A LEAN SYSTEMS APPROACH TO IMPROVING MAINTENANCE OUTPUT AND CONFIGURATION MANAGEMENT

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MS INDUSTRIAL ENGINEERING CAPSTONE PROJECT

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ABBREVIATIONS

ADO – Assembly/Disassembly Organization

AHP – Analytical Hierarchy Process

C/V – Coefficient of Variation

CNS – Consolidated Nuclear Security, LLC

CT – Cycle Time

DOE – Department of Energy

FMEA – Failure Modes Effects Analysis

JHA – Job Hazzard Analysis

KPI – Key Performance Indicators

PMT – Post Maintenance Test

TH – Throughput

TPS – Toyota Production System

WIP - Work in Process

CHAPTER 1: INTRODUCTION

ABSTRACT

The purpose of this capstone paper is to apply a lean systems approach to the current maintenance planning program in the Assembly/Disassembly Organization. This capstone will take a two-pronged approach to address both output rate in maintenance planning and accurate configuration management resulting from maintenance work orders. In short, the current system suffers from waste in the planning process due lack of procedures to address varying maintenance packages, including maintenance packages which include changes to configuration managed systems. The capstone will detail a lean systems approach to proper characterization of maintenance jobs and integration of change management into the maintenance process in order to retain proper control of the systems used to produce in this nuclear facility.

BACKGROUND

At the time which this was written, the current corrective maintenance execution work control and planning is under the direction of the Department of Energy (DOE) and several procedural documents that are intended to ensure precision and safety of all maintenance operations. The documents of focus for this capstone are Y18-012 and Y15-0187, which are the Integrated Work Control Manual and Integrated Change Control Management Manual respectively. Y18-012 defines the work control and planning for Y-12. The three methods defined by the procedure are Complex work, Minor Work, and Dispatch work. Document Y18-012 describes each one as the following:

Complex Work: Complex work by definition requires more formal planning and coordination than minor work. Complex work is used to document step by step compliance. Complex work is also used to aid the worker when multiple requirements documents are required for a given scope of work. For example, compiling requirements from a Job Hazard Analysis (JHA), permit, work steps, and quality inspections into a single, easy to follow work instruction document.

Minor Work: Work that involves a work scope that is bounded by written criteria, such that workers can perform the work using existing skills or qualification with minimal work instructions. Like Dispatch work, workers are responsible for implementing safe and compliant work practices based on their training, qualification, or certification. The scope statement of the Minor Work package generally provides enough detail for the performance of the work, but some level of documentation is needed in addition to the scope of work. This additional documentation could be a Job Hazard Analysis (JHA), permit, sketch, etc.

Dispatch Work: Work that involves a work scope that is predefined in a list of Pre-Approved dispatch work, such that workers can perform the work using existing skills or qualification with no specific work instructions. Workers are responsible for implementing safe and compliant work practices based on their training, qualification, or certification. The scope statement of the job provides enough detail for the performance of the work. Formatted instruction steps are not used.

Document Y15-0187 outlines the process for maintaining configuration control of selected systems throughout the complex. This manual is based upon a directive by the DOE and is ultimately based on the grade of a selected system. The grading system at Y-12 is based on a scale of 1-4 with a grade 1 system being the most controlled system and a grade 4 system being a minimally controlled system (such as process water or a utility). Systems that are given a grade are required to go through an evaluation process before being modified in order to determine that the modification will not result in an adverse condition of system. Additionally, this process is used in order to trace changes to a graded system and ensures that documents are maintained appropriately in order to keep accurate records of system configuration. These documents retain importance throughout the life of the facility as they are records of new installations, change of manufacturer or model for parts, and updates to facility drawings or records reflecting these changes.

PROBLEM

To begin, maintenance execution planning at Y-12 is currently a cumbersome process, particularly in the Assembly and Disassembly Organization. The process includes planning and maintenance work control which is administered by procedures and control documents per order of the Department of Energy (DOE). This process has adapted and changed throughout the 75 years of Y-12's existence, but the effects of each implementation on the systems and processes as a whole have not been thoroughly dissected. This creates issues that cause frustration with everyone from planning and maintenance to engineering and production. Most of the frustration from planning and maintenance stems from the unnecessary complexity of change packages and time wasted due to lack of communication/traceability. Engineering and production are unsatisfied with the amount of equipment downtime, execution reaction time, and the lack of traceability of work packages. This causes a lot of stress for each stakeholder involved, which in turn impairs employee performance, which costs the company money. At the time this was written, there were only two qualified planners in the facility. This meant that the two planners worked long hours each day, including weekends. They were under tremendous pressure to complete the planning of job packages, and had to be on call in case there were any revisions to be made if a situation arose mid-job. Additionally maintenance packages which included changes to a graded system added a further layer of complexity due to the fact that the change requests and work orders are tracked separately. The outcome of this disjointed system is that the change request process or status is not known to the planner and is only available through direct communication with the system engineer. Speaking personally with each planner, both agreed on the need for additional planning resources and displeasure with the waste inherent in the current system which lead to increased workload and opportunities for mistakes due to lack of a transparent and linear planning process.

Another big problem is that currently there is little to no traceability of maintenance planning packages. Often times, packages will be put on hold due to waiting on permits, signatures or, questions, and no one is notified directly of this. It is necessary to integrate a level of automation that will notify invested stakeholders of each package's progress. This creates frustration for the planners, system engineering, maintenance, and production. This will greatly shorten the amount of time it takes to complete maintenances package planning from start to finish and ensures documentation of changes made to the system.

HYPOTHETICAL SOLUTION OVERVIEW

This capstone looks to apply system and process improvements that cause a reduction in variability which in turn will reduce cycle time and waste, increase equipment availability and throughput, and increase transparency and traceability of the process. The goal is to increase maintenance wrench time, improve work package traceability, and enhance system reliability by identifying system bottlenecks and waste. By succeeding in making these improvements, not only will the company as a whole be more successful, but the overall wellbeing of each individual stakeholder will be enhanced. The implementations used will be based on and supported by philosophies and concepts learned through lean manufacturing, reliability, and systems courses contributing to the Masters of Industrial and Systems Engineering cohort through the University of Tennessee Knoxville under the direction of Dr. Rapinder Sawhney. The applied principles include systems thinking, reliability, and lean manufacturing.

CHAPTER 2 – RESEARCH

Performing a literature review showed different techniques and methods that are used in application to process work control and maintenance planning processes. The sources provided will provide some reinforcing information and insight into the different methods that are currently used in maintenance planning programs throughout the industry. A brief description of each source and its application to this capstone will be provided.

Nyman and Levitt say that most maintenance departments do not plan to fail; they simply fail to plan and therefore do indeed fail. The major reason behind failure to plan is that putting out today's fires is given priority over planning for tomorrow. This approach all but ensures that future equipment failures will require reactive responses (ample supply of kindling to be consumed in future reactive fires). Secondary jobs are constantly put first by default. Doing secondary jobs may not be bad-but when we reach the point of putting the twelfth job first, we are in trouble. Reactive maintenance is simply a vicious circle, a continuous downward spiral. (Nyman and Levitt, 2010)

Nyman and Levitt also say that planners must be allowed to focus on tomorrow rather than being caught up in today. Well-planned, properly scheduled, and effectively coordinated jobs can be accomplished more efficiently, at lower cost, with fewer disturbances of operations, higher quality (reduced variability of processes), improved morale with greater job satisfaction, increased longevity of equipment, and reduced parts usage. (Nyman and Levitt, 2010)

A final note from Nyman in Levitt is that craftsmen have no prior knowledge of the detailed job task breakdown. Instead, they are left to decide how to do the job and what materials are required. They then either leave the job site to source materials from the storeroom or stand by and wait for them to be delivered. Even more disruptive is when after a job is started, it is discovered that some required parts or materials are not in stock and must be purchased outside the plant with extra cost for express delivery. The job is halted in a state of disassembly waiting for the items to arrive. (Nyman and Levitt, 2010)

Dr. Rapinder Sawhney, Karthik Subburaman, Christian Sonntag, Prasanna Rao Venkateswara Rao, and Clayton Capizzi suggest using the modified FMEA as a way to allow the lean practitioner to evaluate the reliability of lean systems. Their approach is focused on the four critical resources that are required for lean systems. These resources are people, equipment, materials, and schedules. (Sawhney, Subburaman, Sonntag, Venkateswara Rao, and Capizzi, 2010)

Terry Wireman offers some high level insights into goals for a lean maintenance strategy. He states that lean concepts are usually only applied to production settings, but that they concepts are just as important, if not more important, to maintenance applications due to the cost savings involved. He states that most maintenance organizations only have approximately 20% average wrench time, and that even the best-in-class organizations average only 60%. He also mentions that reducing redundant and unnecessary procurement items could substantially reduce cost for maintenance organizations. Most importantly, he mentions, is that in order to implement these improvements, a culture change is needed within the organization. (Wireman, 2009)

Sherif Mostafa, Sang-Heon Lee, Jantanee Dumrak, Nicholas Chileshe, and Hassan Soltan agree that, like Wireman mentioned above, lean concepts have not been implemented in maintenance applications as much as they have been in production and manufacturing industries. The authors propose a five step process to applying lean concepts to a maintenance strategy. This process includes:

- Step 1: Educate the employees on the types of waste that could potentially be in their system.
- Step 2: Map the value stream. Use this as a map to identify value added and non-value added activities in the system.
- Step 3: Create flow. After removing wasteful activities, ensure that the flow of the remaining steps runs smoothly.
- Step 4: Establish Pull. A pull-based system allows for Just-in-time delivery and manufacturing where products are created at the time that they are needed and in just the quantities needed.
- Step 5: Pursue Perfection. This requires a culture change within the organization. Each individual employee from the top down must strive to achieve a waste-free environment in their everyday processes.

The above-mentioned steps are essential in creating a culture change within an organization. Using these steps, they created the House of Waste. (Mostafa, Lee, Dumrak, Chileshe, and Soltan, 2015)

Idhammar points out eight key areas where maintenance could reduce waste within their organization. These areas include:

- Equipment reliability
- Partnership between operations, maintenance, and engineering
- Root cause problem elimination
- Spare parts material
- Use of increased knowledge
- Precision planning and scheduling
- Too much maintenance

- Use of new technology

Most of these key points are mentioned in this capstone in one way or another. Equipment reliability speaks for itself. The goal is to maintain the equipment in a way to limit disruptions. Team oriented focus between operations, maintenance, and engineering is very important in accomplishing goals and aligning with lean focus. Root cause problem elimination focusses on solving the problem rather than band-aiding it. Spare parts material deals with maintaining the proper about of spare parts, and having the correct parts in inventory. Too much maintenance deals with cutting out activities that don't need to take place such as increasing interims between preventative maintenance. Replacing old equipment with new is sometimes a viable option when the cost of maintaining old equipment exceeds the cost of buy new. The focus of this paper, however, will be on precision planning and scheduling. (Idhammar, 2008)

CHAPTER 3 – Methodology

An iterative model is defined as a model that is repeated as it progressively gains more and more complexity and refinement until the final system is complete. An iterative model was developed which incorporated the principles of systems thinking, lean manufacturing, and reliability engineering. These principles are confirmed using other tools learned such as statistics, economics, and system optimization. The developed model offers a systematic and repeatable method that assists in the understanding of the system, and also helps make system improvements. The iterative model consists of three stages. The first stage is where the system is defined. This can include stakeholders, value stream and process mapping, system requirements, etc. The second stage is where the system is analyzed. In this stage the system is dissected using systems, lean and reliability analysis. And finally, the third stage is where a new and improved system is designed and analyzed. This is where the future characteristics of the new system are laid out including recommended improvements, new value stream and process maps, and final conclusions. Since the model is iterative, this means that each stage is repeated with the expectation that the system improves from one iteration to the next.

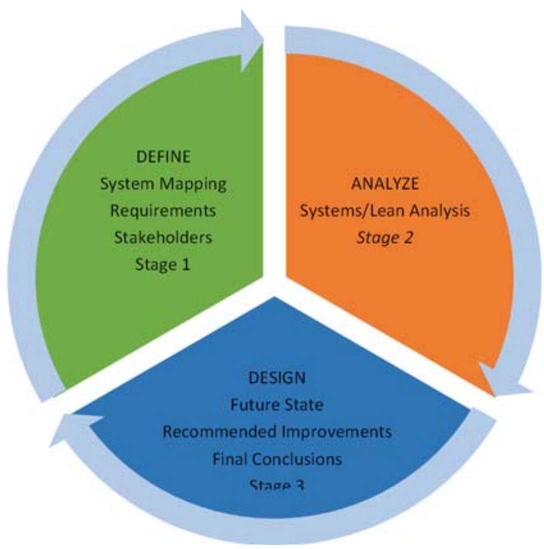


Figure 1 - Detailed Iterative Model

STAGE 1: DEFINE THE SYSTEM

An overview of the definition of a system was outlined previously in the paper. For the purpose of the capstone the system will be defined according to the elements below:

1. Elements – the physical elements of a system. For this system the elements include: Maintenance employees, Planners, System Engineering, Change Administrators, and Equipment.
2. Interconnections – how the elements and entities interact within the system. The interaction of the system elements will be explored using a system diagram shown below.
3. Function – the overall objective of the system. The overall objective of this system is to provide timely maintenance activities in order to:
    a. Increase equipment availability
    b. Retain proper configuration control over graded systems

After identifying the components of a system, the key performance indicators (KPI) are identified. The KPIs are used to measure the current state of the system, which is used as a baseline for improvements to be measured against. The key performance indicators in the case of this study are quality, accuracy, cycle time, employee morale, compliance, and equipment availability.

With these indicators in mind a high-level value stream map will be constructed. This value stream map as stated will be high level and not necessarily delve into the details of each process. However, by creating this value stream map the bottleneck of the overall process will become apparent. With the bottleneck identified the processes inside of the bottleneck step can be analyzed further using a stock and flow diagram. Within the bottleneck step of planning a specific focus will be placed on the following forms of waste identified as part of the Toyota Production System:

Faster-than-necessary pace: creating too much of a good or service that damages production flow, quality, and productivity. Previously referred to as overproduction, and leads to storage and lead time waste.

Waiting: any time goods are not being transported or worked on.

Conveyance: the process by which goods are moved around. Previously referred to as transport, and includes double-handling and excessive movement.

Processing: an overly complex solution for a simple procedure. Previously referred to as inappropriate processing, and includes unsafe production. This typically leads to poor layout and communication, and unnecessary motion.

