Bending Metal: Improving Sheet Metal Repair at Tobyhanna Army Depot through Lean Six Sigma

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Abstract: The Army's Lean Six Sigma methodology includes five phases: Define, Measure, Analyze, Improve, and Control (DMAIC); each of these phases includes interaction between the stakeholder and process team. This paper focuses on the application of Lean Six Sigma methodology at Tobyhanna Army Depot to help reduce overruns and repair cycle time within the sheet metal cost center. At the initiation of the project, the process incurred over 4,000 hours of overruns, a situation in which it takes longer to repair an asset than the standard hours allocated for the repair. Additionally, the average repair cycle time, amount of time required to repair an individual asset, exceeded customer expectations by almost four days. The paper describes recommended solutions to address both problems.

Keywords: Lean Six Sigma, repair cycle time, reduce overruns

1. Introduction

Tobyhanna Army Depot (TYAD) has partnered with a West Point capstone team to conduct an analysis of their sheet metal repair process. The process operated at over 4,000 hours of overrun time annually. The team conducted an in-depth review of the entire process to establish the cause of the overruns in the system using Lean Six Sigma methods. Through small wins and the implemented solution, Tobyhanna will reduce the total annual overruns by 50% for the sheet metal repair process and improve other identified weakness found through the process analysis.

Today's commercial world is full of rapidly developing processes and technology. To stay ahead of competitors, companies are constantly looking for ways to become more efficient. One technique to do this is Lean Six Sigma (LSS). LSS is an integration of Lean and Six Sigma methodologies with the goals of reducing variation and overall defects (Bertolaccini, 2015; George, Rowlands, Price, & Maxey, 2005; Prashar, 2014; Albliwi, 2014). Lean and Six Sigma practices were first seen in 1986 (Muraliraj, 2018) and use statistical tools through a methodology called DMAIC, which stands for Define, Measure, Analyze, Improve, and Control. The next section outlines each phase of Lean Six Sigma through the DMAIC methodology.

This paper presents the summary of a year-long lean six sigma project to reduce the overruns within the sheet metal repair process at Tobyhanna Army Depot. The paper is organized into four three additional sections. First, the literature review provides a background of lean six sigma and the DMAIC process. The third section discusses both the methods and results of the analysis for each of the five phases of the DMAIC process. The final section provides a summary of the paper and discusses future work for the team to sustain the gains of the project over the long term.

2. Literature Review

Lean Six Sigma is a combination of the Six Sigma (SS) process developed at Motorola, and Lean manufacturing developed at Toyota with their Toyota Production System (TPS) (Antony, Snee, & Hoerl, 2017). "SS is a business improvement approach that seeks to find and eliminate causes of defects or mistakes in business processes by focusing on process outputs which are critical in the eyes of customers," and was used to shift process averages to improve overall quality of the products and used the MAIC process (Antony, Snee, & Hoerl, 2017). As companies solved their problems with a blend of Lean

DOI: https://doi.org/10.37266/ISER.2021v9i2.pp99-109

manufacturing and Six Sigma, Lean Six Sigma was born. Today, LSS is used within the financial industry, Small and Medium Enterprises and public sector organizations (Antony, Snee, & Hoerl, 2017). Lately, trends with LSS have shown that it needs to evolve in the face of globalization, big data and IT improvements, and possible integration into educational systems (Antony, Snee, & Hoerl, 2017). Starting from two separate process of Lean management and Six Sigma, Lean Six Sigma was combined to help different companies eliminate defects in business processes and improve efficiencies. In the future, LSS will evolve to work better with globalization and better technology.

Figure 1. DMAIC Process Overview

The Define phase ensures that the project begins with understanding the problem before any money and time are invested into the project (Brook, 2020). The Define phase is centered around understanding the business, the customer, and the process and utilizes tools such as problem statements, and stakeholder analysis to succeed. At the end of the Define phase, a "Define" tollgate validates the problem and goal statements; project scope; a SIPOC map, Supplier, Input, Process, Outputs, Customer; process map; voices of the customers and businesses; and a communication plan which will be used for the remainder of the project.

The purpose of the Measure phase is to determine how the process is currently operating. This is done by translating the process into a measurable form (de Mast & Lokkerbol, 2012). The LSS team will take measurements that are relevant to customer specifications and find the capability of the process. This means the team will discover where the process is operating currently and if it is possible to operate within an acceptable range for the customer. Generally, the Measure phase is the longest phase of an LSS project and can take up to 50% of the total project time. Determining what to measure and how to measure are an important part of any LSS project. There are many tools available to understand and visualize a process that allow the team to identify measures that are key in discovering the main cause of defects in the system. At the conclusion of this phase, the team will have a better understanding of the process and the current capability of said process.

