5th African International Conference on Industrial Engineering and Operations Management, Johannesburg/Pretoria, South Africa, April 23 - 25, 2024
Publisher: IEOM Society International, USA
Published: April 23, 2024 DOI: 10.46254/AF05.20240176

Optimizing Efficiency and Standardization: A Lean Six Sigma Approach in US Small and Medium-Sized Manufacturing—A Case Study of Magnelab Inc

Hossein Soltani
Department of Manufacturing Engineering Technology
Minnesota State University
Mankato, MN 56001, USA
hossein.soltaninejadroodabadi@mnsu.edu
https://orcid.org/0000-0002-0400-6165

Kuldeep Agarwal
Department of Manufacturing Engineering Technology
Minnesota State University
Mankato, MN 56001, USA
kuldeep.agarwal@mnsu.edu

Abstract

This paper examines how Six Sigma's DMAIC (Define-Measure-Analyze-Improve-Control) methodology can be applied to improve operational efficiency by mitigating test set equipment failures within the transformer manufacturing sector. Using Six Sigma principles in conjunction with Lean manufacturing principles, the study seeks to minimize errors and streamline processes. Industrial settings are particularly suited to this data-driven approach, which is adept at addressing both anticipated and unforeseen problems. The paper provides an overview of DMAIC through the use of a detailed case study. In the Define phase, discrepancies are identified in test results and equipment failures are identified, laying the groundwork for improvement. Over a five-year period, the Measure phase involves meticulous data collection and statistical analysis using tools like Minitab. Analysis sheds light on contributing factors by delving into root causes. The Improve phase addresses issues strategically by developing Standard Operating Procedures (SOPs) and undertaking proactive measures such as equipment repairs. Through DMAIC, Six Sigma emphasizes data-driven decision-making, standards compliance, and continuous improvement to overcome industrial hurdles. As a result of this comprehensive analysis, Six Sigma methodologies are shown to be adaptable and effective in resolving production inefficiencies across organizations.

Keywords
Six Sigma, DMAIC Methodology, Operational efficiency, Test set equipment failures, Transformer manufacturing

1. Introduction
In the landscape of the manufacturing industry, achieving optimal efficiency is a constant pursuit for most companies as it delivers operational excellence and competitive advantage. The Six Sigma methodology is considered the best approach for improving quality and reducing the number of defects. It is usually combined with Lean manufacturing techniques, which reduce waste. A combination of Lean Six Sigma helps primarily in near elimination of defects, optimizing resource consumption, better waste management, and solving production process issues (Pugna et al., 2016). This quality improvement process can be linked to manufacturing or non-manufacturing processes marked by

the capability of an organization and its objectives. Various process improvement methodologies such as 5S, Total Quality Management (TQM), PDCA (Plan-Do-Check-Action) cycle, Just-in-time, Toyota Production System (TPS) are used widely in the manufacturing sector to align production processes with the goals of the company and customer. Six Sigma is one of the most efficient methods among them. It is a highly disciplined and thorough data analysis-based improvement approach for removing defects and redundancies from processes. It involves a 5-step project for fact-based decision making and effective control. The benefits of Six Sigma were quickly realized by companies which then expanded the concept to various functional areas where applicable (Ray and Das, 2011).

This paper delves into the applications of the Six Sigma process through a comprehensive case study where the DMAIC (Define-Measure-Analyze-Improve-Control) process was applied to a transformer manufacturing company. The primary objective of the project was to elevate operational efficiency by 50% by reducing failures of the test set equipment – a pivotal component in the testing process, used to measure the accuracy of the transformers. Since it is a manufacturing company, the Six Sigma principles are directly applicable to this field. The organization faces challenges with failures of test equipment with known and unknown causes. The case study was conducted with the DMAIC application to analyze and find the root cause of the issues and thereby suggest solutions to increase efficiency. This research paper unfolds by providing a detailed overview of the concept of the Six Sigma DMAIC process and its application in the context of the case study conducted within the transformer manufacturing industry. The paper explores the critical stages of Define, Measure, Analyze, Improve, and Control where necessary, detailing the tools and methods used in each step to bring impactful change. The paper seeks to provide a clear understanding of the potential of Six Sigma methodologies in resolving production inefficiencies which can be translated to various departments.

1.1 Objectives

SMEs can use this research paper as a valuable resource for implementing Six Sigma methodologies effectively. SMEs face unique challenges, strategies, and outcomes in integrating Six Sigma, and this endeavor explores them comprehensively. In the past two decades, considerable attention has been paid to the presentation of Six Sigma implementation frameworks for large organizations. However, there is still a notable gap in addressing Six Sigma implementation in SMEs and evaluating its success or failure in this unique operating environment. To close this gap, this paper examines the challenges and opportunities associated with Six Sigma adoption in SMEs. Consequently, the research contributes to the existing body of knowledge and provides SMEs with a practical and comprehensive guide to Six Sigma application.

