# Six Sigma Quality: Concepts & Cases- Volume I
## STATISTICAL TOOLS IN SIX SIGMA DMAIC PROCESS WITH MINITAB® APPLICATIONS

Chapter 6

# PROCESS CAPABILITY ANALYSIS FOR SIX SIGMA

# CHAPTER OUTLINE

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> ***This document contains explanation and examples on process capability analysis from Chapter 6 of our Six Sigma Volume 1. The book contains numerous cases, examples and step-wise computer instruction with data files.***

# PROCESS CAPABILITY

Process Capability is the ability of the process to meet specifications. The capability analysis determines how the product specifications compare with the inherent variability in a process. The inherent variability of the process is the part of process variation due to common causes. The other type of process variability is due to the special causes of variation.

*It is a common practice to take the six-sigma spread of a process's inherent variation as a measure of process capability when the process is stable. Thus, the process spread is the process capability, which is equal to six sigma.*

# PROCESS CAPABILITY ANALYSIS: AN IMPORTANT PART OF AN OVERALL QUALITY IMPROVEMENT PROGRAM

The purpose of the process capability analysis involves assessing and quantifying variability before and after the product is released for production, analyzing the variability relative to product specifications, and improving the product design and manufacturing process to reduce the variability. Variation reduction is the key to product improvement and product consistency.

The process capability analysis is useful in determining how well the process will hold the tolerances (the difference between specifications). The analysis can also be useful in selecting or modifying the process during product design and development, selecting the process requirements for machines and equipment, and above all, reducing the variability in production processes.

## DETERMINING PROCESS CAPABILITY

The following points should be noted before conducting a process capability analysis.

- Process capability should be assessed once the process has attained statistical control. This means that the special causes of variation have been identified and eliminated. Once the process is stable, ..............

- In calculating process capability, the specification limits are required in most cases, ...... Unrealistic or inaccurate specification limits may not provide correct process capability.

- Process capability analysis using a histogram or a control chart is based on the assumption that the process characteristics follow a normal distribution. While the assumption of normality holds in many situations, there are cases where the processes do not follow a normal distribution. Extreme care should be exercised where normality does not hold. In cases where the data are not normal, it is important to determine the appropriate distribution to perform process capability analysis. In case of non-normal data, appropriate data transformation techniques should be used to bring the data to normality.

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## SHORT-TERM AND LONG-TERM VARIATION

The standard deviation that describes the process variation is an integral part of process capability analysis. In general, the standard deviation is not known and must be estimated from the process data. There are differences of opinion on how to estimate the standard deviation in different situations. The estimated standard deviation used in process capability calculations may address "short-term" or "long-term" variability. The variability due to common causes is described as "short-term" variability, while the variability due to special causes is considered "long-term" variability.

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Some examples of "long-term" variability may be lot-to-lot variation, operator-to-operator variation, day-to-day variation or shift-to-shift variation. Short-term variability may be within-part variation, part-to-part variation, variations within a machine, etc. However, the literature differs on what is "long-term" and what is "short-term" variation.

In process capability analysis, both "short-term" and "long-term" indexes are calculated and are not considered separately in assessing process capability. The indexes Cp and Cpk are "short-term" capability indexes and are calculated using "short-term" standard deviation whereas, Pp and Ppk are "long-term" capability and

are calculated using "long-term" standard deviation estimate. These are discussed in more detail later.

## DETERMINING PROCESS CAPABILITY

Following are some of the methods used to determine the process capability. The first two are very common and are described below.

(1) Histograms and probability plots,

(2) Control charts, and

(3) Design of experiments.

## PROCESS CAPABILITY USING HISTOGRAMS: SPECIFICATION LIMITS KNOWN

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Suppose that the specification limits on the length is 6.00±0.05. We now want to determine the percentage of the parts outside of the specification limits. Since the measurements are very close to normal, we can use the normal distribution to calculate the nonconforming percentage. Figure 6.2 shows the histogram of the length data with the target value and specifications limits. To do this plot, follow the instructions in Table 6.2.

Table 6.2

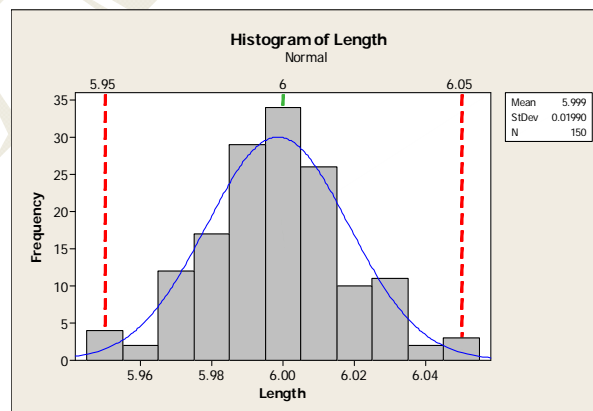| | |
|---|---|
| **HISTOGRAM WITH SPECIFICATION LIMITS** | Open the worksheet **PCA1.MTW** <br> From the main menu, select **Graph ➤ Histogram** <br> Click on **With Fit** then click **OK** <br> For **Graph variables, ……….....**Click the **Scale** then click the **Reference Lines** tab <br> In the Show **reference lines at data values** type **5.95 6.0 6.05** <br> Click **OK** in all dialog boxes. |



