CHAPTER 6
IMPLEMENTATION AND RESULT OF ROBUST FRAMEWORK

Based on the scope and limitation of previous work, this research work has been framed and demonstrated in industries. It can be applied to any kind of shutdown industries, partial success industries and loosed industries. This robust framework has been demonstrated with textile fabric processing industries at Erode district.

6.1 DESIGN OF ROBUST FRAMEWORK FOR PRODUCTIVITY IMPROVEMENT

Figure 6.1 shows the traditional and fuzzy RPN. The computational steps of fuzzy RPN are carryout in the first stage of robust framework. Figure 6.2 illustrates the design of robust framework for productivity improvement. It consists of three stages. They are instrument analysis, fuzzy FMEA and productivity cycle.

6.1.1 Stages of robust framework

The following stages are briefly explained for productivity enhancement. This also could apply for quality improvement. But the research work focuses only for improving productivity. The stages of framework discussed below.
Stage - I Data collection and validation of research instrument analysis:

This stage refers the first part of robust framework in Figure 6.2.

- Data collection starts from existing dying and calendering industry. The surveys from the respondents are generally productivity and quality measures because 95% of literatures review were mentioned both parameter productivity and quality.

- After the deep analysis of productivity study, the respondents are identified and collected the data with regard to design of instrument namely PQDs. This survey, data collection and validation of research instruments were briefly discussed and finished in the fourth chapter.

- All the instruments were strongly reliable and validated using confirmatory factor analysis. These procedures were discussed before analysis of the traditional FMEA because of validation necessity of validation of PQDs.

Figure 6.1 Traditional and Fuzzy RPN model
Figure 6.2 A robust framework for improvement of productivity and quality
Stage - II  FMEA and Fuzzy FMEA analysis

This stage refers the second part of robust framework in Figure 6.1.

- If the confirmatory factor analyses are not satisfied, the identified parameter of PQ dimensions is subjected to be discussed with experts and again redesign the parameter.

- If the test is satisfied, the total and partial productivity in declining industry are to be measured without implementing the productivity improvement tools. If the profit index of industry is satisfied, productivity cycle may be incorporated. Otherwise, it proceeds the traditional FMEA and Fuzzy FMEA in order to identify highly risky dimensions if profit is not satisfied.

- In order to overcome drawbacks of FMEA, the fuzzy FMEA is applied and precisely prioritized the risk dimensions by using Fuzzy Weighted Geometric Mean Method (FWGM) and alpha set levels. It is presented in forthcoming sections.

Stage - III  Implementation of Productivity Cycle (PC)

This stage refers the third part of robust framework in Figure 6.1.

- Based on the fuzzy FWGMM, the risky dimensions are prioritized and solved by applying improvement or rectification tools in order to improve objective of research instrument.

- The Figure 6.1 shows the productivity cycle schematically. At any given time, an organization that is in the midst or declining stage of on-going “productivity program” may be involved in one of the four stages or phase: Productivity Measurement (M),
Evaluation (E), Planning (P), and Improvement (I). Generally, PC is termed as MERI.

- Once the productivity levels are measured, it is subjected to be evaluated or compared against planned values. Based on this evaluation, target levels of productivity are planned on the basis of short or long term bases.

- In order to achieve the planned targets, productivity improvement tools play a very significant role. In order to assess the degree to which the improvement will take place next period, productivity levels must be measured again. This cycle thus continues for as long as the productivity program operates in the organization.

- The productivity cycle concept shows that productivity improvement must be preceded by measurement, evaluation, and planning. Also, this cycle emphasizes the “process” nature of the productivity issue. A productivity program is not a one-time project, but rather a continuous, on-going process.

### 6.2 HIDDEN RISK IMPLICATIONS OF TRADITIONAL FMEA

- Different combinations of Occurrence (O), Severity(S) and Detection (D) produced exactly the same value of RPN in traditional FMEA process. But here, hidden risk implications are totally different.

- The S, O and D values of Management Principle (MP) dimension is 7, 6 and 6. The other two different dimensions such as LPP and BM are 6, 7, 6 and 6, 7, 6 for O, S and D respectively. Hence, the RPN values of all dimensions are 252. Table 6.1 shows the practical implications of traditional FMEA.
Other failure modes were mentioned in previous chapter of Table 5.4.

- However, the hidden risk implications of the three events may not be the same. This will lead a waste of time, cost, resources, further expansion and future planning of industry. Otherwise, some cases high risky events of dimensions are unable to be noticed.

- Ying-Ming Wang et al (2008) mentioned about the relative importance among O, S and D. The dimensions of three risk factors are assumed to be equally important. The three factors are difficult to be precisely estimated. Much information in FMEA can be expressed in a linguistic way such as likely, important or very high and so on. Fuzzy logic FMEA is used to overcome above the drawbacks. The Fuzzy Weighted Geometric Mean (FWGM) and its steps are used to solve these drawbacks.

Table 6.1 Practical implications of traditional FMEA

<table>
<thead>
<tr>
<th>FM</th>
<th>Productivity and Quality Dimensions (PQD)</th>
<th>S</th>
<th>O</th>
<th>D</th>
<th>RPN</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM 1</td>
<td>Management Principle (MP)</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>252</td>
<td>1</td>
</tr>
<tr>
<td>FM 6</td>
<td>Lack of Planning for Productivity (LPP)</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>252</td>
<td>1</td>
</tr>
<tr>
<td>FM 9</td>
<td>Benchmarking (BM)</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>252</td>
<td>1</td>
</tr>
</tbody>
</table>
6.3 FUZZY FMEA AND FUZZY WEIGHTED GEOMETRIC MEAN (FWGM)

Fuzzy sets represented by intervals, which are called \( \alpha \)-level sets. Let \( \tilde{A} \) be a fuzzy set on the universe of discourse \( X \). Then the \( \alpha \)-level sets of \( \tilde{A} \) are defined in the equation (6.1).

\[
A_{\alpha} = \{ x \in X \mid \mu_{\tilde{A}}(x) \geq \alpha \} = \min\{ x \in X \mid \mu_{\tilde{A}}(x) \geq \alpha \}, \max\{ x \in X \mid \mu_{\tilde{A}}(x) \geq \alpha \} \tag{6.1}
\]

Dubois et al (1980) and Zadeh (1965) deliberated Zadeh’s extension principle in the equation (6.2). The fuzzy set \( \tilde{A} \) expressed as

\[
\tilde{A} = U_{\alpha} A_{\alpha}, \quad 0 \leq \alpha \leq 1
\]

Fuzzy numbers are special cases of fuzzy sets. A fuzzy number is a convex fuzzy set characterized by a given interval of real numbers, each with a membership degree between 0 and 1. The membership functions of fuzzy numbers are piecewise continuous and satisfy the following conditions:

(a) \( \mu_{\tilde{A}}(x) = 0 \) for each \( x \in [a,d] \);

(b) \( \mu_{\tilde{A}}(x) \) is non-decreasing (monotonic increasing) on \( [a,b] \) and non-increasing (monotonic decreasing) on \( [c,d] \);

(c) \( \mu_{\tilde{A}}(x) = 1 \) for each \( x \in [b,c] \), where \( a \leq b \leq c \leq d \) are real members in the real line \( \mathbb{R} = (-\infty, +\infty) \).

The most commonly used fuzzy numbers are triangular and trapezoidal fuzzy numbers, whose membership functions are respectively defined in the equation (6.3 - 6.5).
\[
\mu_{\tilde{A}_1}(x) = \begin{cases} 
(x - a)/(b - a), & a \leq x \leq b, \\
(d - x)/(d - b), & b \leq x \leq d 
\end{cases} 
\] (6.3)

\[
\mu_{\tilde{A}_2}(x) = \begin{cases} 
(x - a)/(b - a), & a \leq x \leq b, \\
1, & b \leq x \leq c, \\
(d - x)/(d - c), & c \leq x \leq d, \\
0, & \text{otherwise.} 
\end{cases} 
\] (6.4)

\[
\bar{x}_0(\tilde{A}) = \frac{\int_{\tilde{A}} x \mu_{\tilde{A}}(x) \, dx}{\int_{\tilde{A}} \mu_{\tilde{A}}(x) \, dx} 
\] (6.5)

\(\tilde{A}\) is expressed by its \(\alpha\)-level sets. It represents in equation (6.6)

\[
(\tilde{A}) = U_\alpha \alpha_{\tilde{A}_0} = U_\alpha \left[ \left( x U_{q_i}(x) \right)^{L_i} \right]_{\alpha=0}^{\alpha=1} 
\] (6.6)

The following equations (6.7 - 6.10) are used for centroid of defuzzification.

\[
\int_{\tilde{A}} \mu_{\tilde{A}}(x) \, dx = \frac{1}{2} \left[ \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right] + \sum_{i=0}^{n-1} \alpha_i \left( \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right) 
\] (6.7)

\[
\int_{\tilde{A}} x \mu_{\tilde{A}}(x) \, dx = \frac{1}{6} \left[ \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right] + \sum_{i=0}^{n-1} \alpha_i \left( \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right) 
\] (6.8)

\[
\int_{\tilde{A}} \mu_{\tilde{A}}(x) \, dx = \frac{1}{2n} \left[ \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right] + 2 \sum_{i=0}^{n-1} \alpha_i \left( \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right) 
\] (6.9)

\[
\int_{\tilde{A}} x \mu_{\tilde{A}}(x) \, dx = \frac{1}{6n} \left[ \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right] + \sum_{i=0}^{n-1} \alpha_i \left( \left( x U_{q_i} \right)^{L_i} - \left( x U_{q_i} \right)^{L_i} \right) 
\] (6.10)

\[
\bar{y}_G = f_G(\bar{x}_1, \ldots, \bar{x}_n, \bar{w}_1, \ldots, \bar{w}_n) 
\]

\[
= \left( x_1 \right)^{\bar{w}_1} + \left( x_2 \right)^{\bar{w}_2} + \ldots + \left( x_n \right)^{\bar{w}_n} 
\]

\[
= \prod_{i=1}^{n} x_i^{\bar{w}_j} 
\] (6.11)
Fuzzy Weighted Average (FWA) was expressed and developed calculated in fuzzy numbers. Where $\tilde{x}_1, \ldots, \tilde{x}_n$ are the $n$ positive fuzzy numbers to be weighted and $\tilde{w}_1, \ldots, \tilde{w}_n$ are their fuzzy weights. Obviously, $\tilde{y}_G$ is also a fuzzy number and can be computed using $\alpha$- level sets and the extension principle. Let $(y_G)_\alpha = [(y_G)_\alpha^L, (y_G)_\alpha^U]$ be an-$\alpha$ level set of $\tilde{y}_G$. Then, it is determined by the following equations (6.12-6.16)

\[
(y_G)_\alpha^L = \text{Min} \prod_{i=1}^{n} (x_i)^{\frac{w_i}{\sum_{i=1}^{n} w_i}}; \text{s.t. } (w_i)_\alpha^L \leq w_i \leq (w_i)_\alpha^U, i = 1, \ldots, n, \quad (6.12)
\]

\[
(x_i)_\alpha^L \leq x_i \leq (x_i)_\alpha^U, i = 1, \ldots, n,
\]

\[
(y_G)_\alpha^U = \text{Max} \prod_{i=1}^{n} (x_i)^{\frac{w_i}{\sum_{i=1}^{n} w_i}}; \text{s.t. } (w_i)_\alpha^L \leq w_i \leq (w_i)_\alpha^U, i = 1, \ldots, n, \quad (6.13)
\]

\[
(x_i)_\alpha^L \leq x_i \leq (x_i)_\alpha^U, i = 1, \ldots, n.
\]

\[
f_G(x_1, \ldots, x_n; w_1, \ldots, w_n) = \prod_{i=1}^{n} (x_i)^{\frac{w_i}{\sum_{i=1}^{n} w_i}} \quad (6.14)
\]

\[
(y_G)_\alpha^L = \text{Min} \exp \left( \frac{\sum_{i=1}^{n} w_i \ln(x_i)_\alpha^L}{\sum_{i=1}^{n} w_i} \right); \text{s.t. } (w_i)_\alpha^L \leq w_i \leq (w_i)_\alpha^U, i = 1, \ldots, n, \quad (6.15)
\]

\[
(y_G)_\alpha^U = \text{Max} \exp \left( \frac{\sum_{i=1}^{n} w_i \ln(x_i)_\alpha^U}{\sum_{i=1}^{n} w_i} \right); \text{s.t. } (w_i)_\alpha^L \leq w_i \leq (w_i)_\alpha^U, i = 1, \ldots, n, \quad (6.16)
\]

