Process Capability Analysis at a Manufacturing Company

This case study is about a Six Sigma project implemented by the production manager at a manufacturing firm that produces a critical automobile part used in cars produced by three major automobile companies. The production manager aims to improve the capability of the manufacturing process.

Recall the following process capability ratios from Chapter 2.

\[
C_p = \frac{USL - LSL}{6\sigma}
\]

\[
C_{pl} = \frac{\mu - LSL}{3\sigma}
\]

\[
C_{pu} = \frac{USL - \mu}{3\sigma}
\]

\[
C_{pk} = \text{MIN}\{C_{pl}, C_{pu}\}
\]

where

- \(USL\) = Upper specification limit
- \(LSL\) = Lower specification limit
- \(\mu\) = Process mean
- \(\sigma\) = Process standard deviation

The higher the \(C_p\) and \(C_{pk}\) values are, the better the process is.

Section 6.1 gives a brief description of the define phase. Section 6.2 illustrates the measure phase with detailed instructions for using Minitab\textsuperscript{®}. The analyze phase is briefly discussed in Section 6.3. Section 6.4 illustrates the improve phase with detailed instructions for using Minitab\textsuperscript{®}. Finally, the control phase is briefly discussed in Section 6.5.
6.1 Define Phase

The production manager desires to increase the capability of the manufacturing process with a USL value of 60 units and an LSL value of 50 units for the part diameter. The problem statement is “to increase the $C_p$ and $C_{pk}$ values.”

6.2 Measure Phase

Twenty samples, each containing 5 parts, are collected, and their diameters are measured. The data are shown in Table 6.1.

Before $C_p$ and $C_{pk}$ values are calculated, it is important to check whether the process data are normally distributed and in statistical control. The following is the approach to do so.

Open the CHAPTER_6_1.MTW worksheet containing the data from Table 6.1 in a single column (the worksheet is available at the publisher’s website; the data from the worksheet are also provided in the Appendix). Figure 6.1 is a screenshot of the partial worksheet (it shows only 19 of the 100 numbers). Figures 6.2 and 6.3 illustrate how to check for normality and Figure 6.4 shows the normality test results. Because the $P$-value in Figure 6.4 is greater than 0.05, it is evident that the process data are normally distributed.

Figure 6.5 partially shows the data copied from Table 6.1 to the CHAPTER_6_1.MTW worksheet. In order to check whether the data are in statistical control, the data need to be transposed to have each sample in a single row. Figures 6.6 and 6.7 show how to transpose the data, and Figure 6.8 shows the transposed data in a new worksheet. (Do not delete the previous worksheet because you need it for process capability analysis later.) For clarity, the headings of the columns are revised, and the revised worksheet is shown in Figure 6.9.

Because the data are variable data and the sample size is 5, the appropriate control charts to construct are the $\bar{X}$ chart and R chart. Figures 6.10 and 6.11 show how to construct the R chart, and Figure 6.12 shows the R chart. The sample ranges are in statistical control, therefore check whether the sample means are in statistical control. Figures 6.13 and 6.14 show how to construct the $\bar{X}$ chart. It is evident from the $\bar{X}$ chart in Figure 6.15 that the sample means are also in statistical control.

Because the process data are normally distributed and are in statistical control, we can calculate the process capability ratios now. Figures 6.16 and 6.17 illustrate how to do so. Figure 6.18 shows that the USL and LSL are entered in the respective boxes. Click on “Options” in the dialog box shown in Figure 6.18, and the dialog box shown in Figure 6.19 opens. Uncheck the “Overall Analysis” box and enter the “Title” as shown in Figure 6.19. Click
### TABLE 6.1
Production Data before Process Improvement