The Analyze phase structures problem solving by focusing on root causes and prevents teams from jumping to conclusions too early. The Analyze phase starts by conducting value analysis, which can include value-add, non-value-add, and business-non-value-add process steps (George, Rowlands, Price, & Maxey, 2005). Next, the Process Cycle Efficiency (PCE) is calculated and compared to world-class benchmarks to understand the state of the process (George, Rowlands, Price, & Maxey, 2005). Then, to further understand the efficiency of the process, process flow is analyzed by looking at bottleneck points, constraints, fallout, and rework (George, Rowlands, Price, & Maxey, 2005). Once the process is understood, the data collected in the Measure phase can be analyzed using various statistical tools and tests that are available. Once all this data has been analyzed, theories are generated to explain potential causes by using brainstorming, Failure Mode and Effect Analysis (FMEA), or cause and effect diagrams (George, Rowlands, Price, & Maxey, 2005). Once causes have been established, the search of causes can be narrowed by using brainstorming, selection, and prioritization techniques like Pareto charts or hypothesis testing (George, Rowlands, Price, & Maxey, 2005). Then, once the causes have been narrowed down, additional data is collected and used to verify root causes with scatterplots, hypothesis testing, ANOVA, and regression (George, Rowlands, Price, & Maxey, 2005).

The Improve phase is the turning point in the DMAIC process. This phase marks the change from analyzing and understanding the system, to creating solutions to better the process. The Improve phase creates solutions and implements them to mitigate the negative effects of the root cause of problem. Solutions can be generated through numerous techniques. Once possible solutions are created, the LSS team must use project specific criteria to prioritize and choose one to implement (George, Rowlands, Price, & Maxey, 2005). Implementation will use Lean Six Sigma methods like the 5s, waste reduction, and balancing techniques to positively affect the root cause of problems in the system. (Shaffie, 2012). Once a solution is designed, and the risks are assessed, it can be piloted (George, Rowlands, Price, & Maxey, 2005).

The overall purpose of the Control phase is "to complete project work and transition the improved process back to the project sponsor, with procedures for maintaining the gains" (George, Rowlands, Price, & Maxey, 2005). There are also multiple deliverables that are included in the Control phase. The first deliverable is a documented plan to transition the new and improved process back to the process owner. The second deliverable is before and after data that looks at the process metrics showing how much of a difference the new process makes. The next important deliverable is the process control plan. The process control plan is a system used to help monitor the new implemented solution. The final deliverable is the complete process documentation which includes lessons learned throughout the project as well as recommendations for further actions or opportunities (George, Rowlands, Price, & Maxey, 2005). Figure 1 presents the overall DMAIC process.

3. Methods and Assessment

3.1 Define Phase

After beginning the project, the LSS team completed the Define phase by discussing the problem with the TYAD team to create problem and goal statements. The team defined the problem, understood the scope of the problem, discussed the understanding of the voices of the customers and business, created a SIPOC map, and created a communication plan. For this project the problem statement is: TYAD expects the sheet metal process to operate at 2400 hours of overrun time or less, it currently operates at an average of 4893 hours (7.6%) and overruns have been increasing since June 2019. Figure 2 presents the SIPOC Map for the sheet metal repair process that specifies the suppliers, inputs, process steps, outputs, and customers. All these tools will be used in the later phases.

