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HPT Blades Rework Improvement Design and Implementation At GE Aircraft Engines

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By

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Abstract

This project focused on improving the rework cycle at Glades Park, General Electric Services Cincinnati Shop in Hamilton, Ohio. Analyses of rework cycles through routers, the master menu system and shop floor operators prompted investigation of three main problem areas: turn-around-time (TAT), margin degradation and balancing yield. This lead to improvements in two areas; TAT was reduced by removing unnecessary steps within rework processes and margin degradation was addressed by developing guidelines that advise management when to investigate straggling blades.

Acknowledgements

This project would not have been possible without the help from the staff of WPI, GE and Glades Park. First of all we would like to thank our advisor, Dr. Sharon Johnson, for all of her guidance throughout the project. The project would not have been possible without her.

I would also like to thank the plant managers at Glades Park, who helped everyday with leadership and moving the project forward. The production engineers were all greatly appreciated for their support and assistance throughout. We would also like to recognize the rest of the staff at Glades Park and all of the operators for their input, help and kindness.

We would finally like to recognize GE Aviation management for giving us this experience.

Authorship

The work completed in this project was a combined of effort of Kristine Mischler and Erin Yokay. They both contributed equally to the paper and the project. Some areas of the project were broken down to utilize time most efficiently. This also helped to use both of the team member's skills to the fullest potential.

Kristine Mischler contributed as the data collector and organizer. In counter, Erin put the data together to be analyzed in graphs. After the initial data collection stage, the project was focused on two distinct directions; loops of high frequency with low TAT and loops of low frequency and high TAT. The high frequency loops dealt with a specific operation, Op 400, which Kristine had experience with during the summer portion of her GE stay. She began to concentrate on this project looking into possible solutions, collecting more specific data and eventually changed the planning for implementation.

Erin mainly focused on the low frequency loops, which was more of a financial project as opposed to process issue. She worked on the cost analysis and created the guidelines for making financial decisions. Although they both had focused areas, there was a great deal of collaboration and discussion on the projects. There were always efforts made to agree on final outcomes. The paper and presentation was a joint effort. They both worked on the sections that were in their expertise, which turned into a cohesive end product.

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1 Introduction

General Electric Aircraft Engines is headquartered in Cincinnati Ohio. Besides being one of the world leaders in producing jet engines, GE also services and repairs engine components in several facilities, one of which is the Aircraft Component Service Center (ACSC) in Cincinnati. This division is located in four separate buildings: Symmes Road, Container Place 1, Container Place 2, and Glades Park. ACSC exists to make engine up-keep economically viable. Considering that planes are out of commission when components are sent to ACSC, their main goals are quality, turn-around-time (TAT), and yield.

The Glades Park building services high-pressure turbine (HPT) blades. There are 80 HPT blades in the typical engine sent in by the customer to ACSC. These blades are then received at the service facility, inspected and the repair process is chosen for each of the 80 blades in the batch. The same blades are then sent back to the customer in the lot of 80.

For this procedure, ACSC has set a target TAT of 18 days based on current customer expectations. A blade going through the repair process can encounter problems and then need to be reworked. When rework occurs, the blade has to be sent back through the process and is considered rework until it gets back into the original repair process steps. Rework is a major contributor to extra time in the process.

The goal of this project was to examine the rework process, and through data collection and analysis determine what rework is and solutions to cut down the rework cycle time. Based on current pricing and customer TAT expectations we also looked at developing a system of guidelines to decide when it is no longer economically viable to continue rework of a blade and to then evaluate based on economic considerations.

The issue of rework has been tackled several times before, but there is still need for improvement. The addition of hot tags to the blade routers was an effort at visual management that flagged rework blades. Visually pointing out which blades were rework made it easier for the operators to see the rework blades, which are supposed to be worked before any of the other blades. Although hot tags are in use, they are not consistently used. Changes were also made to the dispositioner position. All blades are sent to the dispositioner who decides, based on what kind of blade it is, what repair process it is going through and what defect the blade has, which steps the blade has to go through to get reworked. There was an attempt to eliminate the dispositioner position and have every blade dispoed by the operator who found the defect. This was found to be infeasible based on the training that would be required. One improvement to the dispositioner position was the creation of stamps for common rework loops so they did not have to be written down. The stamp is not the ultimate solution but has helped improve the situation. Glades even tried assigning all rework to just a few people, making them responsible for all of the steps. This worked for process time, but pulled needed operators from regular services and created downtime for operators when their machines were being used for rework.

Keeping in mind past efforts and using new ideas to reduce the TAT for rework was the ultimate goal of this project. We used the six sigma DMAIC (Define, Measure, Analyze, Improve and Control) process to guide us through both the project and to write the paper as defined in Chapter 3. The define stage was given to us through the GE problem statement and was refined as we went through the background, which is described in Chapter 2. The measure stage occurred during the methodology section where data was collected and organized. We collected data from routers, operators, and archived data and organized it into charts and graphs that focused on frequency in order to pinpoint the problem areas. We then collected more data in these areas that led us to solutions. Gathering data provided the needed information to analyze the situation. The analysis stage involved making decisions to improve the process and is described in Chapter 4. The conclusions from the data analysis gave us the substance we need to implement our ideas. This became the improve stage of the DMAIC process and the conclusions section of our paper. The final step was control. We made recommendations so the shop would continue the improvements that were made, as described in chapter 5.

2 Background

This chapter provides a background about GE: the type of business GE is, their role in the aviation business and the role that Glades Park plays within the business. This section also discusses what Glades Park does and how they do it and the problems they are facing. Finally this chapter explores what rework is and the six sigma techniques to improve it.

2.1 GE

General Electric is a business built on the thought of possibilities. GE is broken down into six businesses, which in turn are broken down into several units that leave ample opportunity to "continually innovate, invent and reinvent." (Company Fact Sheet, 2007) The six businesses include: GE Commercial Finance and GE Money (business and consumer finances), GE Healthcare (design and manufacture medical imaging products and clinical systems), GE Industrial (design and manufacture security technology and other industrial products), GE Infrastructure (includes Aviation, Energy, Oil & Gas), and finally the newest business, NBC Universal.

GE employs over 300,000 employees working in over 100 countries. This vast work arena allows for an investment in growth that creates opportunities that many other businesses do not have. This includes, for example in 2006, investing $15 billion in the intellectual foundation, $5.7 billion invested in research and development and $500 million invested in the four global research centers. (Company Fact Sheet, 2007)

2.2 GE – Aviation & ACSC

GE-Aviation is a unit of the GE Infrastructure business that is the world's leading producer of large and small jet engines for commercial and military aircraft. It operates in more than 40 locations worldwide producing 37 different types of engines. GE-Aviation not only assembles engines, but also services and repairs them as well. The service and repair division falls under GE Engine Services (GEES). GEES performs operations such as manufacturing, over haul, on wing support and component repair. In Cincinnati, the Aircraft Component Service Center (ACSC) department has been in business since 1951 and is comprised of four engine repair shop locations that specialize in servicing separate parts of the engine. Symmes Road shop works on static airfoil repairs. Container Place I (CPL I) repair cases and frames, including work on all engine repairs. Container Place II (CPLII) acts as the Cincinnati Service Shops central location, housing management offices and exists as a main shipping dock. Glades Road, which is the location for the MQP, services high-pressure turbine blades.

2.3 Glades Park

Glades Park services high-pressure turbine blades (HPTB). The shop currently operates 24 hours a day (per weekday) with three 8-hour shifts. This specific location employs 92 operators with the majority working during the 1st shift. The daily total output averages around 150 blades. This number is affected by the high degree of variability pertaining to the number of incoming blades per day. A batch of blades enters the service process in groups of 80. These blades have been removed from the customers' engine to be serviced for both FAA regulation requirements and to keep upkeep cost low (buying new blades is almost 7 times more expensive than servicing the used blades). Glades Park brings the blades up to FAA standards or makes the decision to return non-serviceable blades

Figure 1: Blade

2.3.1 Service Shops

Glades Park, as a service shop, is a key player in the aviation industry. Service shops give companies an opportunity to overhaul their engines, increasing the lifetime of the individual parts. Particularly for blades, servicing is one seventh of the cost of a new blade. A services blade can be described as "good as new" after what can be an extensive repair process. The blades are removed from the engine, sent to a shop, such as Glades, and refurbished to the same standards as when the blades were first made.

GE and other companies are making efforts to design engines with repairability in mind, knowing the effect it has on life-cycle costs (Gamauf, 3). Since the aircraft industry has changed so rapidly in the last 5 years, new planes have fewer mechanical instruments, thus needing less maintenance (MacDonnell, 140). This has caused the maintenance, repair, and overhaul industry value to drop from US$34bn in 2001 to US$34.6bn in 2003 (Back Aviation, 2003). Although the value may be decreasing due to better technology, the need is still very much prevalent and will continue to be for the foreseeable future.

There are several options for customers when it comes to service shops; some customers even have service shops within their own company, but still look to outside options. This makes the market very competitive and affects costs greatly. Glades currently charges a flat price for each service, and if the blades are particularly bad, and require extra repair, Glades gets blamed. Another major factor in the servicing industry is turn around time. There is a great deal of pressure to deliver the blades as fast as possible, with an average of 30 days takt time. This puts an extra daily pressure of expediting blades, and some overhaulers even swap components between orders to make this time (Gamauf, 4). Glades does offer this option, but knows which customers find rotables (floating blades) acceptable.

Expediting is a huge concern as well as yield. It is possible to return a blade based on customer input, condition of the blade if it is too far behind the rest of the lot to make the takt time. Customers are not generally accepting of this practice due to the high cost of buying a new replacement blade. Customers want both expediency and yield. With the current situation at Glades optimizing both factors is extremely challenging. Mostly there is a decision to choose between the two, and typically yield outweighs delivery time. This is not an easy decision, and when made, there are negative repercussions, and disappointed customers. When the customers have a delayed delivery window for this customer's blades to be serviced and received before Gate 3 is affected which pushed back the entire TAKT time for the engine overhaul.

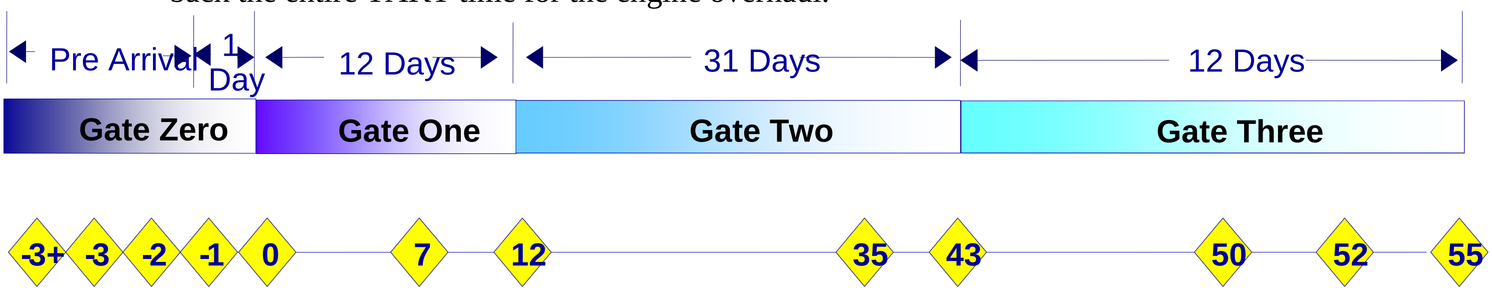

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Figure 2: Customer Timetable for Engine Overhaul

2.3.2 Blades in an engine

An engine is made up of three main components: the compressor, the combustion chamber and the turbines. The compressor is made up of a series of blades that draws in air and compresses it. The compressed air is then pushed rearward into the combustion chamber. In the combustor, fuel injectors mix jet fuel with air and it is ignited. The gas that exits the combustor exerts force against the turbine blades. This force spins the compressor connected to the turbine by a shaft that in turn pulls in more air. The turbine is made up of high-pressure turbines and low-pressure turbines. The blades that Glades Park services are part of the high-pressure turbine unit. (Engines 101, 2007)

