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# Lean Six Sigma: Improving Non-Preventive Maintenance Efficiency at Tobyhanna Army Depot (TYAD)

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**Author Note:** Joseph Dooley, Joseph Dosan, Jack Feightner, Henry Okeke, and Trevor Smith are cadets at the United States Military Academy. The capstone team is comprised of two Systems Engineering Majors, two Systems and Decision Sciences Majors, and an Engineering Management Major. This paper serves as a summary of the team's year-long Capstone project for the Department of Systems Engineering (DSE). Jeremy Schlegel, a Senior Instructor in DSE, serves as the advisor for this Capstone project. The views expressed herein do not reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

**Abstract:** Tobyhanna Army Depot has experienced long-running delays while repairing production equipment due to long lead times for replacement parts. By applying the Lean Six Sigma methodology through the DMAIC process, the project team gained a qualitative and quantitative understanding of the baseline repair process, identified root causes hindering efficient completion of repairs, and implemented changes to reduce machine repair time. The team provided Tobyhanna with a standard operating procedure for government purchase card (GPC) orders pertaining to the branch responsible for equipment repairs, ensuring that budget officials follow the same procedures to reduce variation. By implementing this change, the frequency of arbitrary purchase order denials has decreased, consequently lowering waiting time for critical parts required to repair production equipment.

*Keywords:* Lean Six Sigma, Tobyhanna Army Depot, Process Improvement

## 1. Introduction and Background

Lean Six Sigma (LSS) is a process improvement methodology that integrates Lean Manufacturing and Six Sigma to eliminate waste, reduce variation, and improve process quality through data-driven analysis (Ishak, Ginting, Siregar, & Gustia, 2020). Using the Define, Measure, Analyze, Improve, Control (DMAIC) framework, LSS provides a structured and iterative approach to understanding processes, identifying root causes, and implementing sustainable improvements. The DMAIC phases ensure problems are properly scoped, baseline data is collected, root causes are validated, solutions are implemented, and controls are established to maintain long-term performance (Oladipupo, Adeyinka, & Durodola, 2023).

At Tobyhanna Army Depot (TYAD), the Department of Defense's Center of Industrial and Technical Excellence for C5ISR systems, effective maintenance of production equipment is critical to sustaining operational readiness. However, the Production Equipment Branch currently lacks a consistent preventive maintenance schedule and clear communication within the Facility Equipment Maintenance System (FEMS), resulting in increased equipment downtime. Across 53 cost centers, aging equipment, inconsistent maintenance practices, and supply constraints further degrade system reliability and production capability.

## 2. Literature Review

This project follows the Lean Six Sigma (LSS) DMAIC framework, using a set of commonly accepted tools to understand process performance, identify root causes, and implement sustainable improvements. Each phase applied specific methods that are widely supported in LSS literature for reducing variation and improving process efficiency.

### 2.1 Define Phase

The Define phase focused on structuring the problem using standard LSS tools. A SIPOC diagram was used to map the process at a high level, identifying key suppliers, inputs, process steps, outputs, and customers. This approach is commonly used in LSS to create a shared understanding of the system and highlight where issues may occur early in the process.

## 2.2 Measure Phase

The Measure phase relied on statistical and data-driven tools to establish baseline performance. Descriptive statistics and summary reports were used to understand central tendency, variation, and distribution of the process. Process capability analysis was applied to evaluate how well the process met performance expectations. These tools are standard in LSS for quantifying process behavior before attempting improvements.

## 2.3 Analyze Phase

The Analyze phase used structured tools to identify and prioritize root causes. A cause-and-effect (Fishbone) diagram was applied to organize potential contributors across categories such as methods, materials, and manpower. Failure Modes and Effects Analysis (FMEA) was then used to rank these contributors based on severity, occurrence, and detectability, producing Risk Priority Numbers (RPNs). These tools are commonly used together in LSS to move from broad problem identification to focused, high-impact root causes.

## 2.4 Improve Phase

The Improve phase focused on implementing targeted solutions based on the prioritized root causes. The primary strategy involved standardization of processes and clarification of roles to reduce variability. LSS literature emphasizes that effective improvements simplify workflows and reduce opportunities for inconsistency, which guided the development of process changes in this phase.

