CHAPTER 8

PERFORMANCE MEASUREMENT USING OPTIMAL BASE STOCK LEVEL INVENTORY SYSTEM

8.1 INTRODUCTION

The main objective of this study is to measure the performances after implementation of innovative inventory management system in a stochastic environment and it is carried out in a casting company which currently implementing the Six Sigma concept towards achieving the product quality, on-time delivery and customer satisfaction at the least cost. Maintaining optimal inventory and forecasting future demand are not easy for the decision maker of any enterprise. However, it is possible to strike a balance between the ideal zero inventory and the real-world avoidance of stock out costs through a minimum inventory system called base stock system. The study has examined the performance indicators in order to assess the effectiveness and efficiency of the implementation of the Six Sigma system. This work proposes a generalized approach for determining the optimal base stock level to forecast stochastic demand and improve the on-time delivery and in turn, improve the efficiency of the process.

Chakravorty (2009) has explained a model of measurement that provides a way to improve customer satisfaction (of the business as a whole, a unit, a process, etc.) which includes job satisfaction, Six Sigma, and optimal inventory system provides data to help one to gauge results and identify areas for improvement such as inventory levels, profits and losses, cost of goods or services sold, return on investment, cycle time (an important indicator of
process speed, which is often a key competitive factor), percent of final products or services with defects or the number of defects per product or service, hours required to produce a certain number of outputs or provide a service, customer satisfaction (extent to which products or services meet customer expectations), yield (amount of acceptable goods or services relative to the total number produced or delivered) and cost of poor quality. Ramanarayan et al (1988) have developed a formula for calculating base stock level and this approach is to maintain the stock more economically and at the same time, it should be able to meet the demand. Sometimes, the demand may be more and the stock may not be able to meet demand, then the company will lose the profit and also the good will. In solving most of the real life problems, techniques of applied mathematics play a vital role. If the solution does not offer the sufficient amount of accuracy, then it is reformulated and solved. This iterative process is repeated until the exact solution is found.

The different costs, which are involved in the parameters like demand and supply, are inventory holding cost \((h)\), which is the cost, arising out of storage, rentals, interest on idle capital etc., shortage cost \((d)\), which is due to the unsatisfied demand. Given a particular situation, a number of alternative solutions may be obtained for the inventory problem. The one which minimizes the overall cost is preferred and it is called the optimal policy (base stock system). Therefore, the system effectiveness and the relative efficiency of different policies are measured only by cost. Every company has to store its finished goods until they are sold. It is a buffer between supply and demand. The storage function helps to smooth discrepancies between desired quantities and timing to the market. Whenever inventories are to be maintained, inventory control has to be applied to fulfill the objectives of acceptable quality of customer service, purpose of meeting the demands, optimum investment in inventories. A study of Six Sigma model (Ramanarayan et al 1988) has shown that the process of developing several systems for handling inventory trade–off under varying situations.
Mackelprang and Nair (2010) found that the outcomes and the greatest impact on individual performance outcomes and emphasize the role of process factors in the relationship between JIT practices and performance. The JIT ordering systems combines elements of both fixed order quantity and fixed order period system. JIT seeks minimum inventory by waiting until the actual demand for inventory is known. Where the inventory environment permits actual demand to be known ahead of time (such as for contracted component or product), the JIT system can permit a fixed order quantity for a fixed time period (Usually a day). In other words, the JIT ordering system can be structured to recognize and allow for compromise between the ideal zero inventory goal and the real world avoidance of stock out costs by introducing a new ordering mechanism, sell-one / buy-one system: i.e. base stock system.

8.2 BASE STOCK LEVEL

Ramanarayan et al (1988) have evolved the base stock system, known as sell-one / buy-one system, given in Table 8.1.

