Leaning out the Small Component Paint Process: Using Lean Six Sigma for Process Improvement at Tobyhanna Army Depot

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Author Note: Cadets Adam Bazan, Stephen Grabher, Spencer Knudsen, Joseph Stillings, and Noah Wilson are Cadets at the United States Military Academy (USMA) at West Point. We would like to offer our thanks to Colonel James Enos in the Department of Systems Engineering and the Tobyhanna Army Depot (TYAD) team for their efforts in helping us throughout this process.

Abstract: TYAD repairs and refurbishes a variety of Department of Defense systems that are essential for our military effectiveness and daily operations. Employees at TYAD have noticed a tall number of overrun hours for projects in their small component paint branch. These high number of overrun hours have led to TYAD steadily losing revenue and profitability on their projects. This capstone group utilized Lean Six Sigma's (LSS) DMAIC (Define, Measure, Analyze, Improve, and Control) process to decrease the number of overrun hours experienced and hopefully allow a way for greater throughput to go through the system. The efforts of this group led to discoveries of issues with the implementation of quality control tools. Our discoveries led to a revamped quality control protocol that will decrease the number of overrun hours experienced by TYAD and ultimately save them an estimated $478,000.00 over the course of the next three years.

Keywords: Lean Six Sigma, DMAIC

1. Introduction

Tobyhanna Army Depot's purpose is to provide the equipment necessary for the United States Army to be prepared for any task at hand. In the small component paint branch, their job is to apply camouflage and color to certain materials which assist the warfighter greatly. Due to the nature of the profession, the Army requires TYAD to have equipment prepared in a timely manner. However, the Small Paint Branch at TYAD is facing a significant number of overrun hours that are due to inefficiencies in their system processes. Using Lean Six Sigma and Define, Measure, Analyze, Improve and Control (DMAIC) principles has allowed us to view the TYAD system processes in a critical light that lead to improvements. The DMAIC process is comprised of five individual phases that lead to improvements in the efficiency of the system. The first phase of this process is the Define phase, where the problem or inefficiency is identified, and the scope of the project is established. The second phase in this process is the Measure phase, where important metrics are captured, and the magnitude of the problem is identified. The third phase is Analyze, where the metrics taken are analyzed, and the root cause of the inefficiency or problem is identified. The fourth phase of the process is Improve, where potential solutions are created, and the best solutions are implemented. The fifth and final phase of the project is Control, where a plan to sustain and manage the solution is developed and distributed to the system process owners.

Lean Six Sigma methodology in the manufacturing world applies the concepts of Lean Manufacturing and Six Sigma to create an ideology fit for the 21st century. The Japanese process of Lean Manufacturing involves reducing human effort, stocks, production space, and delivery time while still being efficient and delivering quality products (Drohomeretski, 2014). Six Sigma differs from Lean because Six Sigma focuses more on the reduction of process variation. The Motorola-based process seeks to eliminate defects and identify errors so they can be fixed (Drohomeretski, 2014). Six Sigma relies heavily on achieving stability by using data-driven analytics to make assessments on the defect level (Laureani & Antony, 2019). The process is focused on precision and accuracy with the goal of getting a product manufactured perfectly on the first try (Laureani & Antony, 2019).

DOI: https://doi.org/10.37266/ISER.2023v11i1-2.pp27-41

This paper is organized into three additional sections: a literature review, a methods and results section, and a conclusion. The literature review focuses on the lean and six sigma methodologies which provided a basis for this project and paper. The methods and results section follows the DMAIC methodology through the application of lean six sigma to the small component paint process. Finally, the conclusion section summarizes the paper and discusses potential future work within the process.

2. Literature Review

Both Lean Manufacturing and Six Sigma contribute great change to work environments. However, the business environment is dynamic, and every company is seeking to gain an edge. The clash of both these independent models together is the response to this changing environment (Manville, Greatbanks, Krishnasamy, & Parker, 2012). The Lean Six Sigma methodology focuses on reducing waste, non-value-added work, cycle time, and instability in a process (Drohomeretski, 2014). The goal of a process is to be as efficient as possible while still producing the highest quality products. The methodology takes the good aspects of Lean Manufacturing and Six Sigma to create a contemporary ideology. The benefits of using Lean Six Sigma outweigh the other processes' strengths individually. Lean Six Sigma can increase morale, functional teamwork, consistency, and effective decision-making qualitatively (Manville, Greatbanks, Krishnasamy, & Parker, 2012). Quantitatively, the reliance on data and facts has improved production efficiency across companies in the world (Manville, Greatbanks, Krishnasamy, & Parker, 2012). Companies such as Samsung and Xerox have seen increasing profits and quality improvements with its implementation (Hilton & Sohal, 2012). Furthermore, when Amazon incorporated Lean Six Sigma into their daily routines, their profit skyrocketed (Alshmrani, 2020). The new concept of Lean Six Sigma is revolutionizing the manufacturing industry and driving competitiveness in the business industry.

2.1 Define Phase

The Define Phase is the most important part of the DMAIC process. Real-world problems require real-world solutions, so if one is unable to define the problem properly, then everything that comes after will be useless. The purpose of the define phase is to have the team and sponsor reach an agreement on the scope, finances, and performance goals (George, 2005). This phase consists of gathering data to identify how big the problem is (Sreedharan & Sunder, 2018). It is important to not have a scope that is too broad or vague, and identifying the proper scope may take time and effort (George, 2005). The SIPOC is a useful tool that helps define boundaries for scope identification (Sreedharan & Sunder, 2018).

There are many key steps that must be taken in the define phase to ensure a good product that will set the stage for follow on measure phase. One of those steps is creating and reviewing the project charter. The project charter is ultimately the document containing all the agreed upon information in the project (Shankar, 2009). Though it can be adjusted throughout the project, the initial project charter allows both the project team and project sponsor to reference and build on an agreed understanding of what the project details. The project charter contains two incredibly important aspects of the project which also happen to be major steps in the define phase. Those steps are creating and validating the problem statement and doing the same for the project goals. This requires the project team to attain the voice of the customer as well as the voice of the business to ensure that the problem the team has been given exists, is important to customers, important to the business, and can be improved through DMAIC methodologies (Krishnan & Prasath, 2013). Establishing measurable goals that are validated and explained by existing data allows the project team to estimate the financial benefits of the successful solution to the defined problem. These financial benefits are often essential in creating stakeholder and project sponsor desire to pursue the project.

Another major part of the define phase is the creation of process and SIPOC maps. These high-level maps are excellent tools for developing a deeper understanding of the problem and the process in which it resides. SIPOC stands for suppliers, inputs, process, outputs, and customers (Rasmusson, 2006). When creating a SIPOC map, it is meant to be less detailed so that it does not bog down the project team in stakeholder discussions. It is meant to contain a of detail that should balance as much information on the process as possible while simultaneously garnering the least amount of arguable concepts (Rasmusson, 2006). The maps tend to provide great insight into scope identification and effectiveness (Lynch, Bertolino, & Cloutier, 2003). Scoping is a vital part of the define phase and without proper scoping, Six Sigma projects can experience long term impacts that may lead to project failure (Lynch, Bertolino, & Cloutier, 2003).

