

<sup>1</sup>Tania Diana POP, <sup>1</sup>Corina M. RĂDULESCU

## REDUCING SCRAP WITH LEAN SIX SIGMA: A COMPREHENSIVE APPROACH

<sup>1</sup> Technical University of Cluj-Napoca, Faculty of Sciences, Cluj-Napoca, ROMANIA

**Abstract:** The purpose of this study is to provide empirical evidence of the benefits of implementing Lean Six Sigma (LSM), in a factory setting, for reducing non-conforming costs and improving production efficiency. This paper explores the application of LSM in scrap reduction, underscoring key stages and protocols of the implementation. By applying LSM methodology, the project selected as a case study focused on identifying and eliminating the causes of scraps and minimizing variability in manufacturing and business processes. The resulting improvements led to a significant reduction in rework, positively impacting the costs associated with raw materials. It also resulted in improved production efficiency and a decrease in customer complaints. The application of the study is limited to a single factory case, belonging to a multinational company from the energetic industry in North-western Romania, and the results may not be generalizable to other settings. Further research is needed to explore the long-term effects of the LSM implementation. The successful implementation of LSM in the study demonstrates its potential for improving production efficiency and reducing costs in a manufacturing setting. It provides empirical example for other factories considering similar initiatives. This study contributes to the expansion of the existing literature, by closing gaps between LSM conceptual elements and empirical research, by presenting the results of a project regarding the implementation of LSM methodology within a production process.

**Keywords:** Cost Reduction, Lean Six Sigma, Scrap

### 1. INTRODUCTION

In today's competitive market, manufacturing organizations continuously seek ways to enhance efficiency, reduce costs, and maintain high-quality standards. One crucial area of focus is the reduction of scrap, which not only represents wasted materials and resources but also impacts the environmental footprint of a company [Cooper & Gutowski, 2017]. Reducing scrap in manufacturing processes is essential for optimizing resource utilization and enhancing overall productivity. Scrap, the leftover material or defective products that cannot be sold or used, is a significant contributor to wasted resources [Fernando & Mukui, 2023].

Lean Six Sigma, an integrated approach that synergizes the waste-reduction focus of lean with the variability-reduction strengths of six sigma, presents a powerful methodology for tackling this issue [Salah et al., 2019].

The main goal of this study is to highlight the advantages of this methodology by approaching a case study, in which the implementation of lean six sigma is presented within a production department in the electrical industry.

### 2. LITERATURE REVIEW ON LEAN SIX SIGMA

Recent research has seen a significant increase in the exploration of tools and techniques within the quality management framework, with a special focus on Lean and Six Sigma methodologies. These methodologies are renowned for their effectiveness in enhancing manufacturing and business processes [Deshmukh, M., & all, 2022].

Lean Methodology is centered around maximizing value by eliminating waste and optimizing processes. It includes tools like Just-in-Time (JIT) production, which ensures products are made only as needed, reducing inventory costs, Total Productive Maintenance (TPM), which aims to increase equipment efficiency and availability, Poka-Yoke, or error-proofing that prevents mistakes before they occur [Klein et al., 2021].

Six Sigma is a data-driven approach that seeks to improve quality by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. Six Sigma Methodology aims to enhance business processes by, minimizing defects, identifying, and eliminating the causes of defects or errors, reducing variation, ensuring consistent and predictable outcomes, optimizing quality and efficiency, and improving overall performance [Purba et al., 2021]. This approach employs a comprehensive suite of quality management techniques, encompassing statistical instruments, and establishes a dedicated network of personnel within the organization who possess specialized expertise in these techniques. The infrastructure ensures

that quality is consistently monitored and improved upon by knowledgeable professionals [Bygstad & Øvrelid, 2020].

Lean Six Sigma is a hybrid approach that merges Lean's emphasis on waste elimination and flow improvement with Six Sigma's data-driven focus on variation reduction and process control. [Jagantheran, 2019]. The integration of Lean and Six Sigma methodologies provides a comprehensive approach to process improvement, combining Lean's focus on waste reduction with Six Sigma's emphasis on quality control. This synergy aims to achieve long-term improvements in efficiency and quality. The goal of Lean Manufacturing is to decrease waste by lowering defects, which is consistent with Six Sigma's emphasis on defect reduction as a vital component in improving operational efficiency. The shared objectives and the comprehensive approach they offer through minimizing both defects and waste account for why organizations often employ Lean and Six Sigma together [Erdil et al., 2018].