**Table 8.1 Simple Base Stock System**

<table>
<thead>
<tr>
<th>Time (weeks)</th>
<th>On hand (end of week)</th>
<th>Sell</th>
<th>Order</th>
<th>Order Receipt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1.</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. 2.</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. 2.</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. 3.</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5. 2.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6. 1.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7. 2.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8. 3.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Base stock system is also characterized as an (S,s) order up to policy and it is a new type of ordering mechanism. Base stock system has lower inventory levels but the number of orders issued is higher and this
system is used where orders are infrequent and items are expensive. The base stock level is the lowest inventory position needed to maintain a given service level. Base stock system is defined as the sum of inventory on hand and on order is constant in time. The inventory position is always equal to reorder point. The inventory process begins with an initial inventory of ‘B’ units. Whenever a customer’s order for ‘X’ unit is received an inventory replenishment order for ‘X’ unit is placed immediately. Replenishment orders are filled after the (deterministic) lead-time ‘L’. The customer order is filled, as far as possible, from the supply on hand. Should the total customer demand exceed the supply on hand (negative inventory level), then assume that customers will not cancel any order but they wait for the arrival of sufficient stock. The optimal base stock is essential to meet the demand without fail and at the same time, it reduces the various costs. It follows from our assumption that sum of inventory on the ground and on order is constant in time and equal to ‘B’, the base stock. At a given time, let ‘X’ be the amount, which is demanded during the immediately proceeding time span of length ‘L’. Then ‘X’ units are on order at a particular time. Consequently, the amount of inventory on the ground is (B – X). It we let f(x) be the probability density of demand during a time span ‘L’, the expected cost per unit time of holding and shortages attributable to the inventory on the ground is given in Equation (8.1)

\[ E(c) = h \int_0^B (B - x) f(x) \, dx + d \int_{B}^{\infty} (x - B) f(x) \, dx \]  

(8.1)

where \( h \) and \( d \) are unit costs per unit time of holding and storage respectively.

It follows that the optimal base stock is given by \( F(B) = d/h+d \). The demand is an uncontrollable variable and the decision variable is \( B \). The solution approach is economic marginal analysis where holding and shortage cost are balanced. (holding cost-sufficiently large). The optimal base stock \( B \) is found by optimizing expected cost in the stochastic environment is given in
Equation (8.2). Goodness of fit test is also conducted to evaluate the suitability of potential input model distributions (Banks et al 1996, Thangaraj and Ramanarayanan 1983).

\[
\text{Base Stock System (B) } = \frac{\beta(1 + \mu a)^2}{\mu a \delta (\alpha + \beta)}
\]

(8.2)

Where, \( \beta \)-Shortage cost, \( \alpha \)-Holding cost, \( \mu \)-Lead time parameter follows exponential distribution (with respect to demand), \( a \)- Inter arrival of demands follows exponential distribution (with respect to lead time), \( \delta \)- Cumulative distributions of inter arrival time of demands (exponential) follows gamma distribution.

The Six Sigma improvement group analyzed the current inventory performance and the result showed that the on-time delivery of the flywheel product against demand is not satisfactory. The team has examined the delivery reports against demand and has endeavored to ascertain the inventory tool for the Six Sigma program. After discussing the problem with the production engineers and management in the company, improvement group proposed the following steps.

Step 1. Calculation of parameters

Step 2. Checked the selected exponential and gamma distribution

Step 3. Calculate the optimal base stock level.

Step 4. Calculate the optimal base stock level by extending the proposed inventory system

Step 5. Calculation of future demand by using exponential smoothing technique.

Step 6. Cross check the optimal value obtained.
Step 7. Justifying JIT system with base stock system.

This work proposes a generalized approach for determining the optimal base stock level to forecast stochastic demand and improve the on-time delivery and in turn, improve the efficiency of the Six Sigma process. Based on the literatures, the researchers propose a system to optimize the inventory which minimizes the holding and shortage cost during inter arrival time of demands and when lead times are stochastic in nature for a single item, to improve the customer satisfaction by adding value to the Six Sigma in the company process.

The demand (1 unit) and lead-time (every 2 weeks) is deterministic in the base stock system given in Table 8.1. Problem is considered under stochastic conditions and it consists of three random variables. 1. The number of units demanded per time period 2. Time between demands 3. The lead-time.