2. Literature Review

The process of Six Sigma is characterized by a systematic and data-driven 5-step DMAIC methodology. The principal focus of Six Sigma is to decrease potential variability in processes and products using follows the DMAIC process. It helps in producing products better, faster, and cheaper by improving quality and enhancing the production process. Six-Sigma is a scientific and statistical quality evaluation for all processes that provides opportunity and discipline to minimize mistakes, enhance morale, and save money (Ray and Das, 2011). a company must relate bottom-line advantages to Six-Sigma projects, since the Six-Sigma drive for process improvement occurs project by project by adhering to these principles.

- Determine the process for improvement. Each output is the outcome of a procedure. Improve the process to improve output quality.
- Every process has an inherent unpredictability.
- Data is utilized to understand the variability and its origins, as well as to drive process improvement decisions.

Six Sigma applications are always a project driven scheme that uses a well-structured method which comprises the 5 phases of the DMAIC process as shown in Figure 1.

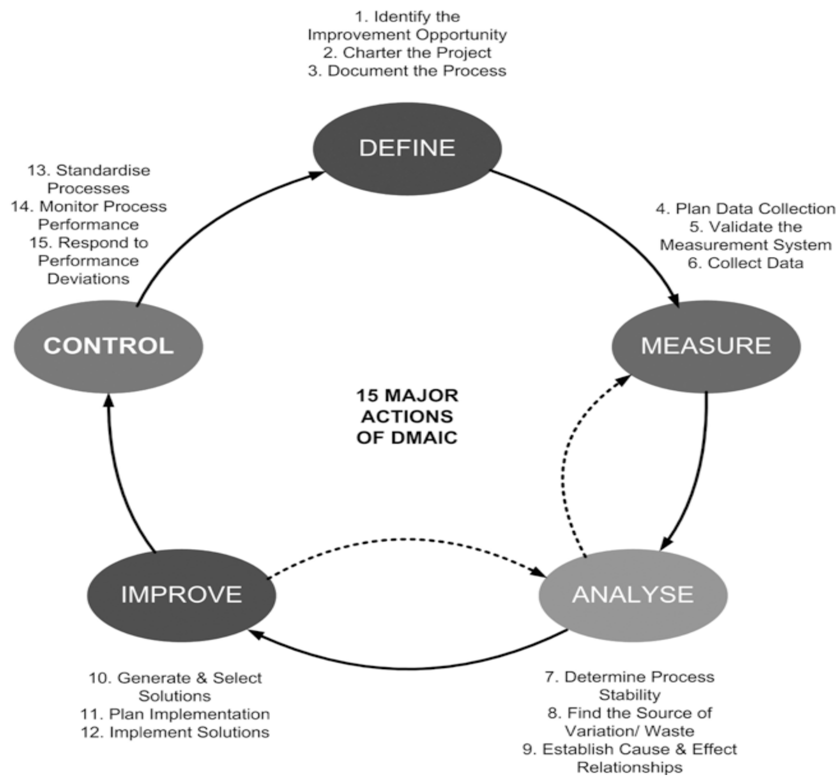

Figure 1: DMAIC process cycle

Phase 1: Define

The DMAIC process begins with the Define phase, a critical step that sets the framework for subsequent steps and actions. At this stage, the project team aims to set a well-defined problem statement that acts as a compass directing the entire project. It is done by identifying the primary problems through resources available at hand like, voice of customers, business data, SIPOC (Suppliers, Input, Process, Output, Customers) and value stream/process maps. The next step in this phase forms the Critical to Quality Characteristics (CTQs) which are simply critical quality parameters for satisfying customer's requirements.

This phase is not just about problem identification but also is an opportunity to align the project with the needs of the organization by making sure that the results produce strategic benefits (Raman and Basavaraj, 2018). The solutions that are achieved at the end of the project can be set as standardized processes to be followed by team members in the future. Clear communication and collaboration are essential during this phase as they will set the groundwork for team members and stakeholders to have a common understanding of the project's goals.

Phase 2: Measure

Having defined the problem and project scope, the Measure phase is dedicated to collecting data that offers insights into the current state of the process. This phase focuses on establishing a baseline measurement of key process indicators and analyzing the system's inherent variability. All problems identified are measured according to requirements and the data is recorded. Accurate measurement techniques ensure the dependability of the data obtained. During the Measure phase, statistical tools such as control charts, histograms, fishbone diagrams, and process capacity indicators are significant.

These tools not only measure the present processes being successful but also serve as a lens through which the project team may spot patterns and trends. As a result, this phase serves as the foundation for the future analytical phases, offering a data-driven view of the existing process.

Phase 3: Analyze

Once the measurements are recorded and the data set is created, the analyze phase begins to find the root causes of the identified issues and inefficiencies. To evaluate the acquired data, statistical approaches and analytical tools are systematically utilized. Cause-and-effect diagrams, regression analysis, and hypothesis testing are instrumental in identifying factors contributing to process variation. The Analyze phase is all about digging deeper to find the root causes of process abnormalities. The goal of pinpointing the root cause is to determine its impact on process variation (Adeodu et al., 2021).

