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Control Chart and Process Capability Analysis in Quality Control of Mosaics Parquet

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Abstract: *This paper describes the analysis of the parqetic mosaics process to determine process variation and process capability to achieve the specified specifications. The analysis is done for only three stages in Multy Rip and Sanding Pcs process. This is because very small errors or non-conformities to specifications occur in other processes and can be fixed at a later stage. Analysis based on samples taken for 30 days. Results of the control chart analysis for the three stages of the process, only one control chart that should be revised is the control chart on the Multy Rip process for working on the slat width. Process capability analysis for three stages of the process, generally three stages of the process has been able to meet the specified specifications. However, if analyzed based on the upper and lower limits of the specification, the three stages of the process have not been able to meet the upper limit of the specification. This is because the data is not scattered in the target area but at the upper limit of the specification. So that process improvement analysis is required to relate to the upper limit of the specification.*

Keywords: *Quality control, control chart, process capability, mosaic parquet*

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I. Introduction

Quality control is a system developed to maintain uniform standards of production quality at minimum cost levels and is an aid to achieving corporate efficiency. Quality control is also said to be technical activity and management which is measured by the characteristics of product quality, compare it with the specification or requirements and take appropriate sanitation action if there is a difference between the actual appearance and the standard.

Statistical quality control is one of the scientific means used by modern management with increasing scope in maintaining the quality standards of the products. This system is based on the laws of probability and can be described as a system for controlling the quality of production within the limits specified by a sampling procedure and an analysis of the results of the examination.

Statistical quality control can be classified into 2 types: process control and product control. For process control, control charts and other quality tools are used and for product control, acceptance sampling is used [Buffa, 1993].

The principal purpose of statistical process control is to investigate rapidly the occurrence of unpredictable causes or shifts in the process in such a way that an investigation of a process and corrective action can be performed before many units are not suitable for production. The control chart is a process control technique used for that purpose [Montgomery, 1990]. The ultimate goal of process control is to remove diversity in the process or reduce diversity to the maximum extent possible.

Many researchers are in the process of identifying the various methods for optimising the input machining parameters which indicates the significance of the machining process optimization in different industrial sectors involved in manufacturing of goods and services [Aravind et al., 2017].

The statistical process control is a widely used method, where the major tools are the control charts. Applying this method, the assignable causes could be found and corrected [Montgomery, 2012; Woodall & Montgomery, 1999]. The most companies apply a lot of processes and subprocesses which need to be statistically controlled to guarantee the high quality of the product. When the expected value of the process changes significantly, the chart detects it and gives a signal for the operators. In statistical process control, a process is said to be controlled, when the ob- served values of product characteristic fall within the given limits [Besterfield, 1994; Shewhart, 1931].

The control chart is a line graph showing the maximum and minimum values that are the control area limits. The control chart was first introduced by Dr. Walter Andrew of Belt Telephone Laboratories, USA, in

1924 with a view to eliminating abnormal variations through the separation of variation caused by special causes (variations caused by common causes variation).

Specific variation causes are events outside the quality management system that affect variations in the system. Specific causes can be sourced from factors: equipment misuse, operator error, misuse of raw materials and so on. This special case should be avoided but managers do not do it. Usually 15% error occurs because of this cause. This type of variation is often characterized by observation points that pass through or out of defined control limits. If the data outside the control limits is due to a specific cause there must be a revision of the central line, upper limit and lower limit until all data are within the control limit [Ariani, 1999].

Common cause variations are factors in the quality management system or inherent in the process causing variations within the system and the results. This type of variation is often characterized by observation points within the defined control limits. Including general causes such as damage to production machinery, delayed arrival of raw materials, unstable working conditions, and others. Usually 85% of errors are caused is because of this cause. If it is a common cause then the data is considered in control so no revision is needed [Ariani, 1999].

A process is said to operate in control when variations exist only from the common cause variation [Vincent, 2003].

Control charts are used for:

- Determine whether a process is in control.
- Monitor the process continuously over time to keep the process statistically stable and contains only a variety of common causes.
- Determining process capability [Vincent, 2003].