Previous research sustains that the synergy between Lean and Six Sigma makes them an effective joint strategy to fulfill an organization's quality requirements. For example, in their study, Shah et al. [2008], involving a survey of 2511 firms, revealed that the integration of Lean Manufacturing and Six Sigma leads to favorable outcomes, supporting their use as synergistic approaches.

The primary goals of Lean Six Sigma are both identifying and removing non-value-adding activities from processes, thus eliminating waste and, using statistical tools to understand and mitigate process variability, leading to more consistent and higher-quality outcomes.

Lean Six Sigma's rigorous, data-driven approach has been crucial in supporting continuous improvement by systematically reducing waste and defects, enhancing measurement systems, improving process capability, and ultimately leading to substantial financial gains.

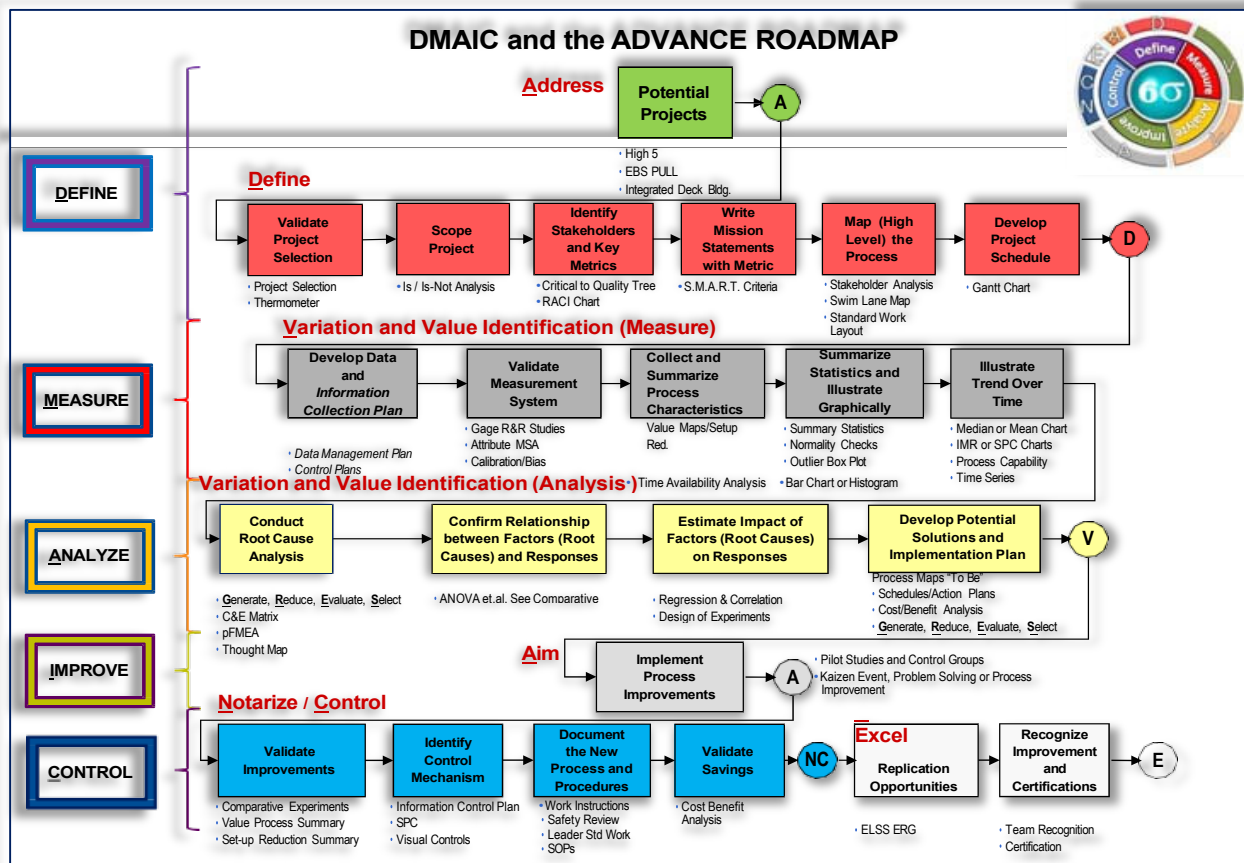


Figure 1. DMAIC and the Advance Roadmap (source: by author adapted from Eaton Internal factory documentation)

