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"Application of Six Sigma in Thickness Control of Stainless Steel Sheets for a New Startup Manufacturing Company "

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Abstract :
The paper focuses on the application of Six Sigma methodologies in controlling the thickness of stainless steel sheets manufactured by a company. The industry standard sheet thickness is 5mm with an allowable tolerance of 5.05 mm (USL) and 4.95 mm (LSL). A set of control charts coupled with process capability indices Cp and Cpk was used to assess the stability and performance of the processes. A sample of 20 to 30 stainless steel sheets was selected and the thickness was tested against the customer parameters. The findings proved that Six Sigma methodologies can be successfully utilized in production process quality control.

Key Words : Six Sigma, Control Charts, Statistical Process Control (SPC), Process Improvement, DMAIC (Define-Measure-Analyze-Improve-Control), Defect Reduction, Quality Management, Defect Tracking, Process Variability, Process Control, Continuous Improvement, Defects per Unit (DPU), Average Number of Defects, Lean Six Sigma, Process Stability

Introduction

The production of stainless products requires the monitoring of thicknesses and tolerances within specific limits to satisfy customer requirements and maintain product quality. Any discrepancies in the thickness can cause problems further in the process, increase scrap rate, and result in customer complaints. Therefore, in this research a Six Sigma approach was taken to manage and control the consistency of stainless steel sheets thickness of 5mm. Customer requirements state that the thickness of the product can be from 5.05 mm to 4.95 mm, and therefore the upper and lower limits need to be strictly adhered to. This clearly shows that six sigma is a useful tool for this problem as it focuses on data and process management alongside checking that everything stays within the limits. Six Sigma aids manufacturers in achieving process and product improvements by lowering variation and defects.

Literature Review :

The study describes the use of control charts developed for monitoring six sigma processes in relation to defects or average defects per unit. These charts serve as a useful device in process control and improvement for companies that use Six Sigma. But the analysis results show that even after implementing Six Sigma initiatives, the processes under examination were out of control. It seems that traditional Shewhart (1931) style control charts with 3-sigma limits are no longer useful for companies that have attained higher levels of quality through Six Sigma, because no points would lie outside those limits. The analysis suggest that for process improvements, control limits based on 6-sigma values, that is, $\mu \pm 6$ sigma, should be used. In this way, the cuts in quality measurement will be achieved and the process will be set in line with standards of Six Sigma. This analysis demonstrates

that when processes are mean-centered with a decrease in variation, still some points outside these appropriate new control limits serve as markers of poor performance in process control that need correction. [1][2]
These techniques enable the achievement of proper planning and monitoring in the control development of engineering deliverables within budget and aid in the timely identification of poor performance for appropriate corrective measures. Project sixsigma improved too as the project progressed from 0.92 at 10 percent phase to 1.74 at 90 percent phase [3]
Six Sigma as a methodology for quality improvement is often presented and deployed in terms of the dpmo metric, i.e., defects per million opportunities. As the sigma level of a process improves beyond three, practical interpretation problems could arise when conventional Shewhart control charts are applied during the Control phase of the define-measure-analyzeimprove-control framework. In this article, some alternative techniques are described for the monitoring and control of a process that has been successfully improved; the techniques are particularly useful to Six Sigma Black Belts in dealing with high-quality processes. The approach used would thus ensure a smooth transition from a low-sigma process management to maintenance of a highsigma performance in the closing phase of a Six Sigma project[4] While traditional control charts play an important role in quality assurance activities, the work on such techniques evolved over the years particularly for early detection of process shifts. Many advanced level control charts have been proposed in the literature to even detect small shifts in the process as early as possible. In order to make use of the prior beliefs and likelihood of the observed data behavior, Bayesian control charts for parameter of the posterior distribution have been proposed by various authors. The Six Sigma-based control charts ensure smaller process variations by enforcing quality improvement activities and as a result, such processes would produce higher quality products with only 3.4 defects per million opportunities (DPMO) even after allowing a shift in the process up to ±1.5 times of process standard deviation. In this paper attempt has been made to develop Six Sigma-based Bayesian control charts. The proposed control charts incorporate various shift (or no-shift) combinations to prior and observed data behaviors to study their influence on the posterior parameter [5] The analysis of production data across three days using x-bar charts with three sigma limits reveals that while the average production values fall within the specified range of 42 to 48 liters, the process quality is inadequate due to high standard deviations (around 3 liters), which closely match the company's tolerance limits of ±3 liters. This indicates the process is only one sigma away from the mean, reflecting poor quality. A Kolmogorov–Smirnov test for normality identified that Day 2's data does not follow a normal distribution (p-value < 0.05), unlike the amalgamated data of Days 1 and 3, which showed normality (p-value > 0.05). However, even for Days 1 and 3, the estimated standard deviation remains high, and the values of Cp and Cpk are less than 1, demonstrating that the process is not capable of meeting the company's specifications. A review of production consistency highlights significant fluctuations: Day 1 shows only two points above the mean, Day 2 is evenly split, and Day 3 has nine observations below the mean. When combining Days 1 and 3, 15 out of 40 observations are below average, further affirming the process's incapability. Additionally, when comparing three-sigma x-bar charts with Six Sigma standards (centered processes with reduced variation), many points fall outside the control limits, emphasizing the need for corrective action to achieve better process control and quality. [6]
The analyzed articles report information regarding Six Sigma quality management and the update changes of the management process control charts. The information depicts a detailed study of Six Sigma including its growth, problems in execution, organizational impact, and gaps in studies which can be furthered in research[7]. The implementation of such techniques as Six Sigma is not free of serious challenges. This includes possible irrational use of resources, lack of acceptance from the employees of a company, and overgeneralization of a monomodel across all branches of economy[8]. These articles concentrate on the optimization design of control charts. Together these studies stress the need to custom tailor and adapt Six Sigma techniques to the operational realities of the

