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A Case Study of Lean Implementation at Sandia National Laboratories

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Abstract

Z Pulsed Power Facility of Sandia National Laboratories is facing many challenges with limited funding. The facility is expected to increase the number of experiments completed per year, while maintaining high quality of data output, with fewer resources available than in prior years. Consequently, Lean Six Sigma methodology was applied to analyze the current situation, define a future state, and generate detailed steps to be followed in order to reach these improvements. This paper focuses on two separate dimensions of potential improvements in R&D laboratories: Effectiveness of the operations and Efficiency of the system. A 3-stage improvement approach was implemented. Stage 1 focuses on effectiveness with an emphasis on stability, which standardizes operations in every department that interacts with the facility. Stage 2 focuses on the efficiency of the system. Once tasks are standardized, the value stream can be improved by analyzing the critical path of the process and sorting out non value-added activities based on customers' perspective. Lastly, Stage 3 is to progress in both dimensions, by continuously improving standard work procedures and the flow of value stream. The result is an improved R&D facility that is flexible enough for job variations within the standardized framework.

Keywords
Lean Six Sigma methodology, scientific R&D laboratory, process stability

1. Introduction
Limited budget and resources have been a common problem for many organizations, including research and development (R&D) areas. This paper presents a case study of lean implementation in scientific R&D environment in a national laboratory. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. The Z Pulsed Power Facility (Z Facility) is the largest pulsed power facility and x-ray generator in the world. The Z Facility is able to generate an electrical pulse of 26 million Amperes with an electrical power of 100 trillion Watts enables it to produce intense magnetic fields far higher than any other device on earth.

Similar to many companies worldwide, the Z Facility is being challenged to reduce its expenses while increasing its productivity. The facility must reduce costs while maintaining/improving the same data generating rates/quality. There are many ways to increase the number of experiments completed per year. As a first thought, most of the jobs are completed by qualified employees, so the easiest way would be to increase the number of personnel per department in order to perform the tasks faster. However the need to reduce expenses makes this option not desirable. An appropriate method of increasing the number of experiments completed per year with less of a cost impact would be to implement lean principles.

1.1 Research Objectives

The purposes of this research are summarized as follows:

- The main goal is to apply "Lean" concepts in a "Scientist R&D" environment to improve the effectiveness and efficiency of the operations.
- For effectiveness, the emphasis is on stabilization to ensure that the current operations are done in a correct way. The mission is to develop several flexible and efficient standard work sheets for every department, specifying the tasks with visual aids for better understanding, time required to finish every job, critical areas, and quality inspection. The purpose of these worksheets is to standardize the work and identify jobs that change every day so that they can be analyzed differently.
- For efficiency, the emphasis is on identifying opportunities for continuous improvement. The mission is to map the process of a regular day at the Z facility, using lean tools such as value stream mapping (VSM) and critical path method (CPM) in order to aid management to better understand the processes and to identify improvements.

2. Literature Review

Since the final goal of this paper is to facilitate an efficient, flexible, and stabilized process, lean manufacturing was a concept that is most suitable. Womack and Jones [1] identify five lean principles, focusing on value, to aid in the transition of traditional organizations to lean organizations. These principles are specifying customer value, identifying the value stream, making value flow without interruptions, letting the customer pull value, and pursuing perfection. The role of lean tools is to make problems visible, enable people to solve them, and capture what is learned throughout the organization [2]. The first step is to establish standards for stability of the process. Standardization facilitates problem solving by providing a standard against which to compare the actual situation, thereby highlighting problems [3].

Once the process is stable through the standardization of the work, value stream mapping will play a role to identify opportunities for improvement that can enable value to flow and be pulled by the customer [4]. Mapping of the current state identifies the current processes, highlights waste and opportunities for improvement, engages the whole group in seeing the waste, and provides a foundation for improvements [5]. Stability and flexibility in processes within the value stream are critical factors in achieving the vision of being lean. Mapping processes can reveal where to make changes, keeping in mind that the future state map will remain a dream if no work is put into making it a reality [6]. This has often resulted in implementation of technical lean tools achieving initial gains that were not continuously improved upon or sustained [7]. In order to transform to a lean culture, there needs to be a deeper understanding of lean principles beyond eliminating waste.