<table>
<thead>
<tr>
<th></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>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.9</td>
<td>54.3</td>
<td>49.3</td>
<td>55.9</td>
<td>54.5</td>
<td>60.7</td>
<td>57.7</td>
<td>54.6</td>
<td>52.7</td>
<td>55.7</td>
<td>53.8</td>
<td>54.4</td>
<td>55.8</td>
<td>56</td>
<td>54.1</td>
<td>57.2</td>
<td>54.3</td>
<td>52.1</td>
<td>55</td>
<td>53.6</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>55.7</td>
<td>53.4</td>
<td>51.9</td>
<td>58.8</td>
<td>53.2</td>
<td>52.6</td>
<td>56</td>
<td>54.5</td>
<td>55.9</td>
<td>55.7</td>
<td>55</td>
<td>54.8</td>
<td>53.3</td>
<td>53.4</td>
<td>55.6</td>
<td>54.4</td>
<td>53.2</td>
<td>54.4</td>
<td>55.4</td>
<td></td>
</tr>
<tr>
<td>55.5</td>
<td>55.9</td>
<td>52.7</td>
<td>56.2</td>
<td>54.4</td>
<td>56.2</td>
<td>54.6</td>
<td>53</td>
<td>51.3</td>
<td>52.9</td>
<td>51.7</td>
<td>56.2</td>
<td>53.2</td>
<td>53.8</td>
<td>54.4</td>
<td>56</td>
<td>54.1</td>
<td>52.4</td>
<td>54.5</td>
<td>56.9</td>
<td></td>
</tr>
<tr>
<td>54.1</td>
<td>58.1</td>
<td>51.1</td>
<td>55.1</td>
<td>56.1</td>
<td>54.2</td>
<td>55.7</td>
<td>56.4</td>
<td>55.7</td>
<td>53.9</td>
<td>52.1</td>
<td>54</td>
<td>57</td>
<td>56.7</td>
<td>53.7</td>
<td>52</td>
<td>52.6</td>
<td>54.4</td>
<td>57.1</td>
<td>53.1</td>
<td></td>
</tr>
<tr>
<td>55.9</td>
<td>55.1</td>
<td>56.5</td>
<td>53</td>
<td>57.3</td>
<td>54.9</td>
<td>54.8</td>
<td>51.4</td>
<td>52.5</td>
<td>59.1</td>
<td>56.8</td>
<td>53.7</td>
<td>56.7</td>
<td>55.7</td>
<td>57.4</td>
<td>57.8</td>
<td>51.8</td>
<td>52.3</td>
<td>52.7</td>
<td>53.4</td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 6.1
Data in one column in Minitab\textsuperscript{®} worksheet before process improvement.

on “OK” and it takes you back to the dialog box shown in Figure 6.18. Click on “OK”, and the graph shown in Figure 6.20 is the result. The current $C_p$ and $C_{pk}$ values are 0.85 and 0.79, respectively.

6.3 Analyze Phase
The production manager, along with her team, analyzes the process, and identifies that a couple of machine tools on the assembly line are not properly aligned.
FIGURE 6.2
Approach to normality test before process improvement.

FIGURE 6.3
Normality test before process improvement.

© 2008 Taylor & Francis Group, LLC
FIGURE 6.4
Normality test result before process improvement.

FIGURE 6.5
Data showing samples in Minitab® worksheet before process improvement.
FIGURE 6.6
Transpose of columns before process improvement.

FIGURE 6.7
Storing transposed data in a new worksheet before process improvement.
Upon realigning the machine tools and running the process, five more samples, each containing 12 parts, are collected, and their diameters are measured. The data are shown in Table 6.2.

Assuming normal distribution of process data, the next step is to check whether the process is in statistical control. Open the CHAPTER_6_2.MTW worksheet containing the data from Table 6.2 (the worksheet is available at the publisher’s website; the data from the worksheet are also provided in the Appendix). Figure 6.21 is a screenshot of the partial worksheet.

In order to check whether the data are in statistical control, the data need to be transposed to have each sample in a single row. Figures 6.22 and 6.23 show how to transpose the data, and Figure 6.24 shows the transposed data in a new worksheet. (Do not delete the previous worksheet because you need it for process capability analysis later.) For clarity, the headings of the columns are revised, and the revised worksheet is shown in Figure 6.25.

**FIGURE 6.8**
Transposed data without headings before process improvement.

### 6.4 Improve Phase

Upon realigning the machine tools and running the process, five more samples, each containing 12 parts, are collected, and their diameters are measured. The data are shown in Table 6.2.

Assuming normal distribution of process data, the next step is to check whether the process is in statistical control. Open the CHAPTER_6_2.MTW worksheet containing the data from Table 6.2 (the worksheet is available at the publisher’s website; the data from the worksheet are also provided in the Appendix). Figure 6.21 is a screenshot of the partial worksheet.

In order to check whether the data are in statistical control, the data need to be transposed to have each sample in a single row. Figures 6.22 and 6.23 show how to transpose the data, and Figure 6.24 shows the transposed data in a new worksheet. (Do not delete the previous worksheet because you need it for process capability analysis later.) For clarity, the headings of the columns are revised, and the revised worksheet is shown in Figure 6.25.
FIGURE 6.9
Transposed data with headings before process improvement.

FIGURE 6.10
Approach to constructing R chart before process improvement.
FIGURE 6.11
Selections for R chart before process improvement.

FIGURE 6.12
R chart before process improvement.
FIGURE 6.13
Approach to constructing $\bar{X}$ chart before process improvement.

