Refurbishment Value Stream Optimization
by
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Abstract

One of Company X’s many services is to refurbish systems at regular intervals during their use. Quick turnaround times are of the utmost importance both to keep Company X’s costs low and to ensure the systems are returned to perform their services in the field as rapidly as possible. This research had two distinct elements in service to accelerated turnaround times:

1) Improving inventory management practices to align with the need for replacements for failed parts to reduce cycle times, and
2) Diagnosing the reasons for and developing mitigations against failures in the blind mating of two connectors.

Regarding the first element of the research performed, Company X hypothesized that improving the inventory management system would yield shorter cycle times. In order to test this hypothesis, part failure and inventory histories needed to be compared to confirm if parts were not in stock at the time of failure. A model was developed to analyze both of these history files but the poor quality of the data precluded accurate conclusions from being drawn. Once the data input methods have controls placed on them, the model will serve to accurately represent the failure rates and types of failures of all parts, allowing for proper stocking of inventory needed to service these failures.

An investigation of process failure rates and their impact on cycle time was also conducted. This analysis included quantifying how many times each operation was performed, at which steps failures occurred or were noticed most, and how much time was required to complete each operation and service each failure. This analysis ultimately yielded the generation of a diagnostic tool with a flexibility that allowed simultaneous analysis to be performed on over 1,100 operations. One of the key insights generated by
using this tool was that the majority of failures are found at late-stage inspections, highlighting that improving the thoroughness of early-stage inspections could prevent the necessity of substantial rework to remedy the issues found late in the process.

With respect to the second element of the research performed, an understanding of why and how connectors were failing was sought out. Through observing the process and analyzing the historical data detailing the connector’s failure modes, multiple explanations for the failures and related solutions resulted. The first failure mode was loose connections, for which a tool was shortened to increase the operator’s ease of accessing the connector to properly apply torque and secure the connection. The other modes of failure were caused due to connector misalignment, for which a bracket was redesigned as an auto-alignment feature to aid in the mating process, and operator deviations from the work instructions were addressed as they pertained to connector failures. The combination of these actions are expected to yield an annual savings of $100,000, net of costs.

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To everyone who is reading this, you can accomplish anything you set your mind to. You are stronger, smarter, and more compassionate than you could ever imagine. Share your gifts with the world and be the best you that you can be.
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1 Introduction

Company X is a global technology leader who amongst other capacities, specializes in defense. The main business of one of their product lines is currently refurbishment and Company X wishes to reduce the overall cycle time of the process.

Chapter one introduces the impetus for the project and provides an overview of what the remainder of the thesis will discuss.

1.1 Purpose of Project

At one of Company X's sites in the United States, refurbishment is the primary business for one of their product lines. Currently, when a system arrives for maintenance and repair from the field, there is uncertainty at the repair site as to what work needs to be done. This uncertainty is due to the system having been in the field (sometimes more than 15 years) with monitoring and documentation that is incomplete in tracking its experience and representing its current condition. This gap of knowledge leads to improper stocking of refurbishment-related inventory and non-optimal resource allocation, resulting in extended turnaround times and thus increased costs associated with refurbishing the systems. To address this issue, Company X is working to improve their forecasts of the demand for repairs and will be reassessing their inventory management practices.

A distinct mechanical failure that occurs during both the initial manufacture and refurbishment of the systems is associated with damaging the pins of two connectors that mate with each other. These failures are often not noticed until much later in the assembly process, at which time much disassembly and rework is required to remedy the issue. To address this issue, Company X is considering redesigning both the features of the mechanical environment and the connection mating process.

With the goal of reducing the cycle time and cost of refurbishment, this project has two main elements: (1) reducing the uncertainty related to planning the refurbishment of systems before they arrive for repair and (2) to reduce the likelihood of mechanical failure of two specific connectors.
1.2 Problem Statement

Refurbishing complex technical products poses a significantly difficult challenge to companies wishing to maintain a consistently efficient turnaround time. This difficulty is exacerbated when those products are comprised of hundreds of unique components whose ages could range from zero to 40 years old, and which operated in environments ranging from hot and dry desert to cold and wet tundra. As a result, the internal demand for replacement parts and resources (both materials and workers) required for refurbishment can be highly variable, resulting in extended contract lengths and associated costs.

One type of part failure that is both highly predictable and currently associated with significant rework time pertains to the blind mating of two connectors. The environment in which the mate is performed grants the operator extremely limited vision of the connection as it occurs, resulting in damaged pins that won't exhibit symptoms of failure until many steps later in the process. In addition, the nature of the contracts being both long term and government affiliated imposes additional hurdles when trying to implement a design change that would increase the ease of the mating process.

Given the nature of both of the aforementioned issues, Company X is interested in gaining insight into existing part failure modes and their impacts on the average cycle time of refurbishing the systems. This project was created to help generate this knowledge and provide solutions to what was determined to be the root causes of the issues.

1.3 Project Hypothesis and Approach

In an effort to generate solutions with respect to both problems mentioned above, a multifaceted approach was taken. It was hypothesized that the internship site's data rich environment would allow ease of analysis that would result in the development of a flexible cost reduction methodology which could be applied to each customer of Company X and utilized throughout the company. Specifically, we assumed that the data would support the hypothesis that optimizing inventory management practices would significantly reduce refurbishment cycle times by preventing the need to wait for parts to service failures.
In attempt to test this claim, value stream maps of the existing refurbishment and mating processes were to be created in order to identify the cost drivers and areas that could benefit most from process improvements.

Next failure history data associated with the refurbishment process and the connector of interest was to be collected, cleaned, and analyzed. The purpose of this data analysis was to aid in the determination of where failures are observed and what specifically was increasing the cycle time of refurbishment (excessive rework required due to noticing issue too late in process, replacement parts not being available, etc.).

Following this analysis, separate approaches were needed with respect to each problem. With respect to the connector issue, multiple approaches were taken to help remedy the issue. Redesign of one or more components in the mechanical assembly was to be performed in addition to investigating room for improvement within the assembly process itself. This was to be performed in an effort to propose solutions that would reduce cost, cycle time, and failure rates of the blind mating process.

In addition to the analysis of the failure history data, the current inventory management system was to be analyzed with respect to the refurbishment goal.

Following the analysis performed with respect to each goal, pilot tests were to be performed in order to validate the mechanical redesign and process improvement recommendations. If validated to a level acceptable to Company X, roadmaps of how to repeat the process across different clients and within Company X's other business units would be generated.