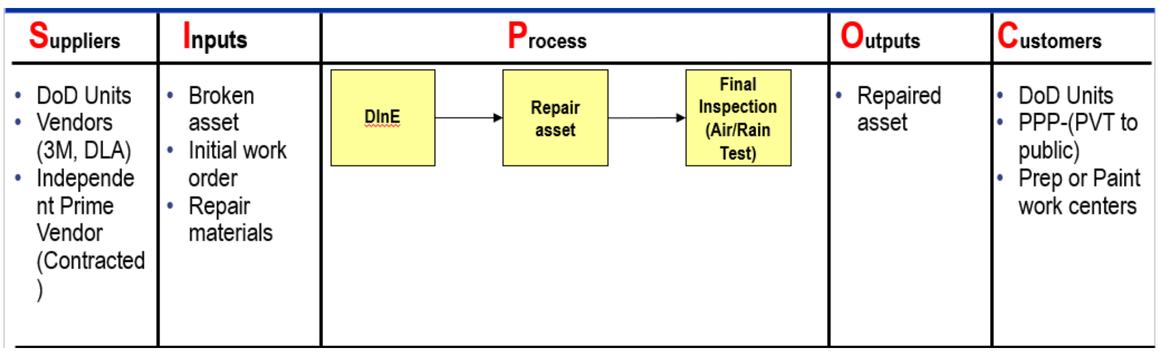

Figure 2. SIPOC Map from TYAD Sheet Metal Repair Project

3.2 Measure Phase

After determining the goals of the LSS project in the Define phase, the team needs to obtain an in depth understanding of the sheet metal repair process. Gaining this understanding will help determine which metrics to look at to determine the current operating capacity of the sheet metal repair process. To do this, the team constructed a process map as seen below in Figure 3. Although difficult to see at this scale, the complexity of the process required an iterative approach given strict travel restrictions. After several video-teleconference meetings, the team was able to construct an accurate, detailed, process map of the sheet metal repair process without having to physically tour the facility.

DOI: https://doi.org/10.37266/ISER.2021v9i2.pp99-109

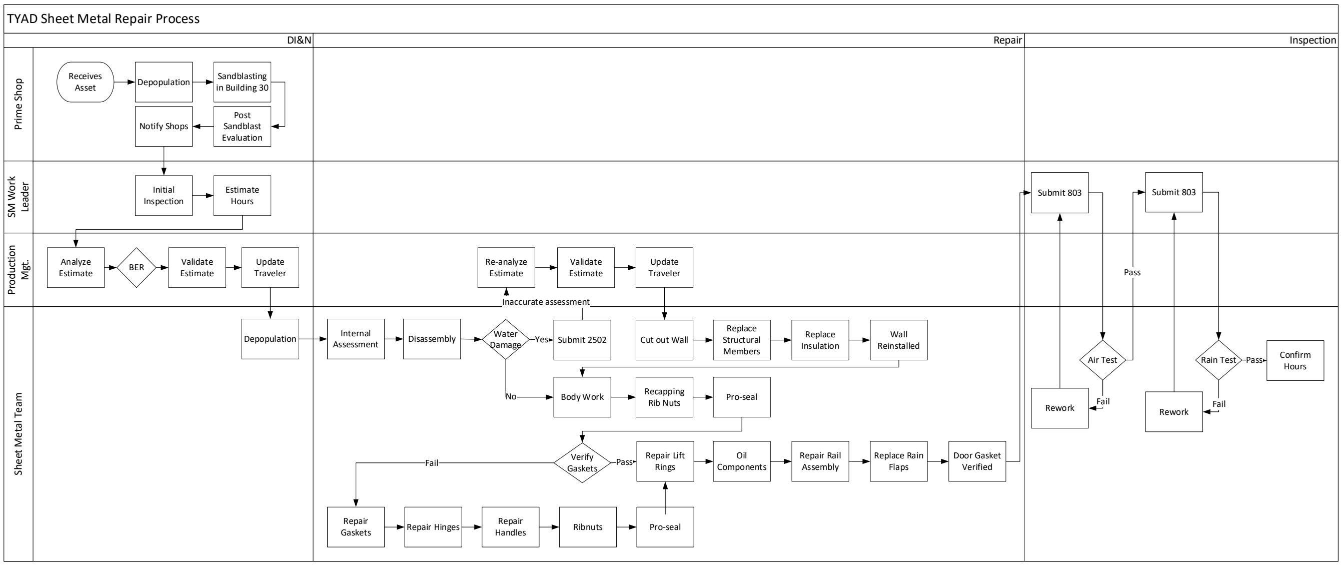

Figure 3. Process Map of the Sheet Metal Repair Process

Next, to gain a shared understanding of the project and measurements to be taken, the team defined the operational definitions and drafted a data collection plan. The data collected was then used to calculate baseline statistics of the process with statistical software. After running baseline statistics, the team used statistical process control to determine if the process was stable over time and determine if the process was capable of meeting the customer standard. Figure 4 presents the summary statistics for the process and shows that the process is not normally distributed, so any statistical analysis will require non-parametric tools. This analysis is for individual asset overruns, additional analysis examined the process by week.