At the conclusion of the define step tollgate review, there will be a few specific project deliverables that must be supplied to the project sponsor. The first is the completed project charter. Next is the documentation of internal and external customer needs. After that, any high-level process mapping tools used in the project will be made into deliverables. This pertains to the initial process map or SIPOC maps created regarding the process (George, 2005). Finally, the complete project communication plan will be provided to ensure successful communication in the future of the project.

DOI: https://doi.org/10.37266/ISER.2023v11i1-2.pp27-41

2.2 Measure Phase

The Measure Phase provides the meat of understanding the causes of problems in the process. The purpose of the Measure Phase is to understand the daily operations of the process and collect data on the processing speed, quality, and costs that will identify the causes in the future (George, 2005). The Measure Phase is all based on the collection of data. The data must focus specifically on the process and be reliable (Sreedharan & Sunder, 2018). After the data collection, the process capability must be calculated to reflect the current efficiency of the process (Sreedharan & Sunder, 2018). The measure phase will be explored more below.

One of the tools of the measure phase is the Value Stream Map which captures all key flows in a system and its metrics (George, 2005). Simply, it is a process map with data. A VSM is a beneficial tool since it identifies and quantifies waste for measures (George, 2005). This Value Stream Process map framework makes it easier for businesses to see the waste (Gibbons, Kennedy, Burgess, & Godfrey, 2012). Research has shown the effectiveness of Value Stream Mapping. In one study, researchers reduced their project duration by 13 days by utilizing this tool (Ramani & Lingan, 2021). This is one of the many examples that emphasize how a VSM is a valuable tool for leaning a system out (Serrano Lasa, Ochoa Laburu, & de Castro Vila, 2008). A VSM should be used after the process map is defined. After this, the material flow should be shown (George, 2005). Material flow refers to the movement of the product in the process. For example, if a component is being painted, the VSM should track the movement of the component from start to finish. Additionally, the information flow should be documented. This refers to the documentation process of the material being moved, which can be tracked digitally or manually. In the paint example, the information flow would be the document that says each phase of the process was complete.

The Measure Phase is the first step that requires an exploration into data and explores what is happening in the process. The Measure Phase is "more than just a number," and represents the process as a whole (Pearson, 2001). This phase requires a certain set of deliverables in order to move on to the next step (George, 2005). The most frequently used Measure Phase techniques are process mapping, control charts, descriptive statistics, graphical summaries, and process capabilities (Hollingshed, 2022). Before the data can be analyzed, the team must develop a data collection plan and conduct a measurement system analysis to ensure that the data collected accurately represents the process (George, 2005).

After setting up a data collection plan and validating the measurement system, baseline statistics can be performed. By using baseline statistics, it gives the viewer what specifically is of concern. By producing visual representations, a clear picture of the process is formed. General Statistics, including mean, median, and mode can simplify the data. The mean is the average of the data set. This can be useful because it accounts for all data values. On the other hand, the median is the midpoint of an ordered data set (George, 2005). Although the mean is most frequently utilized, the median can help for data sets with extreme outliers (George, 2005). Lastly, the mode is the set of values that are most frequently observed (George, 2005). These statistics together can give a general overview of performance measures and narrow down the focus for the problem at hand. To show this, a histogram chart is usually presented to sum up the priority performance measure. A tool that breaks datasets even further are Pareto charts. Pareto charts can help emphasize which specified categories are contributing most to the performance yield (George, 2005). Simply, it determines which attributes contribute most to the problem (Luis Duarte Ribeiro, Schwengber, & Fritsch, 2001). This can identify potential issues in a system easily, which can be focused on further in the Analyze phase.

After understanding the baseline performance of the process, the last component of the measure phase is to see its capability. The purpose is to compare the actual variation of the process against the customer constraints (George, 2005). First, the distribution of the process must be identified. In an ideal world, everything would be normalized, but that is not the case in society. The distribution identification helps produce a higher-quality process capability analysis. After this, the process over time must be understood. In order to show this, control charts over time with performance measurement should be utilized. Control charts monitor a process and identifies when an observation is out of specification limits (Joghee, 2017). Control charts monitor progress over time, and businesses have benefitted from it (Eldin, 2009). Additionally, the process capability report can be produced based on the distribution. The upper and lower limits of the specification limits of the distribution are the control limits determined by the customer (George, 2005). When graphed, if the process distribution falls between the two specification limits fully, the process is meeting the customer requirements (George, 2005). However, if any part of the distribution is over the limit, the process is not capable. If the process is capable in the phase, the project goal should be redefined. If the process is not capable, the data is saying the current process is not meeting the desired customer requirements and that there is a problem that needs to be fixed. These tools are the meat of the Measure Phase.

2.3 Analyze Phase

The Analyze Phase utilizes the previous data to make assumptions on what causes the problems of the process. The Analyze Phase should end with the root causes of the problem and the important controllable factors of the process identified

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(Mandal, 2012). The purpose of the Analyze phase is to identify and establish causes affecting the input and output variables of the process (George, 2005). The flow of analysis in this phase first includes analyzing the process, then developing theories and ideas, analyzing the data found, and lastly verifying and understanding the cause-and-effect (Brook, 2020). Specific tools that I will discuss that help to identify and validate root causes include fishbone diagrams/root cause analysis, FEMA, non-value add analysis, and hypothesis testing.

Fishbone diagrams/root cause analysis helps you identify all potential or probable causes and select the best cause that contributes to the problem or effect (TQP, 2020). Fishbone diagrams are used to analyze existing problems. They can be used to sort out interactions among factors for a cause while focusing on the quality of the problem (TQP, 2020). Ultimately, fishbone diagrams can help classify primary, secondary, and tertiary causes. They help identify possible causes for variation present in a process and increase knowledge of a process and its factors. They can also help to identify areas for future data collection (TQP, 2020). One of the few benefits of fishbone diagrams is that they tend to focus on the "causes" rather than "symptoms" or "assumptions." Furthermore, they break down problems into small pieces to find the real root cause. They bring forth to the table a common understanding of the factors causing the problem. Fishbone diagrams are useful and are one of the deliverables required for this phase.

FEMA is a risk analysis tool that can be useful in environments where you must prevent an event from ever happening or where the failure rate for a process is so low that there is little opportunity to learn from past failures (Brook, 2020). A Process FEMA analyzes key outputs and potential failures at each step of a process and the effect of process failure on the product or service is considered (Brook, 2020). Standard FEMA charts include six steps. The first step is identifying the steps or components of the product. The second step is to list the different failure modes that might occur and rate their severity. Stated differently, how big of a problem is it? Thirdly, for each failure mode listed in the chart, consider different potential causes of failure, and rate their occurrence (number of times). Fourth, for each cause, consider controls in place that prevent it from occurring and/or to detect the failure if the cause does occur. Then you should rate the likelihood of detection. The fifth step requires calculating a risk priority number (RPN) for each potential failure by multiplying the severity by occurrence by detection. The sixth step is to assign actions to fix the RPN. There may be instances where inefficiencies are visible and such changes or notes can be jotted immediately; however, that is not always the case. FEMA charts can become tricky and complex fast. They are subject to rapid expansion in size as each step in any process can have several failure modes, which in turn have several potential causes, which can have many different relevant controls. For this reason, FEMA requires vigilant facilitation to keep on course and completed on time (Brook, 2020).