By identifying these root causes, the project team can create focused solutions that offer long-term gains rather than quick fixes. It is during this phase that the analytical capability of Six Sigma becomes apparent, opening the door for strategic and informed decision-making. During this phase, it is common to go back and forth between the analyze and measure steps to reassure that the data is conforming to the requirements.

Phase 4: Improve

With a clear understanding of the root causes, the Improve phase focuses on implementing solutions that result in actual improvements to the process. This is a time when creativity and innovation are required.
During this stage, methods such as quality function deployment, design of experiments, and process modeling, among others, are used. In this phase, pilot tests and simulations are crucial because they provide a controlled environment for validating suggested changes before full-scale deployment. One of the most significant phases in this phase is to determine the major factors and their effects on quality characteristics variation.
The solution implemented at this level must concentrate on maintaining the current process within the desired limit. This phase is marked by a commitment to continual improvement, and the solutions deployed should not only solve the identified concerns but also contribute to the process's overall efficiency and effectiveness. The innovative potential of Six Sigma is achieved in the Improve phase, when businesses go from identifying issues to adopting meaningful and durable solutions.

Phase 5: Control

The DMAIC method concludes in the Control phase when the emphasis changes to assure the sustainability of improvements. Robust mechanisms are put in place to monitor and control the processes, preventing them from reverting to their prior condition. Control plans, monitoring systems, and people training are essential components of this phase. Statistical process control charts, which provide a visual representation of process performance across time, are useful at this phase. Organizations can detect irregularities or anomalies in critical indicators by continually monitoring them, allowing for quick remedial measures. Each process is documented, and time is allocated based on the needs of each process while keeping productivity in mind. Following the implementation of the new process, it is monitored until the system begins to function properly. Because implementing a new process is far simpler than maintaining it, monitoring becomes an essential aspect of this step.

3. Methods

Company Overview

The case study used in this research paper is conducted on a prominent transformer and Rogowski coils manufacturer with experience over 45 years. As a seasoned manufacturer, it has established itself as a market leader, specialized in the creation of precision current transformers adapted to a wide range of sectors. The organization has earned a reputation for dependability and creativity by demonstrating an uncompromising commitment to quality and a culture of continual development. Aside from its extensive product offering, this company differentiates itself by providing unique solutions, demonstrating amazing flexibility in meeting the various demands of its diversified clients.

Problem Statement

The production facility under close examination is found to be dealing with a persistent and multidimensional problem, characterized by inconsistent test results and frequent testing equipment failures. This situation not only compromises the overall efficiency of the manufacturing process, but it also jeopardizes product quality and operational dependability. Recurring difficulties with testing equipment have resulted in an undesirable rise in unscheduled downtime, lowering facility efficiency and disrupting the production process. To address these critical problems, this project was initiated with a specific and quantifiable goal: a 50% decrease in equipment failures over a three-month period. The key goals are to improve operating efficiency, ensure the dependability of testing equipment, and reduce unexpected downtime.

Define Phase

The major focus of the project's Define phase is on methodically resolving the recurrent challenges observed within the manufacturing plant, notably inconsistent test findings and equipment failures. A comprehensive study of historical data is required to begin this step. The ultimate goal is to achieve a significant 50% decrease in observed discrepancies within a three-month time frame. Data collection in this company is a continuous process which is automatically recorded with every test conducted daily.

The first component of the problem statement concerns the deviations discovered in test results, which question the reliability of testing processes and damage the company's reputation for producing high-quality products. The second aspect is repeated testing equipment failures, which result in unscheduled downtime, production delays, and cost issues connected with equipment repairs or replacements. The project definition is finally created as follows "The identified challenges of inconsistent test results and equipment failures will be systematically addressed. Through a rigorous analysis of historical data, the goal is to achieve a substantial 50% reduction in inconsistency.

In terms of risk assessment, while no high risks have been identified, a moderate risk associated with technological complexity is acknowledged. While no severe hazards have been detected, a moderate risk related to technical complexity has been observed. Implementing new technology may provide unexpected obstacles; to address this, preparations are in place to engage technical experts, undertake detailed feasibility studies, and deploy in stages. The project charter as seen in Figure 2 provides the core structure for leading the project team. It clearly outlines the project's purpose, scope, objectives, and key stakeholders, ensuring a clear knowledge of the project's goals and expectations within the Six Sigma approach.

