</td>
<td>2947</td>
<td>2.53</td>
</tr>
<tr>
<td>2</td>
<td>2544</td>
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<td>54.87</td>
<td>220</td>
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<td>6</td>
<td>387</td>
<td>4234</td>
<td>3.61</td>
</tr>
<tr>
<td>3</td>
<td>3018</td>
<td>20</td>
<td>45.47</td>
<td>240</td>
<td>7</td>
<td>7</td>
<td>397</td>
<td>4311</td>
<td>4.90</td>
</tr>
<tr>
<td>4</td>
<td>3621</td>
<td>20</td>
<td>39.20</td>
<td>260</td>
<td>8</td>
<td>8</td>
<td>420</td>
<td>4539</td>
<td>6.38</td>
</tr>
<tr>
<td>5</td>
<td>4093</td>
<td>20</td>
<td>34.24</td>
<td>280</td>
<td>9</td>
<td>9</td>
<td>424</td>
<td>4567</td>
<td>8.07</td>
</tr>
</tbody>
</table>

**Note:** Above hypothetical problem is solved by C++ Program mentioned in appendix 1. Necessary graphical representation is also mentioned in appendix 2.
2.3.9. Remark:-

Here, \( \alpha \) and \( \beta \) increases simultaneously with increasing demand. Also, the optimal turnover is also maintained which fulfils the objective of this ITOR Model. The Inventory turnover ratio also increases marginally with respect to demand.

2.3.10. Case-II: \( D = \beta Q^x \), \( C_3 = C_3 + \beta Q \)

The Inventory Turnover Ratio is given by

\[
\tau(Q) = \frac{DP}{C(Q)} \quad \ldots \quad 2.25
\]

where \( C(Q) = \frac{QC_1}{2} + \frac{D}{Q}(C_3 + bQ) \)

Let us take demand as \( D = \beta Q^x \) where \( x \) is the unit variable; \( 0 < x < 1 \), \( \beta \) is a constant and \( Q \) is a Contract Quantity.

Now Equation 2.25 can be written as

\[
\tau(Q) = \beta \left( Q^x \right)^{\frac{OC_1}{2} + \frac{\beta C_3}{Q} + bQ} \quad \ldots \quad 2.26
\]

Differentiate equation (2.26) with respect to \( Q \) and equate it to zero, we have

\[
\frac{\partial \tau(Q)}{\partial Q} = \beta \left( \frac{OC_1}{2} + \beta C_3 Q^{x-1} + bQ \right)^{-1} \left( \frac{OC_1}{2} + \beta C_3 Q^{x-1} + bQ \right)^{-2}
\]

\[
\left( \frac{C_1}{2} + (x-1)\beta C_3 Q^{x-2} + x\beta bQ^{x-1} \right) = 0 \quad \ldots \quad 2.27
\]

\[
\therefore -\frac{C_1 Q}{2} (1-x) + \frac{\beta C_3 Q^x}{Q} = 0
\]
Which implies that

\[ Q_{\text{opt}} = \left[ \frac{(1-x)C_1Q^{x-1}}{2\beta C_3^{x-2}} \right]^{1/x} \]  

..... 2.28

\[ C(Q_{\text{opt}}) = \frac{C_1}{2} Q_{\text{opt}} + \frac{D(C_3 + bQ_{\text{opt}})}{Q_{\text{opt}}} \]

\[ I(Q_{\text{opt}}) = \frac{DP}{C(Q_{\text{opt}})} \]

The turnover ratio is maximum, subject to the second derivative

\[ \frac{\partial^2 I(Q)}{\partial Q^2} < 0 : \]

\[ \frac{\partial^2 I(Q)}{\partial Q^2} = \frac{x^2 \beta PC_1 Q^{x-1}}{2} - \frac{xbPC_1 Q^{x-1}}{2} + 2(x-2)\beta^2 PC_3 Q^{2x-2} \left[ \left( \frac{QC_1}{2} + \beta C_3 Q^{x-1} + \beta b Q^x \right)^3 \right] \]

\[ \frac{\partial^2 I(Q)}{\partial Q^2} < 0 \]

2.3.11. Hypothetical Problem:-

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) (D=\beta Q^x)</th>
<th>Holding Cost (C_1) Rs.</th>
<th>Setup Cost (C_1+bQ) b=0.01 Rs.</th>
<th>Cost ant (\beta)</th>
<th>Purchase Cost per Unit (P) Rs.</th>
<th>Variable (x)</th>
<th>Optimal Turnover (Units) Q_{\text{opt}}</th>
<th>Total Inventory Cost C(Q_{\text{opt}}) Rs.</th>
<th>Optimal Turnover Ratio I(Q_{\text{opt}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>65</td>
<td>15</td>
<td>5</td>
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<td>2</td>
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<td>52</td>
<td>30</td>
<td>6</td>
<td>0.8</td>
<td>249</td>
<td>3010.60</td>
<td>4.94</td>
</tr>
<tr>
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<td>50</td>
<td>7</td>
<td>0.7</td>
<td>149</td>
<td>1949.35</td>
<td>5.95</td>
</tr>
</tbody>
</table>

Note: Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.
2.3.12. Remark:-

Here, the optimal turnover mainly dependent on β and x. the Constant β increases while the variable x decreases which indicates the lower turnover with decreasing demand. This shows that the demand of the customers is fulfilled and the firm is handling by a good financial manager.

