Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
May 2, 2019
A Regional Conference of the Society for Industrial and Systems Engineering

Lean Six Sigma Capstone – APN-209

Francis Dwornicki, Ian Mansfield, Seamus McDonald, John O'Malley, Kathryn Silecchia, and James Enos

Department of Systems Engineering
United States Military Academy, West Point, NY

Corresponding author: francis.dwornicki@westpoint.edu

Authors Note: We would like to thank our partners at Tobyhanna Army Depot for assistance with this project.

Abstract: This article outlines the Lean Six Sigma methodology and our application for improving the altimeter repair line at Tobyhanna Army Depot. We describe the methodology and detail the individual steps in the DMAIC process and tools used by our team. This is followed by a detailed review of the application of the methodology in the altimeter repair line. Our team defined the goals for improvement and established a robust understanding of the repair process. Following these steps, the group collected data on the repair line and conducted statistical analysis to identify the primary areas of waste. We developed improvement recommendations from these areas of waste and controlled the process to determine the effectiveness of our recommendations. Our work is concluded with a work assessment and considerations for follow-on work in the future.

Keywords: Lean Six Sigma, Lean Processes, Six Sigma

1. Introduction

The first concept of Lean Six Sigma (LSS) is lean process. Lean processes give customers what they want—and only what they want—for what they are willing to pay. The second concept—Six Sigma—uses data to ensure that there are fewer variations in products. This means that numbers and statistics are used to optimize processes and decisions. The two concepts can be combined via their enemies: lean's enemy is waste (time, material, labor, etc.), and six sigma's enemy is variation (reliability) (Sahay, 2015). LSS will continue to grow together and evolve together over the next several decades, as its history together started merely 30 years ago (Antony, 2017). The five steps to Lean Six Sigma are define, measure, analyze, improve, and control (DMAIC). In the define phase, the process is identified, goals are set, and the project is outlined. In the measure phase, data is gathered about the steps in the system that are under review. That data is used to test hypothesis about possible wastes, variation, and reliability during the analyze phase. Improving the process includes potentially eliminating steps and rearranging tasks, among others, to fix the issues identified in the analyze phase. The control phase returns the project to the owners of the system and points them in the right direction to capitalize on the improvements.

The Lean Six Sigma project is in partnership with Tobyhanna Army Depot (TYAD). Tobyhanna is a recognized leader in providing world-class logistics support for Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Systems across the Department of Defense. Tobyhanna has the sole rights to create and modify some C4ISR systems. Tobyhanna also provides maintenance on systems ranging from radios to aircraft systems. Cadets from the United States Military Academy at West Point are working with a small team Tobyhanna Army Depot that repair altimeters, specifically different variants of the APN-209. Altimeters allow helicopter pilots to know their altitude and need to be able to withstand large temperature ranges, physical damage from anything in the cabin, and remain fogless under varying levels of humidity and air pressure. The APN-209s either have a single unit composed of electrical, mechanical, and software parts, or two units with these components split between a slave unit and a base altimeter that receives and displays data. There are various ways that an APN-209 can break or malfunction. The units come in for repair from either new work orders, routine maintenance, or warrantees. On the repair team, there are approximately thirty workers consisting of work leaders, engineers, and inspectors. The ongoing issue of overrun was first noted in 2017 when new leadership came to Tobyhanna and realized that the numbers for labor hours were erroneously reported. Since then, the laborers and work leaders on the APN-209 line have reported overrun costing the company an extra 1.25 million dollars per fiscal year. TYAD contacted the Department of Systems Engineering for a capstone group of cadets trained in LSS.

This paper begins with an overview and literature review of the Lean Six Sigma process. Each step of the DMAIC process is outlined and explained. After the overview, the process is explained in terms of each cadet's phase as applied at TYAD.

2. The Process

DMAIC is a five-step method used within Lean Six Sigma to drive data driven improvement (Brook, 2017). The DMAIC cycle is used for improving, optimizing, and stabilizing processes. The DMAIC process is the framework that lean six sigma projects use to make sure the problem is solved. Each of the five phases uses different tools that focus heavily on data driven analysis and systematic problem solving. While this mentality has not been implemented on a wide-spread scale, it is growing and becoming more popular (Devane, 2004).

