THE UNIVERSITY OF TENNESSEE KNOXVILLE

A Systems Approach To Nitrogen Delivery

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Bobby Goins

Disclaimer

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Chapter 1-Introduction

Background

Nitrogen gas makes up approximately 78% of the earth's atmosphere making it the most abundant uncombined element (Nitrogen, 2017). It can even be found naturally in the human body. In industry nitrogen has many uses, ranging from the making of commercial fertilize to being used as a purge gas in the HVAC realm. It is even used in cryogenic liquid form (-320°F) as a medium to flash freeze foods (Flash Freezing, 2017).

Liquid Nitrogen (LN_2) is procured in bulk quantities and delivered to the site at various times throughout the week, via truck. During an off load the LN_2 is pumped from the truck's trailer into the site's storage vessels. By doing so allows the site nitrogen generator to have a continuous supply of LN_2 along with having a reserve to supplement the site demand in the event the demand is greater than the output of the nitrogen generator. In addition, the reserve supply is used to feed the site when the nitrogen generator is offline.

During the delivery process there are several support personnel involved including Utility Operators, Security Personnel, and System Engineers.

Problem Statement

In recent months it has been noted that the site incurs numerous demurrage charges from the liquid nitrogen vendor, occurring when a delivery of liquid nitrogen lasts longer than two hours. This is a direct result of the delivery process being very inefficient and full of obstacles. Further, the pool of Utility Operators, which are used during the off load for escorting and valve manipulation, is reducing making it more and more difficult to fill all of the positions needed of the offloads to occur. This combination of predicaments sets the delivery process up to incur numerous demurrage charges from the vendor. These problems are exacerbated when the site's nitrogen generator is offline for repairs and the rate at which nitrogen is delivered to the site increases.

General Approach

A systems based approach will be used to evaluate the nitrogen delivery process. This approach involves principles found in *Lean*, *Reliability*, *Systems Thinking*, and *Requirements*. This style of approach and methodology were developed over the course of four semesters, beginning spring 2016, by Dr. Rupy Sawhney and the cohort. This unique combination of principles and thought process yields a very in depth look into the system to which it is applied.

Hypothesis

By applying a systems based approach to the nitrogen delivery process there should be improvements in *cycle time, efficiency,* and a reduction in the required number of personnel needed to sustain the delivery process. This will in turn reduce the amount of demurrage charges that the site incurs. In addition there should be less frustration associated with the delivery process.

Anticipated Results

It is expected that the demurrage charges are reduced as a result of a reduction in cycle time. Also, the number of personnel required to sustain the delivery process will reduce along with improving efficiency. All of these improvements together will provide a reduction in frustration amongst the personnel associated with the nitrogen delivery process.

Chapter 2- Literary Research

An extensive literary search was performed to see how improvements to processes were tackled using Systems, Lean, requirements, Reliability, and Cost Benefit. The results of the review are listed out below:

Improving road transport operations through lean thinking: a case study. This journal article was centered on improving road transport operations of a leading Mexican brewery. The hopes were to improve the process using Lean thinking and waste reduction. Two lean principles were combined the Seven Transportation Extended Wastes and Transportation Value Stream Mapping. By using these two concepts the team was able to reduce the travelling distance of the trucks along with increasing the number of customers they were able to serve in a given amount of time. (Villarreal, Garza-Reyes, Kumar, & Lim, 2016)

Reduction of Cycle time & Defects of Bogie Frames in Rail Coach Using Lean Principles. This article is focused on improving the bogie frame production process. The company was able to use Lean principles such as waste elimination, and cell design, and value stream mapping to reduce the cycle time of manufacture and reduce the number of defects/rework of the bogie frames. By implementing these principles the company was able to reduce the amount of defects by ~30%, cycle time was reduced by two hours per bogie frame, and productivity was improved by 14%. (Sathishwaran, Jose, & Nithyanandam, 2016)

Lean Supply Chain and Logistics Management. This book details how to eliminate waste within a supply chain by using Lean principles. In chapter 12.7 of the book Transportation Management Systems (TMS) are discussed. Things like real-time vehicle tracking, vehicle load and delivery route optimization, and planning and optimization of transportation routes, when coupled with Lean provide benefits such as decreases in transportation costs and increases in asset utilization. (Myerson, 2013)

Identifying root causes of inefficiencies in road haulage: case studies from Sweden, Switzerland and Germany. This paper expands on some of the existing research by adapting previous root cause models so that they can be used to make systematic improvements in road transport operations. The authors reported that one big issue that plagued several companies was erroneous/inadequate information flows at the beginning of the supply chain. The bad information was rippling all the way down to the transportation level causing inefficiencies. (Sternberg & Harispuru, 2017)

End-To-End Lean Management: A Guide to Complete Supply Chain Improvement. This book covers using lean to improve the entire supply chain. Chapter 7 of the book describes elements of a lean transportation. They include:

- **Contract and Third Party Logistics Providers**: Contracting out the transportation needs of the company. Leaving the transportation to those who specialize in it.
- **Closed Loop Delivery Systems**: Similar to a milk run. Vehicles making dedicated runs within the supply chain to move materials around.
- **Returnable Containers**: Pallets or totes designed to be used multiple times. Providing long term savings to the user.
- **Modified Shipping and Handling Equipment**: Side loading trailers, e.g. Soda Truck. Allows for offloading of goods loaded in the front of the trailer without offloading goods at the rear of the trailer.
- **Information Technology**: Real time tracking of equipment. Allowing better communication between the drivers and dispatching centers.

(Trent, 2007)

A modified FMEA approach to enhance reliability of lean systems. This article focused on using an FMEA to better improve the reliability of Lean systems. A modified FMEA is presented that requires a Risk Assessment Value (RAV) to be calculated. The RAV is calculated using a different arrangement of the same variables found in a standard FMEA. The following formula is used to make the calculation:

$$RAV = \frac{Severity \times Occurence}{Detection}$$

This arrangement has its advantages over the standard RPN in that it allows the user to prioritize failures based on detectability. The traditional RPN focuses on the likelihood of occurrence of the failure and severity of its effects. (Sawhney, et al., 2010)

Lean road transportation – a systematic method for improvement of road transport operations. This journal article proposes using a four step process, based on lean thinking, to improve road transport. The four steps are:

1. Transportation Value Stream Map (TVSM) Analysis
2. Identification of the Seven Transportation Extended Waste (STEW)s
3. Definition of Waste Elimination Strategy
4. Implementation of (STEWs) Elimination Strategy

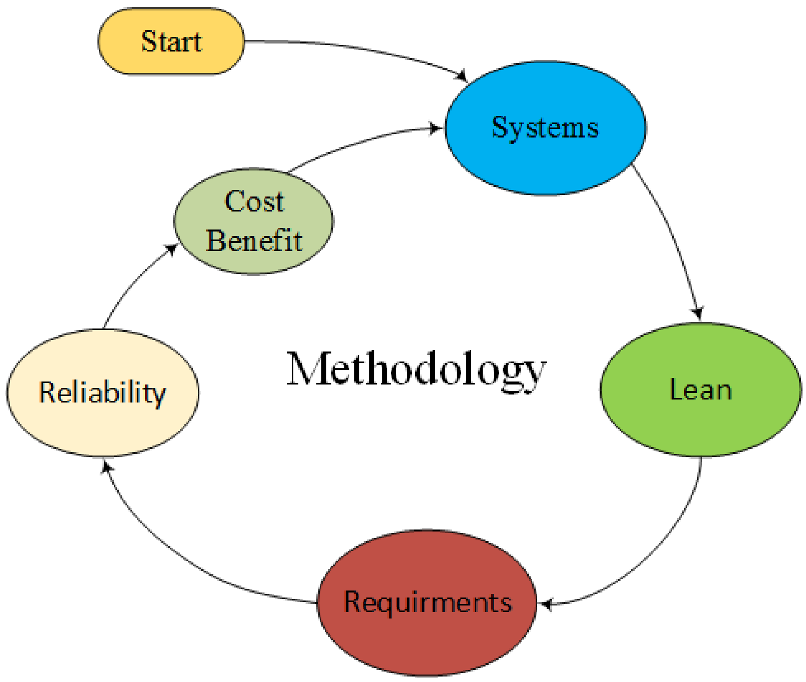
By implementing these steps the organization in the study was able to standardize a routine to improve its transport operations. (Villarreal, Arturo Garza-Reyes, & Kumar, 2016)

Lean Logistics. This article outlines a framework that can be used for lean logistics/supply chain. The authors state that deliveries to a facility should happen more frequently in smaller quantities in a milk run type fashion. They also state that the number of suppliers should be limited. This will reduce the amount of stock that is stored at the facility. (Jones, Hines, & Rich, 1997)

Chapter 3-Philosophy Methodology

Figure 1 illustrates the methodology that will be followed in the systems based approach. The approach is iterative with the main areas of analysis focused in *Systems*, *Lean*, *Requirements*, *Reliability*, and *Cost Benefit.* Other sub areas such as *Statistics*, *Optimization*, and *Economics* can be utilized within each of the main areas as needed to perform a sufficient analysis.

Figure 1-Methodology



Phase 1-Understanding the System

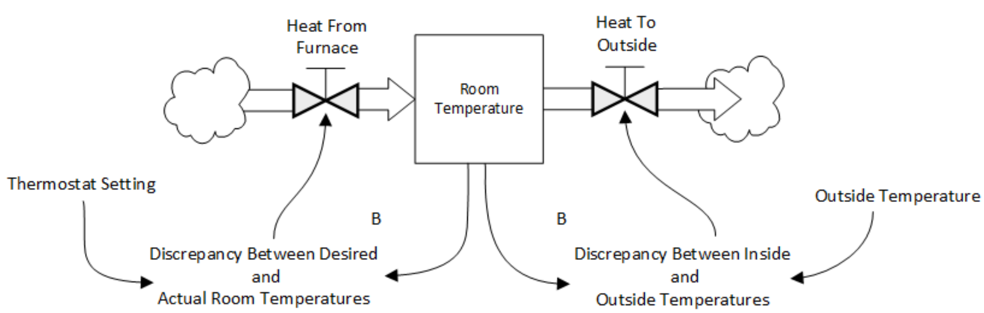
A system must contain three kinds of things: elements, interconnections, and a function or purpose (Meadows, 2008). To solve a problem or make improvements in a system, a clear understanding of the system boundaries along with the system goal/function must be established. This is followed by forming a list of variables needed to analyze the system as a whole. This list can then be aggregated to simplify the analysis. The aggregated variable list will be used in creating a stock and flow diagram. The diagram will aid in understanding the component interaction required for making improvements in the system. The following items are illustrated in the diagram:

<u>Stocks</u>: The elements of the system that you can see, feel, count, or measure at any given time. This can be interpreted as a store, a quantity, and accumulation of material that has built up over time. (Meadows, 2008)

<u>Feedback Loops</u>: A closed chain of causal connections from a stock, through a set of decisions or rules or physical laws or actions that are dependent on the level of the stock, and back again through a flow to change the stock. Feedback loops can be seen in two forms *Balancing Feedback* and *Reinforcing Feedback. Balancing Feedback Loops* are stabilizing, goal seeking, and regulating. This type of loop brings both sources of stability and sources of resistance to change. *Reinforcing Feedback Loops* are amplifying, reinforcing, self-multiplying, snowballing – a vicious or virtuous circle that can cause healthy growth or runaway destruction. (Meadows, 2008)

Figure 2 is an example of how the stocks and feedback loops are laid out in a concise model that allows for a quick reference of all the interactions within the system.