1.4 Thesis Structure

The thesis will begin by providing more context to the problem statement by further detailing the current refurbishment process at Company X, as well as more of the company’s background. Next, the forecasting for inventory management problem will be discussed, including the relevant literature that guided the analysis. This will be followed by the investigation of all of refurbishment operations. Chapter four will present the research and findings regarding the mechanical connector failures and remedies. Finally, the conclusions resulting from implementing the mechanical and process redesigns will be discussed and recommendations of how to apply the solutions to other applications will be made.
Please note that many of the specifics regarding contract sizes, failure rates, and mechanical designs are confidential. For this reason, vague generalities are used throughout the thesis to describe what are in actuality deterministic values.
2 Refurbishment at Company X

Company X's location in the United States is a data rich environment in which refurbishment is the primary business for one of their product lines. This chapter provides insight into the current refurbishment process and how the data that it generates can be used to reduce costs and improve cycle times.

2.1 Company Background

Company X is a global technology leader who amongst other capacities, specializes in defense. The host site of the internship at one of Company X's United States locations, is the home to the manufacturing and production of the system discussed in this thesis, radar systems, and more.

2.2 Overview of Refurbishment Process

The system that is the focus of this paper is sold as a package that has an expected life of many decades. As a result of part wear over time and advancements in technology, service contracts are required to ensure the systems are in the best condition to perform their required function without failure.

Once the system arrives at the facility, there is a known set of components that will need rework or replacement. This process is extremely predictable as the cadence of incoming parts is known months in advance, the process is highly repeatable and Company X has the ability to stock the exact amounts and types of inventory required. Outside of this known group of parts that require attention of some sort, there are additional parts that will require rework or replacement.

A much less predictable part of the refurbishment process is associated with out of scope (OOS) rework. Due to early end of life of parts, unexpected damage caused while in the client’s possession, or damage caused during the rework process, OOS rework is highly volatile and thus adds significant cycle time to refurbishment. An extremely high level view of the refurbishment process and the rework cycle can be found in the figure below:
As shown in the figure above, systems are first broken down into their major sub-assemblies and inspected to see if any OOS rework will be required. If not, the sub-assembly is put into storage and later taken through the remainder of the normal refurbishment process.

If OOS rework is required, the nature of rework is first categorized as either requiring replacement parts or the existing parts are able to be repaired. If both labor and part resources are available, the rework will be performed soon after the failure is reported. If parts or labor are not available, the part will be placed in storage while parts are either made or ordered. Company X believes that there is a high probability of part unavailability at the time of failure, and the need to wait for parts to service the failure is a significant contributor to the cycle time increases recently witnessed.

2.3 Failure Forecasting, Reporting, and Servicing Method

2.3.1 Failure Forecasting

Forecasting part failure rates with respect to refurbishing the system falls into two general categories: parts that will be replaced on all systems with 100% certainty, and parts that have non-zero uncertainty with respect to their failure rates. In addition to knowing the expiration dates of parts, hardware and software upgrades that occur at regular intervals also contribute to this group of known failure rates. Given the perfect visibility regarding the replacement needs of these parts, this group was not seen as a major contributor to the variability in refurbishment cycle time.
The parts associated with non-zero uncertainty around their failure rates were suspected to be the main culprits of the increasing refurbishment cycle time. The limited knowledge around the actual failure rates of these parts has led Company X to stock inventory meant to service these failures in a sub-optimal manner. Currently, the method used to stock inventory meant to service OOS failures is to request that in addition to the X number of systems being sent back for refurbishment, an additional Y systems are sent back to be used as donor parts. In general, Y tends to be a fairly low amount and these parts are consumed quite early on in the contract.

2.3.2 Failure Reporting

For the reason mentioned above (amongst others), Company X has been gathering data regarding OOS failures. The details associated with these failures includes: the log ID, the date and time the failure was logged, the part(s) associated, the quantity of parts that failed, if the failure required replacement parts or repair, and additional comments detailing the nature and history of the failure. During any operation, if the operator notices a physical defect or a test is failed, they write up a non-conformance report. This report is then reviewed by the local manufacturing engineer and entered into the failure log database, including their recommendation for if the part should be repaired or replaced and if donor material should be used in the event parts need replacing. This recommendation is then sent to product control for further review and possible approval.

Each step in the process of reporting failures is subject to error which can negatively influence data analysis. Starting with the operator, often times the failed part number entered into the system is that of the major sub-assembly upon which they are working and not the component that failed. Only sometimes is this mistake caught by noticing the comments detail the specifics of the failure being related to a different component. When comments aren’t included or part numbers not mentioned in the comments, the risk of assuming one part failed when in actuality it was another, increases. When speaking with multiple manufacturing engineers, they also mentioned a lack of clarity existed around the process of how they should be reviewing the failures and making their recommendations. This absence of a defined process or lack of awareness by manufacturing engineers that such a process exists also allows error to be introduced to the data. For example, if they recommend that a specific part be scrapped and replaced with donor material, there is a chance that this request will be denied.
and a new part will be made to meet the part replacement need. This deviation between the manufacturing engineer’s recommendation and what actually occurs is not captured in the data and further prevents accurate analysis.

Until recently, this data was input with no controls in place to check if the part numbers being entered existed. This allowed error to be introduced when operators don’t double check their spelling or they misremember a part number. While the rework or repair is still performed with respect to the appropriate part, issues arise when analyzing the data and attempting to provide a reasonable confidence level around future failure rates of a given part. Fortunately, Company X’s Modernization and Innovation group has been growing in recent years, which has led to improved data input management requiring the part numbers entered in a failure log to match one in the database of known parts, thus eliminating one source of error.

### 2.3.3 Failure Servicing Method

The manner in which failures are serviced is largely driven by how they are forecasted and reported on. As previously mentioned, the primary method of forecasting OOS failure rates is on a general level of “how many extra systems will be needed to replace parts for this contract?” Given that this estimate isn’t driven by accurate data and the entire request for donor systems sometimes cannot be met by the customer, this results in a gap between actual parts available to supply repairs and the true demand that results throughout the contract.

The heavy reliance on donor parts leads to almost all part replacement requests to be met by donors (excluding common parts such as fasteners, wire, etc.). As the supply of donors approaches depletion, these requests then translate into requiring new parts needing to be manufactured or purchased, which often are associated with lead times upwards of one year. During this time, sub-assemblies waiting for these parts to be replaced are inducted into storage, allowing the production line to continue moving forward. Added cycle time is produced when there isn’t buffer stock available to pull from to keep all workstations busy, or if storage locations are in use and the failed component remains on the workstation while waiting for replacement parts.