FIGURE 6.14
Selections for $\bar{X}$ chart before process improvement.
FIGURE 6.15
$\bar{X}$ chart before process improvement.

FIGURE 6.16
Approach to capability analysis before process improvement.
FIGURE 6.17
Subgroup selection for capability analysis before process improvement.

FIGURE 6.18
Specification limits for capability analysis before process improvement.
FIGURE 6.19
Options for capability analysis before process improvement.

FIGURE 6.20
Capability analysis before process improvement.
TABLE 6.2
Production Data after Process Improvement

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>56</td>
<td>55</td>
<td>54</td>
<td>55.9</td>
<td>54.5</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>51</td>
<td>53.4</td>
<td>51.9</td>
<td>58.8</td>
<td></td>
</tr>
<tr>
<td>55.5</td>
<td>55.9</td>
<td>52.7</td>
<td>56.2</td>
<td>54.4</td>
<td></td>
</tr>
<tr>
<td>54.1</td>
<td>58.1</td>
<td>51.1</td>
<td>55.1</td>
<td>56.1</td>
<td></td>
</tr>
<tr>
<td>55.9</td>
<td>55.1</td>
<td>56.5</td>
<td>53</td>
<td>57.3</td>
<td></td>
</tr>
<tr>
<td>53.2</td>
<td>55.7</td>
<td>56</td>
<td>57.7</td>
<td>57.7</td>
<td></td>
</tr>
<tr>
<td>56.2</td>
<td>55.9</td>
<td>53.3</td>
<td>52.6</td>
<td>52.6</td>
<td></td>
</tr>
<tr>
<td>54.2</td>
<td>52.9</td>
<td>53.8</td>
<td>54.6</td>
<td>54.6</td>
<td></td>
</tr>
<tr>
<td>54.9</td>
<td>53.9</td>
<td>56.7</td>
<td>55.7</td>
<td>55.7</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>59.1</td>
<td>55.7</td>
<td>54.8</td>
<td>54.8</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>52.4</td>
<td>53.1</td>
<td>55</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>54.4</td>
<td>53.4</td>
<td>54.4</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

The data are variable data and the sample size is 12, therefore the appropriate control charts to construct are the $\bar{X}$ chart and $S$ chart. Figures 6.26 and 6.27 show how to construct the $S$ chart, and Figure 6.28 shows the $S$ chart. Inasmuch as the sample standard deviations are in statistical control, check whether the sample means are in statistical control.

FIGURE 6.21
Data showing samples in Minitab® worksheet after process improvement.

© 2008 Taylor & Francis Group, LLC
FIGURE 6.22
Transpose of columns after process improvement.

FIGURE 6.23
Storing transposed data in a new worksheet after process improvement.
FIGURE 6.24
Transposed data without headings after process improvement.

FIGURE 6.25
Transposed data with headings after process improvement.

FIGURE 6.26
Approach to constructing S chart after process improvement.
FIGURE 6.27
Selections for S chart after process improvement.

FIGURE 6.28
S chart after process improvement.
Figures 6.29 and 6.30 show how to construct the $\bar{X}$ chart. It is evident from the $\bar{X}$ chart in Figure 6.31 that the sample means are also in statistical control. Because the process data are normally distributed and are in statistical control, we can calculate the process capability ratios now. Figures 6.32 and 6.33 illustrate how to do so. Figure 6.34 shows that the USL and LSL are entered in the respective boxes. Click on “Options” in the dialog box shown in Figure 6.34, and the dialog box shown in Figure 6.35 opens. Uncheck the “Overall Analysis” box and enter the “Title” as shown in Figure 6.35. Click on “OK” and it takes you back to the dialog box shown in Figure 6.34. Click on “OK” and the graph shown in Figure 6.36 is the result. The new $C_p$ and $C_{pk}$ values are 0.89 and 0.89, respectively. As is obvious, the process is improved.

**FIGURE 6.29**
Approach to constructing $\bar{X}$ chart after process improvement.

**FIGURE 6.30**
Selections for $\bar{X}$ chart after process improvement.
FIGURE 6.31
$\bar{X}$ chart after process improvement.

FIGURE 6.32
Approach to capability analysis after process improvement.
FIGURE 6.33
Subgroup selection for capability analysis after process improvement.

FIGURE 6.34
Specification limits for capability analysis after process improvement.
FIGURE 6.35
Options for capability analysis after process improvement.

FIGURE 6.36
Capability analysis after process improvement.
6.5 Control Phase

With the help of the supplier of the machines and their tools, the production manager installs a fail-safe mechanism that prevents misalignment of the two tools.