Excess Stock: an overabundance of inventory which results in greater lead times, increased difficulty identifying problems, and significant storage costs. Previously referred to as unnecessary inventory.

Unnecessary motion: ergonomic waste that requires employees to use excess energy such as picking up objects, bending, or stretching. Previously referred to as unnecessary movements, and usually avoidable.

Correction of mistakes: any cost associated with defects or the resources required to correct them.

The value stream map will be used to calculate the KPIs, and the results will be used to guide the improvements that can be made to reduce WIP and Cycle Time, and increase Throughput. This will be done by identifying the variation in the process, and working to reduce the variation. Using the value stream map, it will be possible to identify the system's bottleneck process, and work to improve it.

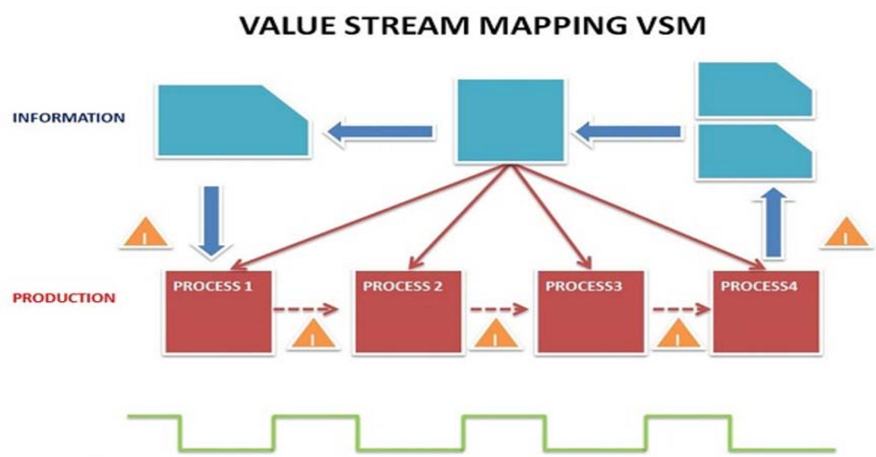


Figure 2 – Value Stream Map Example

Next, the created value stream map will be used to create a list of process stakeholders. The first group of stakeholders identified are part of the bottleneck area of the process. The second group of stakeholders identified are part of the pre-process. The pre-process stakeholders must incorporate change in order to improve the bottleneck. The third group of stakeholders identified are the post-process stakeholders. They will most likely be affected most by the process improvement. This group will include the customer who must be able to handle the enhanced throughput. The fourth group of stakeholders identified are ones necessary to aid the process improvement. Finally, the fifth group of stakeholders are those that have a high impact on the process improvement. This group includes upper management and political affiliates. The stakeholders are then ranked by their level of impact on the system. This is best done using a Failure Modes Effects Analysis. The FMEA will help identify the critical failures of the system, which will then help rank the critical stakeholders needed to develop improvements to the system. After the critical stakeholders are identified, the analyst(s) will hold a meeting so that each stakeholder can voice any concerns, comments, or suggestions that will aide in the process improvement. The Nominal Group Technique is widely suggested. This will prevent duplicate requirements, which will help rank the requirements. The earlier this ranking is done within the group of stakeholders, the better. This will prevent a lot of problems down the road.

2: ANALYZE THE CURRENT SYSTEM

Now that the current system has been defined, the system should be analyzed. To start, a stock and flow diagram will be created. Stocks are elements that can be seen, felt, or measured. Flows are used to manipulate stocks throughout a time period. The flows are controlled using feedback loops, which are actions that can balance or reinforce the stocks. Certain feedback loops have a greater influence on the system, these are referred to as Dominant Feedback Loops. Once these dominant feedback loops are identified, it is necessary to identify the three characteristics of the system which make it successful. The three qualities of highly functioning systems are Resilience, Self-Organizing, and Hierarchy. Resilience is a system's ability to survive and persist within a variable environment. Self-Organizing is the ability of the system to learn, store, and change. Hierarchy is the structure used to rank the entities within a system according to impact or importance (Sawhney, 2018).

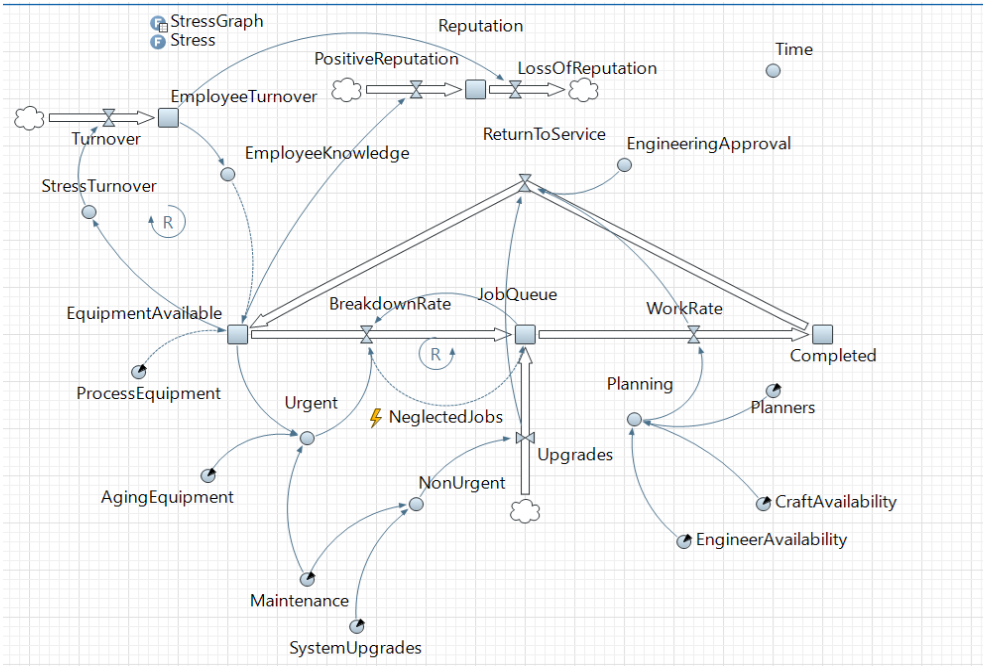


Figure 3 Stock and Flow Diagram Example- use actual generic example here

LEAN ANALYSIS

In continuing the analysis of the model, it is important to apply the Toyota Production System (TPS) principles. The TPS is the roadmap used to apply the three main principles of lean manufacturing. (Hopp & Spearman, 2011) The three principles of Lean Analysis are Reduce Cycle Time, Reduce Variation, and Improve the Quality of Human Life. By utilizing the TPS roadmap, the ultimate goal is to work towards single piece flow within the system, creating balanced conditions and reducing or removing waste, variation, and disruption (Sawhney, 2018).

RELIABILITY ANALYSIS

Reliability is defined as a system's or component's ability to perform its required function over a period of time, under specified conditions. (Sawhney, 2019) The first step includes calculating the theoretical capacity of the system. The theoretical capacity would be the amount of production achieved if the system was functioning perfectly without variation or disruption. If the system requires maintenance, then it is assumed maintenance is required to keep the system functioning. The theoretical capacity in this case would be 80-90% to account for downtime in a perfect situation. (Sawhney, 2018) Once the theoretical capacity is calculated, it is then necessary to calculate the actual system capacity. The goal is to improve the actual capacity as close to the theoretical capacity as possible. Through lean manufacturing, throughput will be used to identify areas of improvement whether that be flow, variation, or disruption.

After the critical path is identified, it will be analyzed for a path forward. Either the flow, variation, or disruption will be chosen based on how large an impact it has on the critical path. People, Materials, Equipment and Schedule will be looked at to see where improvements can be made.

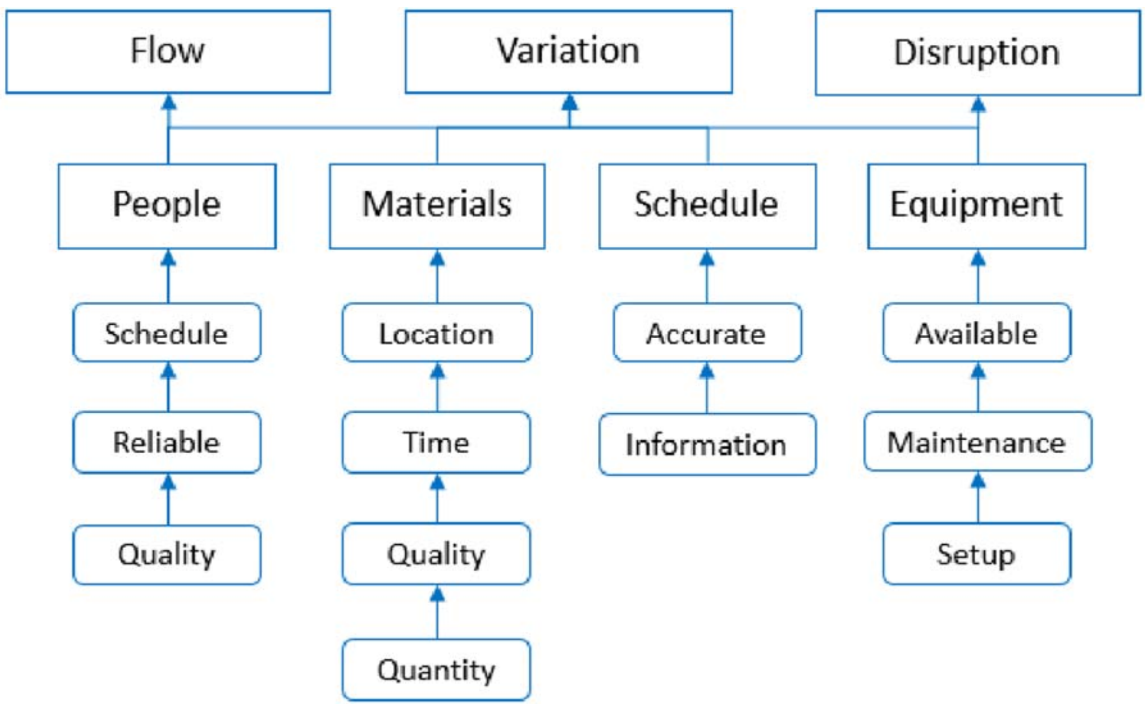


Figure 4 – People, Materials, Schedule, and Equipment

The whole system will be then analyzed regarding People, Materials, Equipment, and Schedule to calculate the system reliability. This can be done by utilizing Failure Modes Effects Analysis (FMES).

Example Design FMEA on a Pencil System, for training purposes (incomplete)

Function(s)	Failure Mode(s)	Effect(s)	Sev	Cause(s)	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN	Recommended Action(s)
To provide a safe and easy-to-use tool to write on paper, according to usages defined in technical requirements	Pencil wood shaft breaks during normal usage	User unable to write, with potential for minor injury from wood splinters	10	Type of wood too soft for high-force users	4	Pencil system design guide #123	Pencil shaft strength test #456	2	80	1. Review pencil wood supplier process and ensure actions are in place to control the hardness of supplied wood to requirements. 2. Add pencil hardness requirements to pencil system design guide #123. 3. Develop wood hardness test regimen and add to pencil test plans.
				Wood shaft diameter too small	1		Pencil system Finite Element Analysis	1	10	
	Pencil lead breaks during normal usage	User unable to write	8	Type of lead material too brittle	3	Graphite material specification #789	User writing test #abc	3	72	
				Sharpened pencil lead extends too far from wood enclosure due to improper sharpening	2		Pencil sharpening test #def	4	64	
	Pencil is not easy to use by an average writer	User able to write but with reduced performance and comfort	7	Wood exterior finish is too rough due to improper finish specification	7	Pencil wooden shaft finish specification #1234	User writing test #abc	2	98	1. Modify pencil wooden shaft finish specification #1234 to include wood exterior finish requirement for smoothness. 2. Perform Process FMEA on pencil exterior paint and finish processes. 3. Conduct customer clinic with typical pencil users to verify ergonomics.
				Wood exterior finish is too smooth due to wrong paint coating specified	1	Pencil wooden shaft finish specification #1234	User writing test #abc	2	14	
To provide an easy way to completely erase mistakes	Eraser does not erase graphite inscriptions on writing paper	User cannot erase resulting in customer dissatisfaction	8	Eraser material has wrong synthetic formula	5	Pencil eraser design guide #123	User writing test #abc	7	280	1. Perform Design of Experiment on eraser composition to optimize erasing performance. 2. Add erasing evaluation to user writing test #abc. 3. Review eraser design guide #123 and modify based on results of DOE.
				Excessive eraser wear due to insufficient soy-based composition in eraser material	8		User writing test #abc	5	320	
	Eraser falls off pencil during normal use	User cannot erase resulting in customer dissatisfaction	8	Eraser ferrule too large for eraser size	1		Geometric Dimensioning and Tolerancing of eraser ferrule and pencil eraser	1	8	
				Eraser ferrule has insufficient strength due to inadequate crimp configuration	6		User writing test #abc	6	288	1. Perform Finite Element Analysis on ferrule crimp configuration and modify number and location of crimps based on results of FEA. 2. Perform Process FMEA on ferrule crimp process. 3. Add periodic eraser checks to user writing test #abc
	Eraser makes objectionable markings on paper	User able to erase but may be dissatisfied with markings	6	Eraser material composition contaminated with foreign particles	2		Supplier design review of eraser material composition	2	24	
The pencil wood and lead must be easily sharpened using a normal pencil sharpener bringing the pencil back to full operation	Pencil wood does not sharpen	User unable to use pencil after it needs sharpening	8	Wood shaft is too hard	1	Pencil system design guide #123	Pencil wood hardness test #456	2	16	
				Diameter of wood shaft is too large for normal pencil sharpener	2	Pencil sharpening test #def		1	16	
	Lead breaks off during sharpening	User unable to use pencil after it needs sharpening	8	Diameter of lead too small	1		Pencil sharpening test #def	1	8	
				Type of lead material too brittle	6		Pencil lead strength test #789	4	192	1. Conduct joint Design Review with pencil lead manufacturer to examine causes and solutions to brittle lead problem. 2. Require pencil lead manufacturer to perform Pencil lead Design FMEA and Process FMEA. Review the results for proper quality. 3. Modify pencil lead strength test #789 regimen to include strength tests after pencil sharpening.

