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Improvement of Quality Processes- Asset Condition Assessment Tool and Process for Vanderlande Industries

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Improvement of Quality Processes

ASSET CONDITION ASSESSMENT TOOL AND PROCESS FOR VANDERLANDE INDUSTRIES

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Table of Contents

Table of Figures

Executive Summary

Vanderlande Industries is the global market leader in the value added logistic process automation for airports, the parcel market, warehouses, and e-commerce. The company's extensive portfolio of integrated solutions results in fast, reliable and efficient automation technology. The VI Marietta office supports airport sites that have an operational BHS. These sites hire VI to operate and maintain the site. Preventive, corrective, and emergency maintenance is completed on the equipment to maintain operational success. Usually, the U.S. sites that are supported have BHS systems that are old and worn down. It is important for VI to determine the risk of maintaining such a system. A health condition assessment process will be designed to determine the health of the system, while finding the assets and components that are most critical. A process is created where the system, assets and components are individually evaluated to determine a total score which altogether sums to equal the health condition rating of the overall system. The DMADV methodology which stands for define, measure, analyze, design, and verify is used throughout the project. Several of the following Six Sigma tools were used: SIPOC diagram, translation of VOC, Kano Analysis, Surveys, Process Mapping, and Statistical Analysis. Statistical analysis was performed with historical data using the Pareto analysis to determine which asset to focus on. The MF1-DV (a high-speed diverter) was chosen because it had the highest CM/PM ratio. The tool determines the health condition of the MF1-DV for when there is data available for a site. The 'data available' tool graded the asset with a 62%. A health index table was constructed so the users can easily interpret and seek a recommended action for each score outcome. In this case, the recommendation for the MF1-DV is to perform a root cause analysis of the CM work orders. A visual inspection tool was also created when there is no data available on site.

Chapter 1: Project Charter

Table 1. Terms and Abbreviations

TERMS AND ABBREVIATIONS

VI	Abbreviation for Vanderlande Industries.
MHS	Material Handling Systems.
BHS	Baggage Handling Systems.
LCP	Life-Cycle Planning.
EOL	End-of-Life. Component is not reliable anymore due to ageing- or wear.
EOS	End-of-Sales. Component cannot be produced or manufactured anymore.
EOT/S	End-of-Technical-Support. Component is not supported anymore
ASSET	Equipment that is part of the baggage handling system. i.e. a conveyor.
SYSTEM	The entire baggage handling system inside of an airport site.
COMPONENT	Spare parts inside the asset. i.e. the motor of the conveyor.
CM	Corrective Maintenance, unplanned maintenance on an asset that needs repair.
EM	Emergency Maintenance, unplanned maintenance on an asset that needs repair immediately.
PM	Preventive Maintenance, planned maintenance to maintain operational performance of asset for the long-term.
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
MTTF	Mean Time to Failure
VOC	Voice of the Customer
CTQ	Critical to Quality

1.1 Introduction

Vanderlande Industries is the global market leader in the value added logistic process automation for airports, the parcel market, warehouses, and e-commerce. The company's extensive portfolio of integrated solutions (innovative systems, intelligent software and life-cycle services) results in the fast, reliable and efficient automation technology. Vanderlande offers their services across all continents, with their main headquarters located in Veghel, Netherlands. This project will focus primarily on the baggage handling systems in the United States airports. The Services department for Vanderlande supports and maintains baggage handling systems (BHS) for airports.

Over time, assets of the baggage handling systems can break or wear down. An asset can be defined as a section of conveyor system or a part that has multiple components inside a baggage handling system. For example, a baggage claim unit has multiple sections of a conveyor pieces that contain components such as a motor, a belt, and others; this conveyor piece is called an asset. The assets are replaced when its parts are completely useless. A system failure triggers the replacement process causing downtime and a decrease in throughput of bags in an airport.

The mode of operation for the replacement process and life cycle planning in the US office has become reactive and not proactive. Assets and parts that belong to unstable or old operating airport systems are replaced once they are no longer operational, but not diagnosed before as having a high possibility of failure. Thus, to reduce the costs and downtimes of assets in the baggage handling systems, a tool is needed to enable the on-site service team to be proactive, and to assess the overall condition of the system, asset and components.

1.2 Overview and Scope

A health condition assessment process will be designed to determine the health of the system, while finding the assets and components that are most critical. Inside the framework, the system, assets and components are individually evaluated to determine a total score which altogether sum to equal the health condition rating of the overall system.

The services department supports sites that either have or do not have data on the system. Therefore, historical data on maintenance is not always collected when a service contract starts. The project will focus on two specific areas that individually determine the health condition of an asset:

- An analysis of an asset based on available data from a site.
- A visual inspection of one asset when a site does not have the available data.

1.3 Project Background

The airport system, also called a baggage handling system (BHS), follows a certain process flow, depicted in Figure 2. The figure shows the process steps within a BHS. There is equipment located all throughout the process, starting with the conveyors located in the Ticket Counters all the way through the end of the Make-up unit where the airline picks up the bags to load on to the respective plane.

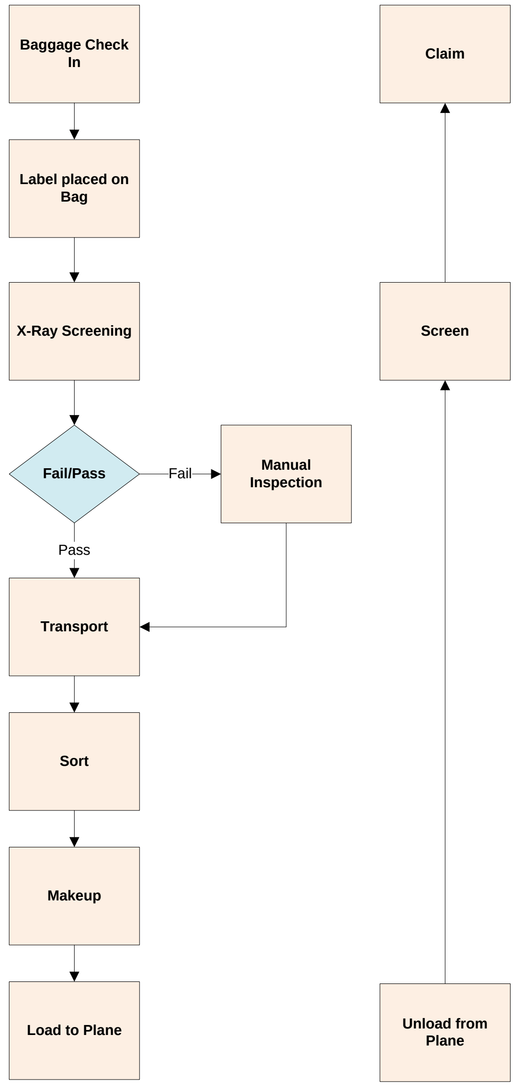

Figure 1. Baggage Handling Process in Airports

VI develops, sells and delivers material handling solutions (MHS), and supports the sites with lifecycle services on the equipment and system. The cycle follows through with a continuous improvement initiative that must complement the value chain of products and services that VI offers its customers.

The VI Marietta office supports airport sites that already have an operational BHS. These sites hire VI to operate and maintain the site. Preventive, corrective, and emergency maintenance is completed on the equipment to maintain operational success. Usually, the U.S. sites that are supported have BHS systems that are old and worn down, some more than others. An older site does not contain the technological level of newer sites. Software, controls, and equipment should be updated, restored or changed for operational success.

1.4 Problem Statement

VI currently has more BHS contracts than MHS and Warehouse. Therefore, it is important to maintain and build a better relationship with the current and future BHS customers. Knowledge of the system is crucial to maintaining a good relationship.

Most BHS in U.S. airports are non-VI systems. Therefore, knowledge and data on the lifecycle status is not available on the company's product library, which contains essential information about an asset and parts. These assets unexpectedly fail or are worn down with time and require going through a complete replacement or reconditioning process. The preventative maintenance during the service contract helps the site maintain the system in excellent condition, eliminate downtime, and extend the lifetime of a system.

Regardless, when starting a new services contract, VI fails to determine the life cycle status of assets that are non-VI because of lack of information from customer or original supplier. Ultimately, making it hard to understand when a certain asset is due to be EOS, EOT, or EOL. This leads to lack of communication with the customer regarding the risk in the system and the possibility of replacement or reconditioning for a specific asset or assets in the system. The following questions came up: When should an asset be replaced? Where is the asset located in the lifecycle curve? How often is it failing and is this critical?

1.5 Objective

Develop a universal toolset and process to guide a high-level and quick system-asset-component health check and assess the current state of a non-VI asset in its lifecycle to make proactive business decisions in baggage handling systems for airports in the US market.

1.6 Project Team

The following organizational chart shows where the project team lies within the Service Department and the members that served as resources during the project period.

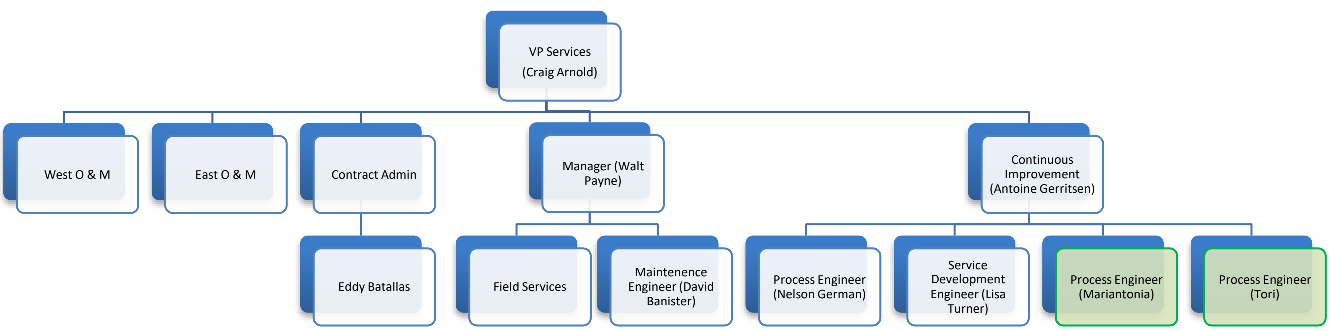

Figure 2. Project Team Organizational Chart

Antoine Gerritsen served as a valuable resource to determine the scope and project background. Craig Arnold proposed the project and determined the problem, in conjunction with Walt Payne. Lisa Turner helped download the data needed to analyze the site-specific information for maintenance.

Chapter 2: Literature Review

2.1 Reliability Engineering

To analyze the life cycle of an asset, reliability engineering concepts must be taken into consideration. Reliability is an essential part of a process or product design, which can provide a competitive advantage. It becomes a critical issue for quality, since it is the ability of a product to perform as expected over time. Therefore, reliability is defined as the probability that a product, piece of equipment, or system performs its intended function for a stated period under specified operating conditions (Evans & Lindsay, 2011).

Preventive maintenance and reliability come hand in hand. The more preventive maintenance done on time for an equipment, more reliable the equipment becomes because breakdowns are less common. Quality and performance are higher on the maintained equipment. On the other hand, the following question arises: when does a product become non-reliable, no matter how many preventive maintenances are done to the equipment? This is a question that Vanderlande would specifically want to answer since their customers require high availability of their systems. A study shows that maintenance and downtime costs accounts for almost 70% of the total cost of major BHS's, making it crucial for the company to deliver the correct service contract so risks can be minimized, and costs predicted (Stein, 2014).

The failure of a system is defined as an event in which the system fails to function in respect to its desired objectives. These failures can be classified as performance failures or structural failures. Regarding VI, performance failure will be taken into consideration, since this type of failure is said to take place when the system is unable to perform to its expectation, even if the structure of the system is not damaged (Singh, Jain, & Tyagi, 2007).

2.2 Life-Cycle Services

Life-cycle services play a huge role in what allows a company to retain its competitive advantage (Sonnemann & Margni, 2015). Companies need to be able to constantly adapt as the business environment evolves. A big part of Vanderlande's portfolio of integrated solutions is made up of these life-cycle services. One of Vanderlande's biggest markets is the processes automation in airports. "Airports continue to be built or expanded around the world to match capacity to the continuous growth of demand for air transportation" (Marcelo, 2016). Thus, it is important to realize how vast VI's presence is in the airport industry, around 600 airports across the world have a VI system or a service contract. Currently, VI takes more of a reactive approach when providing their life-cycle services to clients. For instance, when entering a service contract, Vanderlande has a 60-day window to assess the baggage handling system. After interviewing personnel, it was discovered that majority of this window is spent on cleaning the baggage handling system of soot from its lack of maintenance over the years. Thus, Vanderlande should have be a tool in place to help the onsite service team better analyze the assets during this window to enable Vanderlande to take a proactive approach.

In the prize-winning capstone project, *Influencing Total Costs of Ownership in the Tendering Phase*, by Rutger Vlasblom at Eindhoven University of Technology, Vlasblom develops and goes into detail of an excel-based tool that enables VI to calculate and evaluate the total cost of ownership and the system liability of a design in the tendering phase (Schuman & Brent, 2005).

Accordingly, this resource can be used as a baseline when it comes to creating a tool that determines the condition of an asset in non-VI baggage handling system.

2.3 Asset Management

Another vital component that should be considered in this project is asset management. The management of an asset's physical performance can provide added value to maximize a company's savings. The article, "Asset life cycle management: towards improving physical asset performance in the process industry", provides valuable knowledge on the asset life cycle management (ALCM) model. It states, "An asset life cycle management (ALCM) model is subsequently proposed for assets in the process industry, which integrates the concepts of generic management frameworks and systems engineering with operational reliability in order to address these inefficiencies" (Schuman & Brent, 2005).

In a study conducted on Power Transformers, an asset condition assessment was generated to detect and quantify a long-term degradation and to provide a means of quantifying the remaining asset life. This study used risk of failure and reliability analysis, as well as remaining life, life consumption, and End-of-life concepts. The authors base study of asset replacement on four steps:

1. Remove maintainable condition parameters
2. Estimate the probability of Failure and Effective age of transformer
3. Calculate the remaining life of the transformer
4. Sum the capital cost in each year

The final score given to the power transformer is compared to a health index that represents the overall health. The health index quantifies equipment condition based on condition criteria that are related to long-term degradation factors that lead to the transformer's end-of-life. The study also mentions using the count of corrective maintenance work orders to evaluate the physical health condition of the transformers. This health index can be employed to provide justification for a capital plan that includes asset replacement (Jahromi, Piercy, Cress, Service, & Fan, 2009).