organization, the issues of overcoming implementation barriers, and the use of optimized control tools to ensure the achievement of quality targets in multi-functional operational setting[9].

This paper explains what control charts are, their function in Six Sigma methodologies as facilitators for the monitoring of process control and detecting changes to stability, and variations during processes. This article presents the various types of control charts and their design, use revisions, and application in many fields with emphasis on the industries' need for quality improvement and focus on sustaining quality systems in the management processes[10]. This article proposes a new approach for formulating requisite control charts within Six Sigma activities especially for the cases with multi-sized samples. The described method does not compromise on the monitoring of fraction defective and increases the precision and flexibility of the quality control efforts in the dynamic operational environment[11]. Study examines sophisticated control charts such RS, MDSS, and MDSRS charts which were developed within the Six Sigma paradigm. These tools are focused on monitoring and controlling processes with greater accuracy which is why they are more effective and useful in highly competitive manufacturing industries[12]. Control charts are described in relation to healthcare whereby their usefulness in tracking patient care processes to mitigate errors and enhance service delivery is presented. The study stresses the significance of advanced statistical tools to aid the management of healthcare systems[13] This study analyzes the application of Six Sigma tools in mitigation of variation in oil density characteristics by means of process capability study and the xbar control charts. The study also demonstrates the application of primary industrial engineering concepts and tools to the oil industry as a base for quality improvement approaches[14].

This research presents a new robust scale estimator based on Six Sigma that has a range control chart. The new method incorporates a better set of tools for quality management at different levels of variation of the conditions in processes.[15] This literature review aims at assessing variable control charts and their usage in monitoring healthcare operational processes to enhance the care given to patients.[16] The work presents a case study on the use of control charts in different areas of health care and their impacts so as to determine sustainability of control charts. The article analyses the timeline of the development of Six Sigma, its core values, and how it has affected the quality structures within organizations. It also sheds some light on the growing of Six Sigma in different fields.[17] The authors highlight possible reasons for failure to accept control charts as operational measures to be taken and focus on factors such as organizational culture, information flow, and value perception of the tools in the context of making important choices.[18] This article seeks to determine the effectiveness of Six Sigma zone control charts by studying transition probabilities and average run length (ARL) events, assessing to what degree these charts are effective for process quality control.[19] In service industries, there is an increasing need to meet customer expectations with control chart standards, thus, presenting ways of servicing improvement through customer orientation combined with Six Sigma tools.[20]
This research aims to evaluate the use of the range and standard deviation graphs within the context of Six Sigma for continuous improvement processes. It incorporates a depth of precision into the DMAIC process of Six Sigma for better control and decreased variation, shedding light on quality control tool optimization in manufacturing systems. The thesis compares the efficiency and sensitivity of different statistical tools – Three Sigma, Six Sigma, and Median Absolute Deviation – within the scope of $\bar{X}$control charts. It illustrates the impact on accuracy and control monitoring of these measures as well as distance to control limits, proposing sensitivity improvements in charts for real processes.
This case study incorporates control charts into the integrated process of data mining framework CRISP-DM to shed light on the changes in length of stay within health care settings. The combination of Six Sigma tools within a data analysis procedure depicts an improvement in the decision making

for process optimization [2.A comprehensive literature review on variable control charts to monitor process mean and dispersion is provided.

The article gives an account of the history of invented charts, as well as the uses of charts in various industries, stressing the need for flexibility and adaptability during operations [24].This research presents the development of Six Sigma-type control charts for interval valued data, as an example of innovative methods of solving complicated data structures problems. The research places emphasis on the effectiveness of these techniques in decreasing variability of the processes [25]."