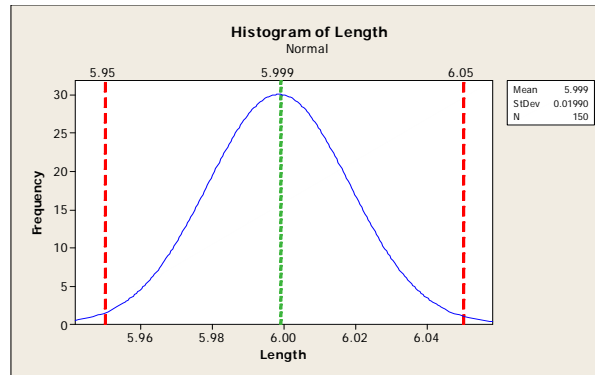Figure 6.2: Histogram of the Length Data with Specification Limits and Target

Figure 6.3: Fitted Normal Curve with Reference Line for the Length Data

Table 6.4

| |
|---|
| **Cumulative Distribution Function** |
| Normal with mean = 5.999 and standard deviation = 0.0199 |
|     x       P( X <= x ) |
|    5.95     0.0069022 |
|    6.05     0.994809 |

From the above table, the percent conforming can be calculated as 0.994809 - 0.0069022 = 0.98790 or, 98.79%. Therefore, the percent outside of the specification limits is 1-0.98790 or, 0.0121 (1.21%). This value is close to what we obtained using manual calculations. The calculations using the computer are more accurate.

## PROCESS CAPABILITY USING PROBABILITY PLOTS

A probability plot can be used in place of a histogram to determine the process capability. Recall that a probability plot can be used to determine the distribution and shape of the data. If the probability plot indicates that the distribution is normal, the mean and standard deviation can be estimated from the plot. For the length data discussed above, we know that the distribution is normal. We will construct a probability plot (or perform a Normality test) .......

Table 6.5

| | |
|---|---|
| **NORMALITY TEST**<br>**USING PROBABILITY PLOT** | Open the worksheet **PCA1.MTW**<br>From the main menu, select **Stat ➢ Basic Statistics ➢Normality Test**<br>For **Variable**, Select **C1 Length**<br>Under **Percentile Line**, .....type **5 0 84** in the box<br>Under **Test for Normality**, ....**Anderson Darling**<br>Click **OK** |

:
:
:

For a normal distribution, the mean equals median, which is 50th percentile, and the standard deviation is the difference between the $84^{th}$ and $50^{th}$ percentile. From Figure 6.4, the estimated mean is 5.9985 or 5.999 and the estimated standard deviation is

$$\hat{\sigma} = 84^{th} \text{ percentile - } 50^{th} \text{ percentile = 6.0183 - 5.9985 = 0.0198}$$

Note that the estimated standard deviation is very close to what we got from earlier analysis. The process capability can now be determined as explained in the previous example.
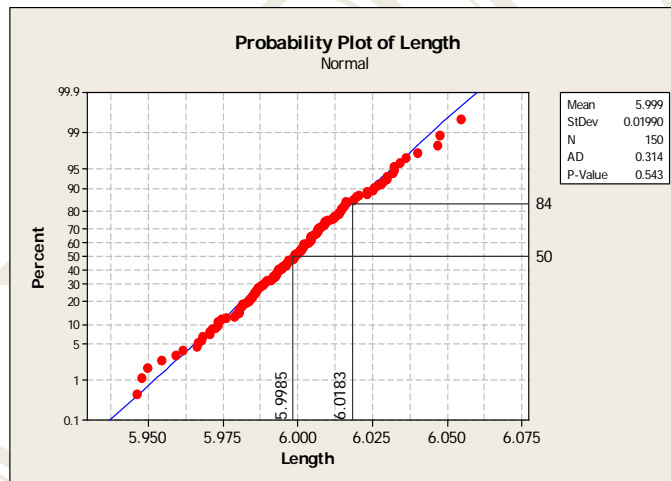


Figure 6.4: Probability Plot for the Length Data

## ESTIMATING PERCENTAGE NONCONFORMING FOR NON-NORMAL DATA: EXAMPLE 1

When the data are not normal, an appropriate distribution should be fitted to the data before calculating the nonconformance rate.

Data file **PCA1.MTW** shows the life of a certain type of light bulb. The histogram of the data is shown in Figure 6.5. To construct this histogram, follow the steps in Table 6. 1.
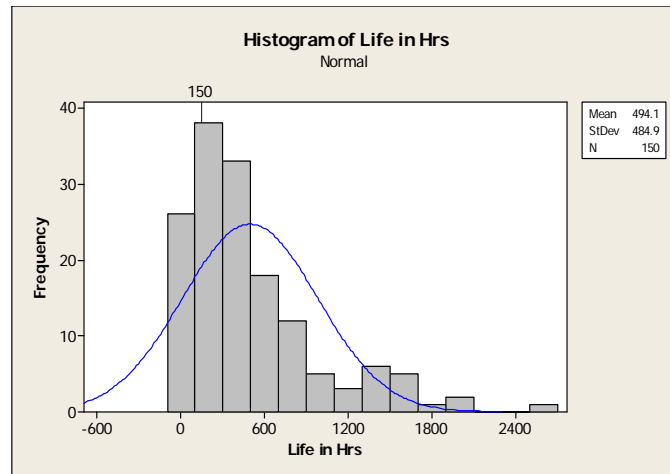
Figure 6.5: Life of the Light bulb

For the data in Figure 6.5, it is required to calculate the capability with a lower limit because the company making the bulbs wants to know the minimum survival rate. They want to determine the percentage of the bulbs surviving 150 hours or less.