The following assumptions are made:

- Lead time and inter arrival time of demands are probabilistic in nature.
- Lead time with respect to demand follows exponential distribution
- Inter arrival of demands follows exponential distribution
- Cumulative distribution of inter arrival time of demands (exponential) follows gamma distribution

The above assumptions are viewed as reasonable within the context. The lead time and demand process would be for single product and the assumption of an exponential process with respect to time is most natural.
The problem in the stochastic case is that the system does not know exactly what the lead-time demand will be. It could carry the expected lead-time demand, but if we face very high backorder costs or very high holding costs then it will be to our advantage to order more or less so that we increase or decrease our probability of over ordering or under ordering to avoid the larger cost. The base stock level that optimally balances these costs can be obtained using the cumulative distribution function of the lead time demand distribution (exponential). This is acceptable given environment to determine the inventory requirements for the system and to show how these requirements depend on system model design and operating parameters. It is this work environment that is taken for analyzing and Six Sigma program is tried by the research team to improve the process. When tangible results are achieved in the casting process after implementation of Six Sigma, the researchers decided to determine the optimal base stock level to ensure on-time delivery to increase the effectiveness of the implemented Six Sigma strategy to improve the customer satisfaction. The main purpose of this work is to study the performance efficiency of a factory where Six Sigma is being implemented towards achieving better performances. The conventional Just-in-case (JIC) technique is the norm earlier. The research has concentrated on an inventory system of the company to improve the performance through determining optimal inventory system and thereby improve the on-time delivery of the products. Measurement is the process of quantifications of the outcomes. From the point of customer focus, organizations achieve their goals if they could satisfy their customers with greater efficiency and effectiveness than their competitors. Effectiveness refers to the extent to which customer requirements are met, while efficiency is a measure of how economically the firm’s resources are utilized in providing the given level(s) of customer satisfaction. Hence the implementation of Six Sigma and its effectiveness satisfies the requirements of customers by determining the base stock system to meet on-time delivery. From the analysis of the casting processes within the company, the sand casting process is highlighted as the area requiring
greatest attention with scrap rates in excess of 10% and on-time delivery at only 55%. The definition stage triggered the development of a base stock system by Six Sigma team within the company. This involved the training of team members in the principles of base stock system as well as the implementation of a Six Sigma program aimed at improving the performance ‘on-time delivery’ and ‘right first time’ quality levels through chartering.

The Six Sigma improvement group analyzed the current inventory performance and the result showed that the on-time delivery of the flywheel product against demand is not satisfactory. The team has examined the delivery reports against demand and has endeavored to ascertain the inventory tool for the Six Sigma program. After discussing the problem with the production engineers and management in the company, proposed the following steps.

**Step 1. Calculation of parameters:**

Data are collected in the existing inventory level for four months and it is given in Table 8.2.

**Table 8.2 Order Arrival Date and Quantity**

<table>
<thead>
<tr>
<th>Order arrival date</th>
<th>Order dispatch</th>
<th>Demand in units</th>
<th>Lead-time in days</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.04.’10</td>
<td>06.05.10</td>
<td>10</td>
<td>08</td>
</tr>
<tr>
<td>07.05.’10</td>
<td>31.05.10</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>07.06.’10</td>
<td>28.06.10</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>05.06.’10</td>
<td>13.07.10</td>
<td>06</td>
<td>38</td>
</tr>
<tr>
<td>24.08.’10</td>
<td>30.08.10</td>
<td>16</td>
<td>06</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>54</td>
<td>97</td>
</tr>
</tbody>
</table>

The demand arrival is purely stochastic and 54 units of demand are actually satisfied by the company during the lead time of 97 days. Lead-time
parameter follows exponential distribution with respect to demand and it is 1.79 for the given period of time.

1. Lead-time parameter follows exponential distribution with respect to demand is given in Equation (8.3):

\[
\text{Exponential mean } \bar{X} = 1/\mu_t
\]

\[
= \frac{54}{97} = 0.56 = 97/54
\]

Suggested parameter \( \mu_t = 1.79 \)

2. Inter arrival time of demands follows exponential distribution:

The ratio of the total lead time to number of arrivals follows exponentially for the period of 97 days and this is taken for analyzing inter arrival time of demands to the company.

\[
\bar{X} = \frac{\text{Total lead time}}{\text{No. of Arrivals}} = \frac{97}{14} = 6.93
\]

Suggested parameter \( a = 1/\bar{X} = 0.144 \)

3. Inter arrival of demands follows exponential distribution

During the duration of four months, the actual demand arrived in terms of number of times and units are given in the Table 8.3. The demand arrived from 28.4.2010 to 30.8.2010 is 210. The number of inter arrival of demand is 100. It includes satisfied demands and unsatisfied demands. Based on the inter arrival time of demands, the company has to take steps to calculate the optimal inventory level to meet on-time delivery. The inter arrival time demand follows exponential with respect of individual time to one another and in some cases it falls on the same time period noted in the Table 8.3. The total five arrival dates are taken as reference for
representing individual inert arrival time during the five arrival date. Every order arrival can be calculated exponentially and it is given as $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5$.