Enhancing Test Equipment Reliability and Accuracy through Six Sigma				
	Project Information			
Project Name	Test Equiment Enhancement	**Project Sponser**	HR Manager	
Project Start Date	29th August 2023			
Project End date	06th December 2023	**Project Manager**	Dr.Kuldeep Agarwal	
	Project Team's Information			
Name	**Tech ID**	**Email ID**	**Phone Number**	**Responsibility**
Harrison Soltani	158456152	~	720-526-9976	Data Collection
Santhosh Ashokan	15898153	~	763-321-5987	Data Analyst & Reporting
Naim Islam	15848954	~	636-112-5679	Data Analyst
	Project Scope			
* Implement Six Sigma principles to enhance test equipment reliability and accuracy at the customer company * Address inconsistent test results and frequent equipment failures				
Objectives		**Milestones**		
* Achieve 50% reduction in equipment failures in three months. * Establish consistent and accurate testing procedures. * Identify and address root causes for sustainable solutions.		1: Analyze current processes and equipment performance. 2: Identify root causes and initiate corrective actions. 3: Implement sustainable solutions and conduct final evaluation.		
Financial Status		**Share Holders**		
Project Cost		HR Manager		
		Kuldeep Agarwal		
Net Value		Harrison Soltani		
		Santhosh Ashokan		
ROI		Naim Islam		
	Risk Management			
Risk		**Risk Ratings**		
Supplier or Vendor Delay		Moderate		
Unforeseen Technical Issues		Moderate		
Unexpected External Events (Natural Disasters, etc.)		Low		
	Conclusion			
This project holds the promise of significantly enhancing the reliability and accuracy of the test equipment, ensuring improved operational efficiency and product quality. With a clear roadmap and thoughtful risk mitigation, we are poised to make substantial strides in achieving our objectives.				

Figure 2: Project charter

Measure Phase

During the Measure phase, data samples covering four years (2020, 2021, 2022, and 2023) were chosen, with each year containing six months of test outcomes data. Using Minitab, a popular statistical analysis software, descriptive statistics were generated to provide an overall view of the data, including key metrics such as mean, median, and standard deviation. This is consistent with Six Sigma best practices, where a solid statistical basis is required for informed decision-making. An important component of the Measure phase is determining if the data follows a normal distribution.

A normality test is critical for making correct conclusions and predictions about the process. The normal distribution indicates that the data is uniformly distributed, with most data points concentrated around the mean and fewer data points clustered around the curve's edges. The normality test results of this case study revealed that there were "outliers" in the data which meant it required data cleaning as shown in Figure 3.

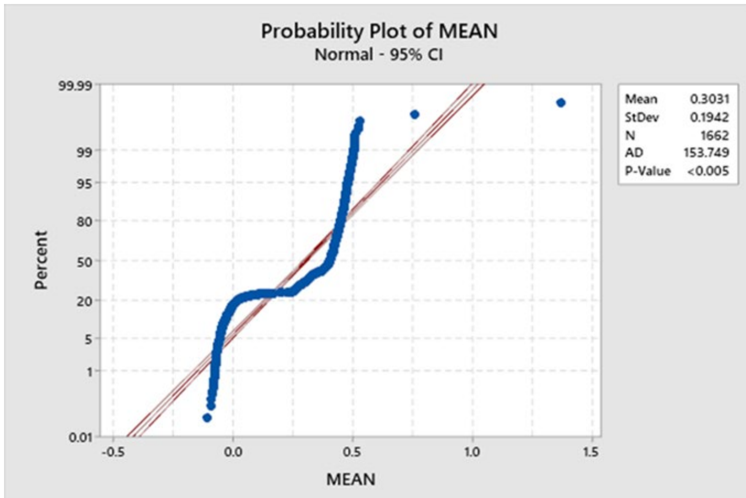

Figure 3: Probability plot of data mean

The results of the normality test were examined further using visualizations such as histograms and box plots. These visual tools not only supplement statistical analysis, but they also give a more in-depth knowledge of data distribution. The existence of outliers in the data emphasizes recognizing and correcting outliers in statistical analysis.

Process capability tests, another important aspect of the Measure phase, were carried out to check the process's repeatability and alignment with specification limitations. This is commonly stated as the capability index (Cp) in Six Sigma, which assesses the process capability within the set limitations. A lower Cp value implies that the process may not satisfy standards on a consistent basis. The deviation from the center, as indicated by the tests, and certain results going beyond the specification limits, highlight the crucial need for process improvement measures. Figure 4 displays the process capability analysis.