Numerous literature reviews [Sodhi et al., 2023], [Gutierrez-Villalpando et al., 2022], [Shokri, 2019], [Gutierrez-Villalpando et al., 2022] assess the key principles and goals of Lean Six Sigma in scrap reduction. It is stated that these are the basis of designing the implementation protocols within projects. Several studies argue that, the stages in the development of this protocol are: firstly, the identification (define=D) of the problem, setting goals, and outlining the scope of carried out. Then, the investigation of the root causes of scrap through data analysis leads to the development and project is needed. Secondly quantifying (measure=M) the current performance

and gathering relevant data has to implementation of solutions to eliminate or reduce scrap (analyses=A). The final step is monitoring the process to ensure the improvements(I) are sustained and control (C) scrap levels remain low. It can be concluded that, most authors develop the stages of this methodology (DMAIC), in a unitary way.

### **3. CASE STUDY: ANALYSIS OF THE LEAN SIX SIGMA METHODOLOGY APPLIED TO REDUCE SCRAP AT EATON GROUP**

Busag Factory, within Eaton Group is an industrial setting activating in the electrical sector. The firm faced high scrap rates in their electrical cabinets production.

Imminent measures for diminishing negative effects imposed to introduce a project aimed to reduce the scraps rate in the punching process. The actual costs of non-conform products represents \$89K (aprox. 36% from scrap), is planned to be reduced with \$15K by September 2020, implementing Lean Six Sigma solutions to sustain the improvements. Thus, the results of the project falls into the 5% threshold of CONC (cost of non-conforming) goal of EATON's company production strategy.

Using Lean Six Sigma tools like Failure Modes and Effects Analysis (FMEA) analysis and root cause analysis, our research team identified that improper punching process techniques were the major contributors to the scraps. After training employees on standardized punching procedures and implementing LSS solutions, resulted a significant decrease in scrap and rework.

The project was implemented by following DMAIC methodology.

#### **— Defining the Problem and setting goals (D)**

From the total technological scrap recorded in 2020, according to the Pareto analysis, the punching process has an impact of 36% (\$89K), a significant impact on the scrap in the punching area is caused by components that are stamped with the emboss tool. The overall objective of the project is to improve the quality of components, to reduce the customer complaints and decrease the scrap rate.

#### **— Measuring Scrap (M)**

The project aimed at setting 4 types of metrics regarding scrap reduction:

- a. The scrap rate, which is the percentage between the scrap value and the production value, being a financial indicator, the data is continuous, and the goal is to reduce the scrap average, which will be analyzed through a type graph Individual Moving Range (I-MR).
- b. The scrap value, is the sum of the half-finished and finished goods parts, being a financial indicator, the data is continuous, and the goal is to reduce the scrap average, which will be analyzed through Individual Moving Range (I-MR) chart.
- c. The value of production values (in RON) which is the sum of the value of the raw material and the directly productive work, being a financial indicator, the data are continuous, and the goal is to reduce the average scrap, which will be analyzed through an Individual Moving Range (I-MR) type graph.
- d. Defect parts per million (DPPM) which is the sum of defective components divided by one million, being a quantitative (quality) indicator, the data is continuous, and the goal is to reduce the scrap average, which will be analyzed graphically of the Individual Moving Range (I-MR) type.

The metrics monitored in the project and information on the implementation data of the Lean Six Sigma project are presented in table 1.

Implementing data collection systems was performed to track scrap generation at different stages of production. Non-conforming procedure for product/component identification was carried out to analyze and decide on scrapping or reworking, and follow the steps for both processes. In doing so, the machine operator informs the quality technician of the problem involved. After checking the the conformity of products according to the documentation, a decision will be made for accepting rework the component, or rejecting it. For the components that are defined as scrap, it will be prepared the register in the scrap form, fill in all required data. The form will be automatically printed after completion and then collected by the quality supervisor and the parts will be segregated.