## 2.5 Control Phase

The Control phase applied tools to sustain improvements over time. Control charts were used to monitor process performance and detect abnormal variation. Standard operating procedures (SOPs) were developed to ensure consistency in execution, and a responsibility matrix was used to clearly define ownership of key process steps. These strategies are widely used in LSS to maintain gains and prevent regression.

# 3. Analysis

Analysis in this project was built on stakeholder input at TYAD, with a focus on personnel in the Production Equipment Branch. The project team regularly synchronized with the branch chief, work leaders, and mechanics to develop a clear understanding of the problem from multiple perspectives. In addition to stakeholder input, quantitative analysis was conducted on work order data extracted from FEMS. This data was used to identify trends and highlight problem areas within the process.

## 3.1 Stakeholder Engagement

Stakeholder engagement was crucial throughout the DMAIC process to ensure that qualitative findings and operational realities were aligned throughout all TYAD's Production Equipment Branch. On multiple visits to TYAD, the team conducted stakeholder engagement sessions both organically and pre-planned. Of the team's early engagements with stakeholders, reports pointed towards differing work order submissions and lack of documentation. These early inputs from stakeholders drove data collection variables in both the Measure and Analyze phases, all to test whether these inputs were data-backed drivers. The constant, iterative engagement with stakeholders enabled continued improvement on the project and operational feasibility in accordance with TYAD's capabilities.

## 3.2 Initial Process Measurements

As determined by stakeholder analysis in the Define Phase, surface-level process inefficiencies initially appeared as "informal" or "non-detailed" work orders. Informal work orders were defined as those not entered in FEMS through the work order desk, but rather direct requests from the shop or operator to a repairman from the Production Equipment Branch. Non-detailed work orders were those (both formal and informal) that lacked sufficient detail for Production Equipment personnel to begin repairs without first inspecting the machinery. To understand how these perceived problems quantitatively impacted the non-preventive maintenance process, the team randomly selected March 2025 to serve as the statistical baseline for the Measure Phase, as there was a low likelihood that adequate data could be collected in the allotted six-week timeframe. However, the team did arrange for Production Equipment artisans to collect data on the frequency of informal work orders over a three-week timespan from late September to mid-October. Initial analysis showed an average work order length of 20.18 days for the 94 opened in March 2025, while the data collection on informal work orders averaged to an estimate of 22.4 per month. Of the 94, three reflected no charged labor or material costs, establishing a generalized estimate that 3.2% of work orders lacked sufficient detail and required rework.

In interviews, mechanics attributed the maintenance backlog to outdated equipment, theorizing that aging equipment was responsible for a disproportionate number of asset breakdowns. The project team investigated this claim utilizing a Pareto chart (Figure 1), finding that two of the twenty most broken-down assets required markedly more maintenance than the rest. However, all twenty assets cumulatively accounted for less than 40% of total non-preventive maintenance, failing classification under the Pareto principle, in which 20 percent of observations account for 80 percent of problems (Brook, 2024). Recognizing that the issue was unlikely to be explained by a small number of assets, the team pivoted to examining the process in the aggregate. Figure 1, a statistical summary report for formal work order lengths during March 2025, provided significant insights about the distribution of work order times and aided the team in focusing their efforts in the Analyze and Improve phases.