Process capability is a critical performance measure that demonstrates the ability of the process to produce products according to the specifications set by management based on customer needs and expectations [Montgomery, 1990]. Montgomery asserted that process capability is a vital part of any quality-improvement process program. A process capability study includes two objectives: measure variability of process output and compare that variability to product tolerance [Montgomery, 2009].

Traditional process capability analysis has used process capability indexes that are measurable properties between manufacturing process variations and specification limits. Over the years there have been many studies and proposed methods developed to assess the process capabilities. [Koopel and Chang, 2016]

The limits of the specifications are the limits of certain engineering sciences to product dimensions. These limits are determined freely from process variations. The limits of this specification may be one side or two sides with or without the target values. Only when a process is in a statistical control is it possible to assess whether the process is capable of or unable to meet predetermined specifications.

One of the common measures to explain the potential of a process to meet specifications is the ratio of process capability or the Cp index. This relates the process difference (the difference between the limits of scientific tolerance) to the difference between the bounds of the two-sided specification [Belavendram N, 1995].

As an essential part of the statistical process control, process capability analysis is commonly measured by process capability indices (PCIs) and widely used to determine whether a process is capable of producing items with required specification limits or not. The most commonly used PCIs are Cp and Cpk, which are defined by the following equations, respectively [Wang et al., 2016]:

$$Cp = \frac{USL-LSL}{6\sigma} \tag{1}$$

$$Cpk = \left\{CPU = \frac{USL-\mu}{3\sigma}, CPL = \frac{\mu-USL}{3\sigma}\right\} \tag{2}$$

Where μ is the process mean, σ is the process standard deviation, *USL* is the upper specification limit, and *LSL* is the lower specification limit.

The above mentioned PCIs are often estimated based on three basic assumptions [Jose & Luke, 2013]:

- The process is statistically in control.
- The collected process data are independent and identically distributed.
- The collected process data follow a normal distribution

In order for the process to be acceptable, the process must be within the statistical control and variations attached to the process (capability) must be smaller than the specified tolerance. Capability is used as a basis for estimating how the process will operate based on the quality data collected from the process.

The purpose of this research is to:

- Know the variety of processes that occur in producing the product.
- Knowing the process capability in producing products that are within the limits of specifications as specified.

II. Methodology

In the early stages, a literature study was conducted to look for various theoretical concepts that were used as theories, such as: knowledge of processes, qualities and others. This literature study can be done through textbooks, journals and others.

The second stage, collecting data related to the production process, product specifications at each stage of the process, dimensions of product dimensions (thickness and width).

The third stage, the processing of data that has been collected. Data processing using minitab program. Data processing to determine the control limits on the control chart and measure process capability (Cp).

A. Control Chart

The control charts used are variable control charts, among others, range control chart (R) and average control chart (X-bar).

Steps to create a Range control chart (chart R):

a. Determining the sample size (n=5)
b. Collect 30 sets of samples
c. Calculate the range value. The Range of each set of samples is calculated by the formula:
   R = Biggest Data – Smallest Data (3)
d. Calculate the average value of all Range, which is the center line of the Range control chart (R control chart).
   $$\bar{R} = \frac{Number\ of\ Range\ Sample}{Number\ of\ Samples} = \frac{\sum R}{g} \quad (4)$$
e. Calculate the control limits of the control chart R.
   $$CL_R = \bar{R} \quad (5)$$
   $$UCL_R = D_4.\bar{R} \quad (6)$$
   $$LCL_R = D_3.\bar{R} \quad (7)$$
   Where $\bar{R}$ is the center line of the control chart R which is the average value of the range of data, D_3, D_4 is constans based on sample size.

The control limits obtained will be used to determine if any data is out of control. If there is any data outside the limits of control then analyzed and revised. If all data has been within the control limit then it can proceed to create an average control chart (X-bar).

