A Systematic Approach to Applying Lean Techniques to

Optimize an Office Process at the

Y-12 National Security Complex

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Acronyms

5S - Sort, Set in Order, Shine, Standardize, and Sustain.

AHP – Analytic Hierarchy Process

ANOVA – Analysis of Variance

CNS – Consolidated Nuclear Security

BOM – Bill of Material

DC – Derivative Classifier

DOE – Department of Energy

DOE - US Department of Energy

DOT – Department of Transportation

EC - Environmental Compliance

ES&H – Environmental Safety and Health (ES&H)

FMEA - Failure Modes and Effects Analysis

IT – Internet Technology

KPIs – Key Performance Indicators

ORR - Oak Ridge Reservation

PES – Performance Enterprise System

PM - Project Manager

SME – Subject Matter Expert

SWEA – Special Waste Evaluation Application

TDEC – Tennessee Department of Environment and Conservation

TPS – Toyota Production System

VSM – Value Stream Mapping

WAC – Waste Acceptance Criterion

WIP – Work in Progress

Abstract

This capstone offers the introduction of Lean concepts to an office activity to demonstrate the versatility of Lean. Traditionally Lean has been associated with process improvements as applied to an industrial atmosphere. However, this paper will demonstrate that implementing Lean concepts within an office activity can result in significant process improvements. Lean first emerged with the conception of the Toyota Production System. This innovative concept was designed to improve productivity in the automotive industry by eliminating waste and variation. Lean has also been applied to office environments, however the limited literature reveals most Lean techniques within an office are restricted to one or two techniques. Our capstone confronts these restrictions by introducing a systematic approach that utilizes multiple Lean concepts. The approach incorporates: system analysis, system reliability, system requirements, and system feasibility. The methodical Lean outline provides tools for a successful outcome, which ensures the process is thoroughly dissected and can be achieved for any process in any work environment.

Introduction

Lean manufacturing is an approach derived from the Toyota Production System (TPS). The goal of TPS is to eliminate waste, or non-value added activities. Companies continuously search for ways to find more efficient ways to produce their product. This also occurs in an office environment and non-production tasks. Lean is an enhancement methodology that eliminates non-value added activities. Lean has been implemented in the manufacturing realm for many years, however, limited studies have been found where Lean is used to improve an office activity. When Lean is implemented to improve non-production tasks, execution is usually limited to one or two Lean practices. Our capstone will introduce Lean to improve the lead time of an office document at the Y-12 Nuclear Complex (Y-12). Our approach is different from previous papers. We will use a strategic approach that incorporates multiple facets of Lean, generally applied in a manufacturing arena, and apply them to a document generated in an office. Our systematic approach utilizes the following Lean concepts:

- Systems Analysis
- Lean Analysis
- Reliability Analysis
- Requirements Analysis
- Feasibility Analysis

These concepts will incorporate value stream mapping (VSM), casual loop, stock and flow, identification of critical processes and stakeholders, analytic hierarchy process (AHP), and key performance indicators (KPIs). The induction of all these Lean components will ensure that the improvements are attainable and sustainable.

Although Lean techniques are widely accepted throughout the manufacturing realm as a means of streamlining processes, the question of this capstone is “Can a systematic Lean approach significantly improve an office process?” The objective of this capstone is to implement Lean and reduce the lead time and eliminate waste in an office process at Y-12.

1.1 Background

The Y-12 National Security Complex is located in Oak Ridge, Tennessee, approximately 23 miles west of Knoxville, Tennessee, and is one of three U.S. Department of Energy (DOE) installations on the 35,000-acre Oak Ridge Reservation (ORR). The facility is managed and operated by Consolidated Nuclear Security (CNS). Y-12 occupies approximately 800 acres, employs nearly 5,000 people; and maintains the safety, security, and effectiveness of the U.S. nuclear weapons stockpile. Over the years, either through production processes or infrastructure reduction, Y-12 has generated tons of waste from building demolitions and will continue to generate waste while moving towards modernization. Some of the waste may be regulated through federal, state or local policies. All hazardous waste is shipped off-site for disposal, however, there are some regulated "special waste" allowed to be land disposed on-site at the landfill, if the waste acceptance criteria (WAC) is met. Special wastes are wastes that are either difficult or dangerous to manage. Special wastes may consist of hazardous wastes that are not subject to regulation under Tennessee Department of Environmental and Conservation (TDEC) Rules 0400-12-01-.03 through 0400-12-01-.07. Special wastes may also include sludges, pesticide, medical, industrial, liquid, friable asbestos, and combustion wastes. The approval to dispose on-site reduces time and costs associated with waste disposal. In order for the special waste to go to an onsite landfill, a Special Waste Evaluation Application (SWEA) must be submitted to the TDEC for consideration and approval. Special wastes require review and approval by TDEC prior to disposal in ORR landfills. Only TDEC has the authority to determine whether a potential special waste is indeed a special waste. The waste generator must create an application to the landfill operator and TDEC for review and approval of a special waste application. Prior to submitting the SWEA to TDEC, the SWEA is evaluated by multiple organizations within CNS and DOE to ensure compliance with the WAC.

1.2 Problem Statement

Discussions were held with employees and management of the Environmental Compliance (EC) at Y-12 to identify office processes that were cumbersome or convoluted. After several management meetings, the SWEA process was selected as our Lean capstone project.

Y-12 currently processes approximately 20 SWEAs annually. The mean lead time from submittal to approval is 65 days. Many SWEAs are submitted as a result of building demolitions. Building demolitions create considerable amounts of debris. The concern involves storage of building debris until landfill approval is received from TDEC. The destruction of unwanted or unnecessary facilities result in a tremendous amount of waste stored in piles outside, until the waste has been accepted and approved by TDEC for on-site disposal.

Many of the buildings demolished are in close proximity to occupied structures. Safe access is required for fire protection equipment and security personnel. Obstruction of the movement of people and emergency equipment can create potential safety, health and environmental concerns. The possibility of radioactive and other hazardous contaminants means that additional health and safety controls sometimes being required for the protection of both the employees and the environment. The only other option is to store the building debris in large Department of Transportation (DOT) containers. Although a safer alternative, the amount of space needed to store the DOT containers creates its own quandaries.

Not all SWEAs are related to demolition activities. Even storing smaller items becomes an issue with outdoor storage due to the elements and packaging requirements. In addition, locating adequate indoor storage is difficult due to egress and safety controls within the facility. As Y-12 continues to reduce its footprint and remove unwanted material, the availability of storage space is diminishing.

The primary complaint associated with the SWEA is the amount of time it takes to receive approval from TDEC. A hardcopy is manually routed for each SWEA through each organization. Many times the data is delivered as it becomes available, but the information is sporadic and confusing. Documents are sometimes misplaced, lost or forgotten. The lack of due diligence, missing data, and errors from the waste generator can result with the SWEA being rejected or, most often, requiring rework. In the event the waste is eligible for landfill disposal, the associated project is unable to close out the project until receiving TDEC approval. Every day the SWEA remains open results in additional cost and time to the project. Often, the project remains open, but the valid charge numbers are closed, resulting in additional time and costs to locate a current charge number. Utilizing the Lean methodology this capstone will evaluate the SWEA, with an expectation of reducing the SWEA lead time by fifty percent.

1.3 Approach

Lean concepts are widely accepted as an effective means to reduce waste in manufacturing, but can they significantly improve a system within an office environment? A system is a grouping of elements, interconnections, and functions or goals. All work can be considered a process or system. Lean is not limited to manufacturing, (Brophy, 2013). The SWEA was identified as an office process that EC management would like to see improved. With management’s concurrence, the SWEA process will be modified by utilizing the systematic approach. This approach will enable us to understand the process and apply the Lean techniques to optimize the SWEA.

Our capstone hypothesizes that Lean concepts can effectively be applied within an office environment to significantly reduce lead time. The Lean methodology that will be applied to the SWEA process for the capstone is as follows:

- Systems Analysis
- Lean Analysis
- Reliability Analysis
- Requirements Analysis
- Feasibility Analysis

The application of these methods will identify non-value added activities, bottlenecks, risks, reliability, stakeholders and requirements criterion. We anticipate that implementing the Lean methods listed above to the SWEA will significantly improve the lead time. The metrics used to evaluate the effectiveness of our systematic approach are as follows:

- Time – Change in lead times
- Cost – Change in annual cost
- Quality – Change in reliability
- Complexity – Change in the numbers of steps

Literature Review

2.1 Formation of Lean

The Toyota Production System was implemented by two employees working for the Toyota Motor Company in 1950s, Taiichi Ohno and Eiji Toyoda. The main objective of TPS was to eliminate inconsistencies and waste within a system or process (Ohno, 1998). “The basic idea was to produce the kind of units needed, at the time needed and in the quantities needed such that unnecessary intermediate and finished product inventories can be eliminated” (Shah & Ward, 2003). The TPS aimed to reduce variability at every opportunity (Hopp & Spearman, 2008). The TPS system in essence shifted the focus of the manufacturing engineer from individual machines and their utilization, to the flow of the product through the total process, (www.lean.org).

Overall the success of TPS allowed Toyota to produce quality products in a timely manner. Customer service was elevated from a continuous expected production stream.

“Lean production” evolved from the TPS. Womack, Jones and Roos (1990) stated in, *The Machine that Changed the World*, “half the human effort in the factory, half the manufacturing space, half the investment tools, half the engineering hours to develop the product in half the time.” Lean production also reduces the onsite inventory, reduces rework, and can increase a variety of products. The Lean philosophy focused on flow, VSM and eliminating waste (Hopp and Spearman, 2008). Lean manufacturing stresses the importance of empowering employees. The earlier the project can engage stakeholders the better the outcome.

2.2 Lean Production Versus Lean Office

Lean techniques are generally associated within the manufacturing realm, but this paper proposes to successfully implement Lean techniques within an office environment. Attempting to apply Lean methods to office jobs have proved difficult because they are not repetitive (Staats & Upton, 2011). It is recognized that lean tools employed in the administrative proceedings have more difficulties in operation mainly due to variations that occur in processes, the existence of less information from the people involved, and lack of reference in the literature (Monteiro, Pacheco, Dinis-Carvalho, & Paiva, 2015). There are many case studies evaluating the effectiveness of Lean in a production environment, however, the case studies evaluating Lean in an office environment are limited. Some may argue the waste is more difficult to identify in an office. The differences between an office and production waste are not substantial. Waste just looks a little different. For instance, work in progress (WIP) in production could be excess inventory or parts waiting to move to the next step. In an office, waste could be documents awaiting approvals. The available Lean office literature predominantly approached the process by assembling a team; VSM; sort, set in order, shine, standardize, sustain (5S); and Kaizen. This capstone proposes a more in depth approach to optimize an office process. Whether the waste occurs in an office process or a production system, the utilization of Lean practices such as, but not limited to, casual loops, VSM, and AHP, will offer solutions to attainable Lean goals. The process or system should be evaluated holistically. There should be an understanding between the structure and the behavior and how that relationship can produce desired results (Meadows, 2008). In many instances, fixing one problem can create unforeseen problems in other areas. “Nothing is ever influenced in just one direction” (Senge, p. 75).

2.3 Conclusion

Shah and Ward state that Lean is an attitude that is involved with the disclosure of waste within an organization and its affected parties. When Lean is implemented effectively, it can reduce cost and improve quality and efficiency. This literature review reveals a gap not only in the amount of information available of Lean in an office, but also the limited Lean tools used in the application of Lean in an office environment. This presents an ideal opportunity to introduce a strategic systematic approach in an office environment. This capstone will use Lean concepts traditionally confined to a manufacturing environment and apply to an office environment. The template will provide a schematic approach to where the system is understood, stakeholders are identified, and priorities and criterion are recognized.

Methodology

3.1 System Analysis

Over the past years the Environmental Compliance has received several complaints concerning the amount of time involved to receive approval the SWEA process. Our capstone will demonstrate how Lean techniques can be instituted into an office environment to improve the process and reduce lead times in the SWEA. The following diagram, Figure 1, illustrates the systematic approach used to evaluate a process.

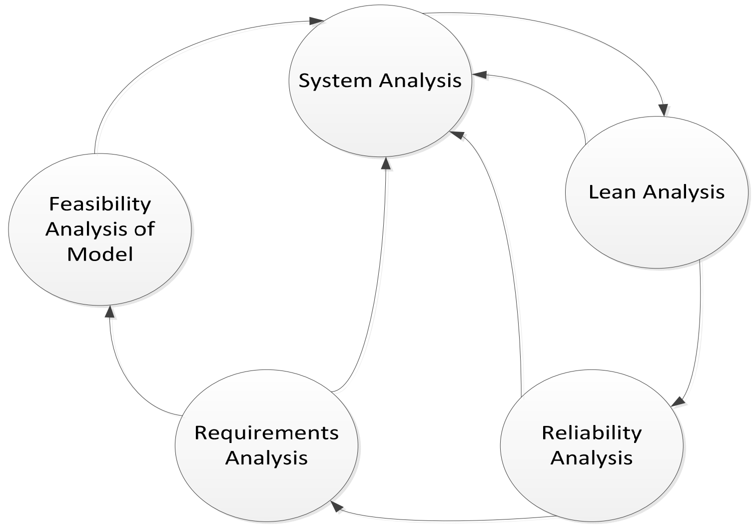


Figure 1: Systematic Approach

The methodical approach involves: system analysis, Lean analysis, requirements analysis, reliability analysis, and feasibility analysis.

The first step was to assemble a team of subject matter experts (SMEs) to outline the SWEA process so each member can get a better understanding of how one action can effect another. Each member described their steps performed in the SWEA. The information received from the SMEs was used to develop a stock and flow diagram and a causal loop for the system. The stock and flow diagram illustrates the interconnectivity between organizations within the SWEA process. It also assists to understand the influences that have created an impediment. Figure 2 illustrates the stock and flow of the SWEA process.

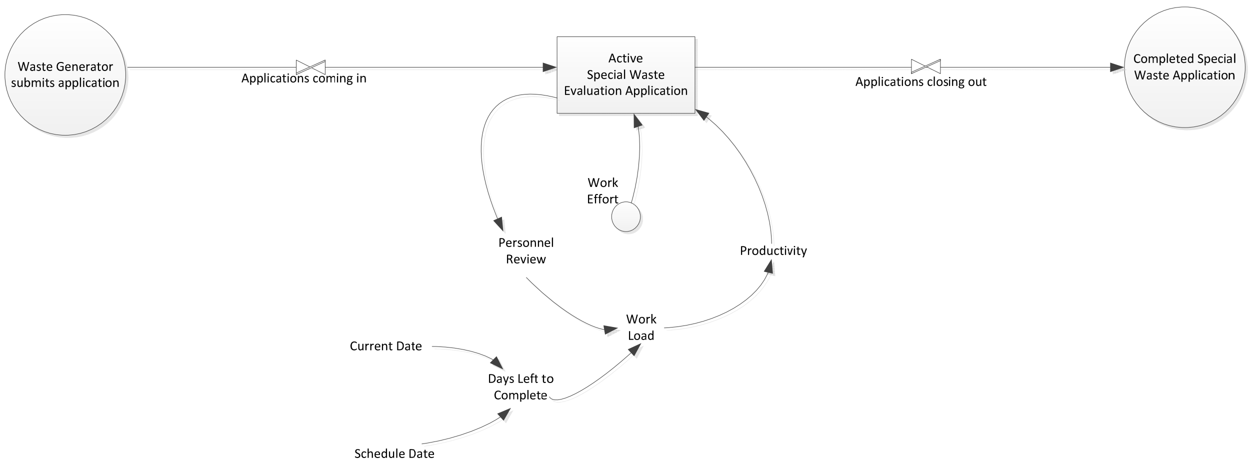


Figure 2: SWEA Stock and Flow Diagram

As displayed in the stock and flow diagram, the waste generator requests approval for landfill disposal of special waste by completing and submitting a SWEA. The active application increases the inventory as a stock. The active SWEA is evaluated by personnel. The personnel review is dependent upon the reviewer's work load and productivity. The work load is dependent upon the days left to complete the task, the current date, and the scheduled to complete date. If the SWEA is errorless, the application is submitted to TDEC. TDEC reviews and either approves or denies the SWEA. Either determination completes the waste application. In addition, the stock and flow diagram displays that reviewer personnel will return the SWEA to the waste generator, if the application is missing data or is incomplete.

Variables were identified in order to establish boundaries to the system. The variables identified include both internal and external. The internal variables include: CNS Y-12 employees and application payment. The external variable is TDEC personnel and transportation to TDEC. The SWEA approval is contingent on the waste meeting the WAC. The special waste characterization process in order to submit the application, the check payment, and the United States Postal Service (USPS) transportation are beyond the boundaries of this capstone.