For successful and sustainable lean implementation, lean manufacturing principles aims to create a culture of continuous improvement achieved through teaching, coaching, and enabling people to solve problems [8]. Problems are identified as the gap between actual conditions and the standard. Therefore, this paper presents a theoretical model to address two dimensions of lean, i.e., effectiveness and efficiency, for lean implementation in research and development laboratories. The approach is described in the methodology section.

3. Methodology

In this research, a system improvement approach has been proposed, which focuses on two separate dimensions of potential improvements in R&D laboratories: *Effectiveness* of the operations and *Efficiency* of the system. In order to identify and achieve potential improvements, a three-stage implementation approach of Lean and Six Sigma has been developed, as shown in Figure 1.

3.1. Stage 1, Effectiveness of the Operation

Stage 1 focuses on improving the effectiveness of the operations by the implementing standardized work. In R&D environment, various protocols and rules exist, but standardization is not a common practice, which leads to lack of stability in performance. Standardized tasks are the foundation for continuous improvements and employee empowerment. Standard work sheets and the information contained in them are important elements of Lean implementation. As Imai [9] explained in his book *Kaizen*, it is impossible to improve any process until it is standardized. When the baseline standard is achieved on a consistent basis, more advanced standard will be established gradually, resulting in continuous improvement of the organization [10]. One must standardize, and thus

stabilize the process, before continuous improvements can be made. In this particular environment, stabilization would allow workers to focus their efforts on doing their work and knowing the time needed to develop every job.

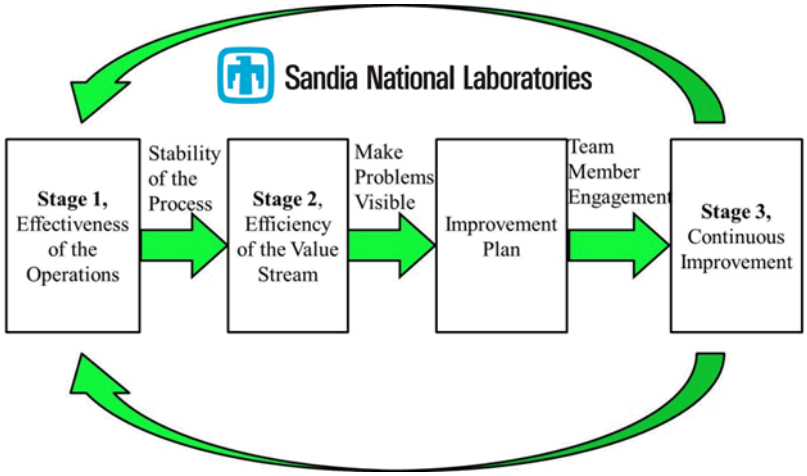

Figure 1: Diagram Flow for Lean Implementation at R&D Laboratories

3.1.1 Process Description

After two months analyzing the Z process, the project team identified the critical path of the process, depicted in Figure 2. The critical path was defined through the gathering of time-based information from 20 days of experiments, and the time described in every task in Figure 2 is an average of this data gathered. We identified those tasks that really affected the process. As it was explained before, there are several activities performed in parallel, by different departments at the Z facility. By applying the critical path method technique we were able to identify these activities that falls into the critical path that determines the time to perform an experiment.