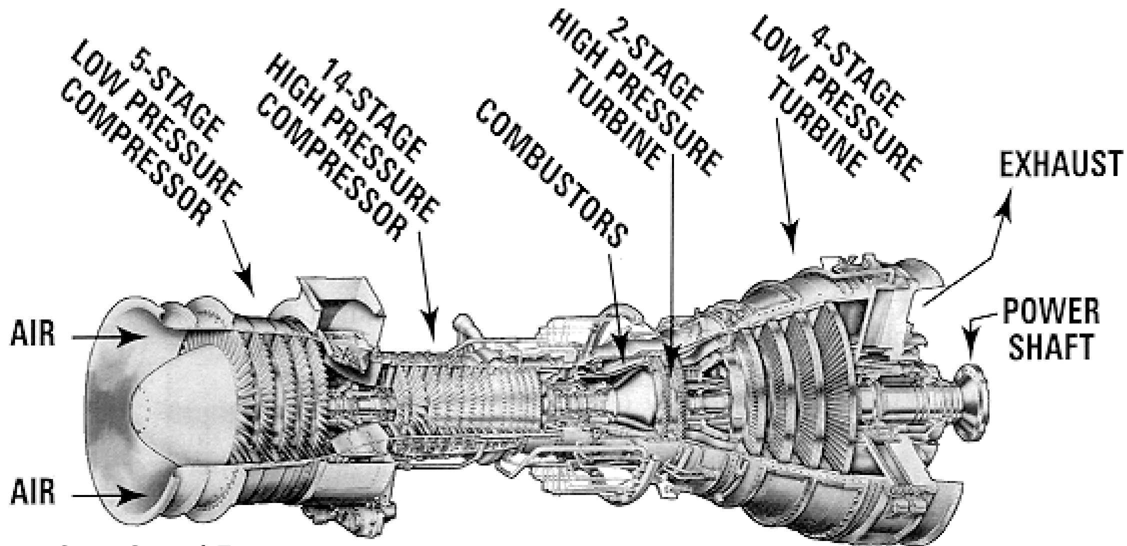

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Figure 3: Jet engine

2.3.3 Product Lines

Glades Park services four different engine models. The CF6 –6, CFM 56 –7/ 56 –5BP/ -7, LM 2500 and LM6000. Each engine model is assigned different routers which describes what path that particular blade will follow during servicing. The most popular product line, feeding almost 30% of the total input of blades, is CFM 56 –7/ 56 –5BP/ -7 blades.

2.3.4 Blade service process

There are over 100 operations that can potentially be performed throughout the blade service process. The services required by each product line requires vary, causing an inconsistency in production, but every product goes through eleven checkpoints and six gates, as shown in Figure 4. The 80 blades that come in as an engine set stay together within checkpoints unless a defect has occurred, in which case they get split up. The checkpoints are a way of dividing the operations into categories, while the gates are a way to group the checkpoints. Initially, the gates were supposed to act as “toll gates”, having each blade inspected and approved for the next gate. The gate system is still in use, but operators focus mainly on the checkpoints as their production guide.

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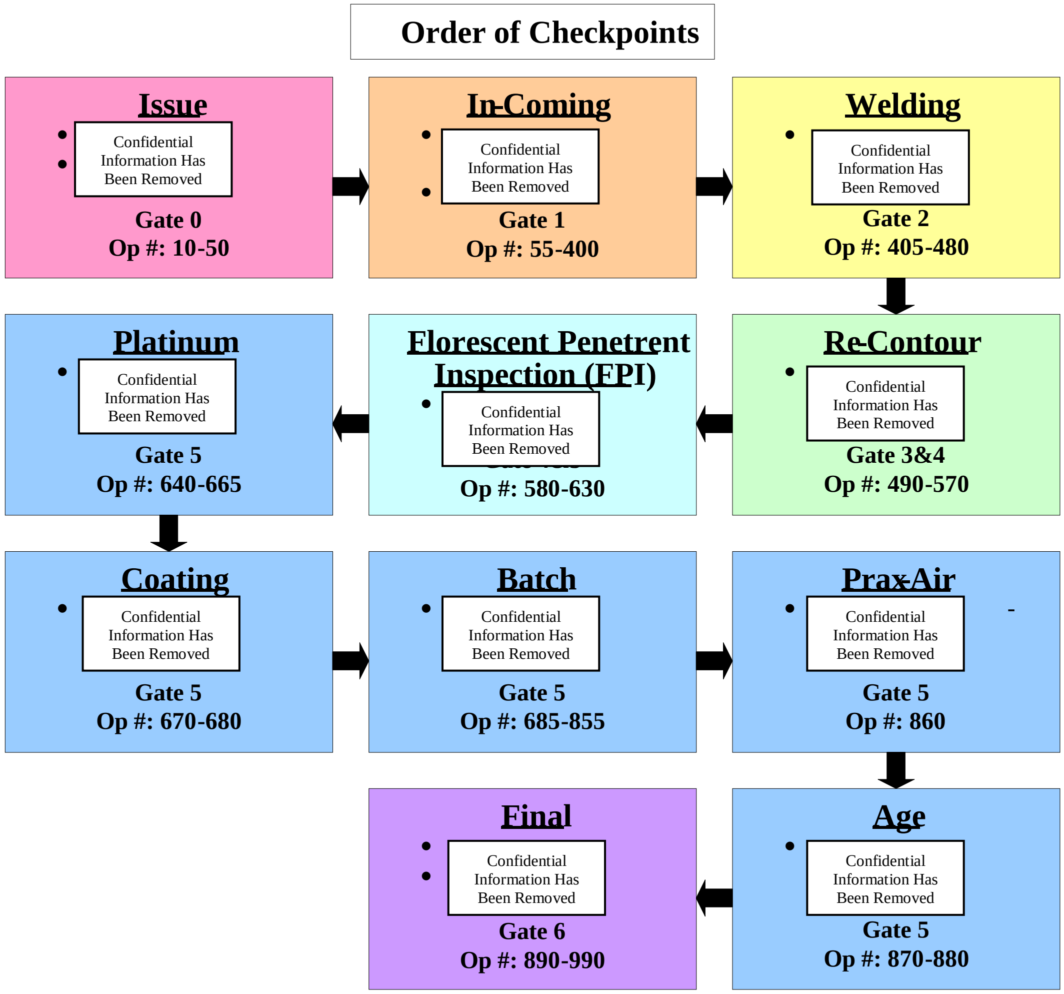

Figure 4: Checkpoint order

There are two routers assigned to each blade. The first router, known as the clean and inspect router, is shown in Table 1 and is for the beginning processes, followed by the second router assigned for the main processes. During issue, specifically at the operation called pre-review, the operator decides how the blade will be repaired and which route it must take to be repaired. This depends on the how the blade comes into the shop, the incoming condition, and what the customer wants done to it. Depending on the part number, there are two Full Repair paths the blades can take: with shank strip and without shank strip. The full repair process repairs the entire blade including removing the Thermal Barrier Coating (TBC) on the outside, welding and re-contouring a new tip, regenerating holes and putting a new TBC on the outside. The process with shank strip is used for earlier model blades that need the excess coating on the inside to be removed (shank strip). This repair process includes all of the processes that a particular blade can go through. If the blades do not need Full Repair, they undergo the Rejuvenation process, where separate routes again are established for the process with or without shank strip. This process does not take the TBC coating off of the airfoil initially but goes through the rest of the processes of welding, re-contouring and regenerating holes.

Another possible path is Tip Repair. This process is included in other services, but it can also be chosen as the sole repair. Tip Repair only removes coating from the tip and then welds and re-contours the tip. The last available path tests Serviceability limits by putting it through inspection processes to make sure it is serviceable. This is provided because certain customers can actually service their own blades, this test lets them know if the blades are worth treating. (Fryman, 2007)

Description (Engine Model)	**Clean & Inspect Router** (Initial Service Process)	**Router** (Service Process)
CF6-6	**Z171A**	**Z171**
CF6-6		**Z083**
CF6-6		**Z051**
CFM56-7	**Z772A**	**Z728**
CFM56-7		**Z772**
CFM56-5BP/-7	**Z843A**	**Z843**
CFM56-5BP/-7		**Z854**
LM2500	**Z448A**	**Z448**
LM2500		**Z497**
LM2500		**Z534**
LM2500	**Z588A**	**Z449**
LM2500		**Z450**
LM2500		**Z588**
LM2500+	**Z448A**	**Z808**
LM2500+	**Z588A**	**Z806**
LM6000	**N/A**	**Z656**
LM6000		**Z654**
LM6000		**Z872**
LM6000		**Z435**

Table 1: Service Process Dependent on Engine Type

2.3.5 Rework loops

Rework is a common occurrence in the Glades Park shop. Typically in manufacturing there is a goal to eliminate rework, but because this is a service shop, some parts require extra processing and rework is inevitable. Typically rework stems from the incoming condition of the blade or problems encountered during servicing. When blades arrive in below average condition, it can take more than one time through a process to accomplish the necessary outcome. If the blade does not pass one of the inspection points during the process loop or an operator notices a flaw the blade will "fall out". This means the blade needs rework and that it has fallen out of the normal loop and will be sent to the dispositioner. The dispositioner determines which rework loop the blade needs to follow before it can return to its originally assigned loop. The most common loops are put on a sheet called a "TBR" so that blades that have specific, recurring defects follow the same loop every time. If the blade does not have a recurring defect, the dispositioner decides based on their knowledge of the blades and the process, which processes to put the blade back through. Some of the most common operations for blades to fall out at are operation 400, [redacted], operation 580, [redacted] and operation 625. The most common rework loops go back to the welding checkpoint where they then have to go through re-contour and FPI as well.

There are three issues that need attention for rework: TAT, margin degradation and balancing yield. The main issue though is the amount of time rework adds to the process. The blades come into the shop as batches and must leave as batches. With the system in place right now, if one blade from the batch needs rework, it could hold up the entire order from being shipped. When blades fall out of the process for rework it splits up the order so when some of the blades are ready to be shipped they have to wait for the rest of the blades to catch up. There have been batches that have actually stayed an excessive amount of time due to rework. This is dependent on how many blades fall out and how many times. Some blades could have multiple rework loops based on not being able to fix the defect the first time around or having multiple defects that occur. The length of the rework loop has many contributing factors. The blade could sit at a station for several days before being worked on. The established guideline for rework is that it should be processed before other blades at a station, but it is not always obvious that a rework blade is at a station. At one point an effort was made to put rework blades in red bags, as opposed to the normal clear bags, but the quality of the purchased bags were too poor. Another issue is that the blade could be grouped with other blades for batch processes. When a rework blade makes it to a batch process, it cannot be serviced alone, the operators wait until they have enough blades to fill the batch, which can add a lot of time. Sometimes a blade may even need several rework loops. As loops are added, costs also increase. At a certain point it is actually economically valuable to return the blade to the customer, as opposed to fixing it. As of right now, there are no guidelines set in place for when to return a blade. There are other factors that contribute to rework issues, but they can mostly fall under these three categories.

2.3.6 Consolidation of Glades Park to Symmes Road

The Glades Park operations are in the process of being moved to Symmes Road. The two shops are consolidating into one; this will cause the movement that the blades currently make between shops to change because of capacity issues. The following two figures show how the blades have to move within the process breaking it down into gates, locations they are at for that gate and checkpoint.

Figure 5 shows the movement while they are at Glades Park and Figure 6 shows when the entire shop moves to Symmes Road. With the move to Symmes Road, because of the capacity issues, the blades will be making two extra trips between shops.