These are linear programming (LP) models is solved using MS Excel Solver. Let $z_1^*$ and $z_2^*$ be the optimal objective function values of the above models (6.17-6.18) respectively.

\[
\text{Min } z_1 = \sum_{i=1}^{n} u_i \ln(x_i)_\alpha^L \quad (6.17)
\]
\begin{equation}
\text{s.t. } u_1+u_2+\ldots+u_n = 1; (w_i)^L_\alpha \cdot z \leq u_i \leq (w_i)^U_\alpha \cdot z, \ i=1,\ldots,n, \quad z \geq 0,
\end{equation}

\begin{equation}
\text{Min } z = \sum_{i=1}^n u_i \ln(x_i) (6.18)
\end{equation}

\begin{equation}
\text{s.t. } u_1+u_2+\ldots+u_n = 1; \quad (w_i)^L_\alpha \cdot z \leq u_i \leq (w_i)^U_\alpha \cdot z, \ i=1,\ldots,n, \quad z \geq 0,
\end{equation}

Then \((y_G)^L_\alpha = \exp (z_1^*)\) and \((y_G)^U_\alpha = \exp (z_2^*)\) by setting the different \(\alpha\) levels, different \(\alpha\) level sets of \(y_G^*\) expressed in the equation (6.19). There are \(n\) failure modes, \(FM_i \ (i=1, \ldots, n)\), evaluated and prioritized by a FMEA team consisting of \(m\) cross functional team members, \(TM_j \ (j=1, \ldots, m)\). The equation (6.20 and 6.21) represents it.

\begin{equation}
\bar{y}_G = U_i \alpha(y_G)_\alpha = U_i \alpha\left[(y_G)^L_\alpha, (y_G)^U_\alpha\right] \quad 0 < \alpha \leq 1. \quad (6.19)
\end{equation}

\begin{equation}
\bar{R}^D_{ij} = (R_{ijL}^D, R_{ijM}^D, R_{ijH}^D, R_{ijU}^D), \quad \bar{R}^S = (R_{ijL}^S, R_{ijM}^S, R_{ijU}^S) \\text{and}
\end{equation}

\begin{equation}
\bar{R}^D_i = (R_{ijL}^D, R_{ijM}^D, R_{ijU}^D) \quad (6.20)
\end{equation}

\begin{equation}
w_j^O = (w_{jL}^O, w_{jM}^O, w_{jU}^O), \quad w_j^S = (w_{jL}^S, w_{jM}^S, w_{jU}^S) \text{ and } w_j^D = (w_{jL}^D, w_{jM}^D, w_{jU}^D) \quad (6.21)
\end{equation}

Ying-Ming Wang et al (2008) introduced the fuzzy FMEA procedure and this case study has been followed in order to prioritize the research instruments. This case study identified 5 cross-functional team members. The relative weights of five members are 10\%, 20\%, 30\%, 15\% and 25\% respectively. The following phases are applied and prioritized for \(n\) failure modes. The phases and computational procedure are discussed in further section.

6.4 **FUZZY – FMEA COMPUTATIONS (FOR CASE STUDY VI)**

The following cases explain the computation procedures for case study VI.
Phase 1: The FMEA team members’ subjective opinions are aggregated and calculated using the equation (6.22-6.27).

\[
\tilde{R}_i^O = \sum_{j=1}^{m} h_j \tilde{R}_{ij}^O = (\sum_{j=1}^{m} h_j R_{ij}^{O_1}, \sum_{j=1}^{m} h_j R_{ij}^{O_2}, \sum_{j=1}^{m} h_j R_{ij}^{O_3}, \sum_{j=1}^{m} h_j R_{ij}^{O_4}), \quad i = 1, \ldots, n, \quad (6.22)
\]

\[
\tilde{R}_i^S = \sum_{j=1}^{m} h_j \tilde{R}_{ij}^S = (\sum_{j=1}^{m} h_j R_{ij}^{S_1}, \sum_{j=1}^{m} h_j R_{ij}^{S_2}, \sum_{j=1}^{m} h_j R_{ij}^{S_3}, \sum_{j=1}^{m} h_j R_{ij}^{S_4}), \quad i = 1, \ldots, n, \quad (6.23)
\]

\[
\tilde{R}_i^P = \sum_{j=1}^{m} h_j \tilde{R}_{ij}^P = (\sum_{j=1}^{m} h_j R_{ij}^{P_1}, \sum_{j=1}^{m} h_j R_{ij}^{P_2}, \sum_{j=1}^{m} h_j R_{ij}^{P_3}, \sum_{j=1}^{m} h_j R_{ij}^{P_4}), \quad i = 1, \ldots, n, \quad (6.24)
\]

\[
\tilde{O}_i = \sum_{j=1}^{m} h_j \tilde{w}_{ij}^O = (\sum_{j=1}^{m} h_j w_{ij}^{O_1}, \sum_{j=1}^{m} h_j w_{ij}^{O_2}, \sum_{j=1}^{m} h_j w_{ij}^{O_3}, \sum_{j=1}^{m} h_j w_{ij}^{O_4}), \quad i = 1, \ldots, n, \quad (6.25)
\]

\[
\tilde{S}_i = \sum_{j=1}^{m} h_j \tilde{w}_{ij}^S = (\sum_{j=1}^{m} h_j w_{ij}^{S_1}, \sum_{j=1}^{m} h_j w_{ij}^{S_2}, \sum_{j=1}^{m} h_j w_{ij}^{S_3}, \sum_{j=1}^{m} h_j w_{ij}^{S_4}), \quad i = 1, \ldots, n, \quad (6.26)
\]

\[
\tilde{D}_i = \sum_{j=1}^{m} h_j \tilde{w}_{ij}^D = (\sum_{j=1}^{m} h_j w_{ij}^{D_1}, \sum_{j=1}^{m} h_j w_{ij}^{D_2}, \sum_{j=1}^{m} h_j w_{ij}^{D_3}, \sum_{j=1}^{m} h_j w_{ij}^{D_4}), \quad i = 1, \ldots, n, \quad (6.27)
\]

Table 6.2 Fuzzy ratings to compute occurrence of a failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Probability of occurrence</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High (VH)</td>
<td>Failure is almost inevitable</td>
<td>(8, 9, 10, 10)</td>
</tr>
<tr>
<td>High (H)</td>
<td>Repeated failures</td>
<td>(6, 7, 8, 9)</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Occasional failures</td>
<td>(3, 4, 6, 7)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Relatively few failures</td>
<td>(1, 2, 3, 4)</td>
</tr>
<tr>
<td>Remote (R)</td>
<td>Failure is unlikely</td>
<td>(1, 1, 1, 2)</td>
</tr>
</tbody>
</table>

![Figure 6.3 Fuzzy ratings for occurrence assessment of failures and their membership functions](image-url)
Figure 6.4 Fuzzy ratings of severity assessment of failures and membership functions

Table 6.3 Fuzzy ratings for severity of a failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Severity of effect</th>
<th>Fuzzy No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous With Out Warning (HWOW)</td>
<td>Very high severity ranking with out warning</td>
<td>(9, 10, 10)</td>
</tr>
<tr>
<td>Hazardous With Warning (HWW)</td>
<td>Very high severity ranking with warning</td>
<td>(8, 9, 10)</td>
</tr>
<tr>
<td>Very High (VH)</td>
<td>System inoperable with destructive failure</td>
<td>(7, 8, 9)</td>
</tr>
<tr>
<td>High (H)</td>
<td>System inoperable with equipment damage</td>
<td>(6, 7, 8)</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>System inoperable with minor damage</td>
<td>(5, 6, 7)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>System inoperable without damage</td>
<td>(4, 5, 6)</td>
</tr>
<tr>
<td>Very Low (VL)</td>
<td>System operable with significant degradation of performance</td>
<td>(3, 4, 5)</td>
</tr>
<tr>
<td>Minor (MR)</td>
<td>System operable with some degradation of performance</td>
<td>(2, 3, 4)</td>
</tr>
<tr>
<td>Very Minor (VMR)</td>
<td>System operable with minimal interference</td>
<td>(1, 2, 3)</td>
</tr>
<tr>
<td>None (N)</td>
<td>No effect</td>
<td>(1, 1, 2)</td>
</tr>
</tbody>
</table>

The fuzzy assessments process is determined using Table 6.2- 6.5. Table 6.2 illustrates Fuzzy ratings to compute occurrence of a failure.
Figure 6.3 illustrates fuzzy ratings for occurrence assessment of failures and their membership functions. Figure 6.4 shows fuzzy ratings of severity assessment of failures and membership functions. Figure 6.5 view the Fuzzy ratings of detectability assessment of failures and membership functions. Figure 6.6 shows membership function of fuzzy weights. The five TMs are assumed and given the different importance because of their different domain knowledge and expertise. This evaluation is completed by using Table 6.2-6.5.