The SWEA process causal loop diagram, Figure 3, illustrates the negative and positive impacts on the system. The reinforcing loop, R1, is the waste generator submitting an application and is motivated to have the waste dispositioned. The reinforcing loop, R2, is the reinforcing loop of an application closing and reducing application inventory. The balancing loop, B1, is due to conflicting priorities and workload. The balancing loops, B2 and B3, is due to individual reviewer's schedule demand, effort, and evaluation time. The balancing loops, B4 and B5, are due to errors discovered in the SWEA and is sent back to the waste generator. The reinforcing loop, R3, is due to the evaluation being completed, the application closing, reducing evaluator application inventory, and increasing time to review a new SWEA. The balancing loops, B8 and B7, are due to the current date and schedule demand. If the schedule demand is high, and there is several days between the current date and the scheduled completion, the application review may be delayed until closer to the schedule date. The reinforcing loop, R4, is due to the scheduled due date. The balancing loop, B9, is due to the cost to review the SWEA, the longer the application is open, the more the cost increases. The reinforcing loop, R5, is due to the completion of SWEA and completion of the application costs. The stock and flow diagram and the causal loop diagram represents a push system. The application is physically pushed from one employee to the next.

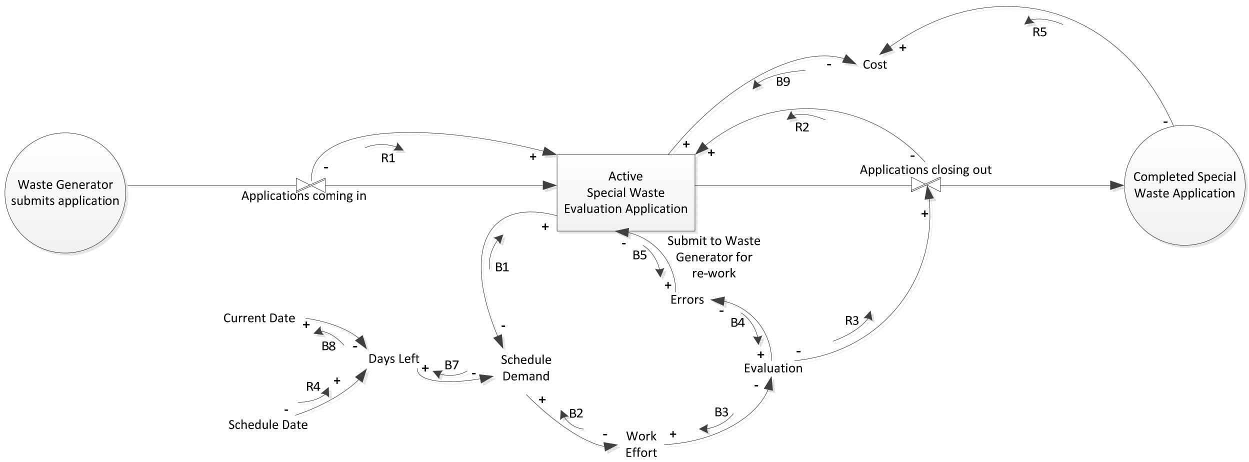


Figure 3: SWEA Casual Loop Diagram

3.2 Lean Analysis

Once the initial interview with the SMEs was completed, a VSM was created utilizing historical data and information gathered from the SMEs. The VSM was utilized in order to identify the critical processes. The VSM for the SWEA process was allocated into three phases to correspond with the legacy data. The legacy data collected over the previous years presented limited options. The mean cycle times were obtained for each phase, however, data was not available for each individual process. This quandary is problematic because the majority of stakeholders interviewed voiced rework as their main concern and there was no data available to calculate rework.

The lead time to complete a SWEA was also available through the historical data. The mean cycle times for Phases 1, 2, and 3 were calculated by measuring the arrival times from one phase to the next. This was vital information because the mean cycle times were utilized to determine the coefficient of variation (CV) for each phase. The CV is a ratio of the standard deviation to the mean. The CV clarifies the bottleneck in the system. A bottleneck is caused by variation, flow, or disruptions. The VSM confirmed the bottleneck to be Phase 1 of the process. Variation increases cycle times, which ultimately increases lead times. The identification of the bottleneck allows a focused view on critical requirements. Figure 4 depicts the SWEA process of the requirements engineering planning model.

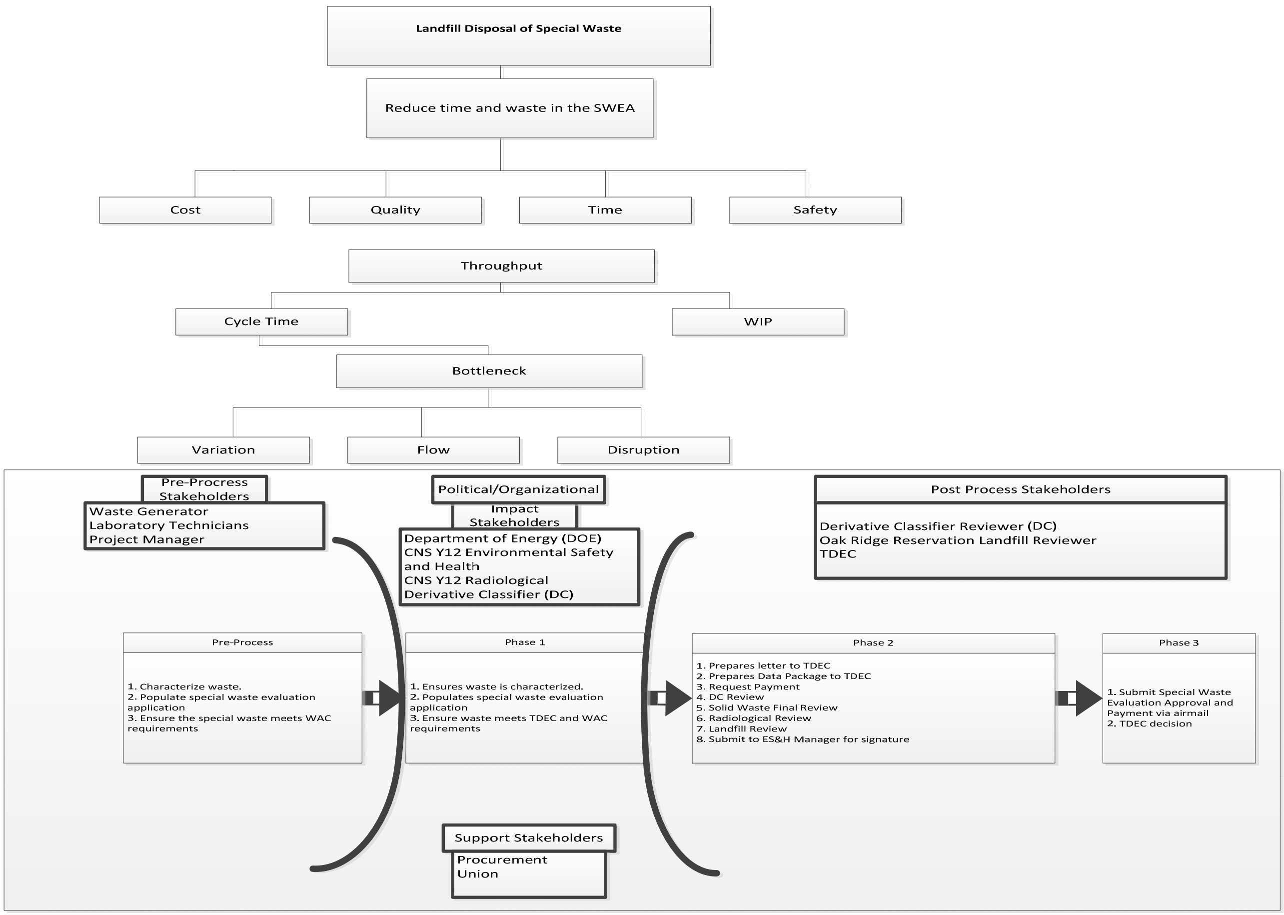


Figure 4: Requirements Engineering Planning for the SWEA

The model identifies the goal, processes, critical process, and stakeholders. The stakeholders were identified as the waste generator, project manager, environmental personnel, Environment, Safety and Health (ES&H) manager, radiological personnel, derivative classifier, landfill personnel, TDEC, DOE, laboratory technicians, procurement staff, and union personnel.

3.3 Reliability Analysis

Reliability is the degree to which an experiment, test, or measuring method produces the same results on repeated trials. The bottleneck process offers the opportunity for the largest initial improvement. The reliability analysis will focus on the bottleneck. The reliability analysis will analyze the structure required to make the process work including: the material, schedule, people, and equipment. The Weibull distribution forms the basis of many reliability models, such as times between failures. The Weibull distribution has the ability to assume the characteristics of many different types of distributions. The Weibull distribution is used in reliability engineering and failure analysis. The reliability analysis will enable the determination of how repeatable the bottleneck process is before, as well as after, the implementation of Lean concepts.

3.4 Requirements Analysis

A requirement is something essential to the existence of occurrence of something else (Webster's, 2017). Requirements planning is the exercise of clarifying stakeholder's expectations for current, new or modified systems. Requirements, or characteristics for the system, must be measureable, applicable and contain clear objectives. Requirements planning is essential to ensure modifications to an existing system succeed. Y-12 National personnel assessed the process required to dispose special waste to the ORR landfills. To strengthen the success of implementing Lean methods, this paper will incorporate requirements planning techniques. The requirements planning techniques include: identifying the critical processes and key stakeholders, performing a failure mode effects analysis (FMEA), and creating an

AHP.

3.5 FMEA

A FMEA is an approach for identifying all possible failures in a new or modified design, assembly process, product, or service. The affected employees should be included early in the modification changes. As modifications are considered to an impending system, a FMEA should be executed to expose potential weaknesses in the new system. The FMEA allows the system to be classified by severity of failure as well as the probability of failure. FMEA can help identify and eliminate concerns early in the development of a process. It is a systematic way to examine a process prospectively for possible ways in which failure can occur, and then to redesign the processes so that the new model eliminates the possibility of failure (Smith, D.L.)

3.6 Analytic Hierarchy Process

Critical stakeholders are identified utilizing the Analytical Hierarchical Process. The AHP technique is a pair-wise matrix analytical method. An AHP identifies the critical stakeholders in the process and prioritizes the criterion. The AHP technique was utilized to rank the criterion and prioritize the stakeholders. The overall priority for each stakeholder is obtained by summing the product of the criterion (i.e., weight) with respect to the overall goal and then multiply by the priority (i.e., preference) of the stakeholder. The AHP for the SWEA are listed below in Figure 5.

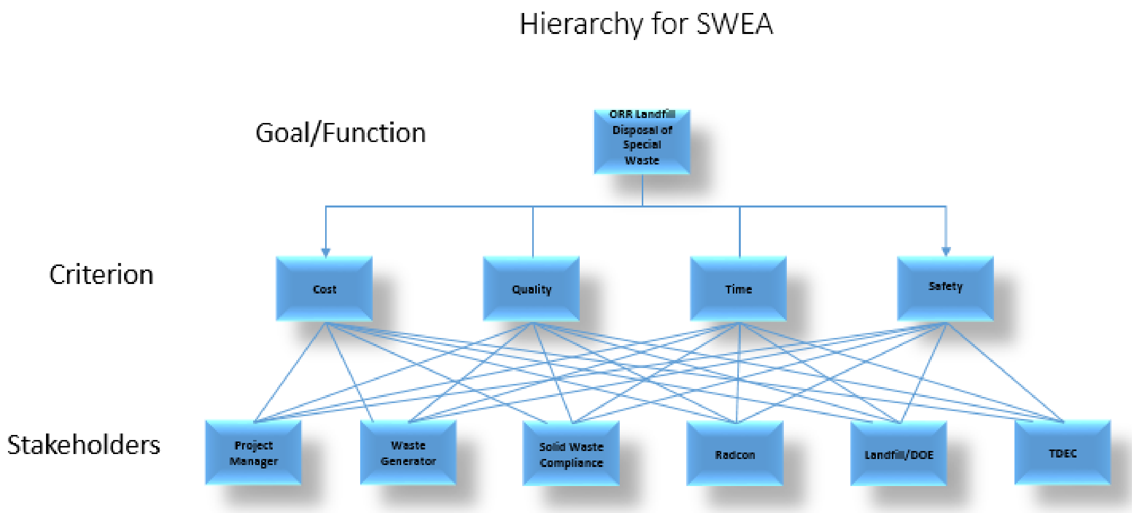


Figure 5: Hierarchy for SWEA

3.7 Feasibility Analysis

The feasibility of implementing Lean will be evaluated through several methods. The first quantifiable method will be statistically examining the data for the CV and the Weibull distribution. An analysis of variation (ANOVA) will compare the mean cycle times between the SWEA before Lean concepts and the SWEA after Lean was implemented. The ANOVA examines and determines whether to reject or accept the null hypothesis by comparing the F statistic to F critical values. If F statistic is greater than F critical, we reject the null hypothesis. The final feasibility analysis will monitor and report the process and performance of the key performance indicators (KPIs). The KPIs for this capstone are time, cost, quality, and complexity.

Case Study

4.1 Case Study Introduction

The company analyzed for the case study is an electrical manufacturer. This company has a variety of customers. Major products the company produces are switch gears and switch boards. These products are made to their customer's exact specifications. This company has been applying Lean concepts in their manufacturing area, however, the company is analyzing their office process. The office process includes reviewing the Bill of Material (BOM) and engineering drawings for each customer order. The impact is low customer satisfaction due to excessive lead times, resulting in customers waiting for their orders. The goal of this case study is to streamline the Blue Book process.

4.2 Case Study Methodology

The case study used limited concepts for their Lean application. Our application will encompass the systematic approach, as illustrated in Figure 1, to evaluate the Blue Book process. The methodical approach involves: system analysis, Lean analysis, requirements analysis, reliability analysis, and feasibility analysis.

The first step in the case study was to assemble a Lean event team and provide Lean training to team members. The Lean team selected the Blue Book process as the process to improve and constructed a VSM. The team targeted three departments: purchasing, electrical design, and structural design.

Our first step in analyzing the case study was to form a team and review the case study processes, in order to understand how one action can impact another. The information gathered from the case study was utilized to develop a stock and flow diagram and a causal loop diagram for the system. The information from the case study VSM was utilized in order to develop the stock and flow diagram and the causal loop diagram. Figure 6 illustrates the stock and flow of the Blue Book process.

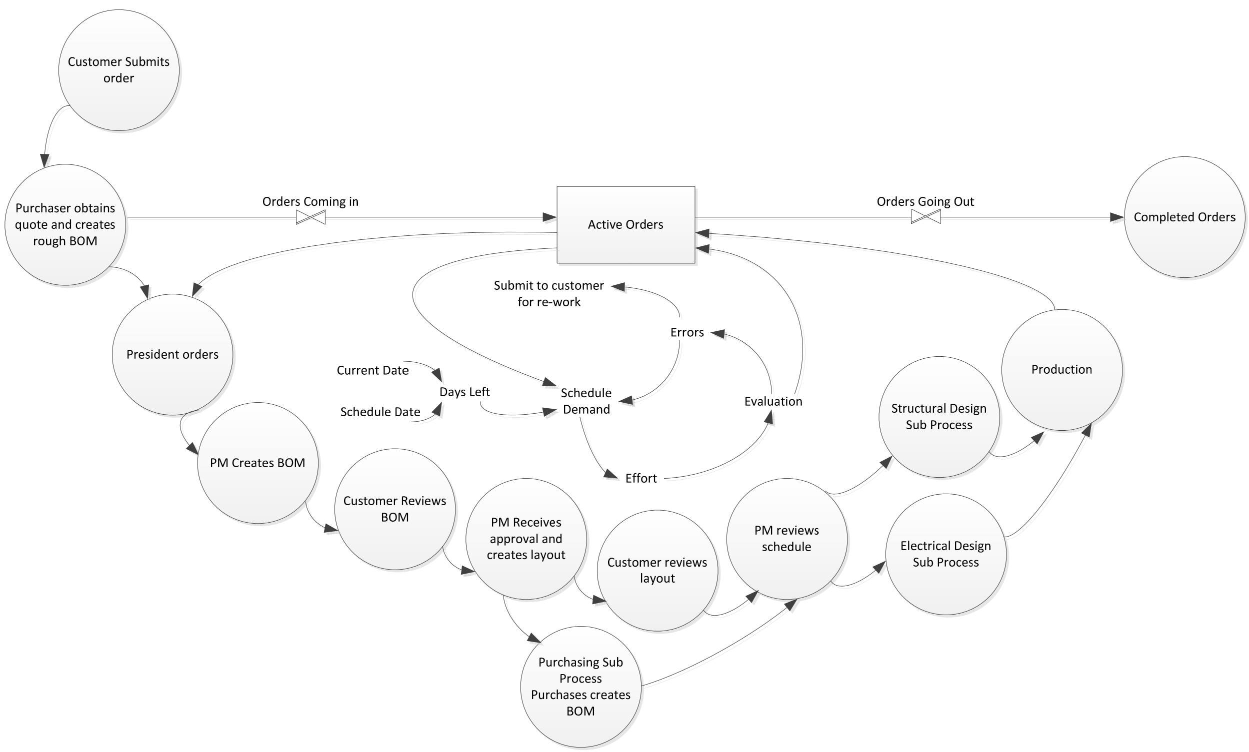


Figure 6: Stock and Flow Diagram of Blue Book

As a part of the pre-process, the customer orders the electrical manufactured product. The purchaser obtains a quote and creates a rough BOM. The purchaser submits the order to the president and the president submits the order to the project manager (PM). The PM creates the BOM and submits to the customer. The customer reviews, approves the proposed BOM, and submits approval to PM. The PM receives approval and creates the layout. After the layout is created, the PM submits the information to the purchasing sub process and purchasing creates a BOM. In parallel, the PM submits the layout to the customer for review. The customer reviews, approves the layout, and proposes a schedule to the PM. The PM reviews the schedule, then submits the BOM and layout to both the structural design process and the electrical design process. After the structural design and electrical design are completed, production receives the designs and submits the order to the customer. In addition, if the BOM, layout, structural design, or electrical design are not approved, then they must go back for rework. The rework is contingent upon the current date and the scheduled completion date, as well as the schedule demand of the reviewer.

