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West Point System Throughput in C4ISR Finishing Division

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Author Note: All cadets contributing to this project are a part of West Point's System's Engineering Department and are participating in their West Point Capstone project through the department. Working with Tobyhanna Army Depot, we are seeking to obtain our Lean Six Sigma Greenbelt upon completion of the project. We would like to thank COL Enos for his help throughout the semester and in the development of this project and paper.

Abstract: Ensuring military readiness is at the forefront of efforts throughout the Army and requires effective sustainment operations. Tobyhanna Army Depot plays a critical role in maintaining and fabricating a wide variety of military assets across the Department of Defense, yet system inefficiencies limit its operational effectiveness to supply the military with its assets in a timely manner. This study applies the Lean Six Sigma methodology, specifically the DMAIC process, to the throughput of Tobyhanna's C4ISR finishing division. The study identified key contributing factors to the process's prolonged repair cycle time, RCT, with delays ranging from 1 to 742 days across dozens of asset types. By analyzing root causes and implementing improvements to the process, this project seeks to improve efficiency, reduce RCT, and ultimately strengthen military readiness by ensuring as many of its critical assets as possible are available.

Keywords: Process, Define, Measure, Analyze, Control, Improve, System, RCT

1. Introduction

Lean Six Sigma methodology is the blending of both the concepts of Lean and Six Sigma, with the goal of improving both the process efficiency and quality of any project (Brenig-Jones & Dowdall, 2017). This project applies the Lean Six Sigma methodology to Tobyhanna Army Depot to remove waste and improve ongoing operations. Tobyhanna Army Depot is a large provider of logistics support for Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) Systems in the Department of Defense (Tobyhanna Army Depot). Tobyhanna officially opened in 1953 and has since been one of the military's largest supporters in keeping equipment in the fight. The depot works to keep our nation's military ready and equipped with fully operational equipment and technology. Tasks within the depot range from technology refurbishment and modification to repairing structural components of hundreds of different vehicles and assets.

The problem statement assigned to this project is, "Systems are taking too long to be completed in the C4ISR Finishing Division which is comprised of the System Preparation Branch, Structural Repair Branch and System Paint Branch. From MAY 23 to AUG 24, the Repair Cycle Time (RCT) delta overruns ranged from 1 day to 742 days for this value stream based on 128 different system types."

This paper will provide an overview of the Lean Six Sigma process broken down into each phase of the DMAIC process (Define, Measure, Analyze, Improve, and Control) and explain how the team implemented these phases into the Tobyhanna process to improve their systems. To conclude, the paper will address how the work done up to this point impacted Tobyhanna and explain any future considerations in stabilizing the improvement process.

2. LEAN SIX SIGMA LITERATURE REVIEW

2.1 Define Phase

The first phase of the DMAIC process, the Define phase, is where the problem to be solved is clearly identified and articulated (ASQ, n.d.). This phase sets the goals, scope, and key stakeholders while remaining in line with the business objectives. This involves key stakeholders agreeing on what the project will focus on and on what the improvement goals will be. The project scope includes capital allocation, customer needs, and ensuring goal alignment (Villanova, 2023). The successful implementation of this phase enables the project to move forward with clear and well-defined objectives, as well as timelines for completion of the project (Tanner, 2024).

In developing the refined problem statement and project charter within this phase, there are a set of common practices to implement and mistakes to avoid. Encouraged practices include making the problem statement specific and as fact based as possible, as well as ensuring the project charter is used to set a direction and gain agreement on the problem, goal, and project parameters (Pande, Neuman, & Cavanagh, 2000). By doing this, a team can ensure that all the members of the project have a clear vision of what needs to be fixed. This shared understanding of the charter allows all the members of the project to be on the same page on the path going forward. Key common mistakes to be aware of when completing the define phase include not describing suspected causes or assign blame for the problem, as well as not over-publicizing preliminary goals (Pande, Neuman, & Cavanagh, 2000). Being aware of these common mistakes is essential initially because it is important to work with the people who have the problem, not to criticize them for having one. Being critical creates hostility and will prevent the best possible solution from being developed. Additionally, it is important to not get over ambitious initially as original goals may change as the DMAIC process continues, and being initially constrained to certain large goals could be counterproductive later in the process.

2.2 Measure Phase

The second phase of the DMAIC process, the Measure phase, focuses on the gathering of data to be utilized in future phases. This phase is critical to developing a solution as data is needed to fully understand the system and processes. While every project is different, there are steps in the Measure phase that can provide a guideline for phase execution. These steps serve an important role in executing the Measure phase and establishing a foundation for future phases.