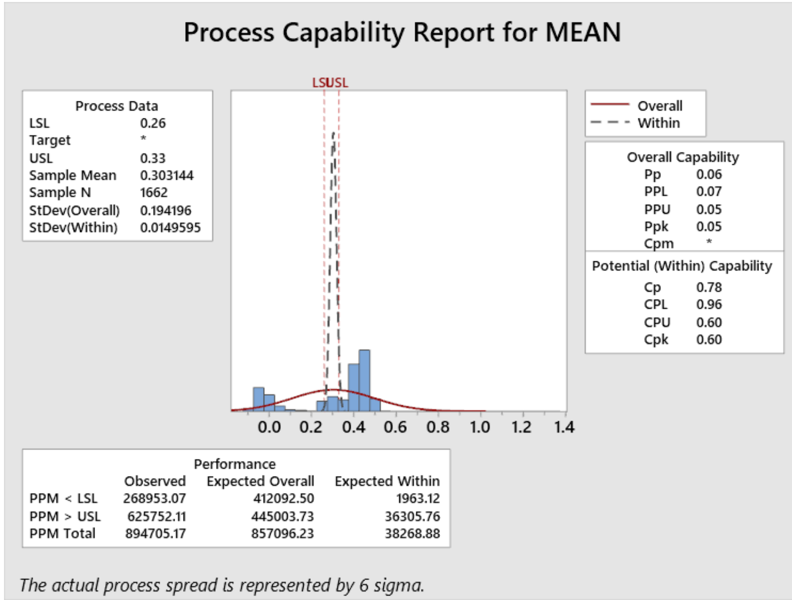

Figure 4: Process capability report

Analyze Phase

In the Analyze phase of the project, a value stream map was developed which outlined the testing process of the test set. The VSM as shown in Figure 5 detailed the process which starts by daily requests from the engineering management department.

The engineer enters the characteristics of the golden parts into the software, connects the golden pieces to the machine, runs the test, records results in the company software, scans each part label, and ultimately transfers data to the database for management access.

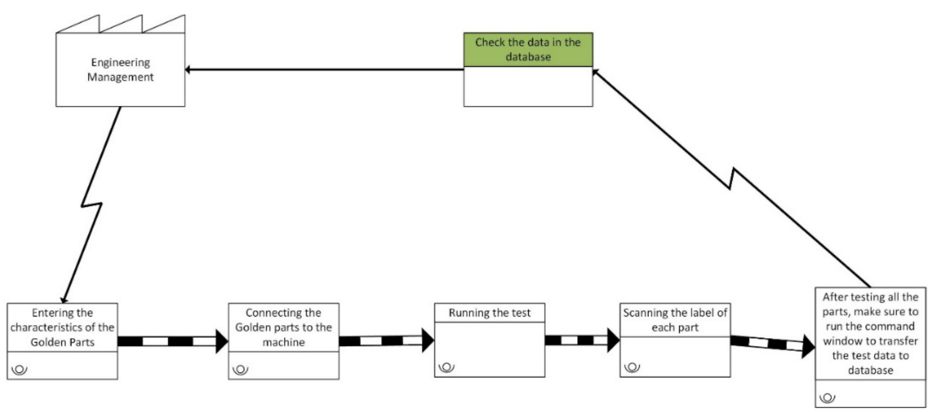

Figure 5: Value stream map of testing process

Samples covering four months from four years were collected to plot I-MR charts. The analysis of this data indicated a trend which shows that the number of failures were growing rapidly, with 2023 having the largest number of failures. Each instance of the test exceeding specification limits entails an expenditure for problem resolution via machine replacement or recalibration.

A Fishbone diagram as shown in Figure 6 was used to investigate the fundamental reasons for these failures. Human error identified as a prominent factor, emphasizing situations when operators may input attributes improperly or link components to the test set incorrectly. Another possible factor was machine failure, which needs periodic calibration

and service. Machine Adaptation Time, which affects the test results following machine replacement or recalibration, and Broken Parts, which may have broken connections and tips, were also found as factors to the problem.
The factors were recognized as Kaizen bursts and added to the VSM. The improve phase would then involve brainstorming and proposing viable solutions to address the causes where possible.