Variables were identified in order to establish boundaries to the system. The variables identified include both internal and external. The internal variables include: purchaser personnel, president, PM, structural design team, and electrical design team. The external variable is the customer. The capstone scope is narrowed to concentrate on the processes abetting the bottleneck.

The causal loop diagram illustrates the negative and positive impacts on the system. The reinforcing loop, R1, is the customer submitting an order. The receipt of the order increases the order inventory as a stock. The balancing loop, B1, is the orders being sent to the customer as the order is completed. The reinforcing loops, R2 and R3, are due to the customer satisfaction in receiving the correct item. The balancing loops, B2 through B15, are due to the individual reviewer's schedule demand, effort, and evaluation time. If an error is found, the order is sent back to the PM and the order returns to the start of the process where the order was rejected. The casual loop diagram for design office process is displayed in Figure 7.

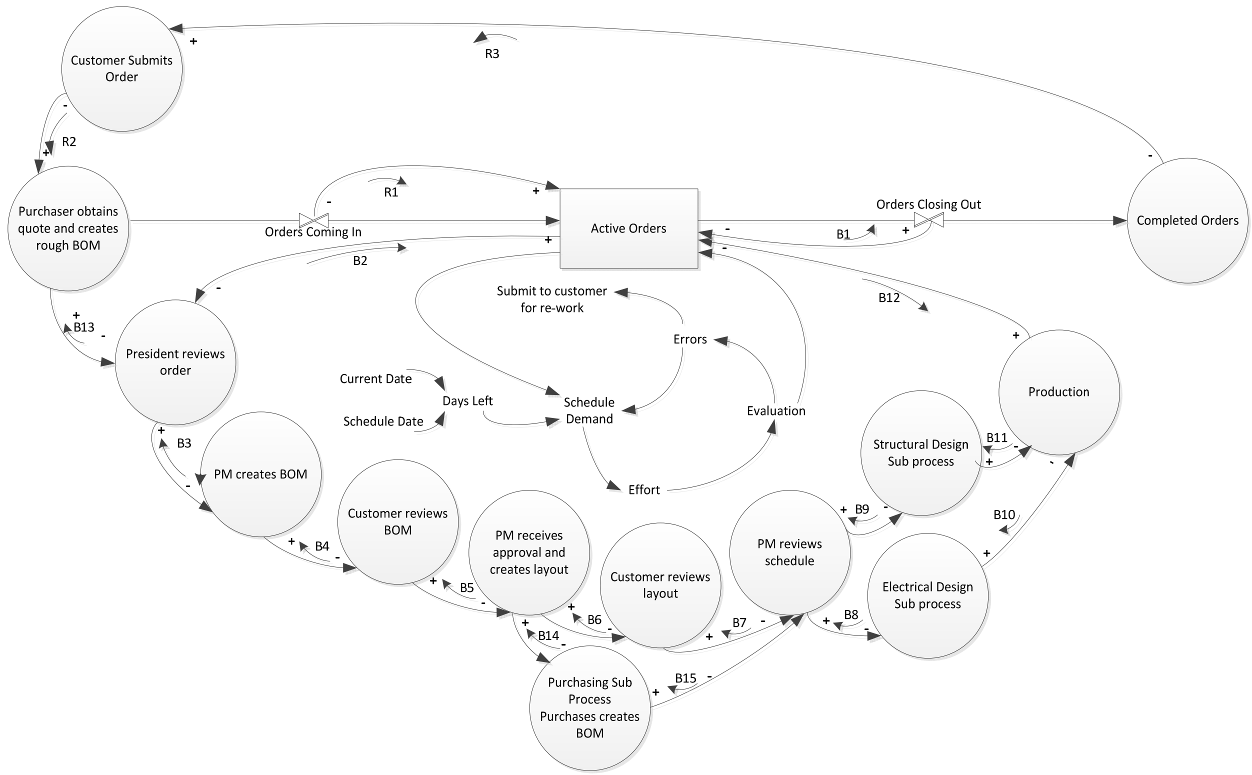


Figure 7: Blue Book Casual Loop Diagram

The cycle times were measured and averaged for each process in the VSM. The only data available were the mean cycle times for each process. Therefore, the bottleneck was determined by locating the highest process mean cycle time. The highest mean cycle time was identified as the electrical design sub process. Changes within the bottleneck process can create the highest impact to the system, consequently the electrical design sub process was targeted.

The identification of the bottleneck allows a focused view on critical requirements. Figure 8 is a model of the requirements engineering planning for the Blue Book process.

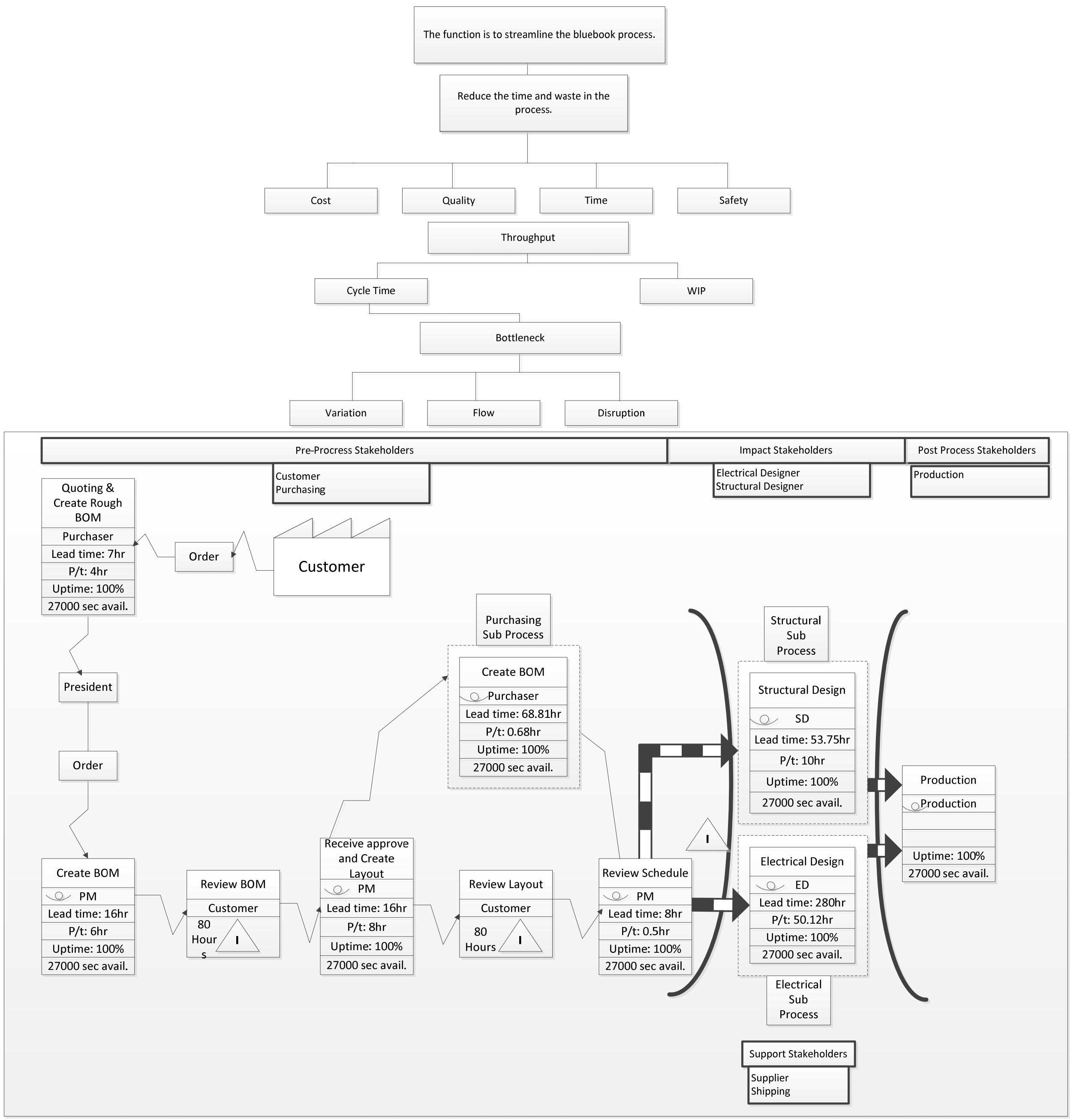


Figure 8: Blue Book Requirements Engineering Planning

This model identifies the goal, the processes, the critical process, and the stakeholders of the process. The case study identified the stakeholders as the customer, purchasing, electrical designer, structural designer, supplier, shipping, and production. It should be noted that the PM was not identified as a stakeholder in the process. Our analysis of the process would have included the PM as a stakeholder.

Once the criterion has been prioritized, then a pair-wise comparison is performed with the alternate or in this case the stakeholder. The hierarchy for the Blue Book Process is displayed in Figure 9. The stakeholder with the highest overall ranking is the best choice

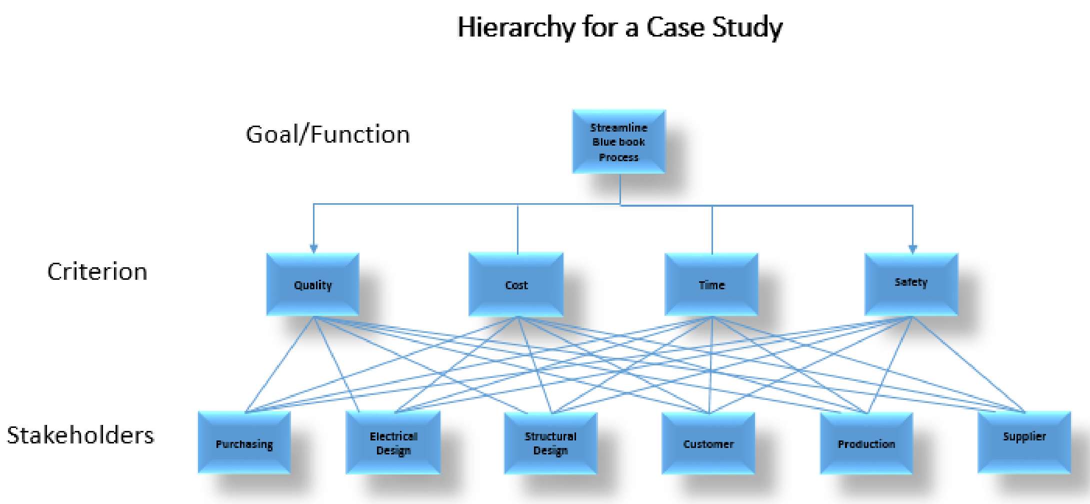


Figure 9: Hierarchy for the Blue Book Process

4.5 Case Study Results

A current state VSM was developed to clarify the flow and office material movement of the process. The VSM also identified the non-value added and the bottleneck within the system. The current state of the Blue Book Process is illustrated in Figure 10, the VSM below.

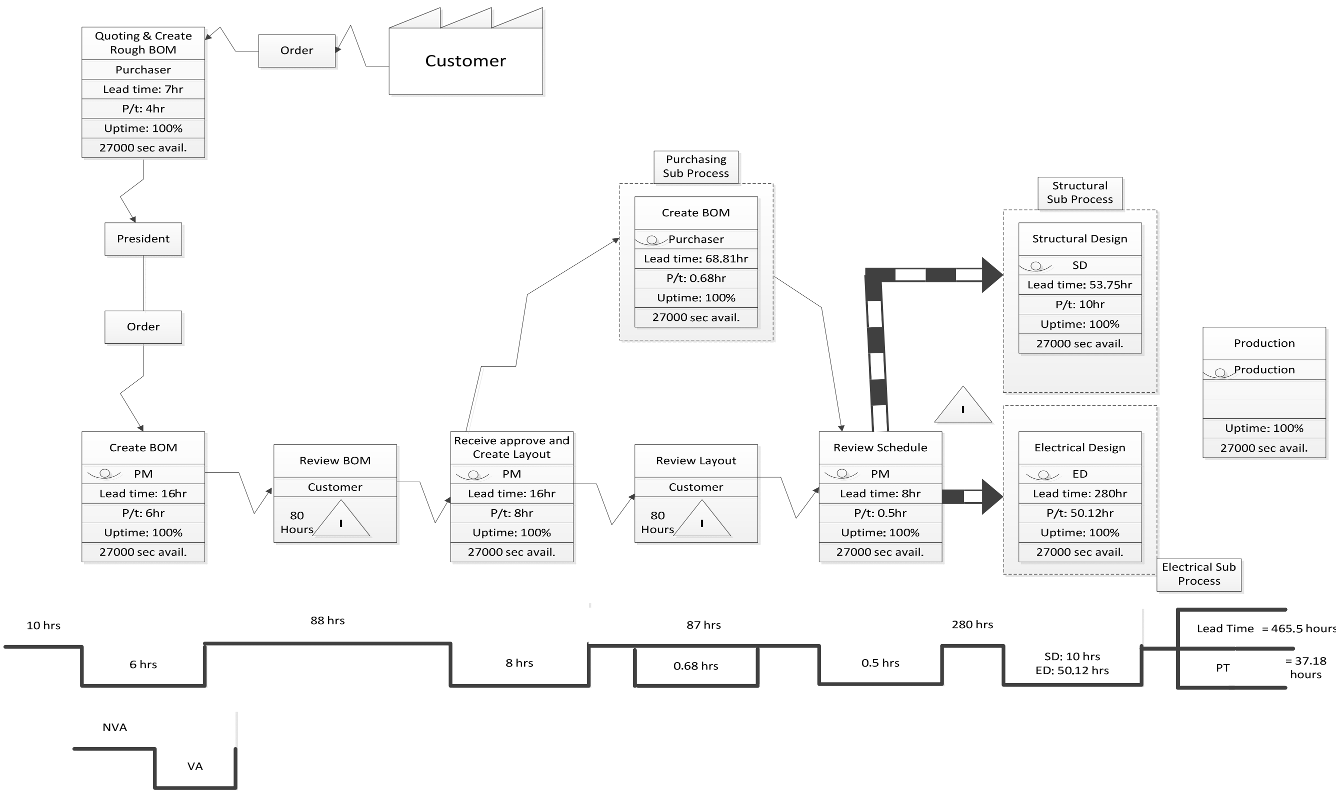


Figure 10: Blue Book Process VSM

The graph displayed in Chart 1, represents cycle times of each phase in the Blue Book office process. The mean cycle time was highest for the electrical design sub process.