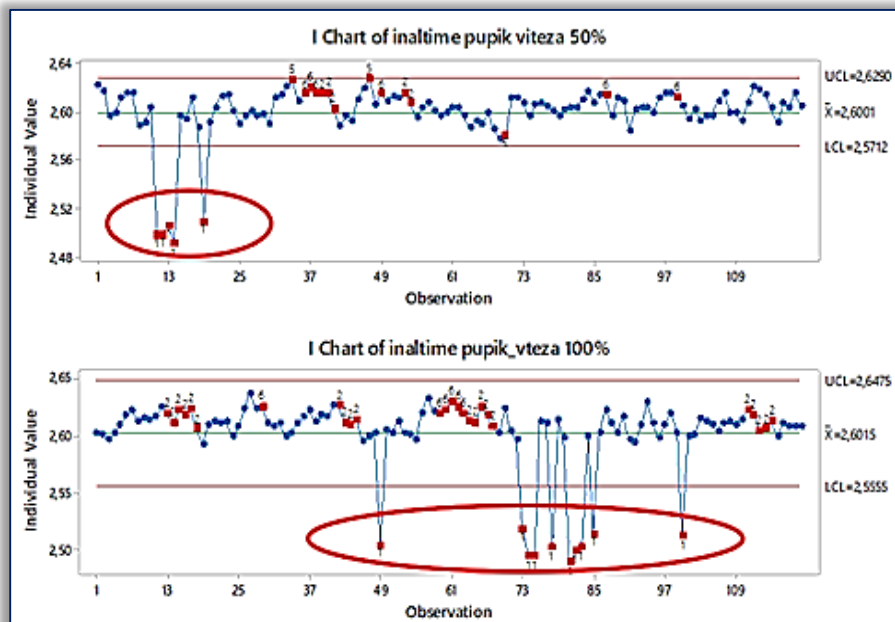
#### **— Analyzing the Root Causes Lean Six Sigma (A)**

To identify the root cause, 10 possible root causes were identified and cataloged according to the 6M categories (machine, environment, measurement, material, method and man). Out of these, two specific causes were selected to apply the 5why analysis method. The 5why technique (Lean Six Sigma) is one of the most effective tools for root-cause analysis, especially when identifying

roadblocks of the teams in their daily work. In this project the 5why was generated by a cross-functional team (core team), after which corrective actions were implemented for each root-cause found. Proceeding the 5why analysis it was found that the punching machine does not consistently punch the shape emboss (pupik). The analysis is performed by using Minitab software, through statistical process control (SPC) charts to monitor the process, i.e. I-MR, Laney P-chart, Histogram and X-Bar chart. Graph 1 depicts that at the speed of 100% we have several values out of the control limits, which measurably demonstrates the fact that there is no stability in emboss (pupik).

Table 1. Scrap reduction data Management Plan (source: by author, adapted from Eaton Internal factory documentation)

Metric (Unit of measure)	Operational Definition (Verbal) or Formula (Symbols)	Family of Measure	Data Type	Desirability	Graphical Display of Central Tendency and Variation	Graphical Display of Time Ordered Data	Data Source or Location	Collector	Sampling Plan	Stratification Factors (ANOVAs et al)
Scrap rate	Percent between scrap value and production value	F/P	Continuous	Shift mean reduction	Histogram	IMR	excel/ERP	CMG	1/week	N/A
Scrap	Sum of MB51 and ZOPS	F	Continuous	Shift mean reduction	Histogram	IMR	ERP	CMG	1/day	Reason Code
Production values (RON)	Value of Raw material(MB51) and Sap hours at punching tariff (ZHRS)	F/P	Continuous	N/A	N/A	N/A	ERP	CMG	1/week	N/A
DPPM	Defected parts produced / 1 million	Q	Continuous	Shift mean reduction	Histogram	IMR	excel	SDE	1/month	Process



Graph 1. I-MR Chart emboss (pupik) for 50% speed vs 100% speed (source: by author, data processed in Minitab)

— **Measurement System Analyze**

In the Measurement System Analysis (MSA), four operators were chosen to measure each of the eight selected components, three times (Graph 2). The measured dimension was 45.50 mm between two extruded holes, using a caliper. Following the measurement session, the calculated system variation was 26.7%, which falls into the marginal category, as it lies between 10% and 30% (Graph 2).