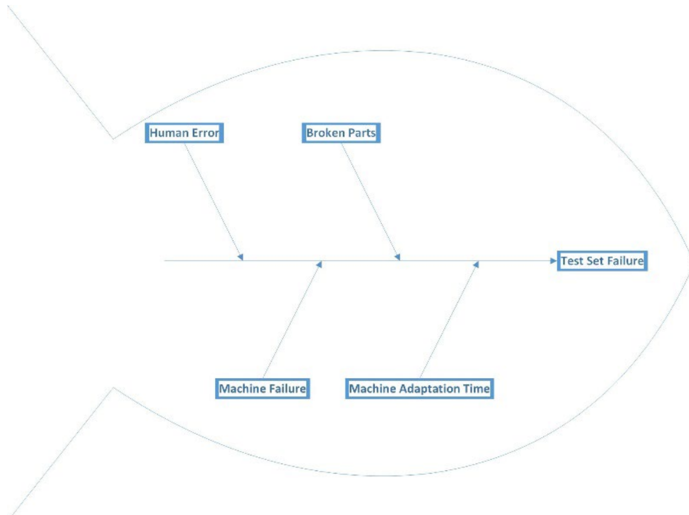

Figure 6: Fishbone diagram of root causes

Improve Phase
The improve phase oversaw a few brainstorming sessions to find viable solutions for the identified causes. One notable initiative was the creation of a Standard Operating Procedure (SOP) as shown in Figure 7 to expedite and standardize the testing process to address the issue of human error.

```
# Standardized Operating Procedure

## Purpose

The purpose of this Standard Operating Procedure (SOP) is to provide
clear and consistent guidelines for process of calibrating the test
equipment. This SOP aims to ensure that all employees follow a
standardized approach, thereby maintaining quality, efficiency, and
safety while reducing the risk of errors and inconsistencies.

## Scope

This SOP applies to all employees who are responsible for performing test
set equipment testing. The SOP covers the following equipment:

*   1\. Transformer
*   2\. Test sets
*   3\. Golden pieces
*   4\. Data recording tools
*   5\. Climate control system
*   6\. Safety equipment (thermal gloves, etc.)

## Procedure

The following steps outline the procedure:

#### Step 1

*   **Preparation: **
*   Ensure the testing environment is controlled and maintained at a
stable temperature.
*   Confirm that all testing equipment is in proper working condition.
*   Personnel involved in the testing process must wear appropriate
safety gear.

#### Step 2

*   **Transformer Connection: **
*   Carefully connect the transformer to the designated test sets,
ensuring proper alignment and secure connections.
*   Handle transformers with utmost care, considering their sensitivity
to temperature and touch.

#### Step 3

*   **Golden Piece Calibration: **
*   Calibrate the golden pieces before each testing session to ensure
accuracy.
*   Verify that the golden pieces meet the specified standards.

#### Step 4

*   **Testing Procedure: **
*   Execute the testing procedure as outlined in the company guidelines.
*   Record values systematically, ensuring attention to detail.
*   Monitor the testing environment to prevent sudden temperature
changes.

#### Step 5

*   **Data Recording: **
*   Record all values promptly and accurately using the designated data
recording tools.
*   Highlight any unexpected variations or discrepancies during the
testing process.

#### Step 6

*   **Quality Control Measures: **
*   Implement periodic checks to ensure the functionality of the test
sets and golden pieces.
*   Establish a system for cross-verification of results to detect
potential errors.

#### Step 7

*   **Temperature Management: **
*   Install and maintain a climate control system to regulate the
temperature in the testing area.
*   Avoid exposing transformers to extreme temperature fluctuations.

#### Step 8

*   **Error Investigation: **
*   In case of values exceeding specification limits, conduct a thorough
investigation.
*   Examine potential external factors such as temperature changes and
human errors.

#### Step 9

*   **Continuous Improvement: **
*   Periodically review and update the standard operating procedure to
incorporate lessons learned and improve testing efficiency.
*   Maintain detailed records for each testing session, including
environmental conditions and any deviations from the standard procedure.

#### Step 10

*   **Incident Reporting: **
*   Report any anomalies or deviations from the standard operating
procedure immediately to the designated supervisor.

## Related Resources

#### FAQs

**Why is golden piece calibration necessary before each testing session?
**
*   Golden piece calibration is essential to maintain the accuracy of the
testing process. Transformers are sensitive devices, and variations in
their performance can occur over time. Calibrating the golden pieces
before each session ensures that the reference standards are up to date,
providing a reliable baseline for accurate comparisons and measurements
during testing.

**What safety measures are in place to protect personnel during the
testing process? **

*   Personnel safety is a priority during transformer testing. Engineers
involved in the process are required to wear appropriate safety gear,
including thermal gloves, to protect against potential burns.
Additionally, regular checks are conducted to ensure the proper
functioning of safety equipment, and personnel are trained to handle
transformers with care due to their sensitivity to temperature and touch.

**How often should quality control measures, such as checks on test sets
and golden pieces, be implemented? **

*   Regular quality control measures are essential for reliable testing.
Periodic checks on test sets and golden pieces should be conducted
according to the company's internal schedule, which is typically outlined
in the quality control plan. This ensures that the equipment remains in
optimal working condition, minimizing the risk of errors and
discrepancies during testing.

**What actions should be taken if values during testing exceed
specification limits? **

*   In the event of values exceeding specification limits, a thorough
investigation should be conducted. This includes examining potential
external factors such as temperature changes or human errors. The
objective is to identify the root cause of the deviation and take
corrective measures. If necessary, the incident should be promptly
reported to the designated supervisor, and documentation of the
investigation should be maintained for future reference and analysis.

#### Links

Calibration Records

Incident Reports

Testing Logs

Quality Control Plan

Safety Guidelines

## Review & Revision

**SOP Owner: ** Project Team (**Santhosh Ashokan**, **Naim Islam**,
**Harrison Soltani**)

**Revision Request Form: ** _Link Form_
```

Figure 7: Standard operating manual

This approach is consistent with best practices in process improvement, stressing the value of standardized procedures in increasing efficiency and decreasing variance. To address the broken parts issue, the team created a workable solution by soldering wires onto possibly damaged equipment. This intervention adheres to the concepts of proactive maintenance and preventative measures, with the goal of eliminating probable failure sources.

There isn't much that can be done about Machine Adaptation Time and Machine Failures, which are recognized as recurring obstacles. The firm has maintained records of Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) in order to be prepared for failure intervals. These metrics are critical for analyzing equipment dependability and downtime, allowing for proactive maintenance planning, and reducing disruptions.

Control Phase

As the project advances into the Control phase, the emphasis shifts towards solidifying the implemented solutions and ensuring their enduring efficacy in enhancing the reliability and precision of the test equipment. This critical phase involves a meticulous evaluation of solution performance over an extended period, typically spanning six months to a year, aligning seamlessly with industry best practices of continuous improvement through data-driven insights.