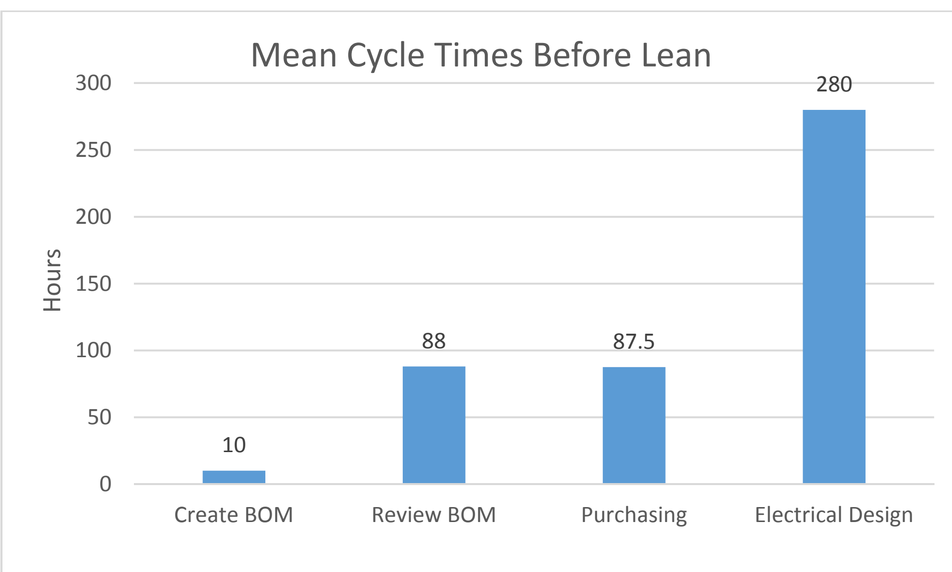


Chart 1: Blue Book Mean Cycle Times Before Lean Introduced

The bottleneck was identified as the electrical design sub process. To confirm the bottleneck location, the coefficient of variation was calculated for each phase. Four orders were assumed to have been ordered by customers. The four orders had a mean cycle time, as indicated in the case study information. From the estimated four orders and the mean cycle times, the standard deviation (SD) and CV were calculated. Chart 2 confirms the electrical design process as having the highest variation, and therefore this will be the process of concern.

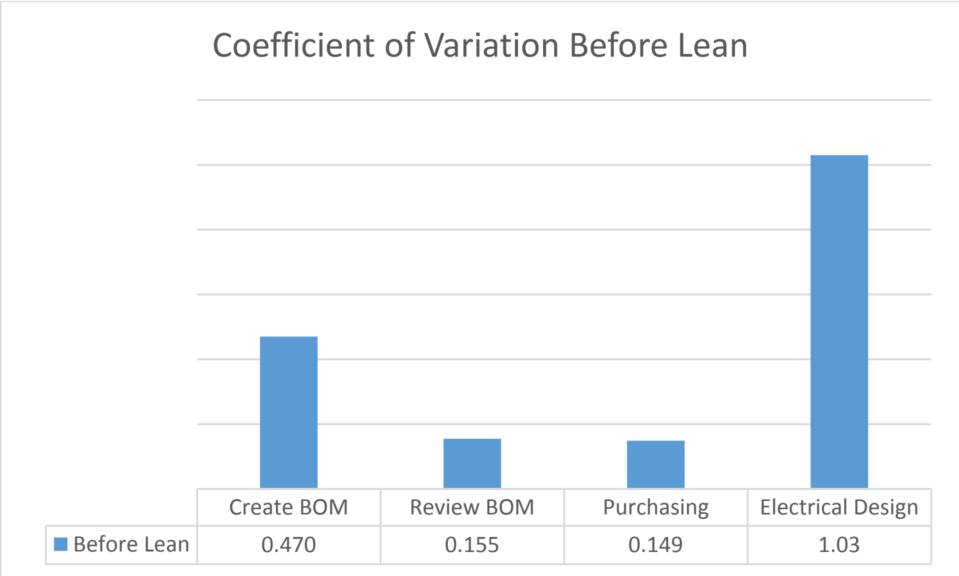


Chart 2: Blue Book Coefficient of Variation Before Lean Introduced

Figure 11 depicts the analysis of the bottleneck process. The equipment, materials, and people enabling the creation of the electrical design to be submitted and evaluated were considered to have an estimated reliability of 0.90. The structure around the electrical designer's, customers, and PM's schedules in the bottleneck process were analyzed. The schedule reliability was calculated by using estimated cycle time values, as the time-to-failure. The estimated cycle time values mean is equal to the mean of the electrical design sub process, 280 hours. The schedule reliability was evaluated utilizing a Weibull distribution by plotting on the Weibull distribution chart.

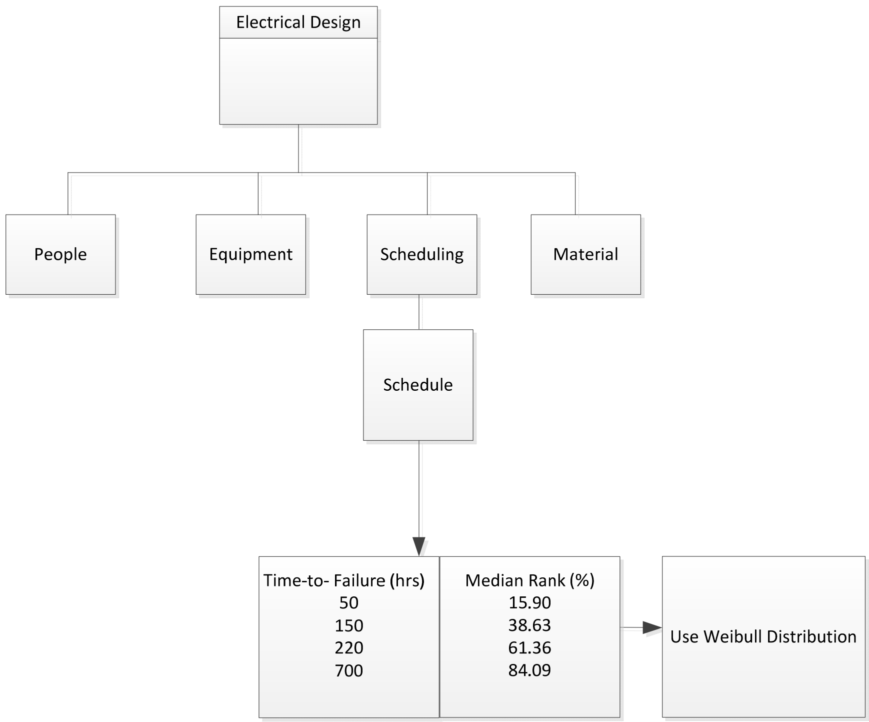


Figure 11: Blue Book Comprehensive View of the Bottleneck Process

The schedule reliability before Lean concepts were introduced into the office is displayed in Chart 3. The time-to-failure was ranked in ascending order. The median rank was calculated and numbers were transferred to a Weibull distribution graph. The values determined in the Weibull graph was utilized in the reliability equation: $R(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$. The schedule reliability equation was determined to be: $R(40) = 1 - e^{-\left(\frac{40}{298}\right)^{1.18}}$ The reliability at time equal to 40 hours, or one work week, is 14.65%. The reliability of the electrical design sub process was calculated by multiplying the estimated reliabilities of the equipment, materials, and scheduling in series or 0.9*0.9*0.9*0.1465 = 0.1067 or 10.67% reliable.

1

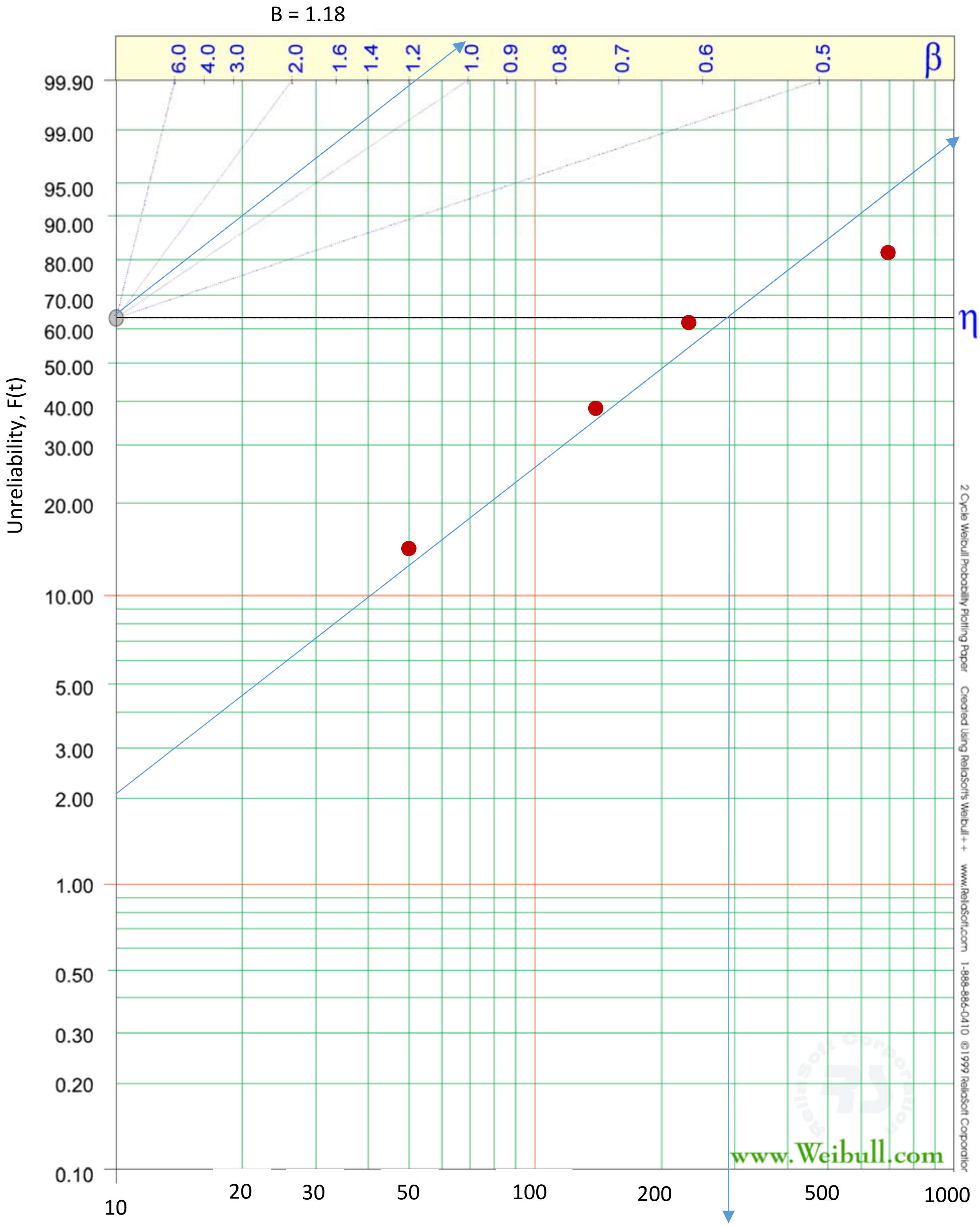


Chart 3: Before Lean Concepts Implemented: Schedule Reliability

The reliability was measured after the Lean concepts were introduced into the bottleneck. Figure 12 displays the blue book bottleneck process after Lean was introduced. The schedule reliability was calculated by using estimated cycle time values, as the time-to-failure. The estimated cycle time values mean is equal to the mean of the electrical design sub process, 250 hours. The time-to-failure hours were then plotted on a Weibull distribution graph, displayed in Chart 4.

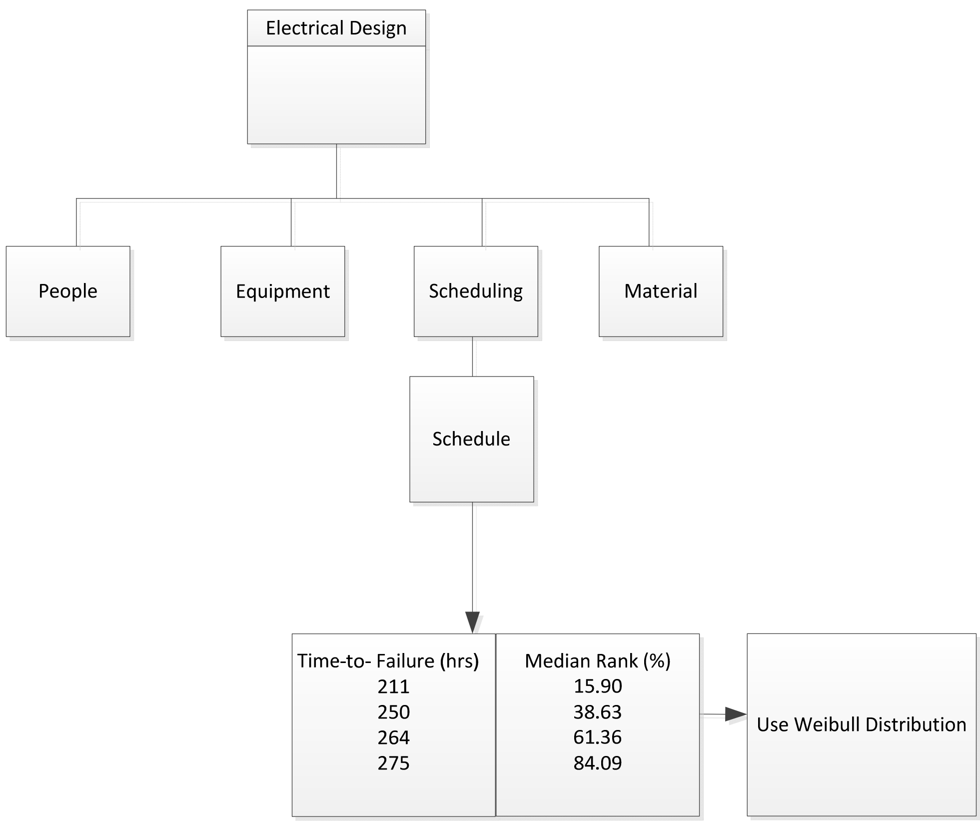


Figure 12: Blue Book comprehensive view of the bottleneck process

The schedule reliability was determined utilizing the reliability equation: $R(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$ The schedule reliability equals: $R(40) = 1 - e^{-\left(\frac{40}{345}\right)^{4.2}}$ When time equals 40 hours, or one work week, reliability is 0.3855%. The reliability of the scheduling in series or 0.9*0.9*0.9*0.3855 = 0.2810 or 28.10%.

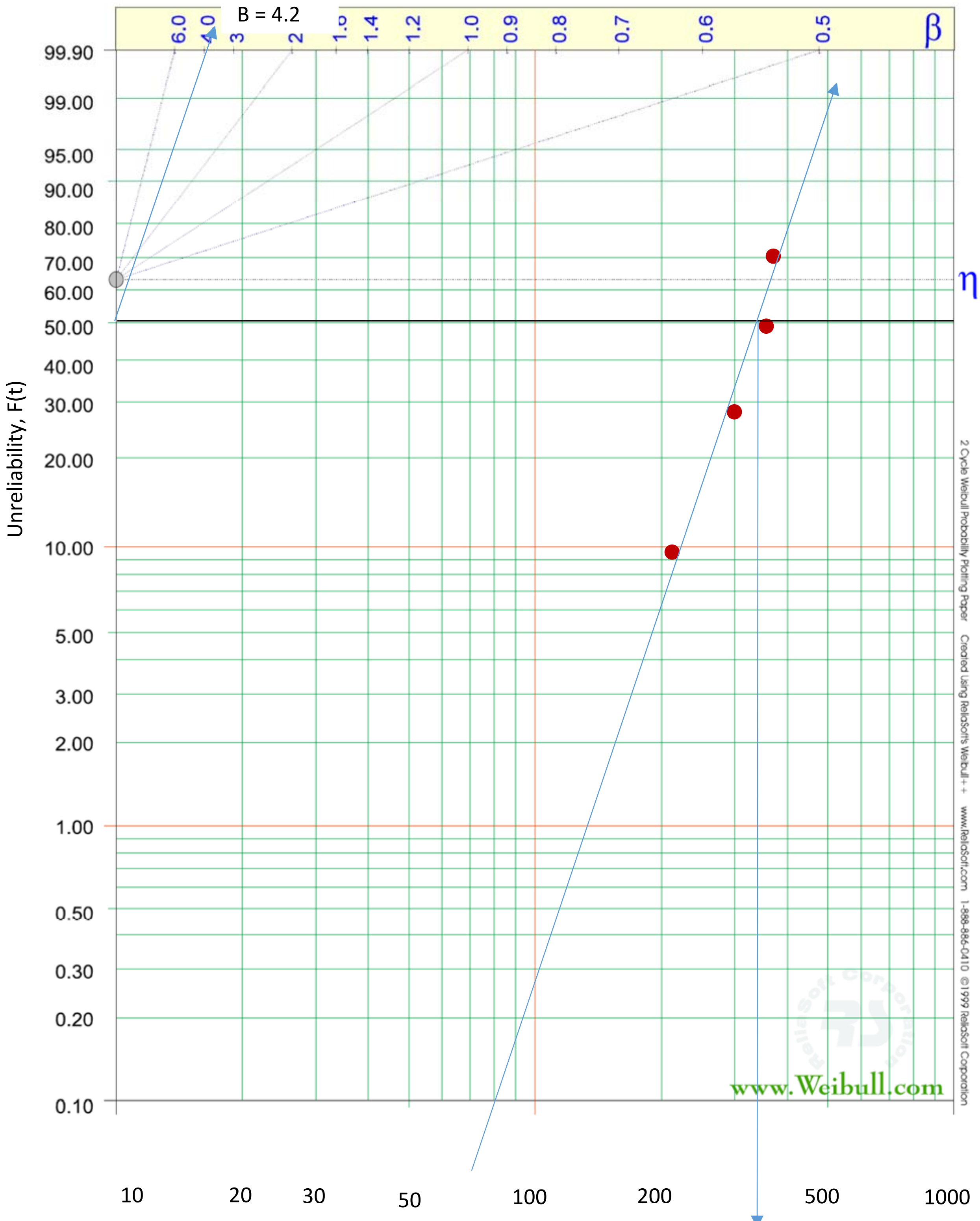


Chart 4: Schedule Reliability After Lean Concepts

4.4 Requirements

Requirements planning is the exercise of clarifying stakeholder's expectations for current, new or modified systems Table 1 displays the Blue Book FMEA approach.