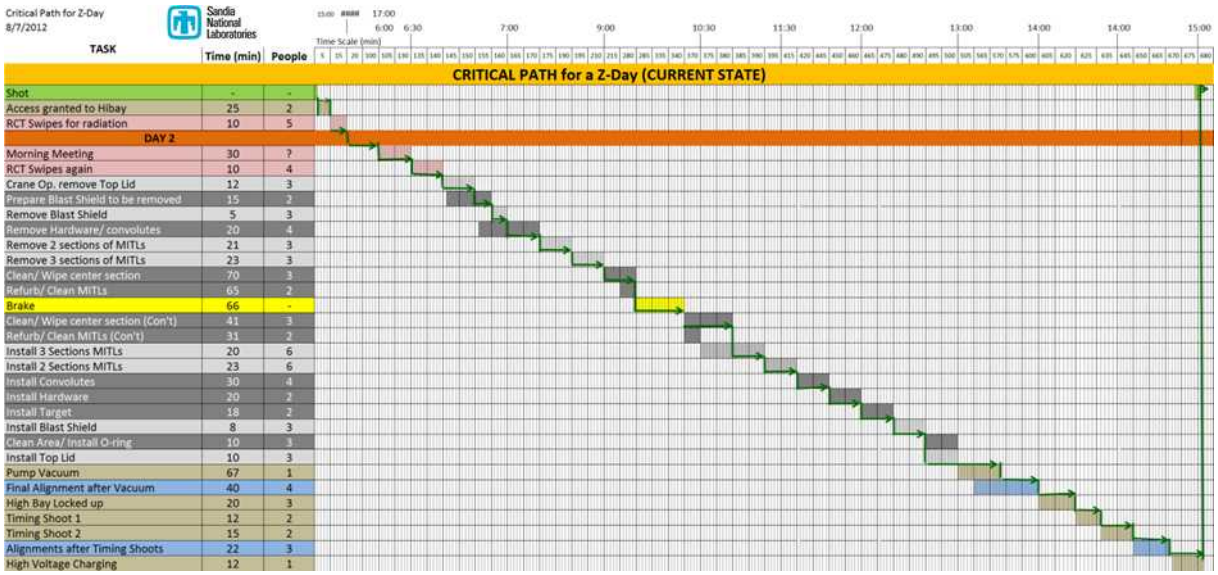

Figure 2: Process description of the Z facility

On a regular day, after the shot (i.e. an experiment) takes place, Control Monitor department analyzes the data collected from the diagnostics fielded on the shot, and the Radiation Protection (RP) makes sure there are no radiological hazards inside the high bay. Once assured that there are no radiological concerns, access to the high bay

for other personnel is allowed. Each department will then begin its post-shot inspections, which consist of following a checklist to identify potential hazards or post-shot damage to equipment.

Usually the experiment takes place around 15:30 hours MDT, allowing for the post-shot inspections the same day. Therefore, first thing next morning, machine reconfiguration, maintenance where needed, and MITLs and insulator stack refurbishment are completed. After ESS/ PFS sections finish their inspections/reconfiguration, the water and oil tanks are refilled, and the center section team loads the convolutes/hardware and the experiment's target. After completing these tasks, Center Section coordinates with the diagnosticians to align the diagnostics for the shot. In the meantime, Control Monitor department coordinates all the timing for the shot.

Once everything is setup according to the experiment specifications, a blast shield is installed on top of the hardware, and the top and bottom lid are placed so the vacuum system can be pumped down. Pumping down the center stack takes about 60-80 minutes depending on the vacuum needed for the experiment. After vacuum is achieved, Control Monitor department will perform at least two "timing shots", which consist of testing the different diagnostics in order to ensure they will work properly on the experiment. ESS/ PFS departments perform a pre-shot checklist, which includes locking up the high bay, which consist into ensure no one is in the high bay (workstation) when the shoot takes place. Finally, when everything is ready for the experiment (vacuum achieved, diagnostics aligned, high bay locked up), high voltage is charged on the Marxes, and the shot takes place.

3.1.2 Stabilization of the Process

Stabilization is an essential piece to the implementation of lean tools in any environment and to standardize the process. The work done at the Z facility is performed by well trained and experienced personnel that have been working on the machine for several years. The personnel do not follow any standards, in terms of process workflow. They do have standards and procedures regarding the specifications of the machine, but not for the time required to perform each task.

The first step to implement lean tools in any environment is to stabilize the work so measurements can be taken before any improvement or modification is made. For this reason, we suggest that the first step to implement lean tools at the Z facility is to create standardized worksheets that will help the personnel perform their work, reduce variability, more easily train new operators, and most importantly, to create a baseline for improvements activities. Figure 3 shows an example of proposed standard worksheets to be implemented in the more critical areas at the Z facility. The main purpose of these worksheets is to provide the personnel with a visual aid explaining step by step of the work to be performed their job.

3.2 Stage 2, Efficiency of the System

In Stage 2, the mid-term focus is on improving the efficiency of the value stream. Once tasks at the Z Facility are stable and standardized, the value stream can be improved by analyzing the critical path of the process and sorting out non value-added from value-added activities based on customers' perspective.

Among many Lean Six Sigma tools, Value Steam Mapping appears most suitable for the purpose of this analysis. The efficiency of the value stream will be improved through recognizing the problems and creating an action plan to solve them. After the process is stable and we have defined the non value-added activities, other lean tools, such as TPM, SMED, and cause and effect analysis can be implemented to identify the root causes of the problems and to create alternatives to avoid recurrence.