The combination of inaccurate forecasting, availability of the client to provide the recommended amount of donor systems, and overall sub-optimal inventory management methods were hypothesized to be a major contributor to the cycle time creep, and thus was the focus of this project.
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3 Refurbishment Value Stream Optimization

This section details the research performed in regards to how to improve Company X’s inventory management methods. This includes an overview of general concepts and industry standards, the data gathering and analysis methods, perspectives of internal experts, and the summation of all of the aforementioned information. The approach taken in an effort to improve the inventory management process follows the problem-solving template outlined in chapter seven of Steven Spear’s The High Velocity Edge [1]. This iterative process encompasses: observing the current condition, determining the problems and root causes associated with the current condition, developing countermeasures to the root causes, and a vision of the target condition that would result from remedying the problems (Figure 3-1). Recall that the initial root cause of increasing cycle time of refurbishing product was hypothesized to stem from sub-optimal inventory planning. This hypothesis served as the launching point to the process improvement learning cycle.

Figure 3-1: The Problem-Solving Template Used to Approach the Project [1]
3.1 Literature Review

3.1.1 Inventory Management

Attempting to replace failed components without adding cycle time due to stock outs allows parallels to be drawn to the newsvendor model. "The newsvendor model considers a setting in which you have only one production or procurement opportunity" to meet the demand of a sales event. Traditionally, "underage cost" is the opportunity cost of not ordering an extra unit that could have been sold, while "overage cost" is the cost associated with ordering an extra unit that is not sold. In Company X's case, if there is a lack of inventory available to replace the failed components, an "underage cost" equal to the cost of added cycle time will result. Similarly, if more inventory than necessary is stockpiled and not used, the overage cost is equal to the cost of holding the additional inventory. In general, the objective of the newsvendor model is to balance the costs of overage versus underage, and to do so requires an understanding of the demand uncertainty of the product [2]. At the beginning of this project, Company X had limited visibility into failure rates of a certain set of parts on the system (demand uncertainty), thus precluding the immediate application of the newsvendor model to their situation. This knowledge gap presented an opportunity in which value could be generated through determining part failure rates. Knowing these failure rates would serve as the demand distribution function needed to allow the application of the newsvendor model to the potential inventory management issue in question. For this reason, a significant portion of this project centered around finding and analyzing data regarding part failure rates, which will be discussed in detail in the following sections.

3.2 Inventory Management at Company X

As mentioned in the previous section, one of the foci of this project was to determine the failure rates of parts in order to facilitate an understanding of how best to manage inventory levels. The initial theory was that talking to major stakeholders would provide a holistic view of which parts have greater failure rates and also where to find the sources of data that might support these claims. These data sources would validate or refute the holistic claims in addition to presenting new findings. Taking
these findings back to the stakeholders would confirm if the data was correct or was being misinterpreted and allow for iteration of the process.

3.2.1 Handling of Common Parts and Inventory Systems

With respect to the system, Company X has two primary systems to manage inventory. The first of these is an enterprise-wide system that manages all of the official storage locations. Every time parts are inducted into or removed from one of these storage locations, the action is logged along with all relevant information (part number, date, location, quantity, etc.). While these transactions are recorded into an inventory tracking database, snapshots of daily inventory levels are not recorded which adds a layer of complexity when attempting to analyze the history of inventory levels.

In most cases, this system accurately captures the amount of parts available for use in the facility. However, there are a few scenarios in which inventory is dispersed throughout the facility and incurring holding costs while not being captured by this management system.

One such scenario occurs when parts are released from an official storage location to the production floor where they sit for extended periods of time. One example of this could be requesting a few hundred fasteners to be placed line-side to reduce how often someone needs to go to storage and request the same part repetitively. Although this may save one person time, this action often results in parts being pulled from inventory that aren’t used in the near term. This results in inventory being held on the floor and an unnecessarily early replenishment of inventory occurring so parts will be available in the official inventory location.

3.2.2 Donor Parts and Inventory Systems

Another completely separate system of inventory management is associated with the donor systems. As a brief reminder, as part of each refurbishment contract the client returns additional systems (donors) to be scrapped and used for parts to service the rest of the systems. These donors are not inducted into the inventory systems previously discussed. Rather, the status of which parts have been pulled from donors and which parts remain is controlled via a single Excel spreadsheet.

This spreadsheet holds information regarding the major and minor sub-assemblies and parts that are often needed during the refurbishment process. However, this
spreadsheet does not contain details of all levels of sub-assemblies nor does it allow proper tracking of when and where donor parts were used. Dates of when parts are pulled from donors are not tracked, and although the spreadsheet references a failure log to show where the parts were used it is not immediately apparent and requires a few additional actions to discern this information.

In addition, not having a checks and balances system in place allows more human error to be introduced into this inventory tracking method. For example, updating it isn't a mandatory part of the process when taking parts from the donors and thus can lead to inaccurate representations of what donor parts are available for use. This is one potential source of added cycle time, as work may be scheduled in a way that they believe donor parts are immediately available, while in actuality these parts have already been consumed and new assemblies must be made from scratch.

Finally, this and the previously mentioned inventory management system do not communicate with each other. Having two separate systems to manage inventory can lead to overstocking of parts and increased holding costs, or in a best case scenario, only result in an increased amount of manual time required to search both systems before making inventory management related decisions.

3.3 Cycles of Data Collection and Analysis

The data collection and analysis portion of the project was found to be the most difficult and time consuming, and thus will be the focus of much discussion in the sections to come. The general approach to collecting and analyzing information pertaining to the project goals was to find and analyze relevant data, investigate sources of error, and then repeat this process until accurate results were output (see Figure 3-2 for detailed data collection and analysis cycle).
3.3.1 Data Collection from Historical Records

To initiate the data collection cycle pertaining to the inventory optimization project, the types of information desired were first determined through interviewing a Senior Operations Engineer within the Modernization and Innovation group (refer to Figure 3-2 for the remainder of this section). After agreeing that histories of part failures and inventory levels would be the most relevant groups of data to analyze, the Digital Manufacturing Lead’s skills were utilized to obtain the data. While there are filtered and formatted versions of the data available via different graphical user interfaces, only two people with access and the ability to manipulate the raw data were found (including the Digital Manufacturing Lead). The lack of direct access to the raw
data paired with there being limited points of contact who could, often created delays within the initial data gathering and interview cycles. This was one of the reasons why the interview cycle was found to be the most cumbersome.