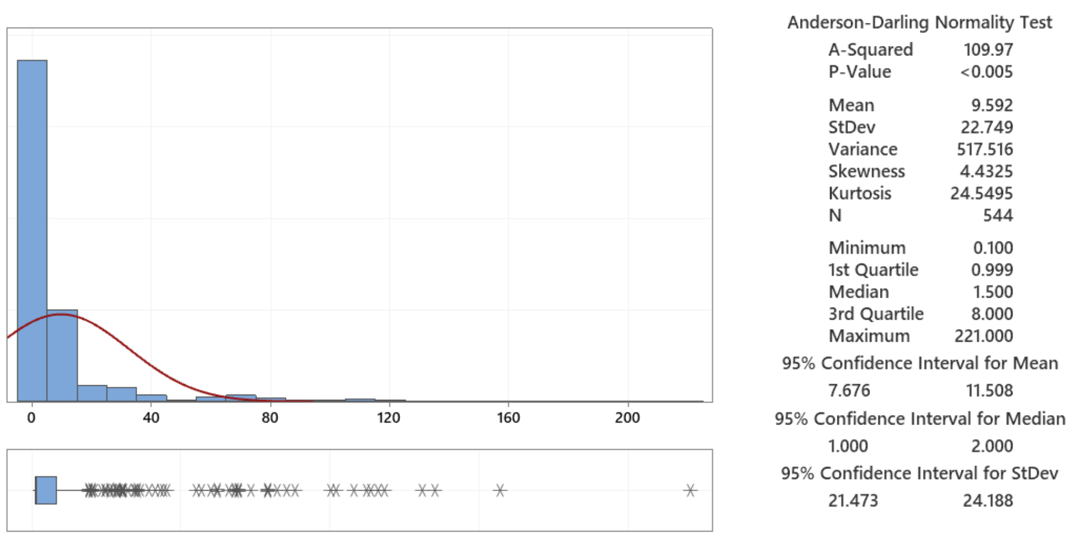

Figure 4. Summary Statistics for Sheet Metal Repair

Figure 5 presents a control chart for the total weekly overruns for the sheet metal repair process and indicates that two weeks were out of control given the three-sigma control limits. In both cases, the weeks with significant overruns, Week 39 of 2019 and Week 15 of 2020, included a large number of AN/ASM 146/147 Avionics Repair Shelter, which the team validated later through pareto analysis. Based on the data, the process is not in control, so one of the first steps in the improvement will be to ensure the process gets into statistical control.

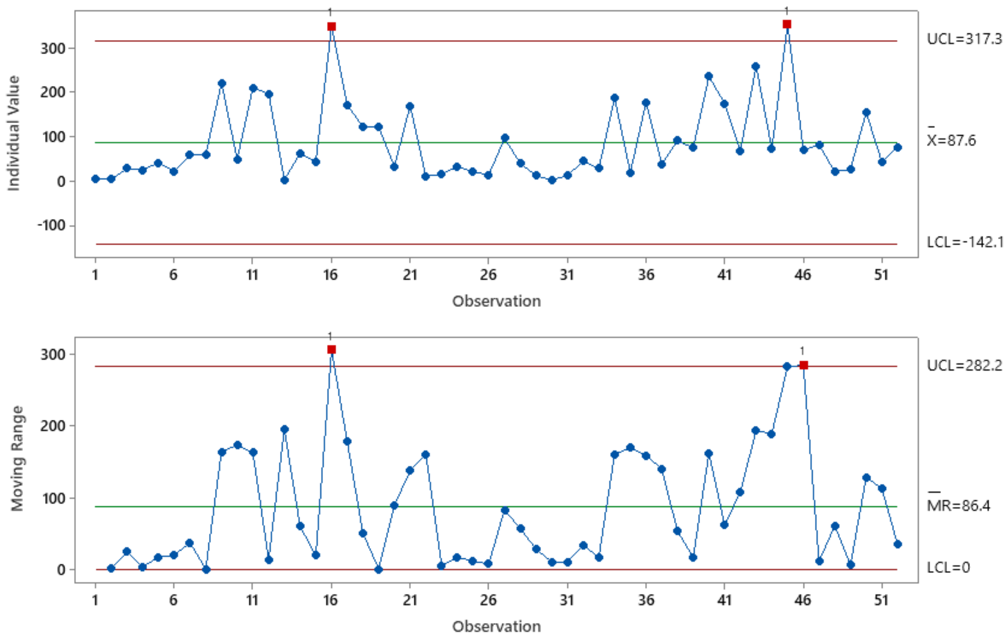

Figure 5. Control Chart for Weekly Overruns of the Sheet Metal Repair Process

Following this discovery, a process capability chart, Figure 6, showed the process as it was currently not capable of operating at Tobyhanna's desired specifications. In this case, the weekly data followed an exponential distribution, so the appropriate type of process capability chart enabled the team to determine if the process was capable of meeting the customer specifications. For this analysis, only assets with overruns were used as anything with an underrun had a negative overrun and caused an error with the exponential distribution's process capability chart. As shown in the figure, the process was not capable of meeting the upper specification limit of 25 hours per week in overruns. This upper specification limit was set and verified with Tobyhanna in order to achieve a 50 percent reduction in overruns as the goal of this project.