2.4 System Engineering Tools and Techniques

According to Elizabeth Cudney and Tina Agustiady, Design for Six Sigma (DFSS) develops better products and services. In the article, "Do it right the first time", by Cudney and Agustiady (both certified Six Sigma master black belts), the methodology and tools for DFSS are discussed. The article gives great evidence of when and how to use DFSS. It states, "Design for Six Sigma improves customer satisfaction and net income by providing a methodology to institute change, make decisions based on analysis, gather data and ask the appropriate questions" (Agustiady & Cudney, 2017). The DFSS uses the five-step methodology DMADV: define, measure, analyze, design, and verify. The figure below provides a framework with steps and corresponding tools for the project based on the reference mentioned.

Table 2. DMADV Phases and Tools

Phase	Phase Description	Tools Used
Define	• Define Customers (internal and External) • Define Customer Requirements • Gather Needs • Develop Project Plan	• Voice of the Customer • Project Plan • Project Charter • SIPOC • KANO
Measure	• Translate customer requirements to engineering requirements • Develop and determine design alternatives	• CTQ's: Critical to Quality • VOC
Analyze	• Evaluate Concepts • Develop Process Designs • Evaluate to select best design	• FMEA • Criticality Analysis
Design	• Optimize the Process or Design	• DOE • Gage RR
Verify	• Verify Design Performance • Develop Design and Process control plan	• Statistical Process Control • Consistent Output

Design for Six Sigma is used when products or processes do not currently exist and when new products and services are introduced. DFSS is based on redesigning or designing a new product. One source states that DFSS consists of the following four phases based on ICOV (Yang & El-Haik, 2003):

- Identify requirements
- Characterize the design
- Optimize the design
- Verify the Design

The software application, Splunk, is a very resourceful tool to search, and analyze big data. In the case study, “Dubai Airports Flies into The Future with Splunk”, all the remarkable business impacts that have been accredited to the use of Splunk. The Dubai Airports are faced with the problem of increasing their capacity without any further expansion. Michael Ibbitson, the executive vice president of technology and infrastructure in the Dubai Airports, states, "The only way to do that is to apply technology on customer-centric processes and use our data and a platform like Splunk to give us real-time insights to drive efficiency across the airport” (Zadrozny & Kodali, 2013). Where they felt operations could be optimized, they placed sensors to gather data. For instance, they placed sensors on metal detectors, X-ray machines, restrooms, and on 3D cameras that measure queues and security processes. Next, they used Splunk to monitor and analyze all the data collected from these sensors. With the sensors, they measured the following:

- Where metal is detected on bodies going through security.
- The bathrooms that have been used the most, which even includes toilets and faucets.
- The high congested parts of the airport, and the internet access points to ensure fast WIFI.

Splunk is being used all over to drastically improve the travel experience for millions of persons (Zadrozny & Kodali, 2013). Because of VI’s access to Splunk, there are hopes to use this application in the creation of the tool.

The book, *The Lean Six Sigma Pocket Toolbook: A Quick Reference Guide to Nearly 100 Tools for Improving Process Quality, Speed, and Complexity,* is used a quick reference when brainstorming. This book allows quick access to all Six Sigma tools and techniques, explains how and when to use them, and provides very simple and easily understandable examples. “This publication is designed to provide accurate and authoritative information regarding the subject matter covered" (George, Rowlands, Price, & Maxey, 2005). The pocket book described and recommended the best system engineering tools for the project.

Chapter 3: Problem Solving Definition

3.1 Approach

It is important to mention that even though there is a current process in place for the Life Cycle Planning in Vanderlande Industries globally, there is not such a tool available that can assess the condition of non-VI assets. Therefore, a new process will be designed. DFSS or Design for Six Sigma is a methodology that is based on redesigning or designing a new product.

The DFSS methodology includes several different system engineering tools that will be used for analysis and design of the new tool and process for the asset condition assessment in U.S. airport sites. The tools that will be used are based on the DMADV process:

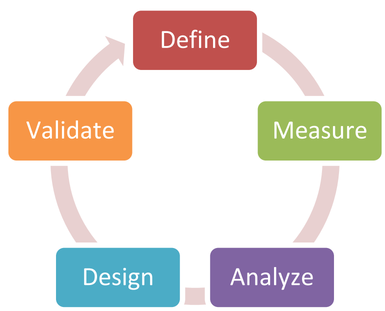

Figure 3. DMADV Cycle Process

3.2 Success Criteria

Because there is not an established process or design that analyses a system accordingly, the following are success criteria points for this project:

- Define data needed to conduct analysis on non-VI systems and that should be entered to MAXIMO.
- A logical step by step process of how to define an asset's health condition.

3.3 Design Requirement

The design requirement necessary to complete and succeed in the project is to determine the health condition score with a ‘No data available’ tool that should output a similar score determined with the ‘Data available’ tool. Variation must be within +/- 5%. The verification approach for the design requirement is based on statistical analysis.

3.4 Gannt Chart and Project Planning

The project followed defined due dates for specific deliverables, see more details on the Gannt chart under Appendix I.

3.5 Flow Chart for Design Solution

The current process is under Research and Development and is not part of the VI Marietta life cycle services process. The asset condition assessment will be included into a new process. The following flow chart shows a brainstormed process of where the system-asset-component assessment can be located:

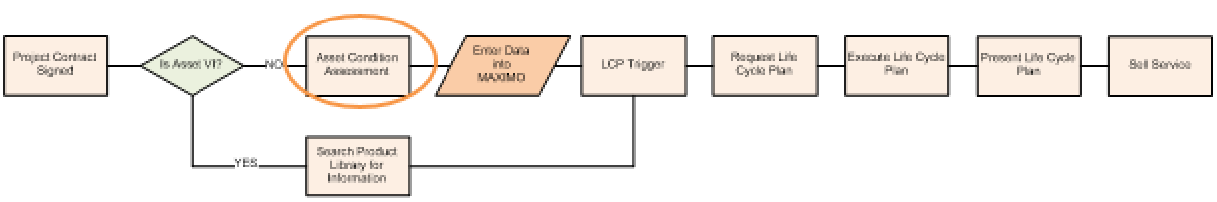

Figure 4. Design Solution Location inside Flow Chart

3.6 Materials Required and Resources Available

The materials required for the project and the specific analysis was based on software tools such as Visio to create the process maps, MAXIMO to download the data needed, SPLUNK to generate statistical data analysis on large sets of data, Excel for calculations, and Minitab for statistical analysis. Data was administered by Vanderlande Industries.

3.7 Budget

The budget is open to discussion. A minimum of one site visit will be needed to understand the function of a baggage handling system and its specific assets. Vanderlande Industries is willing to cover the costs of the visit for Mariantonia Hoyos, who is currently a part-time employee.

Chapter 4: Problem Solving Phases

4.1 Define

The main question to answer in the define phase of the problem-solving approach is: What is the product intended to do? VOC (Voice of the Customer) and a SIPOC diagram are tools used to answer this question, define the problem, and understand the needs of the customer.

4.1.1 SIPOC Diagram

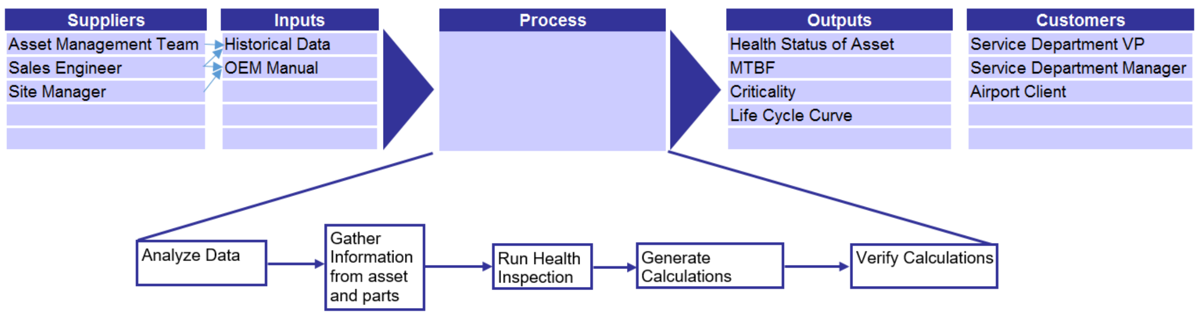

Figure 5. SIPOC Diagram

The SIPOC diagram depicts the suppliers and connects with the inputs that each create for the process. The brainstormed process is explained in high-level. The output of the process will ultimately be presented to the customers interested in the information.

4.1.2 VOC

The define phase of the project contained challenges that made it difficult to tackle the project definition correctly from the beginning. The team decided to focus on a VOC, which would incorporate the needs of one direct customer, Craig Arnold, the VP of Services.

Before administering the VOC, different scenarios where presented to the customer that describe the different paths that the project could focus on based on the main objective:

1. **Scenario**: When will I run out of spare parts? (EOS/EOL)

   Case: An asset in a bad condition needs a motor replacement and the supplier finds that the motor is not available anymore (EOS) and no other motor fits the asset specifications.

   Outcome: If there are no more spare parts left, the asset needs to be replaced, rent spare parts, other.

   Needs: EOS/EOL dates based on original manufacturer specifications, MTBF, asset alternatives/substitutions for a successful integration, criticality analysis and contingencies, investment plans regarding assets/total system, part alternatives, inventory level and the lead time of parts and how much more parts to buy. until the investment/replacement plan.

2. **Scenario**: When does the component/part fail? Parts usage prediction and mean time of failure.

   Case: An asset contains a motor that fails unexpectedly, causing downtime.

   Outcome: Predicting the health status/utilization of the parts and predicting a failure/risk of failure. Lifecycle sheet and parts consumption prediction.

   Needs: Life Cycle Status (hours), MTBF of a part, operational risk/impact in case of failure, investment plans regarding assets/total system, inventory level and the lead time of parts and how much more parts to buy until the investment/replacement plan.

3. **Business Decision:** How much effort am I putting into this asset? (measure in $ or time)

   Case: An asset with a very high PM/CM Ratio is more expensive to maintain whereas buying a new asset will last longer and run better at overall less cost.

Outcome: A. Replace or Retrofit asset. Availability of parts and overall status gives me cost of maintenance of asset. B: Increase contract scope, more work than planned (change order). C: If on new site, what size budget is needed to reconsider, the assessment will output more maintenance and therefore more budget. Compare CM/PM cost to New system cost in a specified time frame.

Needs: Total cost of Maintenance, Total cost of Parts (estimated), Total cost of new asset, investment plans regarding assets/total system, new PM schedule.

4. **Business Decision:** Replace or Retrofit the asset or change order to increase contract scope (increase of PM/CM work).

   Case: An asset has been categorized as unfit with a health check and can no longer run properly and 1 or more parts have been categorized as EOL/EOS/or EOTS.

   Outcome: Grading of an asset based on failure factors, criticality, and a visual inspection. Determining the overall physical condition of the asset in the system and used as an indication of future replacement or retrofit. Indicate time and cost of the change order to increase the contract scope.

   Needs: Total cost of maintenance, total cost of parts, total cost of new asset, investment plans regarding assets/total system, new PM schedule.

The VOC was administered with an interview and analyzed via a KANO model.

4.1.3 Kano Analysis

Based on the Kano Analysis (Appendix C), the general idea of the project is to create a process that will ultimately guide a high-level and quick health check of the assets in a system, to assess the current state in the lifecycle of an asset and ultimately create a valuable engineering study on the system. The Kano Analysis determined the customer requirements and the high or low customer satisfaction. The following are the results of the analysis:

Basic

- Determine the health condition of an asset

Performance

- Determine when a component/part fails.
- Determine the mean time between failure of assets

Exciters

- Effort (hours in PM/CM) Vanderlande is putting into asset
- Determine the criticality of an asset
- Determine a potential risk or impact in case of failure
- Predict the total cost of maintenance for an asset
- Could show where the asset is located on life-cycle graph
- Determine the predictive life of the asset

4.1.4 Constraints

- Time: the health check should be tested in various moments. The closest site is Myrtle Beach, to schedule some time with the Field service or Site manager that can test this tool on a specific asset is challenging.
- Data availability: Vanderlande is willing to help access the data available, but data on Non-Vanderlande assets is not documented properly or not present.

4.2 Measure

In the DFSS methodology, the measure phase of the DMADV cycle is based on understanding the customer requirements and generating specifications for the new process or product. It is different from the DMAIC cycle because the project is creating a new process. Therefore, there is no past data or current process to measure.

The Kano analysis was used to determine the VOC needs. During the measure phase, the VOC needs are translated into design requirements or CTQs, the most important CTQs are identified and a measurement system for each is developed as shown in Table 3.

Table 3. VOC needs to CTQ Requirements

VOC Needs	Justification	CTQ Requirement
Determine when a component/part fails.	The life of the parts determines when a CM/PM/EM needs to occur.	- MTBF of Spare Parts
Determine how much effort (hours in PM/CM) Vanderlande is putting into this asset.	Vanderlande should communicate to the customer the difference between the number of hours worked in an asset and how this can affect them.	- Average hours a field technician works performing a CM/PM/EM on assets.
Determine the criticality of an asset.	Criticality of an asset is based on the risk of a high cost arising from failure of the asset.	- Criticality of asset
Determine the mean time between failure of assets.	It gives an idea to the service site teams and the customer how reliable the asset is and how the service should be scheduled.	- MTBF (Maximo Data Note: Create Process)
Determine the health condition of an asset.	The health condition is important to determine because it gives an idea to Vanderlande and the customer how to prioritize investments and maintenance, it may also help determine service contract agreements.	- Health Index Rating
Determine the potential operational risk or impact in case of failure.	The asset failure can affect the system in several ways, which ultimately guide a site team to	- Total number of assets in the system - Total number of asset types

	understand the consequences of the asset failing and how to prevent or mitigate the failure.	- Contingency/Redundancy in the system
Predict the total cost of maintenance for an asset.	Vanderlande should be able to predict the maintenance cost based on the health status of the asset to budget accordingly or improve the customer's system with an RMR opportunity.	- Average duration of a PM and CM. - Labor cost per hour. - Average cost of spare parts - Total spare parts of Assets
Show where the asset is located on its life-cycle graph.	The life cycle graph shows where the asset stands during its life. It is a visual representation that guides the customer and Vanderlande to make business decisions regarding the assets.	- Location on the graph
Determine the life left of the asset.	The amount of productive life the asset has left gives the customer and Vanderlande an idea on when the next investment needs to be made.	- Number of years left of life for an asset.