2.1 Define Phase

Every Lean Six Sigma project begins with the define phase. This step in the DMAIC methodology is where the problem is identified, and goals/desired end state are established for the project. This step links the problem to the customer through a value-based approach where tools such as process maps and Voice of the Customer (VOC) are utilized to shape to the path for follow on phases. When the Define phase is complete, the team should have a clear understanding of the process to be improved, how it affects the customer, what the goals are, and what metrics will be used to measure successful achievement of said goals (George, Maxey, Price, Rowlands, 2005).

2.2 Measure Phase

The measure phase moves the project from qualitative definition to quantitative measurements. It begins by developing process measures or learning how to measure the problem. This portion contains creation of definitions and measurements that will be gathered from the process. The next step is to collect process data. This means outlining data collection methods and creating data collection plans along with creating a plan for sampling the data. The next step is to check the data quality. Data quality refers to the usability of the data. Examples of quality are whether the data is continuous, discrete, or attribute. This phase also considers whether the data is measured in the correct way. Another example is the resolution of the data. Resolution means how small or large the data is to show changes. The next step is to understand the process behavior. This shows whether the process is stable over time, and whether the data from the findings are normal and if so, what are the distributions of the data. The process behavior is the first step in the statistical analysis necessary for the analyze phase and the rest of the project. The final step is the baseline process capability and potential. This is the test to see if the process currently fits specifications and finds the sigma level of the current project.

2.3 Analyze Phase

The analyze phase is key to supporting the overall Lean Six Sigma project. The first part is mapping and understanding the data gathered during the measure phase using a detailed process map. This map lists every step in a process and is color coded for clarity. Green portions are ‘value added’ to the customer, yellow is ‘non-value added required’, and red is ‘non-value added.’ Generally, the red steps are highlighted and investigated first. Reducing waste, instability, non-value-added work, and cycle time of the hiring process is key to ensuring success in a Lean Six Sigma project (Drohomeretski, 2014).

The second part of analyzing a process is creating theories for why a system is not meeting its goals. Fishbone diagrams split an effect into causal factors: man, machine, method, materials, and mother nature. After the factors causing the effect are listed, a FMEA chart is made to measure the likelihood and impact of failure. A cause and effect matrix can also be created to see how and where factors can fail.

The final part of analyzing the process revolves around statistical tests to highlight and prove the importance of certain factors and discrepancies. For a comparison of normal data, generally a two-sample t-test can be used. If fit is not normal, either data transformations or non-parametric tests or are appropriate (Brook, 2017). These tests can include the Mood’s Median Test or the Kruskal-Wallis Test.

2.4 Improve Phase

Identifying wasteful and value-adding activities using a value stream map (VSM) and then eliminating waste is a decisive part of the Improve Phase (Rosa and Broday, 2018). These methods significantly improve efficiency and reduce cost. Control charts and FMEAs are particularly useful to the Improve Phase because they identify opportunities for reducing process variability (Christopher & Lee, 2004). The activities through the Improve Phase can be tailored to meet organizational requirements, which is essential to account for the variation in structure and robustness of the given process. The most important activities through the Improve Phase are developing potential solutions for the prioritized root causes, developing evaluation criteria and selecting solutions, evaluating solutions for risk, optimizing solutions, developing a vision of the future state, developing an implementation plan, and piloting the best solutions. Successful Lean Six Sigma processes can implement many of these activities using a variety of tools, including brainstorming, process flow improvement, process balancing, design of experiments (DoE), "to-be" process mapping, and solution selection matrices.

One of the most difficult aspects of implementing the Improve Phase is generating buy-in from employees. Employees may have to get out of their comfort zone and change their habitual work methods. After the Analyze Phase helps identify wasteful activities, the Improve Phase shifts toward implementing or changing standard operating procedures, new support structures, continuity challenges, and scope conflicts. Support from the organization's top leadership is critical for success. Successful organizations need to be deliberate about evaluating value-adding and non-value adding activities to truly optimize their process.

2.5 Control Phase

The control phase is the final step of the DMAIC process. Completing this phase is crucial in ensuring that the work from the previous phases are implemented correctly. Even more importantly, the control phase ensures that the new process standard is sustainable and measurable. The most important activities of the control phase consist of developing Standard Operating Procedures (SOP), training plans, and process controls. Additional activities important to this phase include: implementing solution and ongoing process measurements, developing a final cost estimate, completing the control gate, and transitioning the project to the process owners. During the control phase, analytical tools such as control charts and Statistical Process Control (SPC) are used to ensure the process is monitored and maintained. Equally as important is addressing the worker element of the process which requires training plans, SOP, visual process control tools, and team feedback sessions.