TRUNCATED

TRUNCATED

Figure 5 - FMEA Example

Begin by calculating the reliability, which is determined by the structure of the system. The reliability calculations are as follows:

Series:

$$\emptyset(\underline{x}) = \prod_{i=1}^{n} x_i$$

Parallel:

$$\emptyset(\underline{x}) = \coprod_{i=1}^{n} x_i = 1 - \prod_{i=1}^{n} (1 - x_i)$$

N out of K:

$$Reliability = \sum_{i=k}^{n} \binom{n}{i} p^i (1-p)^{n-i}$$

$$P_p(n|N) = \binom{N}{n} p^n q^{N-n} = \frac{N!}{n!\,(N-n)!} p^n (1-p)^{N-n}$$

Minimum Path Method:

$$\emptyset(\underline{x}) = \coprod_{j} \rho_j(\underline{x}) = \coprod_{j} \prod_{i \epsilon P_j} x_i$$

Minimum Cut Method:

$$\emptyset(\underline{x}) = \prod_{j} \rho_j(\underline{x}) = \prod_{j} \coprod_{i \epsilon P_j} x_i$$

Figure 6: Reliability Calculations

The failure rates that are collected are then analyzed with statistical distributions. The main reliability distributions used in engineering are:

1. Weibull – Models between failures (Most Commonly Used)
2. Normal – Models failure times
3. Exponential – Models functional life interval of a device, is memoryless
4. Log Normal – Models fatigue-stress nature failures

STAGE 3: RECOMMEND A SYSTEM SOLUTION

The last stage of lean systems analysis is recommending a solution to the problem. This means that a future state of the system must be evaluated using previously acquired tools such as engineering economics, optimization, probability, and statistical analysis. The future state must be a feasible solution that provides improvements when compared to the current system state. Engineering economics will be helpful in estimating the fiscal outcome of alternative system states. Probability and statistics can be used to provide calculations which contribute to confidence levels of stakeholders. Optimization will be useful in determining the maximum and minimum scope of the problems. Each of these tools will be used to create a new value stream map for the recommended system configuration.

CHAPTER 4 – THE CASE STUDY

The method of approach will follow the outline laid out for us in the previous chapter. This method will be utilized and applied towards the planning process of maintenance work at Y-12. The focus of the case study will be steps of the planning process and the elements of the process which spans the three categories of package complexity, dispatch, minor, and complex jobs. The level of job package complexity plays a huge role in the takt time for the job planning process. The more complex a job is, the longer it takes to plan and complete the job.

STAGE 1: DEFINE THE SYSTEM

A system is defined as an entity consisting of interconnected elements performing a function to achieve a goal. (Sawhney, 2018)

1. Elements – the physical elements of a system. For this system the elements include: Maintenance employees, Planners, System Engineering, Change Administrators, and Equipment.
2. Interconnections – how the elements and entities interact within the system. The interaction of the system elements will be explored using a system diagram shown below.
3. Function – the overall objective of the system. The overall objective of this system is to provide timely maintenance activities in order to:
    a. Increase equipment availability

b. Retain proper configuration control over graded systems

The elements or entities contained within the planning process are people, equipment, and documents or paperwork. Each of these elements are interconnected, with the objective to perform the same function of completing maintenance jobs in the facility. The planning process adheres to the definition of a system by meeting these criteria. The steps included in the planning process include, but are not limited to:

- Identify the problem requiring maintenance
- System Engineering submits work request
- Planning the Work Package
- Walk down the job
- Obtain proper permits (Job Hazard Analysis, Lockout Tagout, etc)
- Post Maintenance Test developed by Engineering
- Schedule the work to be performed
- Perform the work
- Perform Post Maintenance Test
- Ensure proper documentation of changes to configuration managed systems
- Close job

Lean/Reliability Analysis

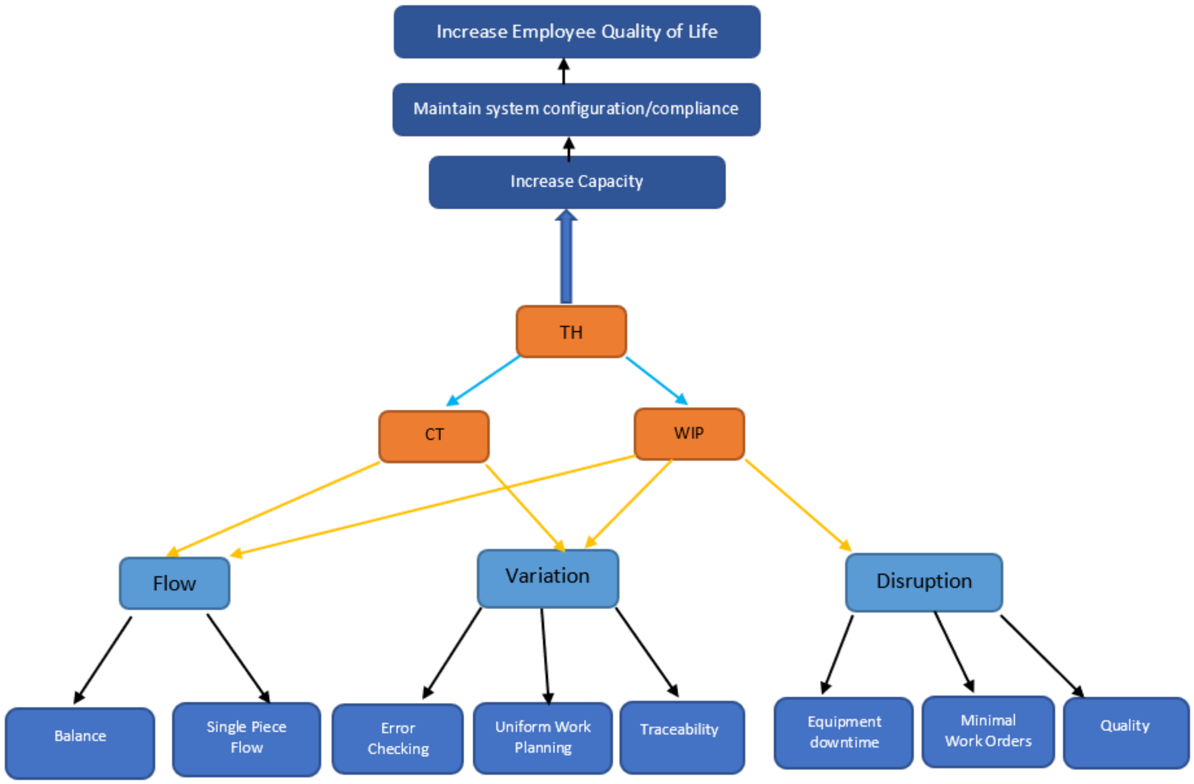


Figure 1: Influencing Lagging Indicators Through Reliability

The first goal of the reliability analysis is to reduce cycle time through balanced flow. To achieve this the system is diagrammed below in a value stream map (Figure 2). This along with collected data will help calculate the capacity of each step and determine the process bottleneck (Table 1). The high-level value stream map and results of the analysis are shown below in the table. The goal of the reliability analysis is to ultimately influence, through the changes recommended in this paper, leading indicators which will in the future lead to larger changes in more overarching lagging indicators as shown below. Overall, the changes in lagging indicators will be affected by balancing process flow and minimizing variation and disruption. This in turn will lead to an increase in throughput resulting in changes to the lagging indicators. This can be seen above in Figure 1.

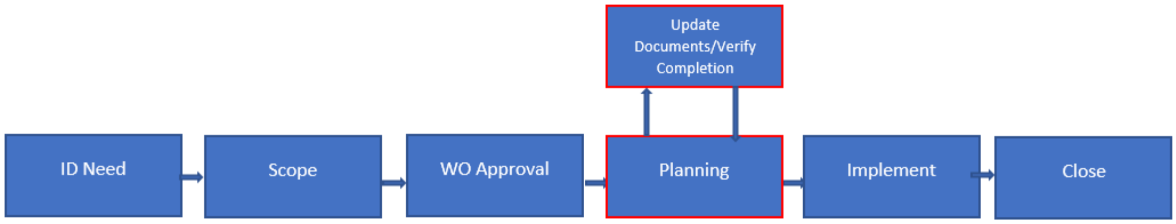


Figure 2: Critical Path

Step	Description/Objective	Process Time (days)	Capacity
ID Need	Be alerted to a condition in the field in need of correction. Determine proper maintenance path from an engineering standpoint.	1.5 hours = .06 days	16.7/Day
WO Submission	Determine proper personnel to inform. Identify need to materials, LO/TO, configuration change, submit work order	1 hour = .04 days	25/Day
WO Approval	System health manager evaluates need for work, determines proper charge number, informs production operations	12 hours = .5 days	2/Day
Planning	Multistep process including walkdowns with system engineering, skilled craft, safety, preparing appropriate permits, obtaining materials. Purpose of this step is to stage the job for eventual work.	14 days	.07/Day
Implement	When planning is complete job is worked in the field by skilled craft with the support of system engineering	2 days	.5/Day
Update Documents	Documents can include configuration managed drawings, facility calculations, etc. This includes a walkdown with design and system engineering to verify system configuration. The work order must remain open in order for design engineering to complete design.	12 days	.083/Day

Close	Planner communicates with system health manager that work is complete. Charge number is closed.	10 hours= .4 days	2.5/Day

Table 1: Process Descriptions, Capacities

As can be seen from the table above the bottleneck of the process is the planning stage, which consists of many steps, the majority of which are completed by one person. However while the planning step is the bottleneck of the system the Updating Documents step also poses a similar problem in that the very low capacity of this step creates a very unbalanced production. The value stream maps of these two processes will be discussed in detail in order to understand the failure modes and reliabilities associated with these two steps. First the updating documents bottleneck will be analyzed. The value stream map showing the bottleneck and reliability components of the updating documents step is shown below in Figure 3.

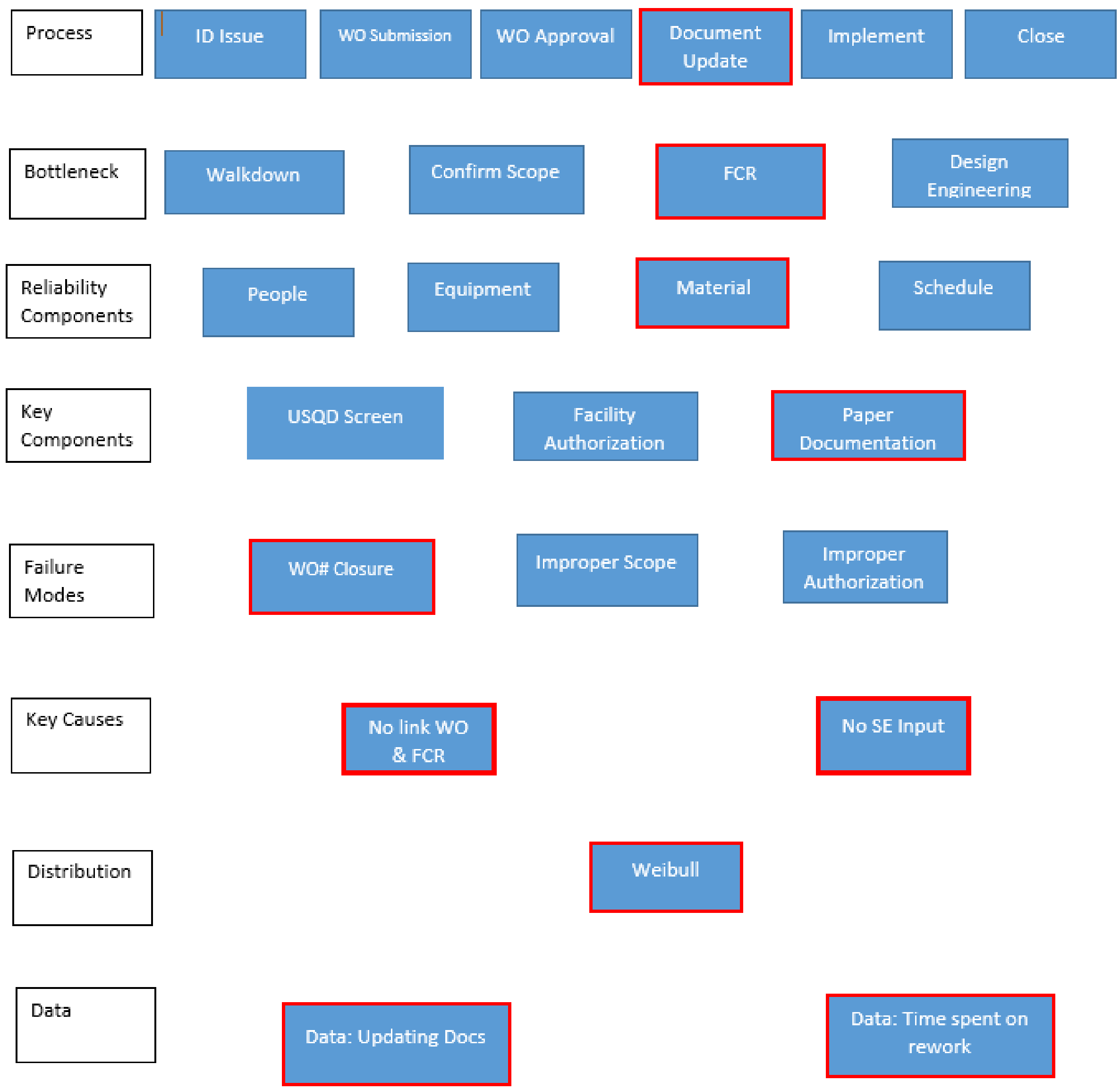


Figure 3: VSM For Updating Documents Step

Through this value stream map the key failure mode is through premature Work Order closure. The key causes of this are determined to be a lack of tie between the work order number and the change request number which drives the updating of configuration managed documents. The second cause of this is lack of input from system engineering during the work order closure process. Generally, work orders are closed by schedulers and planners without input from system engineering despite the fact that many work orders also touch configuration managed systems which need to be documented. To collect reliability information on this step 10 system engineers from two different system engineering groups were consulted and asked for the approximate amount of time spent on updating drawings after a work order has been inadvertently closed. The second is the time spent reopening work orders to complete unfinished work due to scope changes which are captured in the ICR/FCR process.