Figure 2- Stock & Flow Diagram



(Meadows, 2008)

In some cases systems can be arranged in a manner that they exhibit very problematic behaviors called *Archetypes*. The system in question should be examined for the presence of any *Archetypes*. The following is a list of the common *Archetypes*:

<u>Policy Resistance-Fixes that Fail:</u> A result of one of the actors associated with the system attempts to pull a stock towards goals of their own by implementing new policies. This pulls the stock away from the goals of other actors. (Meadows, 2008)

<u>Tragedy of the Commons:</u> A commonly shared resource from which every user benefits from, also sharing in the costs of its abuse with everyone else. This results in the resource eroding until it becomes unavailable to all of the users. (Meadows, 2008)

Drift to Low Performance: This occurs when present performance standards are influenced by past performance. This establishes a reinforcing feedback loop of eroding goals that sets a system drifting toward low performance. (Meadows, 2008)

Escalation: This occurs when one stock is determined by attempting to surpass the state of another stock. This sets up a reinforcing feedback loop that results in a competition between the two stocks. With the escalation being exponential. (Meadows, 2008)

Success to the Successful: This occurs when winners of a competition are rewarded with the ability to win again. This sets up a reinforcing feedback loop that could allow the winners to take all and eliminate all of the losers. (Meadows, 2008)

Shifting the Burden to the Intervenor: Occurs as a result of a solution to a problem (intervention) in a system masking the symptoms rather than correcting the problem setting up a destructive reinforcing feedback loop. Over time more and more of the solution to the problem will be required to maintain the system. (Meadows, 2008)

Rule Beating: A behavior that results in the appearance of the rules being obeyed or the goals are being achieved. This results in a distortion of the system. (Meadows, 2008)

Seeking the Wrong Goal: If a goal is defined inaccurately or incompletely, the system may obediently work towards a result that is not intended or wanted. (Meadows, 2008)

Any Archetypes that are uncovered should be noted, allowing them to be addressed and resolved later.

Phase 2-Lean Analysis

With a better understanding of the system, the *Critical Process*, the area that needs to be investigated, can be defined. A well-defined critical process is important to help prevent scope creep of the study. *Cycle Time, Coefficient of Variation (CV), Takt Time, Throughput,* and *WIP* should be recorded, calculated, and used to determine the current condition of the system. The following is a descriptive list of the metrics:

Cycle Time (CT): The actual time required to complete a step.

WIP: Work In Process. Inventory that is in process at any moment in time.

Throughput (TH): The average output of a production process. Little's Law relationship is employed here to calculate throughput.

$$WIP = Throughput \times Cycle\ Time$$

Coefficient of Variation (CV): A measure of the variability.

$$Coeficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation}{Average}$$

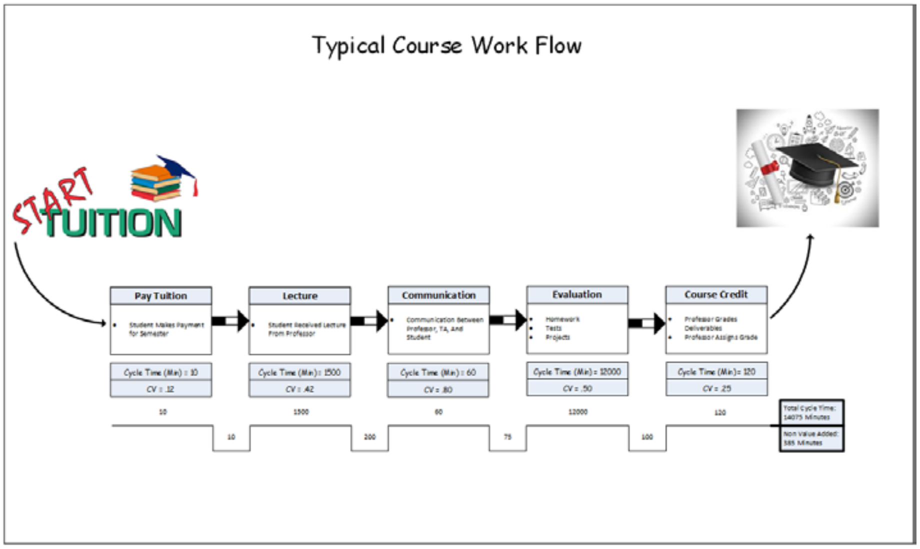
Takt Time: A measure of customer demand rate.

$$Takt = \frac{Alloted\ Time}{Customer\ Demand}$$

(Hopp & Spearman, 2011)

These metrics will also be used as a comparison to measure the future state of the system against. A value stream map, *Figure 3* , must be constructed, listing all of the steps of the process sequentially. The map is a convenient location to list cycle times, coefficient of variation, and any other pertinent data. The value stream map will become the central hub for all the other parts of the analysis.

Figure 3- Value Stream Map Example



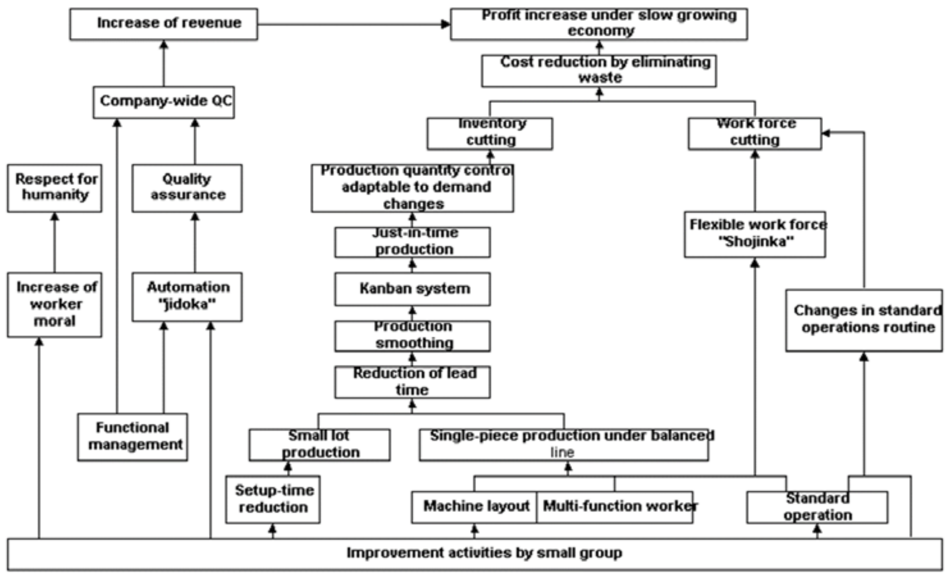
With the whole process laid out sequentially it can be easily investigated, identifying bottlenecks and individual steps with high coefficients of variation (CV). Coefficients of variation can be classified into three categories low, moderate, and high:

Variability Class	Coefficient of Variation
Low (LV)	$cv < 0.75$
Moderate (MV)	$0.75 \leq cv \geq 1.33$
High(HV)	$cv \geq 1.33$

(Hopp & Spearman, 2011)

The step in the critical process having the longest cycle time can be classified as the bottleneck. The step in the critical process with the largest CV can also be classified as the bottleneck. Once defined the bottleneck will become the focal point for the remainder of the study.

Figure 4-Toyota Production System Model



(Monden, 1998)

Figure 4 is an illustration of the Toyota Production System Model. This model should be referenced when examining the critical process for improvement ideas. Additionally, the critical process should be examined for steps that can be combined, re-arranged, or removed. If the process involves batch type flow, reducing the batch size is favorable, single piece flow is ideal.

Ultimately, any improvements stemming from this section should satisfy the three principles of Lean:

Reduce Lead Time

Reduce Variation

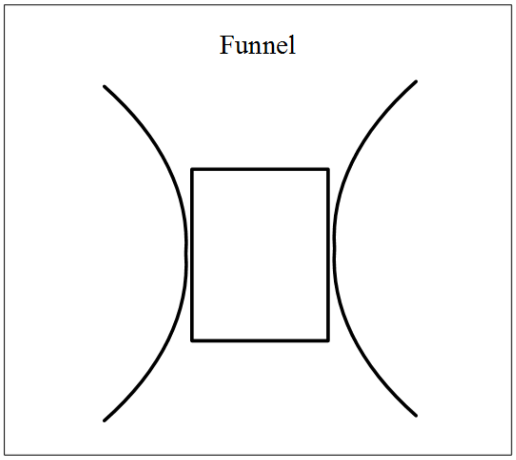
Improve the Quality of Human Life

(Sawhney & Macias de Anda, 2016)

Phase 3-Understanding the Requirements

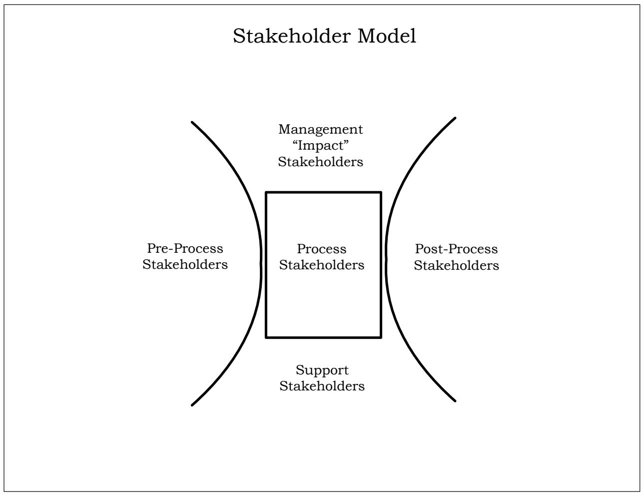
With the focal point in the process defined, additional analysis can be performed. The first of which should be a requirements. Understanding the requirements of a system will provide insight to the frame work of limits under which the system is currently operating. This begins by understanding who the stakeholders are that are associated with the focal step. A great visualization tool that can be used to zoom in on the bottleneck, or point of interest in the critical process is the "funnel" *Figure 5*.

Figure 5-Funnel



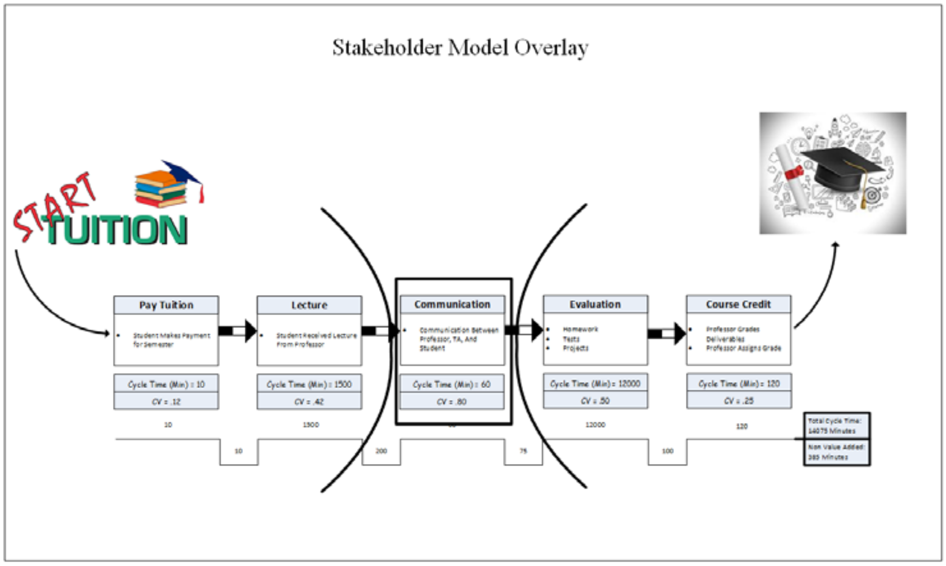
Utilizing the funnel, *Figure 6* illustrates the stakeholder model. It includes the *Management "Impact" Stakeholders* that fill the area in the top of the funnel, the *Pre-Process Stakeholders* that are associated with the steps that happen prior to the bottleneck, the *Process Stakeholders* that are associated with the process itself, the *Post-Process Stakeholders* that are associated with the steps that occur after the bottleneck, and the *Support Stakeholders* that occupy the bottom area of the funnel.

Figure 6-Stakeholder Model



Using this approach in laying out stakeholders yields an easy and efficient way of collecting and organizing all of stakeholders related to the process. Overlaying this model onto the process stream, with the box centered over the bottleneck in the flow, aids in understanding each of the stakeholders and their role in the process. *Figure 7*is an example of the stakeholder model being over laid onto the process flow.

Figure 7-Stakeholder Model Overlay



All of the stakeholders for each area should be listed out including a description of their role in the process. A systems based Failure Mode Effects Analysis (FMEA) can be performed for each of the stakeholder areas. This brings an understanding of the types of failures associated with each area. These failures can then be prioritized. Each of the failure modes are assigned a Risk Priority Number (RPN) and a Risk Assessment Value (RAV) by using the following formulas:

$$RPN = Severity \times Occurence \times Detection$$

$$RAV = \frac{Severity \times Occurence}{Detection}$$

Severity- How severe the impact to the customer.