Steps to create an average control chart (X-bar chart):

a. Determining the sample size (n = 5)
b. Collect 30 sets of samples
c. Calculate the sample mean (X-bar) of each sample set by the formula:
   $$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (8)$$
d. Calculates the average of the sample mean ($\bar{\bar{X}}$) by the formula:
   $$\bar{\bar{X}} = \frac{Average\ number\ of\ samples}{Number\ of\ samples} = \frac{\sum \bar{X}}{g} \quad (9)$$
e. Calculates the 3-sigma control limits of the average control chart (X-bar control chart):
   $$CL_{\bar{x}} = \bar{\bar{X}} \quad (10)$$
   $$ULCL_{\bar{x}} = \bar{\bar{X}} + A_2.\bar{R} \quad (11)$$
   $$LCL_{\bar{x}} = \bar{\bar{X}} - A_2.\bar{R} \quad (12)$$
   Where A_2 is constants based on sample size, and $\bar{R}$ is average of the range of data.
f. Create a control chart X-bar using existing control limits. Plot or scatter each X-bar sample data on the control chart as well as observe whether the data has been in statistical control. [Vincen, 2003].

The control limits obtained will be used to determine if any data is out of control. If there is any data outside the limits of control then analyzed and revised. If all data has been within the control limit, then the control limits can be applied.

B. Process Capability

Process capability can be calculated in 2 (two) ways.

a. Supposing that the average process is centered on the average specification and shown as the process capability index (Cp).
   $$Cp = \frac{USL - LSL}{6\sigma} \quad (13)$$

$$\sigma = \frac{\bar{R}}{D_2} \tag{14}$$

b. Used when the average process is assumed is not centered on the average specification and is intended as a kane performance index (Cpk).

$$Cpk = \min\,(CPU; CPL) \tag{15}$$

$$Cpk = \min\left[\frac{USL-\bar{\bar{X}}}{3\sigma}; \frac{\bar{\bar{X}}-LSL}{3\sigma}\right] \tag{16}$$

Where *Cp* is process capability index, *Cpk* is capability index kinerja cane, *USL* is upper specification limit, *LSL* is lower specification limit, *CPU* is capability index for upper specification limit, and *CPL* is capability index for lower specification limit

Assessment criteria:

- If Cp = 1, it means that the specification and average limits center on the process boundary ± 3σ of the process average.
- If Cp < 1, it means that the specification is smaller than the deployment process. The level of defect will be greater than 3 pieces per 1000.
- If Cp > 1, it means that the specification is larger than the deployment process. The level of defect becomes less than 3 pieces per 1000.

The fourth stage is the analysis of the results. At this stage, the information from the data processing is further analyzed related to process variation that occurs in the control chart and process capability based on the specification desired by the company.

The fifth stage is the final stage. At this stage, conclusions are based on data processing and analysis results. The conclusion drawn is the answer of the purpose of research conducted.

The final stage, analyzing the control limits on the control chart and process capability analysis based on the specifications desired by the company.

III. Result And Discussion

The research was conducted on the process of making Mosaics Parquet consisting of 13 stages of the process: Cross Cutting, Drum Saw, Double Planner, Multi Rip, Sorting, Wire Assembly, Sanding Pcs, Glue Assembly, Squaring, Sanding Panels, Sealer, Sanding Sealer, Top Coat. Each stage of the process has a specification of control that has been determined by the company according to consumer desires. After studying the stages of the existing process, then the research is done only on the process of Multi Rip and Sanding Pcs. For other processes not examined because the error or incompatibility to the specification is very small and can be fixed in the next process/stage.

A. *Control Chart Analysis*

The control charts analyzed are X-bar control charts because X-bar control charts will be used as standard and process work guidelines