The general criteria for assessing system capability are as follows: less than 10% is considered acceptable, between 10% and 30% is marginal, and greater than 30% is deemed unacceptable.

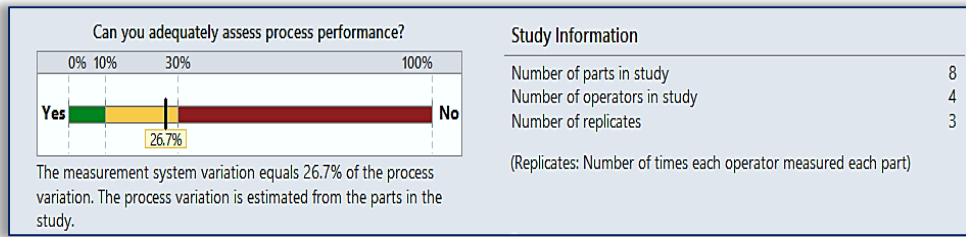
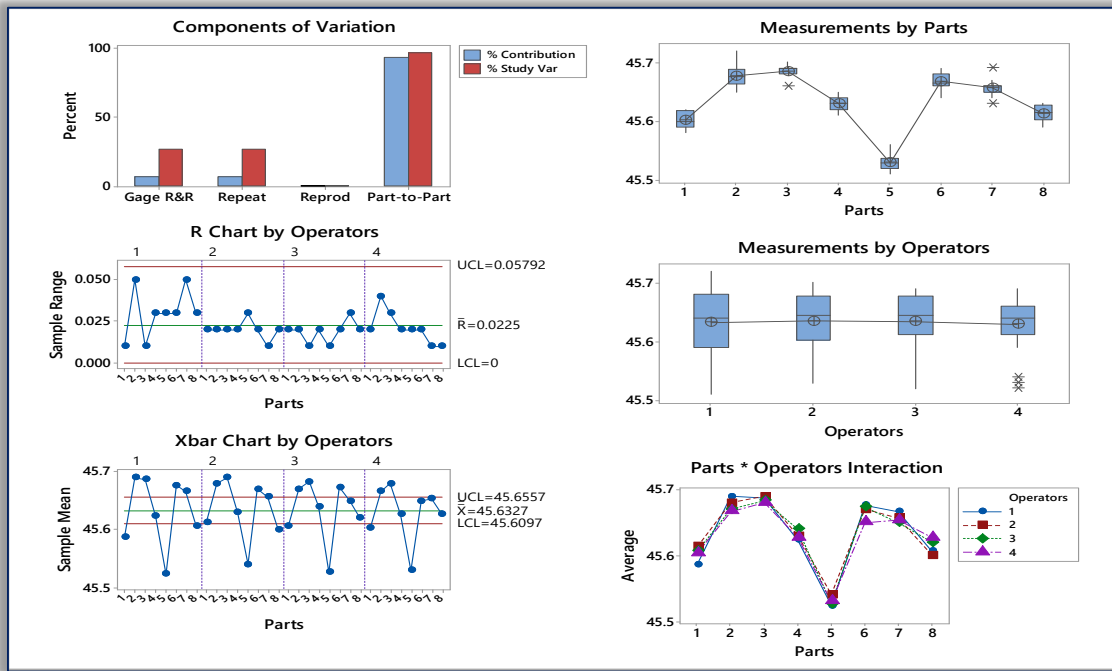
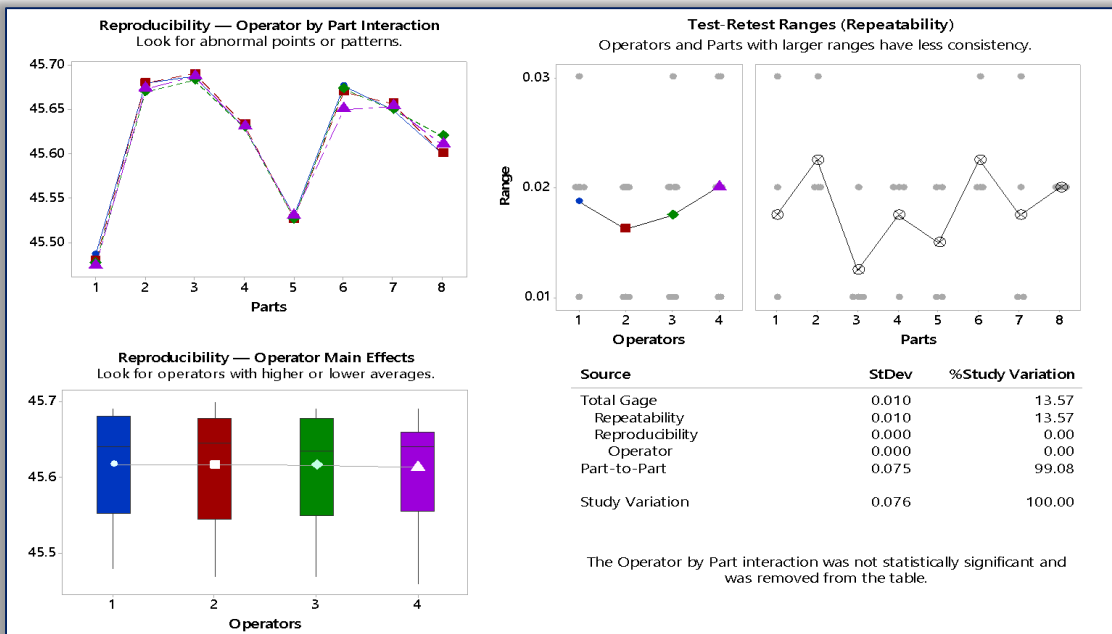