(Low Number = Low Impact, High Number = High Impact)

Occurrence- How frequently is it likely to occur.

(Low Number = Not Likely To Occur, High Number = Likely To Occur)

Detection- How easy is it to detect.

(Low Number = Very Likely To Be Detected, High Number = Not Likely To Be Detected)

(Sawhney D. , Systems based process FMEA for Stakeholders, 2017)

With both RPN and RAV numbers assigned, the stakeholders or project group members have a very systematic way of tackling the failures. Requirements for the system can be modeled and prioritized around these failures allowing them to be mitigated. *Figure 8* is an example how the systems based is constructed in a spread sheet for the process stakeholders.

Figure 8- Systems Based FMEA Example

Systems Based FMEA										
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
PROCESS	Human	Operator Fails To Show Up For Shift	Customer information delayed in getting into the system.	9	Unexpected sickness	8	Check with employees scheduled to come onto the next shift to ensure they are still going to make it	2	144	36
	Equipment	Dispatching Computer Stops Working	Customer information isn't dispatched to the waiting ambulance	10	Power to computer is turned off	4	Ensure computer's power cables are securley plugged in and check backup power supply before the start of each shift	2	80	20
	Schedule	Delays In Customer's Call Connecting To The Dispatch Office	Customer information delayed in getting into the system. If it get completely put in at all.	9	Not enough operators scheduled for a particular shift	3	Management should double check operator schedules a week in advance to ensure enough operators are scheduled for any given shift.	2	54	13.5

From the five areas of stakeholders listed above it is necessary to determine which stakeholders are critical. This is accomplished using the Analytical Hierarchy Process (AHP). AHP allows for pair wise comparisons between two of the stakeholders at a time against a criteria. The four criteria that all of the stakeholders are compared to include *Cost*, *Service*, and *Safety*, and *Security*. The top ranked stakeholders can then be invited to a meeting to discuss and prioritize the current requirements of the system. If there isn't a comprehensive list of requirements, one can be established.

To prevent any one of the stakeholders from dominating the meeting the nominal group technique can be utilized. This will consist of each of the stakeholders reviewing all of the requirements brought to the table, selecting three, writing those three down on a sticky note, and handing them to the meeting facilitator who hangs them on a board. This process will continue for as many steps as needed until the group decides on a concise set of requirements. During the meeting the facilitator will be observing the participants to ensure that each of them are engaged and actively participating in the meeting.

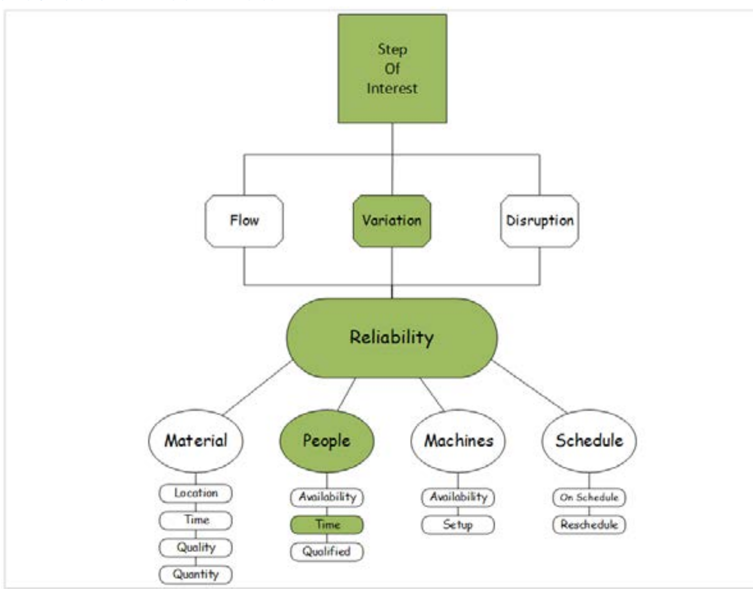
Phase 4-Reliability

After analyzing the requirements, a review of the current reliability of the system should be performed. This starts with obtaining the theoretical capacity, the throughput at which the system performs without any problems. A down time of up to 15% for maintenance should be considered and accounted for. With the theoretical capacity in hand the baseline capacity, throughput of the system currently, should be calculated as a comparison. Throughput for, both instances, is calculated using the Little's Law relationship:

$$Throughput = \frac{WIP}{Cycle\ Time}$$

The value stream map with the funnel overlay as seen in the stakeholder model overlay, *Figure 7*, should be referenced to obtain the location of the bottleneck in the critical process. The reliability for the bottleneck should be calculated first. This is accomplished by first calculating the reliability of each of the sub areas *(people, material, machines, and schedule)* that make up a process step. *Figure 9* is an illustration of how the step is broken out into sub groups.

Figure 9-Reliability Calculation Break Down



Failure rate data should be collected and plotted on a *Weibull* chart allowing β and η to be determined. These values can then be used with formula $R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$ to calculate the reliability for the area. With the reliability for each of the steps calculated, the reliability for the entire system can be calculated using the method applicable to the layout of the process flow:

Series: Process steps that are aligned in series.

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

Parallel: Process steps that are aligned in parallel

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

k out of n: If a minimum number out of the total number of components are required for operation. The following formula should be used.

$$R = \sum_{i=k}^{n} \left(\frac{n!}{i!\,(n-i)!}\right) p^i (1-p)^{n-i}$$

Cut & Path: A method of determining the reliability of a system that isn't known.

The *Process* portion of the systems based FMEA created in *Phase 3* should be referenced allowing for a better understanding of failures in the step. A better understanding of the failures in the step will allow for recommendations to be made that should help to mitigate the failures in an effort to improve the reliability.

Phase 5-Recommended Changes, Future State, Cost Benefit

The recommended changes along with a predicted future state of the system are to be presented. A complete cycle through the methodology, *Figure 1*, should be made starting with *Phase 1* and going through *Phase 4* for the future state. This will allow a comparison of the current and future states to be made. Any improvements in the metrics (*Coefficient of Variation, Cycle Time, Throughput, and WIP*) should be noted.

Cost benefits as a result of the recommended changes should be evaluated and reported. This is accomplished by comparing the costs associated with the current and future states. If a specific rate of return is required by the customer, it can be evaluated here as well.

Chapter 4 - Case Study

Phase 1-Understanding the System

To be classified as a system three criteria must be met. There must be *elements*, *interconnections*, and *function/purpose* (Meadows, 2008). Elements such as delivery trucks, truck drivers, storage tanks, utility operators, utility escorts, and security escorts, are used during the delivery of nitrogen. These elements, some being stocks, have interconnection among one another. They also have a common goal or function of delivering nitrogen to the site thereby maintaining the plant nitrogen gas supply. With these thoughts in mind, the nitrogen delivery process can be considered as a system.

Variables

The nitrogen delivery process will be investigated using the following variables:

Delivery Trucks
Delivery Drivers
Utility Operators
Utility Operators - Escorts
Security Personnel
Security Escort
Site Nitrogen Inventory
Vendor Nitrogen Inventory
Quality
Schedule
Budget
Availability

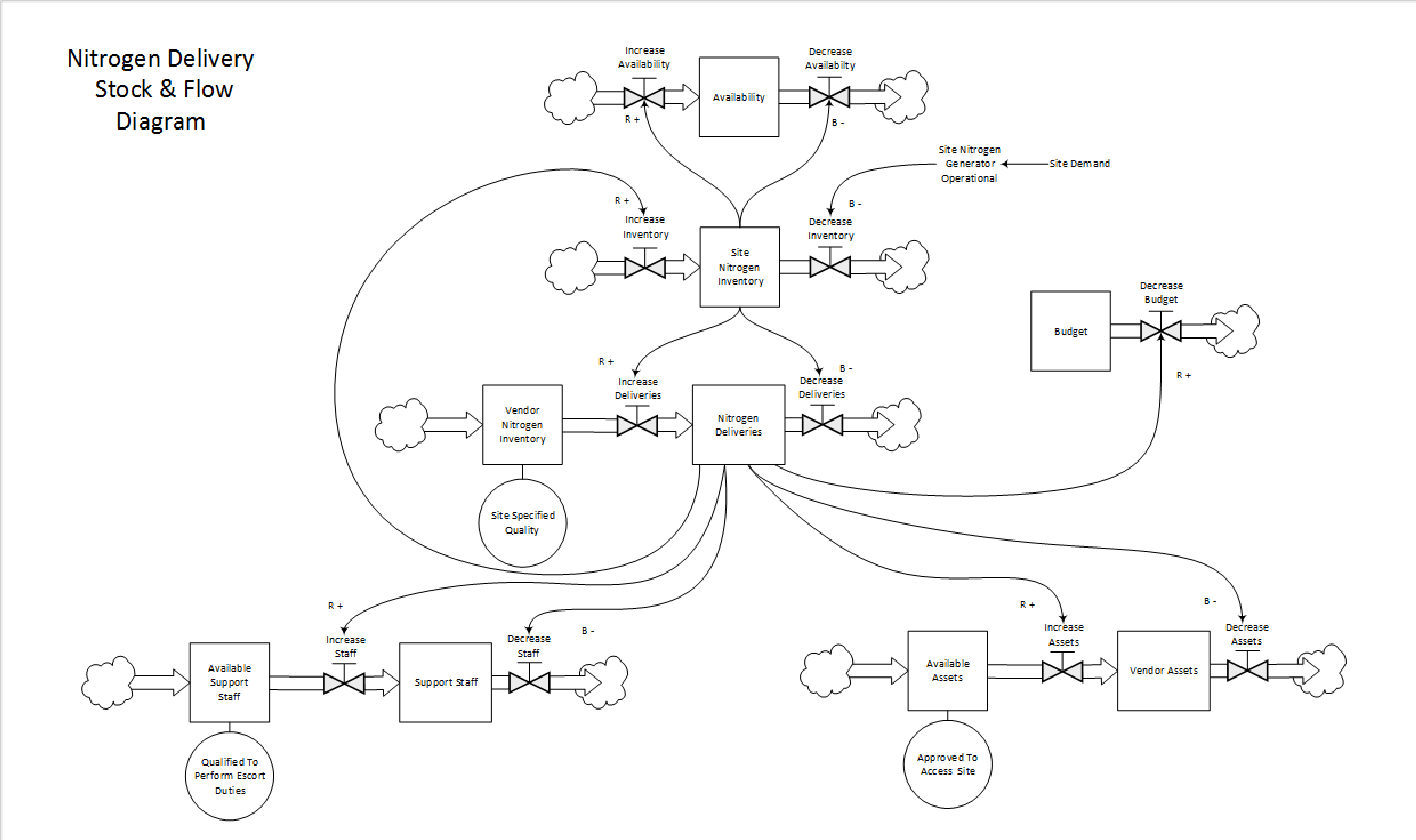
Aggregating this list of variables, one can look at the following:

Vendor Assets
(Truck Drivers, Delivery Trucks)
Support Staff
(Utility Operators, Utility Operators-Escorts, Security Personnel, Security Escort)
Nitrogen Inventory
Quality
Schedule
Budget
Availability

Stock and Flow

Combining previous knowledge and a current study of the system a stock and flow diagram can be generated. The diagram combines an array of stocks, the elements of the system that you can see feel touch or measure at any time, reinforcing loops, self–enhancing leading to runaway collapse over time, and balancing loops, equilibrate or goal-seeking structures in a system which are both sources of resistance and resistance to change. (Meadows, 2008)

Figure 10-Nitrogen Delivery Stock & Flow



Stock & Flow Explanation

An explanation of the stock & flow diagram starts with the *Site Nitrogen Inventory*, the amount of inventory present onsite dictates the rest of the process. The inventory is increased by the reinforcing loop from Nitrogen Deliveries and, decreased by the state of the site nitrogen generator along with plant demand. If the generator is offline the use of the *Site Nitrogen Inventory* goes up significantly. Next, the *Site Nitrogen Inventory* controls two other stocks directly, *Availability* and *Nitrogen Deliveries*. *Availability* is increased via a reinforcing loop from the *Site Nitrogen Inventory*. As the *Site Nitrogen Inventory* increases the stock of *Availability* goes up. When it decreases the stock of *Availability*, being controlled by a balancing loop from the *Site Nitrogen Inventory*, also decreases. Following *Availability*, the stock of *Nitrogen Deliveries* is also controlled by the stock of *Site Nitrogen Inventory*. The stock of *Nitrogen Deliveries* increases with as a response to the reinforcing loop coming from the *Site Nitrogen Inventory*. As the inventory gets low the reinforcing loop activates increasing the number of deliveries. Oppositely, as the *Site Nitrogen Inventory* increases a balancing loop engages slowing the amount of deliveries, decreasing the stock of *Nitrogen Deliveries*. Lastly, the stock of *Nitrogen Deliveries* controls four other stocks *Site Nitrogen Inventory*, *Support Staff*, *Vendor Assets*, and *Budget*. As the stock of *Nitrogen Deliveries* increases, reinforcing loops that increase the *Site Nitrogen Inventory*, *Support Staff*, *Vendor Assets*, and *Budget* stocks activate simultaneously. This causes the stocks of *Site Nitrogen Inventory*, *Support Staff*, and *Vendor Assets* to increase while decreasing the *Budget*. When the stock of *Nitrogen Deliveries* decreases, balancing loops and engaged to reduce the stocks of *Support Staff* and *Vendor Assets*.