3.2.1 Identify Improvement Opportunities

In this particular environment (Scientist R&D) finished goods are not physically produced. The product is the data created and collected from every experiment. Therefore, we must focus our efforts on improving the data production and collection while we eliminate any source of waste in every department that interacts with the Z facility.

When creating a Value Stream Map, there are areas or symptoms in the value stream that we should review, such as looking at the process from the "final customer" perspective. The project team needs to be familiar with the process and with all the areas or departments that interact at the facility. Tasks that could be performed in advance, without affecting the value stream, should be identified. Look for symptoms in the process that generates unexpected delays in a regular basis, such as, realignment diagnostics after the top lid was installed, causing a delay in the process by not having efficient alignment standards.

Considering the information described in Figure 2, we create the following Value Stream Map of the critical path, shown in Figure 4. The total lead time of the process is 596 minutes, and the value added time of the process is 485 minutes on average. With this analysis, we identify 7 categories of opportunities for improvements, which were marked in the current state map as *Kaizen Bursts.* These non value-added activities are described in detail in Table 1.

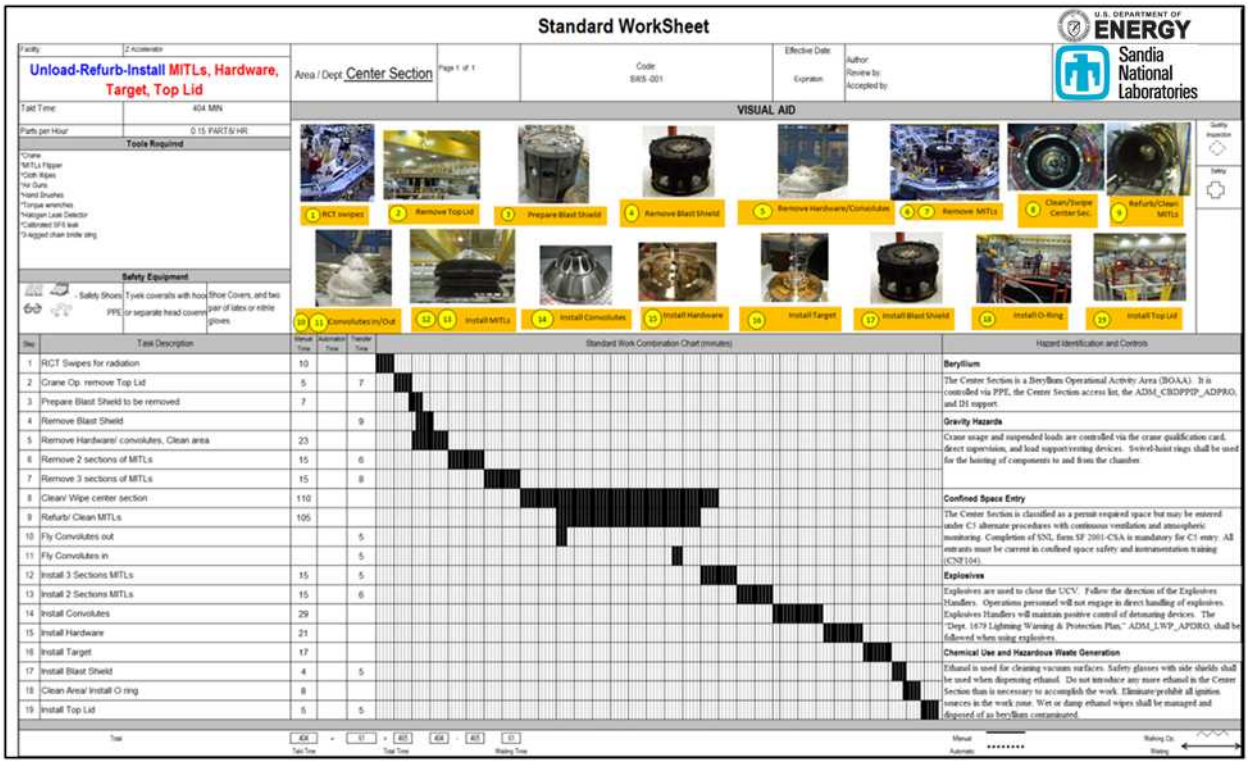

Figure 3: Proposed standardized work sheet for Center Section

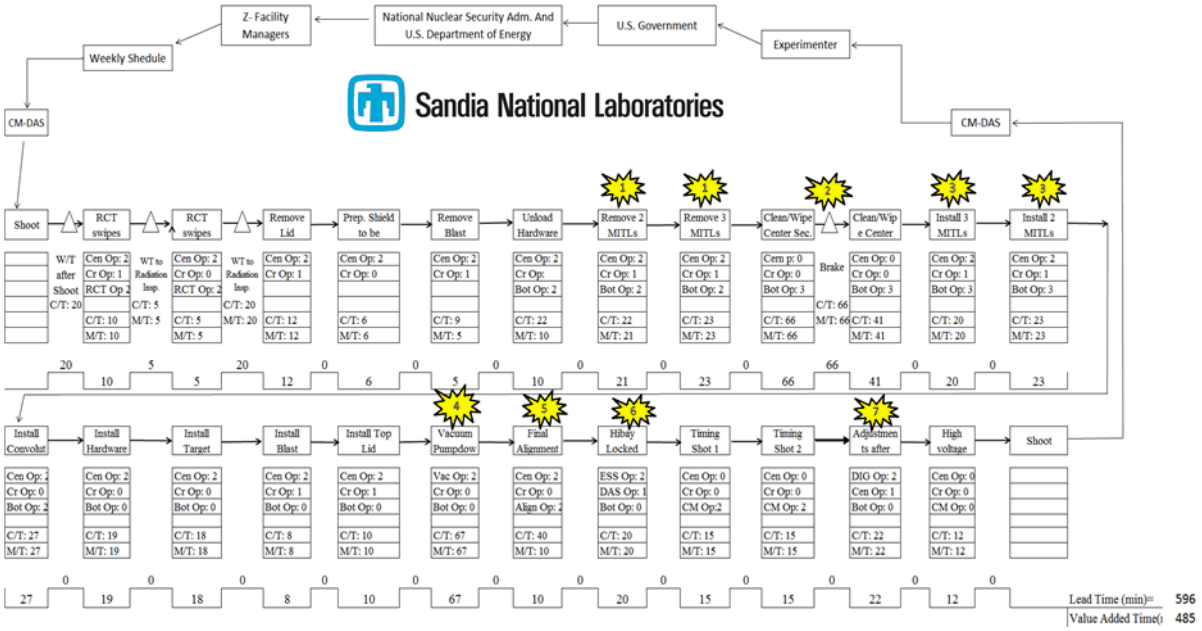

Figure 4: Value Stream Map, Current State with Kaizen Bursts

The 66 minutes of break time taken between MITL (Magnetically Insulated Transmission Line) refurbishment and MITL installation is suggested to be eliminated as this is an additional break to the lunch break.

The 45 minutes spent on removing and installing the MITLs are definitely needed. Every MITL weighs over 3 tons, and the current MITL flipper is not designed to handle this much weight at the same time.