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s) of Failure	Prob	Current Controls	Det	RPN
Prepare and create documents supporting BOM	Inaccurate data	Excessive response times; Customer's full expectations may not be realized; Rework	3	Human error	3	Cross team review; PM review	2	**18**
Customer Review BOM	Away from office	Excessive response times	2	Human error	3	Strict design specification with multiple reviews	1	**6**
Purchasing	Raw material not available; Inaccurate data on PO	Delays; Customer's full expectations may not be realized	6	Material unavailable; Human reliability	4	Suppliers are copied on PO; Customer review	1	**48**
Electrical Design	Inaccurate designs; Unanswered e-mails	Delays; Customer's full expectations may not be realized	8	Human reliability	6	Point to point check; PM review	2	**96**

Table 1: Blue Book FMEA Approach

A FMEA is an approach for identifying all possible failures in a new or modified design, assembly process, product, or service. The affected employees should be included early in the modification changes. The FMEA revealed the electrical design process is the highest risk for failure. Intentional consideration will be given to personnel in the process. The FMEA rating scale can be found in Appendix A.

The FMEA revealed that the electrical design process had the highest risk for failure. The AHP will allow the team to prioritze the stakeholders identified in the hierarchy.

Table 2 shows the pair-wise comparisons of the criterion and the stakeholders with respect to the goal. A rating scale for the comparision can be found in Appendix B.

Criteria Priority	Quality	Kaizen	Flow	Interruptions
Quality	1.0000	0.7500	1.0000	0.5000
Kaizen	0.3330	1.0000	0.2400	1.3333
Flow	1.0000	0.2500	1.0000	3.0030
Interruptions	0.2000	0.7500	0.3330	1.0000
Sum	2.53	2.75	2.57	5.84

Normalized Matrix	Cost	Safety	Time	Quality	***Weights***
Quality	0.39	0.27	0.39	0.09	0.29
Kaizen	0.13	0.36	0.09	0.23	0.20
Flow	0.39	0.09	0.39	0.51	0.35
Interruptions	0.08	0.27	0.13	0.17	0.16
Sum	1.00	1.00	1.00	1.00	1.00

Evaluation of Stakeholders	Quality	Cost	Time	Safety
Purchasing	0.3	0.25	0.75	1
Electrical	0.75	0.25	1	0.75
Structural	0.1	0.66	0.25	1
Customer	0.1	0.25	0.5	1
Production	0.1	0.5	0.5	1
Supplier	0.5	0.25	1	0.5
Sum	1.850	2.160	4.000	5.250
Purchasing	0.162	0.116	0.188	0.190
Electrical	0.405	0.116	0.250	0.143
Structural	0.054	0.306	0.063	0.190
Customer	0.054	0.116	0.125	0.190
Production	0.054	0.231	0.125	0.190
Supplier	0.270	0.116	0.250	0.095
Sum	1.000	1.000	1.000	1.000

Prioritized Stakeholders	
Purchasing	17%
Electrical	25%
Structural	13%
Customer	11%
Production	14%
Supplier	20%
Sum	100%

Table 2: Pair-wise Comparison

The overall priorities are derived from the weights of the criterion and the normalized matrix of the stakeholders. The prioritized stakeholders and calculated hierarchy is displayed in Figure 13 below.

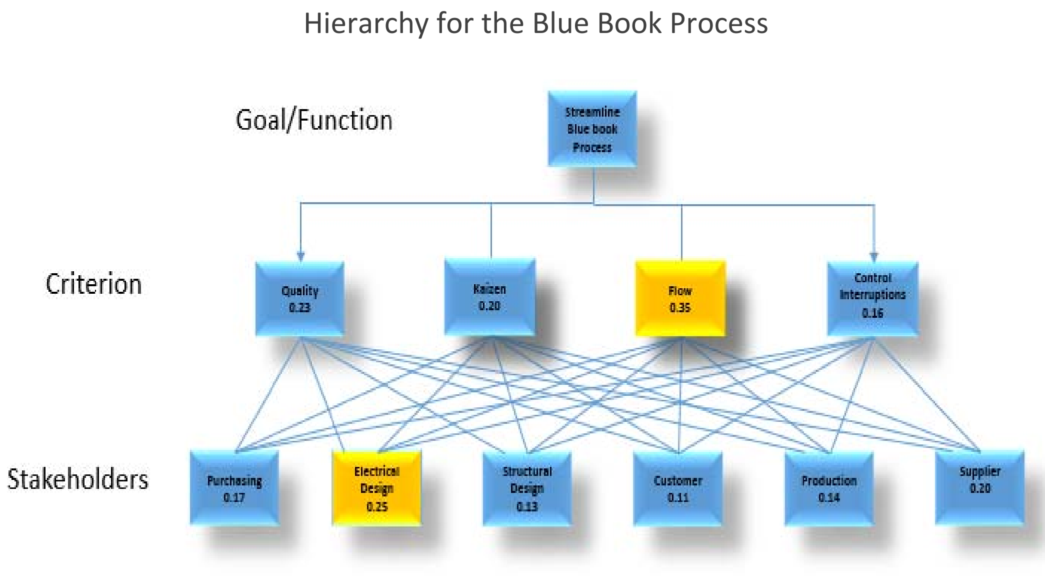


Figure 13: Hierarchy for the Blue Book Process

Our capstone evaluated the significance of Lean as it was applied to the Blue Book Process. The graph displayed in Chart 5 depicts the coefficients of variation in the Blue Book Process before and after Lean concepts were implemented.

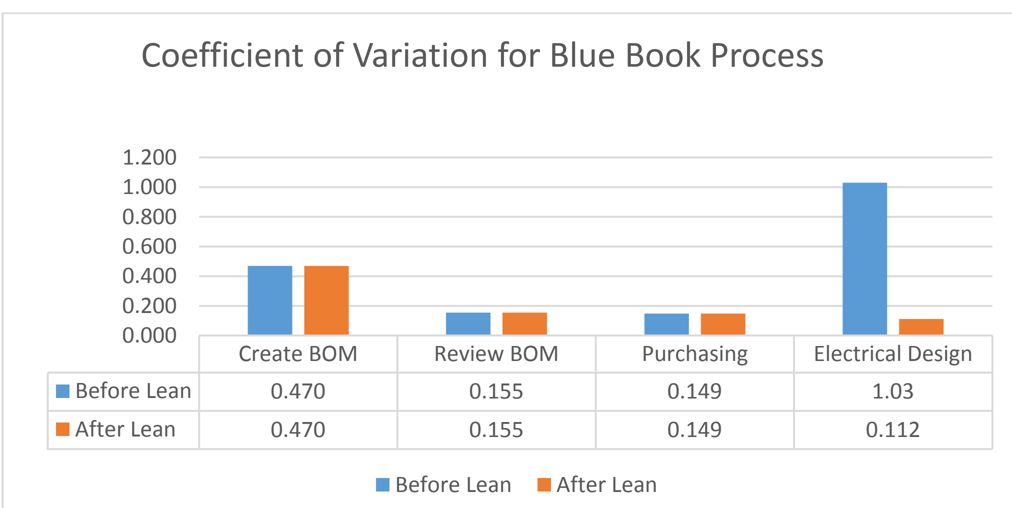


Chart 5: Coefficient of Variation for the Blue Book Process

As Table 5 displays, there is no change in the variation to the processes with the exclusion of the electrical design process. The question now is did the implementation of Lean have a significant influence to the Blue Book process? We performed an ANOVA to compare variances and determine if the difference in the means were attributed to Lean or was it just by chance? Our null hypothesis is H_0: The difference in the means are not attributed to the application of Lean concepts.

ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Current	4	40	10	22
	4	352	88	186
	4	350	87.5	171
	4	1120	280	83266.67
Future	4	40	10	22
	4	352	88	186
	4	350	87.5	171
	4	1000	250	780.6667
	4	30	7.5	1.666667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	320994.9	8	40124.36	4.25813	0.002081	2.305313
Within Groups	254421	27	9423			
Total	575415.9	35				

Table 3: ANOVA Single Factor

The ANOVA concludes that F statistical is greater than F critical and therefore, we reject the null hypothesis. The Lean application had no significant influence to the Blue Book process.

Table 4 represents the most current KPIs of the SWEA process.

Metrics Indicators	Before Lean	After Lean	Change
Time (Mean Lead Time)	280 hours	250 Hours	30 Hours
Estimated Bottleneck Variation	1.03	0.112	0.918
Quality (Reliability**)	0.10	0.28	18%
Complexity (Number of Steps)	4	5	1

Table 4: Metrics Indicators

** Reliability was calculated for the bottleneck only

4.5 Case Study Conclusion

Our capstone conducts a systematic Lean approach to achieve process improvements in the office setting. The case study applied limited Lean techniques, mainly VSM and Kaizen, to their electrical design to decrease the lead time for the Blue Book process. Our capstone utilizes a systematic approach that encompasses; systems analysis, Lean analysis reliability analysis, requirements planning, and a feasibility analysis. All these concepts should be incorporated when modifying or designing a process. This case study, as most literature reviewed for Lean in an office setting, was limited to one or two Lean concepts. For a successful process improvement to a new design or modification to the system, multiple Lean concepts should be considered. The systematic approach laid out by this capstone should be utilized to ensure the success and sustainability of the Lean implementation.

Results

Y-12 continues to reduce its footprint. Much of the waste generated during clean-outs and building demolitions will be dispositioned at the ORR landfills. This capstone used Lean techniques to optimize the SWEA process. A current state VSM was developed to clarify the flow and material movement of the process. Relevant stakeholders participate in the VSM in order to get everyone's perspective with the process. The VSM also identify non-value added and the bottleneck within the system. The current state of the SWEA is illustrated in Figure 14.

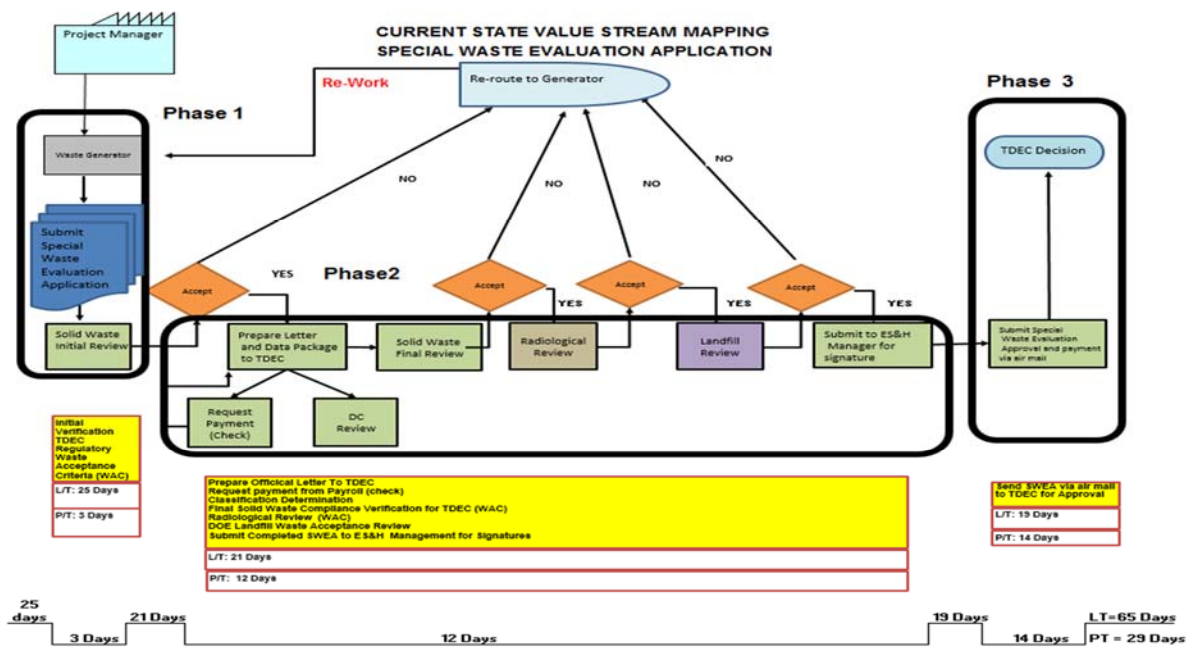


Figure 14: SWEA Value Stream Map

The cycle times of each phase in the SWEA is displayed in Chart 6. The phases were allocated from the legacy data collected over the previous years. The process in which the data was collected presented limited options. We were able to obtain the mean times for each phase but there was no available data for each individual process. This quandary is problematic because the majority of stakeholders interviewed voiced rework as their main concern and there was no data available to calculate rework. The mean cycle times for Phases 1, 2 and 3 were fairly close; 25, 21, and 19 respectively.

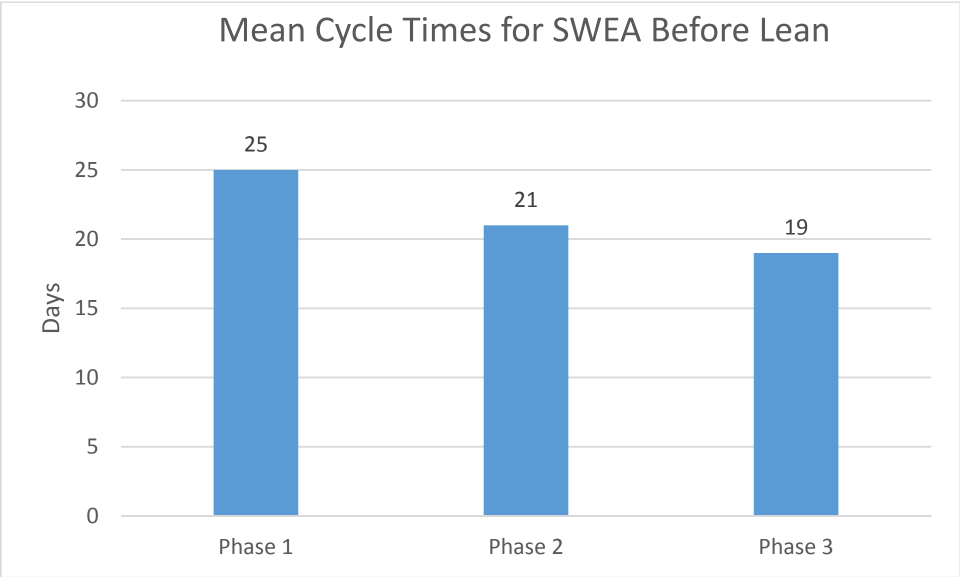


Chart 6: Mean Cycle Times for SWEA Before Lean Introduced

From the mean estimated cycle times it appears the system is balanced with little variation. These figures can sometimes be misleading. To measure the variation in the system, the coefficient of variation should be analyzed. It should be noted that an unbiased random sample of the population from the historical data was used to have consistent data points between the before and after calculations. Chart 7 reveals the coefficient of variation in each phase. Knowing where the greatest variation exists allows us to focus on the bottleneck or the part of the system to have the largest impact.