Dominate Loops

Dominate loops in the system are the reinforcing and balancing loops tied to the *Site Nitrogen Inventory* controlling the stock of *Nitrogen Deliveries*. When these loops activate there is a cascade effect that happens increasing the stock of *Nitrogen Deliveries*, *Support Staff*, *Vendor Assets* and decreasing the *Budget stock*.

Archetypes

The Archetype that can be seen in this system is *Drift to Low Performance*. Drift to Low Performance is defined as the present performance being dictated by past performance. With actors in the system believing bad news more than good news, and the desired state of the system is influenced by the perceived state (Meadows, 2008). The support staff associated with the delivery process have grown accustomed to the long cycle times. Because of this they show no efforts in trying to improve things.

Phase 2-Lean Analysis

Lean Analysis begins with observing system operation and recording cycle times for each process. This allows *WIP*, *WIP Critical*, *Takt Time*, and *Throughput* to be calculated. Making use of the average nitrogen inventory (WIP) and the average amount of product offloaded WIP can be transformed into number of trucks.

$$WIP = \frac{Average\ Nitrogen\ Inventory\ (\ 950{,}000 SCF)}{638{,}000\ SCF\ Average\ Per\ Truck} = 1.49\ Trucks$$

Minimum LN_2 inventory is dictated by plant procedure. Using this inventory and the average amount of product offloaded WIP critical can also be translated into number of trucks.

$$WIP_{Critical} = \frac{Minimum\ Nitrogen\ Inventory\ (\ 600{,}000 SCF)}{638{,}000\ SCF\ Average\ Per\ Truck} = .94\ Trucks$$

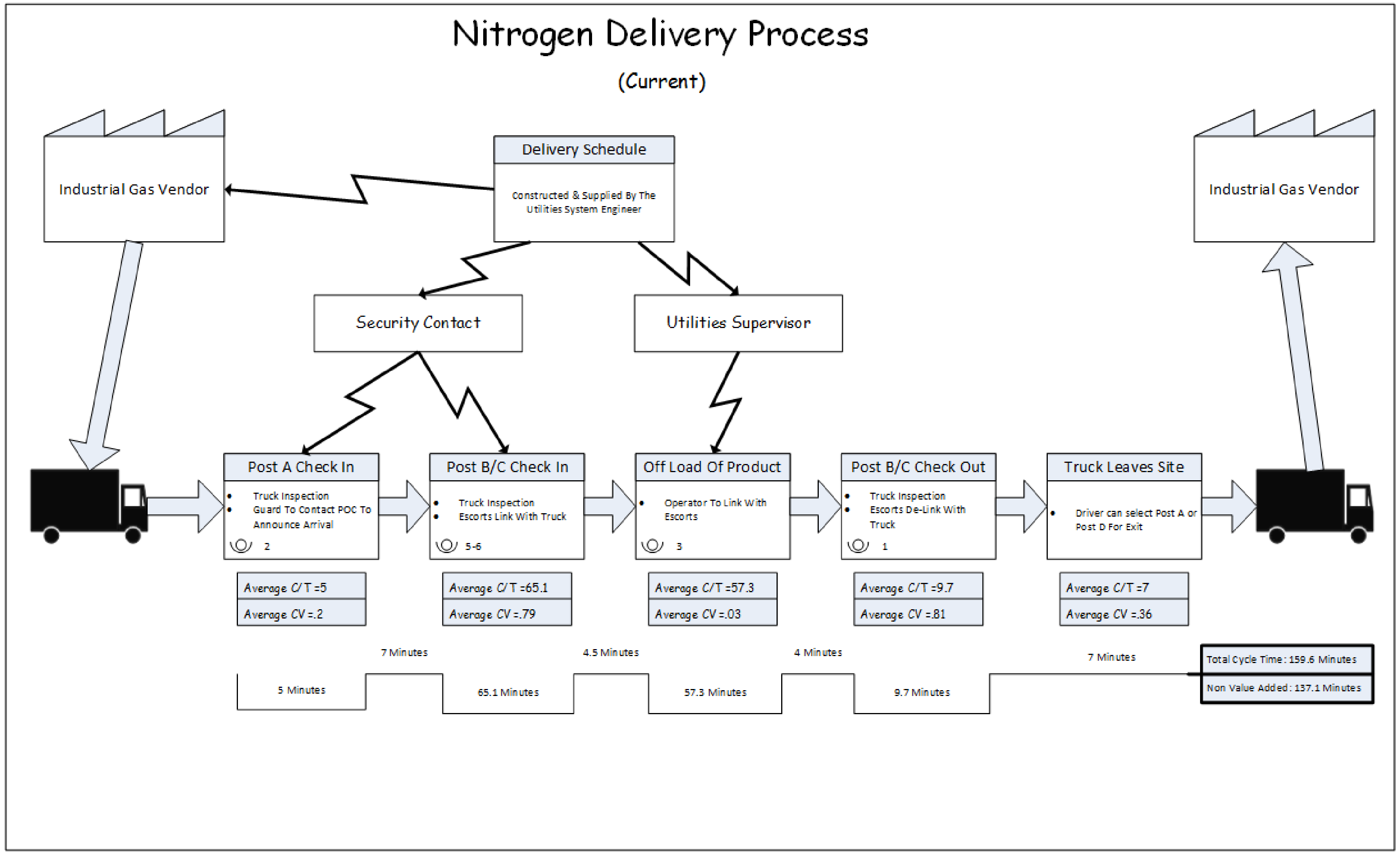
Coefficients of Variation and *Cycle Times* were also calculated and collected. These are displayed on the value stream map *Figure 11* below. The coefficient of variation (CV) was calculated for each step using the below relationship.

$$Coeficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation}{Average}$$

Next, *Throughput* is calculated using the *Little's Law* relationship.

$$WIP = Throughput\ \times Cycle\ Time \rightarrow Throughput = \frac{WIP}{Cycle\ Time} = \frac{1.49}{225} = .006\ \frac{Trucks}{min}$$

Figure 11- Nitrogen Delivery Process Value Stream Map

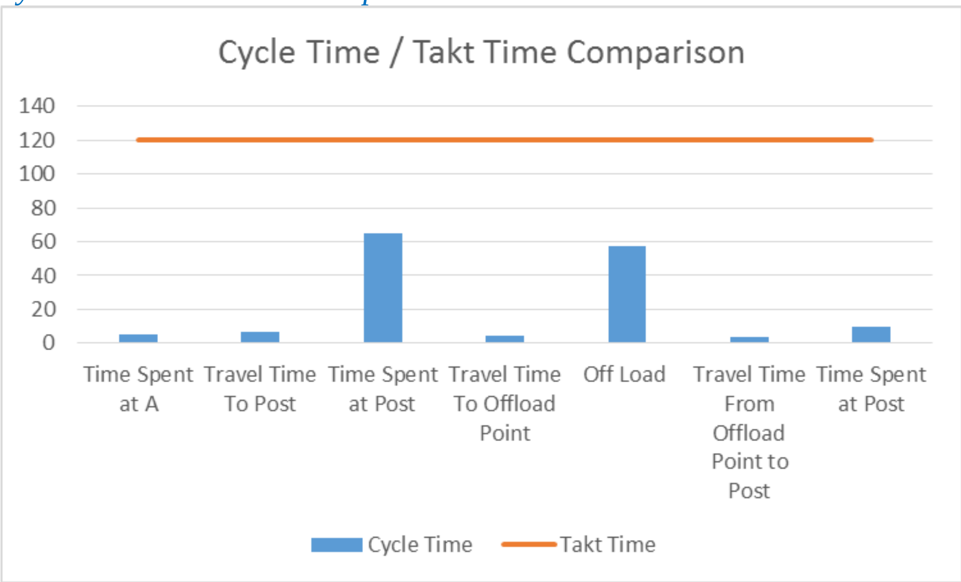


Takt time is calculated by dividing the allotted time of 2 hours (Maximum before demurrage charges start) by the customer demand of 1 truck. The allotted time was selected based on the amount of time the delivery can take before demurrage charges set in.

$$Takt = \frac{Alloted\ Time}{Customer\ Demand} = \frac{120 Minutes}{1\ Truck} = 120\ Minutes$$

A comparison of the process cycle times and the Takt time is made in *Figure 12.* This gives a quick visual reference to see if any of the process times are exceeding the Takt time. Since all of the process times are below the Takt Time requirement, the individual processes will be evaluated for the possibility of elimination and or combination thereby improving the flow.