The first step in the Measure phase is to "Create a value stream map to confirm current process flow" (George, 2005). Depictions such as the value stream map are helpful tools to visualize the system being measured. The second step is to "create a data collection plan" (George, 2005). A list of variables, or measures, whose outcome will be the focus of interpretation should be defined. Within this data plan, additional information should be recorded including the data source and location, how/who/when it will be collected, the sample size, and how the data will be used (Abric, 2024). The next step is to "collect data to establish baselines" (George, 2005). The system baseline serves as the average performance prior to any improvement efforts. It allows one to assess how much the system changed based on the team's efforts. After collection, the final steps in the Measure phase are to, "understand process behavior" (Brook, 2022) and "prepare for Measure gate review" (George, 2005).

Understanding the process behavior is the outcome of successful data collection, and this understanding is then reflected in a tollgate that summarizes the key findings and actions taken during the Measure phase. It provides the customer with an encompassing look at the phase and the deductions that follow.

2.3 Analyze Phase

The third stage of the DMAIC process, the Analyze phase, seeks to identify all the relevant root causes of inefficiency in the targeted process. The first step is defining the performance objectives of the project system. This involves setting either a low-end or world class PCE (process cycle efficiency) goal based on the current system PCE (George, Rowlands, Price, & Maxey, 2005). The second step in the phase is to fully identify each step in the targeted process as value added, non-value added, and non-value added required. This is done by reviewing the process map from the define phase, making any necessary adjustments after the measure phase, and discussing with the project process owner as to the value and necessity of each process step. In completing this step, process flow analyzation is happening naturally, which leads to the following step of identifying potential sources of variation or inefficiency in the process. There are many key tasks and sub-steps within this step which include tools such as Failure Mode and Effect Analysis (FMEA), brainstorming, Pareto charts, and Cause & Effect diagrams. Cause & Effect diagrams visualize cause-and-effect relationships by mapping out potential process inefficiencies. FMEA is a tool that is used to identify the aspects of a process to be improved. It identifies potential failures taken from the Cause & Effect diagram, assesses the effects, and ranks the level of risk to the process (Brook, 2022). Pareto charts are based on the Pareto principle where 80% of the problems in a system can be explained by 20% of the causes. The Pareto chart, depicted as a bar chart, organizes potential causes from the greatest number of problems to the least (Patel & Patel, 2021). The fourth step is to determine the root causes of waste and variation in the project process. The goal of this step is to narrow the potential sources of variation by eliminating incorrect or unimportant theories. This is done through various prioritization techniques such as Pareto charts and hypothesis testing. Once the potential sources of process inefficiency are identified, additional techniques are used to verify them as root causes of process inefficiency (Krishnan & Prasath, 2013).

2.4 Improve Phase

The fourth stage within the DMAIC process, the Improve phase, is when solutions to the root causes are chosen and implemented. The two primary approaches to this are the design of experiments (DOE) and the Kaizen approach. The design of experiments approach is used, "to solve problems from complex processes or systems where there are many factors influencing the outcome and where it is impossible to isolate one factor or variable from the others" (*DMAIC Process: Define,* *Measure, Analyze, Improve, Control | ASQ*, n.d.). While a Kaizen event introduces, "rapid change by focusing on a narrow project and using the ideas and motivation of the people who do the work" (*DMAIC Process: Define, Measure, Analyze, Improve, Control | ASQ*, n.d.). This phase is when the Lean Six Sigma team can finally see the impact of the previous phases and improvement upon the system.

The Improve phase begins after the completion of the Analyze phase and includes generating potential solutions, selecting the best solutions, assessing the risks, and piloting and implementing the change (Quinten Brook, 2020). The goals of this phase are to identify feasible solutions for the root causes, select the best solution using statistical tools, perform cost-benefit analysis, test the solution, and assess the effectiveness of the solution to ensure measurable improvements in the process (PV, 2014). These goals will provide the client with a plan of action to improve their specific system.

The Improve phase is the heart of the DMAIC process as it is the phase in which all the data that has been collected is used to implement a new improvement solution. Previously, the Define, Measure, and Analyze phases focused on problem identification and analysis; the improve phase shifts gears towards generation of a feasible solution. (DiLeo, 2023). This allows an organization to make measurable improvements to a process and finally see the benefit of their effort.