The plot in Figure 6.5 clearly indicates that the data are not normal. Therefore, if we use the normal distribution to calculate the nonconformance rate, it will lead to a wrong conclusion. It seems reasonable to assume that the life data might follow an exponential distribution. We will fit an exponential distribution to the data and estimate the parameter of the distribution. To do this, follow the instructions in Table 6.6.

Table 6.6

| | |
|---|---|
| **FITTING DISTRIBUTION (EXPONENTIAL)** | Open the worksheet **PCA1.MTW**<br>From the main menu, select **Graph ➤ Histogram**<br>Click on **With Fit** then click **OK**<br>**:**<br>Click the **Distribution** tab, check the box next to **Fit Distribution**<br>Click the downward arrow and select **Exponential**<br>Click **OK** in all dialog boxes. |

The histogram with a fitted exponential curve shown in Figure 6.6 will be displayed. The exponential distribution seems to provide a good fit to the data. The parameter of the exponential distribution (mean =494.1 hrs) is also estimated and shown on the plot. In Figure 6.7, two probability plots of the Life data are shown; one fitted using normal distribution and the other using exponential distribution.
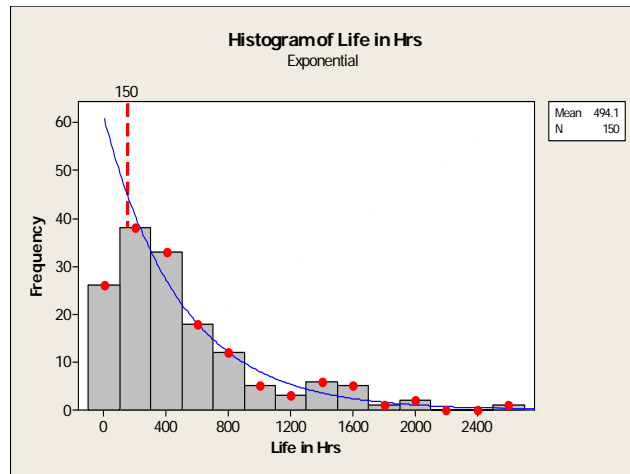
Figure 6.6: Exponential Distribution Fitted to the Life Data

The plot using the exponential distribution clearly fits the data as most of the plotted plots are along the straight line. To do the probability plots in Figure 6.7, follow the instructions in Table 6.7.………

Table 6.7

| | |
|---|---|
| **PROBABILITY PLOT** | Open the worksheet **PCA1.MTW**<br>From the main menu, select **Graph ➤ Probability Plots**<br>Click on **Single** then click **OK**<br>For **Graph variables**, type **C2** or select **Life in Hrs**<br>Click on **Distribution** then select **Normal** ….Click **OK** in all dialog boxes. |
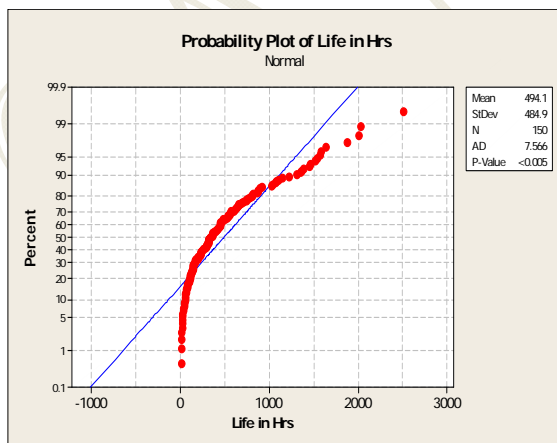


(a)
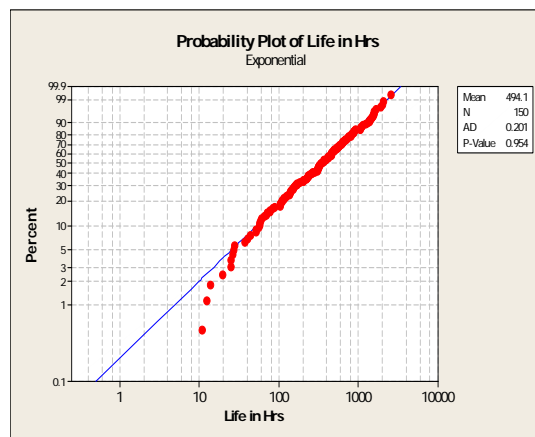


(b)

Figure 6.7: Probability Plots of the Life Data

Table 6.9

| **Cumulative Distribution Function** |
|---|
| Exponential with mean = 494.1 |
| x      P( X <= x ) |
| 150    0.261831 |

The table shows the calculated probability, P (x <= 150) = 0.2618. This means that 26.18% of the products will fail within 150 hours or less.