Figure 12-Cycle Time / Takt Time Comparison



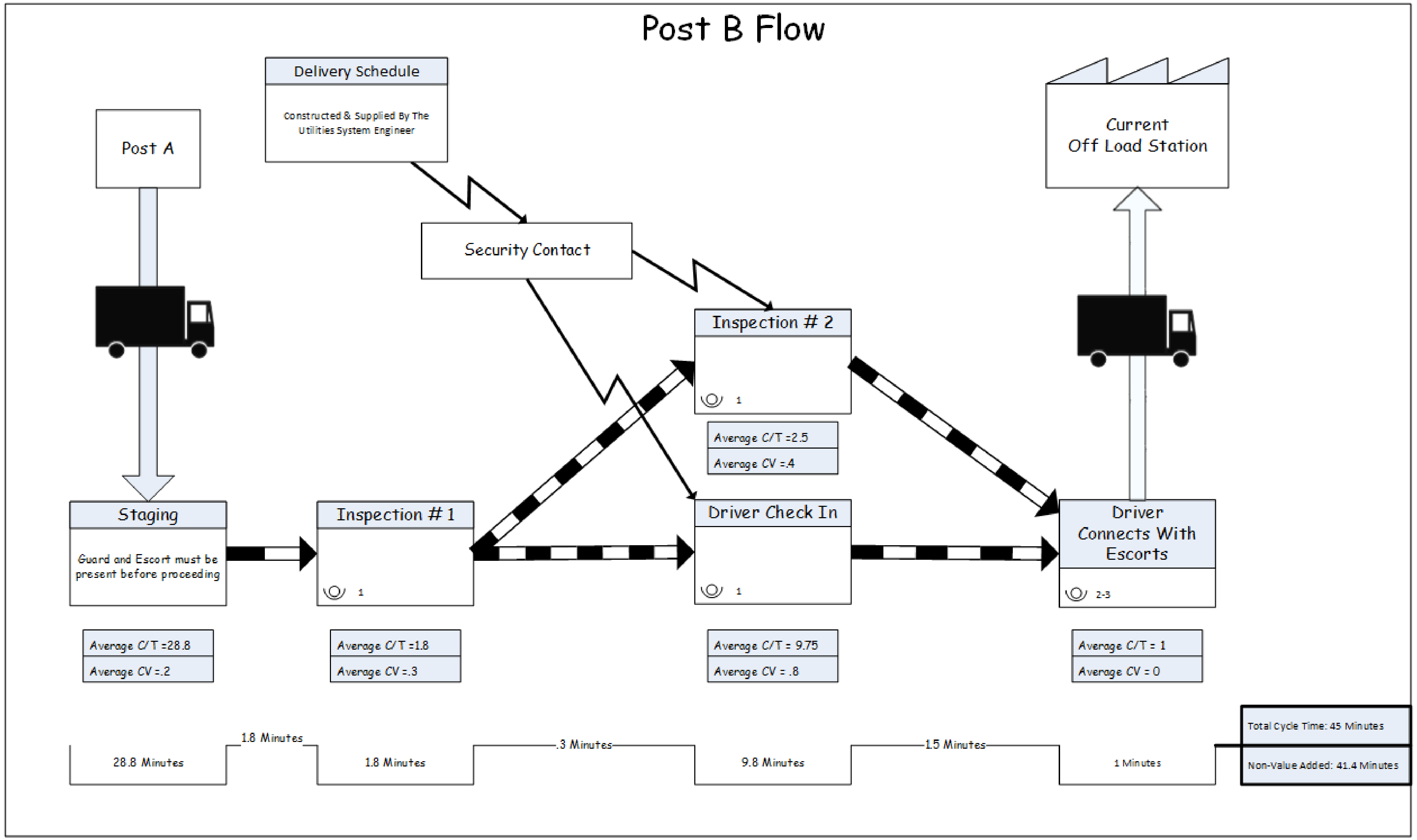
Process Step Evaluation

In reviewing the value stream map, *Figure 11*, the *bottleneck*, consuming the largest block of time was found to be the trucks processing in through the Post B. This process had the largest average time of 65.1 minutes and the largest amount of variation, CV of .79. With the *bottleneck* defined as the trucks processing through Post B, an additional value stream map, *Figure 13*, was created to better understand the inbound flow through post B. In observing the flow of Post B, the overall cycle time of the process is 45 minutes utilizing the same WIP as above throughput is calculated at .03 $^{Trucks}/_{min}$ The largest delay in the flow stems from the staging process with an average time of 28.8 minutes. The reason for the delay comes from the site requirement of having both the guard and escort present before the truck and driver are allowed to continue in the process to inspection one. The guard and escort are both dedicated resources for the purpose of escorting the nitrogen truck and driver while they are making a delivery. They stay with the truck and driver from the time they process through Post B until the truck has been offloaded and the truck processes back out through Post B. Even though this part of the delivery process is fixed due to the site procedures, it might be possible to shorten the staging period or even be eliminated. Elimination and improvement possibilities are discussed in the *Phase 5* of this report.

The process of offloading the truck had the second largest process time, however it has the lowest amount of variation with a CV of .03. Due to the nature of this part of the process, the amount of time that it takes to offload is fixed.

The remainder of the processes all have low average cycle times, ranging from four to seven minutes, when compared to the time spent at post B and truck offloading. These processes cannot be combined, however could possibly be eliminated. Possibilities of elimination are discussed in the *Phase 5* section of this report.

Figure 13-Post B Value Stream Map

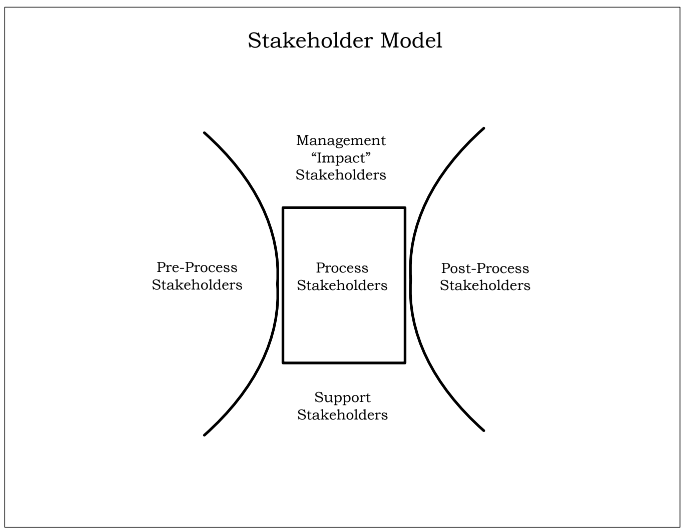


Phase 3-Understanding Requirements

Stakeholders

Figure 14 illustrates the stakeholder model. It includes the *Management "Impact" Stakeholders* that fill the area in the top of the funnel, the *Pre-Process Stakeholders* that are associated with the steps that happen prior to the bottleneck, the *Process Stakeholders* that are associated with the process itself, the *Post-Process Stakeholders* that are associated with the steps that occur after the bottleneck, and the *Support Stakeholders* that occupy the bottom area of the funnel.

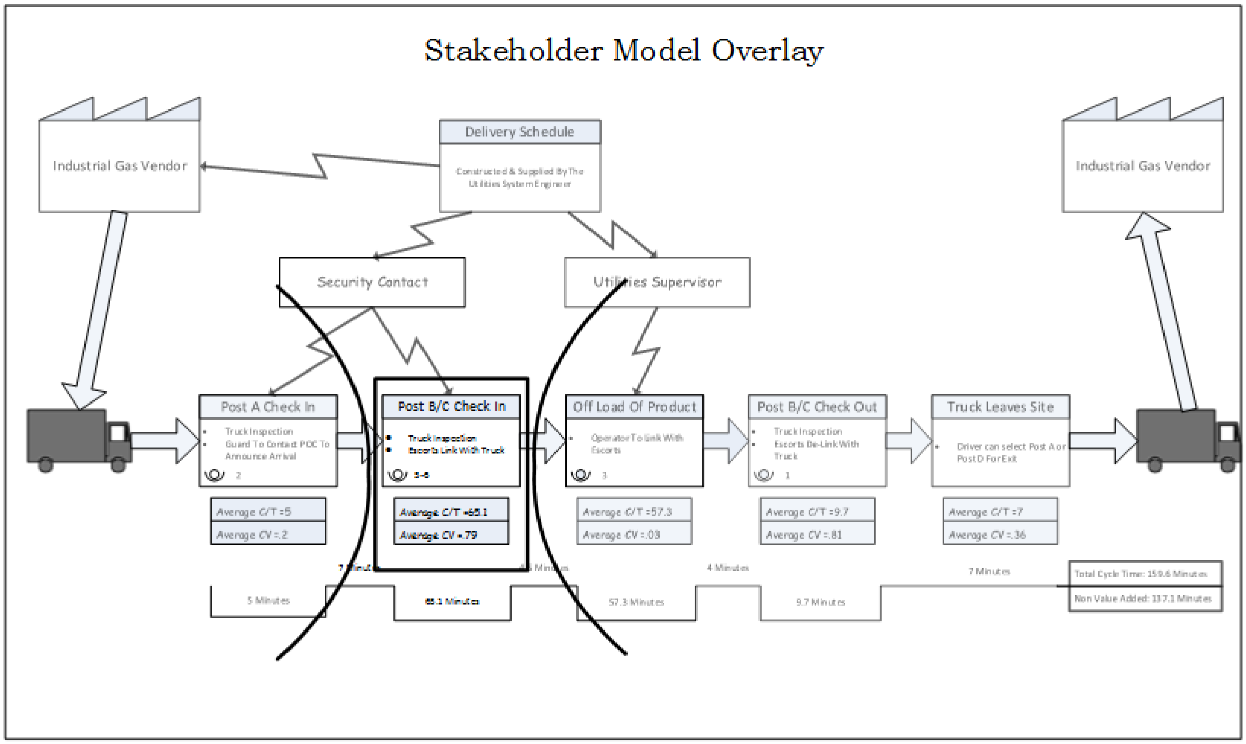
Figure 14-Stakeholder Model



(Sawhney R.)

Using this approach in laying out stakeholders yields an easy and efficient way of collecting and organizing all of stakeholders related to the process. Overlaying this model onto the process stream, with the box centered over the bottleneck in the flow, aids in understanding each of the stakeholders and their role in the process. Reviewing the value stream map, *Figure 11*, the bottleneck is the Post B/C check in. *Figure 15* illustrates the model overlaid onto the value stream map.

Figure 15-Stakeholder Model Overlay



From this, the stakeholders associated with each area can be determined, as shown in *Figure 14*. Characteristics related to each of the stakeholders, such as how they are connected to the process technically, organizationally, politically can be recorded.

Pre-Process Stakeholders

Pre-Process stakeholders connected to the process, before the bottleneck, include:

- *Truck Driver* – This is the vendor representative that makes the delivery.
- *Security Person* – This is the individual that mans the "Post A Check In". This individual would be tied to the process organizationally.

Process Stakeholders

Process stakeholders connected directly to the process are:

- *Operator* - Person who aids the truck driver in the off load. They are tied to the process organizationally and technically.
- *Escort* – Person who escorts the truck driver, usually an operator assigned escorting duties. They are connected to the process organizationally
- *Security Escort* – Person who watches over the truck and driver while it is making the delivery, They are connected to the process organizationally
- *Truck Driver* - This is the vendor representative that makes the delivery and connected to the process technically.

Management “Impact” Stakeholders

Management “Impact” stakeholders include those that give management type oversight to the process. The following would be included:

- *Operator’s Manager* – Provide oversite and guidance to the operators. They are tied to the process organizationally
- *Security Escort’s Manager* -   Provide oversite and guidance to the Security Escorts. They are tied to the process organizationally
- *Vendor Dispatcher* – Schedule deliveries based on the schedule they are provided by the system engineer.

Post-Process Stakeholders

Post-process stakeholders are the stakeholders that feel the effects of the bottleneck. These include:

- *Operator* - Person who aids the truck driver in the off load. They are tied to the process organizationally.
- *Escort* – Person who escorts the truck driver, usually an operator assigned escorting duties. They are connected to the process organizationally
- *Security Escort* – Person who watches over the truck and driver while it is making the delivery, They are connected to the process organizationally
- *Truck Driver* - This is the vendor representative that makes the delivery.

Support Stakeholders

Support stakeholders include those that give support to the process. The following are included in this category:

- *Visitor’s Center* – Provides needed access support to the drivers. The Visitor’s Center is connected to the process organizationally
- *System Engineer* – System engineer provides a schedule to the vendor, security personnel, and operations personnel. The engineer is connected technically to the process.

FMEA

A systems based Failure Mode Effects Analysis is performed for each stakeholder area, shown in the model above, *Figure 13*, allowing prioritization of the types of failures associated with each area. Each of the failure modes are assigned a Risk Priority Number (RPN) and a Risk Assessment Value (RAV) by using the following formulas:

$$RPN = Severity \times Occurence \times Detection$$

$$RAV = \frac{Severity \times Occurence}{Detection}$$

Severity- How severe the impact to the customer.

(Low Number = Low Impact, High Number = High Impact)

Occurrence- How frequently is it likely to occur.

(Low Number = Not Likely To Occur, High Number = Likely To Occur)

Detection- How easy is it to detect.

(Low Number = Very Likely To Be Detected, High Number = Not Likely To Be Detected)

(Sawhney D. , Systems based process FMEA for Stakeholders, 2017)

With both the RPN and RAV assigned, the stakeholders or project group members have a very systematic way of tackling the failures. Requirements for the system can be modeled and prioritized around these failures allowing them to be mitigated.

