Optimization of Shear Testing

Wilfredo Acevedo Liceaga
Manufacturing Engineering
Carlos González, PhD.
Industrial and Systems Engineering
Polytechnic University of Puerto Rico

***Abstract* —** *This research project focused on improving shear testing processes. This project aims to implement a new system that performs shear testing without destroying the piece, thus reducing the scrap percentage. The DMAIC methodology was used to enhance the shear testing process. DMAIC is a concept that measures defects in business processes and improves profitability. DMAIC stands for the process's five main steps: Define, Measure, Analyze, Improve, and Control. This research seeks to improve the measurement process of shear tests. This is important for the process because it will reduce scrap, decrease the error percentage when measuring shear in each piece that undergoes welding processes, and provide a more accurate value, thus improving quality. The DMAIC methodology provides a structure and tools to enhance a process by optimizing and stabilizing the business process. In this case, it would involve eliminating destructive tests and reducing scrap percentage due to shear tests.*

Key Terms *— Optimization, Residential Breakers; Shear Test; Welding Process.*

INTRODUCTION

Manufacturing companies face many challenges in the production area. They focus on reducing scrap, keeping customer complaints to a minimum percentage, and increasing sales while producing products of the highest possible quality. This project will focus on improving the scrap percentage, optimizing the measurement process, and mitigating having parts out of specification while complying with CSA, UL, and ISO regulations.

PROBLEM STATEMENT

From 2022 to 2023, Lightspeed and the welding departments processes manufactured 371 million residential breakers. A crucial functional test to ensure the proper functioning of these breakers is the shear test, a destructive testing method. During this period, the facilities discarded 207,132 contact arms due to the requirements of the shear test.

Out of the 371 million parts produced, Lightspeed accounted for 93% (346 million), resulting in a scrap rate of 0.029% (equivalent to 100,956 parts) due to shear testing. Notably, the Lightspeed department exhibited the highest shear test scrap rate. As a lagging metric, shear testing must be more precise and significantly contribute to the overall scrap percentage and the cost of non-conformance metrics for the Lightspeed department.

Research Description

This research is about reducing scrap due to destroyed pieces in the shear test. It is essential to minimize scrap from destroyed pieces while optimizing the shear test process and obtaining more specific values with the new measurement system.

Research Objectives

This project aims to perform shear tests without destroying the piece and reduce scrap to $0 by implementing the new shear test system.

Research Contributions

This project aims to reduce scrap from pieces destroyed by shear tests. This system optimization allows for better accuracy when measuring shear. It can provide more precise results for each piece, reducing the operator's time in measurement due to a more accurate system. With this optimization, there can be a savings of approximately $29,841.05 in scrap from destroyed pieces.

Literature Review

The manufacturing industry, especially in the domain of electrical equipment like residential circuit breakers, places significant emphasis on quality assurance processes to guarantee the safety and dependability of its products. Among the diverse quality assurance tests available, shear testing emerges as a pivotal method to assess the structural integrity of components. This literature review aims to investigate the importance of shear testing within manufacturing processes, elucidate its inherent limitations, and shed light on its implications for production metrics such as scrap rates and the cost of non-conformance. Shear testing is a destructive evaluation method to gauge the strength and integrity of materials or components. This involves subjecting them to sheer force until they fail. Shear testing is indispensable in the manufacturing of residential circuit breakers. It ensures that the contact arms, crucial components of the breakers, can endure the operational stresses they will face throughout their operational life. It asserts that shear testing is a critical quality control measure. It aids manufacturers in pinpointing potential vulnerabilities in their products before they reach the end-users. This approach helps in mitigating the risk of product failures and the subsequent liabilities they might entail. However, despite its pivotal role, shear testing has its challenges. One significant limitation is its inherently destructive nature. Any component subjected to this test becomes unsuitable for use or sale afterward. Such a characteristic markedly inflates the overall scrap percentage and escalates the cost of non-conformance. Moreover, shear testing is frequently viewed as a lagging indicator. It offers insights into product quality only after the completion of the manufacturing process. This delay in feedback can impede real-time quality control initiatives, making the timely implementation of corrective measures a daunting task.

General Concepts of DMAIC Methodology

DMAIC is an acronym representing five fundamental phases for continuous improvement: Define, Measure, Analyze, Improve, and Control. This approach uses a data-driven cycle to optimize, stabilize, and refine business processes and designs. It is widely recognized as the primary methodology for managing Six Sigma projects, ensuring consistent and high-quality results. Each phase of the DMAIC cycle is essential and should be followed to achieve the best outcomes. The methodology applies to a broad range of projects and situations that require ongoing improvement.