Engineer	Time redoing drawings (hrs/week)	Time completing work (hrs/week)
1	8	6
2	5	8
3	5	5
4	6	4
5	4	7
6	7	6
7	3	3
8	7	4
9	1	2
10	2	1

This data was collected by asking ten system engineers from two different buildings to estimate the time spent per week on reopening old work packages in order to update drawings and time spent per week reopening old work packages due to incomplete work captured in FCRs but not in the scope of work executed by maintenance. The data that was collected was analyzed using MiniTab a statistical software that can be used to identify characteristics of data sets. In this case the software was used to identify the distribution of failure. The results are shown in the graph and figure below. The p-value for this analysis shows a p-value of >.5 for the Weibull distribution and so the data was analyzed in this fashion. The shape parameter for the data set modelling the time spent on reworking drawings is 2.3. For a shape value of 2, the Weibull distribution models a linearly increasing failure rate, where the risk of wear-out failure increases steadily over the product's lifetime.

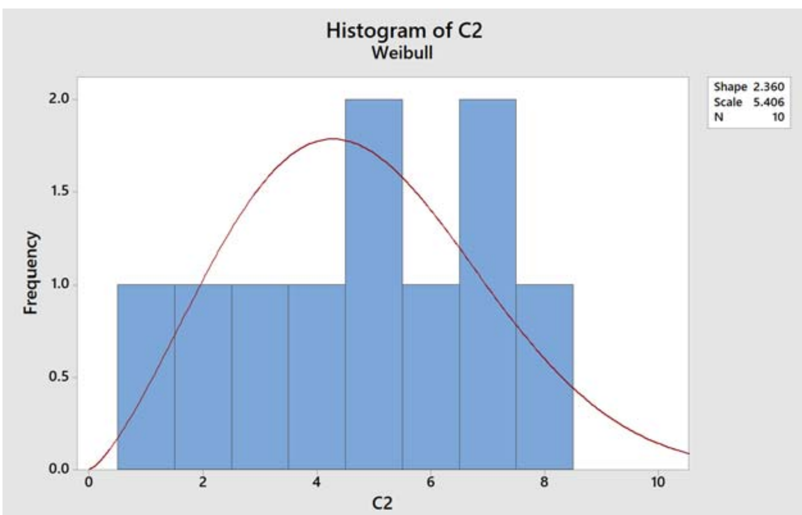
The parameter gained from the analysis is plugged into the equation below (Equation 1) to find the reliability of this component at a given time where *k*> 0 is the *shape parameter* and λ > 0 is the scale parameter of the distribution.

.

$$f(x;k,\lambda) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \qquad (1)$$

From MiniTab we are given that *k*= 2.3 and λ = 5.4 thus the probability density function is:

$$R_1(t) = e^{-(t/5.4)^{2.3}} \qquad (2)$$



Goodness of Fit Test

Distribution	AD	P	LRT P
Weibull	0.309	>0.250	
Exponential	1.243	0.051	
3-Parameter Weibull	0.214	>0.500	0.516
Normal	0.198	0.843	

ML Estimates of Distribution Parameters

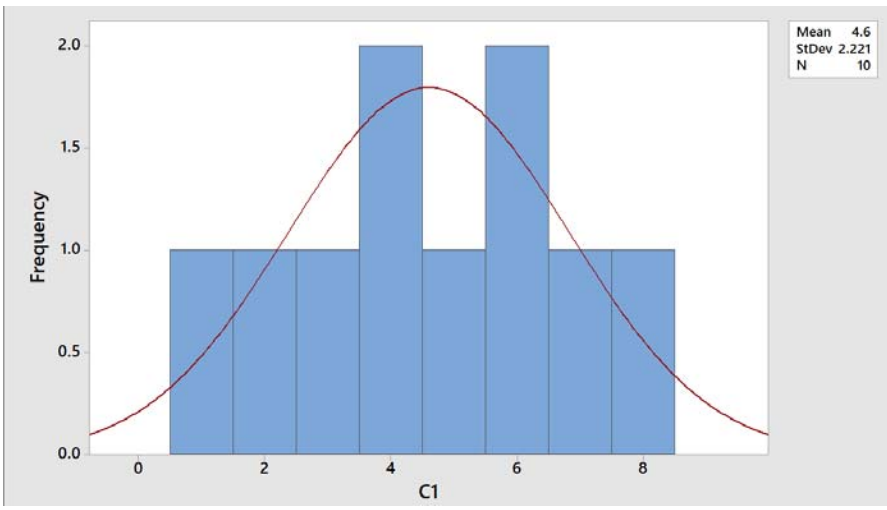
Distribution	Location	Shape	Scale	Threshold
Weibull		2.36019	5.40585	
Exponential			4.80000	
3-Parameter Weibull		5.30826	10.61052	-4.94655
Normal*	4.80000		2.29976	

with a reliability of:

$R_2(t) = e^{(-t/2.33)^{5.18}}$ (3)

These formulas can be used to determine failure at a specific time which will help define the system reliability.

The same process was applied to the data collected on reopening work orders to start new work and the following histogram was built using the data in the table above:



Goodness of Fit Test

Distribution	AD	P	LRT P
Normal	0.149	0.944	
Exponential	1.229	0.053	
Weibull	0.224	>0.250	
3-Parameter Weibull	0.178	>0.500	0.712

ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	4.60000		2.22111	
Exponential			4.60000	
Weibull		2.33704	5.18545	
3-Parameter Weibull		3.18990	6.65735	-1.34579

* Scale: Adjusted ML estimate

The reliability of the document update process is calculated using time t=2 hours with the reliabilities of the material, equipment and schedule estimated from usage. R1 and R2 are found using equations 2 and 3 derived previously and noted above.

$R_1 * R_2 = R_{UpdateDocument} = .641 * .625 = .400$ (4)

People	Material	Equipment	Schedule	Total Reliability (Document Update):
.4	.8	.9	.75	.216

Table X: Reliability of Document Update

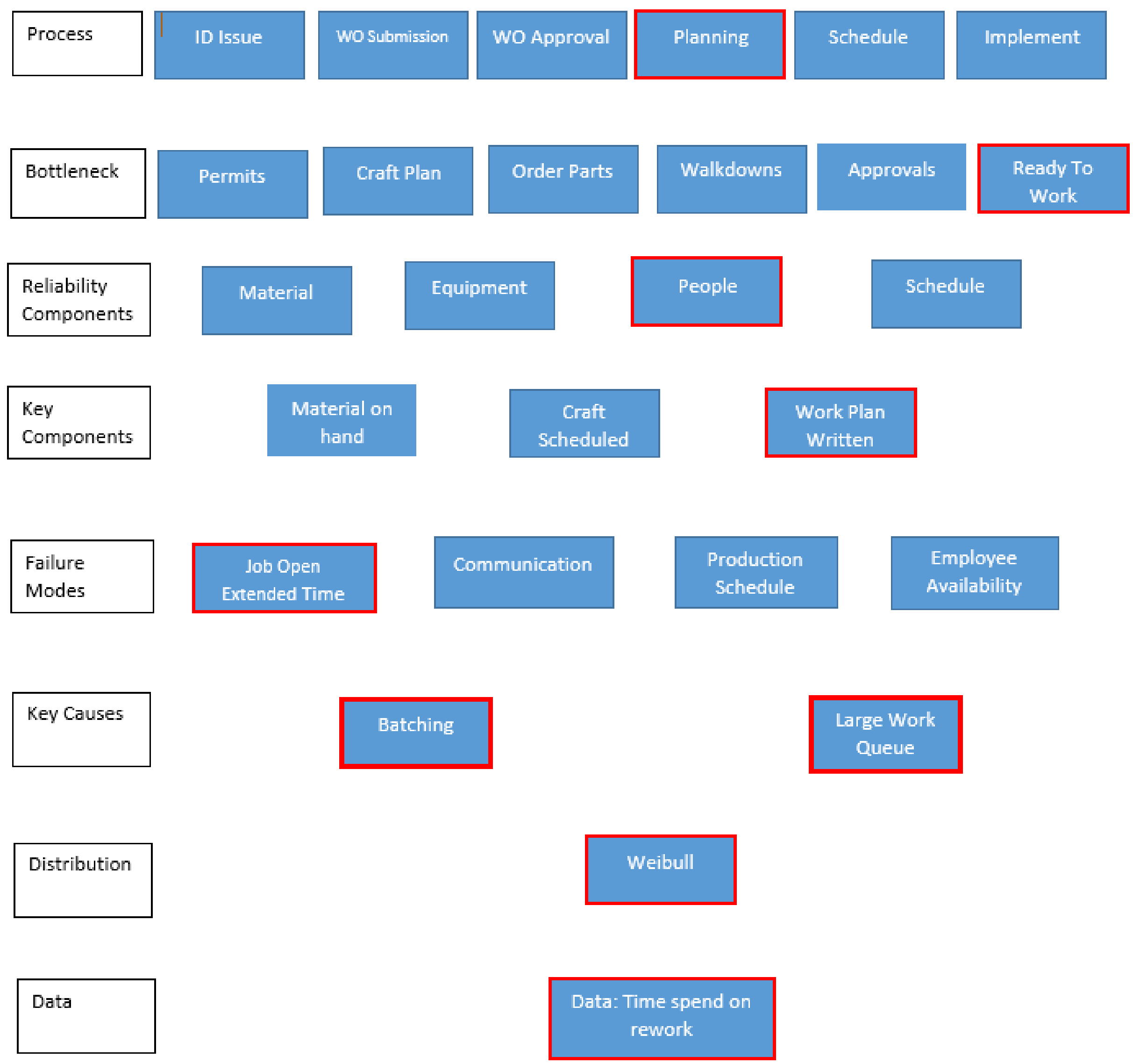


Table X: VSM for Planning

The Value Stream Map for the planning bottleneck is shown above. The 'People' reliability component was chosen for closer review and it was shown that the key causes for the bottleneck at the planning step is caused by batching of work orders and a large work queue. The batching is explored further in the systems model section but ultimately when planners are given a mix of complex, minor, and dispatch jobs the minor and dispatch job package completion time is frequently delayed by interaction with the complex jobs. This is to say that a planner with six simultaneous work packages may focus most attention on the complex job packages due to increased visibility or pressure to the detriment of the minor or dispatch jobs. This leads to a backlog of minor and delayed jobs which are often completed at a time when there is a lull or rest in the complex jobs. This is contrary to a balanced, single piece flow approach to planning work packages in which minor and dispatched jobs are planned as they are received. The reliability of this process was calculated similarly to the document review process shown above. Below is theoretical data collected after discussion with two planners and 2 system engineers. This data shows the amount of time spent on rework after being forced to neglect minor work packages in favor of complex work packages. In this failure scenario it is often necessary to walkdown the scope of the job again and verify materials and permits with the system engineer to ensure a complete work package is submitted.

Engineer	Time revisiting work (hrs/week)
1	3
2	2
3	2
4	8
5	7
6	1
7	8
8	7
9	4
10	1

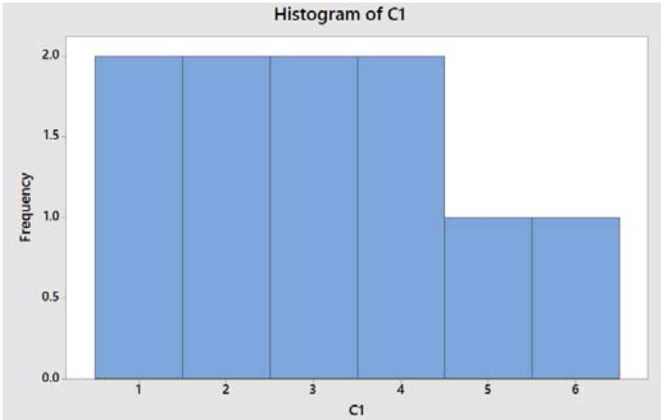


Figure X: Histogram Distribution of Rework Time

Goodness of Fit Test

Distribution	AD	P
Normal	0.236	0.716
Exponential	1.068	0.084
Weibull	0.258	>0.250
Gamma	0.300	>0.250

ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Normal*	3.10000		1.66333	
Exponential			3.10000	
Weibull		2.09311	3.50974	
Gamma		3.36942	0.92004	

Reliability Planning Step: $e^{-(t/2.05)^{3.9}}$ at time t=2 $R_{planning}$ = .403

People	Material	Equipment	Schedule	Total Reliability (Planning):
.4	.7	.8	.65	.15

As with the previous data sets the p-value of the Weibull test was greater than .25 so the Weibull was chosen as an appropriate model for the data set.

These values are derived from self-reported data from multiple system engineers. Additional values for planning time are determined from data found in SAP for work orders completed and closed in the past. Simply from viewing the table and chart above it is clear that the planning step is the bottleneck of this process and is creating a very unbalanced flow of work. With this knowledge based on objective data it is clear that additional resources must be placed in the planning process to create a balanced flow.

Another step that is integral in the planning process is the maintenance of configuration managed systems throughout the maintenance and planning process. This is to say that when corrective maintenance is performed on a system or a system is upgraded in such a way that a change to the system is necessary this change must be documented before the work package (and charge number) is closed. However, in the current system due to a lack of communication between system engineering and planning work packages are closed once the maintenance work is complete meaning that the design drawing and documentation is often left incomplete due to the absence of a charge code.

The second portion of the reliability analysis is to reduce variation in the process where variation is defined as anything that causes the system to depart from regular, predictable behavior. This variation is often seen in the bottleneck step of job planning. The coefficient of variation was calculated for each value-added step of the job process for each work category. In each work category, the value-added steps of *Create Work Order* and *Job Walk downs* were categorized as having Low Variation. *Reviewing the Package* and *Ready to Work the Job* were each categorized as having Moderate Variation. The *Plan the Job* step of each job category was shown to have a high level of variation. These results are unsurprising as this step involves writing the work instructions, gathering work and safety permits, and ordering and waiting for parts to come in. These attribute to the long cycle time of this step in the process.

Evaluating the job process of the Complex, Minor, and Dispatch jobs helped discover the total lead time for each job category to be 23.458 days, 11.101 days, and 3.34 days respectively. There were 4.764 days of non-value added time throughout the complex job process, 2.941 days during the minor job process, and 1.155 days during the dispatch job process. The cycle times for each different category of work package type is shown below. These cycle times were used to calculate the coefficient of variation for each step using the formula shown below. While the coefficients of variation are all considered low for the different types of planning processes it is important to note that the coefficient of variation for the complex jobs is nearly 10x greater than for the minor or dispatch jobs.