This document describes the "Control Phase," which is the last step in the Lean Six Sigma paradigm with a particular focus on sustaining improvements to the processes. It highlights the application of control charts as a means of sustaining the benefits obtained in the earlier phases of Six Sigma projects.[26]

The analysis captures the use of process control charts in the construction and service industries. It notes the inability of SPC tools in complex and fast moving systems, and proposes changes that will improve productivity.[27]

The document describes Shewhart control charts and tests of special causes as the most simple and basic form of process variation methods. This scholarship has formed the basis of quality control practice.[28] This research examines the utilitarian aspects of Ishikawa's seven old tools for the purpose of their inclusion in the Six Sigma strategy, thus aiding the elementary quality control concepts in its vigorous implementation. The fusion of fundamental tools with Six Sigma is known to broaden its horizons for different operational environments.[29] These authors design a range process control chart under the framework of Six Sigma initiatives, so that it contributes towards the reduction of process variation and enhances the culture of continuous improvement in mechanical engineering.[30]

The study examines Lean Six Sigma tools from different angles with a focus on the integration of different approaches to achieving optimal quality management. It focuses on how the Lean and Six Sigma tools, in conjunction, can deal with complex operational problems in both the manufacturing and service industries. The research examines the concepts of these tools in solo and integrated forms as part of continuous improvement (CI) processes and their usefulness in different industries. [31]

The paper investigates factors influencing the use of control charts in monitoring operational measures. Some considerations such as the industry, the organization's structure and culture, and the information available were important to the adoption of control charts. From the study, it is evident that these factors have to be understood to enable the application of quality control tools across different settings like health care services and manufacturing industries [32]

The objective of this research is to develop control charts that are aligned with Six Sigma practices, especially in terms of defect per unit and defect tracking. The paper also outlines in detail the use of control waivers as part of Six Sigma's Define-Measure-Analyze-Improve-Control (DMAIC) cycle, which considerably assists in achieving stability and quality of processes in production. It also draws attention to the use of statistical techniques in the management of defects and high quality products.

Like any other modern manufacturing industry, Defect Control has applied Six Sigma in its Processes with the DMAIC system, focusing on perceived obstacles with control charts. The Incorporation of Control charts into quality management processes serves determination of stability, processes control and detection of outliers while ensuring adequate production.

This paper attempts to uniquely contribute to the existing knowledge on Six Sigma and its use in quality management by providing a systematic approach on how to utilize statistical instruments to set, measure, control, and improve processes.

Six Sigma Methodology

The Six Sigma methodology improves processes through a systematic approach termed DMAIC. Instead of focusing on target goals, it focuses on eliminating any defect throughout the set guidelines which are termed as variation. The term variation itself refers to a process deviation of more than 3.4 defects per 1 million opportunities. In a perfect world scenario, Six Sigma strives to achieve a near perfect quality outcome.

While Six Sigma aims for near perfection, identifying problem statements is step one of the DMAIC methodology. The next step is measurement, capture and screenshot process performance targeting the thickness of steel sheets. The next step would be execution which will focus on corrective action that targets all analytic deviations obtained: discrepancy detection, usage of variation sources, and implementing changes that reduce overall variance. After correction, achieving and maintaining goals is prioritized. Time could potentially reduce defect components per 1 million opportunities.

Problem Statement :

New manufacturing company is focused towards aiming for a target thickness of steel sheets of 5mm, while the customer requests fall between 5.05 – 4.95. Suppose range set gets violated. In that case, correct product quality will break towards significant issues possessing high chance of customer aggravation. While we analyze the thickness data obtained from the whole, we simultaneously try to gauge if our company's existing processes would still need enhancement to reach Six Sigma threshold goals. The following are the processes and methodologies relevant to the completion of this research study.

Data Collection and Analysis

The data for this study consist of thickness measurements taken from a sample of 20 to 30 sheets. Each sheet is supposed to satisfy the customer specification requirement of 5mm 0.05mm. For this analysis, we compute the average thickness, standard deviation (σ), and the Process Capability Indices (Cp, Cpk) that determine the stability and capability of a process.

Mean: The average thickness across the sample. Standard Deviation: A measure of variability in the thickness values.Upper and Lower Control Limits: They act as a measures of control in tracking the adjustments to the process variation. Cp: It is that Process Capability Index which gives the capability of the process spread as the thickness specification limits 5.05 mm and 4.95 mm.Cpk: The Process Capability Index that takes into account the degree of centering of the process with respect to the specification limits.

Statistical Process Control and Capability Indices

Control Charts

In Six Sigma, control charts are the main tools designed to show how the monitored process behaves over time. For this research, the X-bar chart is used splot the sample means including the control limits set at ±3 standard deviations from the process mean. The person watching the data performs check to see whether the data points are controlled or not. If all data points lie within these limits, the process is said to be stable and in control.

Process Capability Analysis

To measure the capacity of a process to continuously manufacture or synthesize sheets within the thickness range of 5.05 mm to 4.95 mm as specified by the customer, the following capability indices are determined.

Cp (Capability Index): Cp = (USL - LSL) / (6σ). The index gives a measure of the process potential effectiveness in terms of spread. For meeting quality standards, a Cp value of 1.33 or higher is desired in manufacturing processes.