Although there are additional phases that involve statistics and data searching, hypothesis testing is the main component that separates this phase from the others. In-depth statistical analysis to understand the root cause and cause-and-effect scenarios is accomplished through data findings in this phase. Hypothesis testing is essentially statistical inference given from specific data to draw conclusions about a particular parameter. The purpose of hypothesis testing is to test whether the null hypothesis is true or can be rejected in favor of an alternative hypothesis. Parametric (normal data/distributions that are predictable) statistics are based on assumptions of the population from which a sample was taken. Associated with parametric statistics are 1 and 2 sample t-tests and analysis of variance (ANOVA). 1 sample t-tests allow you to compare the average of just one sample against a known average value, such as an industry benchmark or well-established historical average (Brook, 2020). A 2-sample t-test looks at the differences in the averages of two different samples (Brook, 2020). Sample sizes in a 2-sample do not have to be the same as the test itself considers the sample sizes and adjusts the results accordingly (Brook, 2020). For best results, data should be normally distributed for a 2-sample t-test (Brook, 2020). ANOVA allows for the analysis of averages with three or more samples at a time while still taking into consideration the null and alternative hypotheses (Brook, 2020). Non-Parametric (non-normal data/distributions that aren't easily predictable) are not based on assumptions and require data from a sample that does not follow a particular distribution. Three tests that can provide you with considerable results toward your hypothesis include Moods Median, Krukus Wallis, and Chi-Squared Tests. The Moods Median test compares the medians of different samples of data, where samples are not normally distributed and where there are obvious outliers in the data samples (Brook, 2020).

2.4 Improve Phase

The Improve Phase is where the solutions to the problems are generated. In this phase, one should "attack" the root cause and project the problem head-on (Sreedharan & Sunder, 2018). The first steps in the Improve Phase are to develop and evaluate potential solutions. This is where Lean Six Sigma thinking is exhibited. The use of a Solution Matrix and Pugh Matrix help evaluate solutions and when one solution is chosen, an LSS method (Design of Experiments, Pull systems, Defect Prevention, etc.) is piloted. Once the optimal solution is implemented, the solution should be compared to the original data to see if project goals were met (George, 2005). Finally, key documents such as the project charter and project plan should be updated.

Arguably one of the hardest parts of the improve phase is coming up with a large selection of potential solutions. Some techniques are more or less optimal depending on the scenario at hand. It is important to remember that the purpose of the solutions is to overcome the impact of previously identified root cause(s). The first technique, and one of the more widely used idea generation techniques, is brainstorming. Brainstorming at its core is getting all of members of a group together and listing off any and all ideas that come to mind (George, 2005). A facilitator should make sure to get all members involved and track all solutions that are produced no matter how outlandish they may seem. Brainstorming can be beneficial since it gets all members to innovate together, but it is important to realize the kinds of bias that can spring up during the process. Two of the biggest downsides that can come from brainstorming are that certain members may feel like they do not have a good enough idea to bring up or all ideas generated are similar because people will be biased to bring up more ideas that align with each other. These downsides need to be mitigated by the facilitator. The facilitator can first keep the brainstorming session silent by having each member put their idea on a sticky note or piece of paper (George, 2005). This will force participation and reduce bias from copying each other. Then once all ideas are gathered and posted, the floor can be opened and more in-depth collaboration can begin.

Properly completing the improve phase ensures that the control phase runs smoothly. The purpose of the control phase is to make sure that the solution is properly implemented, measured, documented, and maintained. If the improve phase does not output a proper solution with an implementation plan, the control phase and possibly the entire project can be derailed. A new practice will almost certainly discard a solution that cannot be easily embedded.

2.5 Control Phase

The control phase is the fifth and final phase of the DMAIC process. The purpose of this phase is to complete the project work and hand off an improved process to the process owner, with the procedures for maintaining the gains from the implemented solution(s) (George, 2005). One deliverable of this phase is a documented plan to transition improved process back to process owner, participants, and sponsor (before and after data on process metrics). The next deliverable would be operational, training, feedback, and control documents. Another deliverable would be a system for monitoring the implemented solution, along with specific metrics to be used for regular process auditing. The last deliverable for this phase is the completed process documentation, including lessons learned, and recommendations for further actions or opportunities. One key aspect of this phase is by locking in the process performance gains from the new solution(s). This is done by creating a means to ensure the process does not revert to going back to the old way of doing things (Wang, 2008). Another key aspect of this phase would be to continue monitoring the implementation of the new solution(s). This entails observing, interaction, data collection, and charting of data. From that point, one additional key aspect of this phase would be auditing the results of the implemented solution(s). This is simply confirming the measures of improvements and assign monetary values if/when necessary and sending the results to the process owners auditing personnel. This will allow the process owners that this can monetarily benefit them (de Koning, Does, & Bisgaard, 2008). The last key aspect of this phase is validating the performance and financial results of the implemented solution(s). That should be completed a few months after the completion of the project. This phase of the process is incredibly important to the sustained success of the process that is being improved upon (Kanani, 2006). This ultimately wraps up the fifth and final phase of the DMAIC process as well as the completion of the project in its entirety.

3. Methods/Results

3.1 Define

In the define phase, information provided by Tobyhanna Army Depot (TYAD) contributed to defining the problem statement and goal statements as well as to outlining the process. It was discovered that TYAD's Component Paint Branch was operating behind schedule, overrunning 242 hours per month with trends remaining consistent. The small paint work center was identified as being a main contributor to the overrun hours in the branch thus providing the scope of focus for the team's work. The goals of this project were to reduce monthly overrun hours by 25% from 242 hours to 182 hours and to increase process throughput by 20% within the Component Paint Branch, specifically the small paint work center, by 01 May 2023.

Figure 1 below provides a clear illustration of the small paint process as a high-level process map where the characteristics of the small paint process are shown. The small paint process consists of five major steps: Receive Asset, Prime Asset, Paint Asset, Stencil Asset, and Ship Asset. TYAD prime shops from around the depot begin the small paint process when they deliver individual components to the Small Paint Work Center. The components are received and enter the first step of the process. From there, individual components move to the paint booths where they are primed and then immediately dried.

DOI: https://doi.org/10.37266/ISER.2023v11i1-2.pp27-41

The components are then moved back to the booth to be painted and dried again. The fourth step of the process is for the component to receive stenciling work if need be. With basic quality inspections happening throughout the entirety of the process, all that is left is for each individual component to be checked off before it is shipped to its next location.