	April	May	June	July	August	September
Dispatch	6.89	7.03	7.62	7.13	6.97	7.49
Minor	9.13	8.43	8.67	8.45	8.24	8.97
Complex	19.28	23.23	21.25	19.04	46.76	32.53

Table X: Cycle Times vs. Job Package Type

Job Type	Standard Deviation	Mean	CV
Dispatch	0.297484	7.188333	0.041384
Minor	0.343419	8.648333	0.039709
Complex	10.87449	27.015	0.402535

Table X: Coefficients of Variation by Job Type

The Key Performance Indicators (KPI) of this system are Work in Process (WIP), Cycle Time (CT), Throughput (TH), Coefficient of Variation (CV), TAKT Time, Availability, Budget, People, and Re-work.

The data for Work in Process, Cycle Time, and Throughput is charted below. The table represents 6 months' worth of maintenance data from the 3rd and 4th quarters of the fiscal year. Little's law was necessary for determining the Work in Process. The formula for *Little's Law is Throughput (TH) x Cycle Time (CT) = Work in Process (WIP)* (Hopp Spearman, 2011). Based on research, it is assumed that the number of work orders that are Ready to Work (RTW) at the start of each week is 66. This will be the Critical WIP. Evaluating the planning of the Complex, Minor, and Dispatch jobs helped discover the total lead time for each category to be 23.458 days, 11.101 days, and 3.34 days respectively. There were 4.764 days of non-value-added time throughout the complex planning process, 2.941 days during the minor planning process, and 1.155 days during the dispatch planning process.

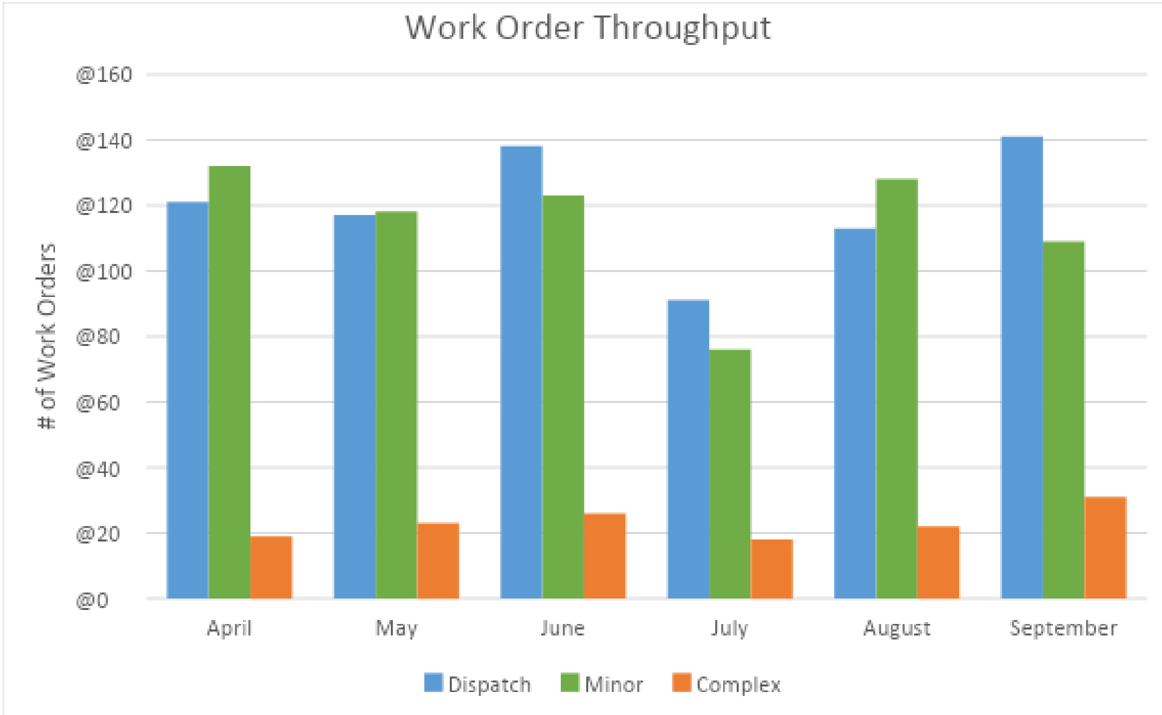


Figure 7 Work Order Throughput

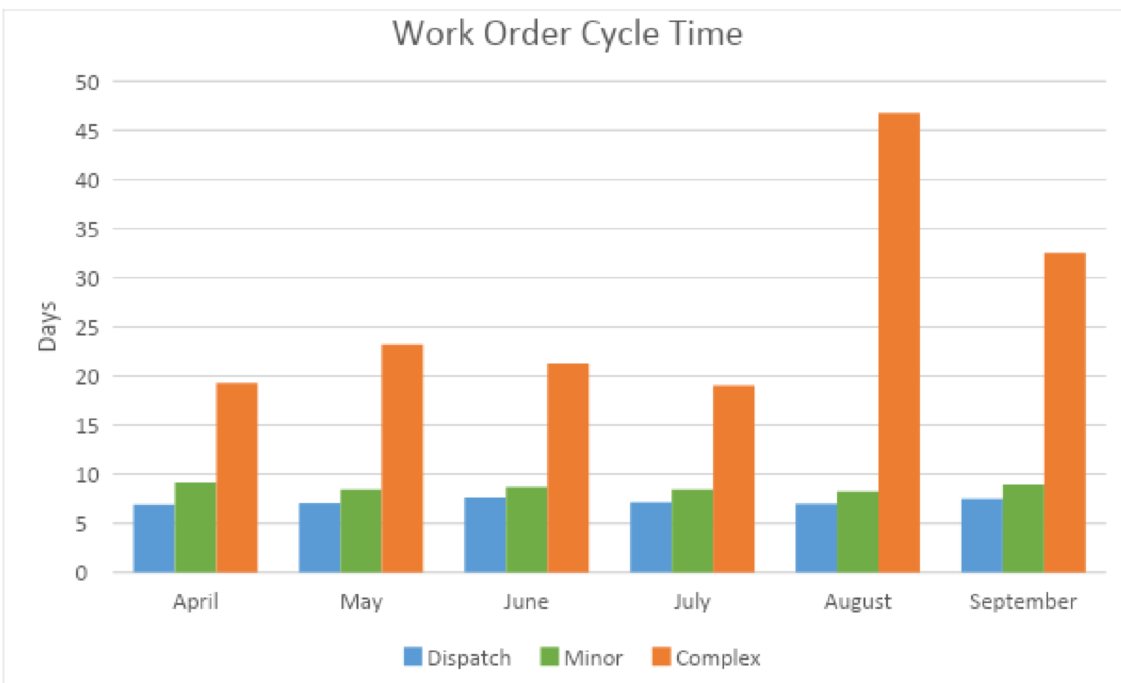


Figure 8 Work Order Cycle Time

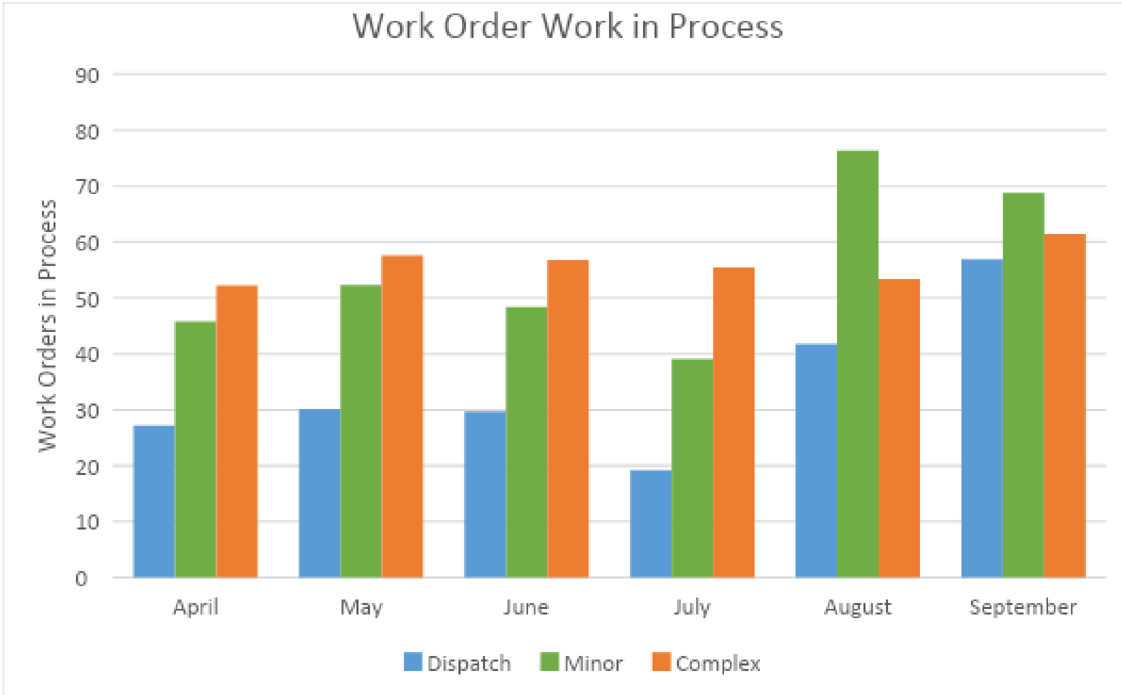
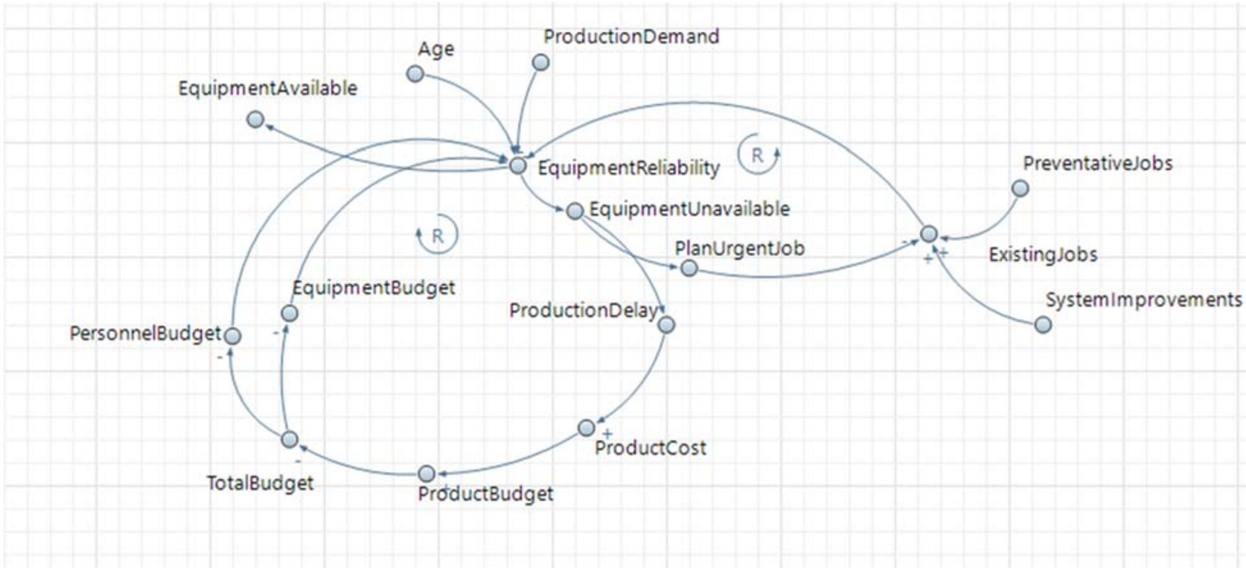


Figure 9 Work Order Work in Process

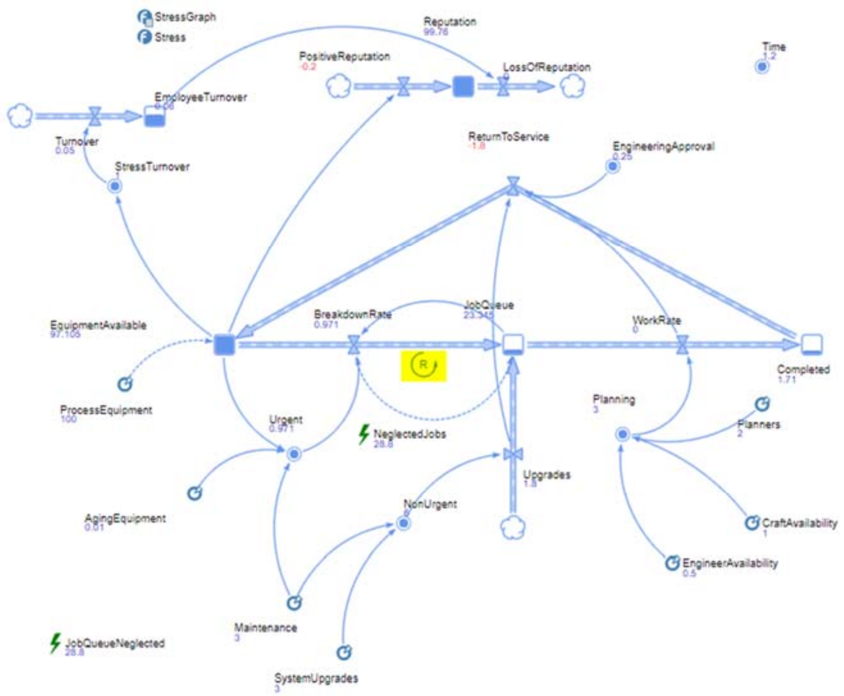
The TAKT time for each category was estimated to be roughly eight days for complex packages. This is equivalent to approximately one work order per every 2 weeks of work where TAKT time is the rate of output necessary to meet demand.

Systems Analysis of Current System



The model above shows the current configuration of the Y-12 maintenance system. As is shown above, there are clearly two reinforcing loops at work in the current planning process which leads to decreased performance of Key Performance Indicators. The Key Performance Indicators (KPI) tracked in this process are Equipment Availability, Job Queue, Employee Turnover, and Company Reputation. Because of the *reinforcing loop* between neglected maintenance jobs and eventual urgent equipment breakdowns due to a large build up of work in the job queue this system behavior is a clear case of a "*fixes that fail*" archetype in which a short term "fix" to a problem results in unforeseen consequences which result in further use of the "fix". The solution for systems with this archetype is to focus on the fundamental solution instead of a solution to the symptoms (urgent equipment jobs). In this case the "fix" is working urgent jobs and use of this fix results in more urgent jobs requiring urgent attention--perpetuating the cycle of neglected minor maintenance turning into urgent breakdowns.

