Overcoming Obstacles to Lean in a Repair Operation

by
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B.S. Electrical Engineering, Brigham Young University, 2006

Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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and
Master of Science in Engineering Systems

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Abstract

Over the last three decades, manufacturing companies have come to recognize the value of institutionalizing continuous improvement efforts. Most of them look to Toyota as a leader in this area and have taken Toyota's model for implementing lean, the Toyota Production System (TPS), and adapted it to fit their business. While the tools created and implemented by Toyota are a big part of TPS, the tools alone will not cause a lean transformation. TPS is not a toolkit at all, but rather, a way of thinking that is often explained to others with tools as pedagogical devices.

United Technologies Corporation has created their own operating system, Achieving Competitive Excellence (ACE), which includes many of the tools espoused by Toyota. ACE has produced extraordinary results and has been a large part of United Technologies' success over the past fifteen years. While ACE has proven successful at the corporate level, it has not taken root at the Hamilton Sundstrand Corporation repair operation in Phoenix, Arizona.

This thesis is based on the research that the author conducted during a six month internship at that Hamilton Sundstrand electronics repair facility in Phoenix. Using this site as an example, it explores a variety of the challenges companies face in their attempts to create a lean work environment. The central finding of the thesis is that for a lean implementation to be successful, four main elements are necessary. First, a company must have the supporting tools and techniques for driving change. Second, managers must become teachers capable of helping others increase their problem-solving ability. Third, process ownership and responsibility for improvement efforts must be pushed to the lowest level possible. Finally, they need methodical and sustained support for lean from the top to the bottom of the entire organization.

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Table of Contents

Table of Figures

Glossary and Abbreviations

ACE	Achieving Competitive Excellence: United Technologies' operating system designed to drive productivity and high quality
CSL	Customer service level: a measure used by Hamilton Sundstrand to assess the percentage of parts that are returned to the customer within the contracted timeframe
FIFO	First in, first out: a prioritization system wherein parts are worked on in the order they arrived
Genchi genbutsu	Go and see: a management principle that suggests that problems are best understood through direct observation
Heijunka	Production smoothing: a principle of the Toyota Production System wherein production schedules are formed by breaking down demand forecasts based on volume and product mix to produce equal amounts of each product daily
Jidoka	Autonomation: system of automated processes that are capable of detecting problems, stopping the process, and alerting operators for rapid resolution of the problems
JIT	Just in time: production strategy where processes only produce a product when required by the operation directly down-stream requires it
Kaizen	Continuous improvement. Kaizen events are improvement projects performed by cross-functional teams to improve processes.
OEM	Original equipment manufacturer
QCPC	Quality control process chart: a chart documenting turnbacks. QCPC teams are formed to solve problems highlighted by quality control process charts.
PDCA	Plan, do, check, act: these are the steps in the Shewhart cycle, a four step problem solving process that follows the scientific method
Poka-yoke	Mistake-proofing: this principle suggests that solutions to problems should address the root cause so that the problem cannot reoccur
Production	The capitalized use of Production is used throughout this paper in reference to the Hamilton Sundstrand production group in Phoenix.
Pull	Pull is the guiding principle of JIT that drives production based on customer demand as opposed to forecasts in an effort to reduce inventory throughout the process and supply chain
Repair	The capitalized use of Repair is used throughout this paper in reference to the Hamilton Sundstrand repair group in Phoenix.
SIPOC	Supplier, input, process, output, customer: A tool which is used to thoroughly define a process and create expectations
Takt time	The amount of time available to do work over some period of time divided by the customer demand over the same period of time
TAT	Turn-around time: a measure used by Hamilton Sundstrand to assess the length of time a part spends in the shop excluding any time they are waiting on information from the customer
TPS	Toyota Production System: Toyota's operating system designed to drive productivity and high quality

Turnback	Documentation of problems that explains cases where a process did not work as expected
UTC	United Technologies Corporation: Hamilton Sundstrand's parent company
WIP	Work in-process: inventory which has started through the process but which has not been completed
5S	Sort, straighten, shine, standardize, sustain: a tool for organizing work by performing each of these steps
5 Whys	A problem solving tool designed to assess an issue by asking why as a means to work from the symptoms back to the root causes
6Ms	Man, machines, methods, materials, measurement, and milieu: the six categories from a fishbone diagram used to assess issues and understand the root causes

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Chapter 1: Introduction

Manufacturing companies today are filled with a variety of methods and tools to support a lean workplace. Most have implemented a formal lean/six sigma system designed to control and improve processes and ultimately to provide higher quality products to their customers as quickly and as inexpensively as possible. These systems come in many shapes and sizes as companies usually look for a customized solution consistent with their culture and vision. In the end, they tend to look a lot like a set of tools popularized by the Toyota Production System (TPS), but many appear to be poorly implemented.

The tools popularized by TPS are useful but they must be appropriately understood. Consider the following example. When I gave my two year old son a toothbrush and walked out of the bathroom for a moment, I came back to find him using it to scrub the bathroom. While cleaning the bathroom is a worthwhile task, there are much better tools for that than a toothbrush. Obviously, the point of handing him the toothbrush was so that he would brush his teeth. Once I showed him what a toothbrush is for, and how to use it properly, he was able to practice and become proficient so that he could use it without my help. However, he still needs regular reminders to brush his teeth as he does not understand the implications of not brushing and the impact it will have on him and thus he does not have sufficient motivation. The point is that providing people with the correct tools for a job is helpful, but to effectively solve problems, those who use the tools must understand their purpose. Having a good teacher will help bridge the knowledge gap, but in the end the user of the tools must have the motivation and discipline to continue using them for their intended purpose.

Lean goes far beyond having a set of tools to solve problems. It is a framework for continuous improvement. Lean organizations do not just fix the symptoms related to their problems; they identify and eliminate the root of problems so they will not reoccur. It is not essential that the root of a problem be correctly identified on the first try. The learning that occurs through experimentation is the most valuable piece of the entire problem solving process. As improvement efforts provide new insights through hands-on experience, employees become capable of solving increasingly complex problems. The learning cycle is perpetual as changing business needs and conditions require constant flexibility and adaptability. Lean organizations acknowledge that there is no "right" solution, because there is always room for improvement.

Creating a lean work environment requires the right tools, knowing how to use those tools, and instilling people with the capability and motivation to solve problems. While these are often recognized as pillars of lean, there are still plenty of other details that get in the way of successfully implementing this system. This thesis further explores some of the issues that are faced in a repair operation. It focuses on a case study based on a six month internship at Hamilton Sundstrand's electronics repair facility in Phoenix, Arizona and the challenges they face as they embark on a lean transformation.

1.1 Project Motivation

The Hamilton Sundstrand electronics repair organization in Phoenix (Repair) has consistently underperformed in terms of turn-around times (TAT) and customer service levels (CSL) in comparison to the other electronics repair sites in the company. In 2010, Windsor Locks, the repair site that most closely parallels Phoenix, had turn-around times that were 30% better and delivered 26% more parts on time than Phoenix. There are however, some things that make Phoenix unique, one of which is the fact that they are integrated with the production organization in Phoenix (Production) for the test operation and some of the support functions. Nonetheless, Repair has struggled to significantly improve their performance. They have been improving, but the rate of improvement is only on par with the other US facilities while their actual performance still lags behind these other sites. Figure 1 shows this comparison.