2.5 Control Phase

The final phase in the DMAIC process is the Control phase. After the team identified and implemented the optimal solutions, they will closely observe the impact their solutions have on the system. Along with monitoring for effects, the team must ensure the plan is sustainable by the system owner. Therefore, the team should document solutions, collect any data relevant to how the solution is producing outcomes, reinforce that the solution is a permanent fix rather than temporary, and inform project management of any discrepancies (Hessing). The key steps of the Control phase are the launching of the implementations for the solution, analyzing performance of the project, and observing the data collected to confirm measures of improvements while adjusting the areas that need work (George, Rowlands, Price, & Maxey).

To ensure process improvements are both successful and sustainable, a structured approach is key. It begins with thorough preparation where the team develops the necessary tools and documentation to ensure that changes can be scaled and maintained effectively. This involves creating detailed process maps, standard operating procedures (SOPs), and performance metrics to track progress and provide insight into future decisions. Additionally, mistake-proofing mechanisms and automated controls should be integrated wherever possible to reduce human error and ensure consistency in the process. This preparation sets the foundation for smooth and effective implementation

The project concludes with a Control Gate Review, which serves as a checkpoint for the full-scale implementation. This review examines all relevant documentation, such as before-and-after data charts and SOPs, to ensure that the improvements are in place and can be sustained. It also assesses whether stakeholders are aligned and that lessons learned have been shared across the organization to inform future initiatives (George, Rowlands, Price, & Maxey). By ensuring that the process is fully optimized and stabilized before it's handed off, organizations can guarantee that the improvements are scalable and long-lasting.

3. Methodology/Results

3.1 Define Phase TYAD Results

Tobyhanna Army Depot had been seeing significant time delays indicated by their Repair Cycle Times (RCT) for systems being processed through Buildings 30 and 9 of their facility. These delays have caused there to be less systems processed through and back out to the force. Over the year of data that we initially analyzed; it was seen that the overruns on RCT have ranged anywhere from 1 to 742 days over a range of 128 different system types that run through the two buildings.

The goal that was defined and agreed upon after speaking with the members at both Tobyhanna and West Point was to reduce the average RCT time from 59 to 20 days to improve process efficiency within the C4ISR Finishing Division by April of 2025. In doing this, the team sought to increase the sigma level from .81 to 1.25 for production orders over planned RCT.

To ensure that this project targets the right areas, our team also identified what was in scope and out of scope after communication with the Tobyhanna team. In-Scope items were identified as all aspects of RCT and the wait/queue time associated with the C4ISR Finishing Division. Out of scope items were identified as aspects not relating to RCT and wait/queue time that still affect the finishing division, as well as Gate Keeper 1, TDY, and finally MDM. These are specific work centers the depot uses but are not involved in operations inside of building 30 and 9. They were taken out of scope because they still appeared within the data the Tobyhanna team provided. The key document produced from this phase was our SIPOC diagram. Figure 1 shows the suppliers, inputs, process, outputs, and customers, and allows the measure phase to begin focusing on certain key metrics.

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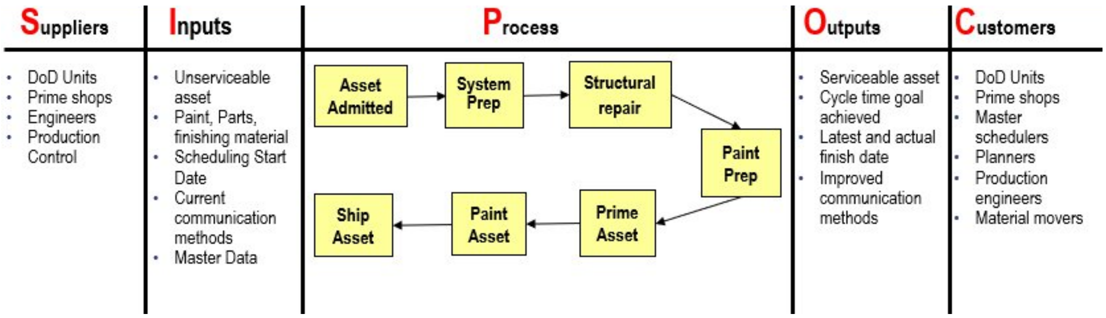

Figure 1: SIPOC Chart

3.2 Measure Phase TYAD Results

The data utilized in assessing RCT and Tobyhanna operations was provided by Tobyhanna from their standard data logging system. This dataset extended from October 2021 to September 2024. The raw data was sorted to exclude all production orders out of scope for this project. The remaining orders were classified into broad Operation Groups to allow for easy identification. For example, all steps labeled as "Quality Mechanical" and "Quality Refinishing" are classified under the "Quality Control" operation group. Other inconsistencies in the data, mainly from the operation start and end dates, were addressed on an individual basis. Addressing these inconsistencies proved to be one of the most difficult parts of the Measure phase, but once complete, the data could be depicted through statistical charts and tools to identify areas for further investigation in the Analyze phase.