3. Application of the Process at Tobyhanna Army Depot

This portion of the paper describes the methods and tools used to improve the APN-209 process at Tobyhanna Army Depot. It describes the define, measure, analyze, and improve phases of the DMAIC process. Each sub-section describes the application of the LSS methodology to the repair line at Tobyhanna and presents highlights from each phase.

3.1 Define the APN-209 Process

The define phase for the altimeter project included identifying process factors, developing an understanding of the altimeter repair process, and identifying a metric for success. Working with the Airborne Indicators Branch at Tobyhanna Army Depot, the cadet team identified overruns in time and cost as the primary source of systematic waste which identified time and cost as our factors for improvement. This step would help align the focus for the follow-on phases. This step was followed by developing a "High Level Process Map" which focused on identifying the general steps within the process of APN-209 repair and compiling them into a visual summary map to promote a shared understanding within the team. The cadet team needed to consider not only the process itself, but also the input and output factors to the process as limiting factors. Lastly, the team met with Tobyhanna to establish goals for the project. Cost Performance Index (CPI) was established as the metric of success, which represents the time allotted for a repair compared to the actual time used to perform a repair. The equation for CPI is below:

$$CPI = \frac{Time\ alloted\ for\ task}{Time\ used\ for\ task} \quad (1)$$

The current state of the APN-209 repair process was at a CPI of .67, and the ending goal for the project was to be at a CPI of .869. This improvement would translate to a cost savings for Tobyhanna of approximately $1.25 million.

3.2 Measure the Problem

During the measure phase, the cadet team identified all the steps of the process and saw them in person to create operational definitions. The cadets generated a data collection sheet to track information that was absent from TYAD's preexisting data collections. This sheet had all the necessary items for a proper data collection plan, so at the end of the phase there would be enough information to sample the data and have enough statistical basis to use in the analyze phase. The new sheet overlapped into the 'check the data quality' portion of the measure phase.

The new data collection sheet had a much higher resolution than previous data sheets, allowing for better determination of significance in the data. Additionally, it changed the time from being collected in a binary measure (did they meet the specifications in time) to how much time was spent on the project itself. Prior to this, TYAD measured project overrun by the amount of labor hours put into a work order that had multiple APN-209s broken down by worker and shift. They took the total labor hours of all the workers dedicated to the work order and divided it by how many objectives were completed. This is a good collection plan for a high-level measurement of cell efficiency but had no statistical significance. Instead, the data was inputted into Minitab and tested for normality and distributions. The team found that the samplings were normal and found the step accounting for 97% of overrun was the first step of the repair process. The variance in the data was so large that the standard amount of time was 8 hours, but some of these processes would be completed in upward of 20 labor hours. The next step was to conduct a baseline process capability and potential. The team found that the CPI was at .67, far from the end goal of .869. The current process did not fit the specifications and had a high count of defects in the process. This set up the analyze phase to find out exactly why the first process step took so long and accounted for nearly all the overrun.

3.3 Analyze Root Causes

During the analyze phase for the altimeter project, the primary tool used to understand the process of repairing the APN-209s was a detailed process map. While earlier phases used value stream mapping and baseline summary reports, the detailed process map allowed the team to further explore the minute steps of disassembling, repairing, testing, and assembling the assets. To create theories about the root causes of overruns in the repair process, a fishbone diagram was created with the project sponsors. The team then created three potential causes of overruns: individual workers not following standard procedures, assets beyond economical repair (BER) have a significant effect on the cost performance index (CPI, target is 1, less than 1 is undesirable), and repairing cards within the altimeters caused a significant impact on the CPI. Figure 2 shows this as a boxplot and demonstrates the bi-modal aspect of declaring an item BER.

A Chi-Square test, along with a Kruskal-Wallis test, was conducted to test the hypothesis that repairing the computer chips within the altimeters caused a significant impact on the CPI. The null hypothesis stated that there was no significant impact on CPI when fixing the computer chip, while the alternative hypothesis was the opposite. Based upon the statistical results, the null hypothesis was rejected. The next test was to prove that workers were not following the standards set out by the organization. A Mood's Median Test, along with a visual analysis of boxplots, allowed the team to prove that the workers did not follow the operating procedures. Figure 2 shows a boxplot of the variety of CPI by worker. Some workers, such as worker 5, have wide variations.