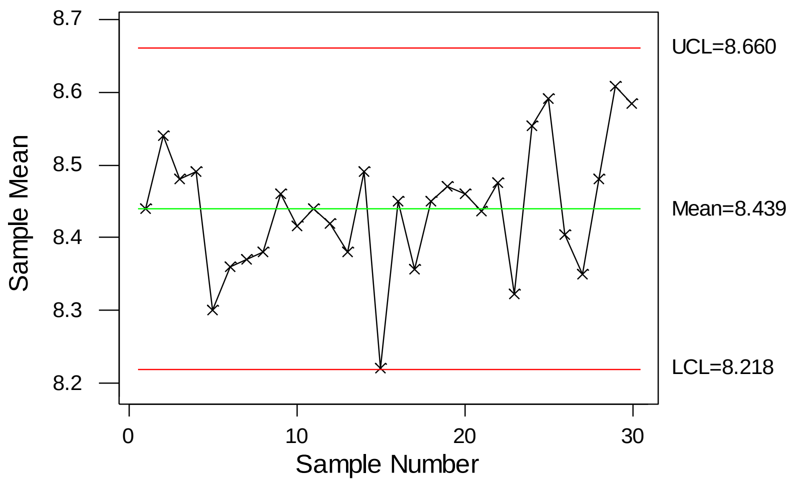

Figure 1. Control chart X-bar for slat thickness in multi rip process

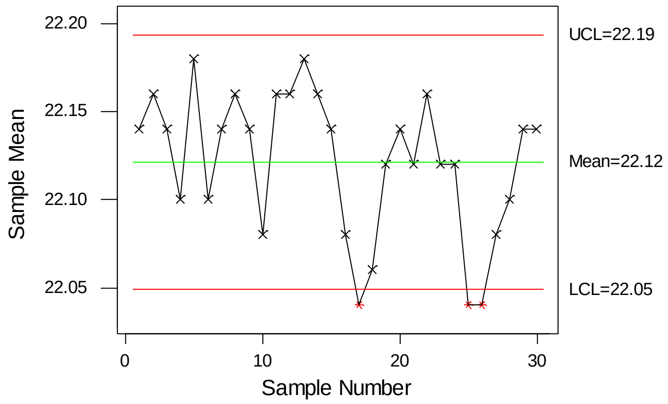

Figure 2. Control chart X-bar for slat width in multi rip process

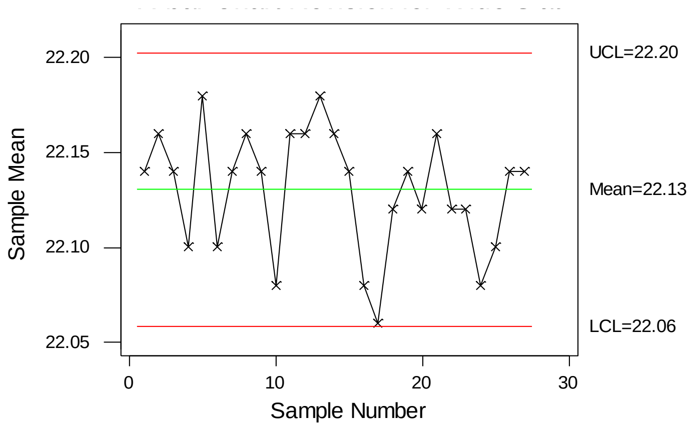

Figure 3. Control chart X-bar revision for slat width in multi rip process

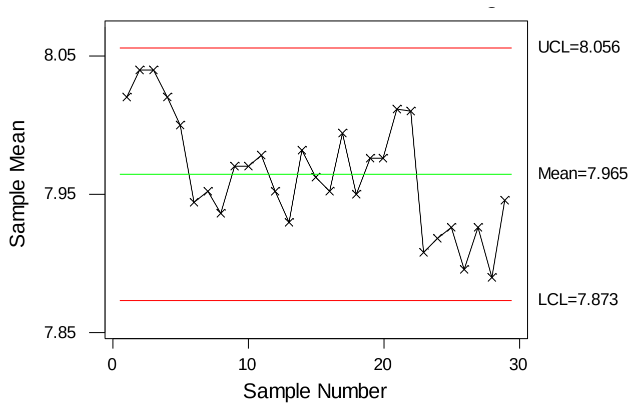

Figure 4. Control Chart X-bar for Slat Thickness in Sanding Process

A.1. Control Chart Analysis for Slat Thickness in Multi Rip Process

From Figure 1 it can be seen that all points (data) are within the control limits. So it is said that the process is controlled statistically. That means, to produce a thick slat on the process of Multi Rip obtained thick variations of the slats are still controlled statistically. Furthermore, the control limit UCL = 8.660 mm, mean = 8.439 mm, LCL = 8.218 mm can be used as a guide in the process.

A.2. Control Chart Analysis for Slat Width in Multi Rip Process

In Figure 2 it can be seen that there are three dots (data) that out of control limits are data numbers 17, 25 and 26. Based on the results of the analysis of data out of control limits, the data out of control limits can be eliminated. For that reason, revision can be done by eliminating the three points that are out of control and recalculate to obtain more uniform variation as shown in Figure 3.