Cpk (Process Capability Index): Cpk = min((USL - μ) / 3σ, (μ - LSL) / 3σ). Cpk is a measure of Process Capability Index which takes into account the alignment of the process mean with the

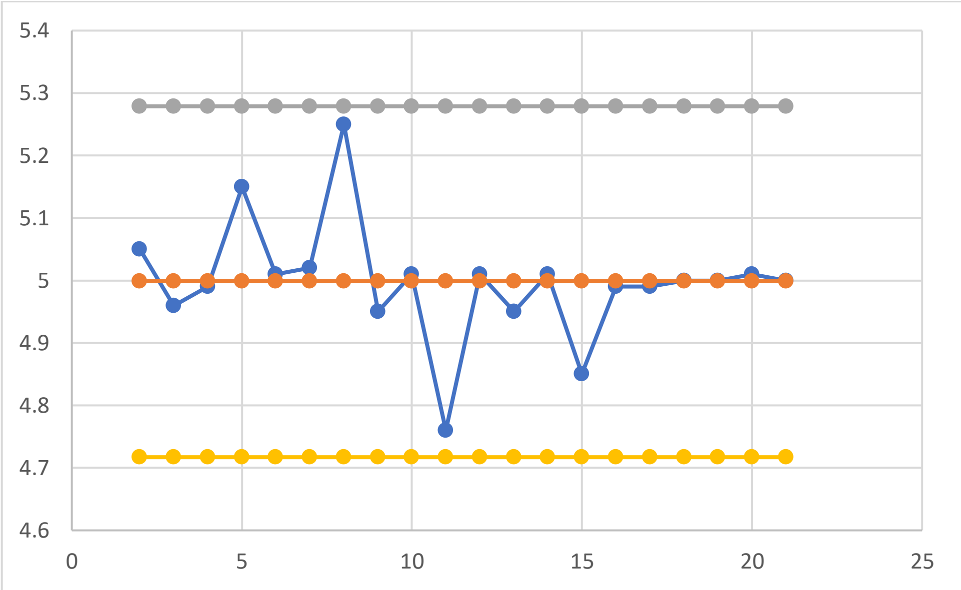
specification target value. A Process Capability Index with high Cpk values means that the process is more centered and therefore more capable of meeting specifications.
Targets for a Six Sigma process are usually set with a minimum requirement of Cp and Cpk values being equal to or greater than 2.0 which would suggest that 99.99966% of the processes undertaken lay within specification limits. With the case at hand, the objective is to make sure that sheets produced have their thickness reliably within the preset limit of 4.95 mm to 5.05 mm.
After obtaining the mean and standard deviation from the sample data along with Cp and Cpk values, the next step is to check if the existing process fulfills the customer's requirements in terms of Six Sigma. Any processes categorized as out of control are reviewed for possible stability issues in the process.

Stage 1 – Starting Phase of Manufacturing Company
Higher Variation and Lower Cp and CPk values

S No	Value	AVG	UCL	LCL
1	5.05	4.999	5.278881	4.717119
2	4.96	4.999	5.278881	4.717119
3	4.99	4.999	5.278881	4.717119
4	5.15	4.999	5.278881	4.717119
5	5.01	4.999	5.278881	4.717119
6	5.02	4.999	5.278881	4.717119
7	5.25	4.999	5.278881	4.717119
8	4.95	4.999	5.278881	4.717119
9	5.01	4.999	5.278881	4.717119
10	4.76	4.999	5.278881	4.717119
11	5.01	4.999	5.278881	4.717119
12	4.95	4.999	5.278881	4.717119
13	5.01	4.999	5.278881	4.717119
14	4.85	4.999	5.278881	4.717119
15	4.99	4.999	5.278881	4.717119
16	4.99	4.999	5.278881	4.717119
17	5	4.999	5.278881	4.717119
18	5	4.999	5.278881	4.717119
19	5.01	4.999	5.278881	4.717119
20	5	4.999	5.278881	4.717119

Average (Mean) or μ	**4.998**
Standard Deviation or σ	**0.093627**
Upper Control Limit at Plus 3 Sigma from Mean, UCL	**5.278881**
Lower Control Limit at minus 3 sigma from Mean , LCL	**4.717119**

The mean value for twenty samples is 4.998 and stabdard deviation 0.093627 and UCL is placed at mean plus three one sigma which becomes 5.27881 and similarly LCL placed at Mean minus three one sigma becomes 4.7171 . UCL and LCL are exceeding the customers specification limits of 5.05 and 4.95.



Cp = (USL - LSL) / (6σ) = (5.2788 – 4.7171) / (6 * **0.093627**)

Cp = 0.17801

For our calculated data, Cp = 0.17801. A Cp value of 0.17801 indicates that the process variation is relatively high compared to the specification limits, which suggests a need for further process improvements to reduce variability

Cpk = min((USL - μ) / 3σ, (μ - LSL) / 3σ) Here μ is mean and average is 4.998 mm.hence the calculation gives

Cpk = 0.17089

Here, Cpk = 0.17089, which is slightly lower than Cp and less than 1, indicating the process mean is not perfectly centered within the customer-specified limits.Cp and Cpk values below 1.0 suggest that the process is not capable of consistently meeting the customer specifications. Ideally, Cp and Cpk values should be above 1.33 for Six Sigma-level quality, which means the process would produce minimal defects within customer tolerance levels.