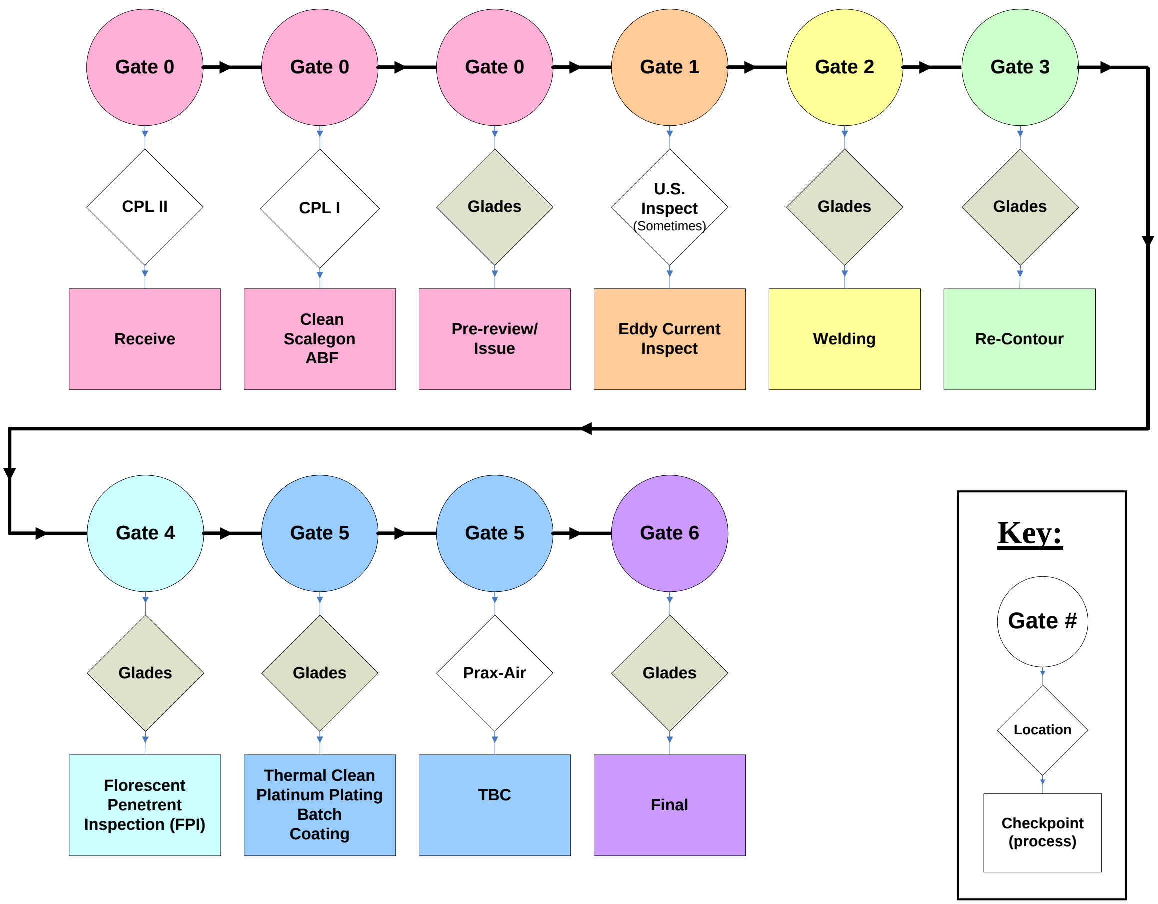

Figure 5: Blade Movement at Glades Park

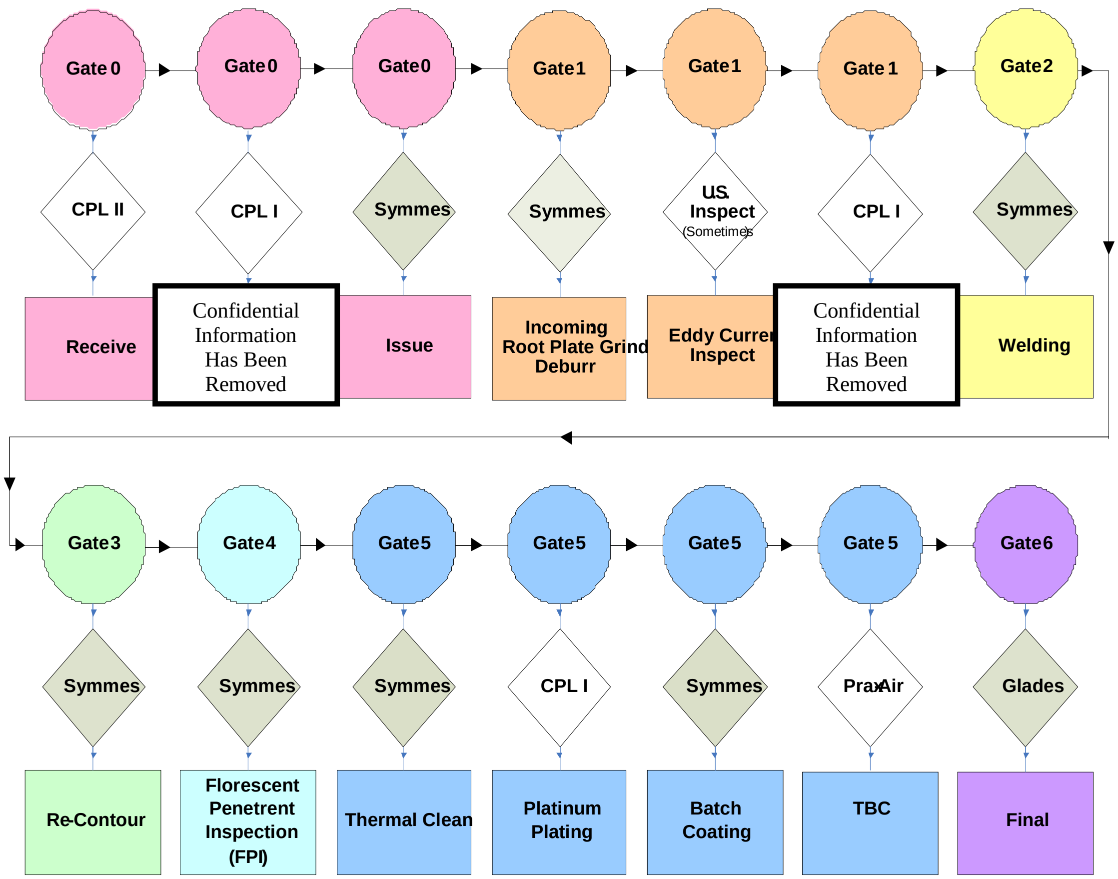

Figure 6: Blade Movement at Symmes Road

Along with changes in how the blades will move, many of the processes such as the furnace operations and inspection processes will be servicing both static airfoils and blades. This will cause both sets of employees to have to learn how to do the others shop's job. It also means as both people and machines are being moved out of Glades one by one, the parts have to move back and forth between the shops more than usual. This adds to turn-around-time (TAT) and is therefore putting a lot of pressure on the blades that have to go through rework, to get through their rework loop faster.

2.4 Literature Review

Six Sigma is a business strategy that focuses on using facts and data to make better decisions and solutions (Pande, 2001). There are several techniques within the broad scope of Six Sigma including DMAIC, and Lean; both process speed and quality and visual management (George, 2003). Our project focuses on rework loops in a service shop. To tackle this project we must look at existing techniques that have several direct applications to our situation. DMAIC is a methodology for problem solving that stands for define, measure, analyze, improve, and control. Following DMAIC will not only help tackle a difficult problem, it will make sure the improvements are optimal and ensure they will be adapted into the work culture (Pande, 2001). Lean is a new way of thinking in the workplace. It encourages creative thinking, waste reduction, and customer consideration (Kastle, 2004). Lean process improvement is the foundation for creating an optimal service shop. Visual management provides communication and efficiency. When several Six Sigma techniques come together they complement each other and lead to success.

2.4.1 Rework

Rework is “work done to correct defects” (Mills, 2007). This is traditionally applied to the initial production of a product. At a service shop rework accomplishes the same goal but is treated differently. Since a service shop involves repairing the product in the first place, rework is classified as a specific piece failing inspection after being serviced. To label a blade rework at Glades, the defect must be caused by a process in house not working correctly. If the blade fails an inspection because of a defect caused by outside variables then it is not labeled rework but is treated as rework. The differences are more relevant to financial interests.

2.4.2 DMAIC

The DMAIC methodology is perfect for problems that involve process improvement. The major steps in DMAIC are shown in Figure 7. There are other avenues to take when a process needs to be changed and rebuilt from scratch (George, 2004). The Glades Park rework project was an ideal DMAIC project. The project was complex and the solutions were not obvious at the initial define stage (George, 2004). Data collection lays the foundation for DMAIC projects. This falls within the measure stage. The analysis stage is where the project really takes shape. This stage begins to show where the key problem areas are located and what should be considered in the steps to come. The Improve stage is when implementations are made. To make sure these implementations stick, the control stage must be well thought out. A plan must be made to assign responsibility to employees for incorporating the improvements.

In DMAIC the critical Y and the critical X’s determine the problem, and what affects the problem. The critical Y is the dependent stated problem. The critical X’s are all of the variables that contribute to the Y. This can be related to a function, as in Y=f(X) (Six Sigma Dictionary).

For this project we began with a structured define stage. We establish our Y as improving rework process; this included reaching goal TAT of 18 days for each blade and increasing profit margin. Our X’s were then found to be the rework cycles’ TAT and the cost of performing each rework loop. As the rework TAT decreased, the total TAT decreased. As for the profit margin, by determining how much each loop cost, we could make guidelines for when to reconsider financial evaluation, thus protecting the profit margin. We then took our critical X’s and focused on how to turn them into applicable solutions leading to the improve stage (Nash, 2006). During control, although we will not be around to see all of the improvement carried out, we are assigning action items to appropriate employees to determine how the Y has been affected.

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Source: Nash, 121

Figure 7: DMAIC incorporating Crtical Y and X

2.4.3 Lean: Improvement in Services

When it comes to services as opposed to traditional manufacturing many of the same improvement techniques still apply. Lean manufacturing links speed, quality, and low cost; the same is true for Lean services (Kastle, 2004). Many of the Lean principles apply such as visual management, but there is a specific means of focusing the right techniques to tailor them specifically to services. Yang (2005) helps describes features between different types of service. Figure 8 describes four different types; for our case Pure Service Shop applies.

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Source: Nash, David pg. 121

Figure 8: Service Types

Yang (2005) points out that servicing is a process that needs to achieve optimal efficiency because there are fewer outside factors such as raw materials. The idea is to take an input, add value, and deliver to the customer. In Figure 9, the reduction of inputs to the final deliverable is visually represented. A main difference between focusing on Six Sigma for typical manufacturing and for servicing is that servicing focuses more on the process (George, 2003). Customers dealing with companies based around services see many steps that add no value. This segues into eliminating waste. At Glades, there are many steps that are “processing steps”. These simply decide what needs to happen to the blade or where it needs to go next. These steps are not physically providing an operation and thus adding no value. To completely eliminate these steps are almost impossible for the current situation for the shop, but there are opportunities to reduce these process steps.

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Figure 9: Process Inputs to Outputs

Source: Yang, Kai (G)

Not only are the individual processes important, particularly for a service shop, the process overview is essential. Service shops have so many variables when it comes to process loops. Glades has several product lines with specialized processes, and levels of servicing within that. Rework loops add another dimension to the process overview with over 30 possible loops. Keeping track of blades, especially rework blades, is of high importance due to delivery time. George (2003) explains that “the answer lies in one of the simplest but most powerful Six Sigma concepts: that the outcomes of any process are the result of what goes into that process”. This statement is pointing out that if the process overview needs improvement, we need to look at what affects the process. This includes individual operations, rework, incoming condition of blades, and the list goes on. Figure 9 again represents just how many variables affect the overall process. There are so many inputs affecting Glades process that to make any progress there must be specific focus for a Six Sigma project. Figure 10 shows our project drill down which was determined by management and shows the focus for our particular project and the other possible options. Drill downs are a great way to look at many of the variables affecting the larger problem to find a solvable aspect.