## CAPABILITY INDEXES FOR NORMALLY DISTRIBUTED PROCESS DATA
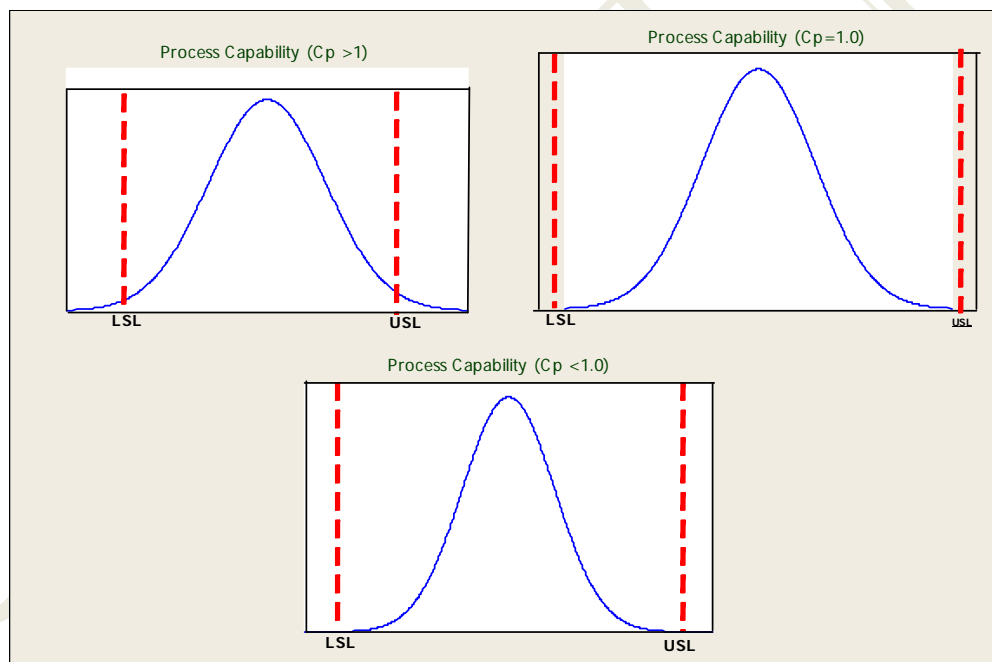


MINITAB provides several options for determining the process capability. The options can be selected by using the command sequence **Stat ➤Quality Tools ➤Capability Analysis**. This provides several options for performing process capability analysis including the following:

- Normal
- Between/Within
- Non-normal
- Multiple Variables (Normal)
- Multiple Variables (Nonnormal)
- Binomial
- Poisson

## DETERMINING PROCESS CAPABILITIES USING NORMAL DISTRIBUTION

The capability indexes in this case are calculated based on the assumption that the process data are normally distributed, and the process is stable and within control. Two sets of capability indexes are calculated: *Potential (within) Capability* and *Overall Capability***.**

Potential Capability

- The potential or within capability indexes are: Cp, Cpl, Cpu, Cpk, and Ccpk

- These capability indexes are calculated based on the estimate of $\hat{\sigma}_{within}$ or the variation within each subgroup. If the data are in one column and the subgroup size is 1, this standard deviation is calculated based on the moving range (the adjacent observations are treated as subgroups). If the subgroup size is greater than 1, the within standard deviation is calculated using the range or standard deviation control chart (you can specify the method you want).
- According to the MINITAB help screen, the potential capability of the process tells what the process would be capable of producing if the process did not have shifts and drifts; or, how the process could perform relative to the specification limits (if the shifts in the process mean could be eliminated).

Overall Capability

- The overall capability indexes are: Pp, Ppl, Ppu, Ppk, and Cpm
- These capability indexes are calculated based on the estimate of

    $\hat{\sigma}_{overall}$ or the overall variation, which is the variation of the entire data in the study.

- According to the MINITAB help screen, the overall capability of the process tells how the process is actually performing relative to the specification limits.

If there is a substantial difference between within and overall variation, it may be an indication that the process is out of control, or that the other sources of variation are not estimated by within capability [see MINITAB manual].

Note: According to some authors, Cp and Cpk assess the potential "short-term" capability using a "short-term" estimate of standard deviation, while Pp and Ppk assess overall or "long-term" capability using the "long-term" or overall standard deviation. Table 6.17 contains the formulas and their descriptions.

FORMULAS FOR THE PROCESS CAPABILITY USING NORMAL DISTRIBUTION

Table 6.17 shows the formulas for different process capability indexes.

Table 6.17

**Capability Indexes for Potential (within) Process Capability**

| | |
|---|---|
| $$C_p = \dfrac{USL - LSL}{6\hat{\sigma}_{within}}$$ | USL = upper specification limit <br><br> LSL = lower specification limit <br><br> $\hat{\sigma}_{within}$ = estimate of within subgroup standard deviation |
| $$C_{PL} = \dfrac{\bar{x} - LSL}{3\hat{\sigma}_{within}}$$ | Ratio of the difference between process mean and lower specification limit to one-sided process spread <br><br> $\bar{x} =$ process mean |
| $$C_{PU} = \dfrac{USL - \bar{x}}{3\hat{\sigma}_{within}}$$ | Ratio of the difference between upper specification limit to one-sided process spread |
| $$C_{PK} = Min.\{C_{PU}, C_{PL}\}$$ | Takes into account the shift in the process. The measure of $C_{PK}$ relative to $C_P$ is a measure of how off-center the process is. If $C_P = C_{PK}$ the process is centered; if $C_{PK} < C_P$ the process is off-center. |
| $$CC_{PK} = \dfrac{USL - \hat{\mu}}{3\hat{\sigma}_{within}}$$ $$\vdots$$ | $$\vdots$$ $$\vdots$$ |
| $$CC_{PK} = \dfrac{Min\{(USL - \hat{\mu}), (\hat{\mu} - LSL)\}}{3\hat{\sigma}_{within}}$$ | $$\vdots$$ $$\vdots$$ $$\vdots$$ |

**Note:** In all the above cases, the standard deviation is the estimate of *within subgroup* standard deviation. As noted above, the formulas for estimating standard deviation differs from case to case. It is very important to calculate the correct standard deviation. The standard deviation formulas are discussed later.

Relationship between Cp and Cpk

The index Cp determines only the spread of the process. It does not take into account the shift in the process. Cpk determines both the spread and the shift in the process.