The model below was run using AnyLogic in order to quantify the behavior of the KPIs in the current system.



This model is intended to show, broadly, the current maintenance process procedure at Y-12. The stocks and flows used in the model are explained below:

Equipment Availability:This is the total number of machines available for work. The goal of production is to have 100% machine availability which in this scenario is 120 piece of equipment.

Breakdown Rate: This rate is determined by various parameters: Aging, Maintenance, Accidents, Increased Production. These parameters feed into an "Urgent Job" variable which represents unexpected equipment breakdowns which are added to the Job Queue stock. The breakdown rate is also reinforced by the number of jobs in the job queue since the rate is defined by a fraction of the job queue if the job queue is greater than 10. Thus as the job queue grows (and maintenance jobs are neglected in favor of urgent jobs) the breakdown rate is increased due to maintenance jobs becoming urgent breakdown jobs.

Job Queue: This stock is the sum of the Urgent Jobs (Breakdown Rate) and Non Urgent Jobs (Upgrades Rate).

Upgrades Rate: This is the sum of maintenance jobs and system upgrades jobs. These jobs are added to the Job Queue at a rate of .3 x (Maintenance Jobs + System Upgrades) to demonstrate the diminished significance of these jobs compared to jobs resulting from equipment breakdowns.

Work Rate: The work rate is defined by Planners x (EngineerAvailability + Craft Availability). This formula was used since it is the planner is the necessary actor in working maintenance jobs. As described above the planner coordinates walkdowns and work procedures between craft and engineering and thus has much higher weighted significance in the work process. Additionally craft availability and engineering availability are much higher than planner availability so the planner is the "limiting resources" in the work process. This results in 3 jobs planned per day with a delay of 1.5 days before this is added to the completed jobs stock. Obviously in practice the number of days required is more variable based on the size and complexity of the job.

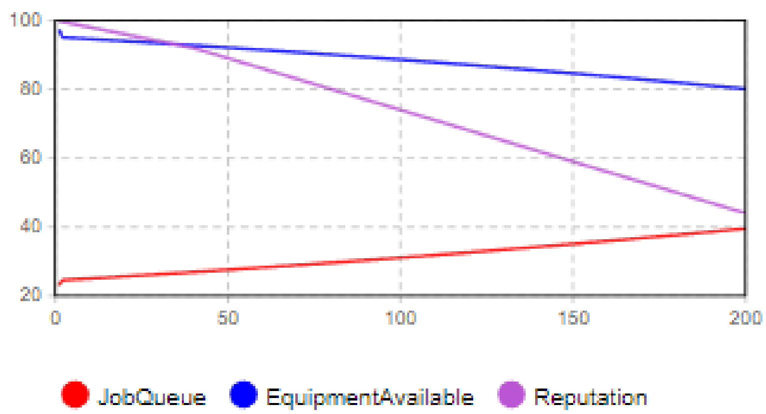
Completed Jobs: This is the stock of completed jobs.

Return To Service Rate: This rate is defined by the work rate and a delay of .25 days for engineering approval before return to service. The work day at Y-12 is 10 hours long and so this translates to roughly 2.5 hours. This rate also excludes the upgrades work rate since the jobs added for system upgrades or suggested maintenance do not mean that the equipment is out of service. This rate feeds back into the Equipment Availability stock which has a maximum of 120.

Employee Turnover Stock/Rate: This turnover rate is defined by the table function StressTurnover. This table function varies stress as a function of the equipment availability. This function is binary and thus if equipment availability is above 110 employee stress is low and there is no turnover. Else, employee stress is high which leads to turnover. However because it is not realistic for employees to quit after one day of stress the rate is defined as StressTurnover>0?.05:0. This models more accurately that if this stress is applied for 20 days then it will result in turnover.

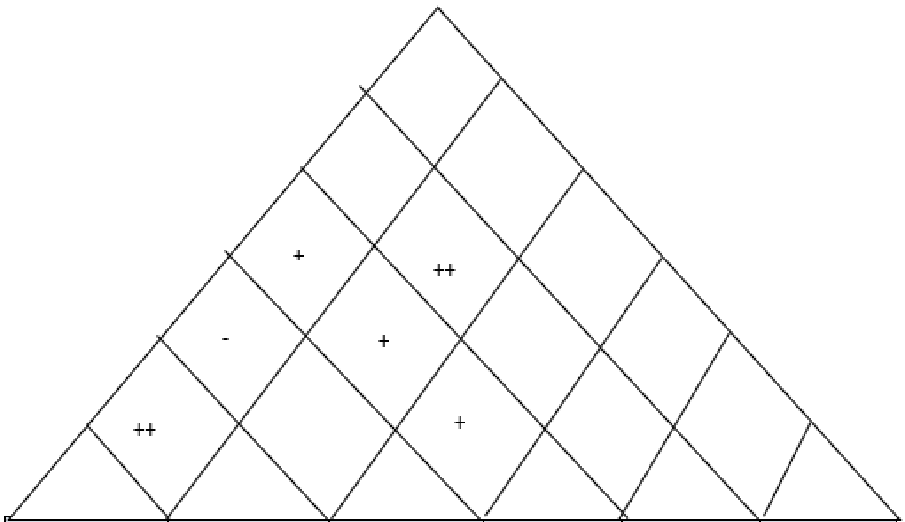
CompanyReputation Stock/Rates: The company reputation stock is impacted by employee turnover and equipment availability. The increase in reputation rate is defined as

EquipmentAvailable>110?1:-.2. The reason that the positive reputation is higher than the consequence of less equipment availability is because when equipment availability is higher it is more likely that management will promote this statistic versus if equipment availability is low this statistic will be available but perhaps management will not draw as much attention. A decrease in reputation is also caused by employee turnover since employees in system engineering require a high government clearance so if a group loses engineers it is difficult, time consuming, and expensive to replace them. Thus a high turnover in this area would result in attention from the federal agencies in charge of management of the complex.



REQUIREMENTS PLANNING

The purpose of requirements planning is to ensure that the solution put forth as the result of this research is one which meets the needs of the customer. This is achieved through which is a system of problem-solving tools used to provide objective weights to what is normally a subjective decision-making process. The first step in this process is known as Quality Function Deployment Quality to create a detailed House of Quality. The house of quality is a tool used to structure customer requirements and necessary attributes of the selected solution. The first step in this process was a quick brainstorming session with four system engineers including both production and facility engineers. The main purpose of this session was to determine the most important customer attributes which are listed below in the house of quality. The technical specifications are then included to finish the body of the House of Quality. The roof of the House of Quality visualizes the connections between the different technical specifications and highlights if any of the technical specifications are negatively related meaning that the addition of a certain technical specification is detrimental to the implementation of a different specification. The house of quality constructed is shown below. The bottom row of the house of quality shows the weighted importance of each technical specification. The results of these calculations show that accessibility is the most important specification followed by , broadly, the need for minimal changes or no changes to the existing final work packages or CCB process which is used to guarantee safety and compliance with the NNSA. The only conflicting specifications are the need for minimal/no training and the need for the changes to be compatible in SAP HANA. Since HANA is a fairly new system of use to many at Y-12 any changes that are to be implemented through HANA require at least some amount of training or guidance. The specification for minimal storage requirements for the work orders was easily ranked as least important. The House of Quality is shown below in Figure X:



		Compatible with SAP HANA	NTK Access for engineering and operations	Minimal/no training required	No change to work package structure for craft	Must not affect CCB/USQD process	Minimal storage requirements
Ease of Use	5	3	5	5	5	4	2
Availability	3	5	5	3	3	2	2
Reduce rework	4	2	1	2	4	4	1
Accuracy of Information	5	1	3	1	1	5	2
Traceability	4	5	5	2	4	3	1
Reduce planning time	3	5	5	3	5	2	1
		78	94	64	86	80	36

Figure X: House of Quality

STAKEHOLDERS-REQUIREMENTS MATRIX

	Ease of Use	Availability	Quality	Time	Funding	Traceability	Totals
Planner	5	5	5	5	4	4	28
System Engineer	5	4	5	5	3	4	26
Craft	5	5	5	5	2	3	25
Operations	2	2	5	3	2	2	16
Scheduler	3	5	4	5	3	4	24
NNSA	3	5	5	3	5	5	26
Totals	23	26	29	26	19	22	

Legend	
0	N/A
1	Very Low Concern
2	Low Concern
3	Medium Concern
4	High Concern
5	Very High Concern

ANALYTICAL HEIERARCHY PROCESS (AHP)

Step 1 - Prioritize the Stakeholders

Funding	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	5	4	4	3	6	3.833333333
System Engineer	1/5	1 1/4	1/20	1/20	1/15	1/30	0.275
Craft	1/4	1/20	1	1/16	1/12	1/24	0.247916667
Operations	1/4	1/20	1/16	1	1/12	1/24	0.247916667
Scheduler	1/3	1/15	1/12	1/12	1	1/18	0.27037037
NNSA	1/6	1/30	1/24	1/24	1/18	1	0.223148148
	2.20	**6.45**	**5.24**	**5.24**	**4.29**	**7.17**	**5.10**

Evaluations	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	4	4	3	5	5	3.666666667
System Engineer	1/4	1	1/16	1/12	1/20	1/20	0.249305556
Craft	1/4	1/16	1	1/12	1/20	1/20	0.249305556
Operations	1/3	1/12	1/12	1	1/15	1/15	0.272222222
Scheduler	1/5	1/20	1/20	1/15	1	1/25	0.234444444
NNSA	1/5	1/20	1/20	1/15	1/25	1	0.234444444
	2.23	**5.25**	**5.25**	**4.30**	**6.21**	**6.21**	**4.91**

Ease of Use	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	3	3	5	5	3	3.333333333
System Engineer	1/3	1	1/9	1/15	1/15	1/9	0.281481481
Craft	1/3	1/9	1	1/15	1/15	1/9	0.281481481
Operations	1/5	1/15	1/15	1	1/25	1/15	0.24
Scheduler	1/5	1/15	1/15	1/25	1	1/15	0.24
NNSA	1/3	1/9	1/9	1/15	1/15	1	0.281481481
	2.40	**4.36**	**4.36**	**6.24**	**6.24**	**4.36**	**4.66**

Availability	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	4	3	4	6	3	3.5
System Engineer	1/4	1 1/3	1/12	1/16	1/24	1/12	0.309027778
Craft	1/3	1/12	1	1/12	1/18	1/9	0.277777778
Operations	1/4	1/16	1/12	1	1/24	1/12	0.253472222
Scheduler	1/6	1/24	1/18	1/24	1	1/18	0.226851852
NNSA	1/3	1/12	1/9	1/12	1/18	1	0.277777778
	2.33	**5.60**	**4.33**	**5.27**	**7.19**	**4.33**	**4.84**

Quality	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	5	4	5	3	4	3.666666667
System Engineer	1/5	1 1/4	1/20	1/25	1/15	1/20	0.276111111
Craft	1/4	1/20	1	1/20	1/12	1/16	0.249305556
Operations	1/5	1/25	1/20	1	1/15	1/20	0.234444444
Scheduler	1/3	1/15	1/12	1/15	1	1/12	0.272222222
NNSA	1/4	1/20	1/16	1/20	1/12	1	0.249305556
	2.23	**6.46**	**5.25**	**6.21**	**4.30**	**5.25**	**4.95**

Time	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	1	4	5	3	5	4	3.666666667
System Engineer	1/4	4/5	1/20	1/12	1/20	1/16	0.215972222
Craft	1/5	1/20	1	1/15	1/25	1/20	0.234444444
Operations	1/3	1/12	1/15	1	1/15	1/12	0.272222222
Scheduler	1/5	1/20	1/25	1/15	1	1/20	0.234444444
NNSA	1/4	1/16	1/20	1/12	1/20	1	0.249305556
	2.23	**5.05**	**6.21**	**4.30**	**6.21**	**5.25**	**4.87**

Step 2 – Synthesize the Data

Ease of Use	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	0.42	0.69	0.69	0.80	0.80	0.69	0.68092622
System Engineer	0.14	0.23	0.03	0.01	0.01	0.03	0.07347811
Craft	0.14	0.03	0.23	0.01	0.01	0.03	0.07347811
Operations	0.08	0.02	0.02	0.16	0.01	0.02	0.04931973
Scheduler	0.08	0.02	0.02	0.01	0.16	0.02	0.04931973
NNSA	0.14	0.03	0.03	0.01	0.01	0.23	0.07347811
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Availability	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	3/7	5/7	9/13	22/29	5/6	9/13	0.68663526
System Engineer	3/28	5/21	1/52	1/84	0	1/52	0.06686197
Craft	1/7	1/67	3/13	1/63	0	1/39	0.07294493
Operations	3/28	1/90	1/52	11/58	0	1/52	0.05871194
Scheduler	1/14	0	1/78	0	5/36	1/78	0.04190097
NNSA	1/7	1/67	1/39	1/63	0	3/13	0.07294493
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Quality	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	30/67	24/31	61/80	29/36	30/43	61/80	0.70840571
System Engineer	6/67	6/31	0	0	1/64	0	0.05402698
Craft	1/9	0	4/21	0	1/52	1/84	0.05827694
Operations	6/67	0	0	5/31	1/64	0	0.04857185
Scheduler	10/67	1/97	1/63	1/93	10/43	1/63	0.07244158
NNSA	1/9	0	1/84	0	1/52	4/21	0.05827694
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Time	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	0.45	0.79	0.81	0.70	0.81	0.76	0.7186416
System Engineer	0.11	0.16	0.01	0.02	0.01	0.01	0.05298212
Craft	0.09	0.01	0.16	0.02	0.01	0.01	0.0486764
Operations	0.15	0.02	0.01	0.23	0.01	0.02	0.07261584
Scheduler	0.09	0.01	0.01	0.02	0.16	0.01	0.0486764
NNSA	0.11	0.01	0.01	0.02	0.01	0.19	0.05840763
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Funding	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	0.45	0.78	0.76	0.76	0.70	0.84	0.71553804
System Engineer	0.09	0.19	0.01	0.01	0.02	0.00	0.0539987
Craft	0.11	0.01	0.19	0.01	0.02	0.01	0.05824863
Operations	0.11	0.01	0.01	0.19	0.02	0.01	0.05824863
Scheduler	0.15	0.01	0.02	0.02	0.23	0.01	0.0724299
NNSA	0.08	0.01	0.01	0.01	0.01	0.14	0.0415361
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Evaluations	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	30/67	61/80	61/80	30/43	29/36	29/36	0.71360438
System Engineer	1/9	4/21	1/84	1/52	0	0	0.05832893
Craft	1/9	1/84	4/21	1/52	0	0	0.05832893
Operations	10/67	1/63	1/63	10/43	1/93	1/93	0.0725109
Scheduler	6/67	0	0	1/64	5/31	0	0.04861344
NNSA	6/67	0	0	1/64	0	5/31	0.04861344
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Step 3 – Rank the Requirements