Interpretation and Recommendations

To improve the process and ensure higher product quality, several measures can be considered:

1.Reducing Variability: Reducing the standard deviation through tighter process controls can directly increase Cp and Cpk. This can be achieved by improving machinery accuracy, enhancing material quality, and ensuring consistent operating conditions.

2.Centering the Process Mean: Aligning the process mean closer to the target value (5.0 mm) will increase Cpk, indicating the process is more centered within the specification limits. Regular monitoring and adjustments will help in maintaining alignment with the target mean.

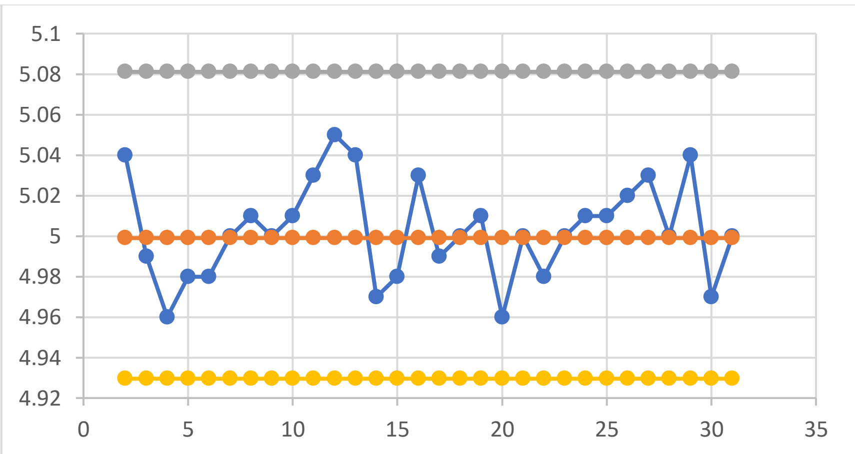
3.Continuous Improvement Practices: Adopting continuous improvement methodologies like Six Sigma can help reduce defects and bring the process into compliance with customer specifications. Regular root-cause analyses and corrective actions will help eliminate sources of variation.

Stage 2: Reducing the variations and Improving CP and CPK

S No	Value	AVG	UCL	LCL
1	5.04	4.999	5.081123	4.929544
2	4.99	4.999	5.081123	4.929544
3	4.96	4.999	5.081123	4.929544
4	4.98	4.999	5.081123	4.929544

5	4.98	4.999	5.081123	4.929544
6	5	4.999	5.081123	4.929544
7	5.01	4.999	5.081123	4.929544
8	5	4.999	5.081123	4.929544
9	5.01	4.999	5.081123	4.929544
10	5.03	4.999	5.081123	4.929544
11	5.05	4.999	5.081123	4.929544
12	5.04	4.999	5.081123	4.929544
13	4.97	4.999	5.081123	4.929544
14	4.98	4.999	5.081123	4.929544
15	5.03	4.999	5.081123	4.929544
16	4.99	4.999	5.081123	4.929544
17	5	4.999	5.081123	4.929544
18	5.01	4.999	5.081123	4.929544
19	4.96	4.999	5.081123	4.929544
20	5	4.999	5.081123	4.929544
21	4.98	4.999	5.081123	4.929544
22	5	4.999	5.081123	4.929544
23	5.01	4.999	5.081123	4.929544
24	5.01	4.999	5.081123	4.929544
25	5.02	4.999	5.081123	4.929544
26	5.03	4.999	5.081123	4.929544
27	5	4.999	5.081123	4.929544
28	5.04	4.999	5.081123	4.929544
29	4.97	4.999	5.081123	4.929544
30	5	4.999	5.081123	4.929544

Average or µ	**5.003**
Standard Deviation or σ	**0.024104**
Upper Control Limit at Plus 3 Sigma from Mean, UCL	**5.075312**
Lower Control Limit at minus 3 sigma from Mean , LCL	**4.930688**



Cp = (USL - LSL) / (6σ) = (5.075312- 4.930688)/ (6* 0.024104)

Cp =0.69145

When compared with stage 1 , In this case, Cp = 0.69145, which suggests that while the process has improved, there is still an opportunity to increase the spread between the control limits and the specification limits

Cpk = min((USL - μ) / 3σ, (μ - LSL) / 3σ) , similarly substituting all values we get

CPK = 0.69145

Here, Cpk = 0.69145, indicating the process centering is better aligned with the specification limits but still requires further improvement to achieve a Six Sigma level.The improved Cp and Cpk values reflect a more capable process. However, for a Six Sigma process, Cp and Cpk values should ideally exceed 1.33, implying the need for additional refinements. The increase in Cp and Cpk values in Stage 2 indicates progress toward achieving this target.

Approaches for Further Elimination of Variation

In order to increase the value of the company's Cp and Cpk, efforts will have to be sustained to reduce their process variability. The following strategies can be pursued:

Root Cause Analysis: Using tools such as Fishbone Diagrams and the 5 Whys, carry out in-depth analyses to find out where the process variability is originating from, which can include machinery, environment, or materials.