Define: In this initial stage, it is crucial to precisely identify who the customer is, define the requirements for the product or service, and understand their expectations. The project scope is also determined, and a detailed process mapping is conducted to understand its flow and critical characteristics.

Measure: A meticulous plan is developed for data collection. It is essential to gather information from multiple sources to identify types of defects and relevant metrics that enable comprehensive evaluation.

Analyze: Once the data is collected, a detailed analysis is carried out to identify the underlying causes of defects and areas of opportunity. This phase helps pinpoint discrepancies between current performance and set objectives and the sources of variability affecting the process.

Improve: This phase seeks effective and creative solutions to optimize the target process. Strategies are developed and implemented to address current issues and prevent potential future failures.

Control: The Control phase aims to maintain and further refine the already optimized process. A continuous monitoring plan is established, which includes the development, documentation, and implementation of tracking tools to ensure that implemented changes are sustained and continuously improved, thereby preventing regression to previous methods. Refer to Figure 1 [1], an illustrative example of the DMAIC process is shown.

Figure 1
DMAIC Process

PROJECT METHODOLOGY

Adopting a systematic approach based on the DMAIC methodology is essential to achieve the project's objectives effectively. Given that the main goal is to enhance the performance of the audit process in the Product Realization phase, specific DMAIC tools will be employed. The ultimate aim is to increase the yield of audit results and reduce the number of defects identified during these reviews.

In the *Define* phase - **Project Charter**: This tool is a document that clearly outlines the project's scope, objectives, and participants. It provides an initial framework that delineates roles and responsibilities, defines the specific project goals, identifies key stakeholders, and establishes the project manager's authority. The Project Charter will be a crucial reference throughout the project's duration.

In the *Measure* phase - **SIPOC**: This essential tool succinctly summarizes the inputs and outputs of one or multiple processes. The SIPOC acronym is Suppliers, Inputs, Process, Outputs, and Customers. A SIPOC diagram provides a panoramic view of the process, facilitating an understanding of who is involved in the process, the variables at play, and the key steps that constitute it.

Analyze, *Improve*, and *Control* phases: The specific tools to be used will be determined based on the results obtained in the previous phases of the project, ensuring a precise adaptation to the identified needs and findings during the project's execution.

RESULTS AND DISCUSSION

Below are the results obtained through the five phases of the DMAIC methodology:

1. **Define** – During the defining phase, the Project Charter tool was employed to clarify the problem statement, establish the project's objective, and define the relevant metrics. Refer to Table 1 for the project charter.

Table 1
Project Charter

Project Charter

Define Phase

PROBLEM STATEMENT	From 2022 to 2023, Lightspeed and the welding departments processes manufactured 371 million residential breakers. One of the functional tests to ensure proper breaker function is the shear test, a destructive test. The facilities discarded 207,132 contact arms in one year due to the shear test requirements. Of the 371 million parts produced, Lightspeed accounted for 93% (346 million), scrapping 0.029% (**100,956**) of it parts due to shear testing. Shear testing in a lagging metric that needs to be more precise and contributes to the overall scrap % and cost of non-conformance metrics for the Lightspeed department.
FINANCIAL BENEFIT	The welding (manual & automatic) and Lightspeed departments have a total annual loss of $81,367.68. Within that amount, Lightspeed contributes $29,841, equivalent to 36% of the total as compared to welding areas. The primary objective of the project is to eliminate these losses, reducing them to $0 completely.
METRICS	• Cost of non conformance (Conc)
OTHER BENEFITS	• Cost savings in rejection and rework. • Improvement in operational efficiency. • Reduction of material waste.

Another tool used for the Define stage is the thought process map. The Thought Process Map (TMAP) is a visual tool that captures and organizes the thoughts, ideas, and questions of an individual or team about achieving a project's objectives. It serves as a structured guide to navigate through the DMAIC process in Six Sigma projects or process improvement initiatives. It is a document that can evolve throughout the project and does not have a pre-established format, facilitating its adaptability according to the project's needs. In our case, we can determine the factors that could affect the shear test. Refer Table 2 where all the thoughts regarding possible causes affecting the shear tests are defined.

The main benefit of using the TMAP in the project is ensuring no critical details are overlooked. This tool effectively addresses all potential questions and challenges of the project. Additionally, it provides us with a visual map that tracks the evolution of ideas and identified issues. Refer Table 2 for the action log.