4. Cumulative distribution of inter arrival time of demands (exponential) follows gamma distribution as given in Equation (8.4).

Gamma distribution:

$$\delta = \delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5$$  \hspace{1cm} (8.4)

$$= 0.2 + 0.36 + 0.53 + 0.58 + 0.43, \ \hat{\delta} = 2.191 \approx 2.2$$

**Step 2. Checked the selected exponential and gamma distribution:**

Kolmogorov-Smirnov goodness of fit test provides helpful guidance for evaluating the suitability of a potential input for exponential gamma distribution. This test is used to decide if a sample comes from a hypothesized continuous distribution. It is based on the Empirical Cumulative Distribution Function (ECDF). Assume that the random sample $x_1 \ldots x_n$ from continuous distribution, with Cumulative Distribution Function (CDF $F(x)$, for the specified significance level 0.01). The $D = \max (D^+, D^-)$, and the sample statistic value is less than of critical value and the hypothesis is accepted (detailed in Appendix 4).
Table 8.3 Inter arrival of demands and its calculation

<table>
<thead>
<tr>
<th>Order arrival No:</th>
<th>Order arrival date</th>
<th>Inter arrival time of demands</th>
<th>Demand in units</th>
<th>Suggested parameter $\delta$</th>
<th>Exponential mean X bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.</td>
<td>28.04.’10 to 02.05.’10.</td>
<td>04</td>
<td>13</td>
<td>$\delta_i = \frac{5}{25} = 0.2$</td>
<td>$\bar{X} = 5$</td>
</tr>
<tr>
<td>02.</td>
<td>05.05.’10</td>
<td>01</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>05</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03.</td>
<td>07.05.’10 to 15.05.’10</td>
<td>11</td>
<td>30</td>
<td>$\delta_2 = 0.454$</td>
<td>$\bar{X} = 2.22$</td>
</tr>
<tr>
<td>04.</td>
<td>20.05.’10</td>
<td>08</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05.</td>
<td>25.05.’10</td>
<td>05</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06.</td>
<td>31.05.’10</td>
<td>06</td>
<td>08</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07.</td>
<td>07.06.’10 to 20.06.’10</td>
<td>13</td>
<td>28*</td>
<td>$\delta_3 = 0.525$</td>
<td>$\bar{X} = 1.91$</td>
</tr>
<tr>
<td>08.</td>
<td>28.06.’10</td>
<td>08</td>
<td>12*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>21</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09.</td>
<td>05.06.10 to 18.06.’10</td>
<td>13</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>30.06.’10</td>
<td>12</td>
<td>18*</td>
<td>$\delta_4 = 0.584$</td>
<td>$\bar{X} = 1.70$</td>
</tr>
<tr>
<td>11.</td>
<td>29.06.10 to 06.07.’10</td>
<td>06</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>13.07.’10</td>
<td>07</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>38</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>24.08.’10 to 27.08.’10</td>
<td>03</td>
<td>07</td>
<td>$\delta_5 = 0.428$</td>
<td>$\bar{X} = 2.30$</td>
</tr>
<tr>
<td>14.</td>
<td>30.08.’10</td>
<td>03</td>
<td>07</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>06</td>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Over lapping of inter arrival of Demands during the lead time
**Step 3. calculate the optimal base stock level:**

Base Stock System (B) = \( \frac{\beta(1 + \mu a)^2}{\mu a \delta(\alpha + \beta)} \)

\( \alpha = Rs.600 \text{ per item, } \beta = Rs.500 \text{ per item, } \mu = 1.79, \ a = 0.144, \delta = 2.20 \)

Therefore, Base Stock System (B) = \( \frac{500(1 + 1.79 \times 0.144)^2}{1.79 \times 0.144 \times 2.2 \times (500 + 600)} \)

= **1.27** units / day.