After analyzing the Vacuum Section deeper and looking for alternatives to reduce the time needed to perform vacuum pumpdown (67 minutes), we determined that this timing is constrained by the performance of the equipment itself (vacuum pumps).

Regarding the 20 minutes to perform the high bay lock up, this time is used by ESS-PFS sections to ensure there is no one inside of the high bay for the incoming shot. If an issue is identified during the 20 minutes of inspection over the proper alignments of the diagnostics, the diagnosticians will need to make final alignments, which are represented as the 22 minutes for final adjustments. These 42 minutes can be reduced or eliminated if we ensure that every section and diagnostics are ready and aligned to perform the first timing shot.

Table 1: List of Non-Value-Added activities at the Z facility

	Non Value-Added Activities Description	**Department**	**Time Spent**
1	Break before the MITLs are installed back to the machine after being refurbished	Center Section	66 minutes
2	Time required to remove MITLs out of the machine	Center Section	45 minutes (performed in two steps)
3	Time required to install back MITLs to the machine	Center Section	45 minutes (performed in two steps)
4	Time required to achieve vacuum level required.	Vacuum Section	67 minutes
5	Time required for realignment of diagnostics before timing shots	Diagnostics Section	10 minutes
6	Time required to perform the high bay lock up	ESS-PFS and CM-DAS Sections	20 minutes
7	Time required for final alignment of diagnostics after timing shots	Diagnostics Section	22 minutes

3.2.2 Proposed Improvement Plan

The process of physically gathering data from the plant floor always reveals some surprises. The best way to gain the current focus on what the Future State should look like is to review issues from the Current State. It is vital to understand the problems within the current stream from a lean viewpoint. This part of the process is critical to achieving the correct direction for an operation's future.