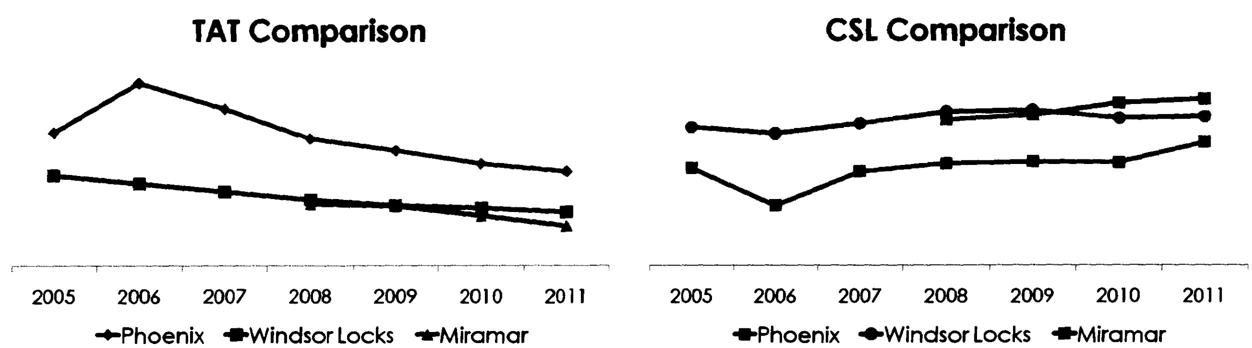

Figure 1: Key Repair Performance Metrics

Hamilton Sundstrand wants to accelerate the rate of improvement and figure out how to close the gap between Phoenix and their other sites. The primary goal is to reduce TAT by 60% and increase CSL by 35%. To this end, they have made a strategic decision to purchase new test equipment so that

Repair can operate independently of Production. The expectation is that this will allow the repair team to dramatically improve performance and achieve their goals.

1.2 Problem Definition

As mentioned above, a strategy had already been formed prior to my internship to transition to a stand-alone business model. But the problem Hamilton Sundstrand is trying to solve is how to reduce turn-around time and improve customer service levels. Repair manages a relatively small portion of their business from end to end. Historical data shows that they are not performing at the desired levels even for the parts which they handle independently. In addition to purchasing new equipment, forming U-shaped cells, and consolidating the repair footprint, they need to become lean. The variability of the process is one of the primary obstacles to implementing lean methodologies that have worked well for others.

Electronics repair is a highly variable process. Nobody can predict when parts will break or which parts will break at any given time. The parts vary greatly in terms of the functions they perform on an aircraft as well as the level of complexity of their circuitry. Additionally, repair contracts are not standardized. They are created for original equipment manufacturers (OEMs, i.e. Boeing) as well as for specific customers (i.e. airlines). The contracts specify things like:

- The length of time Hamilton Sundstrand will take to complete a repair
- Penalties associated with not delivering on time
- Whether or not it is acceptable to swap out circuit boards
- Requirements for a spare part to be swapped with the broken part

All of these variables make it difficult to define processes and create meaningful standards. They require a high-level of coordination between everyone involved in the repair process.

1.3 Hypothesis

During the course of my internship, it became clear that purchasing equipment was not the full answer to improving Repair's performance; that is just the tip of the iceberg. Hamilton Sundstrand's parent company, United Technologies Corporation (UTC), has invested heavily in the creation of their continuous improvement system, Achieving Competitive Excellence (ACE). Unfortunately, its implementation has been less than successful in Phoenix. My research led me to the conclusion that the problem is not with the operating system itself. ACE has a variety of tools that are useful in driving improvement and it maintains a standardized way of doing that across a very large company, which is no small task. The tools are well developed and there are training materials available to help people understand how to use them. However, the variability of repair processes has led many employees to believe that ACE is not well suited to their situation.

While the variability is a challenge, it should not completely hinder improvement. To overcome those challenges the organization must understand how the principles of lean apply to their situation. The principles of lean were first presented by Womack and Jones (2003) in *Lean Thinking*. The principles are: specify value, identify the value-stream, make value-creating steps flow, let the customer pull products, and strive for perfection.

Lean tools can be useful in applying lean principles. However, if the tools are not understood or valued by people in the organization, they are useless. According to Hayes, Wheelwright, and Clark (1988),

> Superior performance is ultimately based on the people in an organization. The right management principles, systems and procedures play an essential role, but the capabilities that create a competitive advantage come from people – their skill, discipline, motivation, ability to solve problems, and capacity for learning. Developing their potential is at the heart of high-performance manufacturing. (p. 163)

Developing people is critical because for an organization to thrive with lean, it requires continual effort from people across the organization and not just a few managers. Relying on the efforts of a few bright managers is a sure recipe for disaster. However, managers can be instrumental in teaching employees and empowering them to improve their work processes.

For a lean implementation to be successful, it must have support from the top to the bottom of the organization. Hoshin Kanri is a method that can be utilized to accomplish this. It is a planning process that focuses on the implementation of business policies and strategies in a way that aligns internal stakeholders across the organization. Carefully planned and coordinated change efforts can produce extraordinary results from any initiative. But any breakdown in linkage between stakeholders will impede the organization's ability to achieve goals effectively.

My hypothesis is, "Lean requires a set of tools that are appropriate for the specific situation. The tools have the greatest impact when practiced by every employee on a regular basis. Managers must become be capable of teaching employees to effectively use the tools to solve the problems they encounter. As lean is implemented it is important for employees at all levels to be linked together in such a way that they are driving towards a common goal." Because of the length of time a full lean transformation requires, I do not have specific transformation results from my internship to share. However, I provide examples of real problems and then examine the application of lean methodologies to these problems and the expected benefits. All of the lean methodologies applied here have been demonstrated repeatedly in the research others have performed. My intention is to provide enough detail to provoke insights that will be useful to those who are struggling to implement lean because of the unique challenges they face.

1.4 Approach

The application of lean to a repair operation is demonstrated through a case study of Hamilton Sundstrand's electronics repair facility in Phoenix. The case study looks at how lean principles could be applied in Phoenix and the potential impact. As noted in the previous section the results of this transformation may take years to achieve, so much of this discussion is qualitative and somewhat subjective. However, the value of a lean transformation is not in question here, as the results in other parts of UTC and other companies are indisputable.

1.5 Thesis Outline

Chapter 2 provides a glimpse into Hamilton Sundstrand and the electronic avionics repair business. It starts with a high-level view of the company's financial performance and organization. It then provides an overview of the customer service organization and how it is structured. Then the challenges faced in the electronic avionics repair business as well as those that are unique to Phoenix are discussed. By the end of the chapter the reader should have a basic understanding of the company and their challenges.

Chapter 3 focuses on ACE. It begins with a very brief overview of lean in general and then continues with the history of lean at UTC. It breaks down the relevant components of the ACE operating system and provides a description of each of these components.

Chapter 4 uses the principles of lean as a framework for exploring areas for improvement in Phoenix. Each of the principles is described and then specific examples are provided to show how application of each principle could improve performance in Phoenix.

Chapter 5 addresses the cultural and organizational challenges Repair faces in becoming lean. It discusses the necessity of human engagement to implement lean. It talks about the roles required of both management and employees in order for lean to be most effective. It also looks at the current organizational structure in Phoenix and some beneficial adjustments.

Chapter 6 uses Hoshin Kanri as a framework for evaluating some challenges to implementing lean. It discusses the need for alignment across the organization. It shows the roles each internal stakeholder plays in the implementation of lean and how they are linked together.

Chapter 7 is the conclusion of the thesis. It presents a brief summary of recommendations and final thoughts.

Chapter 2: Background Information

This chapter aims to provide a basic understanding of Hamilton Sundstrand's avionics repair business. It begins with an overview of the company and its place within a larger corporation. It then gives some insight into the company's organization and where Repair fits within that organization. It continues with a look at the more general challenges faced in the electronic avionics repair business and then delves deeper into specific challenges encountered in Phoenix. The challenges are followed by a discussion about the actions Hamilton Sundstrand is taking to drive improvement.