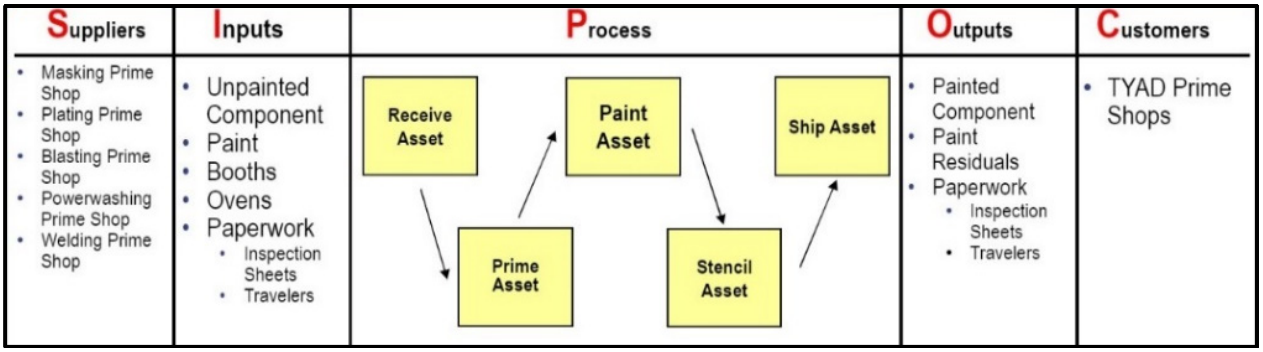

Figure 1: SIPOC Map

3.2 Measure

The Measure Phase Tollgate provided crucial information about the current situation of the process. In general, the measure phase tools and data helped frame the problem which would be further analyzed in the analyze phase. Figure 2 displays the Value Stream Map for this particular process, the five main phases are broken down into Receive, Prime, Paint, Stencil, and Ship. In each of these main phases, the responsibilities of the painter leader, painter and inspector were documented. By completing an in-depth process map, a value stream map was easily created to mock the process. The purpose of a Value Stream Map is to capture all key flows in a system and its metrics, which is beneficial since it identifies and quantifies waste. (George, 2005).

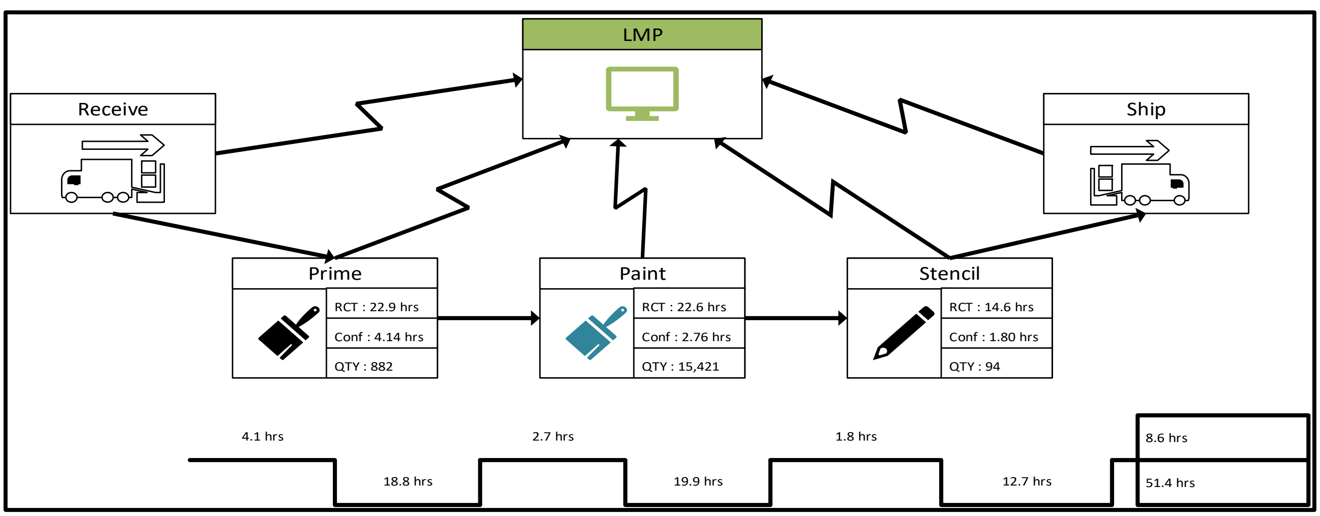

Figure 2: Value Stream Map

From the value stream map, more detailed process maps allowed the team to look at each major step in the process in more detail to analyze the different steps in the process. Figure 3 depicts the first two steps in the process which include receiving the asset from various work centers across the depot and priming the asset which includes applying a primer to the raw material to begin the paint process. One of the critical steps in the process that became evident with the process mapping is the need for ovens to cure and dry the paint for some of the assets, but not all of them. Figure 4 provides a detailed mapping of the painting process, which again begins with mixing the paint, applying the paint, and then potentially putting the item in and oven or air drying the asset. Figure 5 displays the final two steps in the process to apply stenciled lettering to some items as required by the engineering diagrams and then shipping the assets to other work stations across Tobyhanna. At each step, the process includes quality control checks which can potentially result in re-work in the process.

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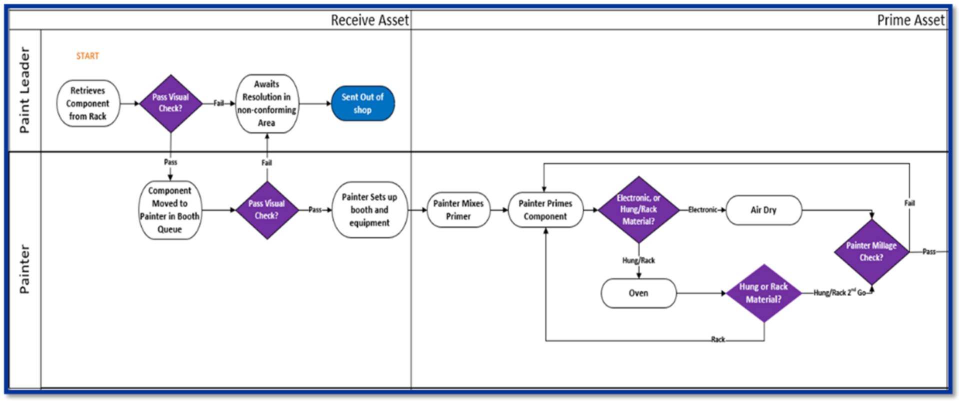