Figure 2
Thought Process Map

Table 2
Action log

Action Log for shear test possible problems			
Samples	**Description**	**Action**	**Date**
1	Raw material	Verify in incoming if the raw material is on spec	9/4/2023
2	Shear test machine calibration	Verify with Instrumentation Technician if the shear machin is calibrated	9/4/2023
3	Excess of welding	Audit the process	9/4/2023
4	Machine set up	Review the set up with the operator	9/4/2023
5	Operator unskilled	Verify if the operator has visuals aid and manual of instruction	9/6/2023
6	Are fixture damage	Varify in tool room if the fixture is good	9/7/2023
7	Contacts	Verify in incoming if the contacts are in spec	9/8/2023
8	Deficiency of welding	Audit the process	9/8/2023
9	High Cycle time	Verify the routing of the p/n in system	9/9/2023
10	Fixture design does not suitable	Validate with the drafter is the fixture design is correct	9/9/2023

Through the TMAP, we identified the critical questions for the project and established an action log to define corrective measures and address potential constraints in the shear test process. This allows us to confirm that the part numbers testing and manufacturing processes are correct, strongly indicating that optimizing the shear testing system is the most viable approach.

2. **Measure** - In this Measurement phase, we will employ the SIPOC tool to identify the specific needs of the lightspeed department and define the processes' inputs and outputs using the SIPOC tool. The results of the SIPOC are presented below in Figure 3.

From the SIPOC analysis, we could delineate the comprehensive process flow for producing the various part numbers for the lightspeed department. This encompasses the steps from material receipt and inspection by incoming to material reaching the production line and the subsequent manufacturing of the different contact arms. This analysis has enabled us to clearly define the beginning and end of the process, making it easier to pinpoint areas for improvement to enhance both efficiency and product quality. Refer Figure 3 for SIPOC diagram.

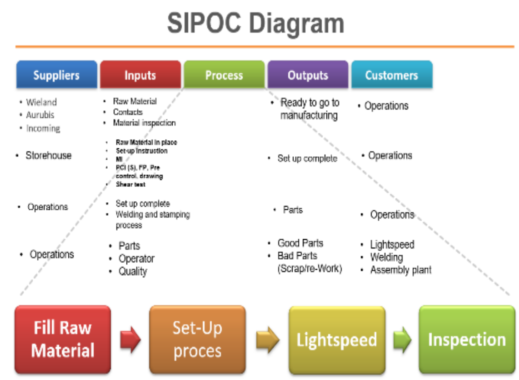

Figure 3
SIPOC

Table 3
Project Plan

Task #	Task Name	Duration	Start	Finish
1	**Methodology**	**20 Days**		
2	Problem Statement	2 days	3/13/2024	3/15/2024
3	Research Objective	4 days	3/18/2024	3/22/2024
4	Contributions	6 days	3/25/2024	4/2/2024
5	Literature Review	3 days	4/2/2024	4/5/2024
12	Methodology	5 days	4/5/2024	4/10/2024
11	**Project Methodology**	**18 Days**		
12	Project Charter	4 Days	4/10/2024	4/15/2024
13	TMAP	3 Days	4/15/2024	4/18/2024
14	Action Log	4 Days	4/18/2024	4/22/2024
15	SIPOC	5 Days	4/22/2024	4/27/2024
16	Project Plan	2 Days	4/27/2024	4/29/2024
17	**Measure**	**2 Days**		
18	Pareto	2 Days	4/29/2024	5/1/2024
19	**Analyze**	**10 Days**		
20	FishBone	2 days	5/1/2024	5/3/2024
	Design	8 Days	5/3/2024	5/11/2024
21	**Validate**	**5 Days**		
22	Poster	4 days	5/11/2024	5/15/2024
23	Project Deadline	1 day	5/15/2024	5/16/2024
	Total Project Days	**55**		

3. **Analyze Phase** In the analysis presented, we show a table with the part numbers of the Lightspeed department that undergoes shear tests. These tests are conducted every half hour, evaluating six pieces, totaling 12 pieces per hour. Each shear test has an estimated time of 6 minutes, meaning 3 minutes for each half-hour. In this analysis, we will examine the unit cost of each piece, the time the operator spends conducting the test, the run time, and the total cost of the shear test per piece. With this data, we will calculate the total cost of the shear test for each part number throughout the year. With this information, we will determine how much scrap we are generating per shear test.