2.1 Hamilton Sundstrand Background

Hamilton Sundstrand is a leading aerospace company and a subsidiary of UTC. They manufacture a variety of aerospace systems for commercial and military aircraft and they are a major supplier for international space programs. The range of aerospace systems they produce is quite broad and includes everything from actuation systems, to auxiliary power systems, to engine controls. With sales of $6.2B in 2011, Hamilton Sundstrand accounted for approximately 10% of UTC's total revenues (UTC 2011 Annual Report, 2012). Figure 2 shows Hamilton Sundstrand's revenues for the last several years. Profit margins have been relatively stable over this time period but growth in revenues has slowed in recent years. This could be attributed to the economic downturn in recent years, but it also provides a good reason to reassess the company from end to end. Most important in that assessment is to understand how Hamilton Sundstrand provides value to their customers, what their existing sources of competitive advantage are, and what opportunities remain for developing a competitive advantage.

Hamilton Sundstrand was formed in 1999 following a merger between Hamilton Standard and Sundstrand Corporation. Sundstrand Corporation was based in Rockford, Illinois and Hamilton Standard was based in Windsor Locks, CT. Hamilton Sundstrand's aircraft systems business is primarily divided in two ways. First, there are business units segmented by systems (i.e. actuator, auxiliary power) and all products related to those systems are developed by that business unit. Second, there are business units segmented by function (i.e. operations and customer service). Of primary interest is the customer service organization, which is discussed in the following section. Of secondary importance is the operations business unit. Operations, as one would expect, is responsible for production of all Hamilton Sundstrand products. The manufacturing process for electronic avionics components includes testing parts to ensure airworthiness. This testing is done on expensive, specialized test equipment. The same equipment is required to diagnose parts when they are returned for repair or modification. However, repair and production operate independently of each other in all Hamilton Sundstrand shops except for Phoenix.

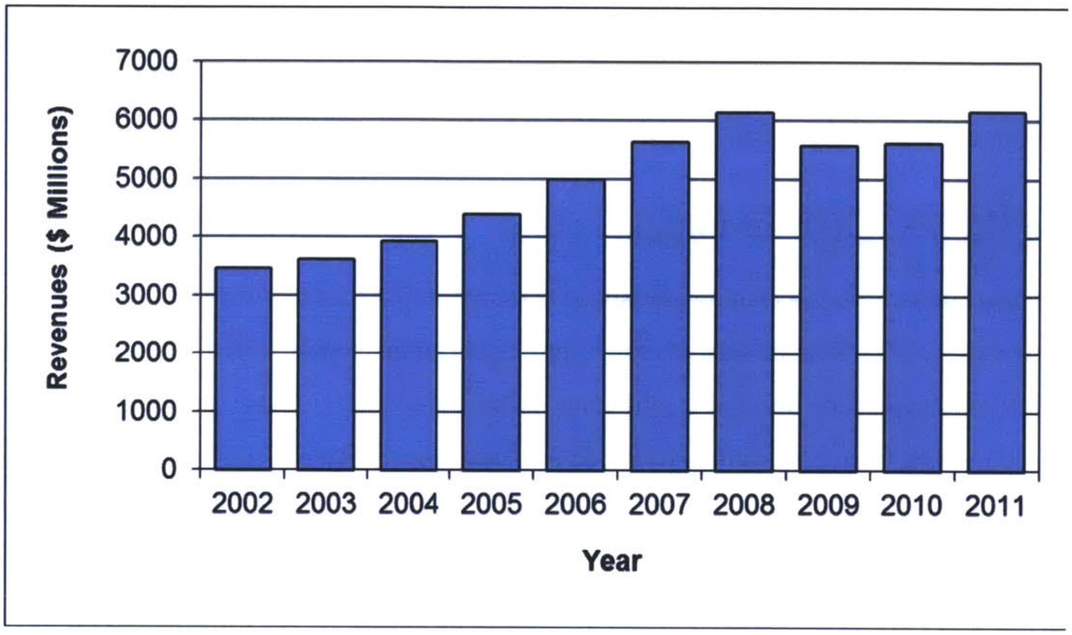

Figure 2: Hamilton Sundstrand Historical Financial Performance (UTC Annual Reports, 2012)

2.2 Customer Service Organization

Hamilton Sundstrand's customer service division is responsible for the aftermarket support of their products. This includes things like on-site support and repair operations. The largest branch of the customer service division is the Worldwide Repair Operations division. Worldwide Repair Operations has twelve repair facilities around the globe.

In the US, there are two other facilities (Windsor Locks, CT and Miramar, FL) with significant electronics repair operations besides Phoenix. Each of the facilities repair different parts with almost no overlap in their capabilities. Phoenix and Windsor Locks are both dedicated to electronics repair. Each shop repairs about 7,000 parts per year. Miramar has a small section of their shop dedicated to electronics repair, but the majority of repair operation in Miramar is for fixing mechanical components. Windsor Locks is responsible for repairing parts that were originally developed by the Hamilton Standard business. Phoenix primarily repairs parts that were developed by the Sundstrand Corporation. Many of these parts are now manufactured in Phoenix.

Phoenix Repair employees are organized by work functions and are grouped together geographically within the plant except for test technicians who are spread over the entire plant. The functional organization is depicted in Figure 3.

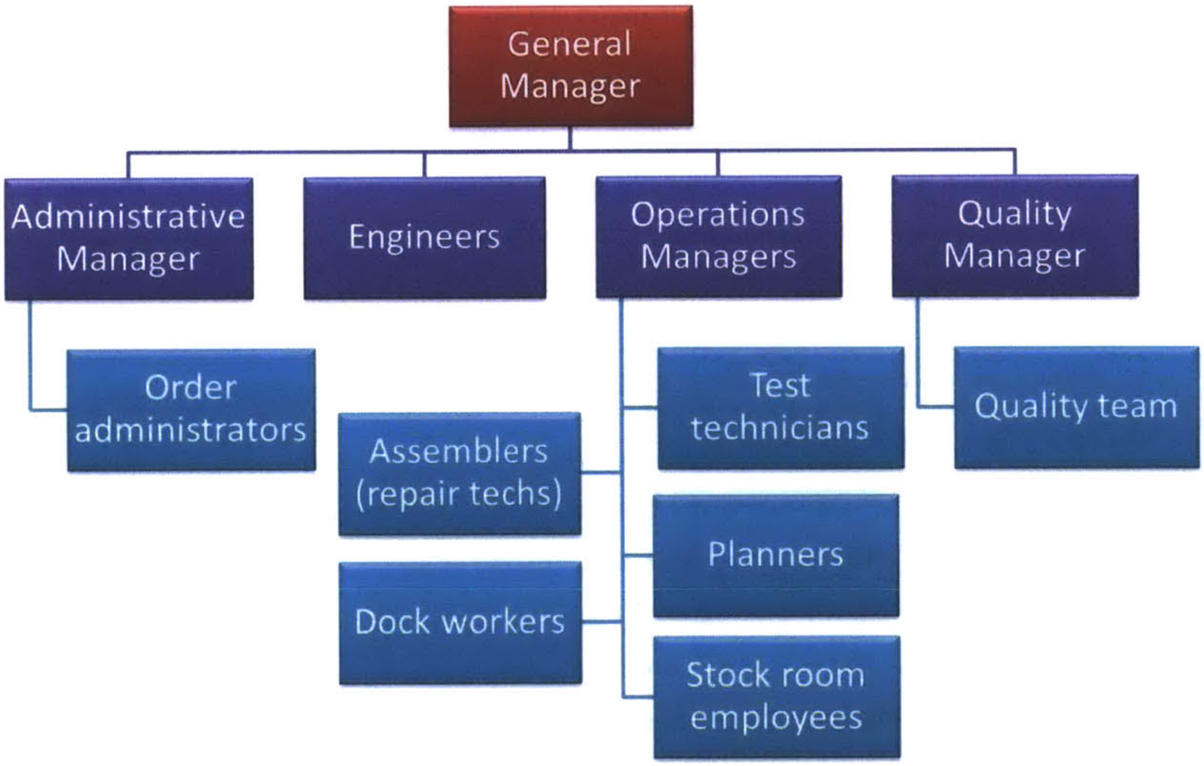

Figure 3: Repair's Functional Organization

The functional organization is driven by a few factors. Those factors are:

1. Nature of the repair work: Electronics repair is a highly technical operation and it requires skilled labor throughout the process. Test technicians must be capable of reading circuit card schematics and understanding the expected behaviors of a wide variety of circuits. Assemblers must be able to remove individual components from a circuit card without causing damage and solder in new components with high quality. Quality inspectors need to have enough skill to review others' work and visually spot mistakes and sloppy

workmanship. It takes a significant amount of time for people to become proficient in any one of these areas and so employees generally hire into a specific function and progress within that function.

2. Efficient handling of uneven demand: Throughout the repair process, parts flow back and forth between test technicians and assemblers and quality inspectors. Since the assemblers and quality inspectors are not specialized by the part being processed, employees in these areas can work on any part. It is more sensible to have a central area where parts are processed so that assemblers and quality inspectors do not have to move around the entire shop looking for work.
3. Space constraints: The plant is filled to capacity with people and test equipment. Repair's functional teams fill in gaps created by the production lines' arrangement (see Figure 4).

2.3 General Challenges of the Electronic Avionics Repair Business

The electronic avionics repair business has a variety of challenges. Some of the challenges include: process variation, priorities, expensive test equipment, fault isolation, technical expertise required for repair, and variability in the number and complexity of parts replaced during repair. These challenges are outlined below.

The most significant challenge is the inherent variability of the repair process. Many books and papers about lean manufacturing focus on creating a level-loaded facility capable of satisfying customer demand using a pull system. Because units coming into the shop are customer specific and cannot be swapped with one another, it is not possible to create the same type of pull system. Units are pushed into the process when they are removed from an aircraft due to system faults and failures. Customers keep a small stock of units, but they cannot keep large stocks of each part their planes require. This is due to the number of unique parts on each aircraft, the scope of customers' networks, and the high inventory holding cost. The cost of an airplane being grounded can be as high as $150,000 per hour (The Boeing Company, 2012). Due to the high cost of grounding, airlines cannot afford to have their parts repaired slowly, so they push for better turn-around times. This adds a level of complexity as customers frequently call to get status updates and try to push their units to the front of the line.

Another complicating factor is the variation from one contract to the next and establishing priorities based on those variations. The military has repair contracts that are more lenient on repair lead times. However, government regulations require companies to prioritize certain military units over all other units from any customer. This completely undermines the idea of single-piece flow. Commercial contracts create an equally challenging task. OEMs ultimately decide on suppliers for future airplane programs and can negotiate favorable terms including short lead times for repair. Their satisfaction is a priority, and meeting contractual commitments is especially important for these customers. Airlines sometimes have separate agreements with different lead time requirements. Even a single customer may have different lead time requirements depending on the part and the diagnosis. The situation makes establishing priorities a challenge, and any non-first in, first out (FIFO) priority system disrupts flow and increases work in-process (WIP), which causes higher turn-around times.

Yet another challenge is the test equipment itself. All components are tested when they come into the shop and again before they are returned to the customer. Most of those tests have been automated, but the automated test equipment is very expensive. Universal test rigs capable of testing a variety of parts can cost upwards of three million dollars. In addition to the universal rig, each part requires a unique test adapter which can also be expensive. The price of a test adapter varies widely depending on the complexity of the part and whether or not an adapter has been designed for the given test platform for a similar part. Dedicated test rigs, while less expensive, can only test a few types of parts at the most and occupy as much floor space as a universal test rig. The various test platforms are not standardized and each one requires training to operate. Both types of rigs only test one unit at a time and tests typically run between 1-2 hours in length. Each unit requires time on a test rig for initial and final testing and most troubleshooting efforts which include checking that the repair actions taken have eliminated faults observed during testing. All of these issues complicate capital investment decisions as well as the flow of parts through the shop.

To further complicate things, fault isolation down to the component level can be extremely challenging. One problem test technicians encounter is the existence of intermittent faults. Unlike mechanical assemblies where problems tend to be more obvious, an electronic component may exhibit failures only momentarily. In order to thoroughly check all circuits, automated tests run quickly and look at snapshots of data to determine the health of the circuits. A test could be run four or five times before a failure is captured. Supplementary test equipment has been developed to evaluate units during temperature cycles and while vibrating them, but this still does not always make the faults manifest themselves. Technicians are faced with difficult decisions about how long to continue troubleshooting to the component level before they replace an entire circuit card. The cost of each circuit card varies based on the specific unit. As a result, there is no defined standard for the amount of time a technician should spend isolating faults down to the component level economically.

Once a technician believes they have isolated the fault to the component level, it is not uncommon to find that the repairs made do not resolve all the issues observed. When there are failed components at the front end of a circuit, it can be difficult to see failed components downstream because they are not getting their expected input. This is a common source of rework.

Electronic avionics repair is a highly technical process. It is difficult to find skilled test technicians capable of reading schematics and understanding expected circuit behaviors so that they can identify failures during troubleshooting. Even skilled test technicians must spend time to learn each different product for which they are responsible. In addition to the product, they must learn and become proficient on the associated test platform. Engineers, assemblers (repair technicians), and quality inspectors also face a high degree of variability in their work because of the product mix and thus require significant technical expertise.

The process of replacing components is also extremely variable. This variability depends on which components need to be replaced, the number of components, and the complexity of the board. Since it is not clear how long any board should take to repair, there are no standards, no expectations, and no goals regarding individual performance.

2.4 Challenges Specific to Phoenix Repair

Historically, Phoenix Repair has underperformed in comparison to other electronics repair organizations inside Hamilton Sundstrand. Its closest counterpart is the repair operation based in Windsor Locks, Connecticut. One operational difference between the organizations is that Windsor Locks owns all of its test rigs and runs independently of any other business unit. In Phoenix, the repair organization and the production organization report up through separate business units but both operate within the same facility and they share many resources.

The building is controlled by Production, and Repair pays them allocations for the space they occupy. Production also owns, schedules, and staffs many of the test rigs that Repair needs in order to troubleshoot and recertify units removed from service. In addition, Production manages many of the employees in support roles including product support engineering, test support engineering, HR and EH&S. No other electronics repair facility is integrated in this way.

Because Production owns all of the test rigs they have determined their location in the shop. The test rigs are located in Production's flow lines. The flow lines are set up by product group. While this works for Production, it is not an optimum layout for Repair. Figure 4 shows the relative layout of the facility. The test rigs are marked with yellow squares and the location of other operations' areas are labeled and highlighted in blue.