Table 6.4 Fuzzy ratings to evaluate detectability of a failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Detectability of failure</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute uncertainty (AU)</td>
<td>No chance</td>
<td>(9, 10, 10)</td>
</tr>
<tr>
<td>Very remote (VR)</td>
<td>Very remote chance</td>
<td>(8, 9, 10)</td>
</tr>
<tr>
<td>Remote (R)</td>
<td>Remote chance</td>
<td>(7, 8, 9)</td>
</tr>
<tr>
<td>Very low (VL)</td>
<td>Very low chance</td>
<td>(6, 7, 8)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Low chance</td>
<td>(5, 6, 7)</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Moderate chance</td>
<td>(4, 5, 6)</td>
</tr>
<tr>
<td>Moderately high (MH)</td>
<td>Moderately high chance</td>
<td>(3, 4, 5)</td>
</tr>
<tr>
<td>High (H)</td>
<td>High chance</td>
<td>(2, 3, 4)</td>
</tr>
<tr>
<td>Very high (VH)</td>
<td>Very high chance</td>
<td>(1, 2, 3)</td>
</tr>
<tr>
<td>Almost certain (AC)</td>
<td>Almost certainty</td>
<td>(1, 1, 2)</td>
</tr>
</tbody>
</table>

Figure 6.5 Fuzzy ratings of detectability assessment of failures and membership functions
Table 6.5 Fuzzy weights for risk factors

<table>
<thead>
<tr>
<th>Linguistic term</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low (VL)</td>
<td>(0, 0, 0.25)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0, 0.25, 0.5)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.25, 0.5, 0.75)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.5, 0.75, 1)</td>
</tr>
<tr>
<td>Very High (VH)</td>
<td>(0.75, 1, 1)</td>
</tr>
</tbody>
</table>

There are n failure modes, FM_i (i=1, . . . , n), evaluated and prioritized by a FMEA team consisting of m cross functional team members, TM_j (j=1, . . . , m). The equation (6.20) and (6.21) represents it. The n modes are

1. Management Principle (MP) – FM 1
2. Research and Development & Capital Utilization (RDCU) – FM 2
3. Supplier Performance (SP) – FM 3
4. Fabric Quality (FQ) – FM 4
5. Order and Customer Perception (OCP) – FM 5
6. Lack of Planning for Productivity (LPP) – FM 6
7. Labour and Work Force mix (LWF) – FM 7
8. Technical Instruments and Technology (TIT) – FM 8
9. Benchmarking (BM) – FM 9
10. Maintenance of Assets (MA) – FM 10

Phase 2: The Fuzzy Risk Priority Number (FRPN) is defined for each failure mode using the equation (6.22-6.28). The assessment details on ten FMs by five FMEA team members are tabulated in Table 6.6.

\[
FRPN_i = \left( R_i^O \right)^{w^O} \times \left( R_i^S \right)^{w^S} \times \left( R_i^D \right)^{w^D} \Rightarrow \text{where } i=1,..n
\]
Table 6.6  Assessment details on ten FMs by five FMEA Team Members(TM)

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>FMEA team members</th>
<th>Factor weights</th>
<th>Failure modes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TM1 (10%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occurrence</td>
<td></td>
<td>L</td>
<td>L H L M L H H L H M</td>
</tr>
<tr>
<td></td>
<td>TM2 (20%)</td>
<td>VH</td>
<td>M M M H M VH VH M VH VH</td>
</tr>
<tr>
<td></td>
<td>TM3 (30%)</td>
<td>H</td>
<td>M M L H M M H H M H M</td>
</tr>
<tr>
<td></td>
<td>TM4 (15%)</td>
<td>M</td>
<td>VH L M L H L VH L M</td>
</tr>
<tr>
<td></td>
<td>TM5 (25%)</td>
<td>L</td>
<td>L M M M H M M VH M H</td>
</tr>
<tr>
<td>Severity</td>
<td>TM1 (10%)</td>
<td>H</td>
<td>VH VH VH VL M H L H M M</td>
</tr>
<tr>
<td></td>
<td>TM2 (20%)</td>
<td>VH</td>
<td>H H H L L VH M M H L</td>
</tr>
<tr>
<td></td>
<td>TM3 (30%)</td>
<td>H</td>
<td>M M M VL H H H M M</td>
</tr>
<tr>
<td></td>
<td>TM4 (15%)</td>
<td>VH</td>
<td>L H L M H L L M H L L</td>
</tr>
<tr>
<td></td>
<td>TM5 (25%)</td>
<td>VH</td>
<td>M M VH MR M M M M L</td>
</tr>
<tr>
<td>Detection</td>
<td>TM1 (10%)</td>
<td>L</td>
<td>H L VR L VR VL H VL M VL</td>
</tr>
<tr>
<td></td>
<td>TM2 (20%)</td>
<td>M</td>
<td>VH M R VL R L MH R L L</td>
</tr>
<tr>
<td></td>
<td>TM3 (30%)</td>
<td>MH</td>
<td>MH VL M VL R M L MH M</td>
</tr>
<tr>
<td></td>
<td>TM4 (15%)</td>
<td>M</td>
<td>H VR M L VL H MH M H</td>
</tr>
<tr>
<td></td>
<td>TM5 (25%)</td>
<td>L</td>
<td>H MH R MH VL M M AC H L</td>
</tr>
</tbody>
</table>

Table 6.7 Aggregated fuzzy assessment information for the ten FMs and the relative importance weights of three risk factors

<table>
<thead>
<tr>
<th>FMs</th>
<th>Occurrence(O)</th>
<th>Severity(S)</th>
<th>Detection(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM1</td>
<td>(2.3,3.3,4.95,5.95)</td>
<td>(5.7, 6.7, 7.7)</td>
<td>(2.4,3.4,4.4)</td>
</tr>
<tr>
<td>FM 2</td>
<td>(4.05, 5.05, 6.8,7.65)</td>
<td>(5.25, 6.25,7.25)</td>
<td>(3.25,4.25,5.25)</td>
</tr>
<tr>
<td>FM 3</td>
<td>(1.9, 2.9,4.35, 5.35)</td>
<td>(6.05, 7.05,8.05)</td>
<td>(6.95, 7.95, 8.95)</td>
</tr>
<tr>
<td>FM 4</td>
<td>(4.5, 5.5, 7, 8)</td>
<td>(3.7,4.7,5.7)</td>
<td>(4.25, 5.25,6.25)</td>
</tr>
<tr>
<td>FM 5</td>
<td>(3.25, 4.25, 5.75, 6.75)</td>
<td>(4.05,5.05,6.05)</td>
<td>(6.25, 7.25, 8.25)</td>
</tr>
<tr>
<td>FM 6</td>
<td>(4.75, 5.75, 7.3 , 8.1)</td>
<td>(5.8,6.8,7.8)</td>
<td>(5.6, 6.6, 7.6)</td>
</tr>
<tr>
<td>FM 7</td>
<td>(4.9, 5.9, 7.15, 7.95)</td>
<td>(5.35, 6.35,7.35)</td>
<td>(3.3, 4.3, 5.3)</td>
</tr>
<tr>
<td>FM 8</td>
<td>(5.7, 6.7, 7.9, 8.5)</td>
<td>(4.5,5.5,6.5)</td>
<td>(4.2, 4.95,5.95)</td>
</tr>
<tr>
<td>FM 9</td>
<td>(4, 5, 6.55, 7.35)</td>
<td>(5.05,6.05,7.05)</td>
<td>(3.4,4,4.5,4)</td>
</tr>
<tr>
<td>FM 10</td>
<td>(5.65, 6.65, 7.9, 8.7)</td>
<td>(4.55,5.55,6.55)</td>
<td>(4.35, 5.35,6.35)</td>
</tr>
<tr>
<td>Weights</td>
<td>(0.3375, 0.5875,0.7875)</td>
<td>(0.6125,0.8625,1)</td>
<td>(0.0875,0.3375,0.5875)</td>
</tr>
</tbody>
</table>

Phase 3: The alpha-level sets of the FRPN of each failure mode are computed for the following Linear Programming models using the equation (6.29 - 6.30).
Min $z_1 = u_1 \ln \left( \frac{R_{1}^{0}}{\alpha} \right)^{L} + u_2 \ln \left( \frac{R_{1}^{S}}{\alpha} \right)^{L} + u_3 \ln \left( \frac{R_{1}^{D}}{\alpha} \right)^{L}$; s.t $u_1 + u_2 + u_3 = 1$, \(6.29\)

\[
\begin{align*}
(w^{0})_{\alpha}^{L} \cdot z & \leq u_1 \leq (w^{0})_{\alpha}^{U} \cdot z, \\
(w^{S})_{\alpha}^{L} \cdot z & \leq u_2 \leq (w^{S})_{\alpha}^{U} \cdot z, \\
(w^{D})_{\alpha}^{L} \cdot z & \leq u_3 \leq (w^{D})_{\alpha}^{U} \cdot z,
\end{align*}
\]
for all $z \geq 0$.

Max $z_2 = u_1 \ln \left( \frac{R_{1}^{0}}{\alpha} \right)^{U} + u_2 \ln \left( \frac{R_{1}^{S}}{\alpha} \right)^{U} + u_3 \ln \left( \frac{R_{1}^{D}}{\alpha} \right)^{U}$; s.t $u_1 + u_2 + u_3 = 1$, \(6.30\)

\[
\begin{align*}
(w^{0})_{\alpha}^{L} \cdot z & \leq u_1 \leq (w^{0})_{\alpha}^{U} \cdot z, \\
(w^{S})_{\alpha}^{L} \cdot z & \leq u_2 \leq (w^{S})_{\alpha}^{U} \cdot z, \\
(w^{D})_{\alpha}^{L} \cdot z & \leq u_3 \leq (w^{D})_{\alpha}^{U} \cdot z,
\end{align*}
\]
\(z \geq 0\), Where

\[
\ln \left( \frac{R_{1}^{0}}{\alpha} \right)^{L}, \ln \left( \frac{R_{1}^{0}}{\alpha} \right)^{U}, \ln \left( \frac{R_{1}^{S}}{\alpha} \right)^{L}, \ln \left( \frac{R_{1}^{S}}{\alpha} \right)^{U} \text{ and } \ln \left( \frac{R_{1}^{D}}{\alpha} \right)^{L}, \ln \left( \frac{R_{1}^{D}}{\alpha} \right)^{U}
\]
are the logarithms of \(\left[ \left( \frac{R_{1}^{0}}{\alpha} \right)^{L}, \left( \frac{R_{1}^{0}}{\alpha} \right)^{U} \right], \left[ \left( \frac{R_{1}^{S}}{\alpha} \right)^{L}, \left( \frac{R_{1}^{S}}{\alpha} \right)^{U} \right] \text{ and } \left[ \left( \frac{R_{1}^{D}}{\alpha} \right)^{L}, \left( \frac{R_{1}^{D}}{\alpha} \right)^{U} \right] \). These are the $\alpha$ -level sets of the aggregated occurrence, severity and detection ratings $\widetilde{R}_{1}^{0}, \widetilde{R}_{1}^{S}, \text{ and } \widetilde{R}_{1}^{D}$ for the failure mode $FM_{i}$, and \(\left[ (w^{0})_{\alpha}^{L}, (w^{0})_{\alpha}^{U} \right], \left[ (w^{S})_{\alpha}^{L}, (w^{S})_{\alpha}^{U} \right] \) and \(\left[ (w^{D})_{\alpha}^{L}, (w^{D})_{\alpha}^{U} \right] \) are the $\alpha$ -level sets of the aggregated risk factor weights $\widetilde{w}^{0}, \widetilde{w}^{S} \text{ and } \widetilde{w}^{D}$, respectively. Then \(\frac{(FRPN_{i})}{\alpha}^{L} = \exp (z_{1}^{*})\) and \(\frac{(FRPN_{i})}{\alpha}^{U} = \exp (z_{2}^{*})\). By setting different $\alpha$ Levels, different $\alpha$ -level sets of $FRPN_{i}$ generated, based on which $FRPN_{i}$ expressed as $FRPN_{i} = U_{\alpha}$

\[
\alpha \left[ \left( \frac{(FRPN_{i})}{\alpha}^{L} \right) \left( \frac{(FRPN_{i})}{\alpha}^{U} \right) \right] 0 < \alpha \leq 1.
\]
**Phase 4:** The centroid defuzzification method is used the defuzzification of FRPNs.

The unit interval $[0, 1]$ is equally divided by eleven $\alpha$ levels into eleven subintervals. The $\alpha$-level sets of FRPNs are generated and solved by solving a series of LP models. The equations (6.9 and 6.10) are used and computed the centroids of the ten FRPNs. Table 6.8 gives the alpha-level sets of the fuzzy risk priority numbers for ten failure modes. It is drawn from the equation (6.9 and 6.10) for ten FRPNs.

The LP models are solved for each of the ten failure modes and all $\alpha$ levels, where the $\alpha$ levels are set as 0, 0.1, 0.2, 0.3, 0.4, 0.5,… 1.0. The results of set level are provided in Table 6.8. A method for prioritizing failure dimension is to defuzzify their fuzzy FRPNs by using equation (6.7-6.11) and prioritize them by their defuzzified centroid values. This potential application of the fuzzy FMEA is computational process to bring the FRPNs. The FRPNs are characterized by $\alpha$-level sets, the centroid defuzzification is determined by the equation (6.7) and (6.8).