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and the relationship between Cp and Cpk is given by

$$C_{pk} = (1 - k)C_p$$

Note that Cpk never exceeds Cp. When Cpk=Cp, the process is centered midway between the specification limits. Both these indexes Cp and Cpk together provide information about how the process is performing with respect to the specification limits.

## OVERALL PROCESS CAPABILITY INDEXES (OR PERFORMANCE INDEXES)

MINITAB also calculates the overall process capability indexes. These indexes are Pp, $P_{PL}$, $P_{PU}$, $P_{pk}$, and Cpm. The formulas for calculating these indexes are similar to those of potential capabilities except that the estimate of the standard deviation is an *overall standard deviation* and not within group standard deviation. The formulas for the overall capability indexes refer to Table 6.18.

Table 6.18
**Capability Indexes for Overall Process Capability**

| | |
|---|---|
| $$C_p = \frac{USL - LSL}{6\hat{\sigma}_{within}}$$ | USL = upper specification limit <br> LSL = lower specification limit <br> $\hat{\sigma}_{overall=}$ estimate of overall subgroup standard deviation <br> This is the performance index that does not take into account the process centering.  Continued... |

| | |
|---|---|
| $$P_{PL} = \dfrac{\overline{x} - LSL}{3\,\hat{\sigma}_{overall}}$$ | Ratio of the difference between process mean and lower specification limit to one-sided process spread <br><br> $\overline{x} =$ process mean |
| $$P_{PU} = \dfrac{USL - \overline{x}}{3\,\hat{\sigma}_{overall}}$$ | : <br><br> : |
| $$P_{PK} = Min.\{P_{PL}, P_{PU}\}$$ | : |
| $$C_{pm}$$ | This index is the ratio of (USL-LSL) to the square root of mean squared deviation from the target. This index is not calculated if the target value is not specified. A higher value of this index is an indication of a better process. This index is calculated for the known values of USL, LSL, and the target (T). |
| $$C_{pm} = \dfrac{USL - LSL}{(tolerance)*\sqrt{\dfrac{\sum\limits_{i=1}^{n}(x_i - T)^2}{n-1}}}$$ | Used when  USL, LSL, and target value, T are known <br><br> T = target value = (USL+LSL)/2 = $\mu$ <br><br> tolerance = 6 (sigma tolerance) |
| $$C_{pm} = \dfrac{Min.\{(T - LSL),(USL - T)\}}{\dfrac{tolerance}{2}*\sqrt{\dfrac{\sum\limits_{i=1}^{n}(x_i - T)^2}{n-1}}}$$ <br><br> : <br> : | USL, LSL, and  target, T are known but <br> T $\neq$ (USL+LSL)/2 |

(Note: The above formulas are very similar to what MINITAB uses to calculate these indexes. See the MINITAB help screen for details).

In this section, we present several cases involving process capability analysis when the underlying process data are normally distributed. The process capability report and the analyses are presented for different cases.

## CASE 1 : PROCESS CAPABILITY ANALYSIS (USING NORMAL DISTRIBUTION)

In this case, we want to assess the process capability for a production process that produces certain type of pipe. The inside diameter of the pipe is of concern. The specification limits on the pipes are 7.000 ± 0.025 cm. There has been a consistent problem with meeting the specification limits, and the process produces a high

percentage of rejects. The data on the diameter of the pipes were collected. A random sample of 150 pipes was selected. The measured diameters are shown in the data file **PCA2.MTW** (column C1).

The process producing the pipes is stable. The histogram and the probability plot of the data show that the measurements follow a normal distribution. The variation from pipe-to-pipe can be estimated using the within group standard deviation or $\hat{\sigma}_{within}$ . Since the process is stable and the measurements are normally distributed, the normal distribution option of process capability analysis can be used.

## PROCESS CAPABILITY OF PIPE DIAMETER (PRODUCTION RUN 1)

To assess the process capability for the first sample of 150 randomly selected pipes, follow the steps in Table 6.19. Note that the data are in one column (column C1 of the data file) and the subgroup size is one.

Table 6.19

| PROCESS CAPABILITY ANALYSIS | Open the data file **PCA2.MTW** <br> Use the command sequence **Stat ➢ Quality Tools ➢ Capability Analysis ➢ Normal** <br> In the **Data are Arranged as** section, click the circle next to **Single column** and select or type **C1 PipeDia:Run 1** in the box <br> Type **1** in the **Subgroup size** box <br> In the **Lower spec.** and **Upper spec.** boxes, type **6.975** and **7.025** respectively <br> : <br> : <br> Click **OK** <br> Click the **Options** tab on the upper right corner <br> Type **7.000** in the **Target (adds Cpm to table)** box <br> In the **Calculate statistics using** box a **6** should show by default <br> Under **Perform Analysis**, **Within subgroup analysis** and **Overall analysis** boxes should be checked (you may uncheck the analysis not desired) <br> Under **Display**, select the options you desire (some are checked by default) <br> Type a title if you want or a default title will be provided <br> Click **OK** in all dialog boxes. |
|---|---|

The process capability report as shown in Figure 6.11 will be displayed.