During the thorough analysis spanning over six months, the Longmont graph of mean linearity, a visual representation incorporating individual and moving range charts, emerged as a powerful tool in elucidating the trajectory of improvement. The Longmont graph in figure 8 vividly illustrates how interventions led to enhanced process control, with data points consistently falling within established control limits. This graphical evidence unequivocally confirms that the process is now firmly under control, marking a significant departure from its previous state characterized by erratic fluctuations and frequent deviations from desired outcomes.

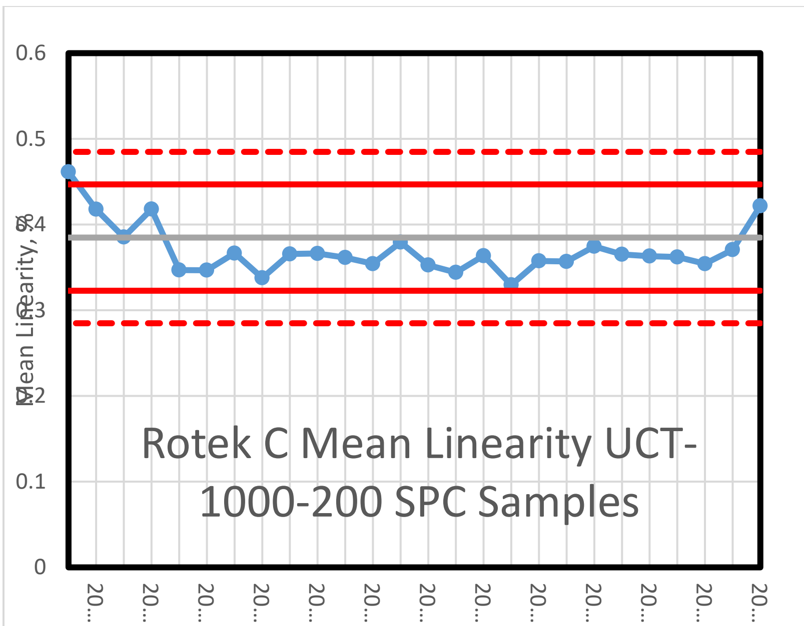

Figure 8: Mean linearity control chart

Moreover, the sustained decrease in equipment failures provides tangible evidence of the effectiveness of proactive measures, such as the implementation of Standard Operating Procedures (SOPs) to streamline and standardize testing protocols. By systematically addressing root causes of human error and equipment malfunctions, the frequency of unscheduled downtime has markedly diminished, bolstering operational efficiency and enhancing overall process dependability.

The diligent monitoring and evaluation of metrics such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) have enabled proactive maintenance planning, empowering the organization to preempt potential equipment failures before they escalate into disruptive incidents. This proactive approach underscores the organization's unwavering commitment to continuous improvement and ensures that gains achieved through Six Sigma methodologies are sustained over the long term.

In line with the ethos of continuous improvement inherent in the Six Sigma framework, the Control phase serves as a platform for ongoing refinement and optimization of processes. Regular reviews and audits will be conducted to validate the continued effectiveness of implemented solutions and identify emerging challenges or opportunities for further enhancement. Should deviations or unforeseen issues arise, the project team will promptly revert to the Analyze phase to conduct thorough investigations and devise alternative remedies, perpetuating the cycle of improvement and reinforcing the organization's pursuit of excellence.

In conclusion, the Control phase represents a pivotal milestone in the journey towards operational excellence, where the organization consolidates gains achieved through rigorous process improvement efforts and lays the groundwork for sustained success through vigilant monitoring and proactive adaptation. By embracing the principles of Six Sigma and Lean manufacturing, the organization reaffirms its commitment to quality, efficiency, and customer satisfaction, establishing itself as a frontrunner in industrial process optimization.

4. Results and Discussion

The Define phase laid the groundwork for the project by identifying key challenges within the manufacturing plant, notably inconsistent test results and equipment failures. Through meticulous data analysis and risk assessment, the team established a clear project definition and quantifiable objectives. This phase provided a comprehensive understanding of the issues at hand, setting the stage for targeted interventions to improve operational efficiency and equipment reliability.

In the Measure phase, extensive data analysis using tools like Minitab provided critical insights into process performance and variability. Descriptive statistics and process capability tests highlighted significant deviations from desired standards, underscoring the urgency for improvement measures. By quantifying process inefficiencies and identifying areas of concern, the Measure phase facilitated informed decision-making and prioritization of improvement efforts.

The Analyze phase delved deeper into root causes underlying operational challenges. Value stream mapping and trend analysis revealed workflow inefficiencies and alarming trends in equipment failures over time. Fishbone diagrams identified key factors contributing to the problems, laying the foundation for targeted interventions. Through strategic brainstorming sessions, the team proposed viable solutions aimed at addressing root causes and enhancing process stability.