The following list of CTQ components were translated from the needs of the customer:

- MTBF of Spare Parts/Assets.
- Average hours a field technician works performing a CM/PM/EM on assets.
- Criticality of asset.
- Health Index: Find with survey and list of factors
- Total Number of Assets in the System and Asset types
- Contingency/Redundancy in the system
- Average duration of a PM and CM.
- Labor cost per hour.
- Average cost of Spare Parts
- Total Spare Parts of Assets

- Location on the Graph
- Number of years left of life for an asset.

The CTQ components will constantly be considered when designing the process and tools for the final product of the project.

4.2.1 Health Condition Decision Tree

Decision trees can be used to define the options available based on a certain topic. To determine how to measure the health condition of an asset, a decision tree was created to map out the components necessary to analyze the data available or the asset inside a system. The decision tree helps define what should be measured and thereafter where to gather the necessary data to analyze.

The health condition of an asset is determined by the reliability of that asset. To understand the reliability of an asset, one must define the respective factors. The performance, time, and the operating conditions are the three main factors that define the reliability of an asset. Performance is achieved by finding the failure rate of the asset and the MTBF, MTTF, or MTTR. The term of time is established by finding the operating hours of the asset, which can be found via historical data or manuals pertaining to an assets' technical specifications. The operating conditions can be determined by defining a visual inspection of the environment in which the asset operates. The measurement tree, shown in Figure 7, helped determine the factors that need to be measured to run a health condition assessment.

At the beginning of the measurement phase, the MTBF criteria was chosen because the assets in the baggage handling industry are repairable and can last up to 10-15 years. After more analysis on the performance factors, the MTTR was taken into consideration instead of the MTBF because of the way that the data would be analyzed. To calculate the reliability factor, the failure rate must first be determined. This calculation is based on the total number of failures and the operating hours. Because the data gathered is based on maintenance work orders, the most amount of information gathered is on Corrective Maintenance, which is a moment in the assets' life where it needs repair to maintain its operational performance. Therefore, Mean Time to Repair (MTTR) was chosen to calculate the reliability factor.

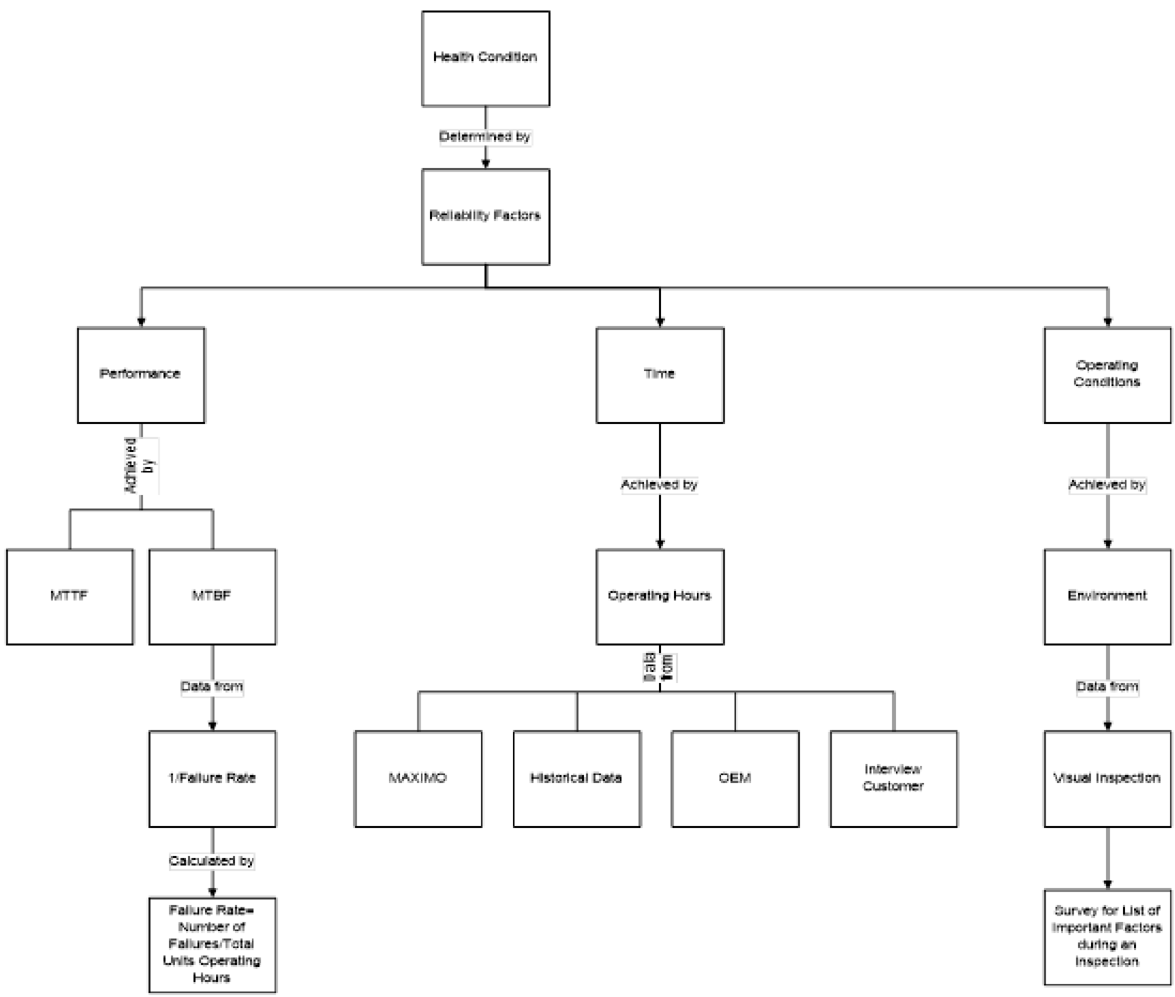

Figure 6. Health Condition Measurement Tree

4.2.2 Health Condition Survey

The following chart was created to understand the relationship between system, asset and component. Inside the system can be hundreds of assets that contain more than one component, as seen in Figure 8.

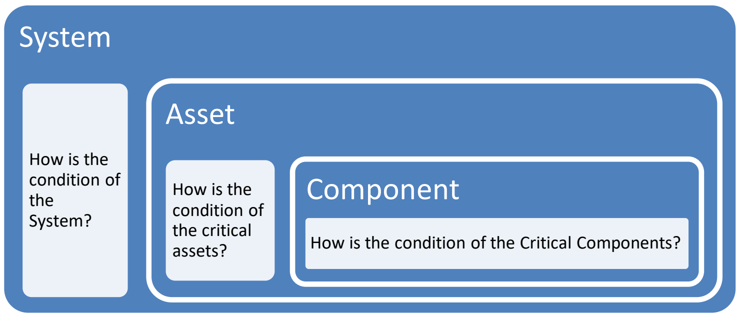

Figure 7. Baggage Handling System Work Breakdown Structure

A survey was given to five site managers and technical engineers to determine the importance, based on knowledge and experience, of factors in the health condition of a system, asset, and component (see Appendix D). Each factor was rated by importance from 1-5, with 5 being the most crucial factor to determine the health condition of an asset.

4.2.2.1 Health Index Survey Conclusions

The results of the survey, seen in Appendix D, were analyzed to understand the importance of the different criteria being evaluated. Figure 9 shows the range in the answer response by Question. The questions with the highest level of importance are questions 1, 4, 5, 6, 9 and 10. These questions had the shortest range and 75% of the data lie at least in the 4 and 5 level of importance. It is clearly noticeable that question 2 should be reconsidered and taken off as a criterion that determines the health condition of the system. On the other hand, question 3, 7, 8, and 11 have a very wide range, meaning that the level of importance varied from one technician to the other.

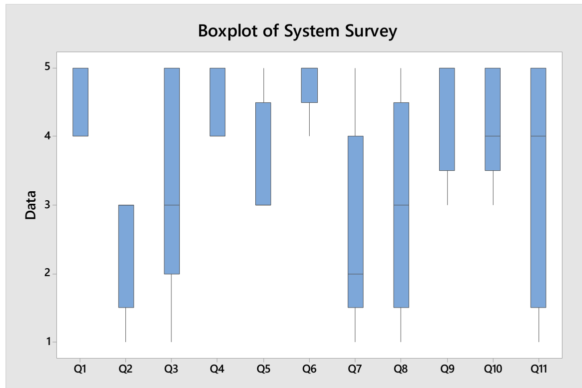

Figure 8. Boxplot for System Survey

Figure 10 is the side to side box plot for the responses of the questions from the health condition of an asset survey. Question 2 had the widest range of responses, while the rest of the questions ranged from a 3-5 level of importance. Since most of the questions had the same type of response, a new survey was created to rank the criteria by importance (see section 4.4.1). Question 2 was therefore not considered in the health rating and Question 3,7,8, and 11 should be weighed low.

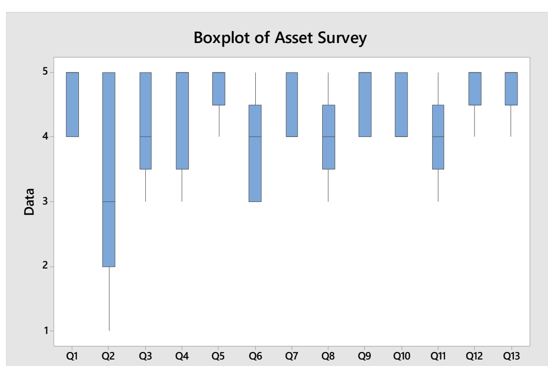

Figure 9. Boxplot for Asset Survey Results

Figure 11 is the side to side box plot for the responses of the questions from the health condition of a component survey. Question 2-4 had the widest range of responses while the rest of the questions had a 4 or 5 level of response. Indicating that most of the criteria are an important characteristic to determining the health condition of an asset.

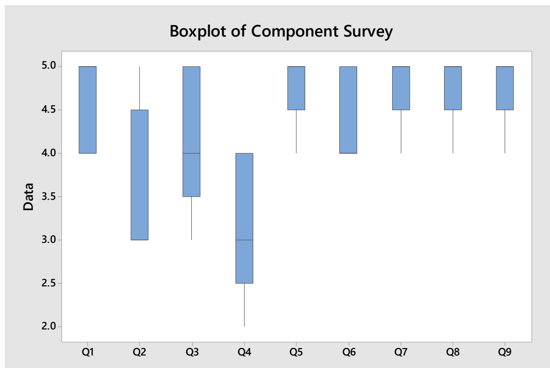

Figure 10. Boxplot for Component Survey Results

4.3 Analyze

The analysis phase of the DMADV cycle focuses on establishing the baselines that will be used to measure the process's improvements throughout the process. Thus, the identification of process areas that deliver improvements to the final deliverable are determined and finalized. Figure 12, the high overview framework, is a summary of the design of the process that will follow the health assessment of a system, asset and component for a baggage handling system. This process will be evaluated for any faults and errors to finalize, improve and optimize. See Appendix I for more details.

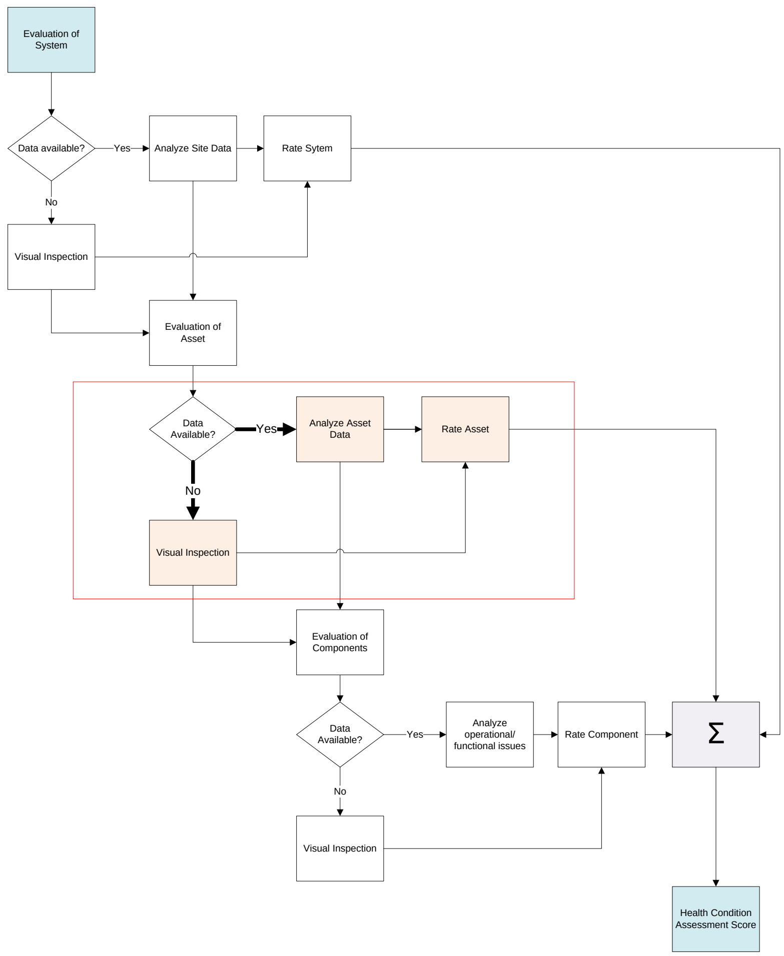

Figure 11. High Overview Framework

4.3.1 CM and PM Definition

Figure 13 establishes the parent to child relationship of all the work order types that are defined by Vanderlande to categorize the type of maintenance completed on an asset. The relationship that the project will focus on will be the PM to CM relationship. A PM, or a preventative maintenance work order, is part of a scheduled maintenance plan. For example, a gas change on a car can be compared to a PM in a BHS asset. A corrective maintenance, or CM, is a work order that is completed based on a failure on an asset or a change that needs to be made to restore the asset back to its operational condition. A CM can be reported due to a PM or SR (service request) petitioned on an asset.