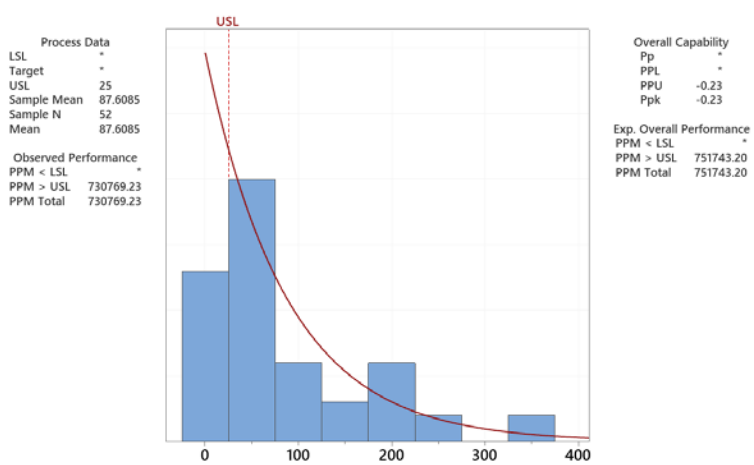

Figure 6. Process Capability Report for Weekly Overruns

The team constructed two pareto charts. The first of which stratified the operational short text, the second by asset type. Figure 5 shows most of the overruns are in the operation sheet metal repair. The sheet metal repair operation produced the most amount of overruns for the entire process and accounted for 63% of total overruns. In this process, the work center identifies damages to the sheet metal of an asset, often due to water infiltration of the asset, and conducts necessary repairs to the asset. The second operation in the process, the sheet metal support repair, accounted for a much smaller amount of overrun hours.

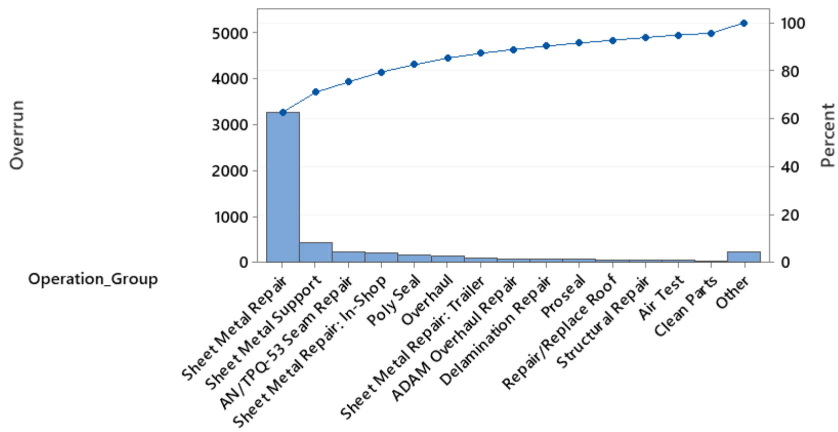

Figure 7. Pareto Chart of Individual Overruns by Operational Short Text

Figure 6 shows that most overrun hours were coming from one asset, the AN/ASM 146/147 Avionics Repair Shelter. The team then analyzed the data by the type of asset to determine if any single asset contributed more than others to the overruns for the work center and the sheet metal repair process. Each asset, or system, is a DoD system repaired by Tobyhanna Army Depot and may present unique challenges to repair. The depot repairs thousands of individual systems, so determining what systems create the most overruns enables the team to focus on a smaller sub-set of these systems. These charts gave the team a starting point for determining what further investigation would be useful in the Analyze phase.