Figure 16 - FMEA (Pre-Process)

FMEA										
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
PRE-PROCESS	Human	Driver Has To Leave Prematurely	Delays in the operator and escort linking up with the driver at the post	7	Unexpected sickness/ Family Emergency	8	Driver to notify the vendor when a family emergency occurs so the vendor can assign a replacement driver.	2	112	28
		Driver Does Not Have Access	Delays in the operator and escort linking up with the driver at the post	7	Driver not on approved list. Driver fails to pick up badge	5	System Engineer to verify driver with vendor. Give instruction as needed to ensure driver is approved and badged.	2	70	18
		Security Person Has To Leave Check In Point Prematurely	Delays in the operator and escort linking up with the driver at the post	7	Unexpected sickness/ Family Emergency	4	Security person to notify their supervisor when a family emergency occurs so management can assign a replacement.	4	112	7
	Equipment	Truck Breaks Down	Product Delivery Is Delayed	8	Numerous (Flat Tire, Air Leak, Engine Problem. Etc.)	4	Vendor to ensure all preventative maintenance is performed on time and that all equipment is in good working order.	2	64	16
		Check Point Access Equipment Is Not Functioning	Delays in truck leaving site	5	Improper Preventative Maintenance	2	System Engineer should be informed by the Security Escort Supervisor of any issues to that delays can be expected.	4	40	3
	Schedule	Product Not Delivered On Scheduled Day	Insufficient product to serve nitrogen generator and backup system	6	Not enough drivers to make scheduled deliveries. Not enough product to fill the demand.	5	System Engineer to verify with vendor 24 hours prior to delivery to ensure scheduled delivery will be made.	2	60	15

Figure 17 - FMEA (Process)

FMEA										
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
PROCESS	Human	Operator Fails To Show Up For Shift	Delays in the escort linking with the driver	8	Unexpected sickness / Family emergency	7	Operator Manager to review the operator schedule the day prior to ensure coverage. If the operator fails to show up for their shift, the Operator Manager should reassign and or bring in additional operators as needed to ensure delivery is covered.	2	112	28
PROCESS	Human	Driver Does Not Have Access	Delays in the operator and escort linking up with the driver at the post	7	Driver not on approved list. Driver fails to pick up badge	5	System Engineer to verify driver with vendor. Give instruction as needed to ensure driver is approved and badged.	2	70	18
PROCESS	Human	Operator Does Not Have Approval To Escort	Delays in the operator and escort linking up with the driver at the post	5	Operator not on approved list.	4	Opeator manager should review the operator assignement schedule the day before and determine if operator is on approved list.	2	40	10
PROCESS	Human	Operator Falls Ill In The Middle Of Their Shift And Has To Leave	Delays in the escort linking with the driver	9	Unexpected sickness / Family emergency	7	Management should be informed at the beginning of each shift of any abnormal medical conditions or if the operator feels that they may need to leave before their shift has ended.	4	252	16
PROCESS	Equipment	Truck Breaks Down	Product Delivery Is Delayed	8	Numerous (Flat Tire, Air Leak, Engine Problem. Etc.)	4	Vendor to ensure all preventative maintenance is performed on time and that all equipment is in good working order.	2	64	16
PROCESS	Equipment	Security Escort's Vehicle Breaks Down	Product Delivery Is Delayed	5	Numerous (Flat Tire, Air Leak, Engine Problem. Etc.)	3	Management to ensure all preventative maintenance is performed on time and that all equipment is in good working order.	2	30	8
PROCESS	Equipment	Operator Vehicle Breaks Down	Product Delivery Is Delayed	6	Numerous (Flat Tire, Air Leak, Engine Problem. Etc.)	4	Management to ensure all preventative maintenance is performed on time and that all equipment is in good working order.	3	72	8
PROCESS	Equipment	Check Point Access Equipment Is Not Functioning	Delays in truck leaving site	5	Improper Preventative Maintenance	2	System Engineer should be informed by the Security Escort Supervisor of any issues to that delays can be expected.	4	40	3
PROCESS	Schedule	Delays In Security Person Linking with Truck Driver and Operator Escort	Product Delivery Is Delayed	5	Not enough security personnel to cover the delivery. Delay in sending updated delivery schedule to security escort's manger.	3	Management should double check security escort's schedules to ensure enough security escorts are scheduled to cover the delivery.	2	30	8

Figure 18 - FMEA (Support)

FMEA										
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
SUPPORT	Human	System Engineer Fails To Issue Schedule	Failure to receive a nitrogen delivery when needed	9	System Engineer work load to great or too much variation in the work load	4	Operator's supervisor should check with System Engineer one week prior to the existing schedule expiring to obatin an updated version.	3	108	12
		System Engineer Fails to Submit Access Paper Work For Drivers	Delay in getting a nitrogen delivery	6	System Engineer work load to great or too much variation in the work load	3	Operator's supervisor should check with System Engineer one week prior to the existing paper work expiring to ensure updated version has been submitted.	2	36	9
		Visitor's Center Fails to Make Provisions for the Drivers to Have Accesss	Delay in getting a nitrogen delivery	5	Access paper work submission was lost	1	System Engineer should touch base with Visitor's Center one day prior to devliery to ensure that all access paperwork has been issued.	2	10	3
	Equipment	Visitor's Center Access Equipment Not Working	Delay in getting a nitrogen delivery	7	Improper preventative maintenance	3	Visitor's Center should inform System Engineer of any potential technical issues preventing the release of access paperwork	2	42	11
		System Engineer's Computer Not Functioning Correctly	Delay's In Submission of delivery schedule and/or access paper work	6	Improper preventative maintenance	4	System Engineer should take action to update these docuements at least one week in advance to ensure documents are submitted with no hiccups	2	48	12
		Phone Lines Are Down	Technician cannot respond to any trouble calls with equipment	10	Power poles are broken	2	Secondary form of communication is available	1	20	20
	Schedule	Delivery Shows Up on an Un-Scheduled Day	Delay in getting a nitrogen delivery	8	Miscommunication to vendor on delivery schedule	4	System Engineer should check with vendor after issuing an updated schedule to answer any questions, helping to solidify the schedule	3	96	11

Figure 19 - FMEA (Post-Process)

FMEA										
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
POST-PROCESS	Human	Driver Has To Leave Before Delivery Is Made	Failure to receive a nitrogen delivery	8	Driver's DOT allowable working hours have expired. Family Emergency	4	Check with employees scheduled to come onto the next shift to ensure they are still going to make it	2	64	16
		Security Person Has To Leave Before Delivery Is Made	Delays in offload of product.	7	Unexpected sickness/ Family Emergency	4	Security person to notify their supervisor when a family emergency occurs so that management can assign a replacement.	2	56	14
		Operator Has To Leave Before Truck Processes Through Check Point	Delays in offload of product.	7	Unexpected sickness/ Family Emergency	5	Operator to notify their supervisor when a family emergency occurs so that management can assign a replacement.	3	105	12
		Security Person Has To Leave Before Truck Process Through Check Point	Delays in truck leaving the site.	4	Unexpected sickness/ Family Emergency	4	Security person to notify their supervisor when a family emergency occurs so that management can assign a replacement.	4	64	4
		Operator Has To Leave Before Delivery Is Made	Delays in truck leaving the site.	4	Unexpected sickness/ Family Emergency	4	Operator to notify their supervisor when a family emergency occurs so that management can assign a replacement.	4	64	4
	Equipment	Truck Breaks Down	Product Delivery Is Delayed	8	Numerous (Flat Tire, Air Leak, Engine Problem. Etc.)	4	Vendor to ensure all preventative maintenance is performed on time and that all equipment is in good working order.	2	64	16
		Check Point Access Equipment Is Not Functioning	Delays in truck leaving site	5	Improper Preventative Maintenance	2	System Engineer should be informed by the Security Escort Supervisor of any issues to that delays can be expected.	4	40	2.5
		Off Load Equipment Breaks Down	Delay In Delivery or Delivery Failure	8	Improper Preventative Maintenance	4	Vendor to ensure all truck mounted offload equipment is in good working order	5	160	6
	Schedule	Driver Makes More Than One Offload On His Route	Limited Amount Of Product Offloaded	9	Product demand higher than product output	3	Vendor should notify System Engineer when a full delivery will not be made.	2	54	14

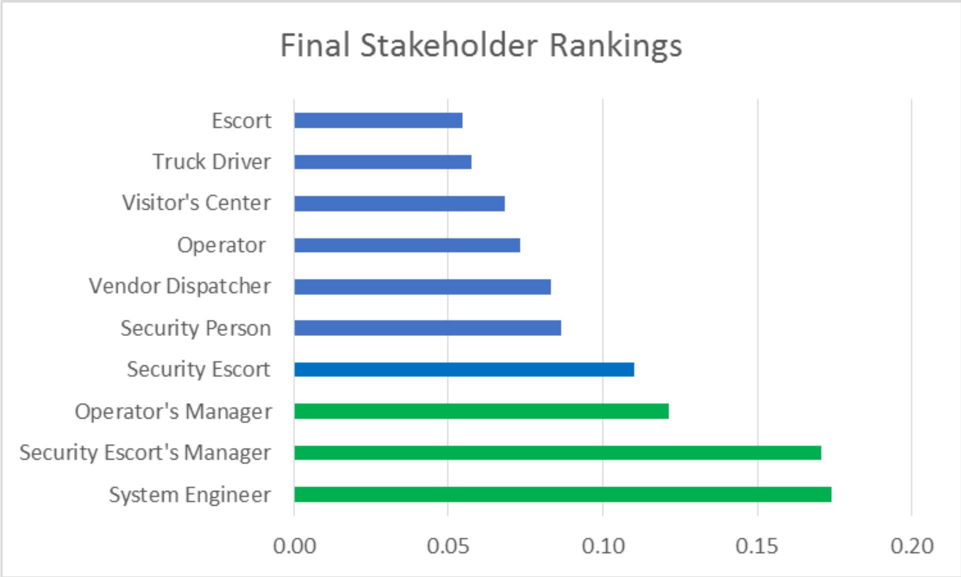
Figure 20 - FMEA (Management Impact)

FMEA											
	Category	Failure Type	Potential Impact	Severity	Potential Causes	Occurance	Detection Mode	Detection	Risk Priority Number (RPN)	Risk Assessment Value (RAV)
MANAGEMENT IMPACT	Human	Dispatcher Fails To Show Up For Work	Deliveries may be disrupted.	7	Family Emergency	5	If one dispatcher is out sick they should perform a proper turnover to another dispatcher to ensure un-interupted deliveries	3	105	12
		Operator's Manager Fails to Schedule an Operator for the Delivery	Delivery may be delayed	8	Manager's work load to great or too much variation in the work load	3	Manager should review the delivery schedule and schedule oeprators a week in a advance	2	48	12
		Security Escort's Manager Fails to Schedule an Escort for the Delivery	Delivery may be delayed	8	Manager's work load to great or too much variation in the work load	3	Manager should review the delivery schedule and schedule escorts a week in a advance	2	48	12
	Equipment	Dispatcher's Computer System Goes Down	Deliveries may be disrupted.	9	Power loss to the dispatching office	2	The Vendor should make efforts to ensure back up power equipment is maintained and functional.	3	54	6
		Operator's Manager's Computer System Goes Down	Operators may not be scheduled for the delivery, delaying potential delivery	7	Power loss to manager's office	2	Efforts should be made, by the system engineer, in the event of a power loss to contact the mangers and inform them of the delivery scheduled.	3	42	5
		Security Escort's Manager's Computer System Goes Down	Security Escort may not be scheduled for the delivery, delaying potential delivery	7	Power loss to manager's office	2	In the event of a computer system going down the manager should touch base with the system engineer to confirm delivery schedule and schedule employees accordingly.	2	28	7
	Schedule	Updated Schedule not sent to Security Escort's Manager or Operator's Manager	Escorts and Operators may not be scheduled for the delivery	7	System Engineer's work load to great or too much variation in the work load	3	Managers should check with system engineer one week prior to the delivery schedule expiring to aquire updated schedule	2	42	11

Critical Stakeholders

From the five areas of stakeholders listed above it is necessary to determine which stakeholders are critical. This is accomplished using the Analytical Hierarchy Process (AHP). AHP allows for pair wise comparisons between two of the stakeholders at a time and then against a criteria. The four criteria that all of the stakeholders are compared to include Cost, Service, and Safety, and Security. The top four stakeholders determined from the AHP are shown in *Figure 21*. (Haas & Meixner, 2017)

Figure 21 - AHP Final Rankings



Each of the critical stakeholders were polled for the current requirements, relative to their area, of the delivery process. The below list was generated from their responses.

Organizational

- System Engineer to provide schedule to vendor, security, and operations.
- Driver must have permission to access site.
- Delivery should be made not later than 11:00, Monday through Thursday unless special permission is granted.
- Driver shall issue operator a shipping ticket detailing the quantity of the offload and the time he was on the campus.

Technical

- Driver must obey all traffic laws while onsite.
- Driver must stop at each checkpoint.
- Driver must be escorted by security escort and operator escort from the time he/she clears checkpoint B until he/she passes back through checkpoint B.

Political

- Driver must operate equipment associated with truck.
- Operator must operate equipment not associated with the truck.