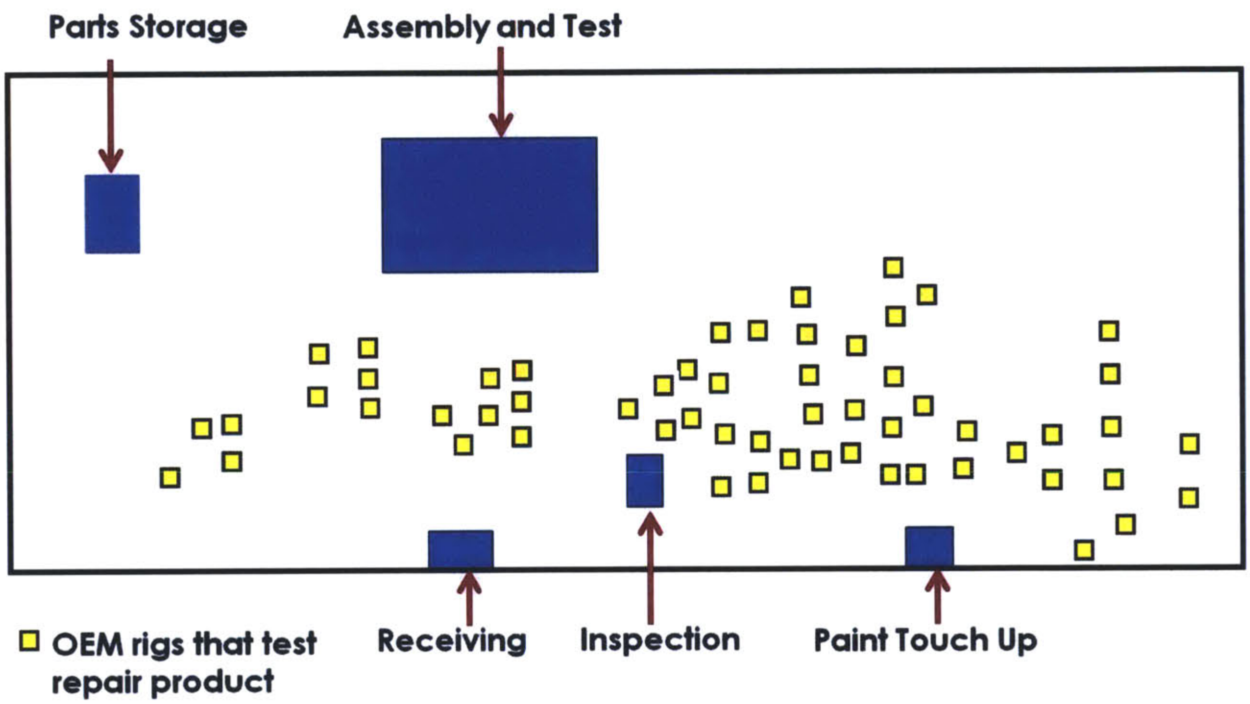

Figure 4: Hamilton Sundstrand Phoenix Facility Layout

The repair process primarily consists of receiving, receiving inspection, incoming test, troubleshooting, repair, repair inspection, final test, engineering approval, paint, quality inspection and shipping. If fault isolation was easier and the parts could be diagnosed on the first try, the flow in the shop would be pretty straightforward. However, due to the challenges with diagnosis, there is more rework than desirable and the flow is much more convoluted as parts move back and forth between test technicians, engineers, assemblers (associates responsible for physically replacing faulty components) and quality inspectors. The actual flow of work is depicted in Figure 5. The confusing flow requires careful coordination between groups to ensure that parts do not get lost and that everyone understands where each part is in the process at any given time. The effort to keep things running smoothly is complicated by the physical distance between operations which forces operators to spend a lot of time walking back and forth or talking on the phone with one another. Additionally, the shop runs three shifts and information sharing and work handoffs are critical to keeping parts moving efficiently through the process.

2.5 Current Strategy

The current strategy is to move from the integrated business model that exists today to a stand-alone approach wherein Repair will be capable of repairing all parts they are responsible for without relying on Production. This will be accomplished by purchasing new test equipment. Repair will then be allocated a block of space at one end of the building so that they can consolidate their footprint and layout the cells as they see fit. In addition, they are looking to add at least some additional engineering staff to their payroll. The expectation is that with the new equipment, new layout, and additional engineers the team will be able to reach the goal to reduce turn-around time by 60% and improve customer service levels by 35%.

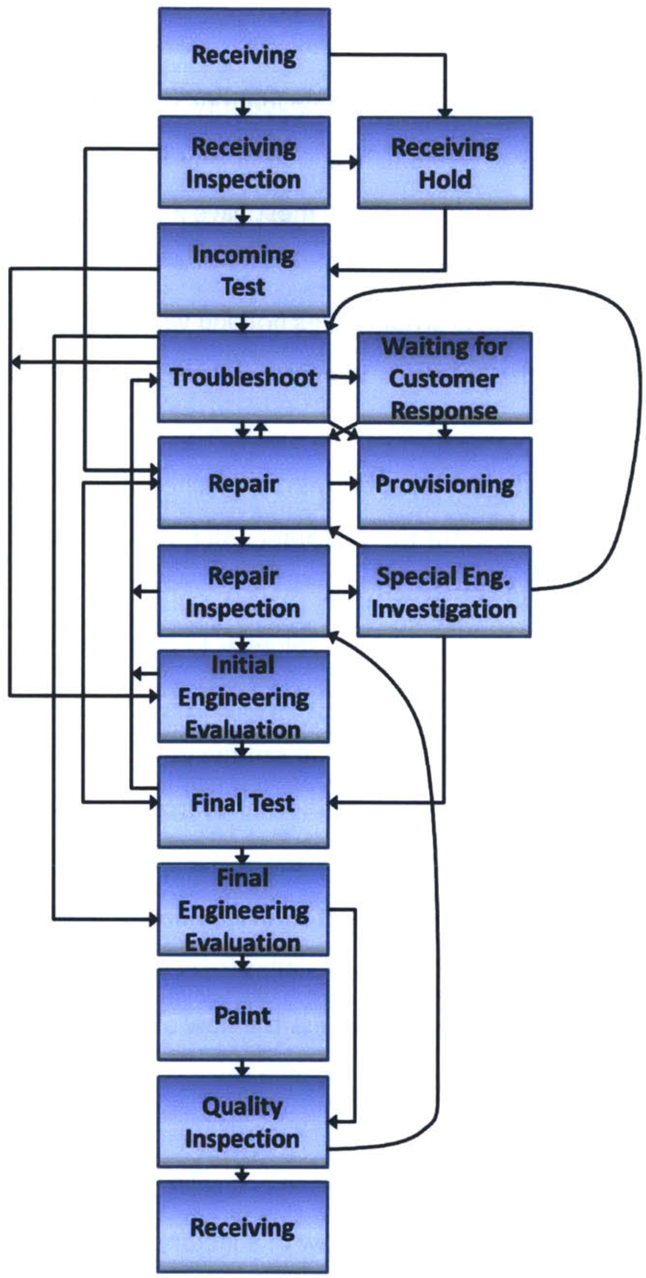

Figure 5: Repair Process Flow

Chapter 3: Lean at UTC

Lean tools and frameworks are designed to help identify and eliminate waste. As part of TPS, Taiichi Ohno identified seven sources of waste (Ohno, 1988). This list is utilized by almost every lean practitioner. In addition to the seven original wastes, most have added underutilization of people to the list. These eight wastes are described below.