As part of this analysis, we will carry out a Pareto chart to identify and prioritize the part numbers that generate the highest scrap costs throughout the year. With these results, we can focus on implementing a new non-destructive testing system, reducing the associated scrap costs (see Table 4).

Table 4
Shear Test Pieces Analysis

Pieces that has shear test									
Part number	Labor cost (FAC)/per hour	Piece cost	shear test 12 per hour	shear time in hour	run time	1/year Time it takes shear test	Time benefit	Run time*pcs with shear test (12 pc)	Total cost of shear test per piece
Lightspeed									
66B1103G01	14.25	0.199659	6 min	0.1	520.72	52.072	26.036	6248.64	1247.61
66B1103G01L	14.25	0.195833	6 min	0.1	1980.95	198.095	99.0475	23771.4	4655.23
66B1103G02	14.25	0.30296	6 min	0.1	1033.42151	103.3421514	51.7	12401.05817	3757.12
66B1103G02L	14.25	0.299134	6 min	0.1	844.74	84.474	42.2	10136.88	3032.32
66B1103G03	14.25	0.492263	6 min	0.1	1.029	0.1029	0.05145	12.348	6.078
66B1103G08	14.25	0.310422	6 min	0.1	228	22.8	11.4	2736	849.51
66B1037G01	14.25	0.278643	6 min	0.1	1467.55	146.755	73.38	17610.6	49.07
66B1037G05	14.25	0.477628	6 min	0.1	33.36	3.336	1.668	400.32	2149.33
66B1037G06	14.25	0.413575	6 min	0.1	747.81	74.781	37.3905	8973.72	165.59
66B1037G09	14.25	0.445903	6 min	0.1	764.22408	76.422408	38.2112	9170.68896	4089.23
66B1057G06	14.25	0.369294	6 min	0.1	317.2	31.72	15.86	3806.4	1405.75
66B1057G07	14.25	0.351564	6 min	0.1	847.67	84.767	42.3835	10172.04	3576.16

This Pareto analysis will examine the shear test data from the lightspeed department from 2022 to 2023. We will focus on the scrap cost generated by each defective piece during this time. In the graph's legend, the green color indicates the loss cost associated with scrap. In contrast, the purple color represents the cumulative percentage, reflecting the accumulation of the loss cost due to shear tests. Refer to Figure 5 for the pareto analysis.[2]

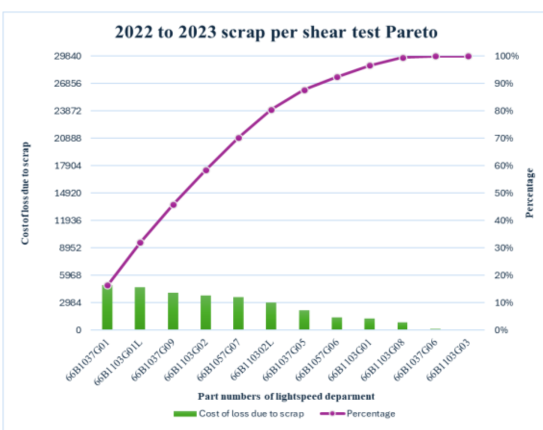

Figure 5
Pareto

In this graph, we identify that part number 66B1037G01 is the principal offender, representing 100% of the total accumulation of costs. Based on this analysis, the goal is for the scrap margin per test to be zero upon implementing the new non-destructive system.

Based on our analysis identifying the primary scrap sources from shear tests, we will create a cause-and-effect diagram to pinpoint all contributing factors to the scrap produced during these tests. This will allow us to understand and address the various scenarios impacting our process and the product realization process. [3]

From the cause-and-effect diagram, it was determined that the non-optimized test procedures are the main contributors to the scrap in shear tests. The current equipment is destructive to the piece, causing this waste problem. By optimizing the test with a non-destructive system, it is possible to improve quality and reduce the generated scrap significantly. Refer Figure 6 for the cause-and-effect diagram (fishbone).