**Phase 5:** The failure modes are prioritized by the defuzzified centroid values of FRPNs.

All the failure modes are prioritized or ranked in terms of the defuzzified centroid values of their FRPNs. The high defuzzified centroid value gives bigger risk. It is considered as high risk priority. Figure 6.7 depicts risk priority numbers of the ten failure modes (FMs). Due to the difficulty in precisely assessing the risk factors and their relative importance weights, the FMEA team members reach a consensus to evaluate them using the linguistic terms defined in Tables 5–8. The five team members’ assessment information is first aggregated by using equation (6.22–6.27). Table 6.7 shows the aggregated fuzzy assessment information for the ten FMs and the relative importance weights of three risk factors.
Table 6.8 Alpha-levels sets of the fuzzy risk priority numbers for ten failure modes

<table>
<thead>
<tr>
<th>α</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>[2.91452, 6.08989]</td>
<td>[4.09001, 7.02880]</td>
<td>[3.50341, 7.03748]</td>
<td>[4.22514, 6.55581]</td>
<td>[4.04094, 6.61548]</td>
<td>[5.20150, 7.87734]</td>
<td>[5.43855, 7.18655]</td>
<td>[4.98005, 7.07873]</td>
<td>[4.21871, 7.23961]</td>
<td>[5.01544, 7.23961]</td>
</tr>
<tr>
<td>0.1</td>
<td>[3.66731, 6.30682]</td>
<td>[4.65153, 6.93298]</td>
<td>[3.58024, 6.93298]</td>
<td>[4.18956, 6.45460]</td>
<td>[3.79630, 6.51491]</td>
<td>[5.35757, 7.78450]</td>
<td>[5.14037, 7.09220]</td>
<td>[5.13516, 6.98998]</td>
<td>[4.78366, 6.77130]</td>
<td>[5.14741, 7.14746]</td>
</tr>
<tr>
<td>0.2</td>
<td>[3.77674, 6.20458]</td>
<td>[4.75249, 6.83711]</td>
<td>[3.69639, 6.83262]</td>
<td>[4.39000, 6.35336]</td>
<td>[3.89725, 6.41433]</td>
<td>[5.45803, 7.69164]</td>
<td>[5.24081, 6.99778]</td>
<td>[5.23480, 6.90109]</td>
<td>[4.85844, 6.77754]</td>
<td>[5.24798, 7.04984]</td>
</tr>
<tr>
<td>0.3</td>
<td>[3.88567, 6.10225]</td>
<td>[4.85342, 6.74118]</td>
<td>[3.81161, 6.73007]</td>
<td>[4.39041, 6.25207]</td>
<td>[3.99816, 6.31372]</td>
<td>[5.55848, 7.59876]</td>
<td>[5.34122, 6.90330]</td>
<td>[5.33442, 6.81207]</td>
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<td>[5.34835, 6.95485]</td>
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<tr>
<td>0.4</td>
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<td>[4.95430, 6.64520]</td>
<td>[3.92598, 6.62744]</td>
<td>[4.49080, 6.15075]</td>
<td>[4.09903, 6.21311]</td>
<td>[5.65891, 7.50586]</td>
<td>[5.44162, 6.80874]</td>
<td>[5.43401, 6.72291]</td>
<td>[5.00770, 6.48988]</td>
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</tr>
<tr>
<td>0.5</td>
<td>[4.10221, 5.89734]</td>
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<td>[4.03958, 6.52472]</td>
<td>[4.59118, 6.04939]</td>
<td>[4.19986, 6.11247]</td>
<td>[5.75932, 7.41295]</td>
<td>[5.54200, 6.71411]</td>
<td>[5.53358, 6.63661]</td>
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<td>0.6</td>
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<td>[4.15246, 6.42191]</td>
<td>[4.69154, 5.94798]</td>
<td>[4.30066, 6.01181]</td>
<td>[5.85972, 7.32001]</td>
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<td>[5.63313, 6.54415]</td>
<td>[5.15656, 6.53019]</td>
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<tr>
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<td>[4.40142, 5.91133]</td>
<td>[5.96011, 7.22706]</td>
<td>[5.74271, 6.52460]</td>
<td>[5.73266, 6.45454]</td>
<td>[5.23087, 6.20796]</td>
<td>[5.75054, 6.57415]</td>
</tr>
<tr>
<td>0.8</td>
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<td>[5.35751, 6.26065]</td>
<td>[4.37632, 6.21599]</td>
<td>[4.89222, 5.74502]</td>
<td>[4.50216, 5.81043]</td>
<td>[6.06049, 7.13048]</td>
<td>[5.84304, 6.42972]</td>
<td>[5.83217, 6.36477]</td>
<td>[5.30509, 6.11387]</td>
<td>[5.85100, 6.47877]</td>
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<tr>
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<td>[5.45824, 6.16434]</td>
<td>[4.48739, 6.11287]</td>
<td>[4.99254, 5.64346]</td>
<td>[4.60286, 5.70971]</td>
<td>[6.16085, 7.04108]</td>
<td>[5.94336, 6.33475]</td>
<td>[5.93167, 6.27483]</td>
<td>[5.37923, 6.01970]</td>
<td>[5.95144, 6.38330]</td>
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<td>[5.09285, 5.54186]</td>
<td>[4.70354, 5.60897]</td>
<td>[6.26120, 6.04367]</td>
<td>[6.03115, 6.23907]</td>
<td>[6.03539, 6.18472]</td>
<td>[5.45329, 5.92547]</td>
<td>[6.05187, 6.28774]</td>
</tr>
<tr>
<td>Priority ranking</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>
6.5 CONCLUSIONS

The following conclusions are drawn after applying the fuzzy FMEA

- The lowest risk of PQD is Management Principle (MP). It has the least overall risk. So less importance may be given in order to enhance the productivity. Lack of productivity Planning (LPP) is maximum overall risk dimension and it should be given first priority. The failure mode FM6 is ranked in first position without doubt and it should be given top risk priority, followed by other dimensions such as FM10, FM7, FM8, FM2 FM9, FM4, FM3 FM5, and FM1.

- This FRPNs is perfectly consistent with the ranking achieved by former intuitive analysis i.e traditional FMEA. The defuzzified centroid values of the ten FRPNs give the priority ranking of the ten failure dimensions as FM6 >
FM10 > FM7 > FM8 > FM2 > FM9 > FM4 > FM3 > FM5 > FM1.

- So, the final conclusion for this case study is that productivity and quality dimension (FM6) i.e. LPP is given top priority for correction, followed by failure modes 10, 7, 8, 2, 9, 4, 3, 5 and 1.

6.6 PRODUCTIVITY CYCLE (PC)

The productivity cycle consist of productivity measurement, evaluation, planning and improvement. The detailed procedure of productivity measurement is follows.

6.6.1 Total Productivity Model (TPML)

Recently, Sumanth (1984) developed a productivity-measurement model that considers the impact of all input factors on the output in a “tangible” sense. This case study has been carried out and followed the productivity cycle. The tangible output and tangible input elements of the total productivity is given in the following figure.

The output element consists of finished units produced, partial units produced, dividend from securities, interest from bonds and other income. The input element consists of human (workers, managers, professionals etc), material (raw materials and purchased parts), capital (fixed and working capital), energy (oil, water, coal etc) and other expenses (travel, tax, marketing, R&D etc).
6.6.2 Total Productivity of Product i in terms of its Partial Productivities

The total productivity of product stated “the ratio of the total output value of product i to the total input cost”. Similarly, the partial productivity of product i with respect to any input factor j is the ratio of the total output value of product i to the input cost of factor j.

\[
TP = \frac{O_i}{I_i} = \frac{O_i}{\sum_j I_{ij}} \quad \text{and} \quad PP_{ij} = \frac{O_i}{I_{ij}} \quad (6.31)
\]

From the above equation (6.31),

\[
O_i = TP_i \times \sum_j I_{ij} \quad \text{and} \quad O_i = PP_{ij} \times I_{ij}
\]

Therefore, 

\[
TP_i = \frac{PP_{ij} \times L_{ij}}{\sum_j I_{ij}} ; \quad W_{ij} = \frac{I_{ij}}{\sum_j I_{ij}}
\]

\[
TP_i = W_{ij} \times PP_{ij} \text{for all } j. \quad (6.32)
\]

\(W_{ij}\) denotes the weight corresponding to the input factor. In other words, \(W_{ij}\) represents the fraction of input factor \(j\) with respect to the sum of all the inputs used to produce product \(i\). The equation (6.32) expresses the total productivity of a product as a function of partial productivity of this product with respect to any of the inputs that have been used to produce this product.

6.6.3 Total Productivity of a firm as a function of Total Productivities of Individual Products

The Total Productivity of a Firm(TPF) is the ratio of the total output of the firm to the total input used by it. The equations (6.33 and 6.34) arrive TPF
\[ TPF = \frac{\sum_i O_i}{\sum_i I_i} \quad (6.33) \]

But,
\[ \sum_i I_i = \sum_i \left( \sum_{j} I_{ij} \right) = \sum_j \sum_i I_{ij} ; \quad TPF = \frac{\sum_i O_i}{\sum_j \sum_i I_{ij}} \]

\[ TPF = \sum_j W_i \times (TP)_i \quad (6.34) \]

Here, \( W_i \) represents the fraction of total output for product \( i \) with respect to total of all such inputs combined for the \( n \) products manufactured in the firm. Therefore the total productivity of a firm is the weighted sum of total productivities corresponding to each of the product.

6.6.4 Total Productivity of a Firm as a Function of Partial Productivities

The total productivity of product \( i \) in terms of its partial productivities and the total productivity of a firm as a function of total productivities of individual products are given in the equation (6.35) respectively

\[ _iTP = W_i \times PP_j \quad \text{for all} \ j ; \quad TPF = \sum_j W_i \times (TP)_i \quad (6.35) \]

\[ TPF = \sum_i W_i \times \left( W_{ij} \times PP_j \right) = \left( \sum_i^{N} W_i \cdot W_{ij} \right) \times PP_j \]

\[ = \sum_i^{N} W_i W_{ij} PP_j \quad (6.36) \]

\[ W_i = \frac{1}{I_{ij}} ; \quad W_{ij} = \frac{1}{I_{ij}} \quad \text{Therefore,} \quad W_i \times W_{ij} = \frac{1}{I_{ij}} \times \frac{1}{I_{ij}} = \frac{1}{I_{ij}} \quad \text{for all} \ i, j = W_i \]

Hence,

\[ TPF = \sum_i^{N} W_{ij} PP_j \quad \text{for all} \ j . \quad (6.37) \]
The total productivity of a firm is the sum of weighted partial productivities, and it is expressed in as many alternative forms as there are input factors. Thus, in this case, considered five input factors, namely, human, material, capital, energy, and other expense inputs. TPF is expressed in five different but equivalent forms.

\[ TPF = \sum_{i=1}^{N} W_{ii}^{i} P_{i} ; \quad \text{Where} \quad W_{ii}^{i} = \frac{l_{ii}}{I_{i}} \quad \text{and} \quad P_{i} = \frac{Q_{i}}{I_{i}} ; \quad \text{Similarly} \]

\[ W_{i}^{i} \]

are derived for all inputs such as Human (H), Material (M), Capital (C), Energy (E), and other expense (O) inputs. The all input factors (m) equations are solved and obtained the following equation (6.38) for N products of TPF

\[
TPF = \frac{1}{m} (\sum_{i=1}^{N} W_{ii}^{i} P_{i} + \sum_{i=1}^{N} W_{im}^{i} P_{i}M + \sum_{i=1}^{N} W_{ic}^{i} P_{i}C + \sum_{i=1}^{N} W_{ie}^{i} P_{i}E + \sum_{i=1}^{N} W_{ix}^{i} P_{i}X ) (6.38)
\]

The equation (6.38) expressing total productivity of a firm, can be expressed in terms of the partial productivities of the individual products with respect to any one of the input factors.