Figure 3: Receive and Prime Asset Process Map

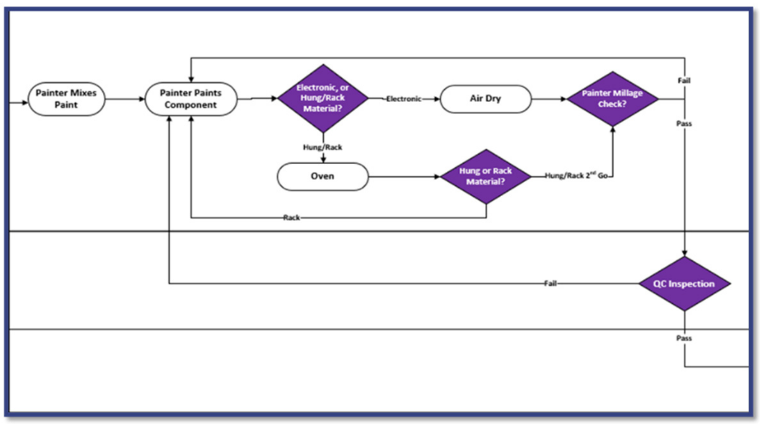

Figure 4: Paint Asset Process Map

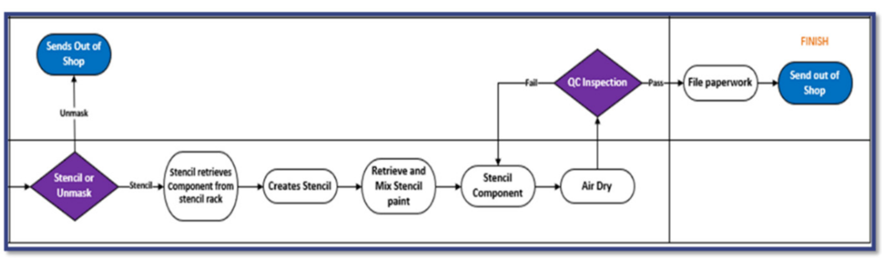

Figure 5: Stencil and Ship Asset Process Map

In order to prepare for the Analyze phase, the data needed to be evaluated, and understood in order to set a baseline. According to the data, on average, TYAD is overrun by 1.2322 hours with a standard deviation of 2.48 hours. This result informs us that when there is an overrun, they are only overrun by a slight amount. In order to understand the overrun hours more, Pareto charts were developed. These Pareto Charts show how batch size, process type, and component type influence overrun hours. The batch size chart reveals that most of the issues came from single batch components, which made up 55% of all overrun hour issues. Additionally, according to the process type chart, Most issues came from the paint process, as 90% of all overrun problems dealt with paint. Lastly, Radio Components, 146/147, TRC-190 made up the most overrun problems. Radio had the most with 23% of all observations having dealt with radio. Figure 6 presents the statistical summary of the overruns (amount of time in excess of the standard for painting a part) which indicates that the data is non-normal with a very wide range between 0.001 and 87.25 hours of overruns.

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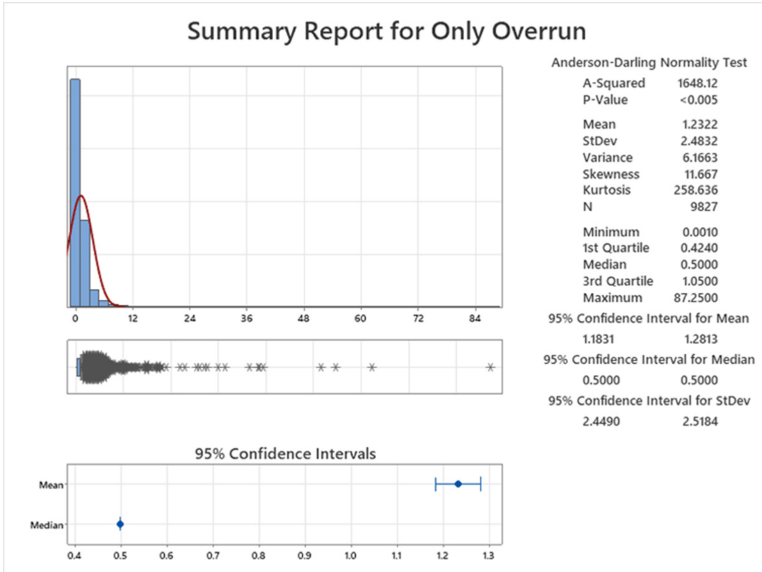

Figure 6: Graphical Summary for Overruns

During the measure phase, the team looked at several different aspects of the paint process to determine potential opportunities for process improvement. Two initial aspects that the team examined where batch size, the number of items that were painted at a time, and the step in the process designated by the operations group. Figure 7 shows the breakdown of overruns by batch size and as indicated in the Pareto Chart, single items accounted for 55.4% of the overrun hours for the process. The team initially thought that large batch sizes (greater than 100) would account for a majority of the overruns, but it turns out this was not the case. Additionally, the team examined the step in the process to determine if any one step introduces additional overruns into the process. Figure 8 displays the Pareto Chart by group and as indicated 91.6% of the overrun hours stem from the paint process. Overruns for stenciling, receiving, and shipping the assets were almost negligible.

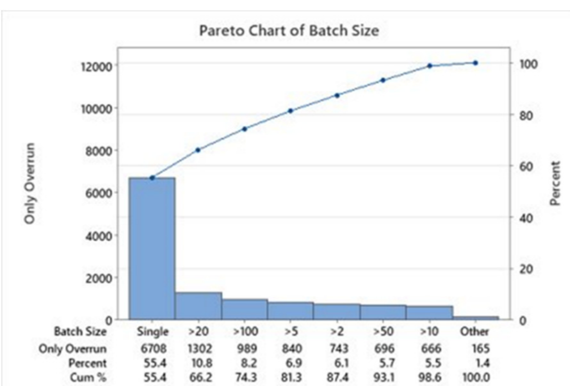

Figure 7: Pareto Chart of Batch Size

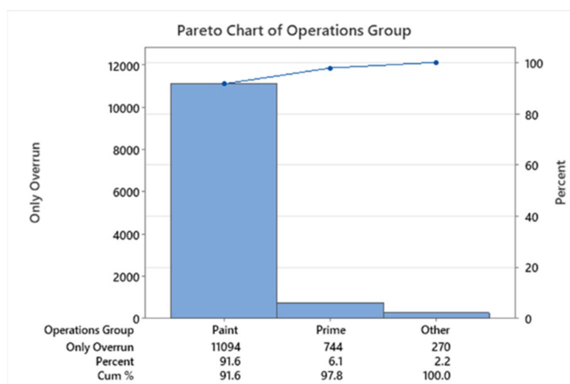

Figure 8: Pareto Chart of Operation Group

The team also analyzed the impact of different types of assets on the number of overruns to determine if any one asset was creating a majority of the problems for the component paint branch for further analysis. Within the data there were thousands of different individual assets, so the team grouped them into major categories for analysis. Figure 9 presents the Pareto Chart of the different asset groups and their associated overruns. The two groups that had the most overruns hours were the "Radio and Component" group which included individual radios and several components for these radios and the "An.ASM 146-147" group which are large shelters that Tobyhanna repairs. With this information, the team could focus on these individual assets during the analyze phase of the project.