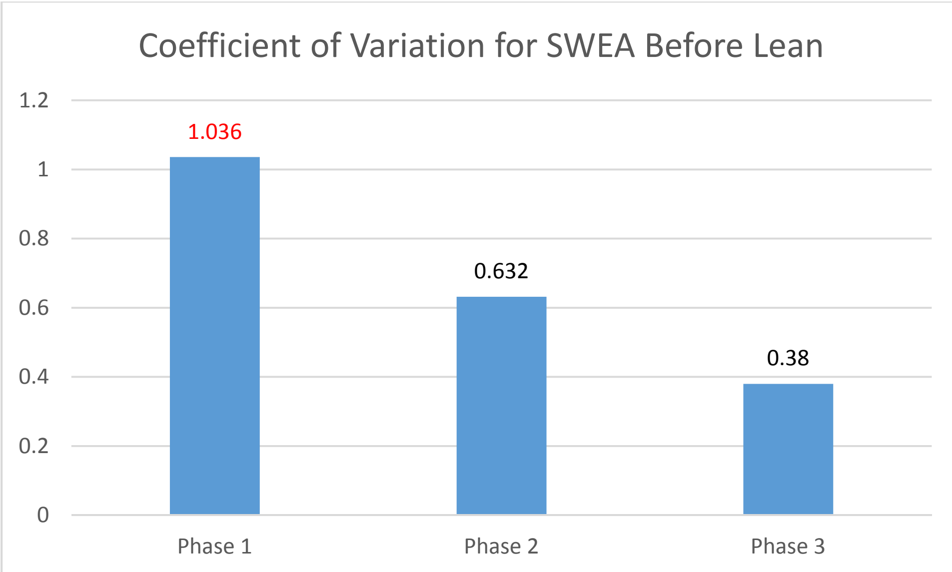


Chart 7: Coefficient of Variation of SWEA Before Lean Introduction

In *Factory Physics*, Hopp and Spearman define the classes of variation in Table 5:

Variability Class	Coefficient of Variation	Typical Situation
Low (LV)	$c < 0.75$	Process times without outages
Moderate (MV)	$0.75 \leqq c \leqq 1.33$	Process times with short adjustments (e.g., setups)
High (HV)	$c \geqq 1.33$	Process times with long outages (e.g., failures)

Table 5: Classes of Variability

Comparing the calculated coefficients of variation identifies Phase 1 as having moderate variation. As stated previously, the data collection does not allow us to calculate the rework in the system. Phase 1 is the first document review in the system of the SWEA. Historically, data was presented to the reviewer as it became available. This could be a phone call, verbal, or email. When the first fragment of data was submitted to the reviewer, the clock started. As the data became available, the generator would submit for review. This would result in incomplete as well as inaccurate data packages. Data would get misplaced or forgotten. If analytical sample results were involved, it could take six to eight weeks to receive the results. The analytical results may not meet the WAC and the waste would be ineligible for disposal in the ORR landfills. All the work performed to this point by EC and other employees was for null. The waste generator may or may not remember to tell associated departments of the waste ineligibility. The SWEA remains open and personnel continue charging billable hours against the project. All these circumstances contribute to the variability and excessive cycle times associated with Phase 1.

One of the Laws of Variation is corollary or variability placement. This law states that variability early in a routing will result in higher flow times than variability later in the movement. An effective means of reducing variation is standardization. Meetings were conducted with appropriate personnel to understand how the application is submitted and reviewed. The reviews were completed and the system revealed certain areas where Lean concepts could be implemented to improve the process. An electronic template was developed to capture all required information needed to successfully route the SWEA with the expectation of zero defects. Each generator had his own way of completing the form. Each organization voiced its expectations of what data is needed to successfully submit the form with zero defects. An electronic PDF was developed that would standardize the data requirements in the SWEA. The form allowed generators to complete the SWEA online and track the progress. The form also tracks the SWEA for essential departments to ensure the application is reviewed in a timely manner. Once the reviewer has electronically approved their part of the SWEA, it is automatically routed electronically to the next reviewer. Along with standardizing the process, the electronic form also establishes single piece flow. All associated data is stored within the form, eliminated data getting lost or misplaced. The electronic form restricts the SWEA from being submitted until all the data, characterization and calculations are complete. The electronic form also modifies the system from push to pull.

The reliability was measured in order to determine the current state of the bottleneck as well as a future state with Lean concepts implemented. If the reliability is effective in enabling a repeatable process, the process will be able to dispose of special waste in a more predictable fashion, reducing time, and reducing cost. The impact of reducing cost and time is enabling the company to identify cost savings, improving processes, and quality of life. In analyzing the reliability of a system, the supporting structure is analyzed. The supporting structure of a process includes: materials, equipment, people, and schedules. Figure 15 depicts the structure of the performance model in the reliability philosophy model.

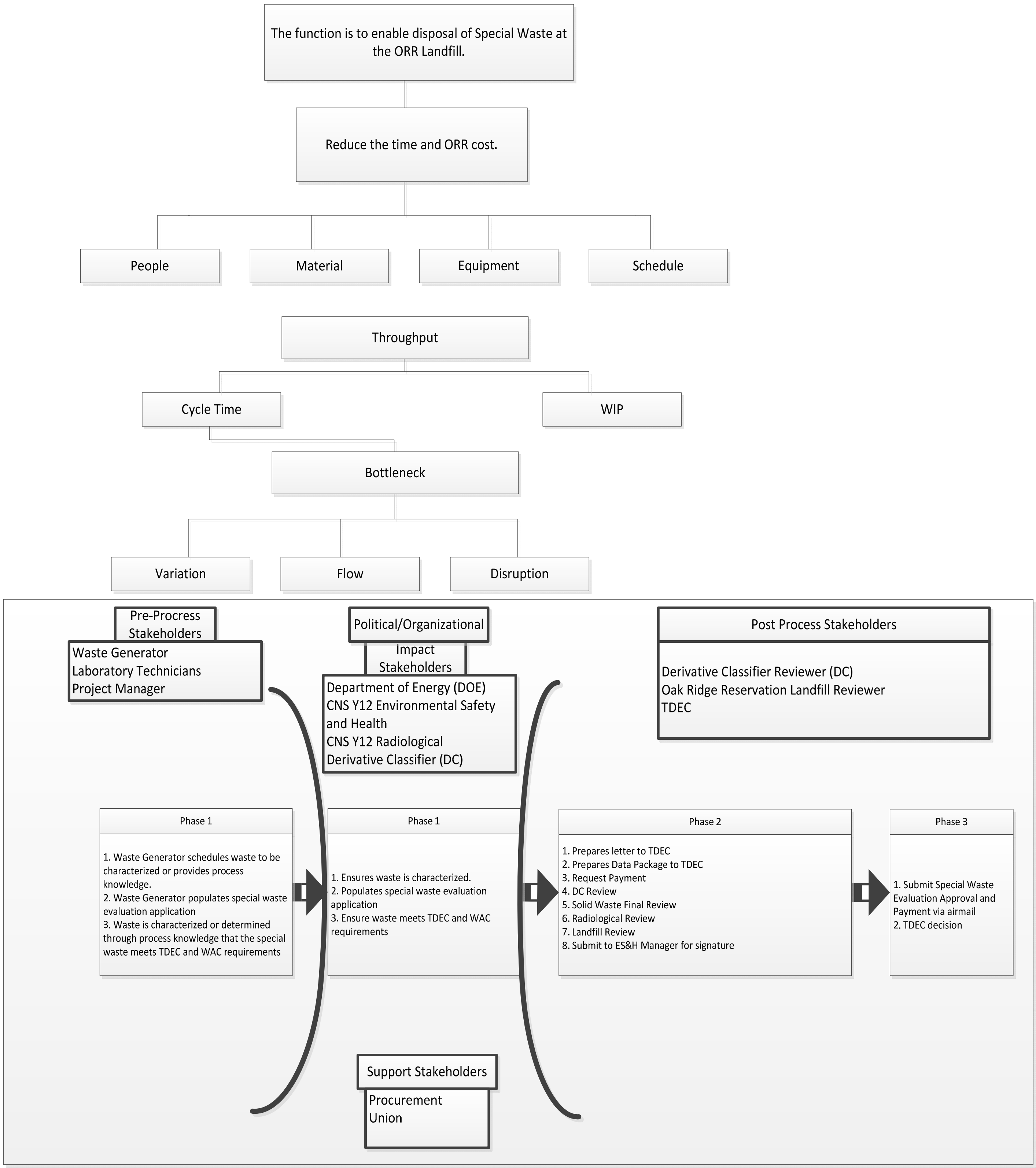
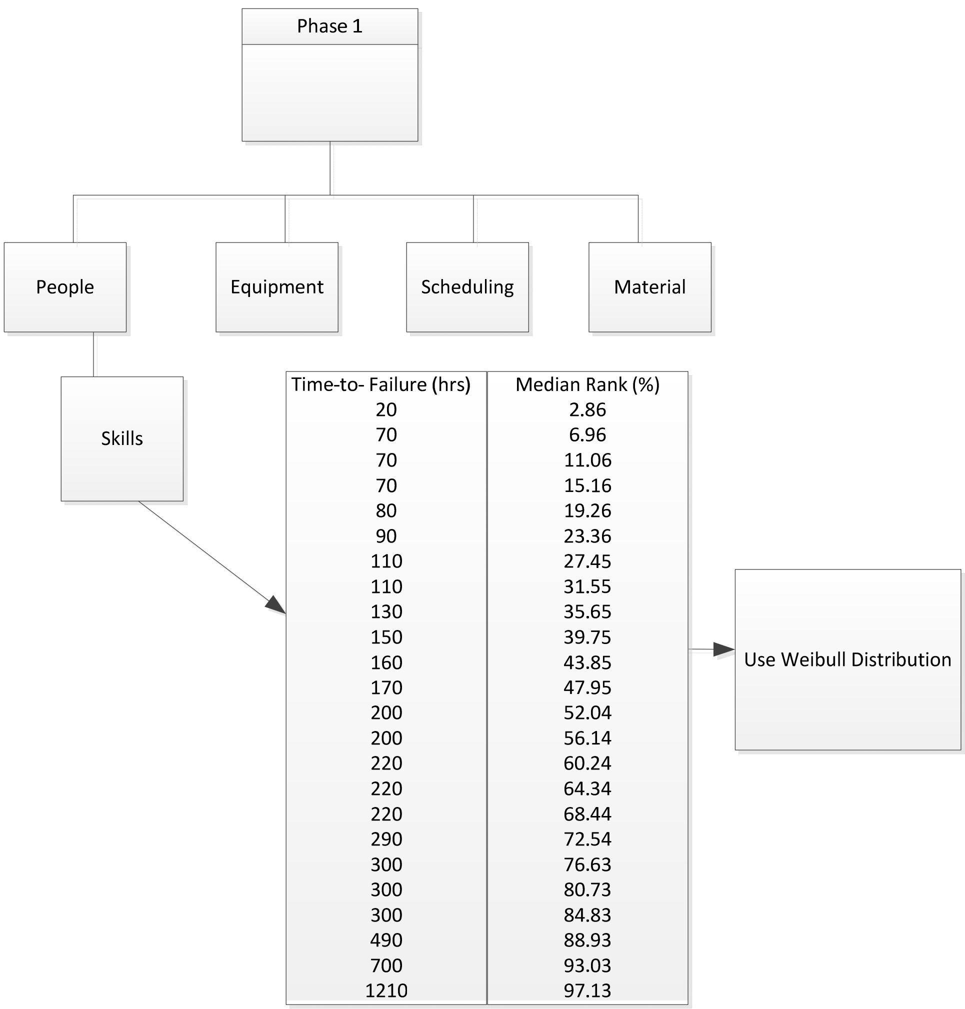


Figure 15: SWEA Performance Model

The bottleneck was the focus of the reliability analysis and was identified as Phase 1. Figure 16 depicts the analysis of the bottleneck process. The materials, equipment and schedules enabling the SWEA to be submitted and evaluated were considered to have an estimated reliability of 0.90. The structure around people in the bottleneck process were analyzed. The skill level of the waste generator submitting a SWEA was evaluated utilizing a Weibull distribution, displayed in Chart 8.



Time-to- Failure (hrs)	Median Rank (%)
20	2.86
70	6.96
70	11.06
70	15.16
80	19.26
90	23.36
110	27.45
110	31.55
130	35.65
150	39.75
160	43.85
170	47.95
200	52.04
200	56.14
220	60.24
220	64.34
220	68.44
290	72.54
300	76.63
300	80.73
300	84.83
490	88.93
700	93.03
1210	97.13

Figure 16: SWEA Comprehensive View of the Bottleneck Process

The review of historical data spent between the SWEA moving from Phase 1 to Phase 2 indicated variation. In order to determine the reliability of Phase 1 to Phase 2, a Weibull distribution was constructed. The time-to-failure was determined to be the amount of working hours between dates of arrival times. The time-to-failure was ranked in ascending order. The median rank was calculated and numbers were transferred to a Weibull distribution. The people's skill reliability was determined utilizing the reliability equation; $R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$. The people's skill reliability equation was determined to be: $R(40) = e^{-\left(\frac{40}{240}\right)^{1.2}}$ The reliability at time equal to 40 hours, or one work week, is 20.28%. The reliability of the people system was calculated by multiplying the estimated reliabilities of the equipment, materials, and scheduling in series or 0.9*0.9*0.9*0.2028 = 0.1478 or 14.78% reliable.

The reliability of the overall SWEA process can be calculated by multiplying the reliability of the pre-process reliability, Phase 1 reliability, Phase 2 reliability, and Phase 3 reliability. Reliability of the pre-process system, Phase 2 system and Phase 3 system were calculated assuming the reliabilities of people, equipment, materials, and scheduling are 0.90. 0.9*0.9*0.9*0.9 = 0.6561 or 65.61.

The reliability of the SWEA process before Lean implementation is calculated by multiplying all reliabilities of the processes together: 0.1478*0.6561*0.6561*0.6561 = 0.0417 or 4.17%. The reliability was measured after the electronic PDF was introduced into the bottleneck. The SWEA PDF will not proceed until the required documentation is attached. The skill level of the waste generator submitting a SWEA was evaluated utilizing a Weibull distribution.

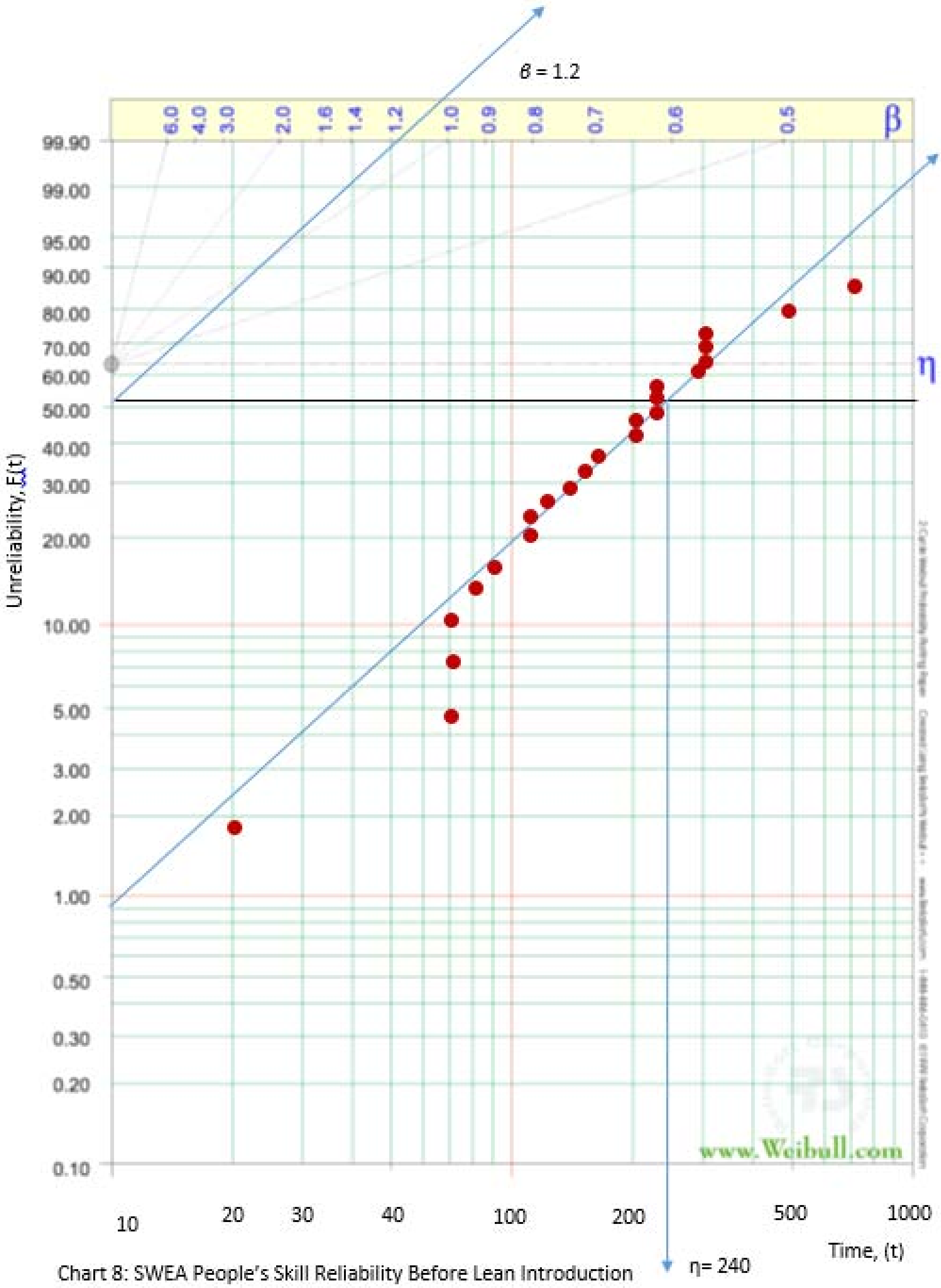
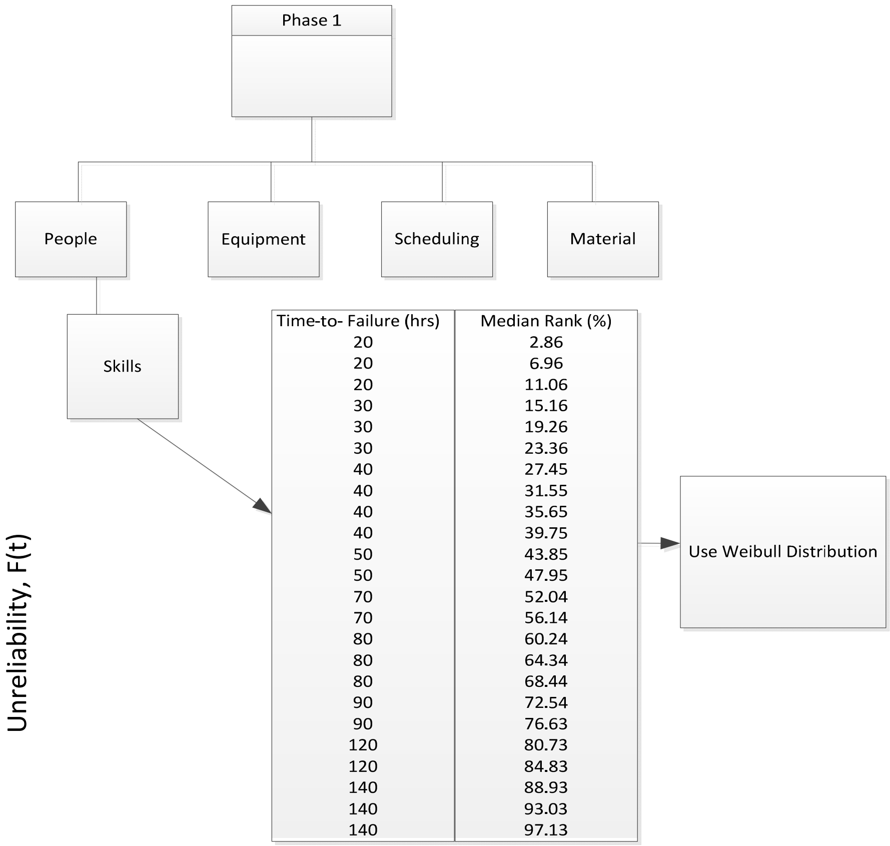