Figure 1. MSA – Study Information



Graph 2. MSA – Measurement System Variation Study before improvements (source: by author, data processed in Minitab)



Graph 3. MSA Results – after improvements (source: by author, data processed in Minitab)

To minimize variation, we investigated the outliers related to operator number four. The issue seemed to stem from incorrect caliper usage, specifically, the operator applying excessive pressure during measurements. The graph 2 highlights three deviations associated with operator number four, significantly impacting the results of the Measurement System Analysis (MSA). To rectify this, operator number four received training to ensure consistent measurement techniques.

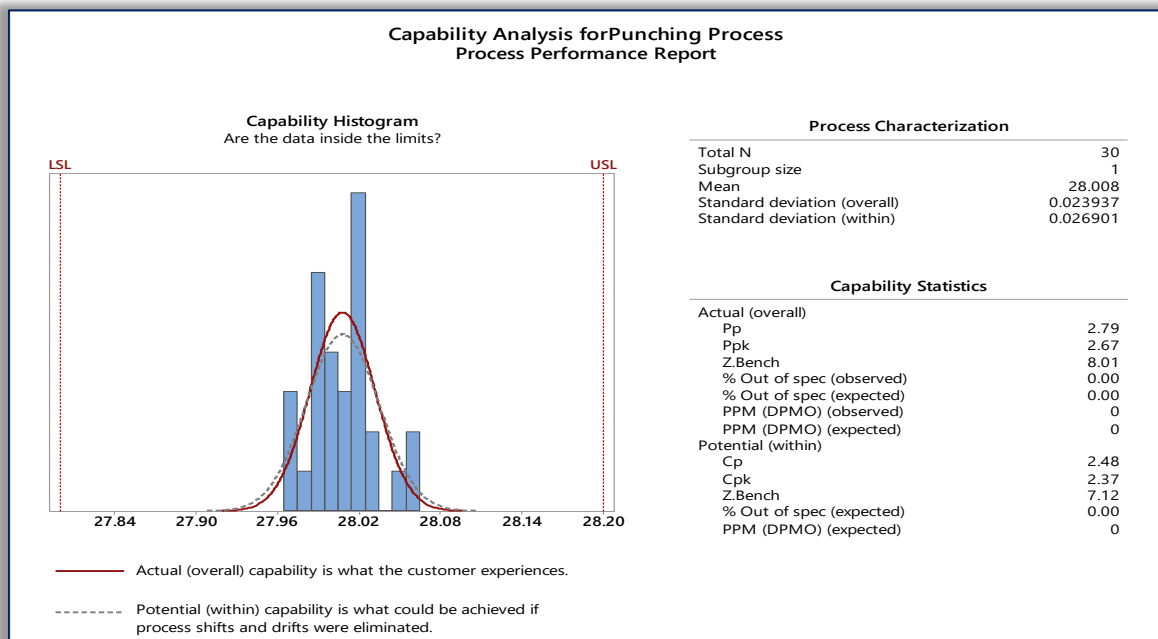
During subsequent measurements, the operator consistently positioned the caliper midway between the extruded holes, maintaining perpendicular alignment with the surface. After measurements training, the system variation was recorded at 13.6% (Graph 3). Although this figure remains within the marginal range (between 10% and 30%), it is notably close to the acceptable threshold of under 10%.