- **Transportation** – Moving products around does not add value to the product. Material handlers' time adds cost to the process and movement increases the risk of damage to the product.
- **Inventory** – Any raw materials, work-in progress, or finished goods that have not been delivered to the customer do not add value for the customer. All forms of inventory tie up capital which otherwise could be used more constructively.
- **Motion** – Excessive movement required by employees to perform their tasks is undesirable. This happens because work stations are poorly laid out, tooling is not ergonomically friendly, and a variety of other reasons. Many also point out the potential for injury to workers caused by excess motion repeated over and over as another source of waste associated with unnecessary movement.
- **Waiting** – Often one of the largest portions of total lead time is waiting. This includes any time a product is sitting in the shop and not actively having work performed on it. While there are many causes of waiting, it is important to assess the flow of an operation to understand the expected wait times at each step.
- **Over-production** – Producing more than is necessary is wasteful in a number of ways. It leads to a buildup of inventory and increases storage costs. It is also likely to increase cycle time as unnecessary items are introduced into the flow of a factory.
- **Over-processing** – Over-processing occurs whenever a company does more to products than what is expected by customers. In some cases it is the result of companies investing into expensive, high-precision equipment when simpler more flexible equipment would suffice.
- **Defects** – Defects can be extremely costly. They increase scrap, increase rework, require rescheduling, and reduce the overall capacity of a plant.

- **People** – Many companies will tell you that "people are our most valuable resource". In line with this thinking, any company personnel that are underutilized in terms of their skills, abilities, and ideas is a shame.

There is no shortage of documentation in books, journal articles, case studies and other publications demonstrating the merits of lean. Virtually everyone agrees that there is no single set of tools or framework that is that is right for every company or even every situation within a company. Furthermore, an operation cannot become lean by simply following a recipe. Many researchers have presented unique frameworks and descriptions of tools utilized by successful companies. In the end, each company must sort through all the information available and create a system that works for their situation and aligns with their goals and strategies.

As part of its lean initiative, UTC created its operating system designed to drive quality and productivity in their businesses. This system is called, Achieving Competitive Excellence or ACE. The first section of this chapter contains a short history of ACE. The history is followed by a basic description of some of the relevant tools and methods used as part of the ACE operating system.

3.1 Foundations

The foundations of ACE can be traced back to former UTC CEO, George David. In 1986, David was appointed President of Otis Elevator. Through a joint venture between Otis Elevator and Matsushita (Panasonic), he met Yuzuru Ito who became his mentor for all things quality (Roth, 2010). Then in 1992 David was appointed President of UTC, in 1994 CEO of UTC, and finally in 1997 Chairman of UTC. In 1994, he convinced Ito to come to Connecticut (headquarters for UTC) to work as a quality consultant. It was in this role that Ito helped build on the growing focus on quality at UTC and was instrumental in the creation of ACE and Ito University, the training and education program designed to support and institutionalize ACE. UTC's financial success since ACE was launched in 1998 speaks for itself. According to Roth (2010), David attributed growth from 5% operating margins in the 1990s to the 14% operating margins in 2007 to the successfulness of ACE. David also noted, "Every time we do a lean event in a plant, and this is broadly true, we double capacity and halve cost" (as cited by Roth, 2010).

ACE is divided into three main features: culture, tools/methodologies, and competency. Each of these is reviewed and discussed in the following sections of this chapter.

3.2 Culture

The culture of ACE is founded upon creating value for customers. It does this through establishing good processes for consistently delivering high quality products to customers in a timely manner. Based on the metrics for these processes, feedback from customers, and overarching business strategies, changes are made to the processes to improve them and bring them into alignment with company goals and customer expectations. This system is based on a feedback structure designed to make sure the company is constantly reevaluating goals and ensuring that the processes in place can support those goals. Figure 6 illustrates the concept.

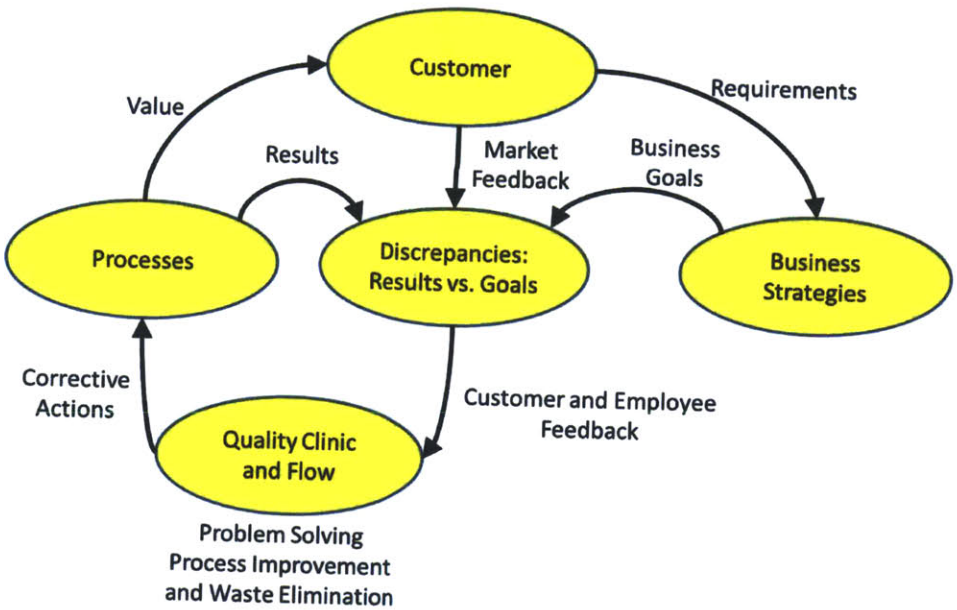

Figure 6: ACE Culture (adapted from Achieving Competitive Excellence, n.d.)

3.3 Tools / Methodologies

This culture of continuous improvement is supported by a set of tools and methodologies. These fall into three main categories: problem solving, process improvement and waste elimination, and decision making. However, only the first two are discussed here because the decision-making process does not fit our discussion.

3.3.1 Problem Solving

A key element of ACE is the focus on problem solving and the process they have established to help people do this. In this system, problems are not viewed in a negative light, but rather as opportunities to learn and to get better. Excellent performance can only be achieved by understanding the problems that exist, working to discover the underlying causes, and then taking corrective action. The ACE problem solving process follows the DIVE methodology. This consists of the following:

- Define the problem
- Investigate the problem
- Verify the root causes and propose mistake-proof solutions
- Ensure the desired corrective action is implemented and achieved (Achieving Competitive Excellence, n.d.)

Problem definition starts by turning to both internal and external stakeholders for feedback. Externally, it comes from customers. Market data and customer surveys are regularly collected and used to identify problems with customer satisfaction. Internally it comes from employees, through quality clinic process charts (QCPC). QCPCs look at data collected from employees in regards to turnbacks and escapes. Pareto charts highlight the most prominent problems reported for a particular process and are used to help teams focus on resolving the most pressing issues.

Once a problem is defined, the investigation phase begins. The investigation phase focuses on relentless root cause analysis. Root causes are identified using popular tools like fishbone diagrams or following the 5 Whys method. Fishbone diagrams are designed to look at the cause and effect of a given problem. In a manufacturing environment, the causes are typically broken down into six main categories sometimes referred to as the 6Ms: man, machines, methods, materials, measurement, and milieu. 5 Whys analysis was developed by Sakichi Toyoda and was implemented as part of TPS (Ohno, 1988). Its intent is to dig down to the true source of the problem to prevent the problem from ever recurring as opposed to simply addressing the symptoms of the problem. After the root cause is identified, teams move forward looking for solutions consistent with the concept of *poka-yoke*, the Japanese term for mistake-proofing. Following this principle, corrective actions should be irreversible, at minimal cost, simple to use, easy to install, durable, easy to maintain, and not hinder the user (Achieving Competitive Excellence, n.d.).