Two of the most significant charts revealing the need for further analysis are shown below. Figure 2 below shows the month on the x-axis and RCT Delta on the y-axis. As can be seen, the RCT Delta was controlled and relatively stable from April 2022 to April 2023, but some event happened in March of 2023 causing an extreme spike. Figure 3 is a Pareto chart organizing the RCT Delta by Work Center. TCHUP01 (Touchup) and SMRP01 (Sheet-metal repair) make up 45% of the total RCT Delta among all Work Centers. These two centers are significantly contributing to the overall RCT and should be further assessed. The two below charts provided insight into the Tobyhanna process, and these insights were used as the basis for the Analyze phase.

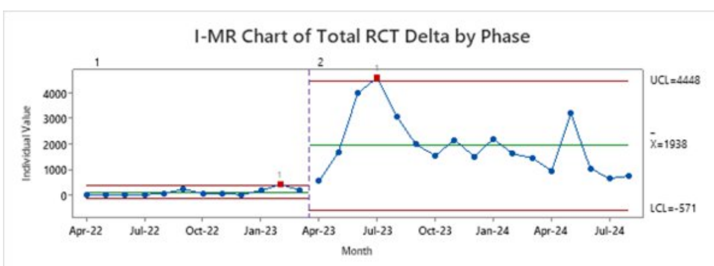

Figure 2: Control Chart

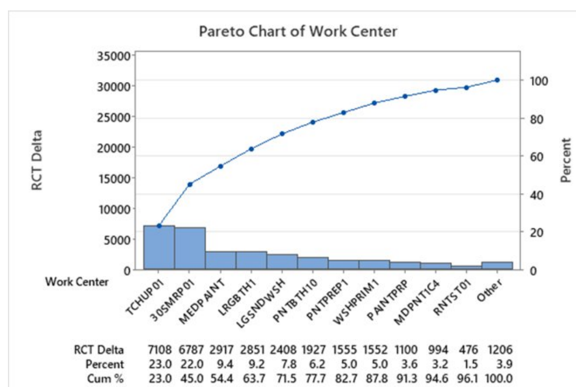

Figure 3: Pareto Chart of Work Center

3.3 Analyze Phase TYAD Results

Taking the key insights from the Measure phase into consideration, the Analyze phase began with identifying the major causes of the planned RCT not being met. Of these causes, the team labeled staffing issues during the TDY season, data collection inconsistencies, and confusion on how to schedule touch up operations as the major causes to be statistically analyzed. Initially, TDY was chosen because it was the only potential cause of the RCT spikes after April 2023 that the Tobyhanna team could think of. A Kruskal-Wallis test was performed on the data and provided statistical evidence that there is a difference in average RCT between the production orders before and after April 2023. During a visit to the depot, the team discovered that April 2023 was when a supplemental workshop to the main building closed operations to support a different process which would cause a significant increase in the flow through the building. The most valuable asset the process lost

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with the supplemental workshop switching to a different process was a small paint booth. This booth was used for touchup operations, and its loss is likely a major contributor to the spike in RCT during that period.

From the beginning of the project, the data has been nonsensical in many respects. The team went through a portion of the data and made logical estimations on the start and completion dates of each step of the process. The estimation for the start date of each step was based on the end date of the previous step, which created an 83.3% reduction in RCT. This uncovered a planning issue where production orders need to go back and forth between work centers and there was no way to close one and come back to it with the same order after. This caused an effect on the data where multiple production orders are seen as all being in a single work center all at the same time, such as the large paint booth. There can only be one to two assets in the booth at a time, which is how the issue was identified. An example of this error is seen in Figure 4 below which graphically shows the planned vs actual time in the large paint booth work center for various production orders. As seen in the figure, there is one point at around 5 July that all four production orders listed are inside the large paint booth at the same time, which is impossible.