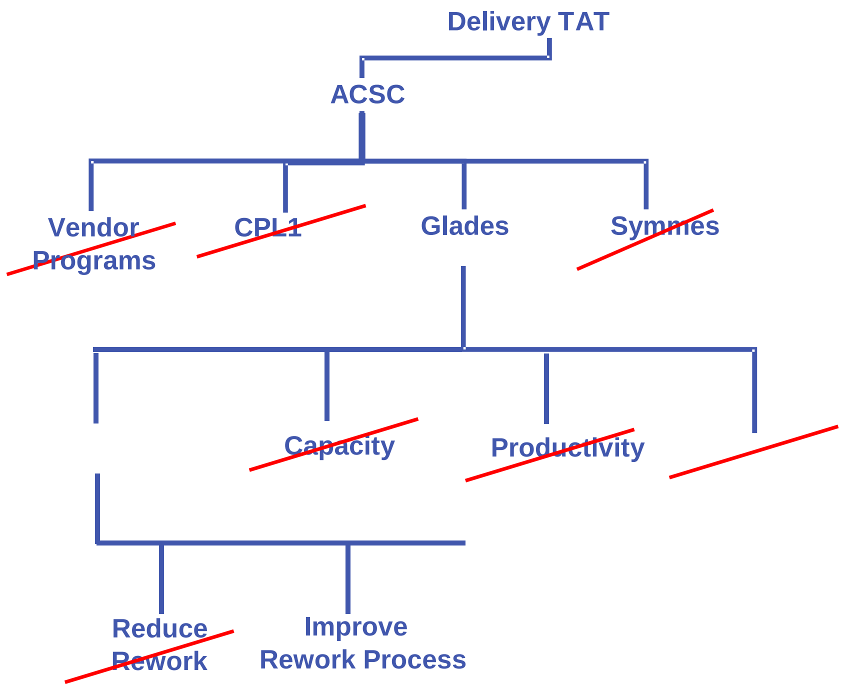

Figure 10: Rework Project Drill Down

The process output is the focus of the customer but as previously stated, the process itself is the focus of the service business. Yang (2007) describes process excellence as "A process that achieves maximum quality and efficiency and uses minimum cost to run". The Glades process would be broken down into 6 parts:

1. Blade Arrival
2. Pre-Review
3. Servicing Blades
4. Rework Necessary Blades
5. Customer Waiting Time
6. Delivery

For our particular project we are focusing on parts 3 and 4. These 6 parts are very similar to the gate system (Figure 11). Parts 3 and 4 correlate directly to Gates 1-5, the service gates. Resource Utilization is a major issue for particular aspects of the blades process. At the dispositioner's station the resource utilization for their time has much room for improvement (Yang, 2007). This does not mean the dispositioners are not busy, but a large percentage of their time is spent doing work that is not specialized to their position. If they only had to dispo blades that needed special rework their time would be optimized. Bottlenecks are also a concern. Typically bottlenecks are referenced for a backup at a particular station but as Figure 11 shows, there can also be a bottleneck in a group. When a set of blades are being held up by straggling blades from that same set because of a rework loop, this causes a bottleneck within the set. The blades may not be stuck at a particular operation, but if the rework loop is too slow the other blades will have to wait for just a few blades so the set can be delivered all together.

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Figure 11: The Slowest Member of the Team Sets the Pace Source: Yang, Kai

Having the blades go through a process in a batch with only a few operations being actual batch operations can affect the flow. Glades Park has a Multi-Product batch process and with a Network batch process structure (Barker, 2005). A multi-product batch process includes more than one product, at Glades they work on several kinds of blades. A network batch process involves a web of operations that can change according to the particular batch. The network batch process is more specific than a typical batch process flow because it is designed to incorporate the different flows for variables such as product line or level of service. Network batch process allows different processes to be predetermined, or determined at a specific gate. This gives a firm structure for rework paths. When a blade needs rework, it fails at inspection, then the network flow helps decides what new path the blade must take with a chance to re-enter the original path at the end of the nested loop. Although the network batch process is working well for Glades, it has a few flaws. If a blade fails and is sent to a non-batch process it moves much faster than if it fails and goes back to a batch process. This hinders delivery time because a rework blade at a batch process must wait for enough blades to come to that operation to run it.

2.4.4 Lean: Visual Management

Visual Management is a part of Lean thinking. Liff and Posey (2004) emphasize that visual management not only aligns the management and the internal structure of the business, it also focuses on critical performance goals. Visual management strives to make the workplace more visual, providing charts and graphs for performance, or color-coding to make items more visible and accessible (Rich, 2006). When information is visual, there is less confusion and everyone is brought to the same level of awareness. Employees are aware of what is expected of them and information that was once hidden from them is readily available. This encourages more pride in an employee’s own work and a sense of team work because performance and service levels are public (Rich, 2006).

As the workplace gets more and more confusing it only makes sense to simplify information flow. This falls back to basic teaching principles. Management cannot send out large reports daily, this would be inefficient and unproductive. If the same information were colorfully displayed in a central location for all to see in an attractive manner it would catch employees’ attention. If summaries and concise data were added this would bring the point home even better. Figure 11 displays an example of an effective communication chart.

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Figure 11: Employee Communication Display

Liff, S. & Posey, P.

For this tactic to succeed it needs to be established as a permanent fixture. At the initial introduction the affects may not be noticeable, but if the commitment is made there will be positive changes. Visual management will improve the quality of the work environment, providing organization and make jobs easier. It will allow people to be more independent and rely less on verbal orders, which can get confused.

For our project it was important to remember that visual management is important for both communicating and pushing tasks to completion (Carroll, 2002). Rework blades are supposed to be the first blade to be processed at an operation, but they are delivered to the stations just as other blades and are only spotted if the operator goes through all of the blades routers and either find an attached rework form, or a stamp from the dispositioner. The president of the Toyota Motor Corp, the company that invented Lean production, stresses that a problem should always be obvious, never hidden (Liker, 2000). Everything must be organized in a way that will allow problem areas to stick out. This projects problem area is rework. The current process is ineffective at communicating to the operator as to which blades are rework and fails to push the blades faster by having them blend in. If the blades were in red bags, as opposed to the regular clear bags, they would communicate quickly that they were rework and would be processed right away without the extra effort of sorting through routers.

3 Methodology

The goal of our project was to improve the TAT, margin degradation and balance yield for the rework cycles for blades in Glades. Turn-around-time and margin degradation both rely on yield, or the output of the shop. Improving TAT and increasing margin can be accomplished if the yield is jeopardized but the goal is to take yield into consideration as well. In order to do this, we followed the DMAIC process. The define stage is when the team identifies a project based on business objectives and the customers of the process and their needs and requirements. (DMAIC Six Sigma Methodology, 2007) This was mostly accomplished before the project started when GE management told us the goal of the project.

Figure 12 shows specific processes we went through to complete our project. These processes work step by step through the DMAIC process. The first step was collecting data to pinpoint where the problem areas occurred. From there we had to decide which of the problem areas we could feasibly attack and actually implement a solution and which were going to be recommendations for the future. For items that we decided we could attack now and implement, we pursued two approaches. The first was actual process changes, while the second was a set of rules for the operators to follow at stations that have a large amount of fallout at their station.

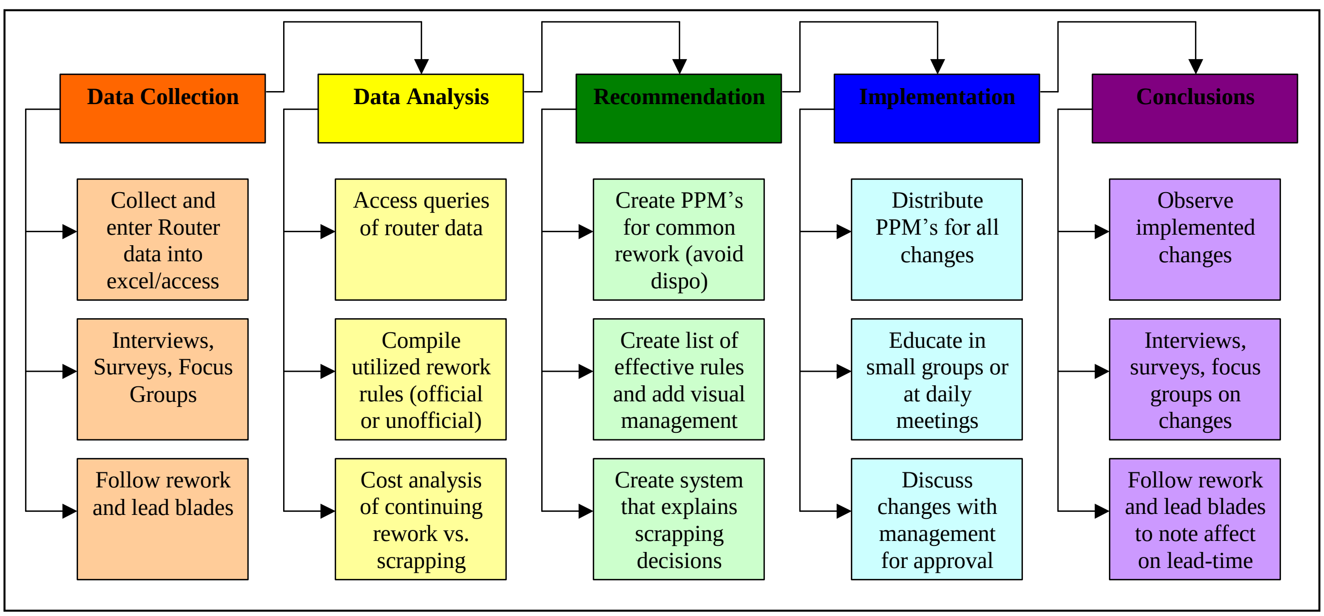

Figure 12: Methodology Flowchart

3.1 Data collection: Define and Measure

Data Collection helps refine project objectives in the define stage and also is the foundation for the second step in the DMAIC process measure. After management defined the problem statement, the specific problems that we were going to focus on had to be defined. This was done through the measurement phase. The measurement phase shows how the process is currently performing. Once the data was collected and measured, figuring out the specifics of the problem was much more exact and less subjective.

3.1.1 General Data

In order to get a high level understanding of rework and what the problems were, we first accumulated the data that had already been collected. We went to multiple sources in order to acquire this information including operators, management, the shared drive and a program called Master Menu.

The first set of data we collected dealt with overall production of the shop. Keith Alexander, the cell leader of Glades Park, developed a spreadsheet breaking down by product line how long each part took for each process. He also included the daily input, daily output goal and rework percentages. This in turn showed how many people would be needed throughout the shop on a daily basis.

3.1.2 Cost Analysis

The second type of data we decided to collect was on cost analysis. We received information from past projects on the shared drive as well as from the plant manager, Cristina Seda-Hoelle. Table 2 is a snapshot of one excel sheet that was given to us that had every operation, the parts per hour for that operation and also the hours it takes per part per operation.

Operation	Operation Name	Avg Parts per Hour	Avg Hours per Part
0440	Confidential Information Has Been Removed	2.32	0.72
0450		0.88	1.21
0470	Confidential Information Has Been Removed	8.19	0.32
0480		2.73	0.72
0490		44.62	0.10
0500	Confidential Information Has Been Removed	27.60	0.13
0510		24.43	0.08
0520		6.93	0.23
0530	Confidential Information Has Been Removed	10.29	0.21
0540		7.60	0.19

Table 2: Snapshot of Cost Analysis Spreadsheet

3.1.3 Master Menu

Master Menu is a large program, which archives data that is collected in all four Cincinnati shops. It ranges from engine manuals to labor hours to financials to defects per unit. The defects per unit section is the part of the program that gave us information about rework, including multiple excel sheets sorting the data by shop, by shop by engine model, or by router. It also breaks the data down by the individual defect or by the defect category and into percentages or shear numbers. With this program, we verified the percent rework received from Keith Alexander's excel sheet. It also specifically showed at which operations the largest number of blades fell out and which engine models incurred the most rework.

3.1.4 Routers

Attached to every blade is a piece of paper called a router with every step that the blade has to go through as part of repair and a space for the operators to date stamp when they finish each operation. The router also has the customer name, the type of blade it is, the type of process it needs to go through and the date received. The most important type of data gathered was from the routers. With these, we collected data two different ways. The first method we used to collect data from the routers was pulling a large number of lots (approximately 30) and capturing a few routers from each lot. A total of 147 routers were collected during this process. This method shows the frequency that a lot can contain at least one blade that falls out at a particular operation. Table 3 gives an example of the data collection and shows that we recorded the rework loop, how many days it took to get through the loop, the PPR and the SO number. The PPR number indicates what engine model the blade goes to and what kind of repair process it is. The SO number provides the customer name and the fiscal week and day the order was opened. The rework loop information included what step the blade fell out at and all the steps the blade would have to go through for that particular nonconformance. For every operation that a blade fell out at, there were multiple loops that it could possibly go through depending on the defect it contained. In order to capture this, we had to use a key for the separate loops a blade had to go through. For example the rework loop "310A" fell out at operation 310 and the 'A' is a symbol for the loop it has to go through. We counted the days it took to get through the loop specifically as the number of days it took to get back to the operation where it fell out.