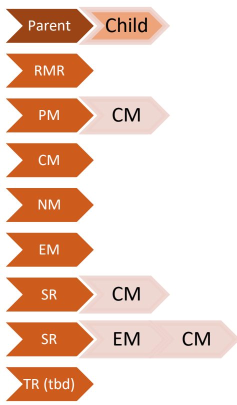

Figure 12. Maintenance Parent to Child Relationship

4.3.2 Historical Data Site Analysis

Data was gathered from an airport site that has been maintenance and serviced by Vanderlande since the installation of the system in 2014. Variables such as type of work order (corrective or preventative maintenance), date of the work order, type of asset related to the maintenance, and a basic description of the work order were supplied by the data. Figure 14 is a pareto analysis on the amount of corrective maintenance work orders that have been documented over the past 5 years of the service and maintenance contract. Based on the pareto analysis, the top 20% of the assets with the most amount of work orders are the following: MU1, CD2-A, and CD1-A.

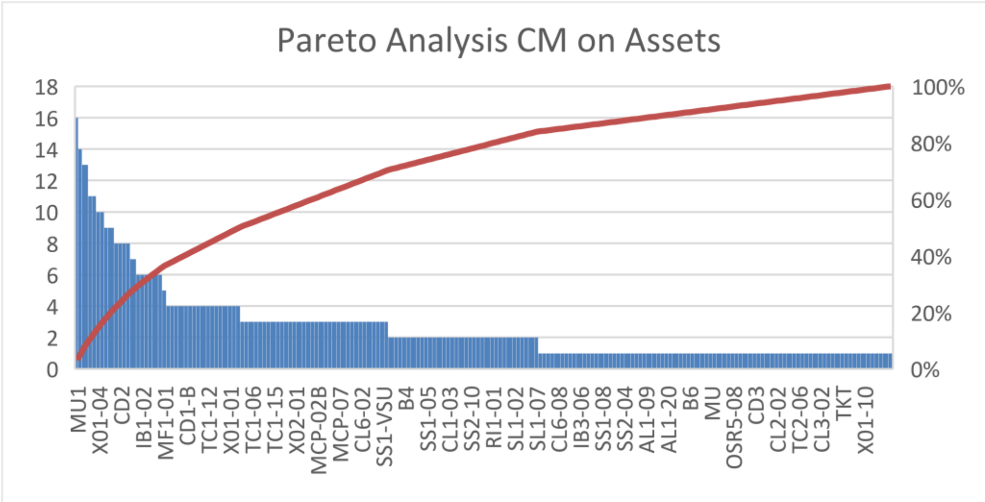

Figure 13. Pareto Analysis of CM on Assets

Figure 15 shows the pareto analysis of the CM to PM ratio on the assets in an airport site. The higher the ratio, the more corrective maintenance work orders have been completed in comparison to the preventative maintenance work orders. The assets with the highest ratio overall are CD2, MF1-DV, and X02-DV.

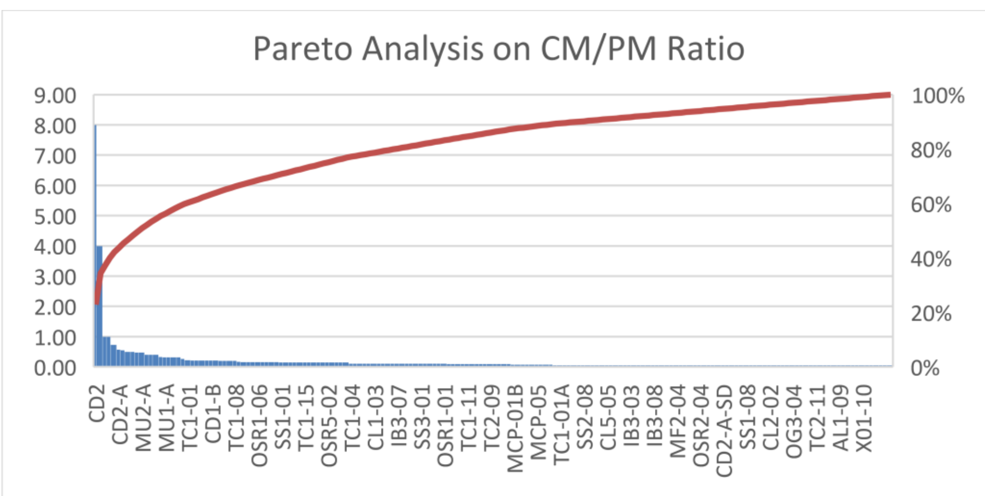

Figure 14. Pareto Analysis on CM/PM Ratio

After analyzing the pareto charts from Figure 14 and 15, 11 assets with a high CM count and CM to PM ratio were chosen to analyze further. Figure 16 is a bar graph that shows the CM to PM ratio drilling down to the assets with the highest ratio. Figure 17 is a bar chart with the total count of the CM work orders for the assets chosen to analyze. On Figure 17, the top 3 assets with the highest count of CM work orders were all diverter type assets. Because of the repetition of a DV (diverter) asset type, the asset MF1-DV was chosen to analyze further and score in the design phase of the project.

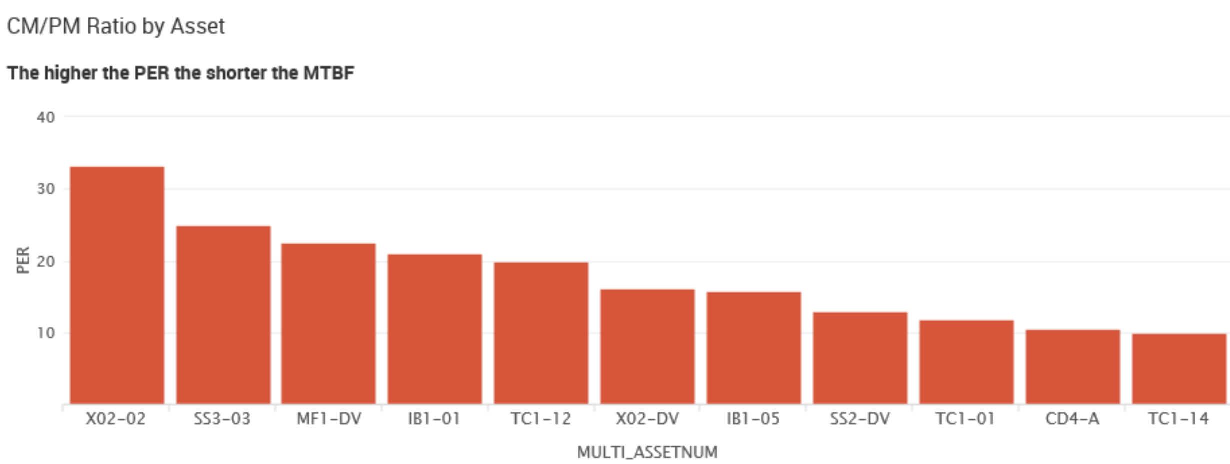

Figure 15. CM to PM Ratio by Device Name

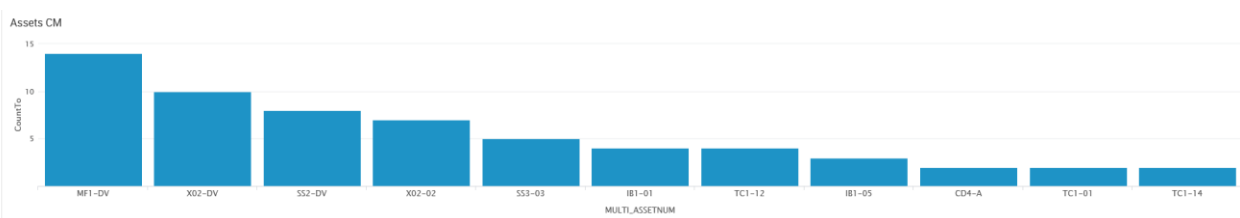

Figure 16. Count of CM by Assets

Figure 18 shows the time chart of the CM over the 5 years in which Vanderlande has maintained the service contract for the airport site.

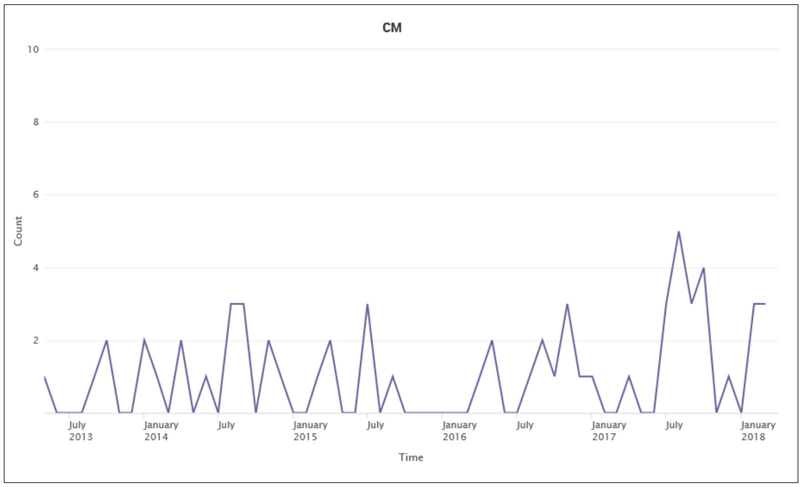

Figure 17. CM time chart for Airport Analyzed

Figure 19 shows the preventative maintenance time chart that has been documented for the past 5 years in which the site has been maintained under contract with Vanderlande.

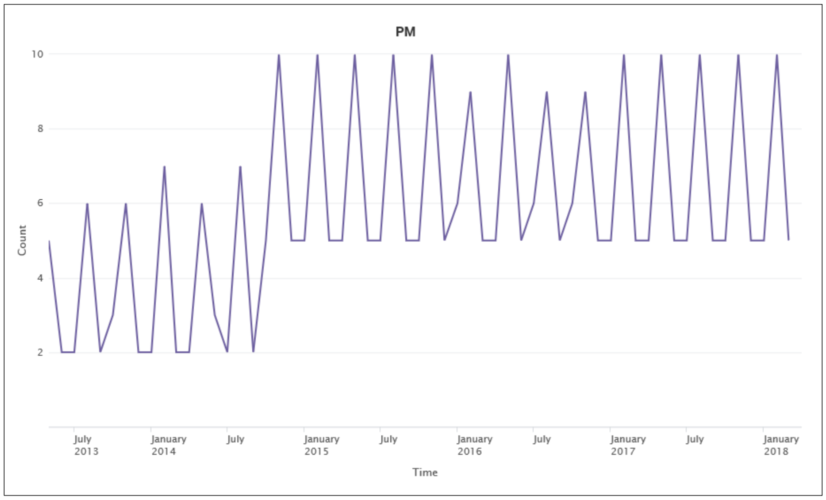

Figure 18. PM time chart for Airport Analyzed

4.4 *Design*

The design phase of the DMADV cycle involves the development of the product or service that correlates with the customer's needs. Thus, the tool to determine the health condition of an asset will be created for when there is data on a site and when there is no data available on the site.

4.4.1 Survey Analysis

After the initial survey data was analyzed, it was noticeable that the criteria needed was not able to be ranked accordingly for ultimate results and further analysis. A second survey was created to establish the most important to least crucial factors that determine the health condition of an asset. The survey was given to five site managers and they were asked to rank each item in order of importance. The following list is ordered by level of importance, the first being the most important criteria, and the last being the least important criteria to determine the health condition of an asset (See Appendix E for more detail on the survey):

1. The risk of failure of the asset.
2. The usage of the asset (the total operating hours).
3. The stress put on an asset (ex. the tightness of a conveyor belt).
4. The cost of the asset (ex. is it cheaply made or is the asset on the higher end).
5. The operating conditions help determine the health condition of an asset.
6. The date the asset was manufactured (current age).
7. The asset's CM history
8. The cleanliness of the asset.
9. The redundancy of the asset.
10. The physical attributes (ex. any tears, bumps, scratches)

11. Noise Level
12. The number of components in the asset that are at risk.
13. The manufacturer of the asset (ex. Vanderlande, Siemens, etc.).
14. PM History of the Asset

4.4.2 Tool Design: Data Available

The factors to analyze, gathered through the Measurement Phase, when the data is available on the asset level, are the following:

1. Dimensions, Capacity, and Operating Conditions
2. Time of Use and Time of Interest
3. Maintenance History
4. Reliability

Factor 1 is calculated by gathering the information necessary from the asset's operating conditions. Figure 20 shows the data used to calculate the score given to the operating conditions. Notice, redundancy is included in the calculation for Operating Conditions, a key component when analyzing the risk of one failing. The less redundancy there is in the system of an asset type, the higher the operational risk when the asset fails.

Capacity	
Average System Capacity (bph)	4000
Speed (FPM)	300
Throughput (Sorts per Minute)	54
Load	25
Redundancy (Number of Assets Redundant	3

Figure 19. Operating Conditions Data, screenshot from 'Data Available' Tool (Appendix G)

Factor 2 considers the time necessary for the asset to maintain in the system and the time it has been in operation. Factor 3 is the maintenance history which considers the number of CM and PM work orders that have been generated since installation of the asset. This Factor also considers the calculation of the CM/PM Ratio. The ratio is useful for the final score calculation. Factor 4, the reliability factor considers the Failure rate, the MTTR and the MTBF of the asset. In this case, the MF1-DV did not have any cases of an EM, emergency maintenance, documented. This type of work order is relevant to the actual failure of an asset. Therefore, the reliability using the MTTR calculation, is more useful for the analysis on the asset.