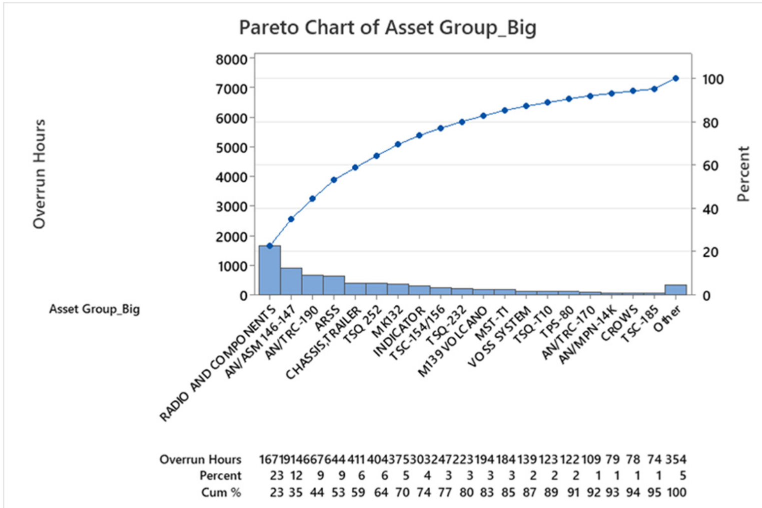

Figure 9: Pareto Chart of Asset Group

Lastly, the process was validated to see if it was capable as it stood right now. Based off the process capability and through put capability, the process was not capable. Since the process is not operating in the implied standards that TYAD set, the DMAIC process can be further applied later on. All of the statistical analyses done effectively visualize the results given to us by TYAD. These baseline statistics are necessary to gain a better understanding of the current throughput at TYAD as well as gain information that could potentially be useful for us in the Analyze phase. Because the individual overruns were not normally distributed and did not follow a specified distribution, the team analyzed the total weekly overruns for the small component paint branch to determine if the process was capable. Figure 10 presents the process capability for the weekly overruns which followed a log-logistics distribution and is not capable of meeting the specification of less than 72 hours of overruns per week.

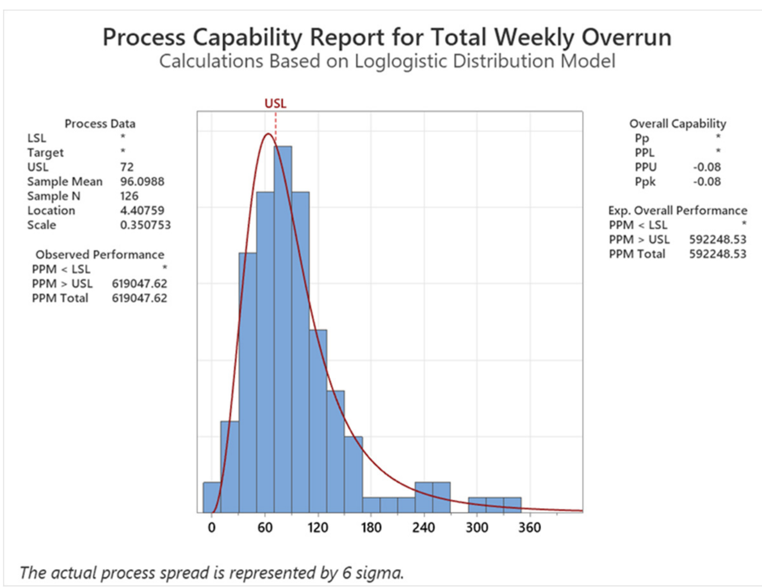

Figure 10: Process Capability - Weekly Overruns

3.3 Analyze

The analyze results were informative in understanding the root cause for the problems at TYAD confirmed what problems to focus on most. Subject matter experts (SMEs) provided assistance in identifying various issues and thoughts of concern that contributed to overrun hours within the component paint branch itself. SMEs included but are not limited to painters, gatekeepers, and chief operators. The team held several in-person and telephone meetings to go over step by step the

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components and subcomponents thereof, that contribute to or have an effect on overrun hours. The team identified several factors to focus on more than others given the statistical data that could support what needed to be improved. The team decided to focus on Batch Size, Operational Months, and Asset Groups to determine whether those factors were substantial contributors to overrun hours. Batch Size and Operational Months were tested using a Moods Median test, whereas Levene's Test was used to find significant levels of asset groups. The tests determined most overrun hours came from single batch components, months of the year do not contribute and are not correlated, and radio and components, AN/TRC 190, ARSS, and AN/ASM 146-146 are the assets that contribute most to overruns.

Figure 11 depicts graphical representation of Batch Size. After the team sorted and filtered out large amounts of data they were able to determine which batches contribute to overruns the most. Mathematically, the Moods Median test would determine if there was statistical significance in whether Batch Size was a contributor to overrun hours, and if so, which sizes were (Brook, 2020). Moods Median was the test of significance here because of the non-normal data for the process. Moods Median allowed us to eventually determine whether the medians of two or more groups differ. The test concluded that most of the overrun hours come from single Batch Size components. However, there are a few outliers visible on the graph (i.e., >20,>100,>500), that contribute to large overruns. With a very low p-value of <0.001 the test confirmed that Batch size indeed is a significant contributor to overrun hours.

Figure 12 is a graphical representation of our Months of the year in boxplot form. From the initial data analysis, the team wanted to determine if overrun hours were significant as it pertains to months of the year and facility humidity. In general, temperature can impact the time it takes for an asset to dry and is something to consider in a painting system. Being that warehouses can typically get hot or cold depending on the time of year, the team sought to see statistically if that had any correlation or effect on reworks or backlog, which in turn can lead to overruns. The Moods Median test again provided a test to determine if there was statistical significance in whether Months of the year (Facility Humidity) cause overruns. Again, Moods Median was the test of significance because of the non-normal data (Brook, 2020). The test determined that there is minimal to zero correlation between months and the humidity factor causing overruns.

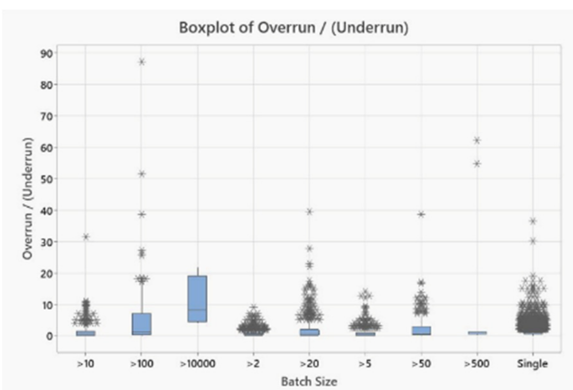

Figure 11: Boxplot of Overruns by Batch Size

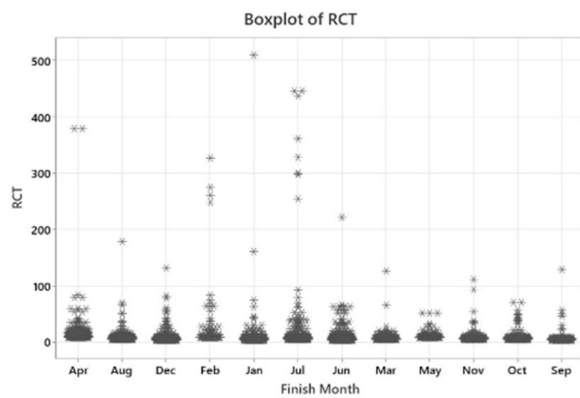

Figure 12: Boxplot of Overruns by Month

Figure 13 presents the final graphical representation of overruns by asset groups. With the data, the team decided to determine if overrun hours were significant as it pertains to certain assets. After trying several other options to determine if the medians of the different assets were statistically different, the team decided to examine the variance of the different assets. Mathematically, Levene Test determined if variances are equal for all assets and can be used when the data follows a non-normal distribution (Brook, 2020). The results using Levene's Test had a very strong p-value of <0.001 and confirmed that the majority variance in overrun hours came from Radio and Components, AN/TRC 190, ARSS, and AN/ASM 146-147.