Rework Loop	Days in Loop	PPR	S/O	Customer
310A	2	Confidential		"Customer 1"
310A	2	information		"Customer 1"
400A	1	has been		"Customer 2"
400A	1	removed		"Customer 2"
400A	2			"Customer 2"

Table 3: Example of Data Collection

The second method we used was pulling a small number of lots and capturing every router in the lots. A total of 270 routers were collected with this method. This captured the amount of fallout points that can occur in a lot. In this method we decided to only record the rework loop and the days it took to get through the loop because we would be using this method when analyzing data in specific problem areas.

3.1.5 Operators

Interviews are a good method for acquiring qualitative information, which cannot be summed up with numbers. We interviewed approximately ten to fifteen operators in total to determine what current procedures were accepted and other opinion based questions. These operators were chosen at random throughout the shop only making sure that the operators' particular jobs were spread out throughout the process. The average time an operator has worked in the Glades shop is twenty-four years. With this much experience, the operators have a lot of insight into what has been done, what has worked and what has not. Also, a lot of the operators have ideas about how they think rework could be improved. We went into two of the interviews with a set of guideline questions, as shown in Appendix B, but ended up mainly having casual conversations about rework with each of them. We used this tactic instead of formal interviews because of the culture of the shop. The operators responded a lot better to friendly conversation asking for their input and suggestions as opposed to what they perceive as judgment or a test. Along with getting suggestions on how they think rework could be improved, we also made sure to ask them how long on average they spent on rework and how they knew they had received rework.

3.2 Data Analysis

A great deal of data was collected. The next step was to figure out what to do with all of it. We organized the data into information that was immediately uselful and then what needed to be looked into further. The places we decided to focus our attention were cost analysis and the routers.

3.2.1 General Data

The spreadsheet received from Keith Alexander showed how the parts moved through the shop. Although the intentions of the spreadsheet dealt with the manpower needed throughout the shop, we extracted the average number of blades the shop serviced, the TAKT time for the entire process without rework and the individual times each blade took to get through each operation. This data was collected to familiarize us with the process so that when we were specifically looking at rework we would be able to see the impact. We also got the percentage of the total blades that were reworked from this file as well.

3.2.2 Cost Analysis

Confidential Information
Has Been Removed

Confidential Information
Has Been Removed

3.2.3 Routers

To analyze the router data we focused on the number of days the blades spent in a rework loop, frequency of fallouts at each station and frequency of each rework loop. For every fall out point there are several different loops. A large database is needed to incorporate such a variety of information, and organization is extremely important. This information had to be analyzed from different points of view to maximize results. Since we had various methods of data collection we had to determine what dataset worked for each area of concern. We broke our data down into three main areas: Frequency, Time, and Op 400.

Most of our analysis came from collecting a large number of lots and a few routers from each lot. Before focusing our efforts, we evaluated the general data. We looked at the outliers and realized one of the engine models was skewing the averages. We removed the CF6 –6 engine model from the data set and updated all of the fields to accommodate the adjustment. The CF6 –6 blades are being phased out of service, therefore the TAT for these blades is higher because the employees are being phased out of working these blades continuously. Table 4 shows how we initially compiled the data, where it was not the easiest to see all the aspects that we would like to analyze.

Rework Loop	Days in Loop	PPR	S/O	Customer	Average days/ Loop	Average days/ fallout Op
310A	2	Confidential info. removed			2	2
310A	2					

Table 4: Snapshot of Original Database

To clarify the data, making it easier to read and understand, we made pivot tables in excel. This allowed us to look at the particular aspects of the data that we wanted to focus on individually or in desired groups. For example, in Table 5, we wanted to see if a specific PPR had more rework than another in the two most common rework loops, so we focused just on the PPR and rework columns. The PPR was important to focus on because it represents the type of blade and which repair process it is going through. This allowed us to examine if particular rework loops correlated to the type of blade or repair process.

PPR	Rework Loop	Total
Z448	625H	3
Z448 Total		3
Z588	625H	2
	625I	1
Z588 Total		3
Z728	620A	4
	625A	4
	625C	2
	625G	1
Z728 Total		11
Z772	625A	1
Z772 Total		1
Z806	620D	1
	625C	3
	625H	1
Z806 Total		5
Z808	625D	1
	625E	3
Z808 Total		4
Z854	620A	1
	625A	4
	625E	1
Z854 Total		6
Z921	620A	2
	620B	1
	625A	5
	625B	1
	625F	1
Z921 Total		10
Grand Total		43

Table 5: Pivot Chart of Rework Data with PPR and Specific Rework Loops Only

The next element of the data we looked at with this data collection method was frequency. We looked at two aspects of frequency including at which operation the blades fell out and the actual separate loops themselves. We created Table 6 to condense and highlight the data for the individual operations where the blades fell out. This showed us which operation(s) we should focus our efforts on.

Operation	# Of Fallouts
OP310	2
OP520	3
OP970	3
OP930	4
OP490	5
OP860	5
OP600	6
OP620	10
OP580	18
OP940	24
0P400	34
OP625	34

Table 6: Number of Fallouts per Operation

When the blades are rejected, they must be put into a particular rework loop. The loop is named by the operation where the blade failed and then a letter distinguishing it from the other loops failing at the same operation (example: 625H). It was important to look at how often the individual loops occur because they each involve a different number of rework operations. One loop could have two operations as part of rework, while another could have 10. The different TAT times for the operations must be taken into consideration as well. We compiled a chart listing how many times each of the 38 different reworks loop occurred in our data set. Table 7 shows the top five most common loops that occurred out of the set of 38.

Rework Loop	# of Occurrences
400A	34
625A	14
940A	8
940C	8
620A	7

Table 7: Top Five Most Frequent Rework Loop

The first operation we focused our efforts on was op 400 because of the frequency with which it occurred. Another data collection method was used when we started to analyze data specific to op 400. We decided to use a small number of lots but collected every router in the lot. This way we got a more exact figure on how many blades actually fell out at op 400 and not a general average from only collecting a few routers from the lots.

Another way we looked into op 400 was the type of defect. Every time a blade fell out at operation 400, it was called out for the same reason; which we call Defect 1. Defect 1 is a major contributor to rework but does not have a long rework loop (see Table

8). The actual loop can be completed within one day so we needed to concentrate our efforts to steps outside the actual loop.

400A	Grit Blast - 320
	Swab Etch - 550
	Vapor Blast - 560

Table 8: Op 400 Rework Loop

The analysis of op 400 prompted collecting a new set of data about how long the blades from op 400 sat in the dispositioner area. When such a large volume of the rework loop from operation 400 was discovered, we decided cutting even one step out of the rework process would have an effect on TAT. Knowing that reducing the time of the rework operations for defect 1 was not the issue; we looked at what was adding time. We collected five shop orders that had a large amount of op 400 rejects and collected how many days they were sitting in dispo.

Although Op 400 accounted for much of the rework volume, we also wanted to tackle the loops that took the longest. We decided that 3 days in a rework loop, although not ideal, is acceptable, while 4 days is the breaking point. With this decision, we looked at all of the routers with 4 or more days in a rework loop. Any loops that fell into 4 or more days were referred to as “problem loops”. There were 25 rework loops in 64 total routers that took 4 or more days, but 3 loops stood out as the most prevalent. Table 9 gives the numbers of the most frequently reoccurring rework loops that took over 4 days.

Rework Loop	# of Fallouts over 4 Days
625A	13
625H	6
940A	6

Table 9: Count of Rework Loops over 4 Days

3.2.3 Operators

The operator interviews led us to several implementable ideas. After looking at the Op 400 data we realized how much time was being wasted at dispo. When we talked to the dispositioner, he pointed out how the blades get bottlenecked at his station. This is mainly due to operators only bringing rework blades to the station at the end of their shift. This led us in two directions, reducing the bottleneck, and reducing volume. If operators dropped off rework even just 2 times a shift it would allow the flow to dispo even out. Volume could be reduced by allowing the very common Op 400 rework pass dispo and go straight into its rework loop. We discussed this idea with dispo and this was a feasible procedure.

Other operators gave us insight to the rework procedures used on the floor compared to actual procedures. Currently hot tags are used as an indicator for what rework needs to go through the fastest, even though all rework should be worked before any other blades. The operators are aware of that procedure, but they end up going in a different direction. Supervisors walk around everyday and tell the operators which blades to work first. As the operators start to expect this, they stop following established procedure. The system needs to be standardized and the procedures need to be followed across the board. Talking with the operators raised another interesting point; reworking blades themselves, if possible, instead of sending them to rework. This is not possible all of the time, but small problems like a partially closed hole can sometimes be opened easily by any of the operators. If fixed at the initial point of discovery, it could save the blade from several days in a rework loop.

3.3 Recommendations and Implementation

One of the most important parts of our project was implementation. Not only did we want to come up with recommendations, we wanted to see our ideas incorporated in the plant. We had to style our implementation methods in relationship to our recommendations. We used three main methods to implement our ideas; presentations, planning changes, and action items.

Presentations were the best method to reach the largest number of people in the smallest amount of time. We created two PowerPoint slideshows to visually illustrate the information as well as clearly explaining what was to be taken from the slideshow. This allowed us to choose specific audiences and include only relevant information for the given topic. We presented to the operators and made a short presentation that only included methods that would be implemented immediately. We also presented to the management team where we had a more extensive presentation that not only showed the methods that were implemented but also how we got there and ideas for the future as well.

Planning changes were extremely specific, reaching only the people immediately affected. Each operation has written planning and to change that operation, planning must first be changed. After the changes have been made, management must then approve it. This implementation creates a standardized, and lasting change. While other implementation may fade out if control is not established, planning has built in control and can only be changed through another planning adjustment.

Action items are for implementations that need supervision. We cannot follow changes after we leave, so establishing action items assigns responsibility to specific individuals. This list is then distributed to the affected people and allow for checks and balances. Action items can include collecting follow up data on a completed project, implementing a recommendation, or following newly established guidelines.

3.4 Design

The design process of the project as a whole was essential to achieve our goals. We had to eventually determine a higher level design to be able to manage the subgroups effectively. DMAIC was an ideal methodology to follow as it organized all levels of focus. We initially tried to structure the overall project, but realized the abundance of variables was too much to handle at once. Each small project had to be planned and organized, and then we were able to compile our master plan with a smaller variable set. The design is formed in a similar fashion to the project drill down, shown in Figure 10. Each small project had a unique set of issues and concerns, but was manageable when focused on individually.

After the initial data collection our project evolved in two different directions; high frequency/low TAT and low frequency/high TAT, and smaller lean projects. By finding the main factors in the data we were able to determine the projects. If we had tried to determine specific projects before data collection we may not have found true problem areas.

The two main projects, Op 400 and return guidelines, followed DMAIC smoothly, but suffered from specific limitations. Since Glades Park was transferring to the Symmes location, we had to adjust our schedule to the relocation schedule. Several schedule tasks were cancelled and moved to later dates due to an unusually hectic atmosphere. This prevented us from early implementation. With delayed implementation we did not have time to collect data to determine actual improvements. We created action items to address this issue so concerned parties can eventually have data to support the changes. While determining what implementations were needed, we had to take into account the change in shop culture. This could affect the follow-up data collection for our implementations because of the added variables of the new plant. We have suggested that further data collection should wait for at least two months for necessary adjustments to Symmes.

The smaller projects involving lean practices did not follow a DMAIC structure as we hoped. The measure stage was difficult to support by numbers, as we had to rely solely on operator interviews. Although we explained to the operators the interviews were private, they were hesitant when asked direct questions on how they perform specific tasks. We ended with conclusions that seemed to fit the general feel of the shop culture, although we did not have quantitative data. The recommendations we compiled were well received when presented to the operators. Although this process was not in direct DMAIC form, it was still effective.

The general overview was needed to manage these several projects. We tried to accomplish each step of DMAIC for all projects around the same time. This was important so one project did not lag behind and lose importance. By keeping all projects up to speed we reached all of our achievable goals.

To achieve our goals we had to consider the basic variables; budget, time, and shop culture. For our project budget was directly correlated to time. Although a budget was available, it took several weeks for approval. Considering we only had seven weeks for our projects we had to create solutions on little to no budget so we could implement them while we were still onsite. The shop culture had two obstacles; the operators and the managers. Many of the operators have worked there for over 20 years which does affect their willingness for change. We had to make sure our project would have the majority buy-in. Although the operators would initially use the changes we wanted the solutions to be sustainable, which would mean the operators would have to decide to use them for the long run. Sustainability was an issue with management as well. Although they wanted to use our changes, their busy schedules can sometimes make them lose focus. We divided our project so there was individual ownership for the different sections. This would prevent necessary communication between two managers, and would allow decisions to be directly made. If ownership was convenient, the project was more likely to be sustained.