Calibration and Maintenance of Machines: Reliable sources of mechanical variation will be minimized if all equipment is properly maintained and calibrated according to the standards set.

Enhanced Process Control: Deviations from set standards and parameters can be monitored and controlled in real time, so action can be taken as soon as abnormal readings are detected.

Operator Training: While enhanced process control will help to mitigate errors made by operators, training on the standardized work procedures surely will eliminate most of the human induced variability.

SPC Monitoring: Constant monitoring of material thickness uniformity can be achieved through frequent utilization of such as the X-bar and R charts.

Material Control: The variations due to properties of raw materials which impact thickness will be minimized by ensuring high standardizations of the raw materials and their properties.

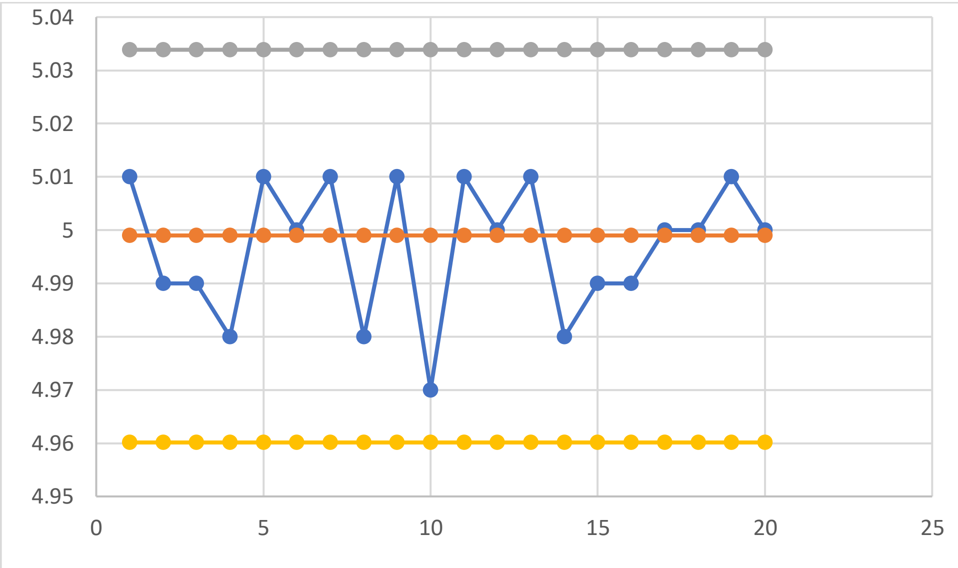
With selective changes and efforts to decrease variability, the production of stainless steel sheets has greatly improved in consistency and quality. Stage 2 has resulted in higher values of Cp and Cpk, compared to stage 1 but there is still needed work to be done in order to reach Six Sigma metrics where Cp and Cpk values to reach 1.33 and make above this. By adopting the reduction of variation methods specified, the company will ensure greater product consistency, more reliably meet customer expectations, and at the same time reduce the expense of controlling defects and rework.

Stage 3 : Reaching Higher Cp and CPk value

S No	Value	AVG	UCL	LCL
1	5.01	4.999	5.033865	4.960135
2	4.99	4.999	5.033865	4.960135
3	4.99	4.999	5.033865	4.960135
4	4.98	4.999	5.033865	4.960135
5	5.01	4.999	5.033865	4.960135
6	5	4.999	5.033865	4.960135
7	5.01	4.999	5.033865	4.960135
8	4.98	4.999	5.033865	4.960135
9	5.01	4.999	5.033865	4.960135
10	4.97	4.999	5.033865	4.960135

11	5.01	4.999	5.033865	4.960135
12	5	4.999	5.033865	4.960135
13	5.01	4.999	5.033865	4.960135
14	4.98	4.999	5.033865	4.960135
15	4.99	4.999	5.033865	4.960135
16	4.99	4.999	5.033865	4.960135
17	5	4.999	5.033865	4.960135
18	5	4.999	5.033865	4.960135
19	5.01	4.999	5.033865	4.960135
20	5	4.999	5.033865	4.960135

Average / µ	**4.997**
Standard Deviation/ σ	**0.012288**
Upper Control Limit at Plus 3 Sigma, UCL	**5.033865**
Lower Control Limit at minus 3 sigma, LCL	**4.960135**



Cp = (USL - LSL) / (6σ) = (5.0338 – 4.9601) / (6 * 0.0122)

Cp =1.35

Cp (Process Capability): 1.35. Achieving a Cp value above 1.33 indicates that the process variation is now well within the customer's specification range, marking a substantial improvement in process precision.