The amount of error embedded in the failure log file was the main culprit for why the interview cycle required the most iterations. The first of the errors found was in regards to the “Days Open” field shown in Figure 3-3. Originally, the time required to service a failure (a source of added cycle time) was thought to be the “Days Open” column in Figure 3-3, as this was assumed to encapsulate the time the failure was logged (“Date Created”) to the time the failure was done being serviced (“Date Completed”). After aggregating the data, it seemed as if the average service rate for failures was artificially high (more than a year for many parts). One of the reasons for this was that the calculation feeding the “Days Open” field was referencing dates in a file that weren’t relevant to time the failure was first logged (not shown here). The dates referenced were much further in the past, artificially inflating the “Days Open” field and misleading interpretation of when failures occurred on the floor. After this issue was remedied, the next iteration of analysis showed the service rate for failures was still unnaturally high.

Combing through the updated data revealed that the calculation for “Days Open” was not consistent across all rows. While the majority of the calculations were performed correctly, an unknown error caused erroneous calculations to result as shown in Figure 3-3. For example, while the “Days Open” number is 632 it is easy to see that the difference between the dates created and completed are approximately one day. Again, this necessitated an update to be made to the raw data and another iteration of the interview cycle to be performed.

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<tr>
<td>2016-08-15 13:31:00</td>
<td>2016-08-17 11:58:16</td>
<td>632</td>
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Table 3-1: Calculation Error Regarding Time Required to Service Failures (all numbers are notional)

The miscalculation would not be the last of the errors associated with the “Days Open” field, and this field was only one of many that was prone to error with no simple fix that could be immediately applied. Another source of inaccuracy that prevented swift and precise analysis pertained to the “Failed Part Number” field (see
A critical piece of information required to allow proper forecasting of parts that may be needed to service failures is how often specific parts are failing. Aggregating the failure history data by part number and reviewing the results with major stakeholders in the area proved the information to not be in line with their experiential expectations of failure rates of some of the major components. Drilling down into these specific parts, the symptoms of a data entry issue was discovered. After cleaning up the keystroke errors associated with operators typing in the wrong “Failed Part Numbers,” the “Comments” section was read through manually to search for additional indicators that the “Failed Part Number” entry may not be the true part that failed (see Figure 3-4). This was found to be the case for a significant number of failure entries.

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<thead>
<tr>
<th>Program</th>
<th>Repair ID</th>
<th>Status</th>
<th>Mother Shop Number</th>
<th>Failed Part Number</th>
<th>Failed Part Description</th>
<th>Failed Part Qty</th>
<th>Date Created</th>
<th>Date Completed</th>
<th>Days Open</th>
<th>Comments</th>
<th>Disposition</th>
<th>Serial Number</th>
<th>Incident Number</th>
</tr>
</thead>
</table>

Table 3-2: Data Fields Available and Example of a Failure Log (all entries are notional)

The initial data analysis cycle showed that many higher level assemblies were failing at unnaturally high rates. Reading through the comments associated with these data entries, it was found that a lower-level part numbers were often mentioned as the actual part that failed. Repeating this process for a few hundred more failure entries, it was found that more than 30% of entries had some error associated with them, either regarding the part number or the “Disposition” (meaning what action was performed to remedy the issue). The significance of this issue required observation of the data entry process to try and determine the root cause of these errors.

3.3.2 Observational Data Collection

The initial inspection stage of the highest level assembly was chosen as the process to shadow as it had the most erroneous failure logs associated with it. This stage is the first place the system is inspected prior to entering the refurbishment process. Additionally, this is where the system starts to be broken down into the major sub-assemblies and usually a few minor issues (chipped paint, etc.) are logged for each, allowing insight into the methods of data entry.
Shadowing multiple operators, it was noted that work instructions regarding how to complete tasks were embedded in the process tracking system, resulting in minimal operator deviation from following prescribed steps. This included which tools to use for a given step, the manner in which to use them, and the specifics of what needed to be done to complete the task. The beginning and ending times of each step were recorded into the data management system as the operator advanced through the process. Observing the operator finding and logging failures, this was found to be an area with less explicit work instruction.

When a failure or non-conformance was found, a different program was opened where this information could be logged. The main difference between this failure tracking system and the process tracking system was that there were no work instructions built in to the failure tracking process. A window with various blank fields to be filled in was presented, with the only control being to check if the part number existed. Watching the operator enter the failure, the hypothesis that the sub-assembly part number was entered in the “Failed Part Number” field while the actual failed part was mentioned in the “Comments” section was confirmed to be one form of user entry error. In addition, when detailing the nature of the failure in the comments, an internal reference “code” was used instead of a part number (e.g. “A3 board” instead of “12345678-01”). When this high level of variation exists with respect to what an individual failure log may look like, attempting to construct an algorithm to analyze the data becomes just as much work as manually analyzing the 1,000’s of individual failure logs. The problem lies in the inconsistency with how data was entered. Sometimes part numbers are put in the comments, sometimes codes with respect to that sub-assembly were entered which represented a part (e.g. A3 board), but there are “A3 boards” for each sub-assembly making data aggregation more difficult. Possible solutions to these issues will be discussed in subsequent chapters.

3.4 Results

3.4.1 Inventory Management

After fixing many errors associated with the data entry and management methods and considering many others in the data analyzer, a final failure analysis script was generated and the inputs and general logic can be found in Figure 3-5.
Combining the bill of materials with the failure log data, results were generated as seen in Figure 3-6 (for security reasons, the part numbers were anonymized and the related numbers were randomly generated to serve as an example).

<table>
<thead>
<tr>
<th>Failed Part</th>
<th>Failure Count</th>
<th>Probability of Failure Based on Contract 1</th>
<th>Std Unit Cost</th>
<th>Lead Time/Unit (Cal-Days)</th>
<th>Projected Failures Count</th>
<th>Probability of Failure Based on First 14% of Contracted Units</th>
<th>Projected Failures for Remainder of Contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>81</td>
<td>70%</td>
<td>$ 0.01</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>56</td>
<td>24%</td>
<td>$ 7,487.29</td>
<td>368</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>47</td>
<td>32%</td>
<td>$ 165.68</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>43</td>
<td>37%</td>
<td>$ 45,095.04</td>
<td>113</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>19</td>
<td>34%</td>
<td>$ 84,386.39</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>32</td>
<td>28%</td>
<td>$ 0.01</td>
<td>134</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>29</td>
<td>25%</td>
<td>$ 0.01</td>
<td>149</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>27</td>
<td>23%</td>
<td>$ 0.01</td>
<td>149</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>21</td>
<td>18%</td>
<td>$ 9,715.23</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Contract 1 Failures**

Figure 3-4: Failure Analysis Results Example (all entries are notional)

This analysis was meant to show the failure rates of all parts of the system based on the completion of “Contract 1.” Given these failure rates being based on a large sample size, a sample of a contract currently under way would be used to compare failure rates. This comparison would be used to predict the estimated number of
failures that would occur throughout the remainder of the current contract. For example, if the failure rates were similar as shown by “Failed Parts” ‘B’ and ‘D’, it could be deduced that these parts may have a common failure rate regardless of client handling and environmental factors and inventory levels could be set based on this number. Alternatively, it may be deduced that for parts with extremely different failure rates like ‘G’ and ‘I’, client handling and environmental factors may have more to do with these parts failing, and larger sample sizes of new contracts must be analyzed prior to setting inventory levels for the remainder of the contract.