While we accomplished most of our goals for DMAIC, it was also important for us to follow MQP procedure. In the Major Qualifying Project Manual for the Industrial Engineering Department there is an emphasis on data collection, design, and evaluation. After our data collection stage we spent a long time on design. This included all of the analysis, which should consist of applicable software and modeling. We used Microsoft Excel to create several graphs and charts. Microsoft Visio enables us to create flowcharts for methodology and even visual representations of process flow. The software made our project user friendly and led us to modeling. We went through several models for the project focusing on creating product return guidelines. Several proposals had to be made before finally deciding on our model to propose. Making several models allowed us to see the project from various angles and viewpoints. The evaluation stage was difficult within the seven week period, but we were able to create action items to address the situation. Although we could not be onsite for all of the evaluation, we provided a plan to make sure the necessary follow up takes place.

4 Analysis and Results

This chapter on analysis and results represents the analyze stage of the DMAIC process. The analyze stage determines the causes of the problem that needs improvement and how to eliminate the gap between existing performance and the desired level of performance (Six Sigma Certification Training, 2007). The goal of this project was to improve TAT, margin degradation and balance yield. In order to eliminate the gap between the existing performance and the desired level we concentrated our efforts in two directions: determine return guidelines based on margin and eliminating a step in the cycle to improve TAT.

4.1 Cost Analysis

We approached the cost analysis by looking at the cost of individual loops and then determined which ones we needed to focus on. In order to figure out how much the rework costs, for every operation, we multiplied the average cost per hour to do an operation by the average time it took to do the particular operation. This gave us the cost broken down by operation. We then took the most common rework loops and added the cost to do the operations together to get a total cost for that rework loop, as shown in Table 10 for rework loop 625A.

625A	Op 430	Confidential information has been removed
	Op 440	
	Op 490	
	Op 500	
	Op 510	
	Op 520	
	Op 530	
	Op 540	Confidential information has been removed
	Op 550	
	Op 560	
	Op 580	
	Op 590	
	Op 600	
	Op 620	
		Total Cost For the 625 A loop

Table 10: Common Rework Loop Cost Analysis

We determined which loops we wanted to focus on by choosing the most expensive loops, as well as the most common loops. Figure 13 shows the 11 loops we chose, which ultimately would need individual guidelines about reworking decisions. The chart incorporates several aspects of the analysis. The % of Total Rework column shows, on average, how often these loops will occur. Cost Per 1 Loop Rotation shows the actual cost to rework a blade in this loop once. The rest of the chart focuses on profit and profit margin as opposed to cost. The target margin percentage (%OM) is [redacted] on all blades.

The chart shows how the OM and OM% decrease as the number of rework loops are allowed increases. Three of the loops that currently have no limitations on the number of rework loops allowed, actually begin to lose money after three times in the loop. The green shading highlights how many times the loop can be reworked without concern. The yellow highlights the number of times reworked at which the blade in that loop should be considered for return. This was determined solely from an OM standpoint. If the blade goes through the rework loop after the suggested (highlighted yellow) loop, or into the grey highlighted area, then it is not economically justified for Glades.

For example, loop 625A costs [redacted] for one rework loop according to Table 10. Figure 13 shows us that a blade in 625A can be reworked once before return consideration. If reworked twice, the blade would only make [redacted] OM and if reworked three times it would actually cause the business to lose money.

Rework Loop (TBR)	% of Total Rework	Cost Per 1 Loop Rotation	# of Times in the Rework Loop					
			1x		2x		3x	
			OM$	% Margin	OM$	% Margin	OM$	% Margin
940C	5%							
400A	22%							
940A	5%							
580D	2%							
625H	4%							
600B	1%							
580C	3%							
600A	3%							
620A	5%							
625A	9%							
620C	<1%							

Confidential information has been removed

Figure 13: Cost Analysis Breakdown

Confidential Information Has Been Removed

Rework Loop	Reduction in	# Days/ Loop	Proposed # of loops before
940C	Confidential Information Has Been Removed	5.13	Confidential Information Has Been Removed
400A		2.15	
940A		7.38	
580D		5.00	
625H		6.00	
600B		4.00	
580C		4.25	
600A		5.25	
620A		2.71	
620A		2.71	
625A		6.54	
620C		N/A	

Table 11: Final Guidelines

4.2 Routers

From the router analysis, we determined the frequency with which blades fall out at particular operations. We created a pie chart, Figure 14, based off Table 6 to visually acknowledge where problem areas existed. Operations 625, 400, 940 and 580 are highlighted, as shown by their majority percentages.

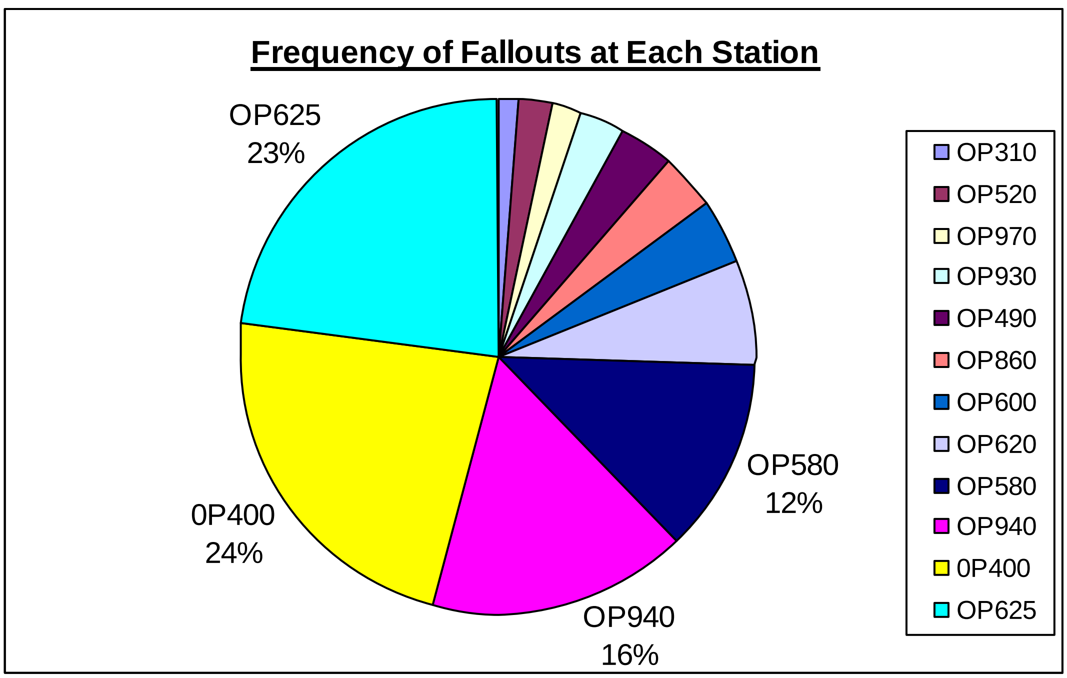

Figure 14: Frequency of Fallout Points

The second aspect of frequency we examined was which rework loops occurred most frequently (see Figure 15). The operation that was highlighted in the graph was rework loop 400A. Because operation 400 showed up as the most frequent fallout operation and rework loop we decided to concentrate our efforts in that direction.

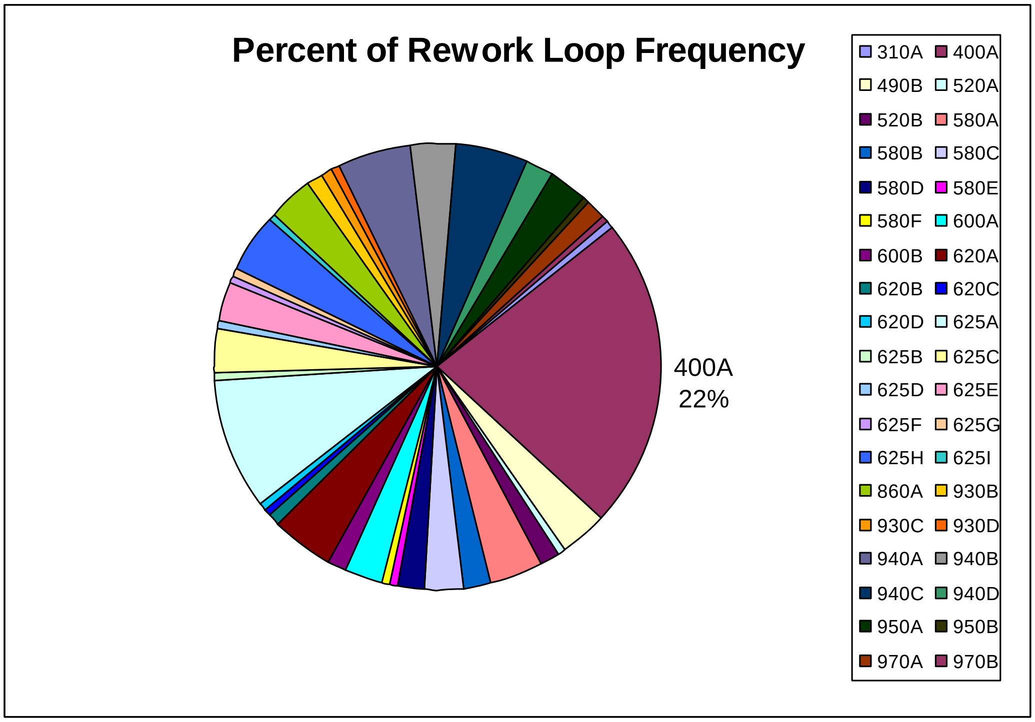

Figure 15: Rework Loop Frequency

Although we were made aware that Op 400 was a problem area before we collected data and this assumption was verified after we collected the initial data, we still wanted solid numbers and evidence. We collected a specific set of data to concentrate on the actual number of blades as opposed to a sample set. We used a second data collection method of pulling a few lots and capturing every router and came up with a more precise percentage, as shown in Figure 16. Based on this analysis, 40% falls out at op 400.

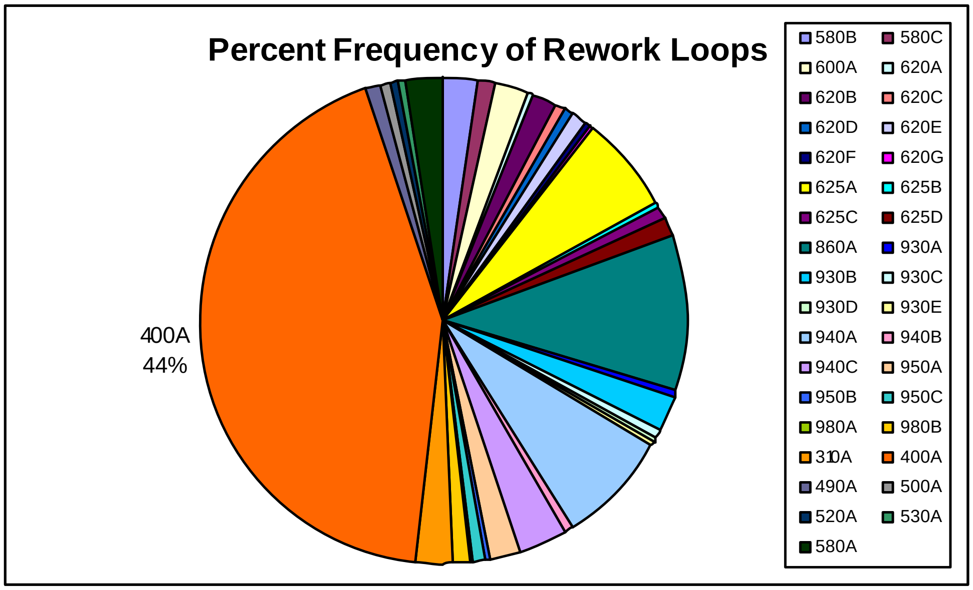

Figure 16: Frequency of Rework Loops

When we decided to concentrate on operation 400 and collect data specific to routers that fell out at op 400, we made a chart as shown in Table 12 that showed the shop order number, the number of rejects from that order and how long it sat in dispo. The days were recorded by looking at the stamps on the routers from the day they were rejected to the day they were stamped by the dispositioner. From this information we got the average number of days the blades sat in dispo. The numbers showed that an average time for a blade to sit at the dispositioners' station was [redacted] of the desired 18-day TAT.