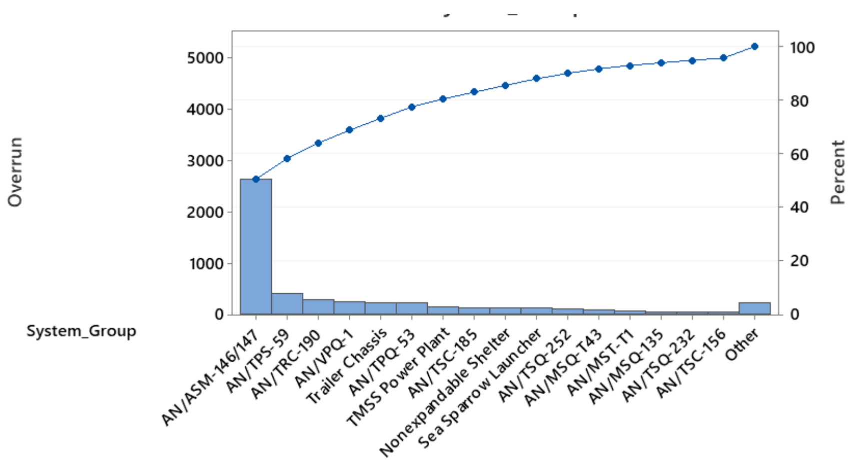

Figure 8. Pareto Chart of Individual Overruns by Asset Type

The measure phase verified the initial hypothesis that a problem existed within the sheet metal repair process as the process did not and was not capable of meeting the customer specifications. This resulted in a significant amount of overruns for the work center on a weekly basis of nearly 87 hours per week, costing Tobyhanna Army Depot thousands of dollars per week. Additionally, the measure phase identified operations that resulted in overruns as well as a specific asset, the AN/ASM-146/147 aviation repair shelter. With the verification of the problem within the process, the team could move into the analyze phase to identify and validate root causes for improvement.

3.3 Analyze Phase

After establishing the goals and scope of the project and proving that the process was not capable of operating at Tobyhanna's desired specifications, the team began to analyze data from the process and search for possible root causes of overruns. To brainstorm root causes, the team scheduled a video call with the Tobyhanna. The team then utilized their input and observations to build a Cause-and-Effect Diagram. On this diagram, there were six different categories of possible root causes for overruns in the process: materials, manpower, facilities and equipment, methods, unforeseen circumstances, and measurements. The West Point team went through each of these categories, asking the Tobyhanna team if they could think of any reason as to why there may be overruns in the process. As the Tobyhanna team responded, the team filtered their ideas into the six categories below in Figure 9.

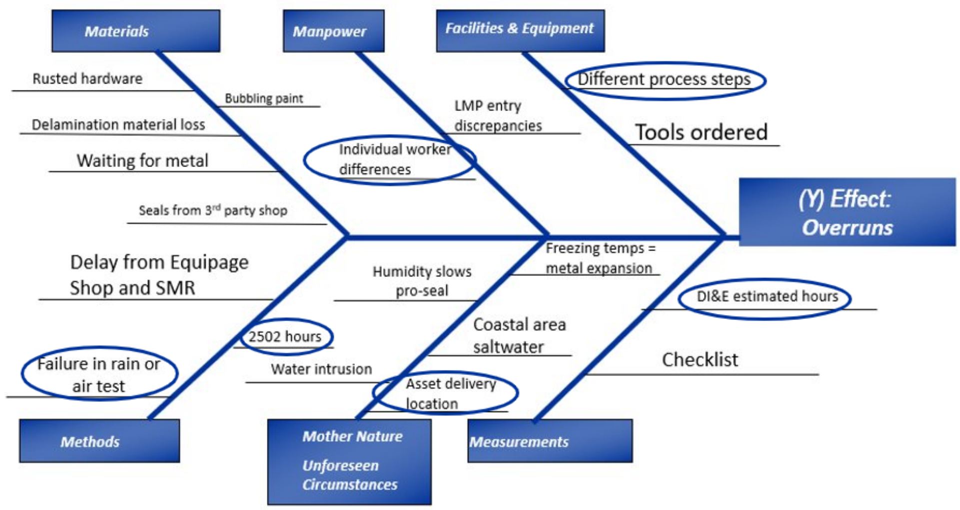

Figure 9. Cause & effect diagram with 6 most prominent root causes circled

Using knowledge of the process and the input of the Tobyhanna team, the team identified six possible root causes to explore further using statistical tests. These six causes are circled in blue in Figure 9, and they are "Different process steps", "DI&E estimated hours", "2502 usage", "Individual worker differences", "Failure in rain or air test", and "Asset delivery location." To test these root causes, we utilized Chi-Square Tests and Mood's Median Tests. Of these six causes, two were statistically significant, and led to the conclusion that the different process steps for sheet metal repair and the use of the 2502 form to request additional hours for repair based on asset condition were statistically significant. Tobyhanna performed an experiment during which they broke down the sheet metal repair operation into five individual steps to determine where the problem was within that sub-process. Figure 10 presents the Pareto Chart of all of the steps and indicates that Step 4 produces the most number of overruns for this sub-set of assets. Step 4 is the actual sheet metal repair of the sides of the asset. Additionally, this step was linked to rework that is incurred by a failed rain or air test which causes more overruns.