### 6.7 PRODUCTIVITY EVALUATION

The second phase in the productivity cycle following the measurement is the evaluation phase. More specifically, the evaluation of total productivity for any given product (i) is evaluated

1. between two periods t-1 : the actual total productivities TP_{it-1} and TP_{it} in period t-1 and t are calculated, respectively
2. within a given period t : the actual total productivity TP_{it} in period t with two types of budgeted total productivities, TP_{it} and TP_{it}^*, are compared.
6.7.1 Total Productivity Change

The change in total productivity for any product i between two successive time periods (t-1 and t) are computed from the equation (6.39). It is in terms of the total productivity, tangible input in period t-1, and the changes in tangible output and input in period t. The following equation (6.39) expresses the total productivity change:

\[ \Delta TP_i = \frac{\Delta O_i - \Delta I_i - TP_{i,t-1}}{I_{t-1} + \Delta I_i}, \quad \text{for } t \geq 1; \Delta O_i, \Delta I_i < 0; \, TP_{i,t-1}, I_{t-1} \geq 0. \]  

(6.39)

\( \Delta TP_i \) = actual change of total productivity of product i between two successive periods, t-1 and t.

\( \Delta O_i \) = actual change of tangible output of product i between two successive periods, t-1 and t.

\( \Delta I_i \) = actual change of tangible input of product i between two successive periods, t-1 and t;

Where \( t \geq 1; -\infty \leq \Delta TP_i, \Delta O_i, \Delta I_i \leq +\infty. \)

The following three possible cases are expressed for its change.

Case 1: \( \Delta TP_i = 0 \); that is, the total productivity has remained constant between periods t-1 and t.

Case 2: \( \Delta TP_i > 0 \); that is, the total productivity has increased in period t as compared to period t-1.

Case 3: \( \Delta TP_i < 0 \); that is, the total productivity has decreased in period t as compared to period t-1.
6.7.2 The Productivity Evaluation Tree (PET)

The condition derived for case 1, case 2 and case 3 are actually feasible “paths” of the more general set of paths. The Productivity Evaluation Tree (PET) gives the path way. Table 6.9 shows the production evaluation tree. It shows the theoretically possible changes in output and input that results in changes in total productivity. It shows at a glance which branches lead to case 1 \((\Delta TP_{it} = 0)\), to case 2 \((\Delta TP_{it} > 0)\), or to case 3 \((\Delta TP_{it} < 0)\).

In PET, there are 8 feasible paths for case 1, 9 for case 2, and 5 for case 3. It must be emphasized once again that the \(\Delta O_{it}\) and \(\Delta I_{it}\) are the actual changes in output and input, respectively. Industry plan the total productivity in the future when change \(\Delta O_{it}\) and \(\Delta I_{it}\). Thus, this tree can be used both the productivity evaluation and for productivity planning.

6.7.3 Evaluation of total productivity between successive time periods

Let, \(TP_{it-1}\) and \(TP_{it}\) be the actual values of total productivity of product \(i\) in periods \(t-1\) and \(t\), respectively, where \(t\) is the current period, \(TP_{it-1} = O_{it-1} / I_{it-1}\) and \(TP_{it} = O_{it} / I_{it}\). Therefore, the actual total productivity of this product from period \(t-1\) to \(t\) is given in the following equation (6.40).

\[
\Delta TP_{it} = TP_{it} - TP_{it-1} = (O_{it} / I_{it}) - (O_{it-1} / I_{it-1}) (6.40)
\]

When the recorded (actual) values of \(O_{it}\), \(I_{it}\) and \(O_{it-1}\), \(I_{it-1}\) are known, planners compute \(\Delta TP_{it}\). It must be emphasized that \(t\) is an integer and it is greater than 1. When \(t=1\); \(TP_{it-1} = TO_{it}\), \(TP_{it}\) corresponding to the total productivity of product \(i\) in period zero base period; when \(t=2\) comparing total productivity between periods 1 and 2; \(t=3\). It is used to compare the total
productivity between periods 2 and 3 and so on. Table 6.10 shows computational scheme for determining the variation of total productivity.

**Table 6.9 Production Evaluation Tree (PET)**

<table>
<thead>
<tr>
<th>Period (t-1)(If O_{it-1}, I_{it-1} known)</th>
<th>Period (t) (If O_{it}, I_{it} known ; ΔO_{it} = O_{it} - O_{it-1}; ΔI_{it} = I_{it} - I_{it-1})</th>
<th>Path Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>O_{it-1}=0 I_{it-1}=0</td>
<td>ΔO_{it}&gt; 0 ; ΔI_{it}&gt; 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 Infeasible</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}&lt; 0 Infeasible</td>
<td>--</td>
</tr>
<tr>
<td>O_{it-1}=0 I_{it-1}=0</td>
<td>ΔO_{it}= 0 ; ΔI_{it}&gt; 0 , TP_{it}= 0, ΔTP_{it}= 0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}= 0, ΔTP_{it}= 0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}&lt; 0 Infeasible</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>ΔO_{it}&lt; 0 Infeasible</td>
<td>--</td>
</tr>
<tr>
<td>O_{it-1}=0 I_{it-1}&gt; 0 ( Where TP_{it-1}= 0 )</td>
<td>ΔO_{it}&gt; 0 ; ΔI_{it}&gt; 0 , TP_{it}= 0, ΔTP_{it}= 0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}&lt; 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>12</td>
</tr>
<tr>
<td>O_{it-1}=0 I_{it-1}&gt; 0 ( Where TP_{it-1}= 0 )</td>
<td>ΔO_{it}= 0 ; ΔI_{it}&gt; 0 , TP_{it}= 0, ΔTP_{it}= 0</td>
<td>3</td>
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<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>4</td>
</tr>
<tr>
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<td>5</td>
</tr>
<tr>
<td></td>
<td>ΔO_{it}&lt; 0 Infeasible</td>
<td>--</td>
</tr>
<tr>
<td>O_{it-1}&gt; 0 I_{it-1}&gt; 0 (Where TP_{it-1}&gt;0)</td>
<td>ΔO_{it}&gt; 0 ; ΔI_{it}&gt; 0 , TP_{it}&gt; 0, ΔTP_{it}≥ 0, ΔTP_{it}≤ 0</td>
<td>13, 16, 18</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}&lt; 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
<td>15</td>
</tr>
<tr>
<td>O_{it-1}&gt; 0 I_{it-1}&gt; 0 (Where TP_{it-1}&gt;0)</td>
<td>ΔO_{it}= 0 ; ΔI_{it}&gt; 0 , TP_{it}&lt; 0, ΔTP_{it}≤ 0</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}&gt; 0, ΔTP_{it}= 0</td>
<td>7</td>
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<tr>
<td></td>
<td>ΔI_{it}&lt; 0 , TP_{it}&gt; 0, ΔTP_{it}&gt; 0</td>
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</tr>
<tr>
<td></td>
<td>ΔO_{it}&lt; 0 ; ΔI_{it}&lt; 0 , TP_{it}&lt; 0, ΔTP_{it}≤ 0</td>
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</tr>
<tr>
<td></td>
<td>ΔI_{it}= 0 , TP_{it}≥ 0, ΔTP_{it}&lt; 0</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>ΔI_{it}&lt; 0 , TP_{it}≥ 0, ΔTP_{it}≤ 0, ΔTP_{it}≤ 0</td>
<td>17, 18, 22</td>
</tr>
</tbody>
</table>
6.7.4 Evaluation of Total Productivity within a given Time Period

The actual productivity with the budgeted total productivity within a given time period is compared and it will undoubtedly enhance the chances of setting up realistic targets of total productivity either for a single product or for a firm as a whole. The budgeted total productivity of any time period has to be determined at least a period ahead.

Figure 6.8 Computational Scheme for determining the variation of total productivity
6.8 PRODUCTIVITY PLANNING

Planning is an analytical process which encompasses an assessment of the future. It refers to the ‘determination of desired objectives in the context of that future, the development of alternative courses of action to achieve such objectives and the selection of a course or courses of action from among the alternatives’.

6.8.1 Importance of Productivity Planning

Planning for productivity improvement emphasizes planning to achieve better productivity. Productivity planning is concerned with setting up targets for productivity level and growth rate i.e. partial or total productivities. Kayis et al (2003) recognized the importance of productivity planning and suggested the following procedure

1. Develop an effective planning process and structure in the organization
2. Prepare productivity goals and permeate the planning process with specific objectives based on these goals
3. Establish productivity surveillance, assistance, and coordination in a manner tailored to the organization’s needs

The productivity program and projects tend toward creeping decadence or offsetting costs unless maintenance is built into the productivity planning system. There is bound to be a point when the productivity level reaches a peak and then starts to decline or saturates unless action is deliberately taken to maintain the growth rate (Monteset al 2003).

The Short-term Productivity Planning (SPP) horizon is less than one year. SPP is relevant to setting the target levels of productivity. The primary objective in the SPP is to monitor productivity changes in much the same way as production or service operations. Long-term productivity
planning is appropriate when productivity levels must be planned beyond one year. LPP is more suitable as a strategic planning tool then as an operational management tool.

6.9 PRODUCTIVITY IMPROVEMENT

The different methods are used to improve the productivity. It has been proved in previous case studies. It is interesting to note that the absence of productivity measurement of nonproduction workers stands as the first cause for the decline of productivity in companies.

In this junction, the TPM ways are effectively utilized and different kind of maintenance procedures are carried out in industries. The model of maintenance procedures of Jigger, Squeezing, Stenter and Calendering machines are listed in appendix.

6.10 PROFIT VERSUS TOTAL PRODUCTIVITY: BREAK-EVEN POINT ANALYSIS

According to Kendrick and Creamer (1965), $TP_i = (I_i - I_{i,c,w} + P_i) / I_i$

$TP_i I_i = I_i - I_{i,c,w} + P_i$; $P_i = (TP_i - 1) I_i + I_{i,c,w}$

where $I_i =$ total input used for product $i$ in constant rupees of base period

where $\{j\} = \{H, M, C, E, X\}$

If we consider all the products manufactured by the firm, then its profit is given by

$PF = \sum P_i = \sum [(TP_i - 1) I_i + I_{i,c,w}]$

$= \sum [(TP_i - 1) I_i] + \sum I_{i,c,w}$

$= \sum TP_i I_i - \sum I_i + \sum I_{i,c,w}$
Hence, \( PF = OF - IF + I_{C.W} \) Where \( OF \), \( IF \), and \( I_{C.W} \) are respectively, the total output, input, and working capital of the firm. Now, \( TPF = \) total productivity of the firm = \( OF / IF \). Hence, \( OF = TPF \cdot IF \)

The equations (6.41 and 6.42) are used to compare the total productivity of firm and break even analysis

Substituting for \( OF \),

\[
PF = (TPF - 1) IF + I_{C.W};
\]

\[
PF = a(TPF) - b \quad (6.41)
\]

where \( a = \) total input for a given period = \( I_H + I_M + I_{C.W} + I_{C.F} + I_E + I_X \)

\( b = \) all input other than the working capital = \( I_H + I_M + I_{C.F} + I_E + I_X \)

\[
PF = (TPF - 1) (I_H + I_M + I_{C.W} + I_{C.F} + I_E + I_X) + I_{C.W}
\]

\[
= TPF (I_H + I_M + I_{C.W} + I_{C.F} + I_E + I_X) - (I_H + I_M + I_{C.F} + I_E + I_X) \quad (6.42)
\]

6.11 BREAK-EVEN CONCEPT OF TOTAL PRODUCTIVITY

Let us consider the following four cases by inserting different values for the total productivity.