Following the investigation phase, teams verify that they have identified the true root causes and devised mistake-proof solutions to address those causes. Root causes must be controllable, address fundamental breakdowns of the process, and if corrected, ensure that the problem will not recur (Achieving Competitive Excellence, n.d.). Solutions are broken down into three levels of mistake proofing. Level-three solutions are those for which the process had additional inspection built-in to catch mistakes after the process but before escaping to the customer. Level-two solutions allow problems to be identified as part of the process and corrected on the spot. Level-one solutions eliminate the source of the problem so that it can never happen within the process. Obviously, level-one solutions are the most desirable, but in certain cases, other levels are deemed acceptable. The selected solution is verified by subjecting it to the "nasty" test, a worst-case scenario designed to confirm effectiveness of the solution (Mistake Proofing, 2012).

The final step of the ACE problem solving method is to ensure the effectiveness of the corrective actions. All employees are trained to adopt changes to the process and the new process steps are documented in the standard work for that process along with the lessons learned and rationale for the changes. In addition, control plans are created and process data is monitored.

3.3.2 Process Improvement and Waste Elimination

The main tools utilized by ACE towards process improvement and waste elimination include: new 5S, value-stream management, process certification, and standard work. A short description for each of the tools is provided below.

5S is a set of principles by which work is designed to organize and simplify work processes. It comes from the Japanese terms *seiri*, *seiton*, *seisou*, *seiketsu*, and *shitsuke*. These terms are most commonly translated as sort, straighten, shine, standardize and sustain. As the workplace is sorted, all items that are unnecessary are removed. Everything that remains is then straightened. A designated space is made for everything required to perform a task. In this system, when something goes missing, it is obvious to even the casual observer. The work area is then cleaned to provide a comfortable work environment. One common benefit noted from cleaning is the ease with which equipment maintenance issues can be identified. For example, if a machine is leaking oil, it is found quickly and the underlying problem is resolved, often times before the equipment quits working altogether. The process for cleaning and organizing must be standardized and scheduled to create consistent habits. With the standardized methods for 5S in place, employees are expected to sustain the effort. The "new" part of new 5S was promoted by Ito because of the importance he placed on the human spirit and the need to engage employees to affect change (Roth, 2010). This idea is represented in the ring around Figure 7.

Figure 7: New 5S (5S: Visual Workplace, 2012)

Value-stream management is the technique by which processes are improved. It starts by looking at processes, evaluating the maturity and impact of those processes, and strategically working on processes, one at time, to eliminate waste. The current state is mapped and things like total cycle time, touch time, inventory, and delays are reviewed. Then, during a series of *kaizen* events, teams apply lean principles like implementing FIFO lanes or adjusting takt time as the means to drive process improvements based on the opportunities identified.

All processes should be subjected to a certification process designed to ensure customers' expectations are met. Process certification aims to increase predictability and minimize variability (Process Certification, 2012). The steps of certification include:

1. Forming teams
2. Defining the process
3. Reviewing and assessing the process
4. Establishing control and capability
5. Documenting control plans
6. Certifying the process (Process Certification, 2012)

Process robustness is also assessed to make sure that customer needs can be met. To assess robustness, teams start by creating SIPOCs, which define suppliers, inputs, process, outputs, and customers for a process. When the process does not meet expectations outlined in the SIPOC, teams enter turnbacks, which detail reasons why expectations were not met. Turnback data is then used to identify and map out improvement projects. Metrics track the overall performance of the process and customer surveys are used to ensure high customer satisfaction. Process maturity is evaluated looking at QCPC team activities, standard work, and the state of value-stream mapping.

Standard work is a method used for documenting each process for maximum repeatability and is also the place where historical information about the process should be recorded. It details process steps, metrics, standards, visual controls, best practices, and lessons learned. It defines the, who, what, when, where, why, and how for each process. Ideally, someone doing a task for the first time could gain immense insight and understanding of the process from reviewing the standard work (Achieving Competitive Excellence, n.d.).

3.4 Competency

ACE loses value without proper training. Training comes in a variety of forms. Ito University provides training on the fundamental principles of ACE and helps employee understand how to utilize it. In addition, training modules have been designed to teach about specific ACE tools. Lean education continues on the job through participation on ACE teams, working on continuous improvement projects, *kaizen* events, and so forth. Finally, employees are encouraged to look outside their work areas and benchmark internally and externally to increase perspective and understanding of what others are doing that can be leveraged.

Chapter 4: Overcoming Operational Challenges

The business results across UTC over the last fifteen years demonstrate the effectiveness of ACE. The tools have been tried and tested with well documented success. However, Phoenix has not realized the productivity gains that are possible through effective utilization of their operating system. Training material for ACE focuses on tools and understanding how to use them. Yet the tools have not produced the desired results in Phoenix. One might wonder, how can lean work in a highly variable repair operation? Are the principles of lean valid and useful in this context? This chapter explores the value of lean through the principles of lean presented by Womack and Jones in *Lean Thinking*. However, the concept of pull is excluded. Pull is a concept more suited for a traditional manufacturing environment but it does not apply as well to the situation in the repair shop. The goal of a pull system is to establish single-piece flow and to force people to think in terms of "right-sizing" their equipment and processes. This avoids delays caused by batch-and-queue systems and overproduction. These characteristics of a pull system should still be present in a repair shop, but parts are pushed into the system. The remaining four principles are diagrammed in Figure 8.

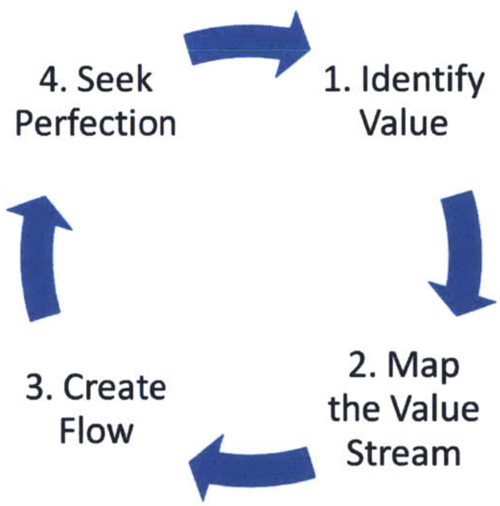

Figure 8: Lean Principles (adapted from Lean Enterprise Institute Inc., 2009)

Each principle is applied to the Phoenix repair shop and demonstrated through specific examples. The intent is not to be exhaustive in assessing the value of these principles, but rather to show from a high-level perspective, some areas where significant improvement is possible by making adjustments consistent with lean thinking.

4.1 Specify Value

The first principle of lean is to specify value. In order to do this, we must understand value from the viewpoint of the customer. Understanding value does not help create flow, but it does ensure that we look at the process anew and start to remove unnecessary pieces from antiquated processes.

Repair's commercial customers (i.e. airlines) value having working parts for their airplanes that provide a comfortable experience for passengers at a reasonable price. Military customers value the same thing but instead of comfort they are looking for high performance. From an overall product standpoint, they really value product reliability. From a holistic point of view, one could question the value of the entire maintenance model in terms of how airplanes are serviced, but that is outside the scope of this document. For our purposes, we assume the current maintenance model. Even the most reliable parts fail occasionally, and in situations where this happens, customers value quick repairs that restore parts to a reliable condition. In other words, they expect that when they put a repaired unit on a plane it is not going to fail again in the first few months of use. With this understanding of value, we can begin to evaluate the value-stream and identify the steps of the repair process that add value.

4.2 Identify the Value-Stream

The value-stream is the set of all steps required to produce a given product. To assess Repair's current value-stream, we start by identifying the value-added steps of the process and then comparing those against the existing process. Assuming replacement is significantly more expensive and less profitable than repair (which is mostly true for this shop); the first value-added step is troubleshooting. Once faulty components or circuitry have been identified, the next step is replacing the faulty components or circuit cards. The final value-added step is to verify that the part is fully functional. These are the only activities that customers are really willing to pay for as part of the repair process. But the ideal flow, based on the repair process when I arrived in Phoenix, is illustrated in Figure 9. The thirteen steps from Figure 9 are broken down and simplified for ease of discussion.