Given the level of error discussed in the previous section, this is where the failure analysis stopped. But, if the accuracy were to be improved, the next steps in mind were to analyze the “Disposition” of each failure to break out how many of these failures (1) were able to continue using parts in their current condition (2) required parts to be reworked or (3) required replacement parts.  

As mentioned in the previous chapter, in order to complete the inventory management analysis the plan was to compare the dates of these failures with historical inventory levels. Doing so would generate insight into whether or not stock outs of the failed part and the need to wait for the part to be made/ordered was what contributed to the increasing refurbishment cycle time. However, the disaggregated inventory histories (donors in an Excel spreadsheet, common parts in a centralized database) paired with mismanagement of the donor inventory spreadsheet prevented this stage of analysis from being completed. While the centralized inventory management system was accurate and easy to interface with, the donor parts spreadsheet was not regularly updated or detailed in a sufficient manner. Given that the donor inventory was the main source of parts to service failures, the lack of clarity regarding the status of available parts and dates of when parts were pulled from donors precluded the ability to integrate the two inventory systems and generate an accurate inventory history.

3.4.2 Process Evaluation and Improvement

In an effort to prevent falling prey to the prescribed solution that inventory mismanagement was the main culprit of increasing cycle time, the steps of the refurbishment process were also investigated. Through shadowing multiple operators completing a wide range of tasks, it was observed that every time an operation was performed an operator couldn’t move on until they logged the progress into the system. Pairing these observations with information gleaned from interviewing the person in
charge of managing the data resulting from these operations provided a high level of confidence around the accuracy of the data (specifically the data regarding how many times the action was performed).

After aggregating all of the information pertaining to the operations performed for the entirety of one contract, a script analyzing operations and their cycle times was generated and the general logic can be found in Figure 3-7. Note that when “actions” are mentioned in the figure, these refer to steps performed within an operation such as “start,” “complete,” and “log failure” amongst others.

![Logic Diagram](image)

Figure 3-5: Operations Cycle Time Code General Logic

Utilizing the aforementioned logic, the outputs that resulted include (1) the cycle times of each step of an operation and (2) where and how often failures occur and their impact on the total operation’s cycle time. A case study with respect to a single sub-assembly was generated and a portion of the output can be found in Figure 3-8 (for security reasons the steps were anonymized).
Figure 3-6: Occurrence of Failed Operations with Respect to One Sub-Assembly (all entries are notional)

Figure 3-6 details how often failures occur (FOP_count) at a particular operation (or step) with respect to one particular sub-assembly. Note that the “FOP_count” values have been altered for security reasons, but the “FOP as % of Total Count” percentages are representative of the true process. The refurbishment process for this sub-assembly is 69 steps, of which the final 10 can be found on the left side of the image and the first 10 on the right. Aside from step 650, each step in which either failures occurred or were found greater than 20% of the time was an inspection step. Additionally, over 25% of failures logged for this sub-assembly occurred in the last 10 steps. Understanding this is critical, as many of the issues found in these late-stage steps require the part to repeat any number of steps, often including retesting which are time consuming operations with high capacity utilizations.

In addition to the results shown above, of the total time spent performing a given operation over the entirety of the contract, the percentage of that time that was attributable to servicing failures can be found in Figure 3-7.
Figure 3-7: Percentage of Total, Cumulative Cycle Time Attributable to Failures (all entries are notional)

Figure 3-7 details the top 10 operations attributing the highest percentage of their cumulative cycle time to failures on the left, and the bottom 10 on the right. This figure reiterates that not only are most failures found late in the process, but finding them this late also requires the greatest amount of time to remedy. Recommended solutions to this issue will be presented in chapter five.
4 Connector Blind Mating Process Redesign

This section details the research performed regarding how to reduce the failures associated with one particular connector mating process. The approach to this portion of the project follows the process detailed at the beginning of Chapter 3. Recall that the root cause of the connectors being damaged was initially hypothesized to stem from the fact that the operation was performed “blind,” meaning that one connector was completely obscured from view. This hypothesis served as the launching point to the process improvement learning cycle.

4.1 Literature Review

4.1.2 Current State of DFMA

Long life products typically have contracts expected to last for multiple decades. The designs of these products go through many meticulous review and approval stages which are extremely costly and can take years to complete. For these reasons (amongst others), robust designs tend to be fixed for many years until a large batch of new designs are ready to be tested together. If the entire life of the design isn’t properly considered, an organization is at risk of locking in a design that may be extremely costly to manufacture or assemble into the final product. This type of environment provides for extreme value to be derived from the use of design for manufacturing and assembly (DFMA).

“DFMA is a process where a cross-functional team concurrently and proactively evaluates a design early in the development process. As a result, attention is given to the manufacturing process associated with a design, and potential manufacturing problems can be averted, thereby reducing manufacturing costs. It also promotes team buy-in and increases organizational ownership. The benefits include a simplified design with reduced cycle times and engineering changes, resulting in a reduced life cycle cost with improved quality” [3]. For each of these reasons, DFMA is central to the design process for all large industrial companies including Company X. These practices guided the analysis and design recommendations discussed in the following sections.
4.2 Cycles of Data Collection and Analysis

The data collection and analysis portion of the connector project was quite similar to that of the refurbishment value stream optimization project, and thus the general approach to collecting and analyzing information pertaining to the project goals was extremely similar. The main difference between the two approaches is that this project focused on the redesign of processes and mechanical components rather than the development of a model (see Figure 4-1 for detailed data collection and analysis cycle).