Following the findings summarized in Table 1, in which we separated the non-value-added activities NOT needed from the necessarily non-value-added activities in the system, we identified a total of 113 minutes classified as not needed in the system or activities. Therefore, if we reduced or eliminated them from our system, there would be no adverse effects.

Consider the removal of the 66 minute break from out critical path. We are not suggesting that the personnel work 8 or 10 hours without a break, but we are proposing to move this break time to either forward or backward this to avoid having it fall into the critical path of the Z process.

The second biggest delay in the process is the final alignment of diagnostics after vacuum is achieved. On average, this delay is 30 minutes, which is the combination of the time described as time required to realign diagnostics before timing shots and the time required to perform the lock up of the high bay. They have a direct impact on the

critical path. Oftentimes, this happens because the scientists request extra diagnostics to be connected to the experiment at the last minute or because some of the diagnostics are not used often and requires longer aligning. For these reasons, we suggest to first implement a checklist or even a TPM (Total Preventive Maintenance) to make sure that every day all of the diagnostics are inspected and working properly even if they are not going to be needed that day.

As described before, oftentimes different problems can be the result of the same or similar root causes. In this case, because of the lack of an effectively alignment of diagnostics during its installation, it creates a delay afterwards of 22 minutes (described as adjustments after timing shots). If we ensure the appropriate alignment and connection of every diagnostic needed for the current experiment, we can reduce or even eliminate 47 minutes out of the critical path. Whit this analysis, we identified wastes in 4 areas, Table 2 describes the list of non value-added activities suggested to be eliminated from the value stream according to the analysis previously made in this chapter.

Table 2 List of non-value-added activities to be eliminated for the Future State

Non Value-Added Activities Description	**Department that Perform the Task**	**Time Spent**	**Time Suggested to be Spent**
Break before the MITLs are installed back to the machine after being refurbished	Center Section	66 minutes	Eliminated, 0 minutes
Time required to remove MITLs out of the machine	Center Section	45 minutes (performed in two steps)	Remain the same, 45 minutes
Time required to install back MITLs to the machine	Center Section	45 minutes (performed in two steps)	Remain the same, 45 minutes
Time required to achieve vacuum level required.	Vacuum Section	67 minutes	Remain the same, 67 minutes
Time required for realignment of diagnostics before timing shots	Diagnostics Section	10 minutes	Eliminated, 0 minutes
Time required to perform the high bay lock up	ESS-PFS and CM-DAS Sections	20 minutes	Reduced to 5 minutes
Time required for final alignment of diagnostics after timing shots	Diagnostics Section	22 minutes	Eliminated, 0 minutes

By achieving the modifications, the total lead time of the process will have a theoretical improvement of 26% compared to time needed to accomplish the critical path previously described.

Table 3 describes the number of shots or experiments per month from the current year 2012. The first row (current state), represents the actual number of experiments that were performed at the Z facility from January through August 2012; the second row (proposed Future State), and represents the number of experiments that could have been performed during this year if we had applied these modifications earlier this year. The third row represents the hours worked on the machine per month. This was calculated by multiplying the number of shots per month by the number of hours required to set up the Z machine on average, described in the current state map as the lead time (596 minutes).

Table 3: Theoretical benefits in terms of shots in year 2012

Year 2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Experiments
Current State	15	15	19	20	12	14	14	11	120
Proposed Future State	19	19	24	25	15	18	18	14	152
Hrs. worked on the machine per month	148	148	187	197	118	138	138	109	26%

It is important to mention that this 26% of improvement of the total process time will only occur if every department commits to applying the suggestions described in this research.

All decisions in a lean environment are made looking toward reducing lead time. Lean implementers know that lead time consists of non value-added time and value-added time. The challenge in developing the future state is to produce the customer's requirements (internal or external customer) in the shortest lead time and at the lowest cost possible [11]. Considering these modifications into the system, the Future State Map shown in Figure 5 was created. The Future State Map eliminated the 66 minute break and the 47 minutes of an alignment before and after the vacuum condition is achieved. The total lead time of the future state would be 468 minutes and the value added time would be 423 minutes.