Category	Ease of Use	Availability	Quality	Time	Funding	Traceability
Ease of Use	1	3	3	3	4	2
Availability	1/3	1	1	1	1 1/3	2/3
Quality	1/3	1	1	1	1 1/3	2/3
Time	1/3	1	1	1	1 1/3	2/3
Funding	1/4	3/4	3/4	3/4	1	1/2
Traceability	1/2	1 1/2	1 1/2	1 1/2	2	1
Total	2 3/4	8 1/4	8 1/4	8 1/4	11	5 1/2

Step 4 – Synthesize the Requirements Data

Category	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Ease of Use	0.364	0.364	0.364	0.364	0.364	0.364	0.364
Availability	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Quality	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Time	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Funding	0.091	0.091	0.091	0.091	0.091	0.091	0.091
Traceability	0.182	0.182	0.182	0.182	0.182	0.182	0.182
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

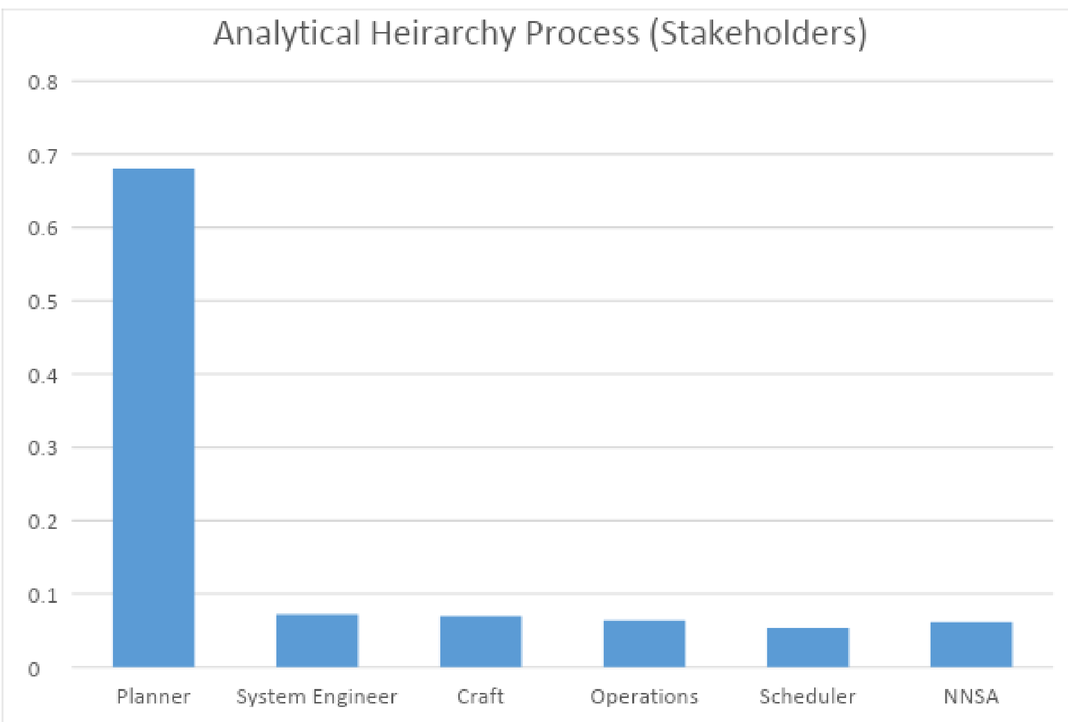
Step 5 – Now use the row average data and categorical data from above to rank the requirements.

Category	Ease of Use	Availability	Quality	Time	Funding	Traceability	Avg.
Planner	0.680926217	0.718641601	0.686635262	0.7084057	0.715538037	0.713604376	0.704
System Engineer	0.073478109	0.052982121	0.066861971	0.054027	0.053998703	0.058328925	0.060
Craft	0.073478109	0.048676403	0.072944929	0.0582769	0.058248628	0.058328925	0.062
Operations	0.049319728	0.072615841	0.05871194	0.0485718	0.058248628	0.072510899	0.060
Scheduler	0.049319728	0.048676403	0.04190097	0.0724416	0.072429904	0.048613437	0.056
NNSA	0.073	0.058	0.073	0.058	0.042	0.049	0.059
	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Step 6 – Finally, we are able to determine each Stakeholder's level of investment for each requirement.

Category	Emphasis	From Step 4
Planner	0.698608644	0.364
System Engineer	0.063308826	0.121
Craft	0.064425752	0.121
Operations	0.058219592	0.121
Scheduler	0.053117663	0.091
NNSA	0.062319522	0.182
	1.00	

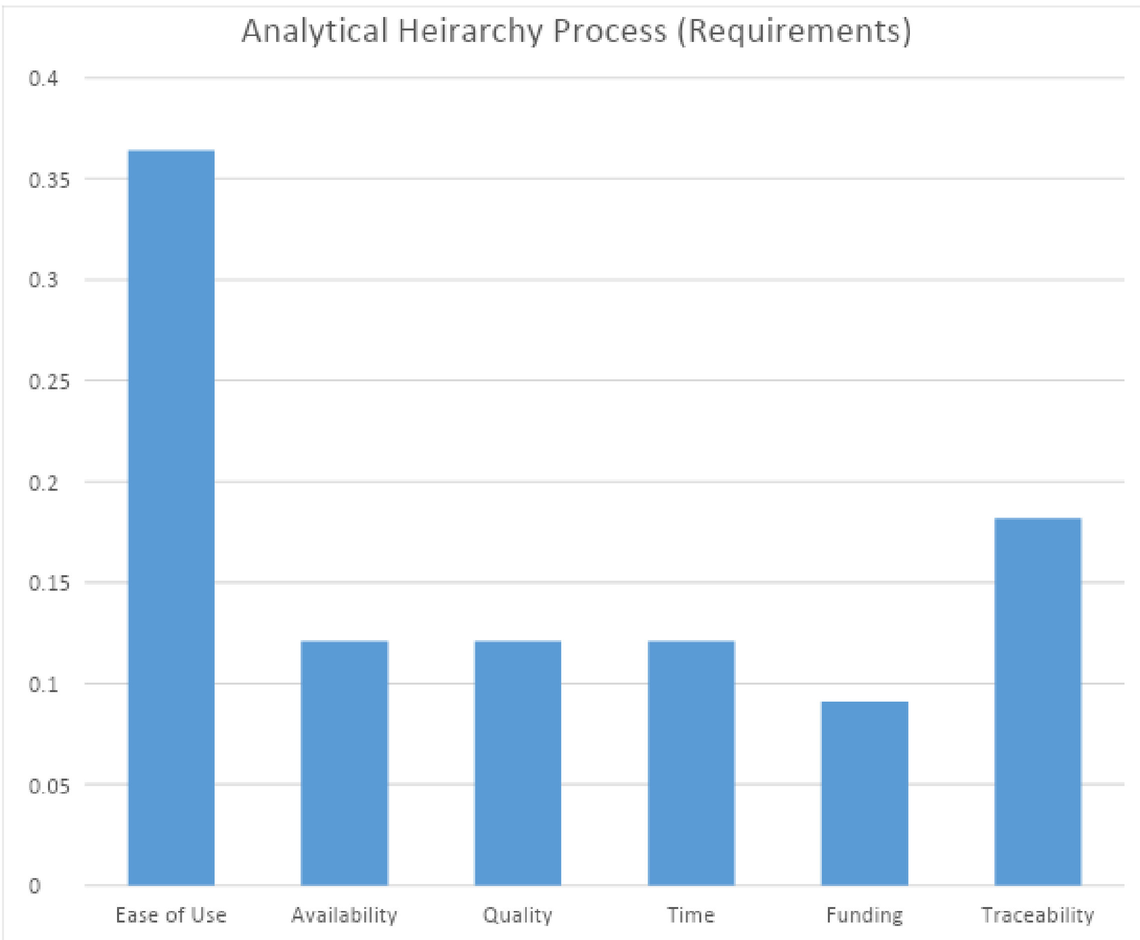
The data is then put into bar graphs to represent a better visual of the hierarchy of stakeholders and their requirements.



Critical Stakeholders Ranking:

1. Planner
2. NNSA

3. Craft
4. System Engineering
5. Operations
6. Scheduler



Critical Requirements Ranking:

1. Ease of Use
2. Traceability
3. Availability
4. Quality
5. Time

6. Funding

FAILURE MODES EFFECTS ANALYSIS (FMEA)

The following FMEA aided in identifying the critical failures of the current maintenance planning process. This information is then used to verify the ranking of the critical stakeholders.

	[redacted]		Potential Failure Mode	Potential Failure Effect	Severity	Potential Causes	Probability of Occurance	Current Controls	Detection	RPN
Stakeholders	Planner	Not enough Planners	Job not planned	Job doesn't get planned in timely manner	8	Absnetee, Not enough planners/planners overloaded	7	None	6	336
	System Engineer	Problem misdiagnosed	Misinformation	Equipment not maintained	8	Misinformation	5	None	6	240
	Craft	Information Not Accurate	Not enough information to do job	No job to be performed	8	Misinformation; Miscommunication	7	None	1	56
	Operations	Wrong Information Communicated	Misinformation	Lack of funding; Agencies misrepresented. No support given	8	Misinformation; Miscommunication	5	None	1	40
	Scheduler	No communication or Traceability	Job not scheduled	Lack of funding; Agencies misrepresented. No support given	8	Misinformation; Miscommunication	7	None	3	168
	NNSA	Poor communication	Lack of Communication	Lack of funding; Agencies misrepresented. No support given	8	Misinformation; Miscommunication	5	None	6	240

Figure 10 - Failure Modes Effects Analysis of Current System

STAGE 3: RECOMMEND A SYSTEM SOLUTION

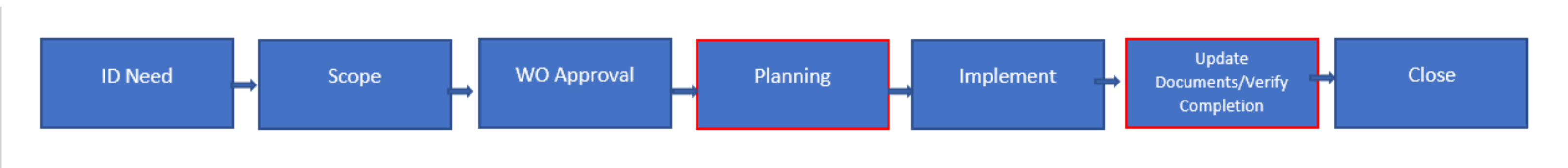
Future System Lean/Reliability Perspective

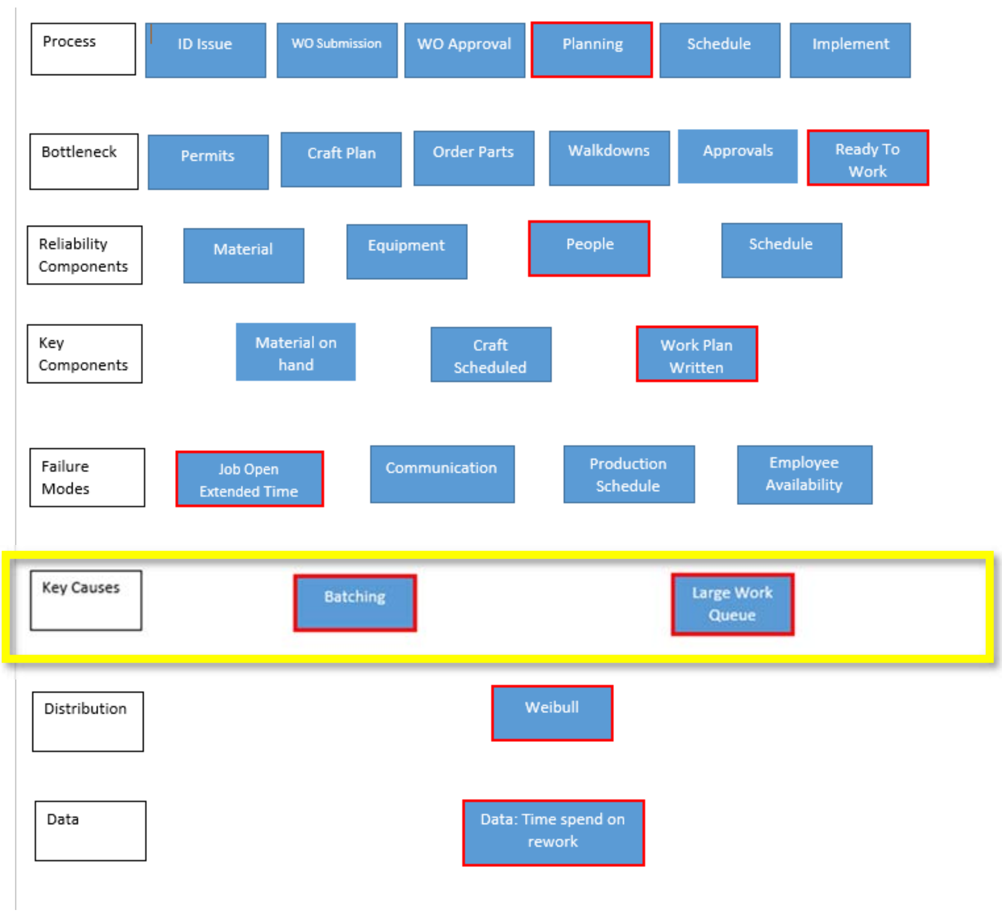
From the analysis conducted previously in this report it is clear that in the work order process at Y-12 there exists opportunity to increase throughput by increasing system reliability. Below in Figure X is the new critical path for the work order process. This path is a linear path as opposed to the previous process which did not integrate the change request process with the work order completion process. This led to wasted time by system engineers in the form of rework and disruption to the design update process. Additionally, often times work orders were closed before revision of necessary documents which results in noncompliance with the change management procedure set forth by the NNSA/DOE but can also result in future delays to work orders as drawings are not updated and may cause delays in diagnosing system issues or order new parts since changes in the system were not properly documented. Furthermore from the analysis of the cycle times and throughput for the work processes it was determined that in order to increase throughput for dispatch and minor work that these jobs should be done by dedicated planners and that complex jobs should also be done by dedicated planners.