Figure 4-1: Connector Failure Data Collection and Design Cycle
4.2.1 Historical Data Collection and Analysis

To initiate the data collection cycle pertaining to the connector project, the types of information desired were first determined through interviewing a Senior Principal Mechanical Engineer within the system group (refer to Figure 4-1 for the remainder of this section). Similar to the approach taken for the inventory optimization project, we agreed that an understanding of the historical failure modes of the connector would help guide the root cause analysis.

Due to the fact that the interest regarding the connector was with respect to all types of failures not just those occurring during the refurbishment process, the search for failure logs needed to be broadened. In interviewing the Section Manager of System Test Engineering, it was discovered that a dashboard was created with the purpose of consolidating exactly this type of information. Taking a cursory look at the fields of data available in this dashboard, it was clear that this data also did not have strict controls on input methods or guidelines on how to report which part number failed. In addition, the combination of the manner by which data could be pulled from the dashboard and the fact that shorthand notations were often used instead of the appropriate part number prevented precise searches from being performed. Thus, in order to try and capture all of the connector failures of interest with respect to the entirety of the previous contract (four years of data), 10 unique search queries needed to be ran. In addition, the dashboard would become overloaded if a query was ran for a period of data greater than six months. The combination of these two issues resulted in 80 manual search queries performed within the dashboard instead of possibly one or two Structured Query Language (SQL) searches. The difficulty associated with finding, obtaining, and cleaning data was a recurring theme throughout both projects and will be discussed in greater detail in Chapter 5.

Aggregating the data from the 80 queries resulted in over 3700 failures. Analyzing this data further proved the total number of unique failure reports of interest to only be 111 (some reports mention more than one mode of failure). Again, the lack of controls being placed on the data input methods resulted in too many unique cases to automate this process with a script and thus needed to be done manually. Having cleaned the data, three failure modes emerged: pin or socket damage, connector damage, or a loose connection as seen in Table 4-1.
<table>
<thead>
<tr>
<th>Blind Mating Failures</th>
<th>Pin/Socket Damage</th>
<th>Connector Damage</th>
<th>Loose Connection</th>
<th>Estimated Rework Time Required Per Failure (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Level Assembly</td>
<td>14</td>
<td>19</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Mid-Level Assembly</td>
<td>25</td>
<td>10</td>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>High-Level Assembly</td>
<td>3</td>
<td>2</td>
<td>33</td>
<td>100</td>
</tr>
<tr>
<td>TOTALS</td>
<td>42</td>
<td>31</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1: Connector Failure Modes

Reviewing this data with the Senior Principal Mechanical Engineer, the focus of the ensuing observational data collection was placed on the “Mid-Level Assembly.” This was concluded to be the target area of where the most value could be added, since the loose connections found at the “High-Level Assembly” most likely resulted from a poor connection being made during a “Mid-Level Assembly” process, and a significant number of the “Low-Level Assembly” failures were found as received from the client.

4.2.2 Observational Data Collection

Being that the comments in the failure reports are “matter of factual” and do not comment as to the potential cause of the failure, interviews and observational data were needed to supplement the reports. With respect to the “Mid-Level Assembly,” there was only one operation in which the operators handled the connectors, which for ease of reference we will call “Step B.” Four operators who were responsible for Step B were interviewed and then shadowed as they performed the operation, as well as those leading up to and following Step B.

From the interviews, a few key insights were gained. One such insight was that the torque tool required to fasten one connector to the other was much too long, making it difficult for the operators to fasten the connectors together. Observing the process, this claim was confirmed as the length of the torque tool and the constrained environment prevent the possibility of torque being applied collinearly (Figure 4-2).
This inability to apply torque collinearly also allows for an axial force to be placed on the connector, which can cause the connector to deflect with respect to the vertical axis and in turn bend the pins. In addition, the handle of the torque tool was in the vicinity of a circuit board, and often impacted the board since the angle of torque application made it difficult for the operator to keep the tool steady. The combination of these issues made the torque tool a target for potential design change.

To cross-analyze if the work instructions for Step B were (1) being followed and (2) were designed to prevent connector failures, they were studied in depth prior to shadowing the process. While almost all steps were precisely followed, it was observed that the majority of the operators skipped cleaning the connectors with spray Nitrogen prior to mating them. The purpose of this step was to remove any debris or dust that may have collected on the pins or sockets to allow for a smooth engagement. Omitting this step could possibly allow residue or dust to collect on the connectors which may increase the difficulty of seating the connectors or increase resistance when placing the pins in the sockets.

The other key insight gained from the interviews was that the process of aligning the free-floating connector with the fixed connector was extremely difficult given the blind nature of the action. Figure 4-3 details the current condition of the blind mating visual constraints. The image to the right shows the best visual the operator can obtain due to angle of access limitations created by the surface covered in electronics shown in the left image of Figure 4-2. In addition, this rightmost image provides a sense for the existing space constraints which will become more relevant when the designs are discussed in the following section.
Figure 4-3: Connector Blind Mating Visibility

The leftmost image of Figure 4-3 presents a rendition of the local environment, the teal object representing the free-floating connector and the red object representing the fixed connector. This view provides a better understanding of the physical constraints of the environment which will be revisited in the Designs and Result section.

The interviews were conducted before and while observing the operator perform Step B, which allowed visual confirmation of the connection issues that were mentioned prior to beginning the process. Figure 4-4 details the modes of misalignment that were mentioned in the interviews and gathered from observing the process.

Figure 4-4: Modes of Misalignment

In all images shown in Figure 4-4, the upper connector is the free-floating connector, and the lower is the fixed connector. The leftmost image of Figure 4-4 details how the two connectors can become misaligned with respect to the vertical plane. This type of misalignment was witnessed to cause cross-threading when fastening the two connectors together which, if not noticed, can give false positives that the torque limit was reached prior to fully engaging the connectors. This often allows the pins to
slightly engage with the sockets thus allowing a positive reading when running a continuity check, but when vibration and other tests are run later in the process, the true nature of the loose connection will surface. These loose connections are often quickly remedied, but the need to rerun the tests requires additional time which comes at the cost of increased labor and usage of test stations which are in high demand.

The rightmost image of Figure 4-4 shows how the two connectors can have a rotational misalignment with respect to the vertical axis. Often, this allows a false positive that both fasteners are aligned while in reality only one has engaged. What often ensues is the operator torqueing down one fastener which can result in some pins getting recessed by being forced into the connector surface, or possibly pushing the sockets in due to slight stacking of the pin and socket. Often this results in damaged pins, sockets, and connectors, and the full extent of the damage often does not present itself until it is tested at a higher level of assembly, resulting in costly teardown and loss of schedule.