**Step 4. calculate the optimal base stock level by extending the proposed inventory system:**

Second approximation is given in Equation (8.5)

\[
\frac{\beta(1 + \mu a)^2}{\mu a \delta(\alpha + \beta)} + \frac{1}{2} \left[ \frac{\beta^2(1 + \mu a)^3}{\mu a \delta(\alpha + \beta)^2} \right]
\]

(Equation 8.5)

\( B = 1.634 \) units / day.

Third approximation is given in Equation (8.6)

\[
\frac{\beta(1 + \mu a)^2}{\mu a \delta(\alpha + \beta)} + \frac{1}{2} \left[ \frac{\beta^2(1 + \mu a)^3}{\mu a \delta(\alpha + \beta)^2} \right] + \frac{1}{3} \left[ \frac{\beta^3(1 + \mu a)^4}{\mu a \delta(\alpha + \beta)^3} \right]
\]

(Equation 8.6)

\( B = 1.77 \) units /Day.

By extending the series…. the 4\textsuperscript{th} to 16\textsuperscript{th} approximations, results are given respectively.

\( B = 1.83, 1.86, 1.88, 1.978, 1.981, 1.983, 1.99, 1.991, 1.993, 1.995, 1.997, 1.999, 2.001 \) units /Day.
Step 5. Calculation of future demand by using exponential smoothing technique:

Exponential smoothing is a procedure for continually revising a forecast in the light of more recent experience. Exponential smoothing assigns exponentially decreasing weights as the observation gets older. In other words, recent observations are given relatively more weight in forecasting than the older observations. In this method, demand is forecasted by using old forecasting data is given Equation (8.7), (8.8), (8.9) and (8.10) respectively. The error equation for exponential smoothing is given in Table 8.4.

Table 8.4 Forecast and Error for Exponential Smoothing

<table>
<thead>
<tr>
<th>Month / Year 2010</th>
<th>Demand</th>
<th>Forecast</th>
<th>Error</th>
<th>α* Error</th>
<th>New forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>76.0</td>
<td>74.0</td>
<td>+2.0</td>
<td>+0.20</td>
<td>74.2</td>
</tr>
<tr>
<td>June</td>
<td>58.0</td>
<td>74.2</td>
<td>-16.2</td>
<td>-1.62</td>
<td>72.4</td>
</tr>
<tr>
<td>July</td>
<td>31.0</td>
<td>72.4</td>
<td>-41.4</td>
<td>-4.14</td>
<td>69.7</td>
</tr>
<tr>
<td>August</td>
<td>30.0</td>
<td>69.7</td>
<td>-39.7</td>
<td>-3.97</td>
<td>69.6</td>
</tr>
</tbody>
</table>

*Where α is exponential smoothing constant; (α = 0.1 to 0.5)

New forecast = Old forecast + α (Latest Observation – Old forecast)

Where α is exponential smoothing constant; (α = 0.1 to 0.5)

\[
F_0 = \text{Forecast for next period.}
\]

\[
F_1 = \text{Forecast for the previous period.}
\]

\[
D_1 = \text{Latest observation made,}
\]

\[
F_0 = F_1 + \alpha (D_1 - F_1).
\]

Let the old forecast is 74 units (known value) and the smoothing constant α = 0.1
(i) \[ F_0 = F_i + \alpha \left( D_i - F_i \right) \quad 74 + 0.1(76 - 74) = 74.20 \quad (8.7) \]

(ii) \[ F_0 = F_i + \alpha \left( D_i - F_i \right) \quad 74 + 0.1(58 - 74) = 72.4 \quad (8.8) \]

(iii) \[ F_0 = F_i + \alpha \left( D_i - F_i \right) \quad 74 + 0.1(31 - 74) = 69.70 \quad (8.9) \]

(iv) \[ F_0 = F_i + \alpha \left( D_i - F_i \right) \quad 74 + 0.1(30 - 74) = 69.6 \quad (8.10) \]

Demands per day:

\[
\begin{align*}
\text{Total demand} & = 74.2 + 72.4 + 69.7 + 69.6 = 285.90 \\
\text{Demand per day} & = \frac{285.90}{4*30} = 2.3 \text{ units / day.}
\end{align*}
\]