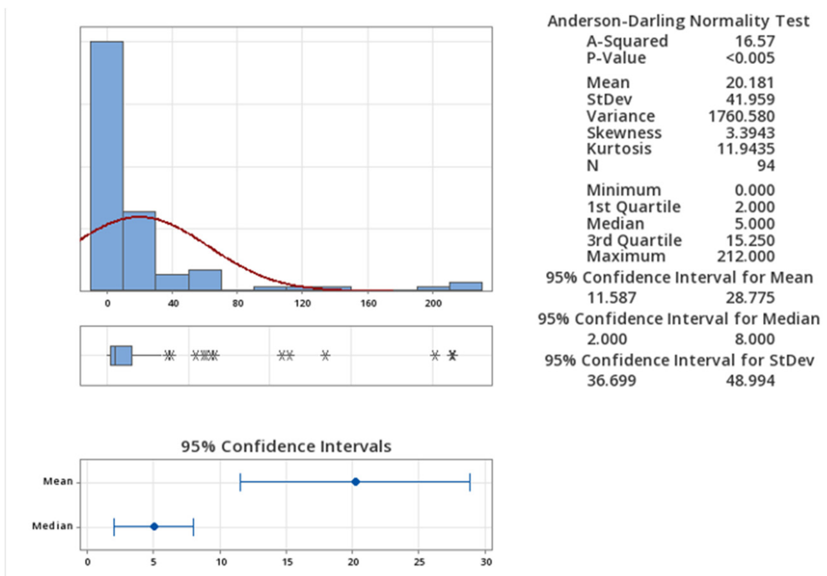


Figure 1. Distribution of Work Order Length (in Days) for March 2025

Notably, this tool allowed the team to determine that the median work order was completed in five days, which was within TYAD's ideal repair timespan of seven days. However, the mean work order took 20.181 days to close, which when considered with the histogram, indicated that a small number of long-running work orders were responsible for the large difference between the median and mean days open. Accordingly, in the Analyze Phase, the team began an investigation into the prevalence and true effect of these long-running work orders on the non-preventive maintenance process.

### 3.3 Statistical Analysis

Statistical tests typically favored by LSS (such as two-sample t-tests and ANOVA) were poorly suited for this project. Common LSS investigative methods rely on numerous assumptions, with a substantial assumption being that the data of interest follows a normal distribution (Lomuscio, 2021). Even before proceeding into the Analyze Phase, it was evident from the statistical summary (Figure 1) that data on TYAD's process was unlikely to meet validity conditions for these tests based on the right skewed histogram and the low p-value of the Anderson-Darling Normality Test, indicating that the distribution of work order lengths was unlikely to follow a normal distribution.

While the work order length data were not normally distributed, the skewness of the observations led the team to investigate whether the problem was localized or had far-reaching effects across the Depot. Accordingly, the team filtered 2025 non-preventive maintenance data down to cost centers with ten or more breakdowns reported in FY25, generating a boxplot that illustrated the lengths of work orders by cost center (Figure 2). Employing the Kruskal-Wallis test (a non-parametric alternative to ANOVA), the team determined a significant difference in the length of work order times existed between at least two cost centers. Next, utilizing Dunn's post-hoc test with a Bonferroni correction, a significant difference between cost center 5M320 and cost centers 52K90, 58360, 5L240, and 5L330 was observed.

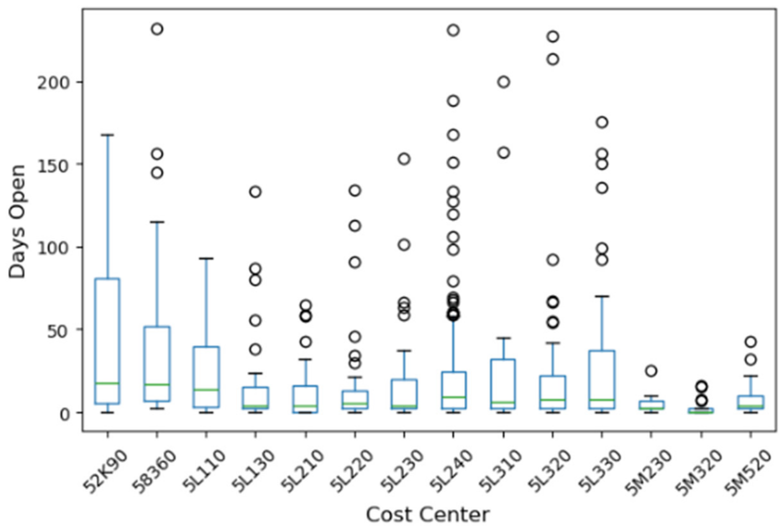

Figure 2. Boxplot of Days Open by Cost Center

The team was interested in the reasons underlying these long-running word orders, since decreasing the length or frequency of occurrence would drive the average closer time closer to TYAD's specified goal. Accordingly, the team conducted a Pareto analysis on the slowest ten percent of work orders from 2025, finding that 88% of these work orders were open for 60 or more days due to waiting on parts, were approved but awaiting action, or were awaiting approval to be actioned. These reasons served as a staging point for focused interactions with personnel from the TYAD budget office and largely aided in the identification of root causes in the Analyze phase.

## 3.4 Root Causes

Four primary root causes were identified through structured meetings, on-site visits, direct engagement with work leaders and artisans, and the Fishbone analysis conducted during the Analyze phase at Tobyhanna Army Depot (TYAD): parts availability delays, insufficient space for parts storage, limited workspace layout, and communication breakdowns. Parts availability delays were consistently raised during working sessions. The artisans and work leaders explained that the required components are not received promptly, leaving equipment down while waiting for materials. This directly extends maintenance cycle times and increases overall downtime. Insufficient space for parts storage was identified as a separate facility constraint. Artisans reported lacking designated and organized storage areas, resulting in parts and equipment being placed in multiple temporary locations. This increases search time, creates congestion, and slows repair execution.