Number of Days OP 400 Sat in Dispo		
S.O.	# Rejects*	Days in Dispo
81315A	45	5
81361D	34	4.5
81373F	53	3
81374F	22	4
81354D	23	1
Average		3.5
Total	177	
*Defect 1		

Table 12: Number of Days Op 400 sits in Dispo

With this information and the fact that almost every piece that falls out at op 400, does so because of the same defect, we decided to redesign the process to pass through dispo whenever an op 400 inspector found that particualr defect. The inspector would get a stamp that had the operations that the common defect would need to go through as shown in Table 8. In order for this to be implemented into the shop, a process planning change needed to be made to the planning. This procedure only needs to go through the Manufacturing Technical Coordinator of the shop. An addition to the process-planning book was made and it was put on the shop floor. Figure 17 shows how this changed the process slightly where instead of the inspector sending the rejected blade to dispo, he or she would stamp the router with the processes and then the blade would go directly into the rework loop. From the information we gathered this means that dispo would receive between 25 to 45% fewer routers. This would cause all rework to speed up because the dispositioner would have fewer routers to go through on a daily basis and therefore the rework loops would begin more quickly.

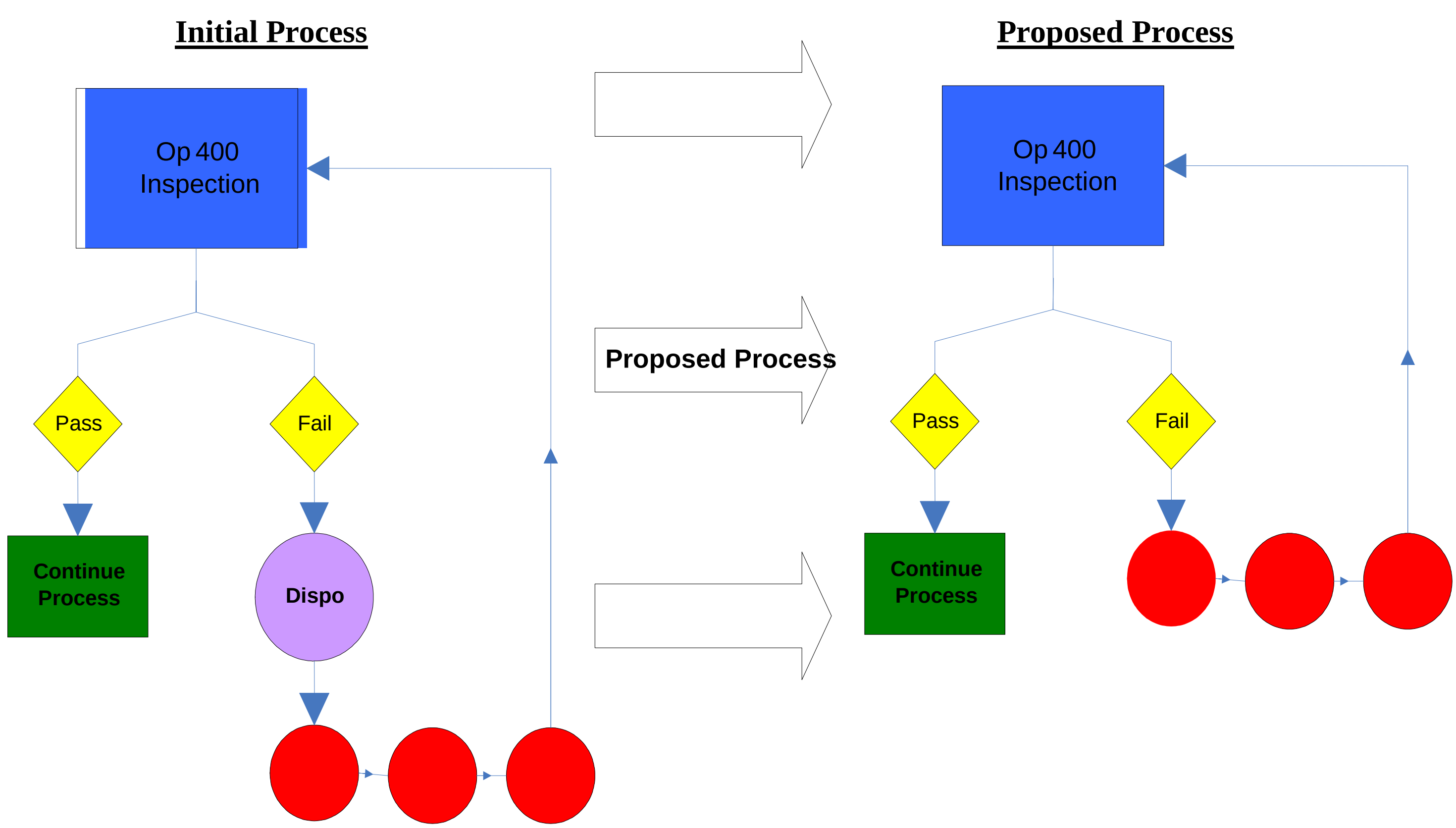

Figure 17: Op 400 Process Change

The next analysis considered how often rework loops occur that take longer than four days. Figure 18 points out that Op 940A, 625H and 625A provide the highest volume of problem rework to the process. Operation 625 is [redacted] and Op 940 is [redacted]. These are both inspection stations so it is not surprising that these stations tend to find a majority of rework. Op 625A and 625H are both found at [redacted] but require different rework. This is how several rework loops are named; they are listed by the Op number where they fell out, along with a letter specifying what rework is necessary. So 32% of the problem rework set comes from Op 625, but 20% of it comes from just one loop out of the 7 different 625 loops. The explanation for this is that rework loops 625A and

625H have fourteen and eleven steps in their rework loop respectively, and so are likely to take longer.

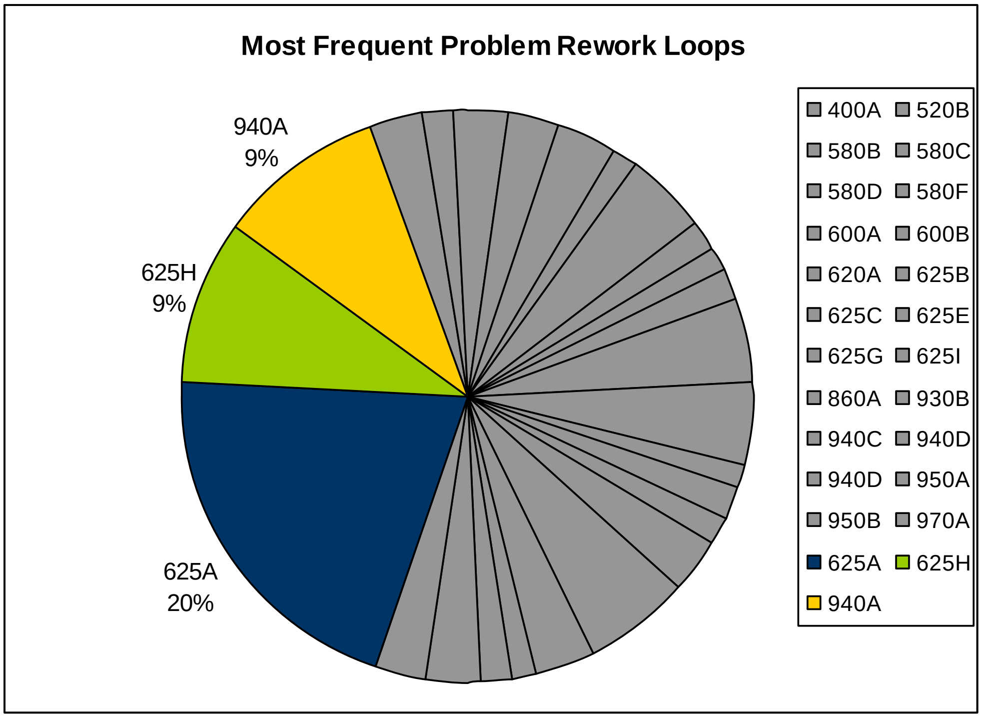

Figure 18: Problem Rework Loops

We then calculated the percent of occurrence, the mean and P90 for number of days in rework as shown in Table 13. The P90 shows the 90th percentile of the data, which for all three of the data points is extremely high. All 3 of these main problem loops also have extremely high averages. This information is vital to determining a standardized procedure for when to return blades. Knowing that a blade needs the 625H rework loop and returning right away could save both GE money from excessive rework, and the customer time waiting on a blade.

	625A	625H	940A
Mean	6.54	10.5	9.5
Median	6	11.5	9.5
P90	8	15	13
% of Rework >= 4	21	10	10

Table 13: Most Frequent Problem Loops

Operation 940 is a problem rework loop that only has one step in it: [redacted]. After speaking to management and the operators, the reason for this one step to take so long was the tediousness of the process. A lot of this rework process involves probing tiny holes by hand, one by one until they can pass through airflow. The operators would sometimes take hours to do one blade. With this information, we decided to develop a time limit for the EDM operator to spend on each blade. Using the cost analysis

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4.3 Recommendations

There were many ideas that came from analyzing the data that did not evolve directly from the data. We researched visual management and during the project realized there was very little in terms of visuals around the shop and specifically for rework. There were also ideas that stemmed from talking to the operators that we thought would be useful and could improve the rework cycles.

4.3.1 Rework Bags

Visual Management is a key way to improve processes throughout the shop. An important aspect of rework in the shop is that it should receive top priority at each operation and be worked before anything else. For example, if an operator receives two lots and one has a flight tag dated before the other the practice is to work the lowest flight tag unless it is rework. Currently, the only way the operator can know if a lot is rework is if they take the routers out of the bag and look through them to see if any have been reworked. The flight tags on the other hand are on the outside of the bag and a quick glance at them will tell which ones came first. If an operator has four or five sets all at once it is unrealistic they will look through every lot and see if it there is rework or not. The flight tag is bright and on the outside where they do not have to pull out any routers, so chances are they will just look for the lowest flight tag and work that.

A solution to this problem is to create a visual for the blades that need rework. An idea of red bags was attempted by another coop but when they were ordered, it was discovered that the bags were too flimsy. We realized that the bags that were ordered were only 0.6 mils. The bags that Glades Park uses everyday are about 3 mils. We found pink antistatic bags that come in 2 and 4 mils and cost $90 per 1000. We proposed this to management who gave us the go ahead to order them. These bags were ordered but were not able to be implemented before the project ended.

4.3.2 Visual Management Chart

Another visual management suggestion is a chart that shows the flag tags sorted in order of importance as shown in Figure 19. The purpose of this chart is to reduce the reliance of operators on managers to determine what to work first. This would be a large poster that had placeholders for the flag tags that were color-coded. There would be green placeholders that were for recently received orders and were to go through the process as normal. The second level would be yellow and would be for the orders that were over the 18-day turn-around-time by one week or less. The final section would be red, and would have every flag tag that had exceeded the 18-day turn-around-time by more than a week. It would be located in the omnimax where there is a pre shift meeting everyday where movements of flag tags from one level to the next would be highlighted. The rules that rework and then the lowest flag tags need to be worked would still be the number one rule but this poster would show approximately where everything was and its importance.

To make the biggest affect with visual management it is helpful to incorporate a full information center. An information center includes company information, such as mission statement and history, goals for various departments and targets, customer satisfaction, and the importance of the employees (Liff, 2004). Liff discusses a specific case study for a semi-conductor manufacturer where the information board was successfully established. The operators found a huge improvement in communication and issues were addressed quickly and with much less confusion. Glades has the potential to implement such a technique. It would require a little effort, but would have a big payoff. There are the beginnings of a visual management program, open orders are now being displayed and quality data is made available as well. If this information is combined and displayed in an easy to read fashion, there would be a greater response to the information.