Consequently, the instructional materials for new operators have been augmented to include potential errors and corresponding preventative measures.

— **Controlling and Sustaining Improvements (I-C)**

Evaluating the CNC punching machine’s capability, we assessed the gap between two rectangles across 30 samples, targeting a nominal dimension of 28.00 mm.

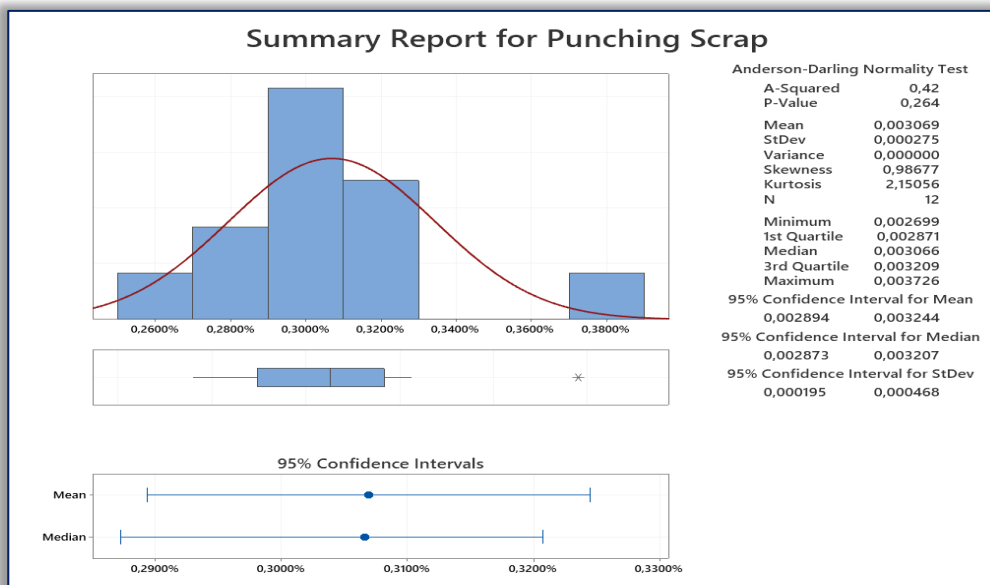
Post-analysis in Minitab, the results affirm the process’s capability (Graph 4). The Process Capability Index (CPK) stands at 2.37, signifying that the punching operation exceeds the 6 Sigma level of quality. In an ideal scenario, where the process operates flawlessly without any disruptions or negative factors, the Defects Per Million Opportunities (DPPM) is expected to be zero.



Graph 4. Capability analysis for punching process (source: by author, data processed in Minitab)

— **Overview of the findings**

The summary statistic (graph. 5) is based on the production value percentages and scrap rates.