**Process Capability of PipeDia: Run 1**

| Process Data | |
|---|---|
| LSL | 6.975 |
| Target | 7 |
| USL | 7.025 |
| Sample Mean | 7.01038 |
| Sample N | 150 |
| StDev (Within) | 0.00971178 |
| StDev (Overall) | 0.00946227 |

Within
Overall

| Potential (Within) Capability | |
|---|---|
| Cp | 0.86 |
| CPL | 1.21 |
| CPU | 0.50 |
| Cpk | 0.50 |
| CCpk | 0.86 |

| Overall Capability | |
|---|---|
| Pp | 0.88 |
| PPL | 1.25 |
| PPU | 0.51 |
| Ppk | 0.51 |
| Cpm | 0.59 |

| Observed Performance | | Exp. Within Performance | | Exp. Overall Performance | |
|---|---|---|---|---|---|
| PPM < LSL | 0.00 | PPM < LSL | 134.53 | PPM < LSL | 92.20 |
| PPM > USL | 53333.33 | PPM > USL | 66163.57 | PPM > USL | 61212.82 |
| PPM Total | 53333.33 | PPM Total | 66298.10 | PPM Total | 61305.02 |

Figure 6.11: Process Capability Report of Pipe Diameter: Run 1

## INTERPRETING THE RESULTS

1.  The upper left box reports the process data including the lower specification limit, target, and the upper specification limit. These values were provided by the program. The calculated values are the process sample mean and the estimates of within and overall standard deviations.

    | Process Data | |
    |---|---|
    | LSL | 6.975 |
    | Target | 7 |
    | USL | 7.025 |
    | Sample Mean | 7.01038 |
    | Sample N | 150 |
    | StDev(Within) | 0.00971178 |
    | StDev(Overall) | 0.00946227 |

2.  The report in Figure 6.11 shows the histogram of the data along with two normal curves overlaid on the histogram. One normal curve (with a solid line) ……..

3.   The histogram and the normal curves can be used to check visually if the process data are normally distributed. To interpret the process capability, the normality assumption must hold. In Figure 6.11, ……

4.   There is a deviation of the process mean (7.010) from the target value of 7.000. Since the process mean is greater than the target value, the pipes produced by this process exceed the upper specification limit (USL). A significant percentage of the pipes are outside of …………………

5.   The **potential** or **within process capability** and the **overall capability** of the process is reported on the right hand side. For our example, the values are

| Potential (Within) Capability | |
|---|---|
| Cp | 0.86 |
| CPL | 1.21 |
| CPU | 0.50 |
| Cpk | 0.50 |
| CCpk | 0.86 |
| **Overall Capability** | |
| Pp | 0.88 |
| PPL | 1.25 |
| PPU | 0.51 |
| Ppk | 0.51 |
| Cpm | 0.59 |

:

6.   The value of Cp=0.86 indicates that the process is not capable (Cp < 1). Also, Cpk = 0.50 is less than Cp=0.86. This means that the process is off-centered. Note that when Cpk = Cp then the process ……

7.   Cpk=0.50 (less than 1) is an indication that an improvement in the process is warranted.

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:

8. Higher value of Cpk indicates that the process is meeting the target with minimum process variation. If the process is off-centered, Cpk value is smaller compared to Cp even …………………

9. The **overall capability indexes** or the process performance indexes Pp, PPL, PPU, Ppk, and Cpm are also calculated and reported. Note that these indexes are based on the estimate of **overall standard deviation……….**

10. Pp and Ppk have similar interpretation as Cp and Cpk. For this example, note that Cp and Cpk values (0.86 and 0.50 respectively) are very close to Pp and Ppk (0.88 and 0.51). When Cpk equals Ppk then the within subgroup standard deviation is ….

11. The index Cpm is calculated for the specified target value. If no target value is specified, Cpm …..

12. ……………For this process, Pp = 0.88, Ppk = 0.51, and Cpm = 0.59. A comparison of these values indicates that the process is off-center.

13. The bottom three boxes report observed performance, expected within performance, and expected overall process performance in parts per million (PPM). The **observed performance** box in Figure 6.11 shows the following values:

| Observed Performance | |
| --- | --- |
| PPM < LSL | 0.00 |
| PPM > USL | 53333.33 |
| PPM Total | 53333.33 |

This means that the number of pipes below the lower specification limit (LSL) is zero; that is, …..

The **expected "within" performance** is based on the estimate of within subgroup standard deviation. These are the average number of parts below and above the specification limits in parts per million. The values are calculated using the following formulas

$$P\left[ z < \frac{(LSL - \bar{x})}{\hat{\sigma}_{within}} \right] * 10^6$$

for the expected number below the LSL

$$P\left[ z > \frac{(USL - \bar{x})}{\hat{\sigma}_{within}} \right] * 10^6$$

for the expected number above the USL

note that $\bar{x}$ is the process mean.

For this process, the **Expected Within Performance** measures are

| Exp. Within Performance | |
|---|---|
| PPM < LSL | 134.53 |
| PPM > USL | 66163.57 |
| PPM Total | 66298.10 |

The above values show the ….

14.     The Expected Overall Performance is calculated using similar formulas as in within performance, except the estimate of standard deviation is based on overall data.