4.4.2.1Reliability Calculations

The following reliability equations (Singh, Jain, & Tyagi, 2007) are used to determine the reliability of the asset to be studied:

$$Reliability = e^{-FR*Operating\ Time\ of\ Interest}$$

$$FR = Failure\ Rate = \frac{Total\ Time}{\#\ of\ Failures\ (CM)}$$

$$Total\ Time = Total\ Time\ since\ Installation$$

$$Operating\ Time\ of\ Interest = Unit\ of\ Time\ (1\ year)$$

It must be taken into consideration that the assets in a baggage handling system have a long useful life. With a correct preventative maintenance plan, these can last 15-20 years. Because the long life of the asset, the operating time of interest is based on years. The failure rate is calculated as total time in years over the average number of CM repairs per year. In this case, the failure rate resulted in 0.52. Once the failure rate is determined, the Reliability can be calculated.

Figure 20 shows the reliability based on CM events for the MF1-DV asset. Comparing Figure 20 to the reliability graphs of the other assets (Figure 21 through Figure 25), it is noticeable that MF1-DV drops the reliability percentage sooner than the others. Therefore, more maintenance will be needed if the asset wants to be kept in the current system.

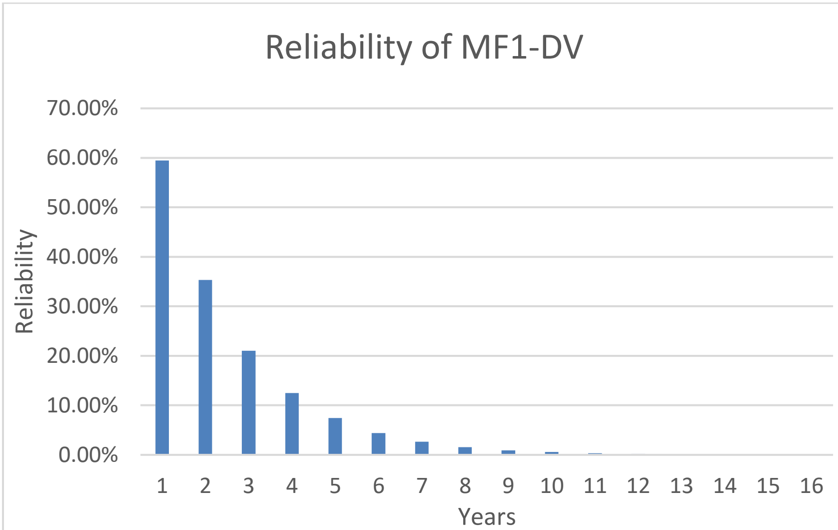

Figure 20. Reliability of Asset MF1-DV

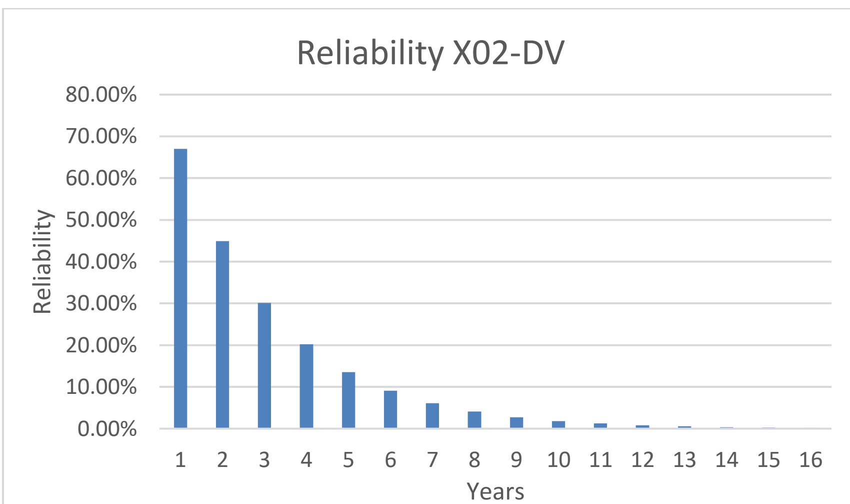

Figure 21. Reliability of Asset X02-DV

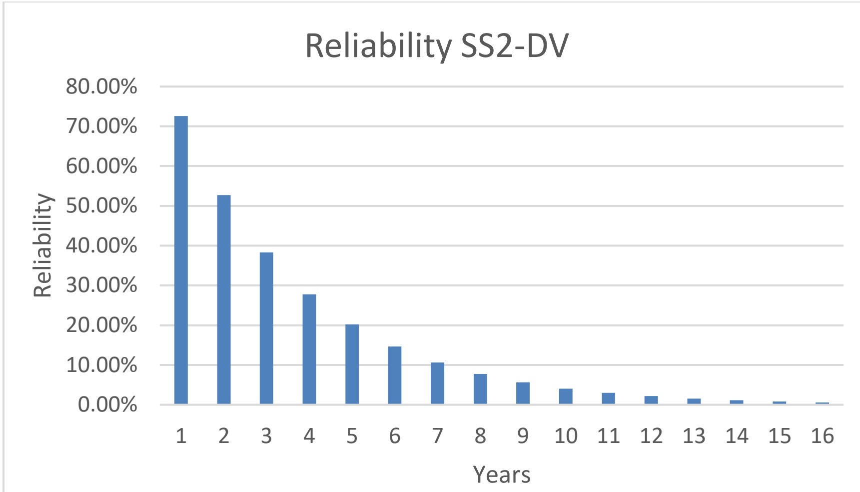

Figure 22. Reliability of Asset SS2-DV

Figure 20, 21, 22, and 23 are reliability graphs indicating that as the years pass, these must be maintained more than other asset types. These 3 assets were in the top 5 of the assets with the most amount of CM over the 5-year period and have had the fastest drop in reliability.

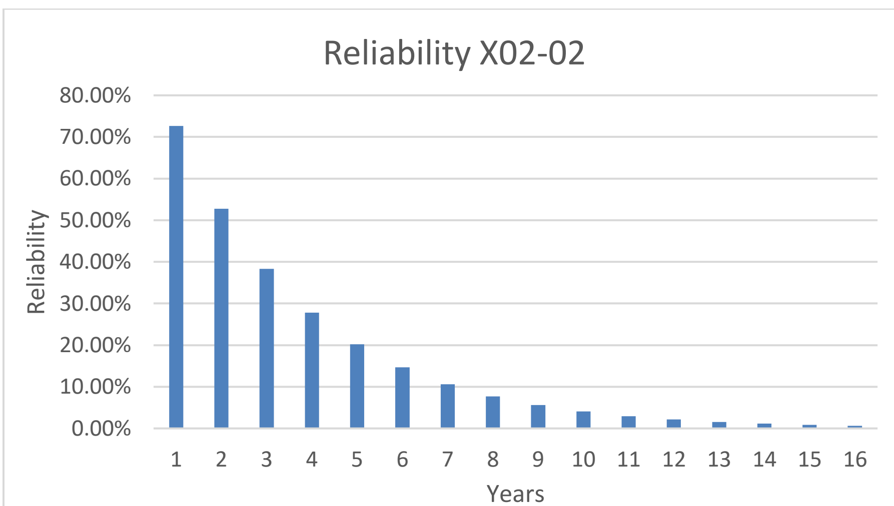

Figure 23. Reliability of Asset X02-02

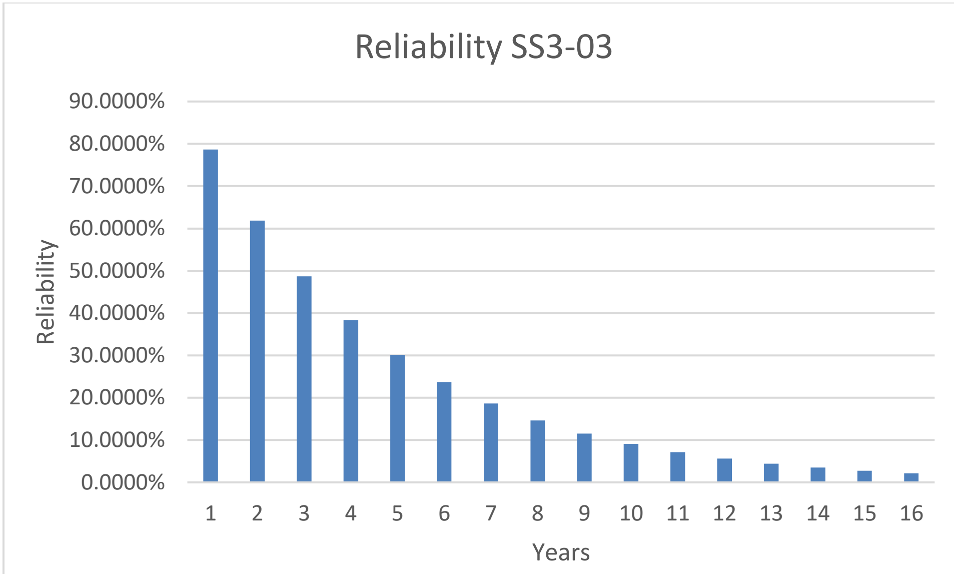

Figure 24. Reliability of Asset SS3-03

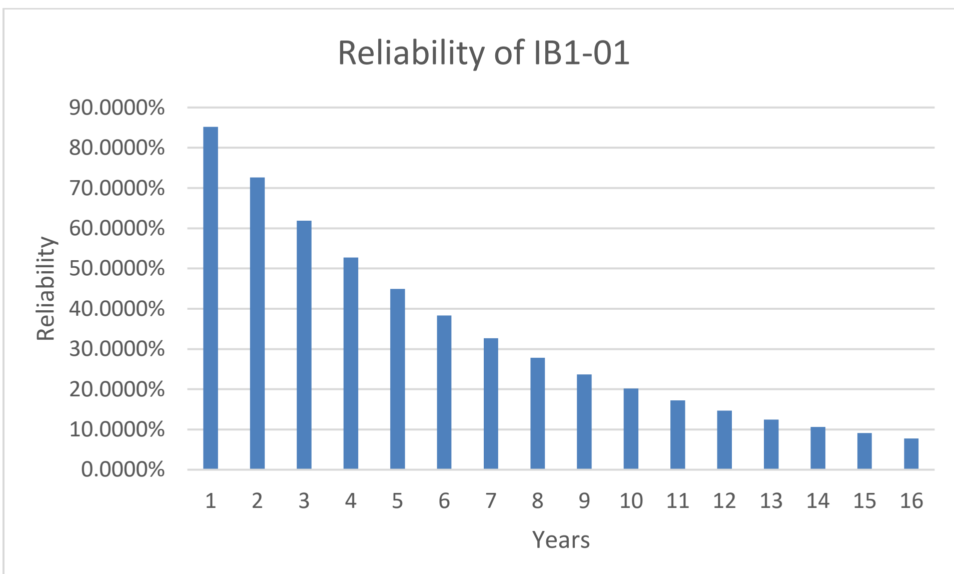

Figure 25. Reliability of Asset IB1-01

Figure 24 and 25 were also in the top 5 of the assets with the most amount of CM over the 5-year service contract, but the reliability does not drop as fast from one year to the next in comparison to MF1-DV or the X02-DV reliability graphs.

4.4.2.2 Score Calculations

The rating and the ranking used for the final score of the health condition of the asset was calculated by averaging the scores gathered from the survey. Afterwards, the criteria were ranked from most important to least important with a numeric value, the highest number being the most important criteria over all. The criteria summarized to the factors of reliability, dimension and capacity, and the CM to PM ratio. The weight was calculated by dividing the criteria ranking by the total sum of all the criteria and multiplying each ratio by 100 to output a percentage, as seen in Figure 26.

Score Calculation				
	Criteria	**Survey Rating**	**Ranking**	
	Usage	4	5	
	Reliability	3	6	
	Age	5	4	
	CM	6	3	
	PM	7	2	
	Operating Conditions	5	4	**Weight**
	Reliability CM	4.0	4.3	27%
	Reliability EM	3.0	5.0	31%
	Dimension and Capacity	4.5	4.3	27%
	CM/PM Ratio	6.5	2.5	15%
		TOTAL	16.2	100%

Figure 26. Score Calculation: Weight of Factors

The total score for the health condition of an asset is then determined by multiplying the score of each factor by the weight and then adding the ratios as seen in Figure 27.

Asset Score			**Weight**
	Reliability EM	100.00%	31%
	Reliability CM	7.43%	27%
	Dimension and Capacity	66.71%	27%
	CM/PM Ratio	73.68%	15%
	=(I34*J34)+(I35*J35)+(I36*J36)+(I33*J33)		

Figure 27. Asset Score Calculation

See Appendix H for more detail on the complete tool with data inputted from the asset MF1-DV.

4.4.3 Tool Design: No Data Available

When there is no data available for a site, a visual inspection tool will be used (shown in Appendix F). The visual inspection tool has various grading criteria and weights that were obtained from the survey in Appendix E, and a preventative maintenance schedule that was found in the airport's OEM manual (source found in VI internal website, Vikepedia).

The following criteria was obtained:

- From the survey: Severity, Age, Cleanliness, Tears/Fraying, Detection, Tension, Manufacturer, Noise/Vibration
- From the PM Schedule: Alignment/Position, Normal Wear, Proper Operation, Secure/Tightness, Lubrication/Oil Level.

The frequency of how often each criterion from the PM schedule was performed was used to rank the criteria. Refer to Table 4 to see the ranking of criteria obtained from Figure 28.

Table 4. Ranking of Asset Health Criteria

Criteria	Frequency	Rank
Noise/Vibration	5	3
Lubrication/Oil Levels	2	6
Tension	3	5
Normal Wear	5	3
Alignment/Position	6	2
Secure/Tightness	4	4
Cleanliness	6	2
Physical Condition(Tears/Fraying)	10	1
Proper Operation	5	3

First, a table was created to determine the weights of the various criteria. In one column, the rankings from the survey were assigned to the applicable criteria and zeros were filled in for the criteria taken from the PM schedule. The second column shows the ranking of the criteria based on the frequency of the PM schedule, where zeros were filled in for criteria obtained from the survey. In the third column, column one and column two are averaged and then sorted in ascending order. From this, the criteria were ranked with 13 the being the most important all the way down to 1 being the least important. The weight was determined by dividing the individual rank by the sum of all the ranks as shown in Table 5.