Finally, another Chi-Squared test, along with a two-sample t-test, came to a similar statistical result that assets that are designated BER are causing a significant impact on CPI, and further analysis proved that the asset was being declared BER either very early on or very late in the repair process. This analysis shows that better criteria is needed to determine when an asset should be declared BER. Using these statistical analyses, the team can suggest improvements to the project sponsors

3.4 Improve the Process

The key to successfully improving the APN-209 repair process is creating a vision and ensuring that there is buy-in across the organization. Organizational structure and information availability at the technician level often act as communication barriers. TYAD is focused on improving employee buy-in to help standardize the repair process and decrease variability.

After analyzing the data and evaluating the FMEA, it was clear that there were serious concerns about standard operating procedures for assets deemed BER. Additionally, the team was concerned that a significant amount of overrun occurred when circuit card assembly (CCA) repair was required. The team also established a few minor improvements while generating ideas.

The process improvement team evaluated technician recommendations during a brainstorming session. Many of these improvements addressed some of the root causes shown in the FMEA. One of the most significant recommendations was establishing "golden units" for all APN-209 NSNs (9090, 9091, 9093, and 9094 assets that are in ideal condition) to save time during overhaul and directly address issues with CCA repairs. In addition to addressing the need for 'golden units', it was clear that improving training on automated machines, allowing more technicians access to The Army Maintenance Management System (TAMMS), and improving the troubleshooting guide would help address the most significant source of overrun by decreasing overhaul time.

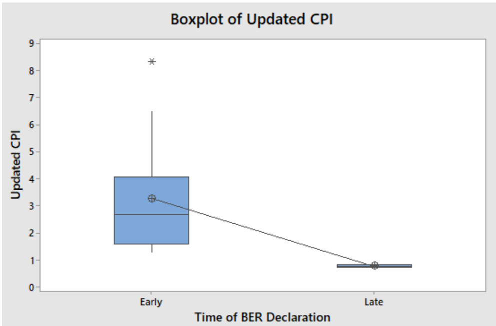

Figure 1. Boxplot of BER Items

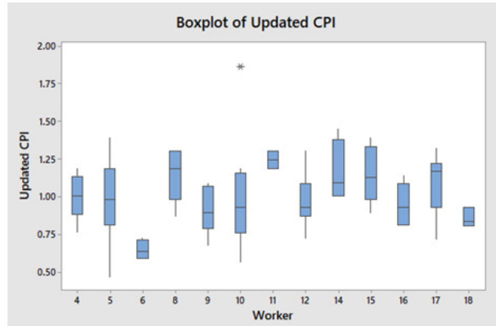

Figure 2. Boxplot of Individual Workers

Since one of the most significant sources of overrun is process variability and BER standards, the cadets assisted in drawing a detailed 'current state' process map shown in Figure 3.