When \( \alpha = 0.1 \) the demand is 2.3 units / day

When \( \alpha = 0.5 \) the demand is 2.045 units / day

**Step 6. Cross check the optimal value obtained:**

Inventory for a day is given in Equation (8.11):

\[
\text{(Total demand – Overlapping of inter arrival of Demands during the lead time)}^* \\
\text{Total Lead-time}
\]

\[
\begin{align*}
(54+25+66+40+65+14) - (28+18+12)^* \\
97 \\
= 2.1 \text{ units / day}
\end{align*}
\]

**Step 7. Justifying JIT system with Base Stock System:**

JIT manufacturing has the capacity, when properly adapted to the organization, to strengthen the organization’s competitiveness in the marketplace substantially by reducing wastes and improving product quality and efficiency of production. The Six Sigma improvement group discusses
the JIT environment with the following points to justify the base stock system in real world application for the inventory problems.

1. In the JIT, the schedule must be stabilized and leveled. This requires constant daily production, within the time frame of the market schedule.

2. Reducing lot sizes, set up times, and leads times is the key to decreasing inventories in a JIT System.

3. Vendor relationship must be established to make JIT work. Frequent delivering and reliable quality is required.

4. JIT system is best suited to repetitive manufacturing (identical components).

5. Implementation of JIT system requires a progression of algorithm. Top management must provide leadership and support the final market schedule, followed by leveling of fabrication process and vendor schedules.

6. Lot size and lead-time must be reduced on all stages of production. Shortage and holding cost are balanced or eliminated.

7. Intensive educating of workers and management at all levels is needed for both the systems.

8.3 PERFORMANCE MEASUREMENT

Performance measures are defined as a tool for assessing how well the activities within a process or the process outputs achieve a specified goal. The manufacturing performance assessment and analysis, introduced and (Antony and Banuelas 2002) has covered the areas of quality, delivery reliability, cost and delivery lead time. Shah and Ward (2003) have found a
project survey is carried out to identify which performance indicators companies’ use and which ones they characterize as important. Global competition demands that manufacturing organizations improve quality, reduce delivery time, and minimize costs. In response to this, many manufacturing organizations have implemented different excellence programs to improve their performance. Lean manufacturing techniques, performance measurement, and Six Sigma, are included in many of those excellence programs (Ahmad et al 2005).

In this work, implemented base stock system is evaluated and the effectiveness of the Six Sigma is measured by using this performance measurement technique. The company evaluated the manufacturing performance evaluation integrating “quality”, “cost”, and “delivery”. The manufacturing performance ($Y$) is measured by Equation (8.12):

$$Y = WqQ + WcC + WdD$$  \hspace{1cm} (8.12)

Where

$Q$: score of quality = \frac{Good \ production}{Good \ production + \ Failed \ QC(quality \ control)}

$Wq$: weight of quality

$C$: score of cost = \frac{(actual \ cost - target \ cost)}{target \ cost} - 0.60

$Wc$: weight of price

$D$: score of delivery = 1 - \frac{\text{Number of delayed lots}}{\text{Number of delivered lots}}

$Wd$: weight of delivery

$Wq + Wc + Wd = 100$
From the rating system defined by the company, the three factors are usually considered when the manufacturer adopts the formula of grading the manufacturing performance.

a. Quality ($Q$)-quality of product
b. Cost ($C$)-price of product
c. Delivery ($D$)-delivery time of product

The weight of each factor can be adjusted while grading the calculations that depend on the needs of manufacturers. Some specific manufacturers just consider quality, while others take quality and cost into consideration. Some of them consider all three—quality, service, and delivery. The following examples of equations are provided for the calculation of manufacturing performance:

Score of manufacturing performance

\[
= 40Q + 35C + 25D = or \quad 40Q + 40C + 20D
\]

In practice, these manufacturing performance measurement systems are unable to quantify the customer orientation and objective orientation requirement levels in the past decade. These measurement systems cannot highlight the quality or business concerns in a just-in-time manner that will promote the effectiveness of improvements. Four main satisfaction indicators in manufacturing established in this study are based and adjusted partially (Ahmad and Dhafr 2002) has shown that the definition of “establishing and improving manufacturing performance measures”: by considering real problems of the customers - $Cc$ (customer complaint), $Od$ (on-time delivery), $Ee$ (equipment effectiveness). $Ee$ will be divided by two sub-indicators, quality rate and availability, and $Cq$ (cost of quality). These performance indicators are selected because they indicate important manufacturing performance areas and they are usually critically linked with Six Sigma
business strategy, inventory system and technological basis to measure or estimate.