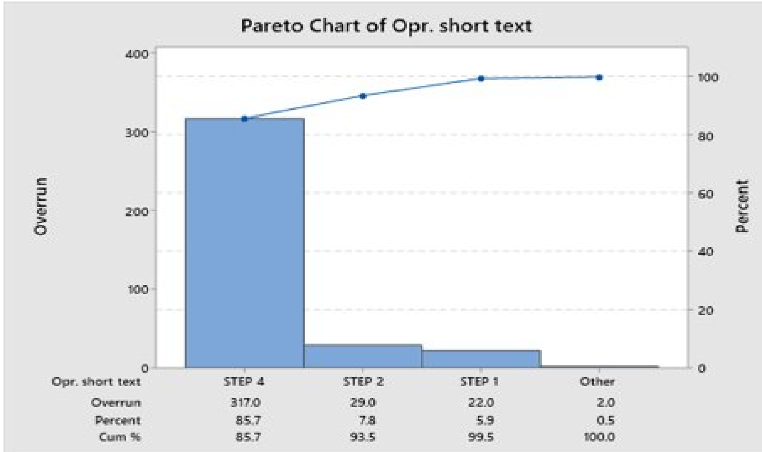

Figure 10. Pareto Chart of Different Steps in the Sheet Metal Repair Process

3.4 Improve Phase

The Improve phase consisted of three parts which are generate, decide, and implement a solution. The first aspect of the Improve phase was solution generation. To generate ideas, the cadet team held a meeting with Tobyhanna Depot to create as many solutions as possible. The team emphasized the importance of having all levels of personnel attend the meeting. Line workers and shop employees were specifically requested to provide their input on solutions they believe could solve the overrun hours problem. Solutions were guided by the fishbone diagram and summarized in Figure 11.

Critical X	Root Cause(s)	Potential Solution	How Developed?
Overrun Hours	Water Intrusion	Thermal Camera	FMEA/Brainstorming
	Water Intrusion	Moisture Probes	FMEA/ Brainstorming
	Water Intrusion	Weighing Assests	FMEA/Brainstorming
	2502 Usage	Supervisors Usage of 2502	FMEA
	2502 Usage	Production Management Collection/Addition of hours (2502)	FMEA
	Rusted Hardware	Casting Lift Rings at Tobyhanna	Brainstorming
	Different Process Steps	Segregate the 250 bulk hours (top and bottom), create more process steps to control hours usage.	FMEA/Brainstorming

Figure 11. Potential Causes and Solutions

The second component of the Improve phase consisted of reducing the total number of solutions down to a single solution for implementation. The capstone team utilized the Nominal Group Technique (NGT) with Tobyhanna to analyze the possible solutions. Each member of the meeting was given an evenly weighted choice in the process. After NGT was completed, the capstone team created a survey with the few remaining solutions. The goal of this survey is to create an easy method of solution feedback that could be widely distributed to the entire Tobyhanna Sheet Metal Repair shop. The team then analyzed the feedback (Figure 12) to understand which solutions had the highest potential to solve the overrun issue. The solution will be implemented in the control phase as a pilot plan.

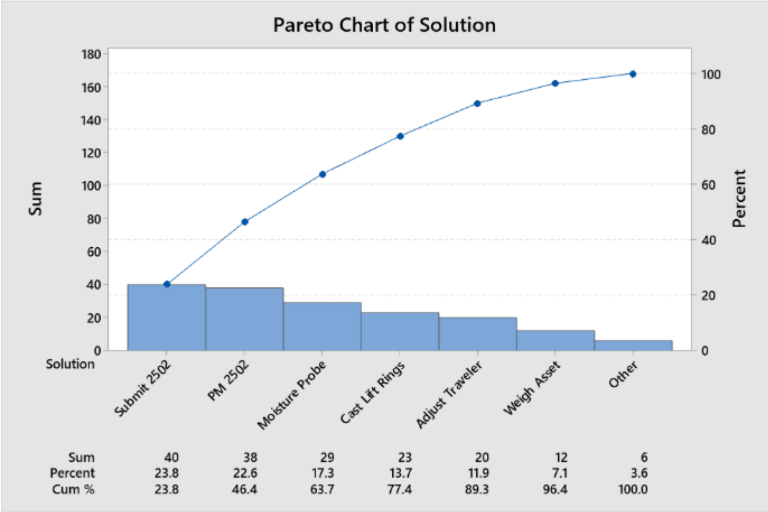

Figure 12. Pareto Chart of Potential Solution Voting

One possible solution the team analyzed was the use of a thermal camera to identify water intrusion within the asset. Generally, water intrusion is not visible during the initial assessment of an asset; however, it creates several problems during the repair process. By identifying the water intrusion earlier in the process, the repair team could prepare for and request additional time to work on an asset that would not be considered an overrun. Figure 13 and Figure 14 present images the team took of an experiment where they constructed an model of a shelter wall and there is a definite temperature difference between the side with and without water intrusion.