Table 5. Weighing Factor for Visual Inspection Tool

Criteria	**survey**	**pm**	**AVG**	**RANK**	**Weight**
Severity	1	0	0.5	13	10%
Alignment/Position	0	2	1	12	9.5%
Normal Wear	0	3	1.5	11	9%
Proper Operation	0	3	1.5	11	9%
Age	3	0	1.5	11	9%
Secure/Tightness	0	4	2	10	8%
Cleanliness	4	2	3	9	7%
Tears/Fraying	5	1	3	9	7%
Lube/Oil	0	6	3	8	6%
Detection	6	0	3	8	6%
Tension	2	5	3.5	7	5.5%
Manufacturer	8	0	4	6	5%
Noise/vibration	7	3	5	11	9%
			Total	126	

Second, a grading rubric (as seen in Appendix F) was crafted for the operator to grade each part/component accurately on the following scale:

- 0 is not applicable
- 1 is poor

- 2 is fair
- And 3 is very good.

Third, the total rating of the asset is calculated by the following formula.

$$\sum \begin{pmatrix} \text{Severity Score \#1} \quad (10\%) \\ \text{Alignment/Position Score \#1} \quad (9.5\%) \\ \text{Normal Wear Score \#1} \quad (9\%) \\ \text{Proper Operation Score \#1} \quad (9\%) \\ \text{Age Score \#1} \quad (9\%) \\ \text{Noise/Vibration Score \#1} \quad (9\%) \\ \text{Secure/Tightness Score \#1} \quad (8\%) \\ \text{Cleanliness Score \#1} \quad (7\%) \\ \text{Tears/Fraying Score \#1} \quad (7\%) \\ \text{Lube/Oil Score \#1} \quad (6\%) \\ \text{Detection Score \#1} \quad (6\%) \\ \text{Tension Score \#1} \quad (5.5\%) \\ \text{Manufacturer Score \#1} \quad (5\%) \end{pmatrix} / \text{Total Possible Points} = \text{Health Rating of Asset}$$

4.4.4 Final Rating Procedure

The final health condition rating evaluates the system. Therefore, the system is mainly comprised of assets and then components inside the assets. There are also other factors that need to be included to evaluate the system such as the system's environment and cleanliness. In Figure 29, the final rating process is shown. The system, assets, and components are rated individually. The system's environmental rating is multiplied by its weight of 15%, and the system's cleanliness rating is multiplied by its weight of 5%. These two scores are then summed to equal part of the overall system's score. Next, each asset in the system is rated and given an individual score, these scores are summed together and then multiplied by its weight of 60% (since assets are the major influencer of the system). This is the assets score. The same calculation is done for the component score; the individual component score is summed together and then multiplied by its weight of 20%. At the end, the system score, asset score, and the part/component score are added together to give the final health condition composite rating of the entire system.

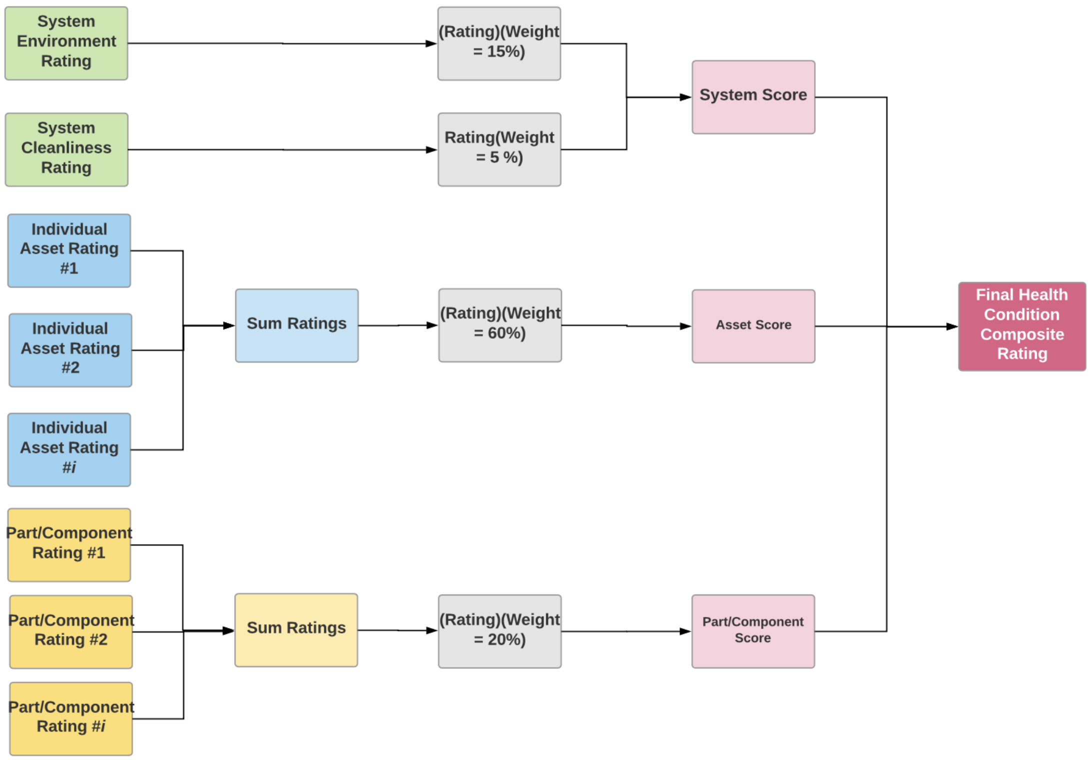

Figure 28. Final Score Tree

4.4.5 Health Condition Action Items

Table 6, the Health Index, was created to help determine the action items and recommendations needed to finalize the analysis of the health condition assessment. Regarding the MF1-DV, the 'data available' tool scored the asset with a 62%. Therefore, the condition of this asset in the BHS is labeled as 'Fair', meaning there is significant deterioration on the asset. An increase in preventative maintenance or a root cause analysis of the CM data should be performed to establish a replacement plan if deemed necessary.

Table 6. Health Index

Health Index	Condition	Description	Appropriate Action Recommended
85-100%	Very Good	Some aging or minor deterioration of a limited number of assets/components.	Maintain the Service Contract and Maintenance plan as-is.
75-85%	Good	Mild or expected deterioration of some assets/components.	Evaluate PM schedule and document findings for future reference.
50-75%	Fair	Significant deterioration or serious deterioration of specific assets/components.	Increase preventive maintenance and create a plan for future replacement. Perform a root-cause analysis of critical assets with deterioration.
30-50%	Poor	Widespread serious deterioration.	Evaluate effort put into preventive maintenance and perform engineering economic analysis to determine 'buy vs. keep' assets. Consult with customers about findings.
0-30%	Very Poor	Extensive serious deterioration that is widespread.	Consult with customers about life-cycle planning, RMR's, and operational improvements.

The conditions in Table 6 are separated in recommendations based on a long-term improvement plan or a short-term improvement plan. 'Very Good' and 'Good' condition scores are classified as short-term improvement plans because these include initiatives that can help improve the process in its present stage. On the other hand, the long-term improvement plans involve the health condition score of 75% and lower. It is indicated to be a long-term plan because it analyses major capital costs or changes. For example, a buy vs keep economic analysis determines a plan that can impact the company in the next 3-5 years, depending on the length of the services contract with an airport site.

4.5 Verify

The verify phase of the DMADV cycle is based on receiving the initial feedback from the customer and making the needed process adjustments to meet the customer's needs. Thus, a pilot test is run to make sure the tools created to determine the health condition rating of an asset meets the customer's needs. The pilot test will provide needed feedback and adjustments to be made accordingly. Ideally, the health condition score with the ‘Data Available’ tool will allow the results from the ‘No Data Available’ tool visual inspection to be validated and vice versa because these should yield related results.

Chapter 5: Results

5.1 Results and Discussion

The DFSS (Design for Six Sigma) five-step methodology was used in conjunction with DMADV tool which stands for define, measure, analyze, design, and verify. During the define phase, the project goals were determined (via Project Charter) based on the customer requirements. A SIPOC diagram, a VOC, and a Kano Analysis were used to define the problem and understand the needs of the customer. The measurement phase measured and ranked the customer needs. Also, the team conducted surveys, interviews, and translated VOC needs into CTQ Requirements. The analyze phase established baselines to be used in measuring the process's improvements throughout the process. The data needed was identified and a process was created based on data needed. Statistical analysis was performed with historical data using the Pareto analysis. The process framework was created in this phase. The design and development of the product correlated with the customer's needs. The tool determines the health condition of an asset for when there is data available for a site and when there is no data available on a site. Lack of time was a big constraint to culminate the verify phase, which determines if the tool created meets the customer's requirements. The health condition assessment tools will be verified for accuracy by comparing the health condition score determined with the 'No Data Available' tool (Visual Inspection) to the score determined with the 'Data Available' tool.

The objective of the project was to establish the criteria needed to determine the health condition of an asset. A Kano analysis was performed, and the needs of the customer were turned into the critical to quality components for the project. Three main functions and six possible exciters were identified (seen in section 4.1.3). The tools created needed to fulfill the critical to quality components. To ultimately determine the health condition of an asset based on the CTQ's, the importance of the components was weighed. Surveys were administered to 5 different Vanderlande employees with BHS experience. The criteria that would define the Health Condition Assessment of a system, asset, and component were determined with descriptive statistical analysis on the survey results. Only the asset survey results would be considered for evaluation and analysis, chosen based on the scope of the project. A side by side boxplot was used to analyze how each VI employee rated the health condition factors. The first analysis determined that out of all the questions from the survey, only one was deemed irrelevant. The other questions were scored with high importance. Therefore, a second survey was conducted to determine the weight of the crucial factors. The survey asked the employees to rank the factors by importance. This way, the tools incorporated the right weighing system to calculate the final health score of an asset.

Historical data was collected on one site that had been under a maintenance contract with Vanderlande since its installation 5 years ago. Using excel and Splunk, the 300 asset BHS was narrowed down to the top 5 assets with the highest reported CM/PM ratio. The MF1-DV asset was chosen based on the Pareto analysis, which had one of the highest CM/PM ratios, meaning that there have been more corrective maintenance work orders performed on the asset than on the others. The ratio of 74%, indicates that out of all the preventative maintenance work orders, there has been almost the same number of corrective maintenance work orders generated on the asset. The higher the CM/PM ratio, the more effort spent on the asset. Effort is translated into labor hours and parts spent, costing the customer more money to maintain the asset. Therefore, the CM/PM ratio is an important indicator that compares in a standardized way the maintenance history of all the assets in a BHS. To understand how the tools would be used, a process framework was created. The process incorporates the steps necessary to determine the system, asset, and component scores. The result of the computation outputs a final BHS health condition score. As seen in the process framework in Figure 12, the BHS is separated into System, Asset, and Component. Notice that the tool chosen for each area is based on available data or no available data. Thereafter, the tool chosen leads to calculating a score for each area. The asset, system, and component scores from the BHS are combined and the health condition assessment of the site is completed. It is important to discuss the idea that the final asset score should be weighed higher than the system and component health scores. The health of the system is defined by the health of its assets. This way, depending on the size of the BHS, multiple assets should be chosen, and their score calculated. The asset health condition assessment score should not be based on a single asset, but a sample size.

The reliability calculations used past corrective maintenance work orders to determine the MTTR (Mean Time to Repair), which leads to understanding how often the asset is being repaired. Therefore, the MTTR of the MF1-DV resulted in 1.92 years. This result indicates that every 1.92 years, a corrective maintenance is being performed on the asset. The ‘Data Available’ tool used reliability, usage of the asset, age, CM data, PM data, and operating conditions as criteria to score the MF1-DV asset. This was based on historical CM data on an airport site serviced for 5 years by Vanderlande. The ‘No Data’ available tool used severity, alignment, wear, operation, age, noise, tightness, cleanliness, tears, oil, detection, tension, and manufacturer as criteria to score the asset. The ‘Data Available’ tool scored the MF1-DV (High Speed Diverter) with a 62.2%. Based on Table 6, the asset is scored with a ‘Fair’, meaning there is significant deterioration on the asset and preventative maintenance needs to be increased. It is recommended to create a long-term improvement plan or a root cause analysis of the past corrective maintenance work orders.

5.2 Conclusion

Vanderlande Industries, a leader in the automation systems for airports, faced an important problem: How does the Services Department determine if a BHS system is worth maintaining? Therefore, the main objective established was to develop a universal toolset and process to guide a high-level and quick system-asset-component health check, to assess the current state of a non-VI asset in its lifecycle and make proactive business decisions in baggage handling systems for airports in the US market. It was imperative to create a process that involved the entire system, assets and components since these rely on each other to operate correctly. The system will not operate without acceptable assets and the assets will not operate without acceptable components. The process scope, at this point, focused on analyzing data and designing a solution on an asset level. Based on the complexity and lack of time that required for a solution to be created for the full process, a solution was designed for assets when data is available and assets when data is not available.

A health index table, Table 6, was constructed so the users can easily interpret and seek a recommended action for each score outcome. A final pilot test will be conducted to verify the accuracy of the scores by comparing the health condition score determined with the ‘No Data Available’ to the score determined with the ‘Data Available’ tool.

Even though the results of this project only provide health condition scores on the asset level, the results provide a process framework that walks through all the steps and actions needed to rate the system, and a final rating procedure that is used to compute the final score when the system score, asset scores, and component scores are individually calculated. A common use for the health condition score is to provide justification for making proactive business decisions in baggage handling systems for airports in the US market.

5.3 Future Projects and Recommendations

The project ultimately determined the crucial factors and created the templates necessary to score the health of an asset based on available data or no available data. Regardless, future additions to the project and the tools must be made to complete the process framework to calculate the final health score of a BHS.

To start, the surveys should be administered to at least 20 more technicians and Vanderlande employees with BHS experience. This way, any statistical error from the previous survey results can be reduced and more accurate results of the key factors to the health condition assessment can be established. Thereafter, separate tools for the system and components can be designed.

Also, not only should this survey be administered to 20 more employees, it should be continuously improved over time to stay relevant to future sites.