Limited workspace layout was validated through both discussion and a visual map presented by work leaders showing how their team is dispersed across the depot. The physical spread and constrained workspaces increase travel time, complicate coordination, and reduce workflow efficiency. Communication breakdowns were identified during stakeholder engagement. Terminology varies across levels of the chain of command, and established reporting channels are not always followed. These inconsistencies create confusion in work order updates and delay coordination within FEMS.

## 3.5 Pilot Plan and In-Progress Handover

Identifying communication breakdowns within the Government Purchase Card (GPC) process as a primary root cause, the pilot focused on reducing delays caused by purchase order rework and denials. Initial feedback from the branch chief and work leaders suggested that GPC purchasing was ineffective due to frequent denials; however, further analysis revealed that these denials were primarily due to incomplete or incorrectly submitted requests rather than the GPC system itself. Additionally, inconsistencies in guidance from billing officials led to variation in how cardholders evaluated requests, meaning identical purchase orders could be approved or denied depending on the reviewer.

To address this, the team implemented two key changes: (1) standardization of the GPC request process through a locally developed SOP that clearly defined required information and submission steps, and (2) centralization of purchasing by assigning a primary and alternate GPC cardholder dedicated to the Production Equipment Branch. This reduced variation in decision-making, improved communication between work leaders, cardholders, and billing officials, and ensured consistent application of requirements.

Success was measured by comparing pre- and post-pilot performance using key metrics, including GPC pushback rates, work order duration relative to the upper specification limit (USL), and overall process variation (standard deviation). Baseline data showed that nearly 100% of GPC requests experienced pushback or rework. During the pilot, only 1 out of 13 requests was returned, representing a significant reduction in rework and indicating improved first-pass quality. Additional expected outcomes include a reduction in average work order duration, a higher percentage of work orders completed within the USL, and decreased variability in processing times.

These early indicators demonstrate that the pilot is effectively reducing process inefficiencies by targeting variation at its source. The improvements are currently being transitioned to the Control Phase, where performance will be continuously monitored and ownership will be formally transferred to sustain gains and ensure long-term process stability.

## 4. Results & Conclusion

Analysis of non-preventive maintenance work order (WO) data revealed that the primary driver of poor performance was not average completion time, but unmanaged variation within the process. While the median WO duration was five days, the mean of 20.18 days indicated a heavily right-skewed distribution, where a small subset of long-running work orders disproportionately increased overall cycle time. This reframed the problem: rather than a system-wide inefficiency caused by aging equipment, the core issue was inconsistency and breakdowns in coordination across the workflow. Further analysis showed that 88% of the slowest 10% of work orders were linked to three delay categories—waiting on parts, approval delays, and work orders awaiting action. This finding significantly shifted the team's understanding of the problem from a hardware-focused issue to a process and communication failure. Pareto analysis reinforced this conclusion, demonstrating that the most frequently failing assets were not the primary contributors to downtime. Additionally, cost center comparisons identified statistically significant differences in WO durations, confirming that delays were unevenly distributed and driven by localized practices rather than systemic constraints.

The primary finding of this analysis was that maintenance delays were not driven by the personnel executing the work, as initially assumed, but by inefficiencies in the parts procurement process, specifically within the Government Purchase Card (GPC) workflow. Process mapping and data analysis revealed that inconsistent requirements from different billing officials led to frequent delays, rework, and approval "kickbacks," significantly extending work order timelines. Further examination showed that one GPC holder consistently operated with a more efficient and streamlined process, which became the basis for standardization. By centralizing this approach into a local SOP applied across all cardholders, the team reduced variability, minimized pushbacks, and improved overall process efficiency. These findings are significant beyond the DMAIC framework, as they demonstrate that performance issues in maintenance operations are often rooted in process variability and unclear standardization rather than workforce capability or equipment limitations, reinforcing the need for consistent procedures, accountability, and coordination in complex operational environments like TYAD.