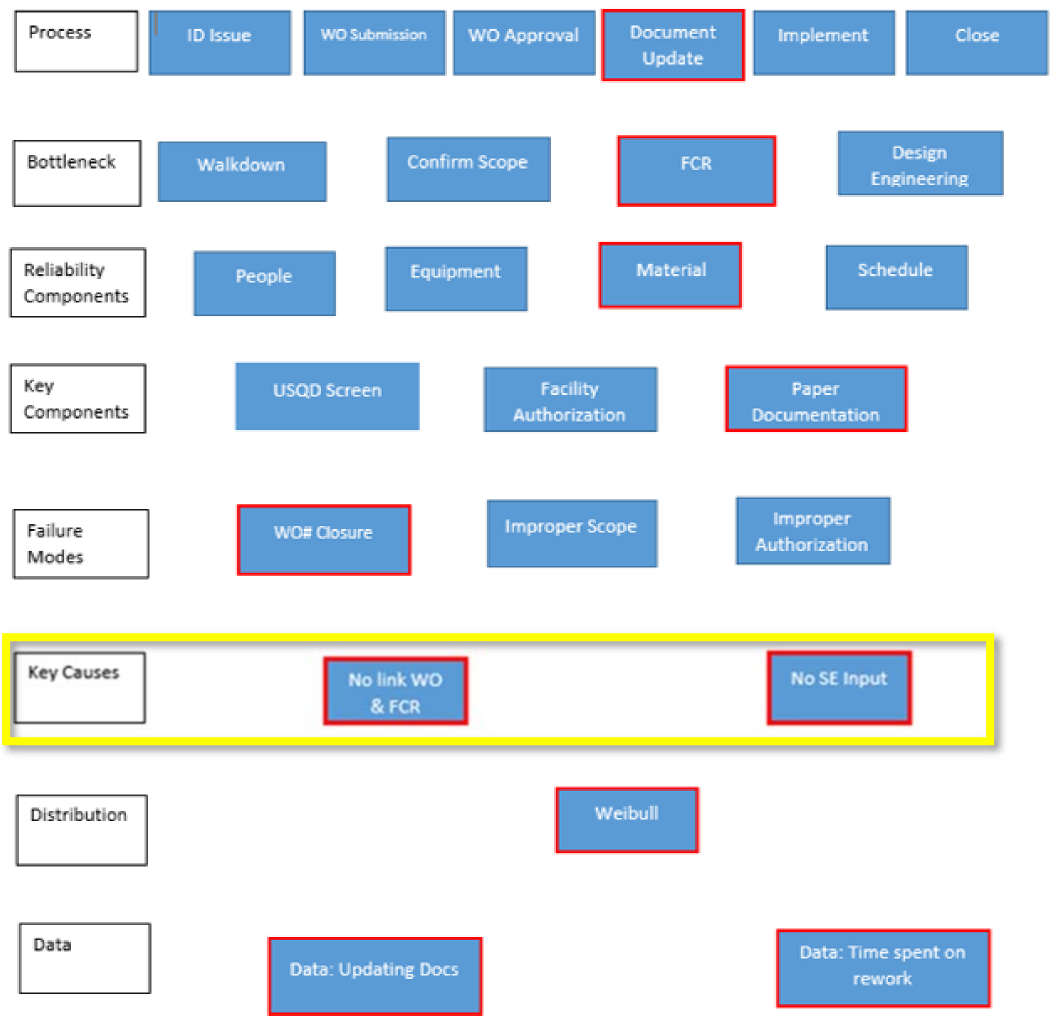
From the charts shown previously the number of dispatch and minor work packages far exceed the number of complex jobs but have lower cycle times. Implementing this solution would result in an elimination of two of the key sources of error in this process as determined by the value stream map. Additionally, an additional planner should be added to the staff of planning. Because the planning capacity is significantly lower than each other process in the work order process flow this merits an additional allocation of resources. The implementation of these two solutions: slightly increasing planning staff and dividing work orders into job type will directly improve or eliminate the two key sources of error shown in the value stream map below which are batching and heavy work load. While the updating documents step also has a very low capacity this step follows implementation and thus does not directly affect equipment availability.

In regards to the traceability and change management portion of the work order process in order to improve the reliability of this process it is suggested that when change requests are created they should be entered digitally into SAP and attached by a link to a work order number. This eliminates a key source of error in the value stream map. By digitally connecting the work order number and the change request number the scope of the change request, any additional FCRs due to scope change, and all affected documents will be linked to the work order. This helps to eliminate the key cause of failure through premature work order closure. This method does not require additional work from system engineering or planning it simply changes the method of relaying information to a more reliable form.

Furthermore, overall, these changes to the work order processing system result in a more linear system as shown below with a clear flow of communication and information. It has reduced potential sources of error through miscommunication or planner turnover since any changes to scope through an FCR are recorded in SAP through the work order number.

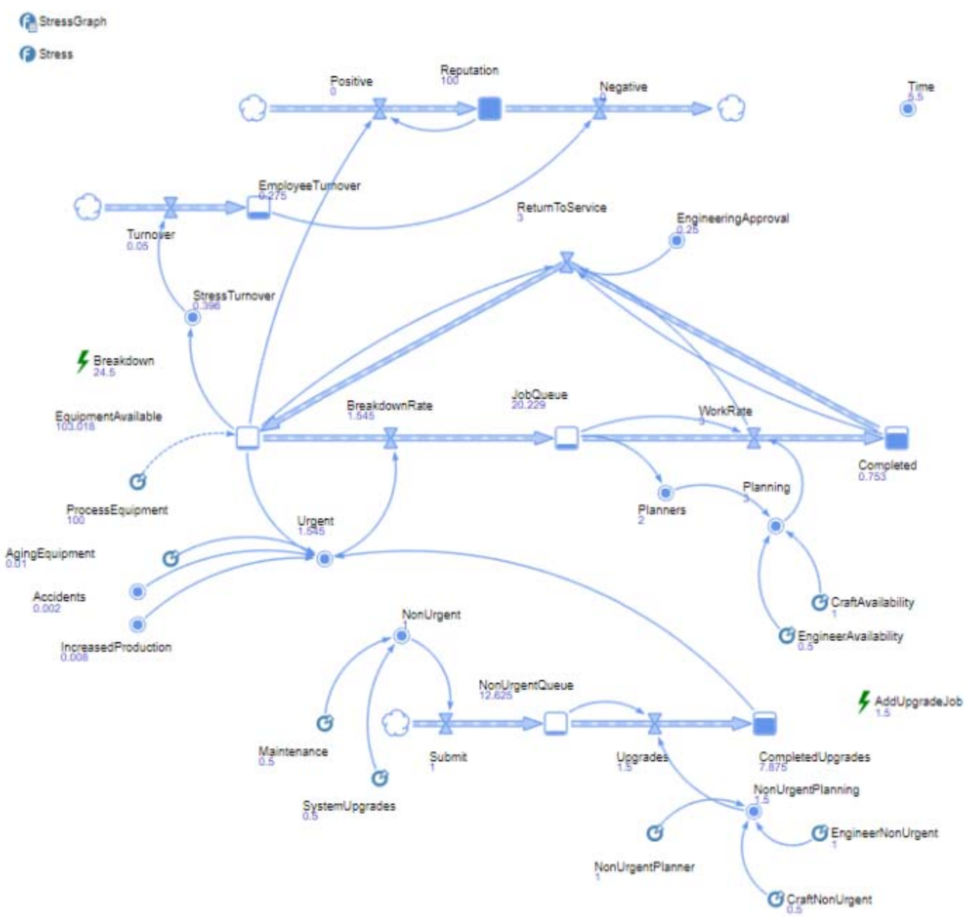






Systems Perspective

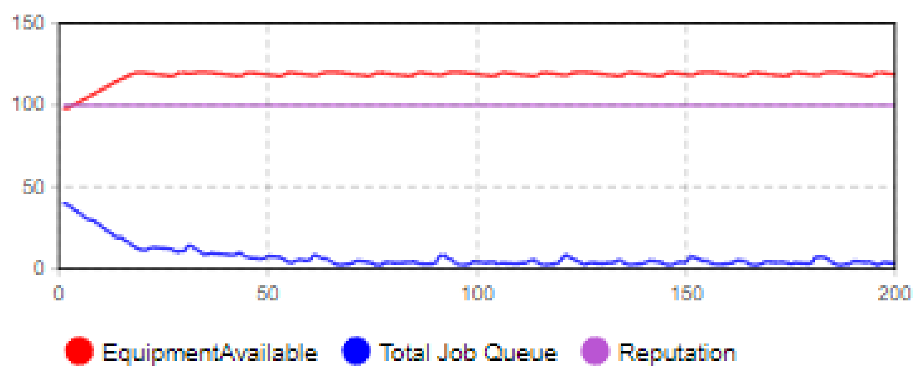
The updated simulation including an extra planner and separate maintenance queue removes the reinforcing loop between urgent breakdowns and neglected maintenance. In this new simulation, completed maintenance jobs increase equipment availability. Additionally, this increased equipment availability leads to lower worker stress, thus less turnover, and a higher company reputation. Additionally, this new simulation varies the number of planners working because once the maintenance work is completed, thus decreasing urgent breakdown related work, the urgent job queue growth slows and at points the job queue drops below 4 at which time only one maintenance planner is used. However, this may not be easily implemented in a work scenario since an employee would have to be redeployed at various times due to dropping work available because of higher equipment reliability. Thus, it is the final recommendation that although at times the queue of work for an additional planner becomes small this planner can aid with other job packages as needed. In the simulation below the number of planners is varied when the job queue begins to become low and a planner is removed which can be observed in the results as the equipment availability drops, at which point the third planner is added again to the simulation.



Upgrades Rate: This rate is defined similarly to urgent jobs however the number of planners is 1 instead of 2. Additionally, since maintenance jobs are less complex than equipment breakdowns the delay before being added to the completed jobs stock is .25 days instead of 1.5 days.

Breakdown Rate: This is affected by the new model through the upgrades rate. In the updated model the Urgent variable is decreased using the Completed Upgrades stock since the breakdowns should be decreased by preventative maintenance.

Breakdown Event: This event adds 4 urgent jobs per month to the jobs queue. This is to account for the fact that breakdowns occur for various reasons and that they will still (most likely) occur outside of the variables listed in this model.



Requirements Perspective

The results of the Requirements Planning which was analyzed previously shows that the two most important attributes to the stakeholders were "Ease of Use" and "Traceability" the suggested system improvements fulfill both of these requirements. As noted above the suggested solution does not change the processes themselves but the method of delivery/ communication in order to redistribute work effectively and to trace changes to the work scope by tying FCRs (scope changes) to work orders in order to effectively update documents before closing change packages. This also takes into consideration concerns brought into the FMEA by leaving existing processes unchanged and only changing the way work is distributed or communicated. This is the suggested solution because this small change in methods results in a large improvement to reliability by eliminating key failure modes of both processes.

CHAPTER 5 – CONCLUSION

To conclude, the recommended solution in order to improve reliability and traceability of the work order process while maintaining or increasing worker quality of life is to:

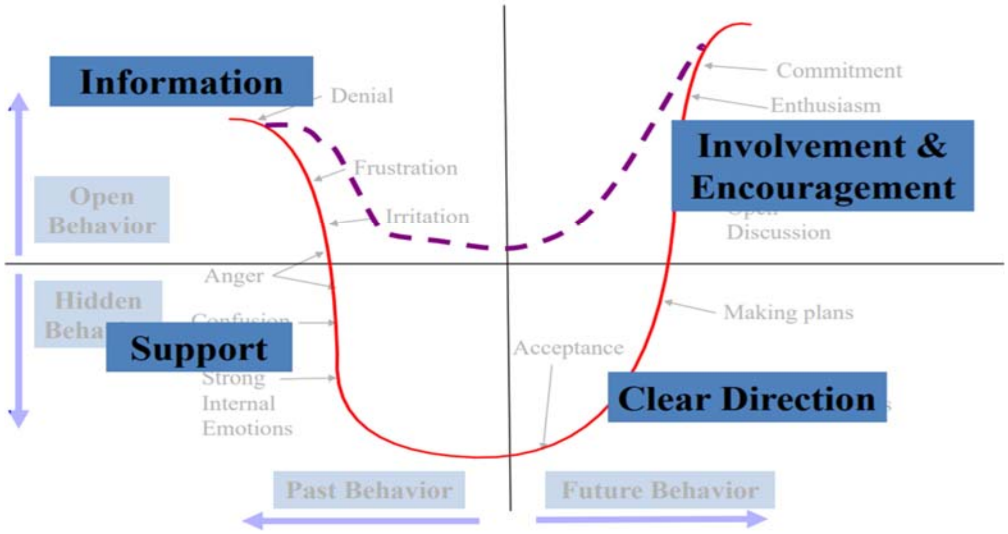
1) Have dedicated planners for: dispatch and minor work jobs and separate planner for complex jobs.

2) Hire at least one additional planner to ease the workload and eliminate the massive bottleneck at the planning stage.

3) Tie change request numbers to work orders in SAP. Each Change Request number requires a work order number to be documented (on paper). Document this electronically to improve traceability and eliminate rework due to poor communication.

One component of the solution that was of high importance to the process stakeholders was ease of use or implementation. This is because at a nuclear site such as Y-12 there are many vital safety procedures in place that, while time consuming, are necessary for safe operation. Thus, if a major change to the system is suggested it is often exceedingly difficult to implement due to a resistance to change. During this program an important point was made about work culture and a resistance to change. Below is a transition curve with the red line representing change with no support and a dashed purple line showing change implementation with support resources. The change suggested in this report is minimal change with a large impact. Furthermore, the types of changes being made can be easily described and the purpose of the changes is clear. Thus, the employees can be given clear direction and support in the suggested improvements. While there are many drastic changes that could potentially be proposed at Y-12 the solution put forth in this paper requires minimal resources from Y-12 or retraining of current employees. In fact, these changes help improve quality of life by eliminating small sources of error that often emerge after new employees are introduced to a new job or roles change. So in short by making the minor changes suggested in this paper Y-12 can help improve traceability, equipment uptime, and quality of life for employees in its production facilities.

The Transition Curve



REFERENCE