For this process, the **Expected Overall Performance** measures are

| Exp. Overall Performance | |
|---|---|
| PPM < LSL | 92.20 |
| PPM > USL | 61212.82 |
| PPM Total | 61305.02 |

These values are based on …..continued

# CASE 3: PROCESS CAPABILITY OF PIPE DIAMETER (PRODUCTION RUN 3)
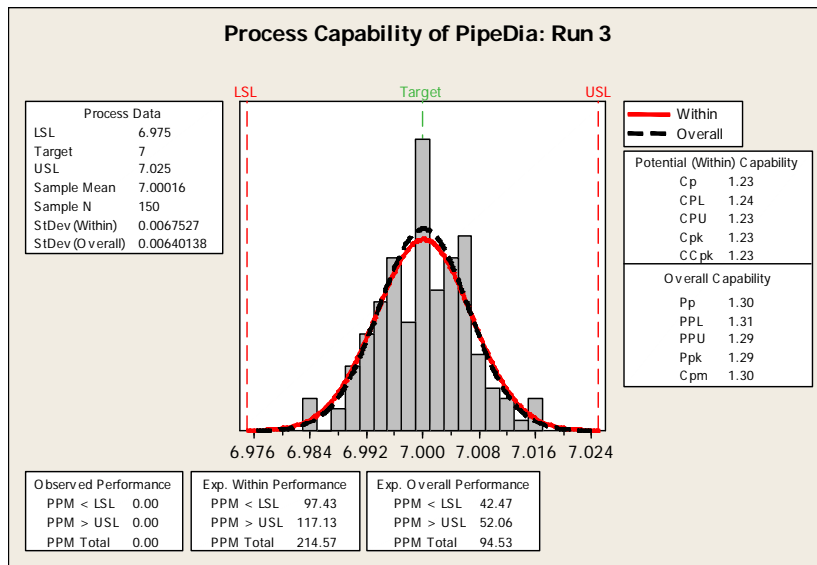


Figure 6.13: Process Capability Report of Pipe Diameter: Run3

# CASE 4: PROCESS CAPABILITY ANALYSIS OF PIZZA DELIVERY

A Pizza chain franchise advertises that any order placed through a phone or the internet will be delivered in 15 minutes or less. If the delivery takes more than 15 minutes, there is no charge and the delivery is free. This offer is available within a radius of 3 miles from the delivery location.

In order to meet the delivery promise, the Pizza chain has set a target of 12 ± 2.5 minutes….

Using the 100 delivery times (shown in Column 1 of data file **PAC3.MTW**), a process capability analysis was conducted. To run the process capability, follow the instructions in Table 6.20. The process capability report is shown in Figure 6.14.
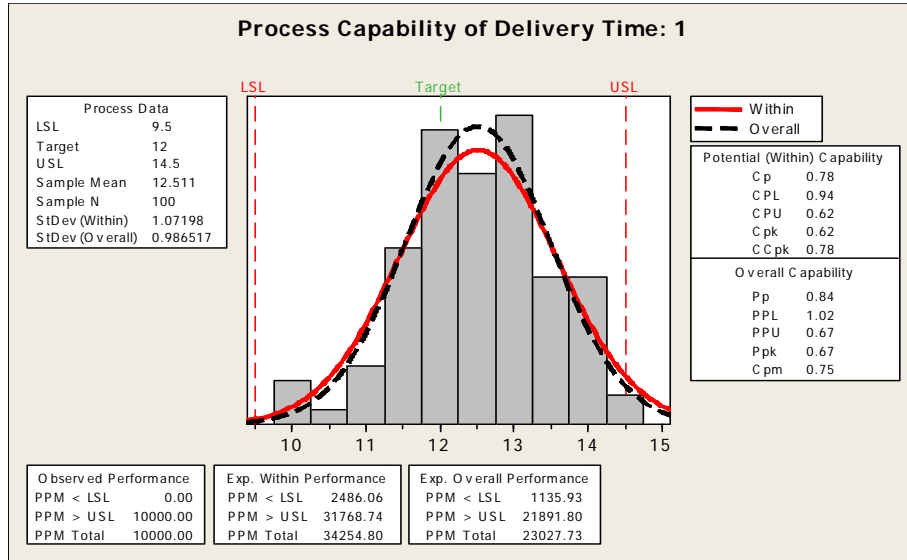
Figure 6.14: Process Capability Report of Pizza Delivery Time: 1 :

:

# CASE 6: PERFORMING PROCESS CAPABILITY ANALYSIS WHEN THE PROCESS MEASUREMENTS DO NOT FOLLOW A NORMAL DISTRIBUTION (NON-NORMAL DATA)

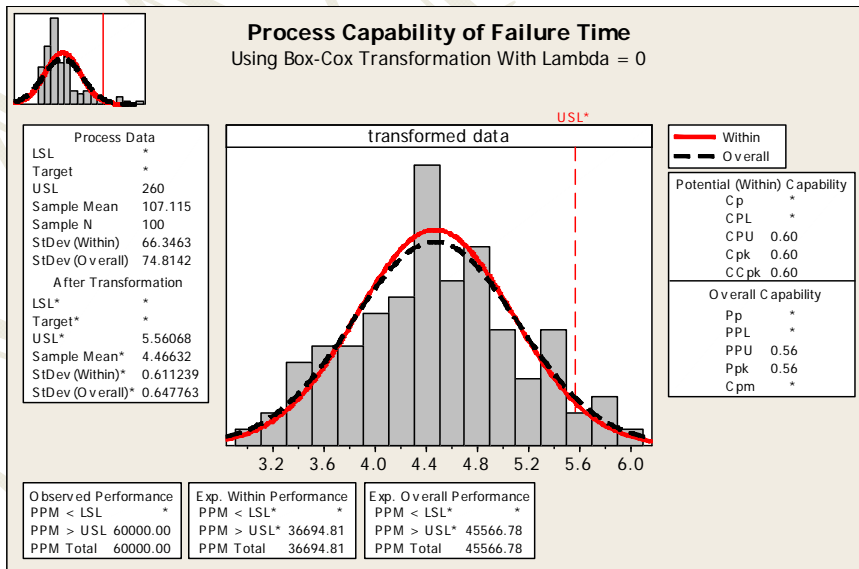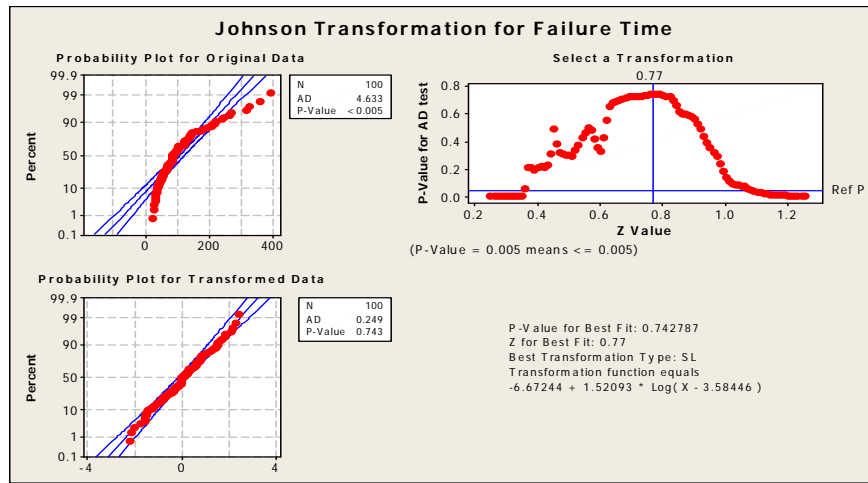The process capability report is shown in Figure 6.21.