Phase 4-Reliability

Theoretical System Capacity

The theoretical capacity for the system is that of which the system should be able to run without any interruptions or hiccups. In terms of the nitrogen delivery process the theoretical capacity can be interpreted as the time it takes to make a delivery. The delivery time starts the moment the vendor's truck arrives at the site and finishes when the truck leaves the site. The act of offloading the LN_2 is also included in this time. The theoretical capacity shall be defined as calculated below:

$$WIP = 638{,}000\ SCF, Average\ Amount\ of\ LN_2\ Per\ Truck = 1\ Truck$$

$$Throughput = \frac{WIP}{Cycle\ Time} = \frac{1\ Truck}{120\ Minutes} = .0083\ \frac{Trucks}{min}\ or\ 1\ Truck\ per\ 2\ Hours$$

The cycle time is drawn from the maximum amount of time the trucks are contractually allowed to stay on site before demurrage charges set in.

Baseline System Capacity

To determine the nitrogen delivery system's baseline capacity, the overall time the truck is on site can be looked at. *Figure 10* is a value stream map of the delivery process. From this illustration it can be seen that the trucks are spending an average time of approximately 160 minutes on site. By using the same WIP as used above, 1 Truck, the baseline throughput is calculated:

$$Throughput = \frac{WIP}{Cycle\ Time} = \frac{1\ Truck}{160\ Minutes} = .00625\ \frac{Trucks}{min}\ or\ .75\ Truck\ per\ 2\ Hours$$

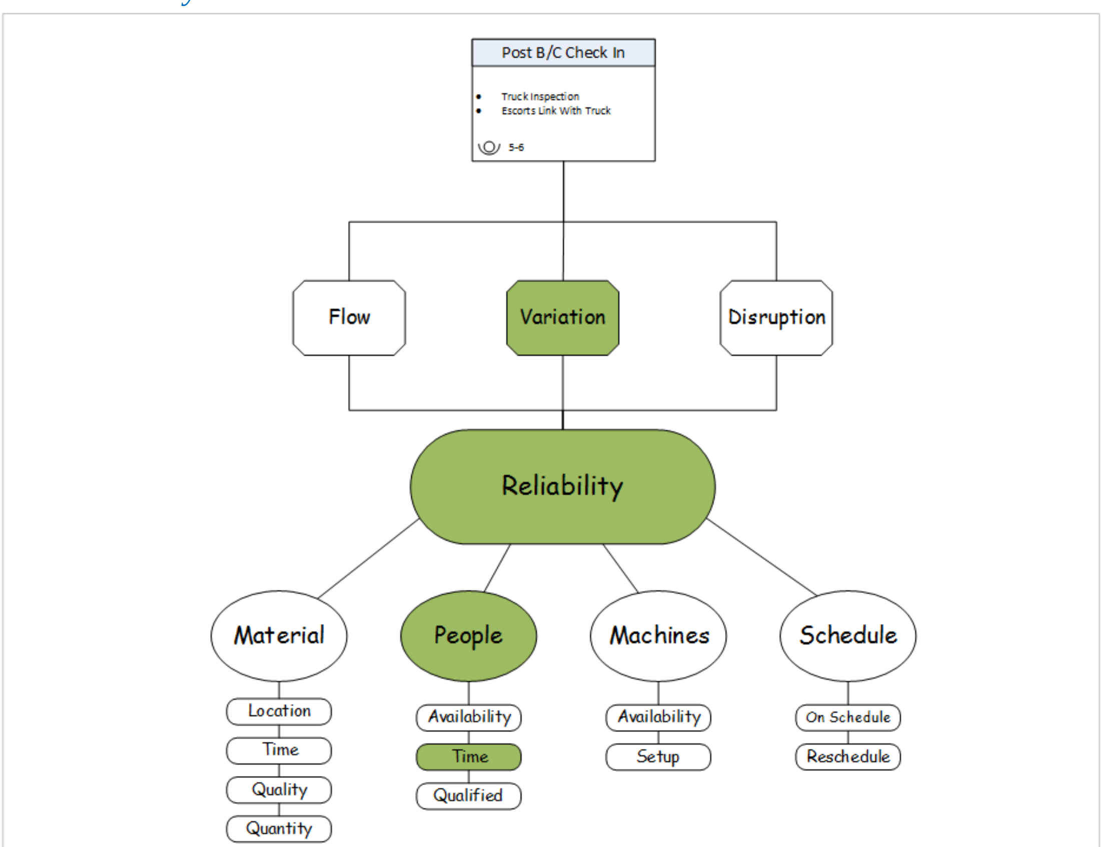
This falls short of the defined theoretical capacity of *1 delivery per 2 hours*.

Problem Identification

The reliability of a system impacts the flow along with the amount of variation and disruption that is present. Each one of those areas are then impacted by material, people, machines, and schedule. *Figure 22* illustrates the connection between the different areas.

In regards to the nitrogen delivery process, one of the major areas of concern is the "Post B/C Check In", *Figure 11*. There appears to be an excessive amount of variation as a result of the number of people involved with the step. Four people are required to show up at the same time before the process is allowed to proceed. A focus will be made on the reliability of this area, highlighted in *Figure 22*.   The systems based FMEA performed for the process area, *Figure 17* , should be referenced for the failures associated with the step. Later sections will discuss ways of improving the reliability in hopes of reducing the cycle time and bringing the baseline capacity up towards the theoretical capacity.

Figure 22-Reliability Connection



Reliability

The analysis of the process starts with reviewing the *People, Machine, Material, Schedule* level of *Figure 23*. In particular the area that is known to have issues, *People*. Time to failure data is collected for the known problem sub area. Failures for the LN_2 delivery process are defined as follows:

- *Machines* – Equipment break down inhibiting truck from processing through checkpoint.
- *Material* – Quality of LN_2 didn't meet spec.
- *People* – Employees didn't show up at the correct time.
- *Schedule* – There was a conflict with employee schedules preventing / delaying them from showing up for the delivery.

(Sawhney D. , Introduction To Reliability, 2017)

The time to failure date for each of the sub areas is shown in *Figure 23*.

Figure 23- Post B/C Time to Failure

Post B/C Check In			
Time To Failure (Hours)			
Material	People	Machines	Schedule
80	55	73	68
82	60	70	56
90	47	68	66
92	66	90	63
86	62	82	50
110	67	76	70

This data is then organized and displayed on a Weibull plot, *People* will be used as an example. Time to failure numbers must be listed in order from lowest to highest, and then assigned a failure order number. From there each failure time is assigned a Median Rank using the following equation:

$$MR\% \sim \frac{i - 0.3}{N + 0.4} \times 100$$

i = Failure Number

N = Total Sample Size

(Sawhney D. , Lecture 6 Weibull Distribution, Cut and Path Vector, 2017)

The results of both are shown in *Figure 24*.

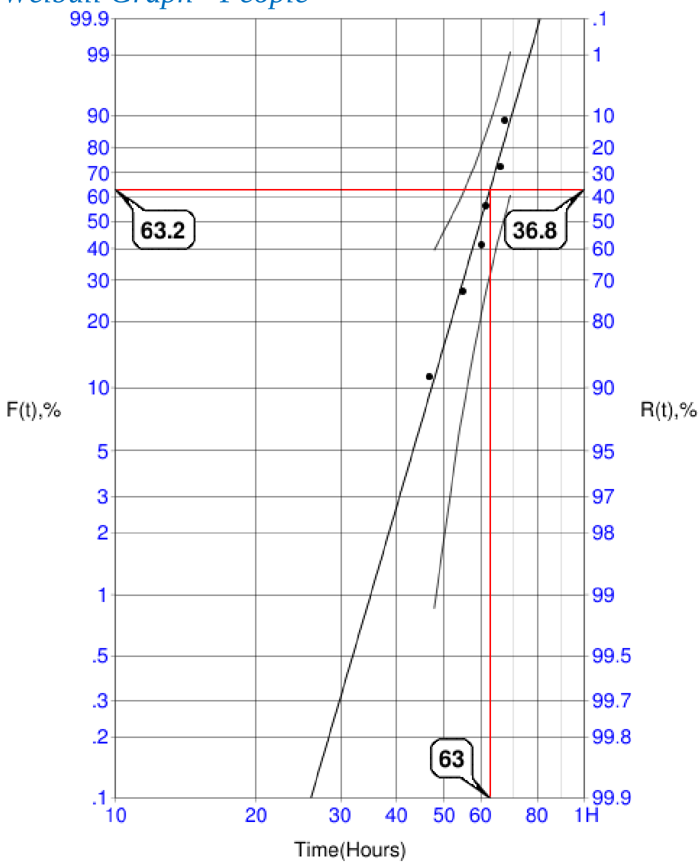
Figure 24-Failure Order Number / Median Rank, %

Post B/C Check In	
People	
Time to Failure (Hours)	Failure order Number
47	1
55	2
60	3
62	4
66	5
67	6

Post B/C Check In	
People	
Time to Failure (Hours)	Median Rank, %
47	10.94%
55	26.56%
60	42.19%
62	57.81%
66	73.44%
67	89.06%

The Median Rank % Vs. Time to Failure is then be plotted on a Weibull graph, *Figure 25*. The Weibull allows the η value and β value to be determined, also shown below.

Figure 25- Weibull Graph - People



Weibull Plot Results	
Beta:	7.85
η:	62.4

(Morris, 2017)

With the results taken from the Weibull plot the reliability of the *People* can be calculated. Calculations for this sub-process will be made at the average cycle time, using the following formula:

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

$$R(t)_{People} = e^{-\left(\frac{65}{62.97}\right)^{7.85}} = .277 \ or \ 27.7\%$$

(Sawhney D. , Lecture 6 Weibull Distribution, Cut and Path Vector, 2017)

This method is then repeated for the remaining sub-sections, the results are listed below:

Machines-

$$R(t)_{Machines} = e^{-\left(\frac{65}{80.27}\right)^{9.48}} = .873 \ or \ 87.3\%$$

Material –

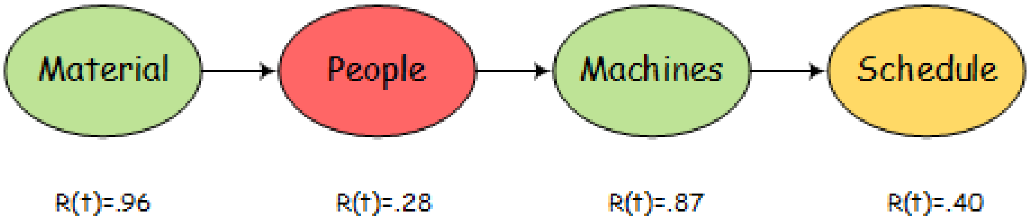
$$R(t)_{Material} = e^{-\left(\frac{65}{95.08}\right)^{8.28}} = .958 \ or \ 95.8\%$$

Schedule –

$$R(t)_{Schedule} = e^{-\left(\frac{65}{65.72}\right)^{8.03}} = .400 \ or \ 40.0\%$$

It is assumed that all of the sub-area need to be present for the process to function. Therefore the reliability of the process will be calculated with all of the areas in series. This is depicted below.

Figure 26- Reliability Flow – Post B/C Check In



Using the values from above, the overall reliability of the process (Post B/C Check In) is calculated using the following formula:

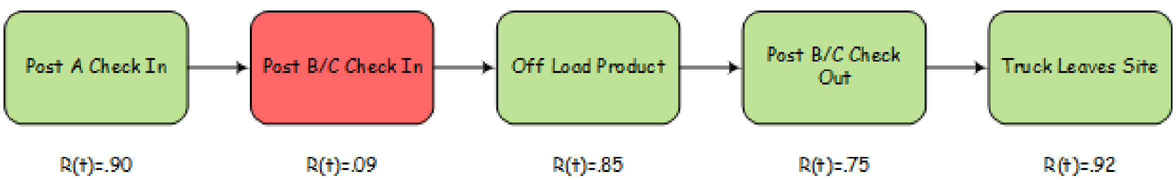
$$\emptyset(\underline{x}) = \prod_{i=1}^{n} x_i$$

$$R(t) = (.96) \times (.28) \times (.87) \times (.40) = .094 \text{ or } 9.4\%$$

(Sawhney D. , Introduction To Reliability, 2017)

This value can then be placed into a similar equation using the reliabilities from each of the other processes in the system flow to calculate the overall reliability of the system. The flow for the overall system is in series.