Another crucial improvement to the project is to analyze the importance of the CM/PM Ratio and how this one can trigger a change or adjustment to the maintenance plan in a BHS. A deeper reliability analysis is also needed to establish the exact time in which the asset will potentially fail or become End-of-Life (EOL). This analysis will have to be based on true failure data and not corrective maintenance dates.

It was mentioned during the Analyze phase that the critical assets to analyze were chosen based on historical data and the CM/PM ratio. During the project, knowledge of a new tool for criticality/ABC analysis was being implemented in the European BHS sites. The ABC analysis tool can be another option that can be used to determine the critical assets of the system to score. It is important to investigate the tools in order to establish its use and part in the process framework for the health condition assessment of a BHS site.

A product library is currently being developed to contain information on assets that are in the EOL or EOS stage. This library only contains information on Vanderlande manufactured assets. A recommendation to the customer, is to push the product library to include non-Vanderlande manufactured assets that are common in the BHS sites. By including this information, sales engineers and the services department can recommend upgrades and changes to assets that are near EOL, EOS, or EOT to the customer.

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Appendix A: Acknowledgements

We would like to thank Vanderlande Industries North America for the opportunity to conduct a project on a current problem within the Services Department. Especially Antoine Gerritsen for being a valuable resource during the define and analyze phase of the project, Lisa Turner for taking the time to gather the data necessary to analyze the maintenance data on an airport site, the site managers who willingly filled the survey that helped us with the design of the tools, Walt Payne for communicating the importance and idea to Craig Arnold, the VP of Services who allowed us the opportunity to build a project based on a problem currently seen in the organization. Last but not least, we would like to thank all the technical specialist that with their knowledge and experience answered the surveys and helped us find the right criteria to measure.

Appendix B: Reflections

The project was a based on a very interesting and challenging real industry problem. This led to us being able to learn much more from it than expected. The Six Sigma and DMADV tools were incredibly useful because they guided and organized the project accordingly. By applying these tools to industry related problems, we were able to understand the concepts much more than before. At the beginning of the project, we were faced with several issues regarding scope and problem definition. The customer needs were not clear enough to define the problem and ultimately guide the analysis. Therefore, several brainstorm sessions and interviews led to completing a Kano Analysis, that helped us determine the problem and define the scope necessary to complete the project. We learned that the Define Phase of a project is the most important section of all. Sometimes, the customer does not understand the problem themselves, but they understand there is a problem. But, by defining criteria, narrowing down to a scope and a timeline, and setting up specific objectives leads to completing the right success criteria. Also, it was a new topic for us! Even though Mariantonia had been working Part-Time for almost 6 months, she had no previous knowledge of the problem Vanderlande was having with their assets. She was able to complete her first visit to an airport site, which leads to greater knowledge in understanding the process and operations of baggage handling systems. Overall, the implementation of the system engineering tools led to a very rewarding experience with Vanderlande and the Senior Design Project.

The following table depicts the topics each team member focused on during the project.

Team Member	**Delegation**
Mariantonia Hoyos	Direct communication with Company and Employees
	Interviewed Customer
	Design of Data Available Tool
	Reliability Calculations
	Pareto Analysis
	Staistical Analysis on Survey Data
	Paper Writing and Editing
	PowerPoint Creation and Editing
	Process Framework
	Poster Creation and Editing
Tori Shonk	Literature Review
	Design of Surveys
	Design of No Data Available Tool
	Paper Writing and Editing
	Design of Health Index Table
	Video Creation
	PowerPoint Creation and Editing
	Poster Creation and Editing
	KANO Analysis
	Measurement Calculation Tree

Appendix C: KANO Analysis

How would you feel if the tool:	I would be delighted to find it that way.	I expect it to be that way.	I am neutral.	I wouldn't like it that way but I can live with it.	It must not be that way.	Analysis
1a. Could determine when you will run out of spare parts?			■			I
1b. Could NOT determine when you will run out of spare parts?			■			
2a. Could determine when a component/part fails?	■					P
2b. Could NOT determine when a component/part fails?					■	
3a. Could determine how much effort(hours in PM/CM) Vanderlande is putting into this asset?	■					E
3b. Could NOT determine how much effort Vanderlande is putting into this asset?			■			
4a. Could determine when Vanderlande should replace or retrofit the asset or change order to increase the contract scope?		■				I
4b. Could NOT determine when Vanderlande should replace or retrofit the asset or change order to increase the contract scope?				■		
5a. Could determine the criticality of an asset?	■					E
5b. Could NOT determine the criticality of an asset?			■			
6a. Could determine the mean time between failure of parts?		■				I
6b. Could NOT determine the mean time between failure of parts?				■		
7a. Could determine the mean time between failure of assets?	■					P
7b. Could NOT determine the mean time between failure of assets?					■	
8a. Could determine the health condition of an asset?		■				B
8b. Could NOT determine the health condition of an asset?					■	
9a. Can determine a potential operational risk or impact in case of failure?	■					E
9b. Can NOT determine a potential operational risk or impact in case of failure?				■		
10a. Could show the lead time required to order parts?			■			I
10b. Could NOT show the lead time required to order parts?			■			
11a. Could predict the total cost of maintenance for an asset?	■					E
11b. Could NOT predict the total cost of maintenance for an asset?			■			
12a. Could predict the total cost of parts for an asset?			■			I
12b. Could NOT predict the total cost of parts for an asset?			■			
13a. Could show you where the asset is located on its life-cycle graph?	■					E
13b. Could NOT show you where the asset is located on its life-cycle graph?				■		
14a. Could determine the ideal state of the asset?		■				I
14b. Could determine NOT the ideal state of the asset?				■		
15a. Could determine the total hours it can possibly run?		■				I
15b. Could NOT determine the total hours it can possibly run?				■		
16a. Could determine the predictive life of the asset?	■					E
16b. Could NOT determine the predictive life of the asset?				■		

Customer Requirement	Dysfunctional (Negative) Question					
Functional (Positive) Question		Like	Expect It	Neutral	Live With	Dislike
	Like	Q	E	E	E	P
	Expect It	R	I	I	I	B
	Neutral	R	I	I	I	B
	Live With	R	I	I	I	B
	Dislike	R	R	R	R	Q

E: Exciters
B: Basic
P: Performance
I: Indifferent
R: Reverse
Q: Questionable

Appendix D: Survey

Survey Objective and Instructions:
The objective of this survey is to list the factors that determine the health condition of a system, asset, and component by level of importance.
It will help determine the factors that should be included in a visual inspection tool to rate the health of a Non-VI system/asset/component.
Type in an **X** in the scale level of 1-5 , with 5 being the a very important factor in determining the health condition of a system/asset/component.

On a scale of 1-5 (with 5 being the most important) how do you think the following factor plays in determing the health condition in a baggage handling system?	1	2	3	4	5
1. The environment of the Baggage Handling System. (ex. The BHS is located near a beach, or part of the system is outside)					
2. The SIZE of the Baggage Handling System. (ex. Atlanta BHS vs Myrtle Beach BHS)					
3. The capacity of the Baggage Handling System.					
4. The cleanliness of the Baggage Handling System.					
5. The regular throughput of the Baggage Handling System.					
6. The site's technical team.					
7. The software used on the Baggage Handling System.					
8. The levels of redundancy in the Baggage Handling System.					
9. The level of past maintenance.					
10. The age of the System is an important factor to determining the health condition of the system.					
11. Are the reporting capabilities of a system important to determining the health condition of the system?					
12. Please list any factors you think are important that are not included.					

On a scale of 1-5 (with 5 being the most important) how do you think the following factor plays in determing the health condition of an asset?	1	2	3	4	5
1. The cleanliness of the asset.					
2. The manufacturer of the asset (ex. Vanderlande, Siemens, etc.).					
3. The date the asset was manufactured (current age).					
4. The usage of the asset (the amount of operating hours).					
5. The stress put on an asset (ex. the tightness of a conveyor belt).					
6. The cost of the asset (ex. is it cheaply made or is the asset on the higher end).					
7. Noise					
8. The redundancy of the asset.					
9. The physical attributes (ex. any tears, bumps, scratches)					
10. The risk of failure of the asset.					
11. The number of components in the asset that are at risk.					
12. PM History of the Asset					
13. The operating conditions help determine the health condition of an asset.					
14. Please list any factors you think are important that are not included.					

On a scale of 1-5 (with 5 being the most important) how do you think the following factor plays in determing the health of a component/part?	1	2	3	4	5
1. The physical attributes (ex. any tears, bumps, scratches)					
2. The manufacturer of the component (ex. Vanderlande, Siemens, etc.).					
3. The date the part was manufactured (current age).					
4. The type of component (ex. is it a motor, belt, or fuse)					
5. The stress put on a component (ex. the tightness of a conveyor belt).					
6. The cleanliness of the component.					
7. The noise the component makes.					
8. PM History of the component					
9. The operating conditions help determine the health condition of a component.					
10. Please list any factors you think are important that are not included.					

Thank you for taking our survey :)

Appendix E: Survey 2 – Ranking of Assets

Please Rank each of the following items in order of importance with #1 being the most crucial factor to #14 being the least crucial factor in determining the health condition of an asset.	**Survey 1**	**Survey 2**	**Survey 3**	**Survey 4**	**Survey 5**	**Average**
The stress put on an asset (ex. the tightness of a conveyor belt).	2	2	6	1	9	4
The usage of the asset (the number of operating hours).	1	3	10	1	14	6
The risk of failure of the asset.	1	1	13	1	1	3
The cost of the asset (ex. is it cheaply made or is the asset on the higher end).	2	10	4	1	2	4
The date the asset was manufactured (current age).	1	5	13	1	3	5
Noise Level	3	4	12	1	13	7
The asset's CM history	2	7	10	1	11	6
The number of components in the asset that are at risk.	2	9	10	1	12	7
The operating conditions help determine the health condition of an asset.	1	8	12	1	4	5
The manufacturer of the asset (ex. Vanderlande, Siemens, etc.).	5	14	3	1	10	7
The cleanliness of the asset.	3	6	10	5	5	6
The redundancy of the asset.	4	13	3	5	7	6
The physical attributes (ex. any tears, bumps, scratches)	2	12	6	5	6	6
PM History of the Asset	1	11	13	1	8	7

Appendix F: Health Condition Assessment with No Data Available

Asset Type	High Speed	**Asset Health Condition Rating via Visual Inspection**
Manufacturer	Siemens	
Asset Name	MF1-DV	
Date	4/5/18	
Performed By		

Part Names	Inspection	CLEANLINESS (1-3)	TENSION (1-3)	NOISE/VIBRATION (1 - 5)	TEARS/FRAYING (1 - 3)	LUBRICATION/OIL LEVELS (1-3)	NORMAL WEAR (1-3)	ALIGNMENT/POSITION (Y/N)	SECURE/TIGHTNESS (Y/N)	PROPER OPERATION (1-3)	SEVERITY (1-3)	DETECTION (1-3)	AGE (1-3)	MANUFACTURER (0-3)	Total Score
Paddle #1	Belt Condition	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Drive Belt Condition	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Bearings	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Pulleys	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Hardware	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Paddle #2	Belt Condition	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Drive Belt Condition	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Bearings	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Pulleys	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Hardware	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Reducer	Hardware	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Motor	Hardware	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	AMP Draw	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Bearings	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Clutch/Brake	Clutch/Brake	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Clutch/Brake Pillow Block Bearing	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Clutch/Brake Drive Chain	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Clutch/Brake Drive Sprocket	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Sprocket	Idles Sprocket	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Crank Sprocket	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Paddle Crank Sprocket	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
	Paddle Sprocket	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Rod End	Rod End	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
Rod End Bolt	Rod End Bolt	3	3	5	3	3	3	2	2	3	3	3	3	3	3.03
													Asset Total Score		72.72
													Asset Rating		100%

Condition		Very Good	Fair	Poor	Not Applicable
Criteria	Scale / Weight	3	2	1	0
Severity	**10%**	Operator can solve the problem. The equipment (sorter/machine) stays operational, but may have a lower capacity or functionality.	Service engineer can solve the problem. After restart the equipment (sorter/machine) may have a lower capacity or functionality.	Service engineer cannot solve the problem immediately. A serious operational problem, the equipment (sorter/machine) is out of use for about one hour or more.	Severity is not applicable to rate this component.
Alignment/Position	**9.5%**	Object/component is in correct alignment.	Object/component is not in correct alignment, but it can easily be fixed.	Object/component is not in correct alignment/position, but significant work needs to be done to be fixed.	Alignment/Position is not applicable to rate this component.
Noise/Vibration	**9%**	No sound coming from the asset, but no irregularities.	Some sound coming from asset, with a few noticed irregularities.	Very loud sound coming from the asset with significant irregularities(Such as vibration).	Noise is not applicable to rate/decscribe this component.
Normal Wear	**9%**	Some evidence of minor deterioration to a limited number of components	Significant evidence of deterioration among some components, but components are still operational.	Widespread evidence of significant deterioration or serious deterioration of specific components, where the components need to be replaced.	Normal wear is not applicable to rate this component.
Proper Operation	**9%**	Component is working properly, nothing needs to be fixed/replaced.	Component is almost working properly, but something need to be fixed/improved. No impact on component's capacity.	Component is not working properly, but needs to be fixed/replaced. Causing a decrease in component's capacity.	Proper Operation is not applicable to rate this component.
Age	**9%**	Equipment/component is brand new and is functioning at full capacity.	Equipment/component is not new, or not old and is functioning at full capacity.	Equipment/component is old as dirt and should be replaced.	The age of the component is unknown, and it is not possible to made an adequate guess.
Secure/Tightness	**8%**	No instances of unsecure objects, very secure/tight, but not too secure/tight.	Few instances of unsecure/tight objects/components.	Several widespread instances of unsecure objects/components.	Secure/Tightness is not applicable to rate this component.
Cleanliness	**7%**	Very clean, little to no work needs to be done.	Fairly clean, would take some time to clean but not too long.	Significantly dirty, there are signs of deterioration and would take a very long time to clean.	Cleanliness is not applicable to rate this component.
Tears/Fraying	**7%**	No signs of any tears or fraying.	Few instances of tears or fraying, but component is still able to function at full capacity.	Several and/or severe instances of tears/fraying. Component is not able to function properly or at full capacity.	Tears/Frays are not applicable to rate this component/asset.
Lubrication/Oil Level	**6%**	Oil levels/lubrication are at recommended levels.	Oil levels/lubrication does not meet specifications, but work can done to easily meet specifications.	Oil levels/lubrication does not meet specifications, and lack of oil/lubrication has caused component to deteriorate.	Oil Level/Lubrication is not applicable to rate this component.
Detection	**6%**	Operator is instantly able to detect a failure/problem on equipment.	Operator is NOT able to detect a failure/problem, but there is a moderate likelihood that the failure/problem can be detected by current controls.	Operator is NOT able to detect a failure/problem, and there are no known controls available to detect failure/problem, which means the failure/problem will likely occur again without detection.	Detection of Failure is not applicable to rate this component.
Tension	**5.5%**	Tension is at required specifications. No work needs to be done	Tenison does not meet specification, and little work needs to be done.	Tension does not meet specifications, but lots of work needs to be done to meet the required specifications.	Tenion is not applicable to rate this component/asset
Manufacturer	**5%**	Manufacture is very well-known and reliable, operator has previous lots of experience working with them. Manufacturer produces the best products on the market.	Manufacturer is somewhat well-known, but operator has previous experience where this manufacturer has been semi-reliable.	Manufacturer is known to not be reliable, based on previous experience or knowledge.	Manufacture of the asset/component is unknown.