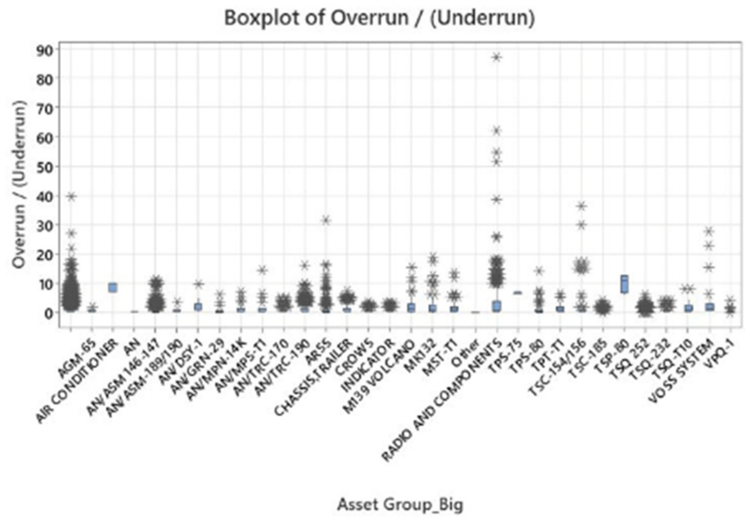

Figure 13: Boxplot of Overruns by Asset Group

We then went into formulating and constructing a FMEA (Failure Mode Effect Analysis) chart that was completed in conjunction with the TYAD team. We took a deep dive into the five-step process from our Value Stream Map and examined potential failure modes, their effects, and the causes of those modes, as well as controls in place that try and limit mishaps or unwanted overrun hours. We then, along with the TYAD, conducted multi-voting to vote on the severity, occurrence, and detection of such issues and concerns and then narrowed down again the big problems and areas we could fix. Upon completing the FMEA, we prioritized our root causes and effects and let the TYAD team know specific areas where we intend to improve and find solutions in the phases to follow. Figure 14 presents the first portion of the FMEA which identifies the highest risk steps in the process of painting the asset and receiving the asset.

Process Step / Input What is the process step and Input under investiga-tion?	Potential Failure Mode In what ways does the Key Input go wrong?	Potential Failure Effects What is the impact on the Key Output Variables (Customer Requirements)?	SEVERITY	Potential Causes What causes the Key Input to go wrong?	OCCURENCE	Current Controls What are the existing controls and procedures (inspection and test) that prevent either the cause or the Failure Mode?	DETECTION	RPN
Receive Asset	Inaccurate Paperwork/Information, Inaccurate Allotted Time/Millage. *Late delivery*	Producing Wrong Asset	6	Attention to Detail. Misplacement of Data, Worksheets	5	Floor LDR Inspection	5	**150**
Prime Asset	Inaccurate Paperwork/Information, Updated Revision Drawing, Forecasting (Prime Materials)	Reworks, Backlog	6	Attention to Detail, Complexity of Asset, Miscalcuation of Important Data	6	Painter Inspection	4	144
Paint Asset	Forecasting (Paint), Inaccurate Paperwork, Cleaning Paint Area for Rework, *Updated Revision Drawing*	Reworks, Backlog	7	Attention to Detail, Complexity of Asset, Miscalcuation of Important Data	6	QC Inspection	5	**210**
Stencil Asset	Inaccurate Paperwork/Information, Size of Stencil, *Updated Revision Drawing*	Reworks, Backlog	5	Attention to Detail, Complexity of Asset, Miscalcuation of Important Data	4	QC Inspection	5	100
Ship Asset	Inaccurate Paperwork, Drop Zones, Pickup Before Catalog	Backlog, Costs, Dissaproval Rating	6	Attention to Detail, Conflicting Guidence	5	Traveler, QC Inspection	3	90
Getting an Asset Ready for Paint (Blasting, Sanding, Priming, etc).	Dirt/Debris in Paint and Inside Paintbooth	Backlog, Ovverrun hours, Painter Frustration	6	Lack of Ventaliation and Frequent Cleaning Inside Booths. Assets Sitting Waiting Collect Debris.	6	Painter	4	144

Figure 14: Failure Mode and Effects Analysis

3.4 Improve

The beginning of this phase consisted of applying solution generation techniques, such as brainstorming, with TYAD at their facilities. The FMEA chart, fishbone diagram, and other statistical analysis depictions is the driving force during the

DOI: https://doi.org/10.37266/ISER.2023v11i1-2.pp27-41

brainstorming session. After the conclusion of the brainstorming session, four clear potential solutions were proposed. Due to inaccurate estimates the refined use of a 2502 form. A 2502 form is a document that is submitted by paint shop workers when they deem that a component clearly and consistently takes a different amount of time than what is specified by TYAD. The form is passed up to management where the work estimate can then be fixed. The second potential solution is to add in more cleaning time and a standardized schedule for when cleaning of both workstations and equipment would occur. This solution addresses the reworks that happen due to paint chips from dirty equipment falling into current components being painted. The third potential solution was to add in a rework step into their system that made it clear which component was being pulled back into the system to be redone. Currently the system does not properly track the time that was needed to fully complete the component. Finally, TYAD let us know that the gatekeeper position would sometimes allow components come through that had wrong paperwork in terms of actual coding or the paint millage specifications. To decrease the amount of time is spent looking for those errors or allowing the errors to come into the system, the team proposed that a reference sheet would be instituted to allow easy checks and to have a standardized training for new gatekeepers since most knowledge was "tribal".

The criteria that were used to determine whether or not a potential solution should be piloted are how likely they are to decrease overruns, how long the solution will take to develop out, and how likely is the solution to decrease defects in the process. The potential solutions were each evaluated by the team and the two potential solutions selected from this chart will be the 2502 form and the gatekeeper reference sheet. Figure 15 presents the evaluation criteria and assessment for the potential candidate solutions.