In Figure 3 it can be seen that all the points (data) are within the control limit. For it is said that the process is controlled statistically. That means, to produce a slat width on the process of Multi Rip obtained width variations of the slats are still controlled statistically. Furthermore, the control limit UCL = 22.20 mm, mean = 22.13 mm, LCL = 22.06 mm can be used as a guide in the process.

A.3. Control Chart Analysis for Slat Thickness in Sanding Pcs Process

In Figure 4 it can be seen that all points (data) are within the control limits. For it is said that the process is controlled statistically. That means, to produce a thick slat on the process of Sanding Pcs obtained thick variations of the slats are still controlled statistically. Furthermore, the control limit UCL = 8.056 mm, mean = 7.965 mm, LCL = 7.873 mm can be used as a guide in the process.

B. Process Capability Analysis (Cp)

Process capability analysis is used to determine the ability of the machine to perform the process of a product in accordance with the specified specifications.

B.1. Process Capability Analysis for Thick Slat on Multi Rip Process

From the specified size specification and control chart analysis, it is known:

- Specification of thick slats = 8,2 ± 0,3 mm
- LSL = 7,9 mm
- Target = 8,2 mm
- USL = 8,5 mm
- Sample mean $(\overline{X})$ = 8,439 mm

From the calculation and figure 5, it is known Cp = 1.31. If analyzed in its entirety, this means that in the process Multi Rip has been able to produce a slat thickness that matches the specified specification. If analyzed specifically based on the lower limit and upper limit of the specification in Fig. 5, the value of Cpk = 0.27 is obtained. This means that the Multi Rip process has not been able to produce a thick slat that meets the upper limit of the specification.

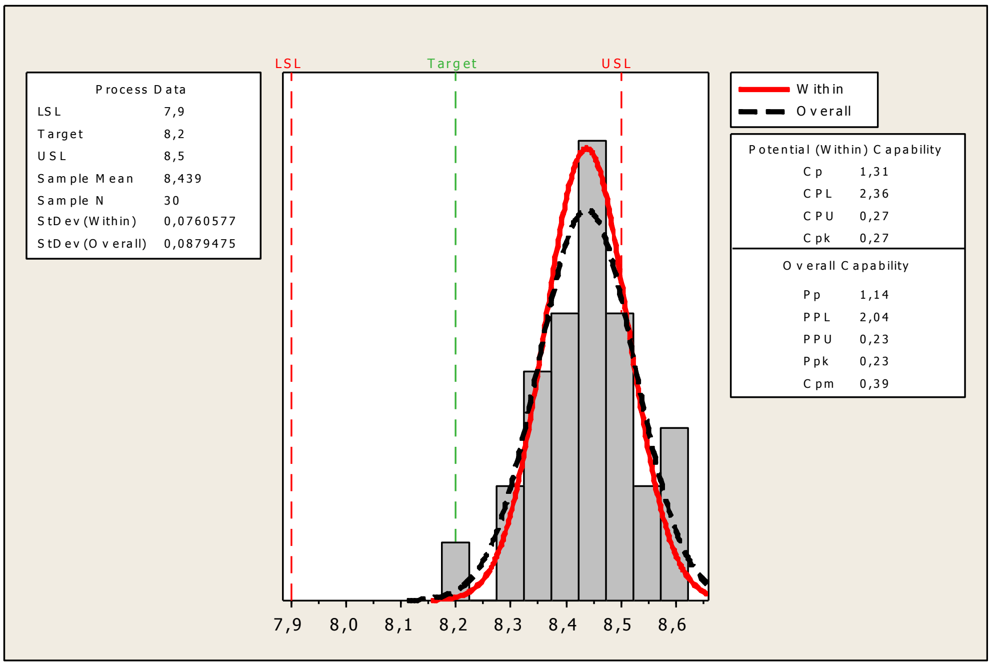

Figure 5. Process capability analysis for thick slat in multi rip processes

- CPU = 0.27, this means that in the Multi Rip process there is a thick slat that exits from the upper limit of the specification so that the process is said not able to meet the upper limit of the specification. In the future the process must be considered the upper limit of the specification although the specified thickness of the speciation can still be fixed but this requires reworking that requires additional time and cost so as to be detrimental to the company.
- CPL = 2.36, this means in Multi Rip process for all variations of slat thickness is within the lower limit of the specification so that the process is said to be capable. Furthermore, this should be maintained not to repair the CPU shifts CPL position.