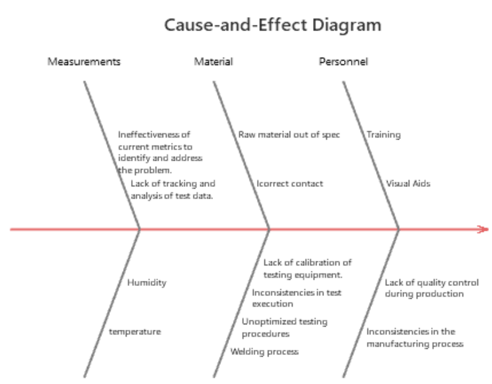

Figure 6
Fish Bone Diagram

4. **Improvement Phase:** In this stage, we will employ the 5 Whys analysis to identify the root cause of the problem. This methodology, developed by Sakichi Toyoda at Toyota Motor Corporation, involves iteratively asking "Why?" to explore the underlying cause-and-effect relationships of a specific issue. Applying this technique, we concluded that the need for more optimization of the test system is the primary cause of the scrap in shear tests. [4]

This analysis confirms that the root cause of the high scrap rate is using the destructive shear test. To reduce the scrap rate, it's essential to explore and implement alternative non-destructive testing methods that can effectively validate the quality of the contact arms without causing damage, potential failures, lack of knowledge, identify gaps, training, and release of the procedures with the new requirements. Refer Table 5 for 5 why's analysis.

Table 5
5 Why's

Why	Question	Answer
1st why	Why does Lightspeed have a high scrap rate of 207,132 contact arms?	Because the shear test, a destructive testing method, breaks a significant number of contact arms.
2nd why	Why is the shear test being used despite its destructive nature?	Because it has been the traditional and accepted method for testing the strength and quality of the contact arms.
3rd why	Why has there been no shift from the shear test to a non-destructive testing method?	Because of a lack of awareness or understanding of alternative non-destructive testing methods that can effectively validate the quality of the contact arms.
4th why	Why hasn't the organization sought alternatives to the shear test?	Because of a possible resistance to change and concerns about the initial investment or reliability of alternative testing methods.
5th why	Why is there resistance to changing the testing method even with the high scrap rate?	Because the shear test is deeply entrenched in the company's testing procedures and there might be a belief that no other method can provide the same level of quality assurance.

5. **Design Implementation** – After a detailed analysis of accurate data, we have identified that the scrap loss problem in the shear tests is due to the current testing system, which damages the part instead of validating it. According to the shear test records from 2022 and 2023, the economic loss amounts to $29,841. This figure is alarming, considering the loss is limited to a single test to validate the weld.

For this reason, we have conducted a comprehensive analysis to find a more efficient non-destructive testing system. After evaluating various options and considering the demand and business needs, we have determined that the best solution is the Olympus OmniScan MX2 ultrasonic system. This equipment offers multiple features and functionalities designed to perform precise and detailed inspections on various materials and applications. [5]

The OmniScan MX2 records and processes the received ultrasonic signal, displaying a real-time image of the material's cross-section. This allows us to effectively detect and evaluate the material's defects, discontinuities, or internal characteristics.

With the implementation of this system, we will be able to identify any anomalies in the welds of all part numbers that require shear testing, thereby contributing to the mitigation of scrap associated with these tests, which is the main objective of this project.

CONCLUSION

This research project has successfully applied the DMAIC methodology to address and resolve the challenges associated with shear testing in electrical equipment manufacturing, particularly in producing residential circuit breakers. The project's primary goal was to implement a new shear testing system that could perform tests without destroying the piece, thereby reducing the percentage of scrap and improving the accuracy and efficiency of the shear testing process.

Through the DMAIC methodology, the project has defined the problem and objectives clearly, focusing on reducing scrap and improving the accuracy of shear tests, measured the current process, identified vital metrics, and quantified the economic impact of the scrap generated by the current destructive testing system, analyzed the data to determine the root causes of scrap and explored alternative non-destructive testing methods, improved the process by selecting and implementing the Olympus OmniScan MX2 ultrasonic system, which offers advanced features and functionalities for precise and detailed inspections, and controlled the process by establishing monitoring and tracking mechanisms to ensure the sustainability of the improvements and prevent the recurrence of scrap.

To conclude this project, the new Olympus OmniScan MX2 ultrasonic system is projected to eliminate 100% of scrap losses, meaning a complete eradication of losses associated with shear testing. Considering that the implementation cost of the system is $40,000 and the total scrap cost due to shear testing during the years 2022 and 2023 was $29,841, the Return on Investment (ROI) is calculated at 1.3 years. This implementation emerges as a financially viable decision, with an impressive ROI of 74.60%. This indicates that for every dollar invested in the new system, a return of $0.746 would be obtained in terms of annual savings from eliminating scrap losses. Additionally, the estimated time to recover the investment is only 1.34 years, reflecting a swift recovery of the initial cost of $40,000 and underscoring the effectiveness and profitability of implementing the new system.

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