**Case 1:** \( TPF = 0 \). \( PF = -b \). That is, there will be a loss to the firm equal to the sum of all but the working capital inputs.

**Case 2:** \( TPF = 1 \), Then, \( PF = a - b = I_{C.W} \)

That is, there will be profit exactly equal to the working capital used.

**Case 3:** \( TPF = 1 - I_{C.W} / (I_H + I_M + I_{C.W} + I_{C.F} + I_E + I_X) = 1 - \{ (a-b)/a \} \)

\[
PF = a \{ 1 - \{ (a-b)/a \} \} - b = a \{ (a-a+b)/a \} - b = 0. \]

In other words, the profit will be zero. This value of \( TPF \) is the break-even point.
Case 4: TPF = $K$, where $K$ is some numerical value greater than 1.0. Then, PF = $K(a-b)$. That is, PF= $K \left( I_H + I_M + I_C + I_E + I_X \right) - \left( I_H + I_M + I_{C,F} + I_E + I_X \right)$, as $K$- infinity, PF-infinity, theoretically.

$$(TPF) = 1 - \frac{I_{C,W}}{I_H + I_M + I_{C,W} + I_{C,P} + I_E + I_X}$$

Since the working capital for any firm is always greater than zero, it follows that the break-even point for the total productivity is always less than 1.0. TPF is always $[1 - \text{(proportion of the working capital in the total input)}]$.

6.11.1 Case Study IV –Break Even and Total Productivity Analyses

This case study IV discussed about the production in industry before implementing the robust framework. The size of all fabrics 1, 2 and 3 are 32”, 40” and 48” respectively. Table 6.10 shows the total input and output data for three fabrics. Table 6.11 has the total productivity index calculation. Table 6.12 shows the breakeven point of total productivity for individual fabrics. Table 6.13 has the total and partial productivity of firm.
## Table 6.10 Total input and output for fabrics before implementing robust framework (Case Study - IV)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Elements</th>
<th>Sub Elements</th>
<th>Unit of Measures</th>
<th>Fabric 1 (Period t=0)</th>
<th>Fabric 2 (Period t=1)</th>
<th>Fabric 3 (Period t=0)</th>
<th>Fabric 3 (Period t=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Output</td>
<td>Finished Fabric</td>
<td>meters</td>
<td>25000</td>
<td>46500</td>
<td>33000</td>
<td>42000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially Completed Fabric</td>
<td>meters</td>
<td>9000</td>
<td>13000</td>
<td>12700</td>
<td>11800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% of Partially Completed Fabric</td>
<td>%</td>
<td>30</td>
<td>55</td>
<td>48</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selling Price Meter</td>
<td>Rupees</td>
<td>2.25</td>
<td>2.25</td>
<td>2.35</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dividends from Securities</td>
<td>Rupees</td>
<td>10500</td>
<td>15800</td>
<td>22000</td>
<td>25000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deflator</td>
<td>Rupees</td>
<td>1,000</td>
<td>1,100</td>
<td>1,000</td>
<td>1,100</td>
</tr>
<tr>
<td>B</td>
<td>Input</td>
<td>Workers</td>
<td>Productive time</td>
<td>Man hrs</td>
<td>700</td>
<td>1200</td>
<td>1119</td>
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<tr>
<td></td>
<td></td>
<td>Productive time</td>
<td>Man hrs</td>
<td>100</td>
<td>90</td>
<td>98</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average wage rate</td>
<td>Rs. Man hrs</td>
<td>24</td>
<td>26</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supervisor</td>
<td>Productive time</td>
<td>Man hrs</td>
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<td>120</td>
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<tr>
<td></td>
<td></td>
<td>Productive time</td>
<td>Man hrs</td>
<td>111</td>
<td>120</td>
<td>139</td>
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<tr>
<td></td>
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<td>Average wage rate</td>
<td>Rs. Man hrs</td>
<td>28</td>
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<td></td>
<td></td>
<td>Manager/ Professional</td>
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<td>Man hrs</td>
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<td>Man hrs</td>
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<td>4</td>
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<td>Rs. Man hrs</td>
<td>36</td>
<td>36</td>
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<tr>
<td></td>
<td>Material</td>
<td>Yard 1</td>
<td>Quantity Fabric</td>
<td>metres</td>
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<td>40000</td>
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<tr>
<td></td>
<td></td>
<td>Yard 1</td>
<td>Price per metre</td>
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<tr>
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<td>Chemical quantity</td>
<td>litres</td>
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<td>8</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Yard 2</td>
<td>Price per litre</td>
<td>Rs per litre</td>
<td>200</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yard 2</td>
<td>Components per metre</td>
<td>500</td>
<td>800</td>
<td>900</td>
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### Table 6.10 (Continued)

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<th>Unit of Measures</th>
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<th>Fabric 2</th>
<th>Fabric 3</th>
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<tr>
<td></td>
<td></td>
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</tr>
<tr>
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<td>1100</td>
<td>1000</td>
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<td>Deflator</td>
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<td>1000</td>
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<td>S. No.</td>
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<td>Fabric 3</td>
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<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Period t=0</td>
<td>Period t=1</td>
<td>Period t=0</td>
<td>Period t=1</td>
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<td>Capital with CC</td>
<td>Current liability</td>
<td>~</td>
<td>12000</td>
<td>15000</td>
<td>15000</td>
<td>16000</td>
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<td>%</td>
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Table 6.12  Break Even Point of Total Productivity for individual fabrics before implementing robust framework (Case Study - IV)

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<td>611.38</td>
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Table 6.13  Total and partial productivity of firm before implementing robust framework (Case Study - IV)

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Figure 6.9 illustrates the Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3. The fabric 1, 2 and 3 for the entire base period zero was lead to loss because Break Even Point (BEP) crossed the Total Productivity (TP) for all fabrics. Management should pinpoint and take actions for all fabrics. In real word situation, the firm may decide to discontinue the manufacture of all fabrics in the particular base period. Figure 6.10 illustrates Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3.

![Graph showing Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3](image)

**Figure 6.9 Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3**

Figure 6.11-13 views the Partial Productivity (PP) and Total Productivity (TP) for fabric 1, Partial Productivity (PP) and Total Productivity (TP) for fabric 2 and Partial Productivity (PP) and Total Productivity (TP) for fabric 3 respectively. It proved that the laws of partial and total productivity. Figure 6.14 illustrates Partial Productivity of Firm (PPF) and Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3. The total productivity index and partial productivity index lay extreme end in Figure 6.13. It shows the poor utilization of firm and leads to financial loss.
Figure 6.10 Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3

Figure 6.11 Partial Productivity (PP) and Total Productivity (TP) for fabric 1

Figure 6.12 Partial Productivity (PP) and Total Productivity (TP) for fabric 2
6.11.2 Case Study V – Break Even and Total Productivity Analyses

This case study V described production of firm before implementing the robust framework. The size of all fabrics 1, 2 and 3 are 32”, 40” and 48” respectively. Table 6.14 shows the total input and output data for three fabrics. Table 6.15 shows the breakeven point of total productivity for individual fabrics. Table 6.16 shows the total and partial productivity of firm.
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<th>Fabric 3</th>
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<td>Fabric 3</td>
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<td>1.0 1.1</td>
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Table 6.15 Break Even Point of Total Productivity for individual fabrics before implementing robust framework (Case Study V)

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<td>Total input</td>
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<td>Break-even point</td>
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<td>Total input</td>
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<td>Firm</td>
<td>Working capital</td>
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<td>Total input</td>
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Table 6.16 Total and partial productivity of firm before implementing robust framework (Case Study - V)

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<td>1.000</td>
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<td>Human productivity</td>
<td>Value</td>
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<td>2.913</td>
<td>3.77</td>
<td>2.783</td>
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<td>Material productivity</td>
<td>Value</td>
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</table>
Figure 6.15 illustrates the Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3. The fabric 3 for the base period zero and one & fabric 1 for period one lead to financial loss for the firm because Break Even Point (BEP) crossed the Total Productivity (TP). Management should take actions with respect to concerned fabric. Figure 6.16 illustrates Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3.

Figure 6.15 Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3

Figure 6.16 Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3
Figure 6.17 Partial Productivity (PP) and Total Productivity (TP) for fabric 1

Figure 6.18 Partial Productivity (PP) and Total Productivity (TP) for fabric 2

Figure 6.17-19 illustrate Partial Productivity (PP) and Total Productivity (TP) for fabric 1, Partial Productivity (PP) and Total Productivity (TP) for fabric 2 and Partial Productivity (PP) and Total Productivity (TP) for fabric 3 respectively. This was expected since it proved that the laws of partial and total productivity. Figure 6.20 shows the Partial Productivity of Firm (PPF) and Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3. The total productivity index and partial productivity index lie somewhere between the index lines for all fabrics.
Figure 6.19  Partial Productivity (PP) and Total Productivity (TP) for fabric 3

Figure 6.20  Partial Productivity of Firm (PPF) and Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3

6.11.3 Case Study VI –Break Even and Total Productivity Analyses

This case study VI reflected about the performance of firm after implementing the robust framework. The size of all fabrics 1, 2 and 3 are 32”, 40” and 48” respectively. Table 6.17 displays the total input and output data for three fabrics. Table 6.18 outlooks the total productivity index calculation. Table 6.19 shows the total and partial productivity of firm. Table 6.20 presences the breakeven point of total Productivity for individual fabrics after implementing robust model.
### Table 6.17 Total input and output for three fabrics after implementing robust model (Case Study - VI)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Elements</th>
<th>Sub Elements</th>
<th>Unit of Measures</th>
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<th>Fabric 2</th>
<th>Fabric 3</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
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<td>A</td>
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<td>6.00</td>
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<tr>
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<td>Quantity</td>
<td>litre</td>
<td>~ 1000 litres</td>
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<td>125.00</td>
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<td>Others</td>
<td>Travel</td>
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<td>~</td>
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<td>1200.00</td>
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<tr>
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<td></td>
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<td>~</td>
<td>1.00</td>
<td>1.100</td>
<td>1.100</td>
</tr>
<tr>
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<td>~</td>
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<td>~</td>
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</tr>
<tr>
<td></td>
<td>Professional, Marketing, Information Processing, Office and other supplies expenses C x Deflator</td>
<td>~</td>
<td>2000 /</td>
<td>2200 /</td>
<td>2500 /</td>
<td>2400 /</td>
</tr>
<tr>
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<td>Sub Elements</td>
<td>Unit of Measures</td>
<td>Fabric 1</td>
<td>Fabric 2</td>
<td>Fabric 3</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>--------------</td>
<td>-----------------</td>
<td>---------</td>
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<td>Period t=1</td>
<td>Period t=0</td>
<td>Period t=1</td>
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<td>18500</td>
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<td>%</td>
<td>%</td>
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<td>%</td>
<td>%</td>
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<td>2500</td>
<td>3000</td>
<td>3000</td>
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<td></td>
<td></td>
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<td>%</td>
<td>%</td>
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<td>5</td>
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<td>1000</td>
<td>1200</td>
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<td>1000</td>
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<td>1200</td>
</tr>
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<td>Sub Elements</td>
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<td>Fabric 2</td>
<td>Fabric 3</td>
</tr>
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<td>-------</td>
<td>-------------------</td>
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<td>Mill 3</td>
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<td>30000</td>
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<td>12555</td>
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<td>1680</td>
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<td>20787</td>
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<td>1000</td>
<td>10999</td>
<td>2000</td>
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<td>*</td>
<td>500</td>
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<td>600</td>
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<td>2000</td>
<td>2000</td>
<td>2500</td>
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<tr>
<td></td>
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<td>Total</td>
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<td>5500</td>
<td>35909</td>
<td>5100</td>
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<td></td>
<td>Total Input</td>
<td>*</td>
<td>138884</td>
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<td>Total Productivity</td>
<td>--</td>
<td>1296</td>
<td>133</td>
<td>0.936</td>
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<td></td>
<td></td>
<td>Total Productivity Index</td>
<td>--</td>
<td>1000</td>
<td>1026</td>
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Table 6.19  Total Productivity (TP) and Partial Productivity (PP) for fabrics after implementing robust model (Case Study - VI)