Another potential point of connector failure occurs at the test stage of the High-Level Assembly. Although uncommon, if a specific set of failures occur requiring access to the cable for further testing, the connection must be disengaged and reengaged. This work is supposed to be performed by the operators who originally performed the mate, but is often performed by the testers. The testers making the connection has been known to result in the fastening being done in a non-optimal orientation and sometimes with a regular flathead instead of torque wrench. All of this can and has resulted in the over-torqueing of the fasteners, crushed pins and sockets, and damaged connectors.

The following section will discuss the mechanical and process designs developed to prevent all of the aforementioned modes of failure from occurring.

4.3 Designs and Results

4.3.1 Process Design Changes

Having found that the length of the torque tool was an issue, an investigation of how to reduce the tool’s length was carried out. This investigation consisted of determining if the tool was used at other steps, if the length was necessary, if it was easier and more cost efficient to reduce the length of the tool or the bit, and testing the proposed solution.

Each work area has a tool dispenser meant for use in the local vicinity. When speaking with the area managers and operators that had access to this tool dispenser associated with Step B, it was confirmed that the local operators were the only ones who would access this specific torque tool. In addition, since the tool was only used for
Step B there was no alternative use that required the tool to have its current length. This meant that reducing the length of the tool was an option that could be pursued without impacting other steps.

The lengths of both the tool and the bit used with the tool were analyzed to see which would be cheaper to change while not sacrificing any performance. Looking into possible areas of length reduction with respect to the tool, the manufacturer's schematic was obtained and a basic version of it can be found in Figure 4-5. Observing the diagram, it can be concluded that the cheapest possible option for reducing the length of the tool would be to minimize the length of the bit holder. The region circled in red is non-functional material as its only purpose is to transfer torque from the handle to the bit which is not a length dependent function. As this was a commercially available product provided by Sturtevant Richmont, a bit holder of a shorter length was sought out but none were found. This meant that either a custom tool would need to be made or a new vendor would need to be approved, both of which would be time consuming and expensive processes. For these reasons, reducing the tool length was concluded to be a non-viable option and reducing the bit length was subsequently investigated.

![Figure 4-5: Schematic of Torque Tool](image)

The bit that was being used with the torque tool required a delrin hood to be attached such that the bit didn’t come in contact with anything besides the head of the fastener (white piece towards the tip of the tool in Figure 4-2). Measuring the existing installed length of the bit from the leftmost end of the bit holder shown in Figure 4-5 to the end of the delrin hood resulted in a length of 0.723 inches. The bit itself was measured to be 1.9375 inches, and the shortest commercially available bit of the same type was found to be 1.00 inches. Given that the bits only cost approximately two dollars per unit on grainger.com, both a 1.00 and 1.50 inch bits were purchased and tested [5].
After fitting the new bits with delrin hoods, each was tested when performing Step B. While the 1.50 inch bit required less of a tilt of the tool to fit into the service region than the existing bit, the use of the 1.00 inch bit allowed for proper collinear application of torque as seen in Figure 4-6.

![Figure 4-6: Torque Tool Use with 1.00 Inch Bit](image)

In addition to allowing a properly aligned application of torque (the main objective of the redesign) and an increased clearance with respect to the electronics near the tool’s handle, the decreased tool length also allowed faster completion of Step B. The new length of the tool granted the operator a less constrained angle of approach as compared to when the tool was longer only one specific approach would allow tool engagement with the fastener. Also, the added clearance with respect to the electronics allowed the operator to turn the tool more quickly with a much lower likelihood of impacting the electronics. These two improvements reduced the torque application time from one minute to 20 seconds.

### 4.3.2 Mechanical Design Changes

To address the various modes of misalignment possible when mating the two connectors, two categories of mechanical design changes were investigated; increasing visibility of the fixed connector and creating an auto-alignment feature. Figure 4-3 has been copied here as Figure 4-7 for ease of reference.
Naturally, if lack of visibility is the main descriptor of a failing process it is logical to begin looking for solutions to improve visibility. Although not shown in the left image of Figure 4-7, there are two standoffs that attach to the bottom of the red connector making it stationary. One idea was to increase the length of these standoffs such that the surface of the fixed connector would be visible to the operator throughout the entirety of Step B. While this would have worked in theory, the implementation issues associated were two-fold:

1) Changing the standoffs out was not part of the refurbishment process and would require additional work/cost to replace old standoffs with the new design

2) The length of the standoff would need to almost double to make the fixed connector visible. Not only would this nearly double the weight of each standoff but it would also increase the risk of failing vibration tests, given the increased length of the cantilever structure

The combination of these two issues necessitated that other means of preventing these connector failures be looked into. An opportunity for developing an alignment aid was found when observing the profile of the strain-relief bracket that was attached to the free-floating connector (tan object in right image of Figure 4-7). It was found that although the bracket sat on top of the free floating connector the dimensions of the bracket were quite close to providing a slip fit with respect to the perimeter of the connector. It was then hypothesized that if the dimensions of the bracket were adjusted to provide a proper slip fit and the profile was extended down to allow engagement with the fixed connector, this could serve as an auto-alignment feature for the blind-mating process. The existing and proposed bracket designs can be found in Figure 4-8.
To introduce as little change as possible, the entire upper half of the bracket design was maintained. This prevented the need to reevaluate the functionality of the strain-relieving aspect of the bracket. In addition, given the extreme physical constraints of the environment, simply extending the profile downward posed little threat of interfering with nearby components.

After having the design approved by the Senior Principal Mechanical Engineer, a prototype was 3D printed as a plastic material to check fit and functionality. While fit was able to be confirmed, functionality could not due to the thin nature of the bracket allowing the plastic to flex while simulating Step B. This would not happen with the final material, and thus the next step was to machine the bracket out of the same material the existing bracket was made from and test its application.

After the bracket was machined, the operators tested it while performing Step B. As predicted, given that the new bracket had the same profile as the existing bracket, the connector and new bracket design were able to fit within the existing environment. The operators who tested the redesigned bracket each commented that it was much easier and faster to install than the existing bracket. They also commented that the increased ease and speed of installation were due to how much quicker the two connectors properly aligned and allowed them begin the torquing process.