**Cc - customer complaint:** Customer complaint is defined as a quality or reliability and delivery issue occurring at the external customer end and confirmed as being caused by manufacturing side. It is determined by the number and nature of customer’s complaint to identify operational improvement projects. Written, verbal, and anecdotal information is recorded. After the determination of base stock level it is reduced from 13.73% to 4.68. Normally the number of customer complaints received and expressed as an absolute number or as a percentage of the dispatches. These complaints are related not only to dispatches and could arise from any business area.

**Od - on-time delivery:** This measures the ability to adhere to the first agreed demand date for each order, and whether any problems occurred with the inventory and production. The commonly used due date performance measures are unit penalty, mean tardiness, and maximum and minimum tardiness is given by Equation (8.13).

\[ L_j = c_j - d_j \]  \hspace{1cm} (8.13)

\( d_j \) as the due date and \( c_j \) as the completion time of job \( j \). Lateness \( (L_j) \) can be positive (indicating a late job) or negative (indicating an early job). Therefore if earliness is important, then the mean absolute lateness or mean squared lateness \( (T_j) \) is considered as Equation (8.14).

\[ T_j = \max(0, L_j) \]  \hspace{1cm} (8.14)

On-time delivery parameter lateness is declined from 74% to 30%.

**Ee - Equipment Effectiveness:** \( Ee \) works on the principle that the best manufacturing performance is possible only when a site operates to full
capacity, always produces perfect product, and never breaks down. Capacity usage, quality performance and breakdown data will be recorded to determine the $Ee$. The manufacturing manager at the site is responsible for providing the information required on a timely basis. Chen and Cheng (2007) have explained a model which explains the targeted performances indicators as;

\[ E_{equipment\ effectiveness} = Quality\ rate \times Availability \]

It is suggested that an $Ee$ of 99.5% on the critical equipment will be the future target. This can be achieved by the Quality Rate $>99.9\%$ and availability $>99.6\%$. To achieve this goal, it is necessary to achieve a very high first-time-right rate (Chen and Cheng 2007).

**Quality Rate**: This is the amount of product that is right the first time without adjustment, recycles and so on. This is achieved by the Six Sigma concepts. It is improved from 86% to 95% at the expected level is given in Equation (8.15)

\[ \text{Quality rate} = \frac{\text{Good production}}{\text{Good production} + \text{Failed QC}} \quad (8.15) \]

**Availability**: The availability is defined as the number of hours the plant operates divided by the number of hours in a month, as given in Equation (8.16). It is increased from 73% to 83%.

\[ \text{Availability} = \frac{550 - (\text{number of hours of total shutdown})}{550} \quad (8.16) \]

Our study establishes a new model through integrating three indicators: $Cc$, $Od$, and $Ee$ with appropriate weights $rI$, $r2$, and $r3$, respectively.
respectively. If a manufacturing project is not suitable for any one of the given parameters, then the performance measure can be changed accordingly and the parameter weights can be given as Equation (8.17):

\[
\begin{align*}
 r1 + r2 + r3 &= 1 \\
\end{align*}
\]  

(8.17)

Comparison of flywheel casting performance measurements using the formula \(40Q+40C+20D\) basis of \(r1+r2+r3=1\) The proposed manufacturing performance measurement model, with customer satisfaction level, for the base stock system, with Six Sigma, attained the results in a positive direction and the Six Sigma process has a continuous improvement. The process stays in control after the solution has been implemented and to quickly deduct the out of control state and determine the associated special causes so that action can be taken to correct the problem before non-conformities are produced.

8.4 SUMMARY

- In this chapter, the performance after implementation of innovative inventory management system in a stochastic environment is measured using base stock system.

- The implemented base stock system is evaluated and the effectiveness of the Six Sigma is measured by using this performance measurement technique quality, cost, delivery and performance indicators. The detailed result analysis given in the chapter 10.