<table>
<thead>
<tr>
<th>PP Derivatives</th>
<th>i=1</th>
<th>i=2</th>
<th>i=3</th>
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<tr>
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<td>P = 0</td>
<td>P = 1</td>
<td>P = 0</td>
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<td>Total productivity</td>
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<tr>
<td>Value</td>
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<td>1.33</td>
<td>0.936</td>
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<td>1.026</td>
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<td>Human productivity</td>
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<td>5.029</td>
<td>4.251</td>
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<td>Material productivity</td>
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<tr>
<td>Value</td>
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<td>2.595</td>
<td>1.584</td>
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<tr>
<td>Index</td>
<td>1.000</td>
<td>0.967</td>
<td>1.000</td>
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<td>Capital productivity</td>
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<td></td>
</tr>
<tr>
<td>Index</td>
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<td>1.371</td>
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<td>Energy productivity</td>
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<tr>
<td>Index</td>
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<td>1.076</td>
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<td>Other productivity</td>
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<td></td>
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<tr>
<td>Value</td>
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<td>63.227</td>
<td>44.849</td>
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<td>Index</td>
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</tr>
</tbody>
</table>

Table 6.20  Break Even Point of Total Productivity for individual fabrics after implementing robust model (Case Study - VI)

<table>
<thead>
<tr>
<th>Fabrics</th>
<th>Item</th>
<th>Period 0</th>
<th>Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric 1</td>
<td>Working capital</td>
<td>1155</td>
<td>1011</td>
</tr>
<tr>
<td></td>
<td>Total input</td>
<td>138884</td>
<td>169576.9</td>
</tr>
<tr>
<td></td>
<td>Break-even point</td>
<td>0.991</td>
<td>0.994</td>
</tr>
<tr>
<td>Fabric 2</td>
<td>Working capital</td>
<td>1636</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>Total input</td>
<td>244290</td>
<td>242671</td>
</tr>
<tr>
<td></td>
<td>Break-even point</td>
<td>0.993</td>
<td>0.993</td>
</tr>
<tr>
<td>Fabric 3</td>
<td>Working capital</td>
<td>2089</td>
<td>1986</td>
</tr>
<tr>
<td></td>
<td>Total input</td>
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<td>273589.2</td>
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<tr>
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<td>Break-even point</td>
<td>0.991</td>
<td>0.992</td>
</tr>
<tr>
<td>Firm</td>
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<td>Total input</td>
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<td>685837.1</td>
</tr>
<tr>
<td></td>
<td>Break-even point</td>
<td>0.992</td>
<td>0.993</td>
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</tbody>
</table>
Figure 6.21 illustrates Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3. The fabric 1 of period zero leads to loss for firm. Management should take actions with respect to concerned fabric. Figure 6.22 elucidates Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3. The TPF lie between the all indexes since the law of TPF is proved.

**Figure 6.21 Absolute level of Total Productivity (TP) and Break Even (BE) for fabric 1, fabric 2 and fabric 3**

**Figure 6.22 Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3**
Figure 6.23 Partial Productivity (PP) and Total Productivity (TP) for fabric 1

Figure 6.24 Partial Productivity (PP) and Total Productivity (TP) for fabric 2

Figure 6.23-6.25 clarified Partial Productivity (PP) and Total Productivity (TP) for fabric 1, Partial Productivity (PP) and Total Productivity (TP) for fabric 2 and Partial Productivity (PP) and Total Productivity (TP) for fabric 3 respectively. This was expected since it proved that the laws of partial and total productivity. Figure 6.26 schemed Partial Productivity of Firm (PPF) and Total Productivity of Firm (TPF) for fabric 1, fabric 2 and fabric 3. The total productivity index and partial productivity index lie somewhere between the index lines for all fabrics.
EVALUATION PROCEDURE STEPS (CASE STUDY - VI)

The following two methods are used for evaluation procedures.

Method 1: In this first budgeting method, it is derived to forecast total productivity by the equation (6.43) single exponent smoothing.
\[ T'_{pt} = aT'_{pt-1} + (1-a) T'_{pt-1} \]  

where \( T'_{pt} \) = budgeted (forecast) total productivity of product \( i \) for time period \( t \)

\( T'_{pt-1} \) = budgeted (forecast) total productivity of product \( i \) for time period \( t-1 \)

\( T_{pt-1} \) = actual total productivity of \( i \) in time period \( t-1 \)

\( \alpha \) = smoothing constant (lies between 0 and 1) If

\( T_{pt} \) = actual total productivity of product ‘\( i \)’ in time period \( t \)

\( V \, T_{pt} \) = variation of actual from budgeted total productivity in period \( t \) using method 1

\( PV \, T_{p1t} \) = percent variation of actual from budgeted total productivity in period \( t \) using method 1, Then

\[ V \, T_{p1t} = T_{pt} - T'_{pt} \]

\[ PV_{p1t} = \left( \frac{T_{pt}}{T'_{pt}} - 1 \right) \times 100 \]

\[ = \left( \frac{T_{pt}}{(a \, T_{pt-1} + (1+a) \, T'_{pt-1})} - 1 \right) \times 100 \]  

(6.44)

From this above equation (6.44), the \% variation of total productivity for product \( i \) in period are computed. Since \( T'_{pt} \) and \( T'_{pt} \) are the actual known values, a reasonable value of \( \alpha \) is assumed and \( T'_{pt-1} \) is computed from the equation (6.45).

\[ T'_{pt-1} = a \, T_{pt-2} + (1-a) \, T'_{pt-2} \]  

(6.45)
An alternate expression for $TP_{it}^1$ is derived recursively as follows:

In period 1  : $TP_{i1}^t = \alpha TP_{i0} + (1+\alpha) TP_{i0}^t$

In period 2  : $TP_{i2}^t = \alpha TP_{i1} + \alpha (1-\alpha) TP_{i0} + (1-\alpha)^2 TP_{i0}^t$

In period 3  : $TP_{i3}^t = \alpha TP_{i2} + \alpha (1-\alpha) TP_{i1} + \alpha (1-\alpha)^2 TP_{i0} + (1-\alpha)^3 TP_{i0}^t$

In general, forecast for period $t$ by recursion is obtained and represented in the following equation (6.46).

$$TP_{it}^t = \alpha TP_{it-1} + \alpha (1-\alpha) TP_{it-2} + \alpha (1-\alpha)^2 TP_{it-3} + \ldots + (1-\alpha)^t TP_{i0}^t \quad \text{(or)}$$

$$TP_{it-1}^t = \alpha TP_{it-2} + \alpha (1-\alpha) TP_{it-3} + \alpha (1-\alpha)^2 TP_{it-4} + \ldots + (1-\alpha)^{t-1} TP_{i0}^t \quad (6.46)$$

**Method 2**: when method 1 uses single exponential smoothing to forecast total productivity in period $t$, this method relies on the PET and judge of the management.

At the end of the previous period $t-1$, $\Delta TP_{it-1}$ is known, depending upon whether $\Delta TP_{it-1} = 0$, $\Delta TP_{it-1} > 0$, $\Delta TP_{it-1} < 0$ and knowing $TP_{it-2}$. We can determine the path in the PET. The management can be decided which path should be aimed as for the period‘t’. $TP_{it}^*$ is determined the ‘best forecast’ represented in the equation (6.47).

$$TP_{it}^* = O_{it}^* / I_{it}^*, \quad O_{it}^* = O_{it-1} + \Delta O_{it}^*, \quad I_{it}^* = I_{it-1} + \Delta I_{it}^* \quad (6.47)$$

The values $\Delta O_{it}^*$ and $\Delta I_{it}^*$ are the ‘best’ values of output and input changes envisaged by the management or the productivity planner to satisfy the best strategy chosen in the PET. The equation (6.48) is percent variation of actual.
$TP_t$ = actual total productivity of product

$VTP_{it}^{(2)}$ = variation of actual budgeted total productivity of product $i$ in period $t$

$PVTP_{it}^{(2)}$ = percent variation of actual from budgeted total productivity in period ‘t’

$$VTP_{it}^{(2)} = TP_{it} - TP_{it}^*$$

$$PVTP_{it}^{(2)} = \{ (TP_{it} / TP_{it}^*) - 1 \} \times 100$$ (6.48)

Figure 6.8 symbolizes the computational scheme for determining the variation of total productivity. It helps to enable a quick understanding of the two methods and the associated sequence of computation.

**Computational procedures for evaluation (Case Study VI):** The total productivity of fabric 2 is 0.936 and 1.012 in period 0 and period 1 respectively. Therefore, the change in total productivity between period 0 and 1 is given by

$$\Delta TP_{11} = 1.012 - 0.936 = 0.076$$

Now, suppose the total productivity of fabric 1 is evaluated in period 2, that is, $t=2$, then, using the methodology outlined in the Table 6.9, calculations are

At the end of period 0: $$TP'_{11} = \alpha TP'_{10} + (1 - \alpha)TP_{10}$$

Suppose, assume that the productivity measurement started in period 0 for the first time, then assumes that $TP_{10} = TP'_{10} = 0.936$. Let us select $\alpha$ value of 0.2 to begin with. Then, the following calculation was accomplished using the equations (6.43-6.48)

$$TP'_{11} = 0.2(0.936) + (1 - 0.2)(0.936) = 0.936$$
At the end of period 1:

\[ TP'_{12} = \alpha TP_{11} + (1-\alpha)TP'_{11} = 0.2(1.012) + (1 - 0.2)(0.936) = 0.951 \]

Thus, at the end of period 1, for which data have been available, the forecast for the total productivity in the next period (period 2) is 0.951. Also, we calculate earlier that the \( \Delta TP_{11} = 0.076 \)

At the end of period 2:

Let, assume that the total productivity for product 1 was 0.999, that is, \( TP_{12} = 0.999 \). Then the variation and percent variation of total productivity is computed using Method 1:

\[ VTP_{12}^{(1)} = TP_{12} - TP'_{12} = 0.999 - 0.951 = 0.048 \]

\[ PVT_{12}^{(1)} = \left( \frac{TP_{12} - 1}{TP'_{12}} \right) * 100 = \left( \frac{0.999}{0.951} - 1 \right)*100 = 5.05 \%

Next, use the method 2 to determine the variation and percent variation and percent variation. In this method, instead of forecasting the total productivity in period 2 by single exponential smoothing, it may be predicted by combining managerial judgment with the actual conditions at the end of period 1. In other words, management predicts the “best” possible value for

\[ TP_{12} : TP_{12} = O_{12} + I_{12} \]

\[ O_{11} = Rs227045; I_{11} = 180000 \]