However, given the variability around the tolerance of where the adjacent blue component can be installed, there was a minimal amount of interference on the bottom left corner of the bracket. A small cutout was made to the bracket at this location and
although there was no time to test it prior to the project’s closure, the project and design was handed off to the Senior Principal Mechanical Engineer who expects the final design to succeed.
5 Recommendations and Conclusions

The original overarching goal of this project was to reduce the cycle time and costs associated with refurbishing the system at one of Company X’s United States facilities. Specifically, optimizing inventory management practices to prevent the possibility of waiting for parts to be ordered or made from affecting the production schedule, and reducing the rate of failure associated with the blind mating of two specific connectors were investigated. While investigating the inventory management characteristics, an evaluation of the entire refurbishment process was performed as well. Regarding the blind mating of the connectors, both the mechanical design of components involved in the process as well as the process itself were analyzed to assess areas of improvement. The findings of each of these studies and associated recommendations can be found in the following sections.

5.1 Inventory Management

One result of this project was that a framework by which to analyze the impact of part stock outs on cycle time was developed. The inputs required for this analyzer to generate precise recommendations are accurate failure rates of parts and inventory histories. While the model is complete and functional, the freedom of choice regarding data input methods severely reduces the quality of the data being analyzed and thus prevents valuable insights from being generated. In addition, this model can be applied across business units and updated by changing file input names and other basic inputs, but the same inaccuracy issues will result unless the quality of the failure data being recorded is improved.

With respect to the failure log data, the two main issues that must be corrected are inaccurate “Failed Part Number” and “Disposition” entries. Although the part numbers are checked against the bill of materials to make sure the part number exists, error is introduced when operators enter the major sub-assembly part number instead of the lower-level assembly or component which actually failed. This can be rectified using a combination of approaches. One would be to inform the operators of the importance that the actual failing component needs to be recorded, not just the sub-assembly part number. In addition, since part of the failure reporting process is for the manufacturing or test engineers to review the report, an added layer of defense against
inaccurate reporting would be for them to validate that both the appropriate part number and disposition (scrap and replace, rework, use as is) are recorded.

The second action that must be taken in order to improve the accuracy of the inventory management analyzer is to consolidate the common and donor part inventories. While the common parts are stored and monitored in a centralized database, the donor parts provided by the client to assist in the refurbishment of their product are stored separately and managed in an Excel spreadsheet. While it wouldn’t make sense to physically store the client-owned donor parts with the common parts, including them in the same centralized database could help improve part tracking and availability. In addition, a field could be added to signify if the parts are for common use or owned by a specific client to prevent false positives from occurring (i.e. believing there is sufficient inventory but most of it is only useable by one client).

Taking both of these actions would allow all business units participating to compare their part failure histories to the inventory history levels of the same part. Doing so will grant insight into if altering stocking strategies could reduce cycle time.

### 5.2 Refurbishment Process

Another result of the project was an analysis of the entire refurbishment process, totaling over 1100 operations and comprising all 20+ sub-assemblies. This analysis included quantifying how many times each operation was performed, at which steps failures occurred or were noticed most, and how much time was required to complete each operation and service each failure. The service times calculated detailed how much time was required to take a part from arriving at an operation to delivering the part to the next operation (not touch time). This analysis was meant to serve as a diagnostic to point to operations that may be taking longer than usual or have high rates of failures being found or occurring.

The utility of this analysis is extremely wide ranging. One example of use would be how a majority of failures occur or are found at the later inspection steps of many sub-assemblies. This could indicate that either the earlier inspection stages weren’t thorough enough and failures weren’t noticed, or it point to the fact that failures are occurring throughout the main body of operations and that moving one of these late-stage inspections up in the process a few steps could save significant rework time. Whatever the root cause may be, the analysis details operations that may be cause for concern, allowing more precise follow-on analysis to be performed.
In addition, this analysis was performed and tracked in a way that can be transferred to other business units. The scripts used have been meticulously commented, detailing where file inputs should be adjusted to allow ease of reusing the tool. The operations cycle time analysis can be further updated to calculate the exact time spent “hands-on” on each operation. As of now, it simply shows how long it took from initially starting the task until the task was completed. Knowing hands-on time will allow cost analysis to be performed to place value on how much each step is currently costing.

5.3 Connector Mating Process

With respect to reducing the failures associated with the blind-mating of two connectors, a few process change improvements were uncovered. One such change recommendation is that the operators start using the 1.00 inch bit with the torque tool instead of the current 1.9375 inch bit. Reducing the bit length allows the operator properly apply torque, collinearly aligning the tool with the fastener. This improved alignment of the tool remedies the issue of applying an axial load to the fastener which has allowed the possibility of this force to translate to pins that are engaged in the fixed-connector’s sockets, resulting in the possible bending of the pins. In addition, the shorter bits grant the operator additional clearance near the handle, which previously came in contact with nearby electronics and caused additional damage. It is recommended that these shorter bits are exclusively used with the torque tool for Step B, and that all of the longer bits are removed from the area to prevent their accidental use.

Two process deviations observed were the lack of use of Nitrogen spray to clean the pins and sockets during Step B, and the wrong personnel using inappropriate tooling to perform the connection at a test step following Step B. Both of these issues could be mitigated by implementing a periodic retraining of how to perform Step B and the test step. Having the relevant cell lead shadow the training would improve accountability by all parties involved, incentivizing the operators to perform each step appropriately and refreshing a sense of quality management in the cell lead.
5.4 Strain-Relief Bracket Redesign

Regarding the mechanical designs impacting the blind-mating of the connectors, the project produced one viable recommendation. The existing strain-relief bracket attached to the free-floating connector is replaced when refurbishing the majority of systems. In addition, its existing profile fits within the tight constraints of the mating region and was close to providing a slip-fit with respect to the perimeter of the connector. The bracket was redesigned to serve as an auto-alignment feature, helping the free-floating connector “find” the fixed connector that is hidden from view.

It is recommended that Company X continue to evaluate the redesigned bracket to ensure its compatibility with flight conditions prior to deploying the bracket. Since a flight test is required, including the redesigned bracket on an upcoming flight test is recommended to mitigate the costs associated with having a flight test just to prove out the bracket’s functionality.

5.5 Closing Remarks

Follow-on projects between Company X and other Leaders for Global Operations (LGO) Fellows could present tremendous value for Company X. Whether it is using the refurbishment process diagnostic tool to optimize Company X’s inspection practices, or working with the Modernization and Innovation Group to improve data input accuracy, there remains much room for improvement. I believe that Company X has the talent and support necessary to drive these changes, and leveraging the skills and added bandwidth an LGO Fellow brings can help Company X see these projects through to fruition.

To all of the people who supported my work, shared their insights with me, and helped me bring as much value as I could to Company X, thank you. Company X was a tremendous host, and I am extremely grateful for the experience I was provided.
6 References