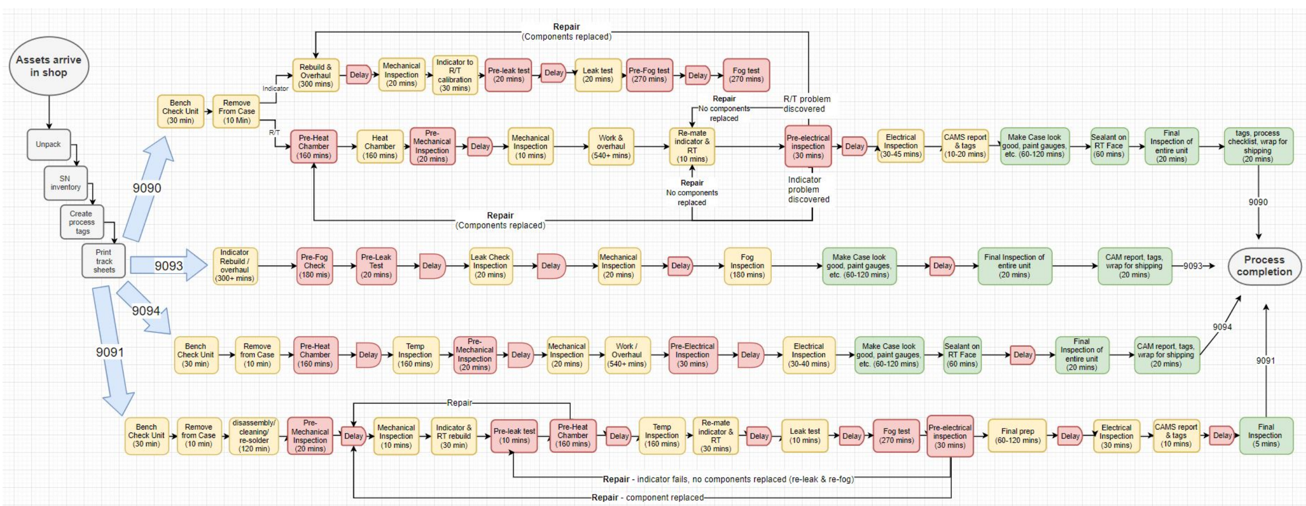

Figure 3. Detailed Process Map

To decrease process variability and eliminate waste, cadets assisted in developing a 'to-be' process map to enforce consistency in asset repair work. The new standardized process is currently under evaluation at TYAD. To attack BER variability, cadets made recommendations for 'escalation criteria.' Based on the amount of allocated time for overhaul steps, workers are required to report issues to work leaders and then the engineer if their work is incomplete at certain times.

4. Conclusion

As a preface, the improve phase of the process is incomplete and the control plan is running concurrently in its infancy. Given this, here is a summary outlining what the team expects to implement during the control phase based off the work done in the previous phases and the current state of the APN-209 line: First, the cadet team will ensure that the processes within the APN-209 line can be measured after the project is done. To do this we will ensure there will be statistical process control features embedded into the line. The main tool the team will use is the control chart (SQC, 2018). Second, the cadet team will ensure that the solutions and process are standardized. We will refine the current SOP on the APN-209 line. For example, one of the largest issues the team identified is that employees are spending too much time working on altimeters only to determine that they are beyond economical repair (BER). There needs to be an addition to the SOP that outlines the maximum time an employee can work on a repair before signaling help from an engineer or determining it BER. This lack of standardization is leading to large overruns and increased cost for Tobyhanna. In addition to refining the current SOP, the team needs to focus on making sure the SOP can be enforced. This is arguably more important than incorporating new guidelines into the SOP. For the APN-209 line to maintain the changes made by this project, the workers need to be trained and educated on the new processes. This is going to require a training plan that relies on the managers at Tobyhanna. For continual quality improvement it is important that the leadership at Tobyhanna has goals for the process even after the project is done (Daniel, 1994). In addition to the leadership at Tobyhanna driving this accountability, visual management tools will make the standardization easy and simple across all stages of the line. Examples include graphs, tables, and visual guides on the APN-209 line. This is something companies built around quality management do. This practice is commonplace in foreign companies, specifically Japanese industries (Ahmad, 2014). The standardization process will be readily available and accessible for all employees.

5. References

Ahmad, M. F., Zakuan, N., Jusoh, A., Yusof, S. M., Takala, J., & Arif, M. S. M. (2014). Comparative study of TQM practices between Japanese and non-Japanese companies: Proposed conceptual framework. In *Advanced Materials Research* (Vol. 903, pp. 371-377). Trans Tech Publications.

Antony, J., Snee, R., & Hoerl, R. (2017). Lean Six Sigma: yesterday, today and tomorrow. *International Journal of Quality & Reliability Management*, *34*(7), 1073.

Brook, Quentin. (2017). *Lean Six Sigma & Minitab*. Opex Resources Ltd.

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International journal of physical distribution & logistics management, 34*(5), 388-396.

Daniel, S. J., & Reitsperger, W. D. (1994). Strategic control systems for quality: An empirical comparison of the Japanese and U.S. electronics industry. *Journal of International Business Studies, 25*(2), 275. Retrieved from: https://search.proquest.com/docview/197154920?accountid=1513.

Devane, T. (2004). *Integrating Lean Six Sigma and High-Performance Organizations: Leading the Charge Toward Dramatic, Rapid, and Sustainable Improvement*. San Francisco: Pfeiffer.

Drohomeretski, E., Gouvea da Costa, S. E., Pinheiro de Lima, E., & Garbuio, P. A. da R. (2014). Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. *International Journal of Production Research*, *52*(3), 804–824.

George, M., Maxey, J., Price, M., Rowlands, D. (2005). *Lean Six Sigma Pocket Toolbook*. New York: McGraw Hill Professional. 4-7.

Rosa, Ana Carolina Martins & Broday, Evandro Eduardo. (2018). Comparative Analysis between the Industrial and Service Sectors: A Literature Review of the Improvements Obtained through the Application of Lean Six Sigma. *International Journal for Quality Research, 12*(1), pp 227-252.

Sahay, P. (2015). Lean Six Sigma tools in the hiring process. *Strategic HR Review*, *14*(1/2), 22-29.

SQC Online. (n.d.). Retrieved March 6, 2019, from: https://www.sqconline.com/about-control-charts.