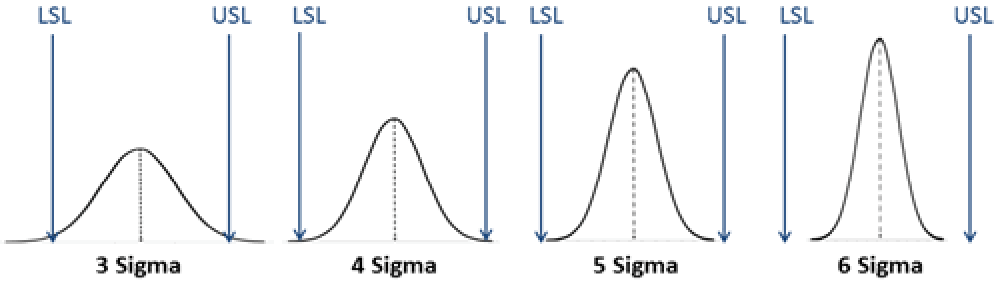
Cpk = min((USL - µ) / 3σ, (µ - LSL) / 3σ) , Similarly substituting all values and taking minimum of two values give Cpk .

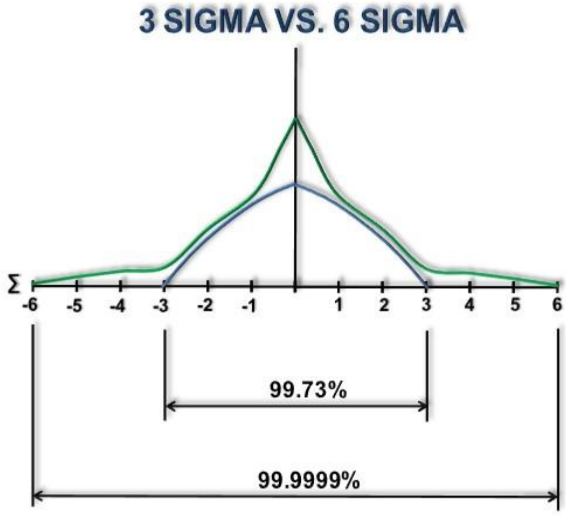
Cpk =1.27 . Cpk (Process Capability with Centering): 1.27. The Cpk value, while slightly lower than Cp, still suggests that the process mean is very close to the target, with minimal deviation. The value being near 1.33 suggests that the process is centered effectively and capable of meeting specifications.These values highlight that the firm has achieved a high degree of capability, performing consistently within the tolerance range defined by the customer. And finally, this portion of analysis shows the results of changes which were made for process improvements, along with meeting customer requirements for the thickness of stainless steel sheets. The changes in this stage were aimed at shifting process capability indices closer to Six Sigma, significantly increasing Cp and Cpk values.

Process Data and Control Limits
In Stage 3, the data indicates that both process variability and mean deviation from the target have been minimized. The refined control limits also suggest that the firm is now achieving increased process control. Unlike the previous stages, Stage 3 reveals narrow range between UCL and LCL and it is improved control of the process and lesser variation.

Customer Requirements And Proccess Capability Indices
The customer tolerates limits for steel thicknesses still lie between 4.95 mm (LSL) and 5.05 mm (USL). The process capability indices calculated for this stage are as follows: The improvements seen during Stage 3 now indicate that the process has neared the achievement of Three Sigma requirements attesting to it by a Cpk and Cp of 1.33.This exceptional process control significantly reduces the chances of nonconformance to customer specifications and improves the product quality along with customer satisfaction.

Steps Taken To Improve Cp And Cpk
Achieving this high level of capability required the implementation of many tactics and alterations such as:
Refinement of Process Controls: We have worked measures to control the mean at 4.997 mm which is for the available target of 5 mm and have continuously sought to reduce deviation from this value which in turn increases the Cpk value.
Expectation also an Enhanced Quality Control Measures: Other joint quality control measures like other calibration checks and more inspection on standard level of 0.0123 mm resulted in greater Cp.
Achieving a High Process Capability for Producing Stainless Steel Sheets: Targeted measures for enhancing process control and quality management have proven to be effective. The results from Stage 3 reveal that a high process capability for stainless steel sheet production can be achieved. The values of Cp and Cpk are near the boundaries set by Three Sigma, indicating that customer expectations can consistently be met while minimizing rework, increasing product quality, and overall efficiency. The company can sustain this level of improvement while remaining committed to operational excellence.
The Adoption of Effective Real-time Monitoring: Effective real-time monitoring made it possible to address potential errors that would have advanced beyond benign scope. These measures allowed for self-correction of any deviations from the ideal mean, thereby easily keeping production within control limits, which in turn reduced unnecessary variability.
The production process was adjusted in a way that makes it possible to achieve a highly stable production process, which in turn enabled the minimization of the potential sources of variation including external factors like the environment, machine vibrators, and material differences.





CP CPK	1.33	2
Sigma Level	3 Sigma	6 Sigma
Percentage of Meeting Specification Limits	99.73	99.99996

Cause and Effects for Thickness of Sheet in Three Sigma Practices
Before and during Three Sigma Practices
A.Human Factors
Before Improvements:
Inconsistent Training: Staff controling the thickness of steel sheets may not be adequately trained, which leads to inconsistencies in the quality of products made.
Unclear Procedures: The communication of SOPs for the operations of handling, bending, cutting, and quality assessment of steel sheets is vague, which affects their utilization, leading to inconsistent sheet dimensions.
Skill Gaps: Employees may not understand process parameters that alter the steel sheet thickness to be produced, hence making mistakes.
Poor Work Discipline: Not paying close attention to the details in production makes it easier to produce shafts with nonuniform sheet thickness and defective steel sheets.