B.2. Process Capability Analysis for Slat Width on Multi Rip Process

From the specified size specification and control chart analysis, it is known:

- Specification of Slat Wid = 22,1 ± 0,1 mm
- LSL = 22,0 mm
- Target = 22,1 mm
- USL = 22,2 mm
- Sample mean $(\overline{X})$ = 22,13 mm

From the calculation and figure 6, it is known Cp = 1.11. If analyzed in its entirety, this means that in the process Multi Rip has been able to produce a slat width that matches the specified specification. If analyzed specifically based on the lower limit and upper limit of the specification in Fig. 6, the value of Cpk = 0.78 is obtained. This means that the Multi Rip process has not been able to produce a slat width that meets the upper limit of the specification.

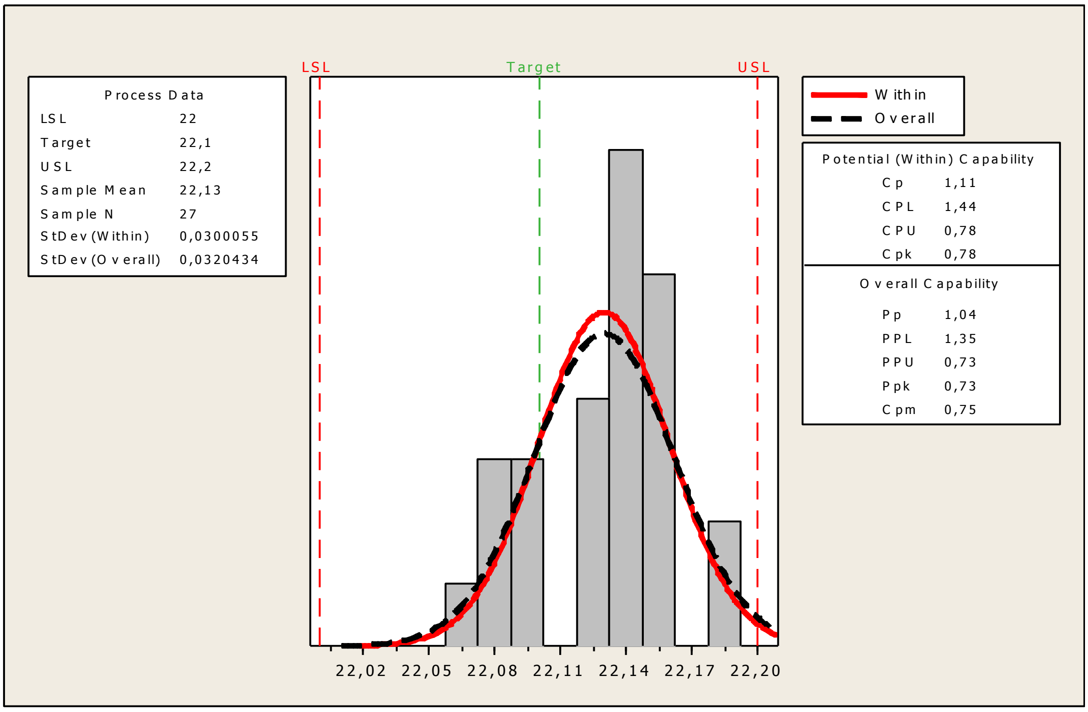

Figure 6. Process Capability Analysis for Slat Width in Multi Rip Processes

- CPU = 0.78, this means that in the Multi Rip process there is a slat width that exits the upper limit of the specification so that the process is said not able to meet the upper limit of the specification. The next step in working on the process should be considered the upper limit of the specification although the excess width can still be fixed but this requires rework so it takes extra time and cost. This results in company losses.
- CPL = 1.44, this means in Multy Rip process for all variations of slat width is within the lower limit of the specification so that the process is said to be capable. Furthermore, this should be maintained not to repair the CPU shifts CPL position.