Figure 6.21: Process Capability Report of Failure Time Data using *Box-Cox Transformation*

# PROCESS CAPABILITY OF NON-NORMAL DATA USING JOHNSON TRANSFORMATION



# PROCESS CAPABILITY USING DISTRIBUTION FIT

The other way of determining the process capability of non-normal data is to use a distribution fit approach. In cases where data are not normal, fit an appropriate distribution and use that distribution-rather than a normal distribution-to determine the process capability. We will illustrate the method using an example.
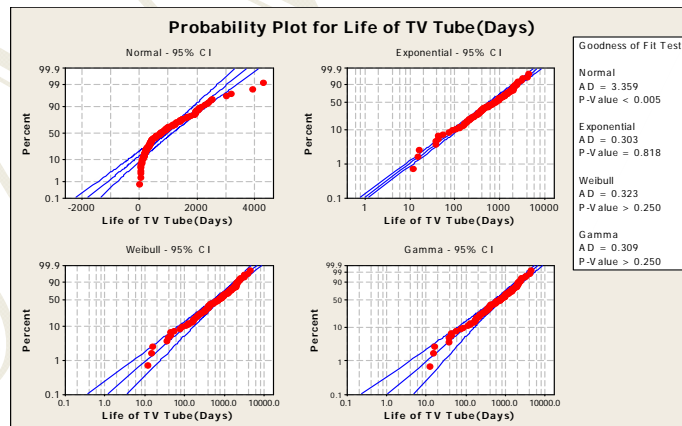


Figure 6.26: Probability Plots for Selected Distribution

## PROCESS CAPABILITY SIX-PACK

Another option available for process capability analysis is *process capability six-pack*. The process capability using this option displays

$\bar{x}$

- A chart (or individual chart for subgroup means),
- An R-chart (S chart for a subgroup size greater than 8),
- A run chart or moving range chart,
- A histogram,
- A normal probability plot of the process data to check the normality, and
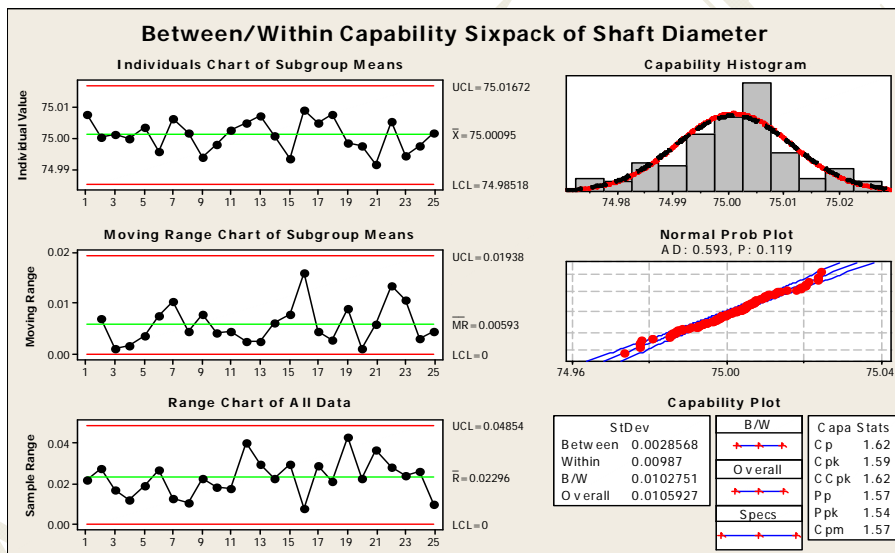- The between/within statistics and overall capability indexes.



Figure 6.34: Process Capability Six-pack of Shaft Diameter

## INTERPRETING THE RESULTS

The report shows the control charts for Xbar and R. The tests for special causes are conducted and reported on the session screen. No special causes were found indicating that the process is stable and in control. The capability histogram shows that the……………………..

*Chapter 6 of Six Sigma Volume 1 contains detailed analysis and interpretation of process capability analysis with data files and step-wise computer instructions for both normal and non-normal data.*

*To buy chapter 6 or Volume I of Six Sigma Quality Book, please click on our products on the home page.*