Chart 8: SWEA People's Skill Reliability Before Lean Introduction



Time-to- Failure (hrs)	Median Rank (%)
20	2.86
20	6.96
20	11.06
30	15.16
30	19.26
30	23.36
40	27.45
40	31.55
40	35.65
40	39.75
50	43.85
50	47.95
70	52.04
70	56.14
80	60.24
80	64.34
80	68.44
90	72.54
90	76.63
120	80.73
120	84.83
140	88.93
140	93.03
140	97.13

Figure 17: Comprehensive View of the Bottleneck Process after Lean Introduction

The time-to-failure was determined to be the amount of working hours between dates. The time-to-failure was ranked in ascending order. The median rank was calculated utilizing the Weibull distribution is displayed in Chart 9. The people's skill reliability was determined utilizing the reliability equation: $R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$ The people's skill reliability equals: $R(40) = e^{-\left(\frac{40}{78}\right)^{1.65}}$ When time equals 40 hours, or one work week, reliability is 57.09%. The reliability of the scheduling in series or 0.9*0.9*0.9*0.5709 = 0.4162 or 41.62%. The reliability of the SWEA process after Lean implementation is calculated by multiplying all reliabilities of the processes together: 0.4162*0.6561*0.6561*0.6561 = 0.1175 or 11.75%.

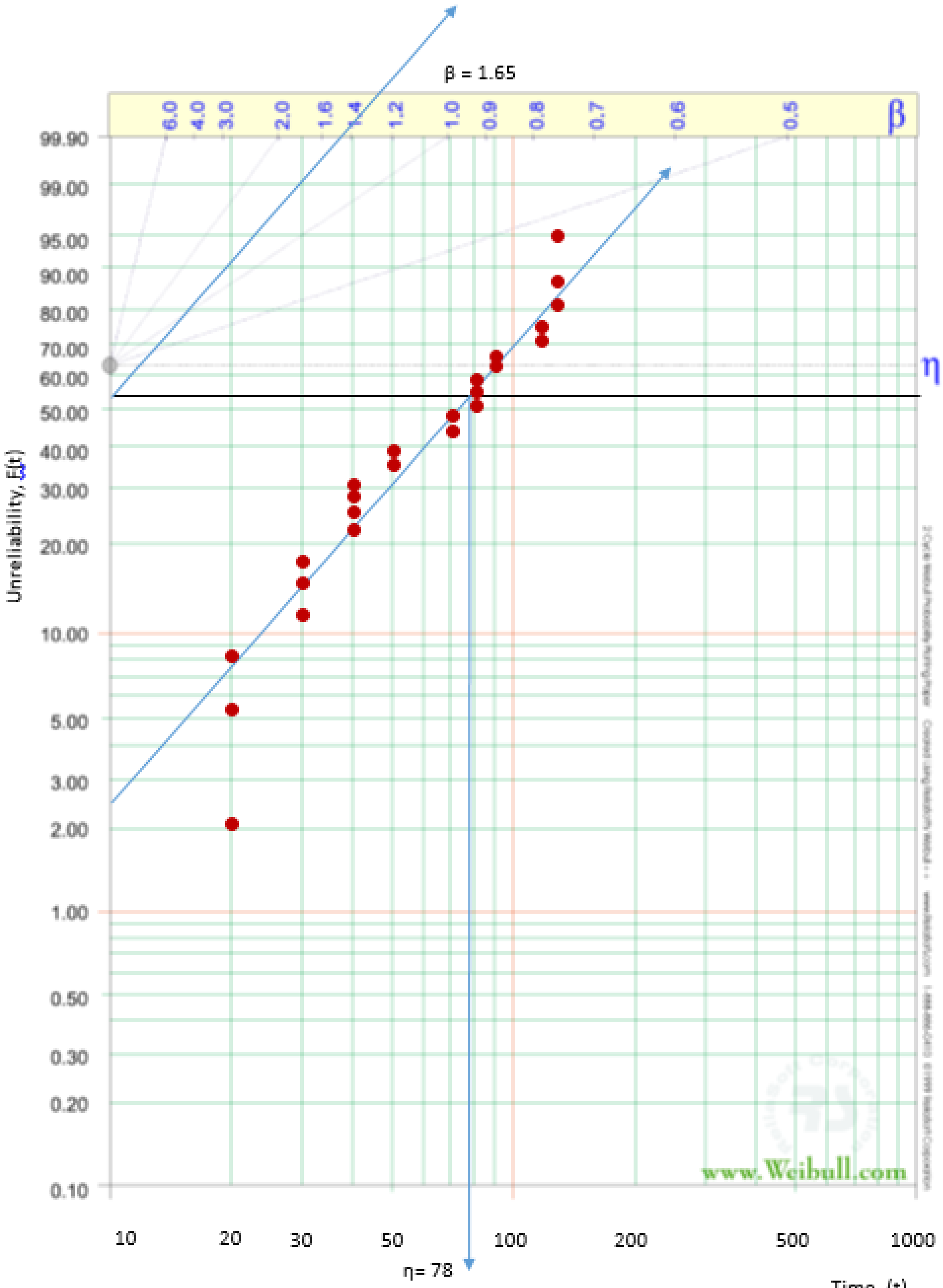


Chart 9: Skill Reliability After Lean Concepts Implemented

Table 6 reveals the transformation in reliability of the SWEA process after Lean concepts were introduced into the system.

System	Reliability Before Lean	Reliability After Lean
Phase 1 (Bottleneck)	0.1468	0.4162
Pre-Phase	*0.6561	*0.6561
Phase 2	*0.6561	*0.6561
Phase 3	*0.6561	*0.6561
Overall System	0.0417	0.1175

Table 6: Reliability Table. The reliability was determined by the calculated reliability for people and the *estimated reliability for schedule, equipment, and material.

The reliability of the SWEA process after Lean implementation is calculated by multiplying all of the reliabilities of the processes together: 0.4162*0.6561*0.6561*0.6561 = 0.1175 or 11.75%. The reliability analysis focused on the bottleneck process. The implementation of Lean concepts allowed an overall improvement of 26.83% in the SWEA process.

As modifications are considered to an impending system, a FMEA should be executed to expose potential weaknesses in the new system. A FMEA is a systematic approach in processes for analysis of potential failure modes within a system. The FMEA allows the system to be classified by severity of failure as well as the probability of failure. FMEA can help identify and eliminate concerns early in the development of a process. It is a systematic way to examine a process prospectively for possible ways in which failure can occur, and then to redesign the processes so that the new model eliminates the possibility of failure, (Smith, D.L.) The FMEA for the SWEA process is displayed in Table 7.

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s) of Failure	Prob	Current Controls	Det	RPN
Prepare and submit documents supporting SWEA for onsite disposal	Inaccurate calculations and incomplete data	Illegal disposal; Rework	7	Human error	8	Multiple discipline review; Standardized electronic form Procedure Y77-903 Waste Acceptance Criteria	2	**112**
Review document for eligibility for onsite disposal	Absence from Plant; Anomalous waste	Excessive response times; Illegal dispoal; Customer's full expectations may not be realized.	7	Human error	3	Waste Acceptance; CriteriaCross train personnel; TDEC Rules 0400-12-01-.03 through 0400-12-01-.07	5	**105**
Prepare official letter to TDEC; Submit form to SWC Manager for final review	Data entry error	Rework; Delays; Customer's full expectations may not be realized	4	Human reliability	2	Data verified by another operator (assumption)	1	**8**
SWC Management review	Absence from Plant; Anomalous waste	Delays; Customer's full expectations may not be realized	2	Human reliability	1	TDEC Rules 0400-12-01-.03 through 0400-12-01-.07 Cross train personnel	1	**2**
Radiological Data Review	Appropriate individuals not available.	Delays; Customer's full expectations may not be realized.	2	Human reliability	1	Cross train personnel	1	**2**
DOE Landfill Review	Appropriate individuals not available.	Delays; Customer's full expectations may not be realized.	2	Human reliability	1	Cross train personnel	1	**2**
ES&H Management signature for TDEC letter	Appropriate individuals not available.	Delays; Customer's full expectations may not be realized.	2	Human reliability	1		1	**2**
Submit SWEA to TDEC for Approval	Appropriate individuals not available.	Delays; Customer's full expectations may not be realized.	7	Human reliability	2	Contact TDEC personnel when SWEA is submitted; Submit electronic credit card payment	1	**14**
TDEC Response	Appropriate individuals not available.	Delays; Customer's full expectations may not be realized.	2	Human reliability	2	Respond via e-mail with multiple e-mail recipients	1	**4**

Table 7: FMEA for the SWEA Process

Team members assigned risks and rankings to the FMEA. The FMEA indicates that the first two cells in Phase 1 have the highest potential for failure. Phase 1 is also where the bottleneck and highest variation occur in the current SWEA system. Particular attention will be given to the stakeholders of these processes. Once key stakeholders are known, persons implementing the new requirements have the mission to develop an effective strategy for influencing them to support the new requirements.

An effective means to analyze complex decisions within a group is AHP. AHP is a prioritization tool used to make group decisions. AHP was developed in the 1980s by Thomas L. Saaty. The AHP uses a hierarchy configuration to define the goal, general criteria, and alternatives. Once the problem hierarchy is constructed, there is a pair-wise comparison between the criterions. The matrices are normalized and prioritized by the calculated values. Figure 18 is a schematic method to assess stakeholder's main concerns. The AHP allows persons implementing the new requirements to prioritize the key stakeholders. Table 8 provide insight into the AHP analysis process in prioritizing stakeholders.

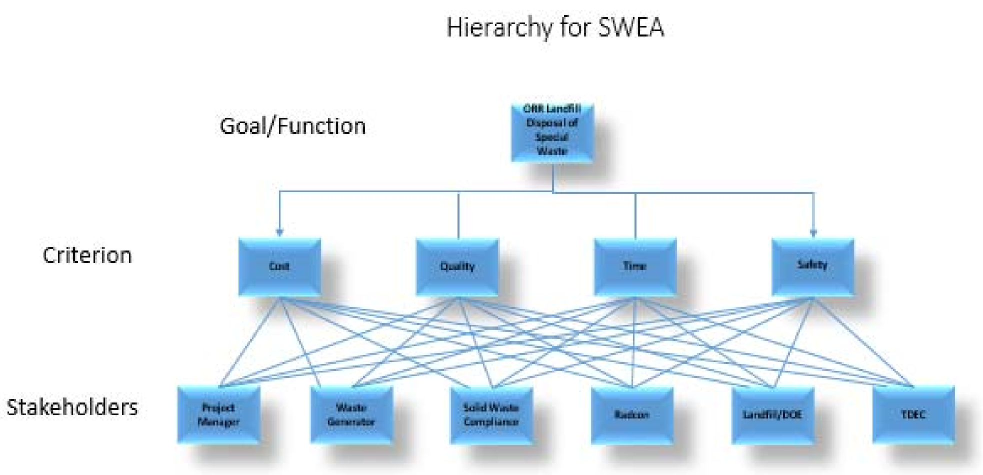


Figure 18: Hierarchy for SWEA

Criteria Priority	Cost	Safety	Time	Quality
Cost	1.0000	3.0030	0.2000	0.1429

Safety	0.3330	1.0000	0.1429	0.1111
Time	5.0000	7.0000	1.0000	0.3333
Quality	7.0000	9.0000	3.0000	1.0000
Sum	13.33	20.00	4.34	1.59

Normalized Matrix	Cost	Safety	Time	Quality	***Weights***
Cost	0.08	0.15	0.05	0.09	0.09
Safety	0.02	0.05	0.03	0.07	0.04
Time	0.38	0.35	0.23	0.21	0.29
Quality	0.53	0.45	0.69	0.63	0.57
Sum	1.00	1.00	1.00	1.00	1.00

Evaluation of Stakeholders	Cost	Safety	Time	Quality
Solid Waste Compliance	0.3	0.25	0.75	1
Waste Generator	0.75	0.25	1	0.75
Landfill/DOE	0.1	0.66	0.25	1
TDEC	0.1	0.25	0.5	1
Radcon	0.1	0.5	0.5	1
Project Manager	0.5	0.25	1	0.5
Sum	1.850	2.160	4.000	5.250

Solid Waste Compliance	0.162	0.116	0.188	0.190
Waste Generator	0.405	0.116	0.250	0.143
Landfill/DOE	0.054	0.306	0.063	0.190
TDEC	0.054	0.116	0.125	0.190
Radcon	0.054	0.231	0.125	0.190
Project Manager	0.270	0.116	0.250	0.095
Sum	1.000	1.000	1.000	1.000

Prioritized Stakeholders	
Solid Waste Compliance	18%
Waste Generator	20%
Landfill/DOE	15%
TDEC	16%
Radcon	16%
Project Manager	16%
Sum	100%

Table 8: SWEA Pair-wise Comparison

The prioritized stakeholder is calculated by multiplying the row of the stakeholders by the columns of the normalized weights of the criterion. Figure 19 displays the SWEA hierarchy pair-wise comparisons and the calculated priorities.