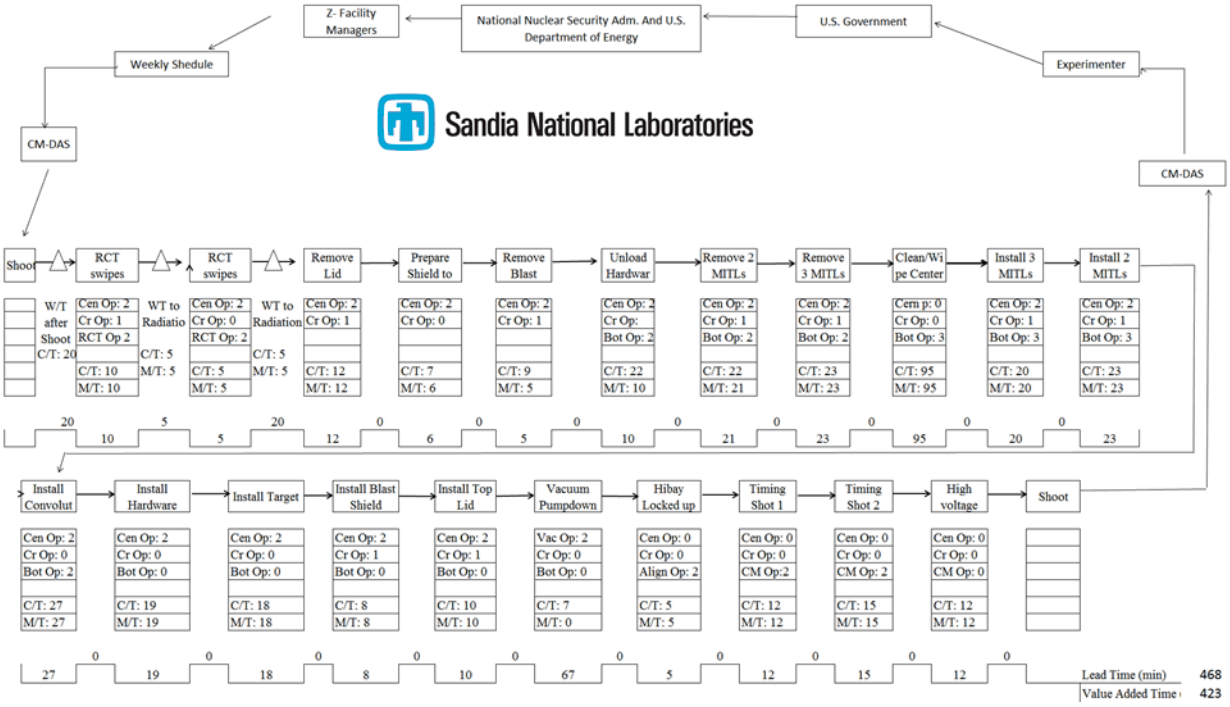

Figure 5: Value Stream Map, description of proposed Future State

3.3 Stage 3, Continuous Improvement

Lastly, the long-term analysis in Stage 3 is to progress in both dimensions by continuously improving standard work procedures and the flow of value stream. Value Steam Mapping and visual management are used to recognize problems, so that they can be solved. Stabilization is used as the foundation of continuous improvement and to support organization learning. The use of lean tools in a manner that resulted in team member engagement while supporting the work effectively and efficiently enabled problem solving and started the process of embedding a lean culture [3].

This final Stage suggests that once we have reached the Future State, it becomes the new current state, and we should *Continuously Look for Opportunities for Improvement* through the value stream. Either improving current standardized work sheets or proposing innovative ideas to perform different tasks at the facility, keeping in mind the final Goal: to produce at the lowest cost with the highest quality while eliminating any sort of waste in the value stream and to always keep looking for continuous improvements within the system. The Value Stream Map at the Z Facility is just the beginning in the transition of moving toward lean implementation. More improvements are expected to be achieved by continuous training and workforce development.