B.3. Process Capability Analysis for Slat Thickness on Sanding Pcs Process

From the specified size specification and control chart analysis, it is known:

- Specification of thick slats = 7,9 ± 0,1 mm
- LSL = 7,8 mm
- Target = 7,9 mm
- USL = 8,0 mm
- Sample mean $(\overline{X})$ = 7,965 mm

From the calculation and figure 7, it is known Cp = 1.19. If analyzed in its entirety, this means that in the Sanding process Pcs has been able to produce a slat thickness that matches the specified specification. If analyzed specifically based on the lower limit and upper limit of the specification in Fig. 5, the value of Cpk =

0.42 is obtained. This means that the Sanding Pcs process has not been able to produce a thick slat that meets the upper limit of the specification.

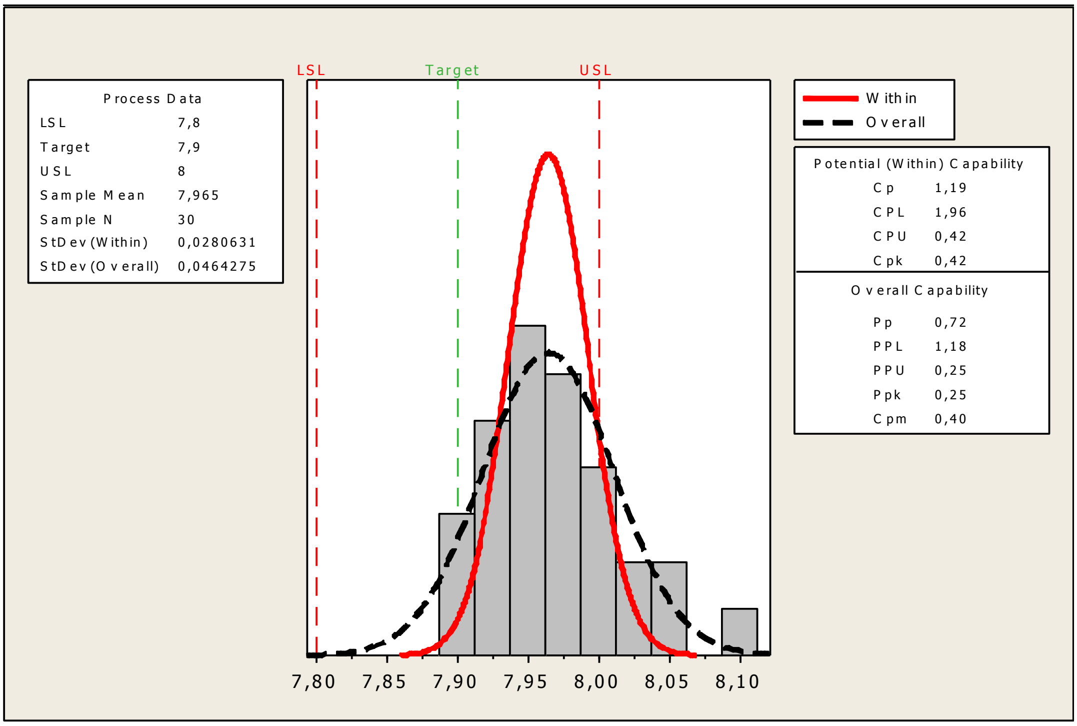

Figure 7. Process capability analysis for thick slat in sanding processes

- CPU = 0.27, this means that in the Sanding Pcs process there is a thick slat that exits from the upper limit of the specification so that the process is said not able to meet the upper limit of the specification. In the future the process must be considered the upper limit of the specification although the specified thickness of the speciation can still be fixed but this requires reworking so it takes extra time and cost so as to be detrimental to the company.
- CPL = 1.96, this means in Sanding Pcs process for all variations of slat thickness is within the lower limit of the specification so that the process is said to be capable. Furthermore, this should be maintained not to repair the CPU shifts CPL position.

IV. Conclusion

Analyze the control charts for the three stages of the process, only one control chart that should be revised is a control chart on the Multi Rip process for working on the slat width.

Process capability analysis for three stages of the process, generally has been able to meet the specified specifications. However, if analyzed based on the upper limit and lower limit of the specification has not been able to meet the specified specification that is the upper limit of the specification. This is because the data is not scattered in the target area but at the upper limit of the specification. So that process improvement analysis is required to relate to the upper limit of the specification.

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