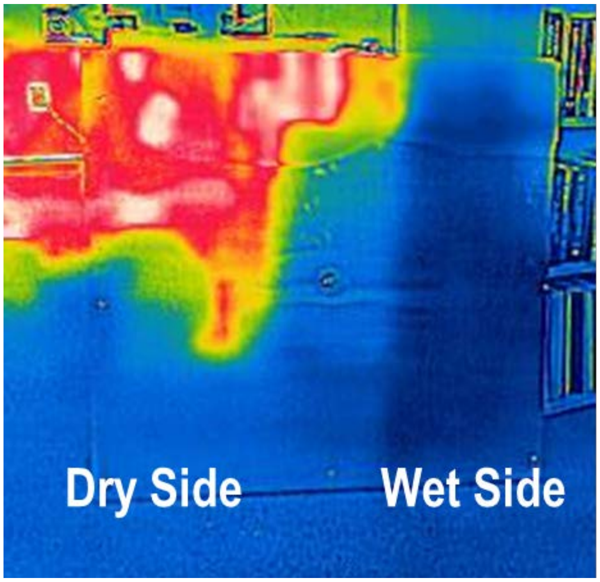

Figure 13: Thermal Image of Experiment

Figure 14: Image of Experiment

4. Conclusion

The Tobyhanna Sheet Metal Repair Shop struggles with excessive overrun hours. The USMA Capstone team was asked to identify, analyze, and reduce the total overrun hours. The team began by meeting with TYAD to define the problem and establish the scope of the project. Next, the team mapped the repair process and collected data on the system. The team analyzed the data in order to establish the root cause of the overrun hours as the AN/ASM-146/147 system. Once the root cause was validated using statistical processes, the team began working to create a solution to reduce overrun hours. The team actively worked with Tobyhanna to agree on a solution to implement h, which identified conclusion of the Improve Phase. The final phase of the DMAIC process, the control phase, is yet to be completed.

Figure 15 presents the final results of the pilot solution developed during the Improve phase and shows an improvement in the overall number of overruns hours. Although the improved process only had seven samples, there was an improvement from a mean of 20.5 overrun hours to 8 hours, a reduction of 60.9%. The main reduction in overrun hours was the enforcement of using the 2502 to request additional hours for an asset based on the initial assessment and identification of water intrusion. So, while it might not reduce the amount of time required to repair an asset, by properly documenting the time required, Tobyhanna is able to properly account for and bill their repair hours.

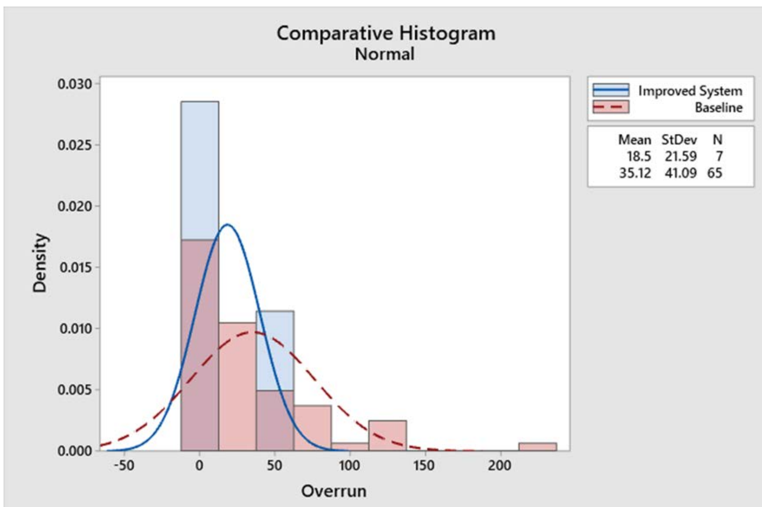

Figure 15. Analysis of Project Implementation

The future work will consist of finishing the DMAIC process. The goal of the control phase is to set Tobyhanna up for future success once we turn the project over to the process owner. Although this phase has not yet been completed yet, there are a few general ways in which to help ensure the success of the new process. The first step is to ensure a smooth transition is to set new standard operating procedures (SOP) for the different task in the new and improved process. Upon project completion, the ownership of the process will transfer back to Tobyhanna. By creating clearly defined SOP it will help to ensure that the process does not lose efficiency over time. Also, the team will utilize control charts to ensure the new process maintains its efficiency. The new SOPs, open lines of communication, and control charts will ensure the new process is implemented effectively.

5. Acknowledgments

Parts of this paper were previously published and presented in the Donald R. Keith Memorial Capstone Conference at USMA in May of 2021. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the United States Military Academy, United States Army, or United States Department of Defense.

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