The implementation of A3 problem solving or DDW (Drill Deep and Wide), as a methodology to guide the future improvement efforts. These powerful lean tools are designed to analyze the improvements made, comparing the current state versus future state, in an organized and more explicit manner, following the PDCA cycle (Plan-Do-Check-Act). Emphasizing the needs of always get into the root cause of every issue. Activities such as, *Kaizen* meetings and feedback collection box will make a big contribution to achieve the engagement of the team members.

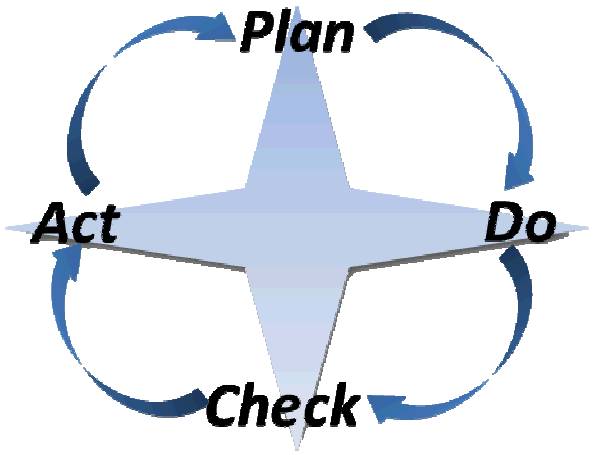

Figure 6: PDCA cycle (Plan-Do-Check-Act)

4. Summary and Conclusion

4.1 Summary of the Approach

The intent of this research was to understand the challenges and develop approaches that resulted in effective practice of lean principles. It is emphasized in lean that there is no one right way to do something and that the approach needs to fit with the objective, culture, and internal and external environments [10].

The most commonly used lean tool to analyze a system is Value Stream Mapping, but there are several aspects that we must ensure in our process before we can analyze it with Value Stream Mapping. Stage 1, describes the steps suggested for implementation before we attempt to implement lean tools to improve the value stream of the operation, such as stabilization of the system and an in-depth process description of every department at the Z facility.

Stage 2, is a thorough case study of how value stream mapping plays a role in the introduction of lean principles while achieving cross-functional integration. These tools were used in a manner that engaged team members while enabling them to develop and modify tools to best support their work. Once tasks are standardized, the value stream can be improved by analyzing the critical path of the process and sorting out non value-added from value-added activities based on customers' perspective.

Lastly, Stage 3 refers to long-term lean tools implementation to progress in both dimensions, to improve the effectiveness of the operations and the efficiency of the value stream. By continuously improved standard work procedures and the efficiency of the flow of the system.

4.1 Opportunities for Future Research

Future research should look at the role of stabilization to enable the stability of the process at any R&D laboratory. Furthermore, to explore in-depth for the more suited lean tools to problem solving and root cause analysis, to be utilized at any R&D laboratories environment.

The future work of this research regarding the Z facility has a wide scope:

- Investigate the unexpected delays deeper, using root cause analysis, especially those events that happen at higher frequencies, and to identify if those events were caused due to a maintenance issue, operational errors, or other traceable issues.
- Validate the effectiveness of the standardized worksheets proposed, in terms of stabilization of the process.
- Explore the possibility to changing to two work shifts; a full analysis should be made in order to show the pros and cons of this modification in terms of process time reduction versus labor cost.

4.3 Conclusion

This research provides a framework for research and development laboratories, like the Z facility at Sandia National Laboratories, interested in applying Lean Six Sigma methodology in their processes. This case study presents a 3-stage approach for Lean Six Sigma implementation, starting with emphasizing the needs of having a standardized process, where its main purpose is to stabilize the process, followed by the implementation of analytical Lean Six Sigma tools, like Value Stream Mapping. This helps us to separate value-added activities from non value-added activities, and to sort out any type of wastes in the process. The final Stage presented, stresses the common goal of Lean Six Sigma methodology, which is to continuously improve the value stream.

As we explained throughout this paper, this is a new field for Lean Six Sigma implementation, and even though an R&D environment is quite different from manufacturing environment, this analysis proved that lean methodology can be applied in this environment. It is important to mention that to analyze and subsequently improve the system using lean tools, we needed to modify them to fulfill our needs. This is a great example of the flexibility of lean tools, we can make use of them and modify them as needed as long as we keep in mind the final goal: to produce at the lowest cost with the highest quality while eliminating any sort of waste in our system and to always keep looking for continuous improvements within the system.

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