The Improve Phase translated these insights into targeted interventions aimed at reducing variation at its source. One key solution was the development of a local Government Purchase Card (GPC) Standard Operating Procedure (SOP). Previously, inconsistent guidance from different billing officials led to conflicting requirements among GPC holders, creating delays and rework. The standardized SOP aligned expectations across stakeholders and reduced approval-related pushback by approximately 98%. Additionally, the number of GPC cardholders was reduced to streamline procurement authority and minimize process variability.

Another major improvement was identified through on-site observation of physical and organizational fragmentation across the depot. During walkthroughs with the Production Equipment Branch, it became clear that personnel, equipment, and repair parts were dispersed across multiple buildings, requiring excessive time to locate and transport materials. This issue was compounded by inconsistent procurement and delivery practices, as parts were shipped to different locations depending on the GPC holder or vendor, with no centralized drop-off point. Recognizing this as a key contributor to delays, the team coordinated with the space layout manager and branch personnel to map current locations and assess consolidation options. This effort led to the selection of Building 92 as a centralized workspace and designated delivery point. The consolidation reduced time spent searching for parts, minimized unnecessary movement, and improved coordination, directly addressing a major source of process variation and delay.

Looking forward, the Control Phase will focus on sustaining these improvements through performance monitoring, standard work enforcement, and process ownership transfer. Key metrics will include updated mean and median WO duration, variance reduction compared to baseline, process capability ($C_{npk}$), and the percentage reduction in long-running work orders. Continued tracking of delay categories will ensure that improvements remain targeted and effective. Broader implications of this effort extend to other depot-level and Army maintenance operations. The findings demonstrate that addressing process variability, standardizing decision-making, and improving spatial and organizational alignment can significantly enhance operational efficiency without requiring major capital investment. This framework can be replicated in similar environments where decentralized practices and unclear ownership contribute to performance gaps.

In summary, this Lean Six Sigma effort established that maintenance challenges at TYAD were fundamentally driven by process inconsistency and coordination failures rather than equipment limitations. By shifting the focus to variation reduction and implementing targeted, high-impact solutions, the project provides a scalable model for improving maintenance performance across comparable systems.

## 5. References

Antony, J. (2006, March). Six Sigma for service processes. *Business Project Management Journal, 12*, 234-248. Retrieved from ResearchGate: https://www.researchgate.net/publication/243461561_Six_Sigma_for_service_processes

Brook, Q. (2024). *Lean Six Sigma & Minitab: The complete toolbox guide for business improvement.* OPEX Resources Ltd.

Gaur, J. (2009, November). *The state of Six-Sigma in service processes: A literature review*. Retrieved from ResearchGate: https://www.researchgate.net/publication/228271046_The_State_of_Six-Sigma_in_Service_Processes_A_Literature_Review

Ishak, A., Ginting, R., Siregar, K., & Gustia, D. (2020, December). A systematic literature review of Lean Six Sigma. *IOP Conference Series Materials Science and Engineering*, 1-9.

Li, N., Ely, S., & Laux, C. (2017, May). *How to use Lean Six Sigma to improve service processes in higher education: A case study*. Retrieved from ResearchGate: https://www.researchgate.net/publication/319285262_How_to_Use_Lean_Six_Sigma_to_Improve_Service_Processes_in_Higher_Education_A_Case_Study

Lomuscio, S. (2021, December 7). *Getting started with the Kruskal-Wallis test*. Retrieved from University of Virginia Library: https://library.virginia.edu/data/articles/getting-started-with-the-kruskal-wallis-test

Oladipupo, O., Adeyinka, A. M., & Durodola, O. I. (2023, November-December). Exploring Lean Six Sigma: A comprehensive review of methodology and its role in business improvement. *International Journal of Multidisciplinary Research and Growth Evaluation, 4*(6), 939-947.

Sony, M., Naik, S., & Antony, J. (2020, January 29). Lean Six Sigma and social performance: A review and synthesis of current evidence. *Quality Management Journal, 27*(1), 21-36. Retrieved from ASQ: https://asq.org/quality-resources/articles/lean-six-sigma-and-social-performance-a-review-and-synthesis-of-current-evidence?id=010afb144a254afe9666f9c1ffce2246&srsltid=AfmBOoogbNTipI2aGNN3HUKJbgqWUzxRKIWFwomnNmFOkf705V9rLwOz

Viswanathan, V., Suresh, M., & Aramvalarthan, S. (2016, September). *Lean in service industries: A literature review.* Retrieved from ResearchGate: https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1108%2F14637150610657558?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19