Appendix G: Health Condition Assessment with Data Available

ASSET HEALTH CONDITION RATING

Asset Type	High Speed Diverter
Manufcturer	Siemens
Asset Name	MF1-DV
Date	4/5/2018

Dimensions	
Length(ft)	8

Time of Use	
Hours a Day	20
Days a Year	350
Years of Operation	4.94
Operating Time Total	34580

Capacity	
Average System Capacity (bph)	4000
Speed (FPM)	300
Throughput (Sorts per Minute)	54
Load	25
Redundancy (Number of Assets Redunda	3

Maintanance History	
CM	14
PM	19
Ratio	74%

Time of Interest	
Time of Interest in Years	5
Installed Time in Years	4.94
Total Time of Interest (Hours)	69580

Reliability	
Failure Rate for CM	0.52
MTBF Estimate (Years) for CM	1.9230769

Dimension and Capacity			
Total Years	Usage(hrs)	87074.400	0.397
9.94	Age(hrs)	34580.000	
	Operating Conditions	0.270	67%

Score Calculation			
Criteria	Survey Rating	Ranking	
Usage	4	5	
Reliability	3	6	
Age	5	4	
CM	6	3	
PM	7	2	
Operating Conditions	5	4	Weight
Reliability CM	4.0	4.3	27%
Reliability EM	3.0	5.0	31%
Dimension and Capacity	4.5	4.3	27%
CM/PM Ratio	6.5	2.5	15%
	TOTAL	16.2	100%

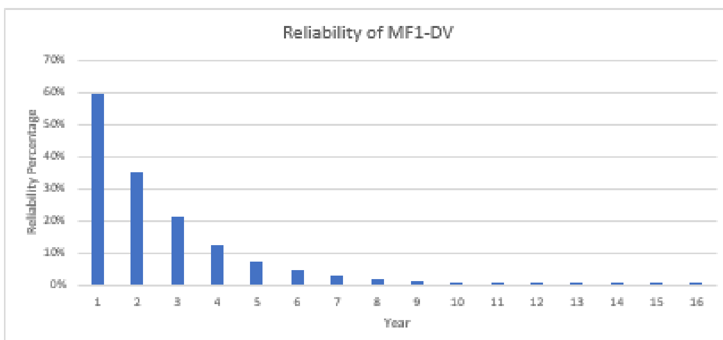
Asset Score		Weight
Reliability EM	100.00%	31%
Reliability CM	7.43%	27%
Dimension and Capacity	66.71%	27%
CM/PM Ratio	73.68%	15%
Final Score	62.2%	100%

ASSET RELIABILITY CURVE

MF1-DV	
TimePeriod	NumberCM
0--1	2
1--2	2
2--3	5
3--4	2
4--5	2

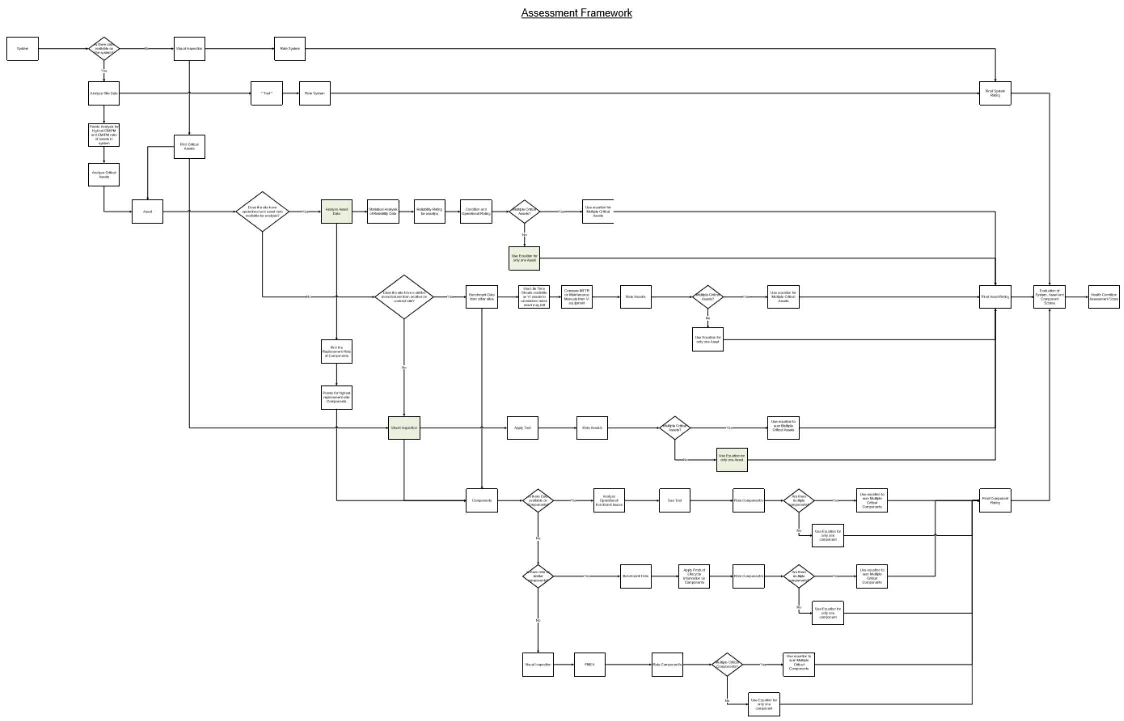
Failure Rate h(t) Lambda	0.52
Total Years	5
MTTR	1.92

Number Years	Reliability
1	59%
2	35%
3	21%
4	12%
5	7%
6	4%
7	3%
8	2%
9	1%
10	1%
11	0%
12	0%
13	0%
14	0%
15	0%
16	0%

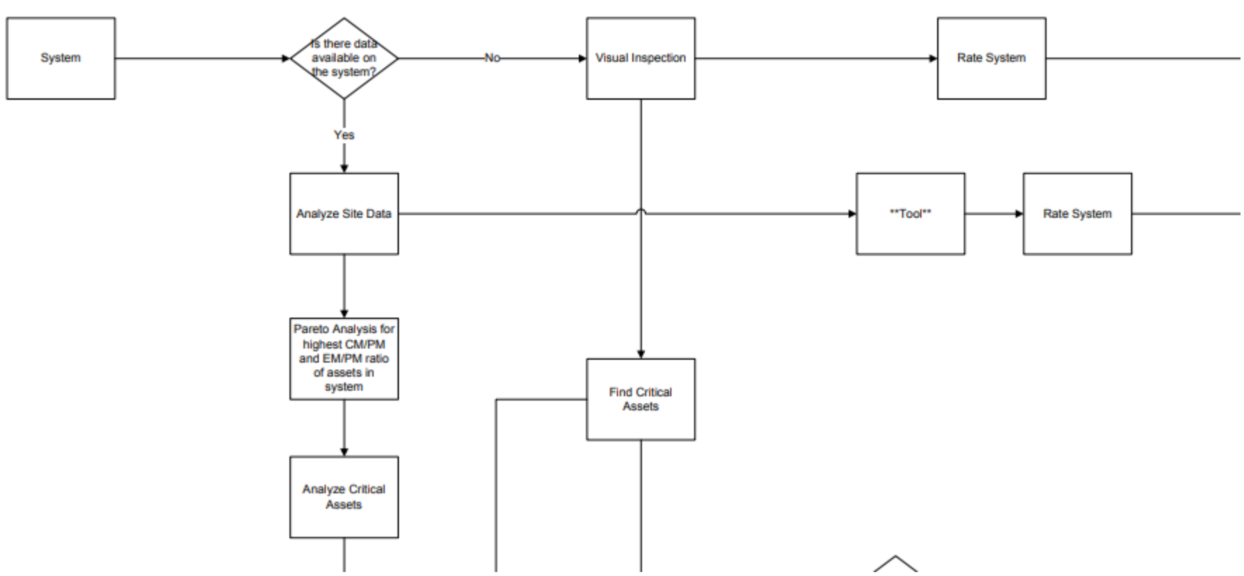


Appendix H: Process for Health Condition Assessment

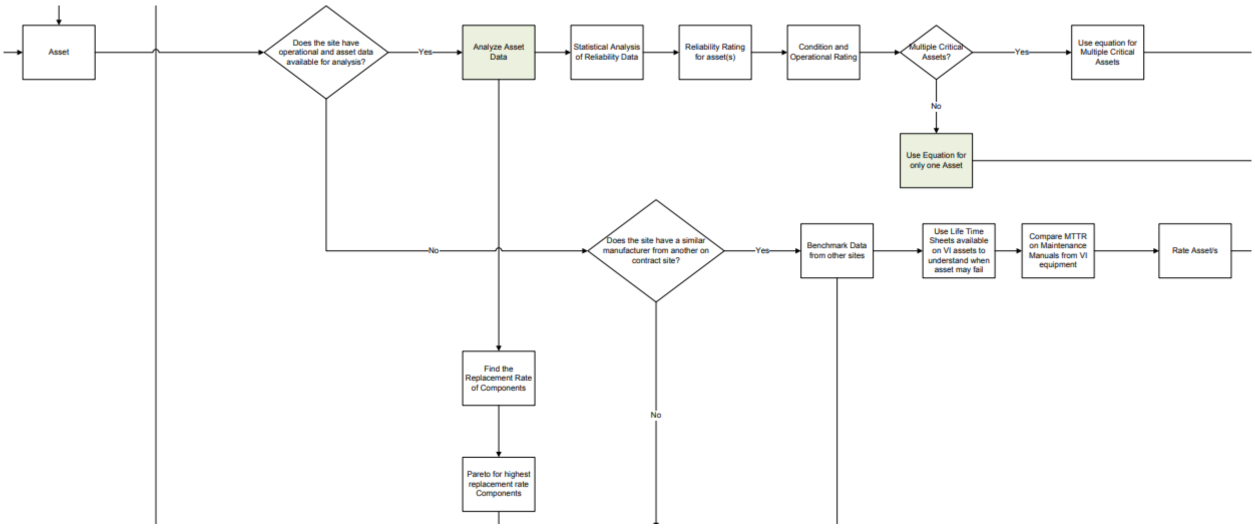
Full Process



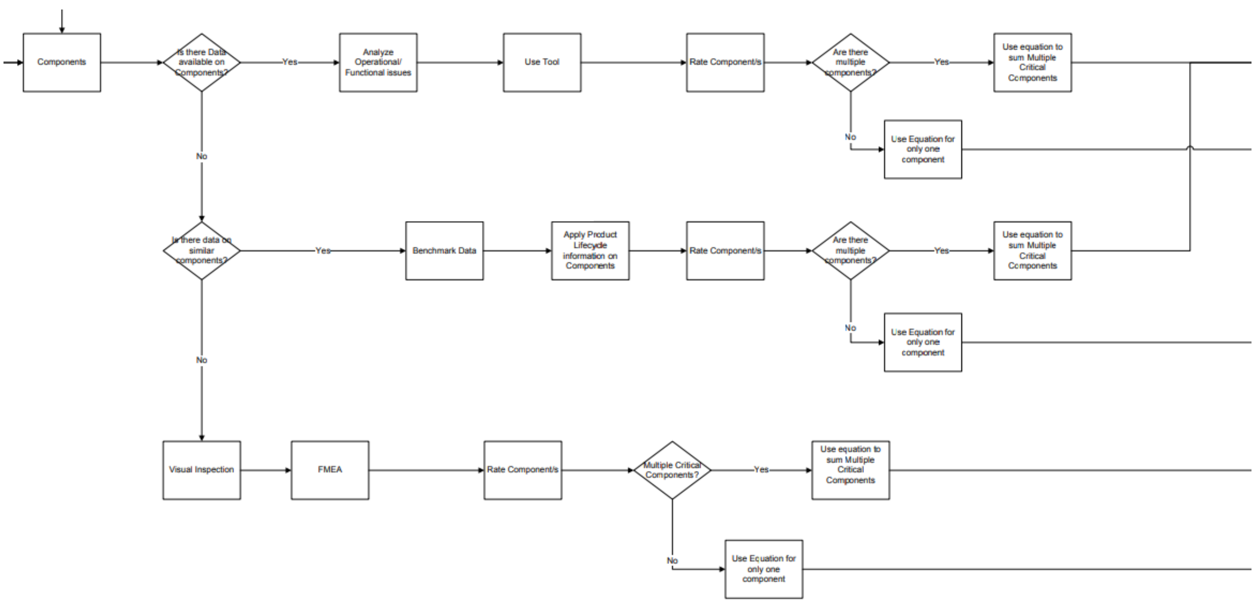
System Process Overview



Asset Process Overview



Component Process Overview



Appendix I: Gannt Chart

Appendix J: Student and Advisor Contacts

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