Figure 27 - Reliability Overall System



$$Overall\ R(t) = (.90) \times (.09) \times (.85) \times (.75) \times (.92) = .047 \text{ or } 4.7\%$$

Phase 5-Recommended Changes, Future State, Cost Benefit

Recommended Changes

In reviewing all of the results from the current status of the different phases, improvement recommendations are as follows:

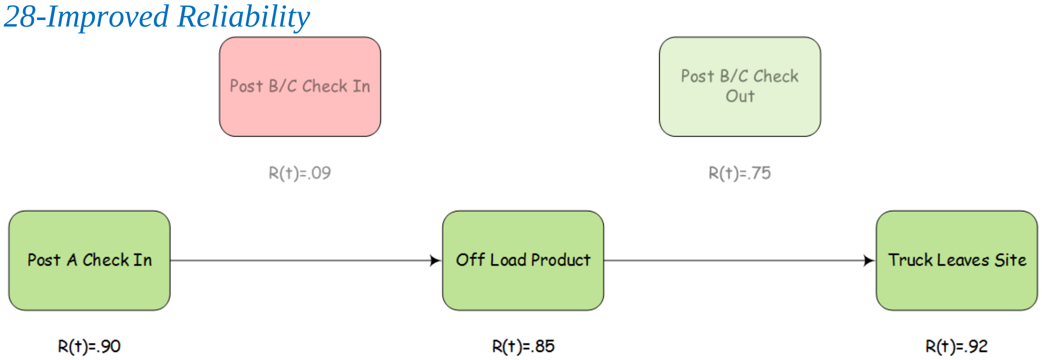
- Replace alternate off load station allowing the Post B/C check in / check out steps to be removed from the system.
- Allow the trucks to have priority at the post, allowing them to go to the front of the line once they arrive.
- Make changes to the contract so that the vendor gets penalized if deliveries are made outside the time frame stated in the contract.
- Establish an incentive program for the operators and security escorts. This would give them a bonus when the deliveries have been made in two hours or less.

Future State

Implementing all of the recommended changes will allow the system's flow and reliability to improve greatly. Replacing an existing off load station will allow the removal of the Post B/C check in/out steps reducing the average cycle time of 160 minutes to 70.3 minutes. A future state value stream map *Figure 29* illustrates this.

In addition, replacing the off load station will improve the overall reliability from 4.7% to 70% of the system. *Figure 28*, below illustrates the improvements.

Figure 28-Improved Reliability

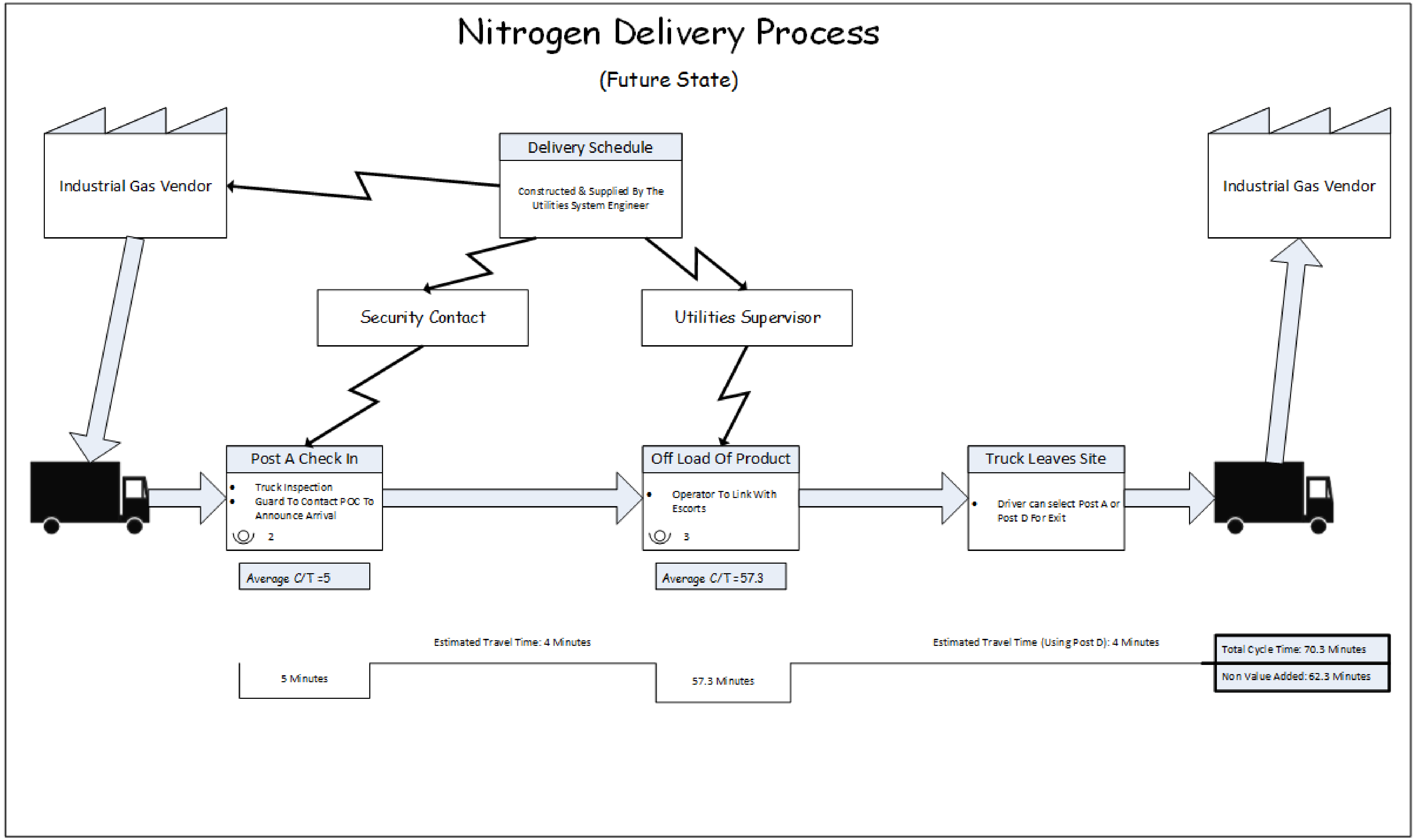


$$Overall\ R(t) = (.90) \times (.85) \times (.92) = .70\ or\ 70\%$$

The improved time will allow the theoretical capacity to be exceeded:

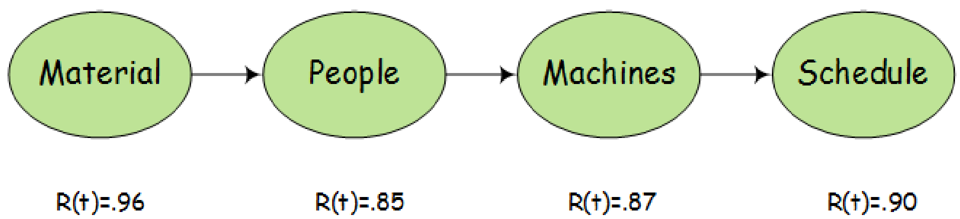
$$Throughput = \frac{WIP}{Cycle\ Time} = \frac{1\ Truck}{80\ minutes} = .0125\frac{Trucks}{min}\ or\ 1.5\ Truck\ per\ 2\ Hours$$

Figure 29-Future State Value Stream Map



During times when the replaced offload station is unavailable or until its replacement, the balance of improvements can be introduced. By making the suggested changes to the contract, giving trucks priority at the post, and by introducing an employee incentive program the variation seen in the Post B/C Check In/Out step will be reduced. Reliability in this area should increase to approximately 60% as shown below:

Figure 30-Improved Reliability of Post B/C Check In



$$R(t) = (.96) \times (.85) \times (.87) \times (.90) = .638 \text{ or } 63.8\%$$

$$Overall\ R(t) = (.90) \times (.64) \times (.85) \times (.75) \times (.92) = .338 \text{ or } 33.8\%$$

Reductions in cycle time should be improved by approximately 35%, reducing the average cycle time from approximately 160 minutes to approximately 120 minutes. The improvements will bring the baseline capacity back up to the theoretical level:

$$Throughput = \frac{WIP}{Cycle\ Time} = \frac{1\ Truck}{120\ minutes} = .00833\ \frac{Trucks}{min}\ or\ 1\ Truck\ per\ 2\ Hours$$

Cost Benefit

Shipping orders from the vendor contain information about the shipment including, total time the truck was on site, amount of product offloaded, etc. In reviewing the shipping orders and comparing the data to that taken in the field a discrepancy is to be noted in the overall time the trucks spend on site (cycle time). The value stream map indicates a cycle time of 159.6 minutes. Data extracted from the shipping orders, and what the company is billed against, indicates the trucks spend an average of *225* minutes total time on site. For the purposes of the savings calculations the average time collected from the shipping orders will be used.

Contract Explanation & Estimated Costs

The Nitrogen contract permits a window of two hours to make a delivery. If the delivery isn't made within that window, a demurrage charge of $40.00 is incurred every fifteen minutes past two hours. For example, if a delivery took 2.5 hours a demurrage of $80.00 would be invoiced. Using this information and the average time of 225 minutes spent on site, an average demurrage charge of $280.00 will be incurred with every Nitrogen delivery. From June 2015 to June 2016 the site has spent approximately $27,500 in demurrage charges.

The personnel costs associated with each offload are listed below in *Figure 30*.

Figure 31-Personnel Costs

Personnel Cost Per Offload

Post A

	Rate	Hours	Cost Per Hour
Guard 1	100	0.08	8
Guard 2	100	0.08	8
		Total:	16

Post B

	Rate	Hours	Cost Per Hour
Guard 1	100	0.03	3
Guard 2	100	0.08	8
Guard 3	100	0.16	16
Guard 4	100	0.25	25
Operator	100	0.25	25
Escort	100	0.25	25
		Total:	102

Offload

	Rate	Hours	Cost Per Hour
Guard 1	100	1.1	110
Operator	100	1.1	110
Escort	100	1.1	110
		Total:	330

Grand Total: $448.00

Billing Rates Were Fictitiously Selected

Cost Savings

By implementing the recommendations outside of the alternate offload station replacement, staging time will shorten by 49%, yielding $3,830 in savings annually. By replacing the alternate offload station the cycle time of the entire delivery process will reduce to 70.3 minutes. The personnel cost using the alternate off load station are as follows.

Figure 32- Personnel Cost Future State

Personnel Cost Per Offload Using Alternate Offload Station

Post A

	Rate	Hours	Cost Per Hour
Guard 1	100	0.08	8
Guard 2	100	0.08	8
		Total:	16

Offload

	Rate	Hours	Cost Per Hour
Operator	100	1.1	110
		Total:	110

Grand Total: $126.00

Billing Rates Were Fictitiously Selected

A savings of 28% in personnel costs will be realized over the current process. Combining shortened cycle time and reduced personnel costs, a minimum total savings of approximately $26,352 would be seen each year with the site nitrogen generator running continuously. With the generator offline the site would see approximately $200,385 in savings each year. Historically the generator has been online only 50% of the time. This would yield a savings of $113,643 annually. An estimate of ~$450,000 to replace the alternate offload station would make the payback 4 years.

Chapter 5-Conclusions

By overlaying the methodology, described in chapter three, on the Nitrogen Delivery Process, significant improvements to the system are able to be made. The first iteration of the analysis will yield a 66% improvement in the throughput rate. Additionally, the cycle times have the potential of dropping from 160 minutes to approximately 70 minutes. With this in mind the methodology and hypothesis, stated in chapter one, have been proven and the rate at which the site incurs demurrage charges will drastically reduce.

Current State of Project

Currently Utilities management have been briefed of the project and are in general agreement that it is worth pursuing. However, current funding and higher priority projects are preventing the project from progressing.

Future Work

Since the conveyed improvement process is one that is iterative, the system should be re-evaluated. This will bring to light the next bottleneck or area of concern that needs to be addressed. With approved funding, the improvement process could continue until the system is running as close to theoretical capacity as practical.

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