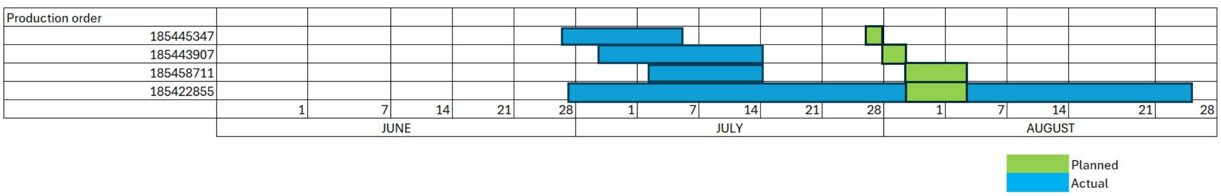

Figure 4: Large Paint Booth Use

The final root cause analyzed was the confusion on scheduling touch up operations which was creating an issue with rework. As seen in the pareto chart in the Measure phase, the touchup work center had the highest total RCT delta, meaning it was the largest contributor to the RCT overrun. A Chi-Square test was performed and yielded that there was statistically significant difference in the average RCT between the work centers. This means there is statistical evidence that the touch up work center is contributing the highest to the RCT overrun. The results of the Chi-Square test as well as the statistical tests for the other two root causes are seen in Table 1 below.

Hypothesis Test	Factor (x) Tested	p-Value	Conclusion
Kruskal-Wallis	TDY	0.030	Event in March 2023 is causing a significant change in RCT
Mood's Median	Data Collection	0.004	Data errors skew RCT results (305 vs 51 days)
Chi-Square	RCT Delta	0.000	Touchup & Sheet Metal Repair are the two most significant contributors to RCT delta.

Table 1: Statistical Test Results for Route Cause Validation

Next, a failure mode and effect analysis chart was created and used to assign risk priority numbers to the validated root causes. The assigned risk priority numbers were then used to develop a prioritized list of root causes for the improve phase to develop solutions to. The top three of this list, which will receive most of the team's focus, are data inconsistencies, the rework process, and floorspace scheduling.

3.4 Improve Phase TYAD Results

Moving into the Improve phase, the team decided to investigate the different routes of the assets that were going through the process. The goal of this action is to create a solution to both the rework and data inconsistency root causes. As identified in the analyze phase, a large contributor to data inconsistency is a system complication involving the route. Currently, production orders are not allowed to return to any work centers it has already passed on its route, even if it is necessary to complete the order. This forces work leaders at the depot to have the asset be in two different work centers at one time in their data system, so that it technically does not pass through it to allow the asset to return to the first work center when it needs to. To begin the investigation, a spaghetti diagram was assembled to help the team identify which routes to further investigate. To improve the routes, the team needed to identify the specific steps of the assets going through the process that needed to be changed. The team mapped out the routes the five most common assets that had a large impact on the process's RCT and sought

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to add steps to allow the asset to return to the necessary work centers. Additionally, hold and wait time steps were added to the routes to account for the time the asset is between work centers waiting to dry or be inspected. At the moment, these wait times are included in the time spent in the previous work center, further contributing to the RCT of the process. This solution addresses both the data inconsistencies and rework process root causes by allowing their data collection systems to capture reality and preventing further rework by improving individual asset routes.

The next solution the team recommended to the depot was scheduling assets to come through the process using floorspace instead of time. This prevents the overcrowding of the shop floor during high tempo periods and allows planners to more accurately predict and schedule the process's capabilities. Scheduling by floorspace in this process is even more essential than others due to the large variation in asset size and enables the process to properly complete its objectives on schedule.

4.1 Conclusion

Tobyhanna Army Depot, a key maintenance and production center for a variety of DoD assets, faces significant variability in RCT within the C4ISR finishing division. To address the challenges they face, the project applied the DMAIC process from the Lean Six Sigma methodology to the production system in an effort to reduce the RCT in key assets. In the Define phase, RCT was identified as the key metric for improvement and recognized its direct link to military readiness. The Measure phase involved the collection and cleaning of data to view the assets within the project scope. The Analyze phase used the data to identify and verify root causes of the extended repair cycle times. It provided key insights to the Improve phase including a prioritized list of root causes to improve. Within the Improve phase, process streamlining initiatives were created, including optimized floorspace and machine time scheduling, standardizing the data collection process, and reviews of the most common asset routes. Finally, the Control phase will later ensure the sustainability of the improvements through continuous monitoring, feedback loops, and process controls to maintain the reduced RCTs.

By competing this project, the depot's ability to sustain mission critical assets has been improved. The reduction in RCT improves both cost efficiency for the DoD and the military's operational readiness by increasing the amount of fully mission capable assets in the force.

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