Now, \( \Delta TP_{11} = 0.076 \), as already computed. This means that \( \Delta TP_{11} > 0 \). From the PET, that condition can be achieved in nine possible ways in period 1. Obviously, would like to continue this trend in total productivity. Suppose the management of industry wants to reduce the inputs without reducing the
output in period 2, it would select path number 16 in the PET. Based on the capability of the industries employees in reducing the total input for period 2, suppose that the management decides on a reduction of input by 10 percent when compared to period 1. That is, \( \Delta I^*_{12} = -0.10 \times 180000 = \text{Rs} - 18000 \). Path 16 implies that \( \Delta O^*_{12} = 0 \).

\[
O^*_{12} = 227045 + 0.0 = 227045 \quad I^*_{12} = 180000 + (-18000) = 162000 \quad TP^*_{12} = \frac{227045}{162000} = 1.402
\]

Therefore, the variation and percent variation of total productivity of fabric 1 in period 2 can be determined by the following formulas:

\[
VT_{P12}^{(2)} = TP_{12} - TP^*_{12} = 0.999 - 1.402 = -0.403
\]

\[
PVT_{P12}^{(2)} = \left[ \frac{TP_{12}}{TP^*_{12}} - 1 \right] \times 100 = \left[ \frac{0.999}{1.042} - 1 \right] \times 100 = -0.041 = -4.1\%
\]

It noticed that the percent variations as determined by methods 1 and 2 are not the same; in fact, they differ by almost 0.95 %. This may be due to the fact that the management expected its input to be reduced by 10 % amount that is not practically feasible. Here the difference is 0.95 %. So the process is stable and it is less than one percent. From this case study VII, the total productivity of a product evaluated between two successive time periods as well as within a given time period through PET.

### 6.13 CASE STUDY VII - QUALITY FUNCTION DEPLOYMENT (QFD)

The case study VII discusses the Quality Function Deployment (QFD) procedure in industry and the QFD deals with House of Quality (HoQ). Table 6.21 gives the requirements and assessment of customer and technical level.
The following steps are carried out in the industry.

1. Identifying the customer requirement of the fabric
2. Identifying the technical requirements of the fabric
3. Relating the customer and technical requirement of the fabric
4. Constructing the HoQ
5. Evaluating with reference to target.

Table 6.21 Requirements and assessment of customer and technical level

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Fabric Characteristics</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Customer Requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Aesthetics (X₁)</td>
<td>X₁₁ Cost</td>
<td>X₁₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₂ Performance</td>
<td>X₁₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₃ Length</td>
<td>X₁₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₄ Body height</td>
<td>X₁₄</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₅ Colour</td>
<td>X₁₅</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₆ Fabric weight</td>
<td>X₁₆</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₁₇ Packaging</td>
<td>X₁₇</td>
</tr>
<tr>
<td>2</td>
<td>Reliability (X₂)</td>
<td>X₂₁ Consistence of the product performance overtime</td>
<td>X₂₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₂₂ Average time for product to fail</td>
<td>X₂₂</td>
</tr>
<tr>
<td>3</td>
<td>Accuracy &amp; Precision (X₃)</td>
<td>X₃₁ Ability to provide right service from first time with minimum errors</td>
<td>X₃₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₃₂ Ability to meet company with the customer requirements</td>
<td>X₃₂</td>
</tr>
<tr>
<td>4</td>
<td>Responsiveness (X₄)</td>
<td>X₄₁ Actual project duration</td>
<td>X₄₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₄₂ Shrinkage</td>
<td>X₄₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₄₃ Color fastness to washing</td>
<td>X₄₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₄₄ Color fastness to rubbing</td>
<td>X₄₄</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₄₅ Print durability</td>
<td>X₄₅</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₄₆ Dimensional changes after washing</td>
<td>X₄₆</td>
</tr>
<tr>
<td>5</td>
<td>Communication (X₅)</td>
<td>X₅₁ Ability to share the information about process of the project</td>
<td>X₅₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₅₂ Ability to listen to the customer complaints and suggestion</td>
<td>X₅₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X₅₃ Understanding the customer</td>
<td>X₅₃</td>
</tr>
<tr>
<td>S.No.</td>
<td>Fabric Characteristics</td>
<td>Primary</td>
<td>Secondary</td>
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<td></td>
<td></td>
<td></td>
<td>Technical Requirements</td>
</tr>
<tr>
<td>6</td>
<td>Management Involvement ((Y_1))</td>
<td>(Y_{11}) Encourage and inherent the quality responsibility to all firm staff</td>
<td>(Y_{12}) Quality and continuous improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{13}) The degree of top management, involvement, support and empowerment</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Manufacturing Process ((Y_{21}))</td>
<td>(Y_{21}) Calendaring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{22}) Squeezing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{23}) Stenter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{24}) Dyeing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{25}) Fabrication</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Testing ((Y_3))</td>
<td>(Y_{31}) Packing</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{32}) Checking</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{33}) Stitching</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{34}) Cutting</td>
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</tr>
<tr>
<td>9</td>
<td>Standards ((Y_4))</td>
<td>(Y_{41}) DIN EN 12127: 1997</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{43}) ISO 105 X12: 2001</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(Y_{44}) ISO 105 C06: 2010 C2S</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Future Development ((Y_5))</td>
<td>(Y_{51}) Employee training</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Y_{52}) Customer feedback and analysis</td>
<td></td>
</tr>
</tbody>
</table>

**Technical Competitive Assessment**

- 11 \(T_1\) Degree of Technical Difficulty
- 12 \(T_2\) Target value
- 13 \(T_3\) Absolute weight
- 14 \(T_4\) Relative weight

**Customer Competitive Assessment**

- 15 \(C_1\) Importance to customer
- 16 \(C_2\) Target value
- 17 \(C_3\) Scale-up factor
- 18 \(C_4\) Sales point
- 19 \(C_5\) Absolute weight
Table 6.22 demonstrates the relationship between customer requirements and technical specifications. It comprises the customer and technical competitive assessment. The colored curved line indicates the level of rating. Table 6.23 illuminates the prioritized customer requirements. The computational process of product has been mentioned in the corresponding parameter. Figure 6.27 displays the Roof of House of Quality (HoQ). It has been derived from customer and technical requirements. The technical and customer competitive assessment computational steps are as follows:

**Determination of Scale up factor and absolute weight for \( X_{11} \)**

- Scale-up factor = Target Value / Product Rating
  
  \[ \text{Target Value} = 4 ; \quad \text{Product Rating} = 2 ; \quad \text{Scale-up Factor} = \frac{4}{2} = 2 \]

- Absolute Weight: (Customer Oriented)

  \[ \text{Absolute Weight} = \text{Importance to Customer} \times \text{Scale-up Factor} \times \text{Sales Point} \]

  \[ \begin{align*}
  \text{Importance to Customer} & = 9 \\
  \text{Scale-up factor} & = 2 \\
  \text{Sales Point} & = 1.5 \\
  \text{Absolute Weight} & = 9 \times 2 \times 1.5 = 27
  \end{align*} \]

**Determination of absolute and relative weight for \( Y_{11} \)**

Absolute weight \( (a_j) \): The absolute weight for the \( j^{th} \) technical descriptor is given by

\[
a_j = \sum_{i=1}^{n} R_{ij} C_i ;
\]
where \( a_j \) = row vector of absolute weights for the technical descriptors 
\( (i = 1 \ldots m) \)

\( R_{ij} \) = weights assigned to the relationship matrix \( (i= 1 \ldots n, j= 1 \ldots m) \)

\( C_i \) = column vector of importance to customer for the customer requirements \( (i= 1 \ldots n) \)

\( m \) = number of technical descriptors

\( n \) = number of customer requirements

\[ a_j = 1 \times 9 + 3 \times 9 + 1 \times 6 + 1 \times 8 + 1 \times 6 + 3 \times 4 + 3 \times 5 + 3 \times 3 + 1 \times 3 + 1 \times 5 = 100. \]

**Relative weight \( (b_j) \):** The relative weight for the \( j^{th} \) technical descriptor is given by

\[ b_j = \sum_{i=1}^{n} R_{ij} d_i \quad \text{Where} \]

\( b_j \) = row vector of relative weights for the technical descriptors 
\( (j = 1 \ldots m) \)

\( d_i \) = column vector of absolute weights for customer requirements \( (i = 1 \ldots n) \)

\[ b_j = 1 \times 13.5 + 3 \times 23.4 + 1 \times 6 + 1 \times 12 + 1 \times 9 + 3 \times 8 + 3 \times 10 + 3 \times 3 + 1 \times 3 + 1 \times 7.5 \]

\[ b_j = 184.2 \]
### Table 6.22: Relationship between customer requirements and technical specifications

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>Technical Requirements</th>
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<td></td>
<td></td>
<td></td>
<td>Y1</td>
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<table>
<thead>
<tr>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
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<td>12</td>
<td>13</td>
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<tr>
<td>16</td>
<td>17</td>
<td>18</td>
<td></td>
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</tr>
</tbody>
</table>

**Legend:**
- **-9**: Strong
- **-3**: Medium
- **+1**: Weak

**Product ratings:**
- **M**: Measured fabric
- **Q and P**: Others

**Customer Competitive Assessment**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Rating</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>teammate</td>
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</table>

**Prioritized Technical Description**

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<tr>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>16</td>
<td>17</td>
<td>18</td>
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</table>
### Table 6.23 Prioritized Customer Requirements

<table>
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<tr>
<th>Customer Requirements</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
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<table>
<thead>
<tr>
<th>Importance to customer (C1)</th>
<th>Target value (C2)</th>
<th>Scale up factor (C3)</th>
<th>Sales point (C4)</th>
<th>Absolute weight (C5)</th>
</tr>
</thead>
</table>

**Inter relationship matrix between HOWs**

- **Strong positive**
- **Positive**
- **Negative**
- **Strong Negative**

**Figure 6.27** Roof of House of Quality (HoQ)
6.14 RESULTS OF QFD CASE STUDY

The following results are drawn from the QFD case study

- In the customer requirements characteristics, scale-up factor of $X_{16}$, $X_{32}$, $X_{46}$, and $X_{53}$ is 2.5 which indicates that more effort is needed for fabric weight, average time for product to fail, dimensional changes after washing and understanding the customer respectively. The computational process of prioritized customer requirements illustrates in Table 6.21. The absolute weight of $X_{51}$ is 3 which indicated that ability to share the information about process of the project is not significant because of low value.

- The absolute weight of manufacturing dyeing process ($Y_{24}$) is 624 which indicate that a high effort is needed in technical requirements.

- Quality and continuous improvement of technical requirements ($Y_{12}$) are 746. This high value indicates that more concentration and effort are needed by management.

- The firm should satisfy the expectation of customers to improve its quality and goodwill for further business.

- Need to redesign and improve the primary and secondary characters of customer and technical requirements with regard to obtained score.

- So there is need to continuously monitor and review the requirements at regular intervals.
6.15 SCOPE AND LIMITATIONS OF QFD

The following scopes are identified in this case study.

- This procedure refers to the current performance of a dyeing and chemical industry.
- This case study provides the relationship between the customer and technical requirement with various dimensions.
- The computational process of prioritized technical and customer parameters gives a big view about the quality of fabric.
- The process provides a means of identifying the important requirements specified by customer.

The following limitations are identified in QFD application.

- QFD process is a shorter for product development cycle.
- In constructing HoQ, customer assessment and technical requirement are evaluated using crisp values. It may be improved through linguistic scale for achieving better results.