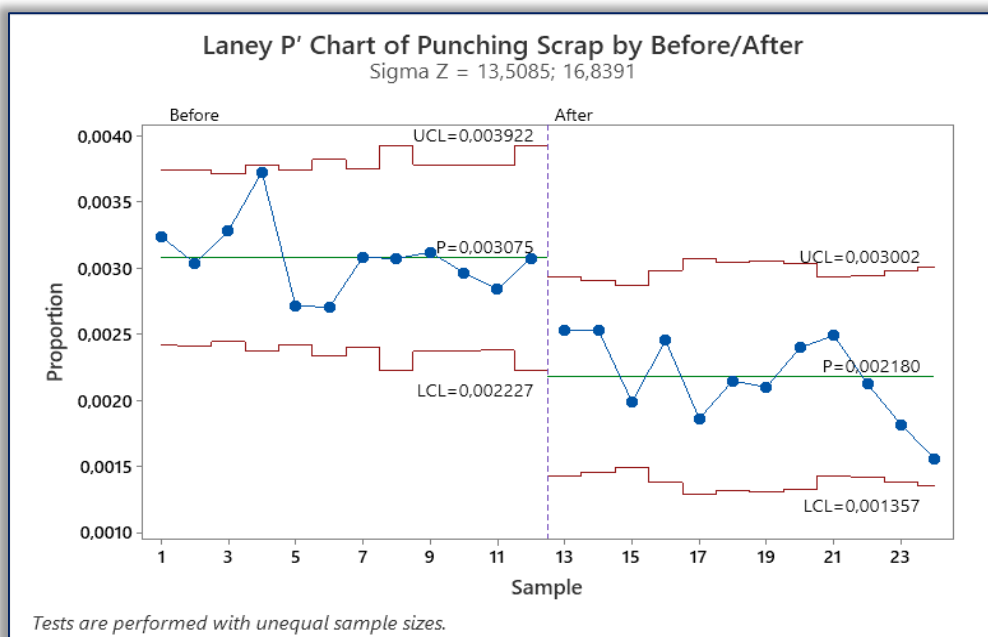


Graph 5. Summary report (source: by author, data processed in Minitab)

The Anderson-Darling test indicates that our data is normally distributed, as evidenced by a P-value greater than 0.05; specifically, our P-value is 0.264. We are primarily focused on the mean value, which is 0,31%. Graph 5 displays a moderate right skew and features an outlier, highlighted by a red circle. This outlier is predominantly attributed to a significant amount of scrap generated by a round tool that malfunctioned during the punching process, affecting approximately 20 metal sheets.

#### 4. DISCUSSION

- The analysis determined that setting a higher embossing tool height on the machine leads to increased variability in the embossed shapes' height measurements on the metal sheet.
- The emboss design, featuring a 5° angle, has been altered to enhance its functionality and minimize tolerance deviations. The objectives of the redesigned 5° angled emboss include: simplifying the adjustment process, expanding the operational boundaries and achieving a plate penetration of up to 2.8mm (inclusive of emboss height and plate thickness).
- After the implementation of improvements, we observed a significant reduction in scrap levels in the punching area. Initially, the mean of scrap was 0.31% (Graph 6). However, with the collective actions and support implemented by the end of 2020, the target mean of scrap reduction improved to 0.22%, exceeding the initial goal of 20% by 29%.



Graph 6. Laney P Chart Punching Scrap before and after improvements (source: by author, data processed in Minitab)

- The savings determined by the implementation of project, until the end of August 2020 is 12.097\$, this value was achieved in 4 months. The forecast of savings is 22.259\$, amount which can be improved by standardizing the actions resulted from the project.
- Measurement System Analysis, showed a system variation of 26.7%, which is marginal. Training and improvements reduced the variation to 13.6%.
- Process Capability for punching machine's capability was confirmed with a CPK of 2.37, indicating a process over 6 Sigma.
- These results should encourage the management and staff members in Eaton company to further deploy Lean Six Sigma projects in the future. However, controlling and sustaining improvements requires:
  - Establishing control plans to maintain new process standards.
  - Continuously collecting and analyzing data to detect and address any recurrence of scrap issues.
  - Engaging and training employees to foster a culture of continuous improvement

#### 5. CONCLUSION

Lean Six Sigma provides a comprehensive and effective framework for reducing scrap in manufacturing processes. By combining the waste elimination principles of Lean with the rigorous analytical tools of Six Sigma, organizations can achieve significant improvements in efficiency, quality, and cost savings. The successful implementation of Lean Six Sigma for scrap reduction not

only enhances profitability but also contributes to sustainable practices and environmental stewardship. Application of Lean Six Sigma in this context serves as a strong endorsement for its continued use in quality and process improvement initiatives.

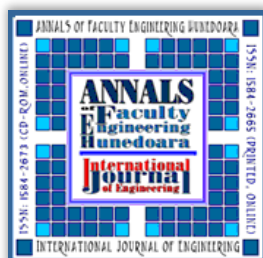
Lean and Six Sigma together create a holistic framework for improving processes, reducing waste, cost reduction and achieving high-quality outcomes. They empower organizations to continuously enhance their operations and deliver value to customers.

#### Acknowledgement

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