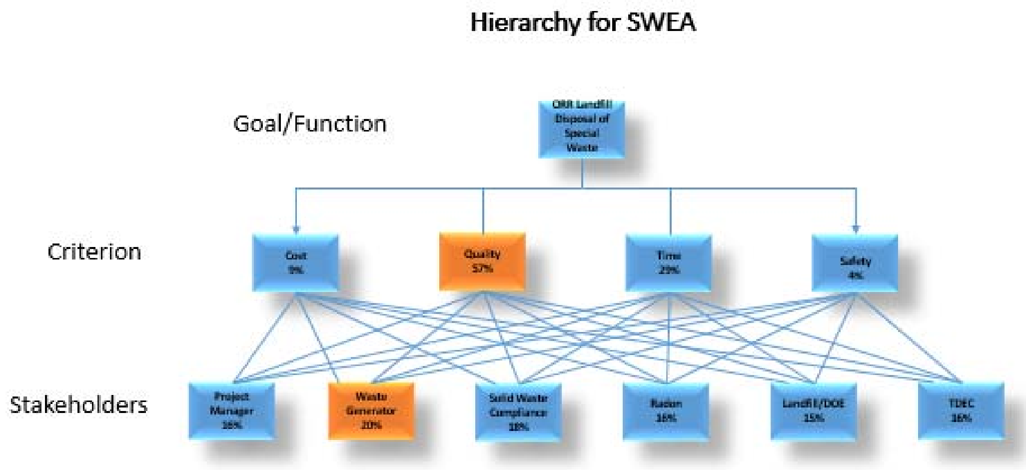


Figure 19: Hierarchy for SWEA

The most high-ranking criteria is quality. The most crucial stakeholder is the waste generator. The waste generators should be consulted prior to any modifications introduced to the SWEA. The team should concentrate on Lean techniques to increase the quality or reduce the amount of rework in the SWEA process. Once the system analysis, reliability and requirements for the SWEA have been evaluated, a future-state VSM reveals the Lean approaches that will be implemented to the SWEA process.

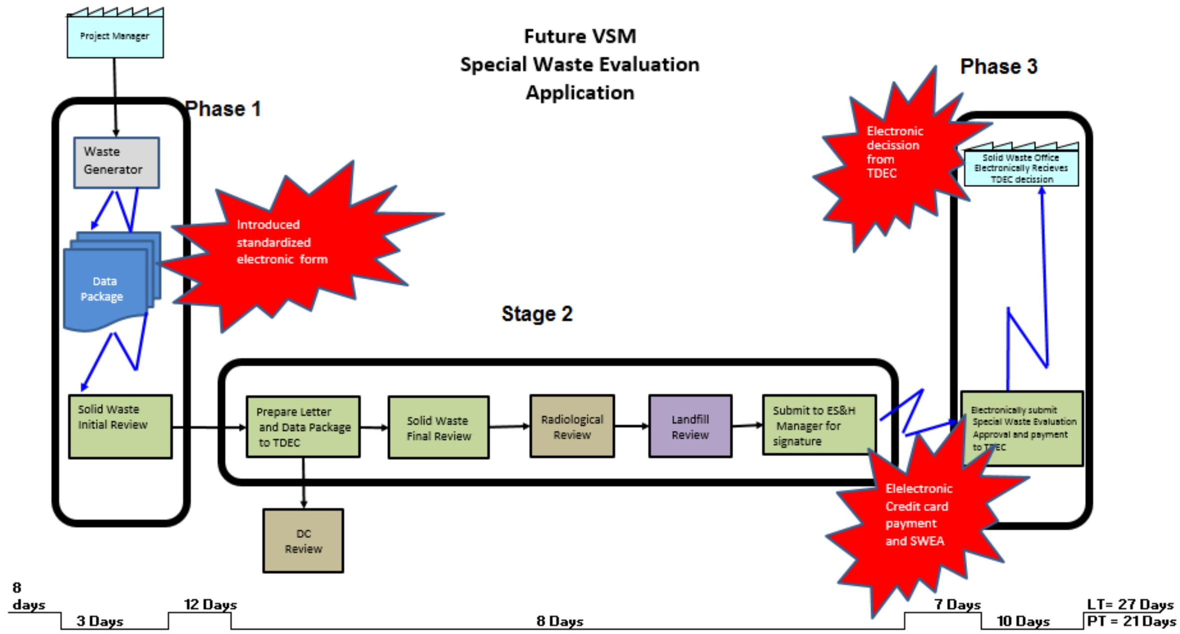


Figure 20: Future-State VSM

The first Lean tactic was to standardize the SWEA submittal process. There are several waste generators each having their own approach as to how the data package for the SWEA should be completed. The electronic form standardizes the process and also changes the process to a single-piece flow and creates a pull system. The PDF also tracks the progress and alerts multiple personnel of the SWEA if someone is away from the office. The tracking progress and alerting multiple personnel of the SWEA is enabling the implementation of a pull system versus a push system. Below shows the coefficient of variation before and after Lean was implemented. Chart 10 reveals that the Lean tactics reduced variation in every phase of the process.

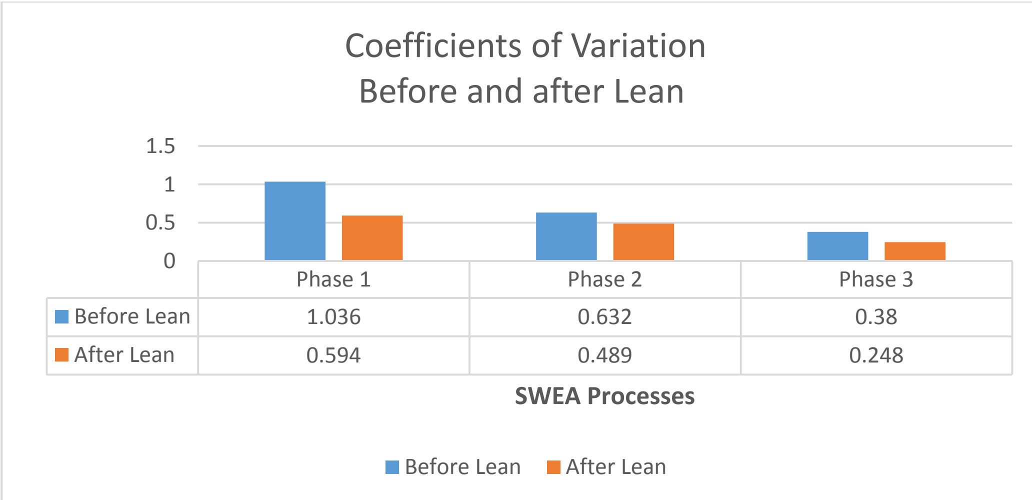


Chart 10: SWEA Coefficients of Variation

In addition to the electronic form at the bottleneck, we eliminated the non-value added steps of requesting, generating, and mailing checks to TDEC for the payment of fees associated with TDEC reviewing the SWEA. Another non-value added step removal was eliminating sending the SWEA data package via USPS. The implementation of Lean concepts allowed the elimination of four steps and reduced the time taken for TDEC to receive the SWEA. The mean lead and cycle times both before and after Lean was implemented and is displayed in

Chart 11.

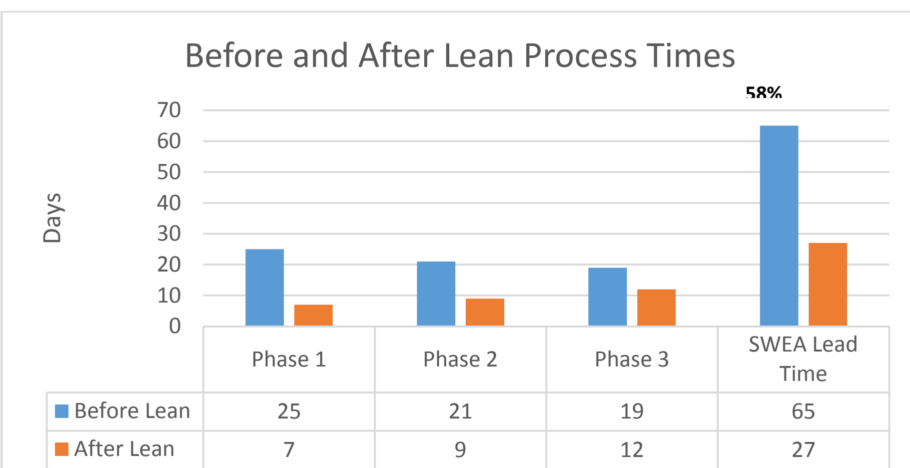


Chart 11: Before and After Lean Process Time

The results displayed in Chart 11 indicate that the Lean treatments indeed reduced the lead time for the SWEA. Our null hypothesis is H_0: The difference in the before and after means is not attributed to Lean treatments. The ANOVA results in Table 9 will either confirm or deny the effectiveness of the Lean treatments.

ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Completion Time Before Lean Concepts (days)	24	1552	64.66667	1170.667
Completion Time After Lean Concepts (days)	24	682	28.41667	51.73188

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F stat*	*P-value*	*F crit*
Between Groups	15768.75	1	15768.75	25.79969	6.73E-06	4.051749
Within Groups	28115.17	46	611.1993			
Total	43883.92	47				

Table 9: ANOVA Single Factor Analysis

The ANOVA concludes that F statistical is greater than F critical and therefore, we reject the null hypothesis. The differences in the means before and after Lean treatments were attributed to the systematic Lean approach to the SWEA. To ensure the Lean treatments are sustainable, the following KPIs were selected to monitor the progression of the SWEA. Table 10 represents the most current KPIs of the SWEA process.

Metrics Indicators	Before Lean	After Lean	Change
Time (Mean Lead Time)	65 Days	27 Days	38 Days
Annual Cost*	$133,714	$55,543	$78,171
Quality (Reliability**)	0.1468	0.4162	0.2694
Complexity (Number of Steps)	13	9	4

Table 10: Metrics Indicators

* Annual Cost = (Number of employees) * (Pay rate) *(Hours charged to the project/wk) * (Mean lead time) * (Number of SWEA completed/yr)

** Reliability was calculated for the bottleneck only

Conclusion

Lean can be a powerful tool for process improvements. Initially, Lean was developed in the automotive industry, our capstone confirms if can also be effective in an office environment. Waste can occur in any process within any environment. If we look at the seven wastes in Lean Manufacturing, displayed in Table 11, they can easily be applied to an office system.

Waste	Office Examples
Transport	Unnecessary routing of documents
Inventory	Excess email messages
Motion	Looking for needed files or data
Waiting	Work waiting to be reviewed, approved, and forwarded to the next step
Overproduction	Doing unnecessary work
Over-Processing	Providing more detailed documentation than needed
Defects	Errors in documents and redundancy in data checking

Table 11: Examples of Waste in an Office System

A systematic Lean approach was applied to an office document at Y-12 to demonstrate the effectiveness of Lean in any environment. A team of SMEs were assembled to review the system. To ensure a positive outcome, stakeholders were involved early. Involving stakeholders early will create a better acceptance of changes that may affect the way their job is performed. The capstone evaluated the current VSM and arrival times to each phase of the system. The results showed the greatest variation to be in Phase 1. After speaking with personnel associated with Phase 1, the variation was believed to come from the amount of rework involved with SWEA. One Lean tactic to reduce variation is to standardize the process. This capstone created an electronic form to standardize the way information was submitted. The VSM also revealed a process improvement by implementing electronic payment and electronically receiving approvals from TDEC.

Our team worked with information technology (IT) personnel to implement these improvements in the SWEA process. Metric indicators were developed to monitor the effectiveness of Lean in the process.

To date, the team saw a reduction in lead time of 58% and an annual cost was reduction of 42%. In addition to these improvements the reliability of Phase 1 (where the bottleneck occurred) increased by 26% and the number of steps was reduced from 13 to 9.

The team will continue to monitor the key performance metrics and practice continuous improvements. A system can always be improved and satisfaction increased in personnel as well as customers. A system can be a production or an office environment. Just because the system is within an office setting does not mean you have to limit Lean concepts to Kaizen or VSM. Any Lean tool that is effective in a manufacturing environment effectively can be implemented within an office environment.

Appendix A

The FMEA rating systems are as follows:

Effect	SEVERITY of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	**10**
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	**9**
Very High	System inoperable with destructive failure without compromising safety	**8**
High	System inoperable with equipment damage	**7**
Moderate	System inoperable with minor damage	**6**
Low	System inoperable without damage	**5**
Very Low	System operable with significant degradation of performance	**4**
Minor	System operable with some degradation of performance	**3**
Very Minor	System operable with minimal interference	**2**

PROBABILITY of Failure	Failure Prob	Ranking
Very High: Failure is almost inevitable	>1 in 2	**10**
	1 in 3	**9**
High: Repeated failures	1 in 8	**8**
	1 in 20	**7**
Moderate: Occasional failures	1 in 80	**6**
	1 in 400	**5**
	1 in 2,000	**4**
Low: Relatively few failures	1 in 15,000	**3**
	1 in 150,000	**2**
Remote: Failure is unlikely	<1 in 1,500,000	**1**

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	Design control **cannot** detect potential cause/mechanism and subsequent failure mode	**10**
Very Remote	**Very remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**9**
Remote	**Remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**8**
Very Low	**Very low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**7**
Low	**Low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**6**
Moderate	**Moderate** chance the design control will detect potential cause/mechanism and subsequent failure mode	**5**
Moderately High	**Moderately High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**4**
High	**High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**3**
Very High	**Very high** chance the design control will detect potential cause/mechanism and subsequent failure mode	**2**
Almost Certain	Design control **will** detect potential cause/mechanism and subsequent failure mode	**1**

Appendix B

Pairwise Comparison Scale

Verbal judgment	Numeric value
Extremely important	9
	8
Very Strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

Appendix C

Special Waste Evaluation Application Electronic Form

Special Waste Application Evaluation Request

Date*
10/02/2017

Requester*
ELIZABETH OWENS

Email Address*
elizabeth.owens@cns.doe.gov

Badge*
037736

Charge Number*

Volume (Cubic Yards)*

Description of Waste*
Physical form, color, container?

Select Radiological Characterization Statement*
Must select one

Prohibited Items
Select all that apply

- ☐ PCB Bulk Product
- ☐ PCB Detectable
- ☐ No PCB by PK or Analysis
- ☐ No RCRA by PK or Analysis

Other Documentation

Sampling Analysis Plan (SAP) if applicable

Sampling Analysis Plan (SAP)
Browse...

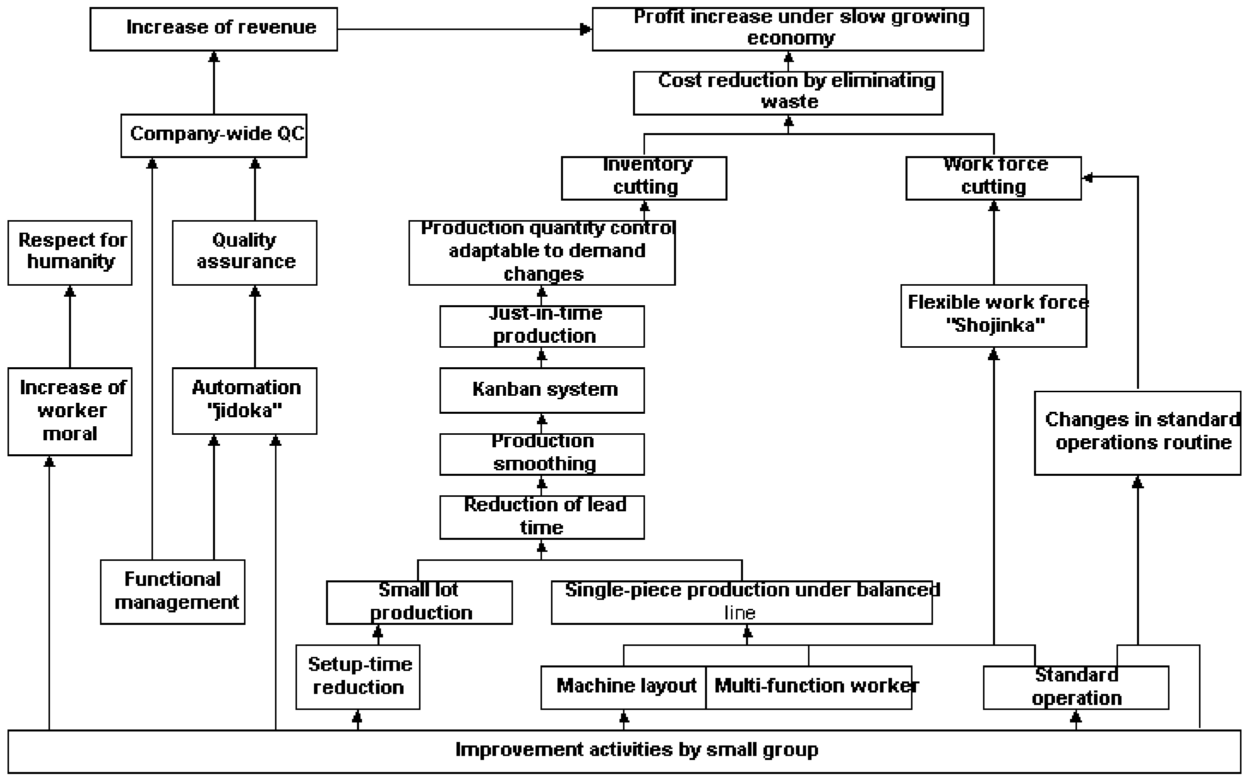
Additional Documentation
Pictures, letters, etc.

+ Add Document

Submit

Appendix D

Toyota Production System



Toyota Production System (1998), Yasuhiro Monden

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