After Improvements:
Comprehensive Training Programs: By employing the aforementioned benchmarking techniques, relevant standard and controlled training is issued to operators and workers on thickness and defect control during production, measurement and quality assessment, as well.

Effective SOP Dissemination: Comprehensive SOPs for material control in steel sheet rolling, cutting, handling and even thickness measurement are properly communicated and made known to all concerned staff.
Regular Skill Assessments: Workers are routinely trained and assessed in an effort to increase their precision and productivity in dealing with steel sheet thickness.
Enforced Discipline: Heightened emphasis on discipline at the workplace reinforces adherence to SOPs and mitigates neglect during each production stage to control for thickness.

B.Materials Factors
Before Improvements
Inconsistent Raw Materials: Steel sheets as raw materials, particularly coils or slabs, have an inherent disparity in thickness, affecting the overall product's consistency.
Poor Material Identification: Coils and sheets of steel as raw materials do not carry an adequate description for ease of differentiation, resulting in mistakes when used for production.
Quality Control Gaps in Materials: The raw materials, such as the final sheets, are not adequately subjected to promised testing quality verification such as tensile strength and uniformity, hence the variance in sheet thicknesses.

After Improvements:
Quality Raw Material Inspection and Verification Processes: It is possible to put in place processes that check the incoming steel slabs to verify that the materials satisfy required quality standards in terms of thickness and quality.
Clear Material Identification: There is a clear marking specification for inventories at each stage (steel coils, slabs, etc.) like thickness, gauge, and other relevant properties to avoid chances of error during production processes.
Improved Material Testing: A dedicated material testing lab is established, and raw materials undergo thorough testing for uniform qualities. This ensures that only materials that meet the level specifications are used, leading to more constant steel sheet thickness.

C. Machine Factors
Before Improvements:
Inaccurate Machine Calibration: The Rolling machines that process the steel sheets might not be calibrated frequently, thus the accuracy of a sheet's thickness is not reliable.
Infrequency Of Machine Repairs: A machine is not serviced frequently, which could lead to mechanical problems concerning the steel sheets' thickness controlling devices.
Unreliable Machine Settings: Rolling mills or any other machines might not be appropriately set or optimized; hence the thickness of the produced sheets might not be uniform.

After Improvements:
Regular Machine Calibration and Maintenance - SOPs for calibration and preventative maintenance of machines are followed involving periodic checks on the machines to guarantee that they are optimally controlled on an ongoing basis.
Condition Monitoring - A system for the continuous monitoring of machines conditions such as roll pressure, roll speed, and roll alignment is implemented. This enables early detection and correction of problems.
Optimized Machine Settings - Operators are now provided with training on how to set and adjust the machine parameters like roll gaps, tension, speed, type of steel being used, and the required sheetness to have better control of the product's dimensions.

Machine Performance Tracking - Records of the machine performance during production such as the thickness control during production are kept to enable the rough diagnosis of any problems that may cause inconsistent results.

D. Method Factors

Before Improvements:

No Clear Process of Methodology: There seems to be no definite way of controlling the thickness of steel sheets which would result in a definitive end product.

Ineffective Monitoring and Control System: There might be moderate monitoring on sheet thickness during the rolling process, but adjustments to machine controls is likely not done on time.

Poor Management of Critical Process Parameters: Important variables such as the temeperature, speed, and pressure of a system are regarded as uncontrolled which leads to inconsistently controlled steel sheet thickness.

After Improvements:

Detailed Instructions on Sheet Steel Thickness Control Procedure: There is an action plan on the control of the thickness of steel sheets, it includes the appropriate temperature, roll pressure, and machine settings.

Adjustments Using Data Exchange: During the production on every stage, thicknes of steel sheets is controlled with advanced sensors and systems which allows for immediate changes to be made in order to keep sheet thickness even for all steel sheets.

Optimization Using Monitoring Information: In real-time monitoring of production, more temperate parameters can be set to let operators have control over mid range bottom parameters in order to increase consistency in sheet thickness.

Consistent Quality Checks: The thickness variability is tracked using SPC techniques and quality checks are conducted regularly.

Conclusion:

Each section of the production process, from one to three, strives to reduce variations which herbs the sigma. This results in an increased value of CP and CPK, which can be achieved with less variations. The processes are then monitored for the cause-and-effect of the variations followed by period stage improvements are targeted towards reaching the three sigma target. Lastly, the three to six sigma difference is analyzed with the help of the diagram and table. With the help of this, it is guaranteed that the steel sheets to the customer's specifications of thickness 5.05 and 4.95 mm. After a thorough six sigma review within the company, all operators and employees are required to meet strict quality standards enabling the company to benefit from actionable proactive control.

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