Building upon insights gained from the Analyze phase, the Improve phase focused on implementing and testing solutions to mitigate identified issues. Standardized procedures, proactive maintenance initiatives, and process optimizations were among the key interventions deployed to enhance operational efficiency and equipment reliability. While some challenges persisted, proactive measures aimed to minimize their impact and drive continuous improvement.

The Control phase marked the culmination of the project, focusing on sustaining improvements and monitoring progress over time. Control charts and ongoing data analysis provided real-time insights into process stability and performance, allowing for timely adjustments and interventions as needed. By systematically evaluating the effectiveness of implemented solutions, the Control phase ensured sustained improvements in operational efficiency and equipment dependability, validating the efficacy of the project's interventions and the DMAIC methodology as a whole.

Overall, the comprehensive application of the DMAIC (Define-Measure-Analyze-Improve-Control) methodology, supplemented by Lean manufacturing principles, proved instrumental in mitigating operational challenges and driving tangible improvements within the transformer manufacturing sector. Through a data-driven approach and a focus on continuous improvement, the project showcased the adaptability and effectiveness of Six Sigma methodologies in addressing complex industrial problems and fostering organizational growth.

5. Conclusion

The transformer manufacturing project's journey through the DMAIC process delivered significant benefits, demonstrating the efficient use of Six Sigma concepts. In the Measure phase, spanning five years of meticulous data collection and analysis, a commitment to a systematic and data-driven approach to problem-solving was demonstrated, with Six Sigma principles actively applied.

The relevance of data in decision-making was emphasized, with advanced statistical tools and techniques such as Minitab being used to gain useful insights and guide strategic interventions throughout the Improve phase. This data-driven decision-making method was critical in targeting a 50% decrease in equipment failures, demonstrating the usefulness of strategies in improving operational efficiency.

The monitoring of the Control phase is the next big step over the next year to assess the effectiveness of the solutions. A commitment to standardization and sustainability demonstrated through the creation and execution of standardized processes and proactive maintenance solutions, such as the establishment of a Standard Operating Procedure (SOP) and soldering techniques. These efforts established the basis for long-term changes, assuring the organization's long-term success.

As the transition into the Control phase occurs, the outcome of efforts becomes more than simply at the end, but the basis for long-term success. A precise roadmap for continual monitoring and refining has been laid out, keeping with the principles of continuous improvement, and guaranteeing that the beneficial effects obtained are not short-term but long-lasting.

References

Adeodu, A., Kanaka-Katumba, M. G., & Rendani, M., Implementation of Lean Six Sigma for production process optimization in a paper production company. *Journal of Industrial Engineering and Management*, 661-680, 2021.

Demchuk, L., & Baitsar, R., Integrated use of TOC, lean and SIX SIGMA in quality assurance of manufacturing processes. *Symposium on Measurement and Quality Control (ISMQC 2013)*, 11-13, 2013.

Durakovic, B., & Basic, H., Textile cutting process optimization model based on six sigma methodology in a medium-sized company. *Journal of Trends in the Development of Machinery and Associated Technology*, 107-110, 2012.

Gangai, J., & Naik, G. R. , Process Optimization by using Lean Manufacturing Technique (Six Sigma)–a case study in manufacturing industry. *International Journal of Innovations in Engineering and Technology, 2014*.

Ly Duc, M., & Thu, M. N., Application of Lean Six Sigma for Improve Productivity at The Mechanical Plant: A Case Study. Manufacturing Technology. 124-138, 2022.

Pugna, A., Negrea, R., & Miclea, S., Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company. *Procedia - Social and Behavioral Sciences*, 308-316, 2016.

Raman, R., & Basavaraj, Y., Defect reduction in a capacitor manufacturing process through Six Sigma concept: A case study. *Management Science Letters*, 253-260, 2019.

Ray, S., & Das, P., Improve Machining Process Capability by Using Six Sigma. *In 5th International Quality Conference, 2011*.

Youssouf, A., Rachid, C., & Ion, V., Contribution to the optimization of strategy of maintenance by lean six sigma. *Physics procedia*, 512-518, 2014.

Biographies

Hossein Soltani is a Master's Student and Graduate Assistant, studying Industrial and Engineering Management at Minnesota State University, Mankato, USA. His bachelor's degree is in Electrical Engineering from Shahid Bahonar University of Kerman, Iran. Previously, he worked as an Electrical Engineer and Technical Project Manager at Pangan Electronics, an electronic manufacturing company. After that, he founded a company that produces NIR Moisture Analyzers that can improve the plant's production process. As a student member of the Industrial Engineering and Operations Management Society (IEOM), he is also actively involved in the field. His research interests include the application of disruptive technologies in process and supply chain management. Among his other skills are project management, process improvement, business development, data science, etc.

Kuldeep Agarwal is a professor in the Department of Automotive and Manufacturing Engineering Technology at Minnesota State University Mankato. His research is in the areas of Additive manufacturing, metal forming, process improvements, and robotic welding. He is the graduate coordinator and works with local industries on lean, project manufacturing, and Six Sigma methodologies.