Evaluation Criteria

	Criteria 1: Decrease Overruns	Criteria 2: Time to Develop	Criteria 3: Decrease Defects	Total Score
Weight	4	3	3	10
2502	9	9	1	66
Gatekeeper	3	3	9	48
Rework Step	3	1	1	18
Clean	1	3	9	40

Figure 15: Solution Evaluation Criteria

The pilot plan for the small component paint branch consisted of the team going back through historical data for when TYAD had used 2502 forms in the past and the subsequent decrease in overrun hours that would potentially follow. The data points that were analyzed fell under the Radio & Components asset group. Due to the fact that the number of observations for each order material was under ten, so the data was normalized across many of the individual order materials to create a data set that had greater than 290 observations.

Figure 16 presents the results of the pilot plan compared to this to historical overruns. The data was determined to be non-normal, so a Mood's Median Test was conducted. After running this statistical test the null hypothesis was rejected due to its low p-value leading the team to know that the population medians were not all equal between the pre-2502 data and the post-2502 data. The greatest changes that are observed after the implementation of the 2502 form can be seen in the mean and standard deviations of the data sets. The mean and standard deviation of the pre-2502 data is 2.3 hours and 4.47 hours respectively. After the use of the 2502, there is a 93.7% decrease in the mean overrun hours to 0.14 hours and a decrease of 91.8% of the standard deviation to 0.36 hours. This statistically proves that TYAD should continue to use the 2502 form and the potential solution is now accepted.

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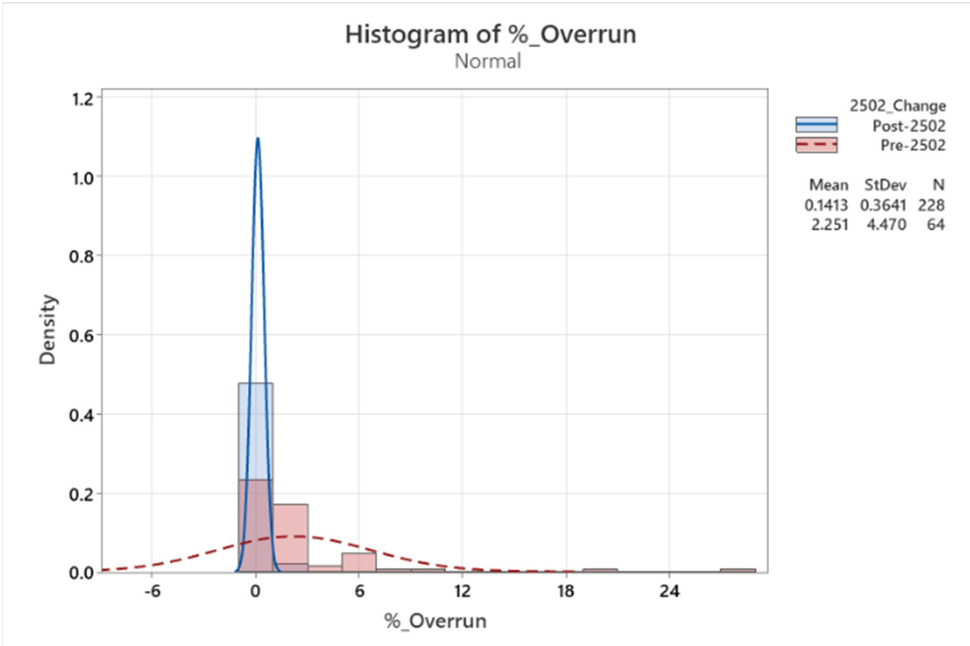

Figure 16: Pre-Post Adoption of the 2502 as the Pilot Plan

3.5 Control

The fifth and final phase of the DMAIC process is the control phase. To complete this phase of the project, we had to implement the solution that was outlined and decided on from the improve phase. This solution must also be passed off to the process owner during this phase. The implemented solution that we decided upon was utilizing 2502 forms as well as creating and standardizing gatekeeper training. These two solutions are in an effort to limit the overrun hours that are being experienced by TYAD in the small component paint branch. Additionally, this solution is designed to be iterative, specifically with the 2502 forms, so that the process can be continually improved. This phase took us roughly three weeks to complete from start to finish. The major obstacles that arose in this phase were determining responsibility for each portion of the solution and bouncing ideas on feasibility with the SME's. The first portion of the solution that needed to be addressed, however, was the 2502 forms.

The 2502 forms are a method in which to better gauge the number of hours it takes to complete a process or activity. This form would have to be submitted by supervisors at TYAD who are responsible for marking down the number of hours that it took to complete a specific process or activity. From there, the engineer would be held accountable to address this 2502 form and rationally determine if the number of hours that are being allotted for a specific process or activity are adequate. This process can be repeated as many times as it takes to ensure that the number of hours that are being allotted for a specific activity or process are an accurate representation of how long it will take. This iterative process will continue to help TYAD reduce the number of overrun hours that they are experiencing in the small component paint branch and give them a large amount of cost avoidance. With our implementation of the 2502 forms, we estimate that over the next two years we will be allowing TYAD to avoid a net cost of $996.7K. This simple iterative change will prevent TYAD from hemorrhaging money and time unnecessarily for years to come.

Moving forward, TYAD has additional things that they will be able to work on. For starters, TYAD will be transitioning to a fully automated 2502 system later this year that will continue to help curtail overrun hours. However, the scale of this change will take place in the entire depot, not just the small component paint branch. This increase in scale will likely provide even more benefits to TYAD as a whole in the future. This automation of the 2502 form is an excellent continuation of our own efforts to help TYAD avoid costs as well. That being said, until this automated 2502 system is in place, the manual 2502 standardization must continue. This will help ensure that time and money are not being wasted until the automated 2502 form changeover occurs. TYAD must continue to monitor and analyze the process efficiencies so that they can continue to move towards more accurate time estimations for activities and processes. Another important future work would be to ensure that the engineers at TYAD are constantly being updated on the 2502 processes and SOP's. This will ensure that the people who are being held accountable for the 2502 forms are aware of what they need to be doing with the 2502's at any given point in time. Although there are multiple future works for this project, they are all important to ensure that TYAD is decreasing overrun hours and avoiding cost in the best way possible.

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3. Conclusion

The Lean Six Sigma and DMAIC processes and methodology allow for process owners or businesses to effectively identify problems in their process or systems that lead to inefficiencies. Subsequently, a more efficient way to identify problems or waste in a process or system makes the formulation of a solution easier. As process owners or businesses introduce more and more effective solutions, they will conclude that the Lean Six Sigma processes work not just once but can be utilized iteratively to continually improve their process or system. As long as these processes or systems can still be improved in the slightest, there will always be a place for the Lean Six Sigma and DMAIC processes and methodology to make those improvements.

As is the goal in any lean six sigma project, part of the future work is to ensure that the process remains stable and the improvements are maintained. To this end, the team at Tobyhanna has fully adopted the practices developed as part of this project and presented in the paper. They will continue to seek to improve the process and conduct follow-up checks on the process to ensure the gains are being sustained. This is a major component of the lean six sigma culture that is prevalent at Tobyhanna and other organizations throughout the world that have adopted lean six sigma.

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