2.3.13. Case III: D=β1Q - β2Q^2, C3=C3+bQ

The Inventory Turnover Ratio is given by

\[ I(Q) = \frac{DP}{C(Q)} \]  \[ \cdots 2.29 \]

where

\[ C(Q) = \frac{QC_1}{2} + \frac{D}{Q}(C_3 + bQ) \]

Let us take demand as D=β1Q - β2Q^2 Where β1 and β2 are Constants, Q is a contract quantity.

Now equation 2.29 can be written as:

\[ I(Q) = \beta_1 Q P - \beta_2 Q^2 P \left[ \frac{QC_1}{2} + \beta_1 C_3 + \beta_2 bQ - \beta_2 QC_3 - \beta_2 bQ^2 \right] \]  \[ \cdots 2.30 \]

Differentiate equation (2.30) with respect to Q and equate it to zero, we have,

\[ \frac{dI(Q)}{dQ} = (\beta_1 P - 2\beta_2 Q P) \left[ \frac{QC_1}{2} + \beta_1 C_3 + \beta_2 bQ - \beta_2 QC_3 - \beta_2 bQ^2 \right]^{-1} \]

\[ - (\beta_1 Q P - \beta_2 Q^2 P) \left[ \frac{QC_1}{2} + \beta_1 C_3 + \beta_2 bQ - \beta_2 QC_3 - \beta_2 bQ^2 \right]^{-2} \]

\[ \left[ \frac{C_1}{2} + \beta_1 b - \beta_2 C_3 - 2\beta_2 bQ \right] = 0 \]

This implies that,

\[ (2\beta_2^2 C_3 - \beta_2 C_1)Q^2 - 4\beta_1 \beta_2 C_3 Q + 2\beta_1^2 C_3 = 0 \]  \[ \cdots 2.31 \]
\[ Q_{opt} = -\frac{b \pm \sqrt{\Delta}}{2a} \]

\[ Q_{opt} = \frac{4\beta_1\beta_2C_3 \pm \sqrt{8\beta_1^2\beta_2C_1C_3}}{4\beta_2^2C_3 - 2\beta_2C_1} \]

\[ C\left( Q_{opt} \right) = \frac{C_1}{2} Q_{opt} + \frac{D(C_3 + bQ_{opt})}{Q_{opt}} \]

\[ I\left( Q_{opt} \right) = \frac{DP}{C(Q_{opt})} \]

The turnover ratio is maximum subject to \( \frac{\partial^2 I(Q)}{\partial Q^2} < 0 \)

Therefore,

\[ \frac{\partial^2 I(Q)}{\partial Q^2} = \left( -\beta_2QC_1P - 2\beta_1\beta_2PC_3 \right) \left( \frac{QC_1}{2} + \beta_1C_2 + \beta_1bQ - \beta_2QC_3 - \beta_2bQ^2 \right)^3 \]

\[ + 2\left( \frac{C_1}{2} - \beta_2C_3 + \beta_1b - 2\beta_2bQ \right) \left( \beta_1^2PC_3 - \frac{\beta_2PQ^2C_1}{2} - 2\beta_1\beta_2QPC_3 \right) \]

\[ \left[ \frac{QC_1}{2} + \beta_1C_3 + \beta_1bQ - \beta_2QC_3 - \beta_2bQ^2 \right]^3 \]

\[ < 0 \]

### 2.3.14. Hypothetical Problem:

<table>
<thead>
<tr>
<th>Item</th>
<th>Demand (Units) ( (D=\beta_1Q - \beta_2Q^2) )</th>
<th>Holding Cost ( (C_1) ) Rs</th>
<th>Setup Cost ( (C_3+bQ) ) b=0.01 Rs</th>
<th>Purchase Cost per Unit ( (P) ) Rs.</th>
<th>Cons ( \text{tant} \ (\beta_1) )</th>
<th>Cons ( \text{tant} \ (\beta_2) )</th>
<th>Optimal Turnover (Units) ( Q_{opt} )</th>
<th>Total Inventory Cost ( C(Q_{opt}) ) Rs</th>
<th>Optimal Turnover Ratio ( I(Q_{opt}) )</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3735</td>
<td>15.59</td>
</tr>
</tbody>
</table>

**Note:** Above hypothetical problem is solved by C++ Program mentioned in appendix 2. Necessary graphical representation is also mentioned in appendix 1.
2.3.15. Remark:-

Here, the optimal turnover mainly depends on $\beta_1$ and $\beta_2$. $\beta_1$ and $\beta_2$ are inverse in relation. i.e. if $\beta_1$ increases then $\beta_2$ decreases. This shows the high turnovers with increases in demand. Moreover the risk of stock out is minimized with lower setup cost.

2.4. Conclusion:-

Financial Analysis reveals that the turnover plays a very important role in the overall performance of a firm. A low or high turnover is an indication of poor or good management. A low turnover implies too much of inventory being held as obsolete and a high turnover imply incurring shortages, there by losing the good will of the customers. Thus, usually a balance is struck between these two turnovers.

In this chapter, the problem of turnovers has been considered under the ITOR Schedule where in the units are supplied according to the demand, there by eliminating the waste. Using this analogy the ideal situation of ITOR production and supply is undertaken. In the various model studied in this chapter, it is unanimously proved that a high turnover is very beneficial to the firm under the ITOR schedule because shortages are not permitted. Thus, an overall review of the different models formulated reveal that high turnover is an indication of good management leading to the better performance of the firm. Moreover the risk of large stock outs is minimized. Also, with the change in the setup cost there is no large difference in the situation stated above.