For Glades to be successful, they should also consider established success factors for visual management. Parry (2006) discusses a set of success factors determined by three successful case studies. First, there must be a group that wants to establish a visual effort. Without people who are excited about the process the idea will eventually fade away. The information centers must not just be about metrics. There needs to be an initial focus on format and clear layout for expressing the information. If confusing graphs are dsisplayed they will be passed by, but if the boards are interesting enough to draw people in the information will be absorbed. Metrics are considered after format. The information is ultimately what is being shown, but how it is being shown is the number one concern for a visual display. The ability for operators to contribute to the boards is also very important. Allowing them to contribute strengthens the team effort and gives them a voice. The initial establishment can take a substantial amount of time, but it is important to start off well and will help avoid many adjustments in the future. It is also important to keep in mind that much of the information displayed changes frequently, so any magnets, dry erase boards, or other reusable and changeable displays are the most user friendly. After the implementation sustainability is key. If initial development goes well, operators and managers will see the benefits and will want to keep the method going.

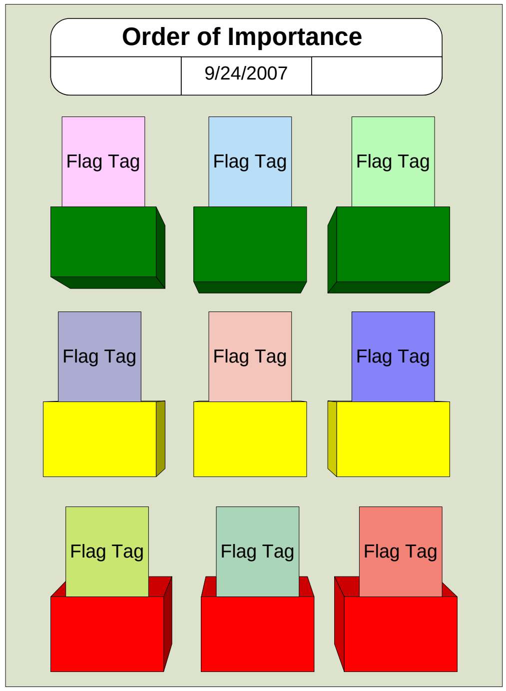

Figure 19: Flag Tag Chart

4.3.3 Rework Delivery

When rework is found, the operator or inspector who found the defect has to physically walk the blade or blades to the dispositioner. The current guidelines are that the operator is supposed to work five parts and if within those five parts they have rework they should bring it to the dispositioner. This has the operators getting up and down frequently throughout the day and is disruptive. Although, from speaking with the dispositioner, what is actually practiced is that most operators bring all of their rework to dispo at the end of their shift. This causes a bottleneck at dispo and delays the rework from getting into the loop. To solve both of these problems, we proposed that the operators bring their rework to dispo on their lunch break and then again at the end of the shift. Doing this would decrease the bottleneck because there are two dispositioners between the times of 12 and 2.

4.3.4 Facilitator

Glades Park is currently discontinuing the service of one of their product lines. This frees up an employee to act as a facilitator. As a facilitator they would track parts and make sure orders do not get lost. With a free body who knows the process very well, we proposed that they use this person for rework. The facilitator would pick up the rejected blades from the operations and bring them to dispo. They would also pick up the blades at the dispostioners and bring the blades to the beginning of the rework loops.

4.4 Implementation

Implementation is the foundation of any DMAIC project. Our methods of implementation consisted of two parts, a presentation to the operators and a presentation to our managers to inform all affected parties of our ideas.

4.4.1 Presenting to the Operators

To introduce our ideas to the operators and other staff we gave a presentation during the weekly transition meeting. There were about 40 people in attendance, with approximatley 90% unaware of our project. This was a great time to present ideas without officially making changes. Creating a laid back atmosphere made it easier for the operators to hear our ideas, rather than rejecting change before giving anything a chance. We came with an approach of this presentation being a work in progress and that we were looking for any input, comments, or suggestions. We focused on 4 main topics; Op 400 and dispo, visual management chart, anti-static bags, and rework delivery times.

When presenting we did not place blame and changed the original PowerPoint to be as sensitive as possible. The presentation was received well. Although there were not any direct suggestions, we had a few questions. When the whole meeting was finished several people approached us to say they enjoyed the presentation. This gave us a sense of hope that if this was well received, actually making the changes will be a smooth transition. Times are very stressful at the plant because of the nearing transition to a new building. There is going to be a lot of change and the employees are hesitant to try anything new. Being responsive to our presentation was a very important signal. We realized we would not be stepping on any toes and while these changes may not be made right away, they will be straight forward for others to implement.

4.4.2 Final Presentation

Presenting our material to management was a very important step in implementation. The operators accepting the suggestions will keep the ideas going once they are implemented but management has to implement them. In order for management to want to implement the ideas, they have to believe that it will work. The final presentation is selling what we think to people who can act on it.

In the presentation, we presented to the Vice President and General Manager of Global Operation, Bill Fitzgerald, the Plant Leader for the four Cincinnati service shops, Nate Manning and our Plant Manger of Glades Park, Cristina Seda-Hoelle. We also presented to two other groups doing projects in different departments and their managers as well. The presentation was an overview of everything we had done. We gave them where we worked and what we did there, our problem statement and goals and the issues we faced. We then went into what and how we collected data. The majority of the presentation focused on analysis and results. We concentrated the presentation into our two main accomplishments instead of presenting every single idea that we had. This way we could get more in depth and be able to show the evidence of how we came to our conclusions. Our final slide basically compiled everything we did and suggested in a list of seven action items. This was received very well and management is supportive on moving forward with our ideas.

5 Conclusions and Recommendations

The goal of this project was to improve TAT, margin degradation and balance yield for rework cycles at the Glades Park service shop. With this project, we specifically concentrated on improving the current rework loops as opposed to reducing the amount of rework, thus targeting short-term effects. Reducing rework is the focus of other ongoing GE efforts. We focused in two directions to improve the rework cycles. The first was improving the TAT for a specific rework loop that accounts for about 40% of the total rework. The second direction we pursued was to improve the average operating margin by targeting the longest, most expensive rework cycles.

The first problem we attempted to fix was the long TAT. This is a problem for Glades Park because their goal for the full repair process is 18 days but the average TAT is currently 31 days. The rework cycle takes an average of four days to complete, which is about 25% of the intended TAT. So reducing the time in rework loops is key to reducing the overall TAT.

We first looked at the operation that occurred most frequently, which would therefore have a high impact. Operation 400 accounts for about 40% of total rework but has a very short rework cycle. In order to see where this rework loop could use improvement, we examined the routers and saw that when this blade waited, it was at the dispositioner station. With the frequency of how often this specific loop occurs in mind, we decided to bypass the dispositioner and have directed dispo. This means that the inspector who formerly rejected the blade and sent it to the dipositioner, would now stamp the router with the rework loop and send right into the beginning of the loop.

In order to see how much impact this action will have on the rework loop TAT time, we recommend that management assign someone to go through the routers as we did. This way they can see the effect it had on the rework cycle and make future decisions about the dispositioner with other rework loops.

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	Action	Owner	Status	Implem. date
1	Create Rework/NSMR decision matrix guidelines	Kristine Mischler Erin Yokay	Complete	Oct-07
2	Complete directed disposition planning for root radius cracks	Kristine Mischler Erin Yokay	Complete	Oct-07
3	Analyze and pareto directed disposition candidates based on frequency of occurrence	Kristine Mischler Erin Yokay	Complete	Oct-07
4	Train salary team on decision matrix guidelines	Mark Lingg Greg Kozma	In-Process	Oct-07
5	Collect Data to analyze impact of direct to dispo	Jessica Hinkle	In-Process	Oct-07
6	Determine candidates for directed disposition and implement changes	Mark Lingg	In-Process	Oct-07
7	New cell layout for visual identification and placement of racks/rework racks to assure hardware in rework	Bill Marquis Dave Piatt	In-Process	Oct-07

Table 14: Action Item Table

Although we spent a significant amount of our time on operation 400 and cost analysis, we also had other ideas that we thought would be useful to implement. Visual management is an improvement process that rarely has data to back it up until after it has already been implemented but is proven to be effective. Red bags was one idea for the reworking blades so operators and management can see where the rework is from across the shop and therefore notice if it is sitting or not. Another idea is a flight tag chart that shows priority of blades so operators do not have to rely on management to tell them what to work first. These ideas are explained in Chapter 4.

We also found out that the delivery to the dispositioner was very irregular. We were told that most people do not give their rework to the dispositioner until the end of the shift. This created a bottleneck during that time. If the operators would bring their rework even one other time during the day it would improve this. We suggested at lunch because between the times of 12 and 2 there are two dispositioners. The final suggestion we had to improve the flow of the rework cycles was to implement a facilitator to carry the blades from fallout point to dispositioner and from dispostioner to beginning of the rework cycle.

The overall accomplishments of the project and recommendations for the future, are summarized in Table 14. The first three items are new methods that we developed that we have implemented. The last four items are suggestions for how we think the methods could be maintained and improved. Items 4 and 5 are direct follow-ups to the implemented methods that tie up the loose ends. We would not collect data to measure impacts because the shop moved to Symmes during the last week of our project. Items 6 and 7 are recommendations that we gave management that we think would improve the rework process but we were not quite able to implement in the allotted time.

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Appendix A: Interview With Carl Fryman

Operation: Pre review
Date: 9/5/07

Q: What are the different repair processes a blade can go through?

A:

1. Tip Repair
    a. Remove coating
    b. Weld and re-contour new tip

2. Serviceability limits
    a. Waterflow
    b. Airflow
    c. Xray

3. Rejuvenation
    a. Doesn’t take airfoil TBC coating off
    b. Shank strip
    c. New tip
    d. Regenerate holes
    e. VPA
4. Full Repair
    a. All of the above

Appendix B: Operator Interview Guideline Questions:

Record: Station and Shift
Current Rework Process “Rules”:

1. Do you look for rework when you receive a set of blades?
2. How much time of your day is spent on rework?
3. At what point in your day do you take blades that have fallen out of you station to Dispo?
4. What do you think could be done to improve the rework process?
5. For stations where blades fall out: How can blades that need rework get from this point to their rework loop faster?
6. For stations at the beginning or within a rework loop: What could be done to help you get rework through faster?

Appendix B1: Airflow

Operation: Airflow
Shift: 1
Date: 9/7/07
Current Rework Process "Rules":

1. Do you look for rework when you receive a set of blades?
    - At Airflow rework blades always have a TBR so it is not hard to spot
    - Does rework first unless told it will not close an order
    - Keith comes around to point out the hot blades, those are reworked first
    - Hot tags are disregarded: go by what is told to them
    - If rework comes that will close an order, they will stop the lot they are working on to finish it; if not going to close an order, then wait to do rework
    - Not always worth stopping in the middle of the order because of calibration
2. How much time of your day is spent on rework?
    - A good run: 10%
    - A bad run: 50%
    - A bad run happens around 2 times a month
3. At what point in your day do you take blades that have fallen out of your station to Dispo?
    - When rework is found
    - Tries to rework it first; will try to open the holes
4. What do you think could be done to improve the rework process?
    - Anyone can open the holes but a lot of people don't because it's not in their planning
        1. Do this rework for up to 5 to 10 holes
        2. Saves 3 days
5. For stations where blades fall out: How can blades that need rework get from this point to their rework loop faster?
6. For stations at the beginning or within a rework loop: What could be done to help you get rework through faster?

Appendix B2: Disposition

Interviewee: Dispositioner
Shift: 1
Date: 9/7/07

NOTE: The dispositioner is unique from an operator so the interview questions were pointed in a different direction.

1. At what point in the day do you receive rework?
   - At the end of a shift
   - Would like to receive the rework throughout the day as it is discovered
   - Waiting until the end of the day creates backup and he then has to catch up as opposed to having a steady flow of work
   - The operators are actually supposed to bring the rework to dispo as they find it
   - How would you actually enforce the rule of bringing rework to dispo?
   - At one point the operators used to bring rework over to dispo when they took the other blades to the next station; this only lasted a few months
   - X-ray is the worst at bringing rework to dispo
   - Operators should at least bring rework at lunch time (11:30-12:30) ->1st and 2nd shift dispo overlap from 12 to 2 so the most work can get done then
   - Even 2 drop-offs per day would help
   - Op 400 (common defect) constitutes 47% of the rework -> could have this loop pass dispo
   - The common defect stamp helped a lot
   - Too many stamps is counter productive
   - He delivers rework to operators 10-15 times a day
   - Jim or the facilitator point out hot blades