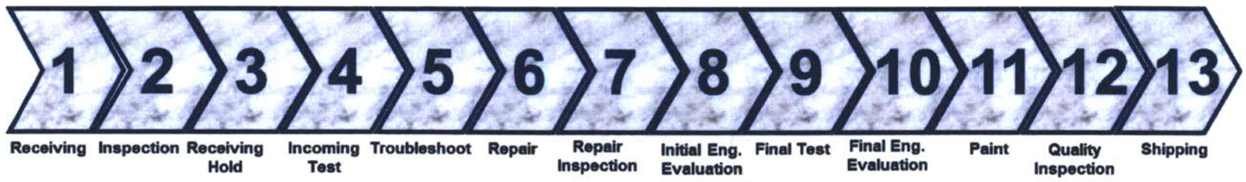

Figure 9: Ideal Repair Process

1. Receiving – When a package arrives in Phoenix it is separated from Production units and parts and stacked in a pile for Repair. It is then unpacked and preliminarily inspected to determine if further inspection is necessary by a member of the quality team.
2. Receiving Inspection – If the team working at the dock determines that additional inspection is necessary, a member of the quality team performs this inspection and determines if the unit is damaged in a way that requires attention before it undergoes automated testing.
3. Receiving Hold – Once a unit moves past receiving, or receiving inspection, dock workers scan paperwork and create work orders which are then supplemented with detailed instructions by order administrators who are familiar with the requirements and needs of the individual customers. At this point, the work order is sent electronically back to the team at the dock where it is printed out and delivered with the unit to the test cell. Order administrators also assess the status of the customer's account to ensure that the customer is current on their payments. The only units that are actually "held" are those whose accounts have past due balances.
4. Incoming Test – Incoming tests are automated and they are the same tests that are performed to certify that a unit is flight-worthy prior to returning it to the customer. If the test fails, the technician immediately begins troubleshooting based on the specific failures. If the test passes, the technician consults with an operations support engineer to determine next steps. Usually, these conversations result in additional testing.
5. Troubleshoot – Test technicians use the results of the incoming test to try to isolate the component that is causing the test failures. Once they have some idea which components are causing the failures, they send the unit to the repair operation.
6. Repair – When a unit comes to the repair operation from test technicians, it waits on a rack until the components required to perform the repair are ready and placed with the unit. Once the components are all ready, the unit is opened, and faulty components are removed and replaced.

7. Repair Inspection – When repair work is complete, qualified technicians or members of the quality team inspect the work to ensure that no mistakes were made. Assuming that the work passes inspection, the unit is sent back to the repair operation where it is closed and then sent to the test operation for verification, to ensure that it passes the tests that it failed during initial testing.
8. Initial Engineering Evaluation – Once all tests pass, a unit is sent to the operations support engineer responsible for the specific product family. The engineer reviews the repair history and correlates the failures observed on the aircraft to the repairs performed.
9. Final Test – Following initial engineering evaluation, a unit is subjected to the same tests performed during initial testing. These tests demonstrate that the unit is airworthy and can be returned to service.
10. Final Engineering Evaluation – After the final round of testing passes, an operations support engineer writes up a summary of work performed at the repair shop including failures observed and corrective actions taken to resolve the issues.
11. Paint – Once engineers finish the write-up, units that require slow drying paint are sent to a paint station. All other units are sent directly to quality inspection.
12. Quality Inspection – During the final quality check the unit is inspected externally to ensure everything is put back together correctly. Also, paperwork is evaluated for completeness and the work performed is reviewed to make sure that no process steps were missed.
13. Shipping – In the final step of the process, the unit is packaged and loaded onto trucks for return to the customer.

With an understanding of value in the eyes of the customer and a reasonable understanding of the high-level repair process we can look for opportunities to streamline the process. A few key examples of this are demonstrated below.

In the receiving hold operation, work orders are sent back and forth between dock workers and order administrators. This is a point of confusion where units get stuck with no clear owner. Sometimes dock workers think that order administrators are updating work orders for a unit while order administrators assume that dock workers are processing it. Neither group is responsible for making sure units are moved from the operation and there is currently no way to separately measure the groups to determine how much time each group spends processing units at this operation. Even when work handoffs go smoothly, the dock workers do their initial processing then store the units on a rack only to pick them back up and deliver them to the appropriate test cells. An alternative that eliminates the need for dock workers to touch the units repeatedly is for them to complete their work and deliver the units immediately to the test cells at the time they move them electronically into this operation in the IT system. Order administrators would then have responsibility for the entire operation and could signal test technicians that units are ready for testing by moving them in the IT system to the incoming test operation. This would require test technicians to pull up the work orders, but they do this anyways since they need to read the detailed instructions from the order administrators. Without making any other changes, this action is expected to reduce total flow time by roughly 2.8%.

Another area for improvement is the automated testing that each unit is subjected to upon arrival. To a great extent this is necessary since technicians have little visibility into what caused the removal from the aircraft. Although many parts store some information about the faults, technicians generally do not have the tools to appropriately decode this data. Almost all parts are capable of storing more information with some relatively minor modifications to either hardware or software or both. If the data were stored more effectively, technicians could immediately begin troubleshooting the failure while targeting specific areas of the circuitry based on the available data. Additionally, problem reports from customers could provide more insight into the failures observed on the aircraft and the maintenance response to those failures. These recommendations require the involvement of the design teams and customers. While these changes will take some time to implement, they present an enormous potential for future improvement.

The level of engineering involvement in the repair process should also be reassessed. Customers are not concerned with the title of the employees who work on their units as long as they come back operating properly. Yet, engineers review and approve the repairs done for every single part that passes through the shop. They are also responsible for providing a summary of work performed and correlating the repairs done with the failure reports from the field. Based on observations and benchmarking of other facilities, it is clear that Phoenix engineers are much more involved in the process than is required. Test technicians are capable of isolating failures and there is no reason to assume that units that pass final test need further evaluation. Engineers could provide more value to the process by working to improve it at its core. For example, some parts return to the shop multiple times for the same reason. One reason this happens is because test procedures do not always realistically simulate the aircraft environment. For these cases, engineers could work to improve the test procedures themselves. Using conservative estimates, changing the role of engineers in the process would reduce the overall flow time by 10%.

This section has focused on the high-level opportunities for streamlining the repair process. However, this is only a small portion of what needs to be done to thoroughly identify the value-stream. A similar process must be followed for each operation. To determine the appropriate level of process definition it is easiest to separate operations into two main categories: those that are relatively routine and those that are highly variable. Routine operations include: receiving, receiving hold, incoming test, final test, paint, quality inspection, and shipping. Variable operations include: incoming inspection, troubleshooting, repair, and repair inspection. Engineering operations are excluded from this list based on the recommendation above that the role of engineering should be adjusted. After adjustment, engineering will fall in the highly variable category.

For routine processes, employees should clearly define the steps they take and decide which steps add value and which do not. They must ask themselves why they take any non-value added steps and look for opportunities to eliminate them or reduce the amount of time performing them. Time-studies will help better define the length of time required for each of the processes. These routine operations would benefit from expectations about what they need to accomplish each day to support shop TAT goals. The value is more evident in a specific example. Figure 10 shows the distribution of service times for a high-volume part at the test operation. Since the test is automated one would expect to see very little variation in the service times. However, the data from this one example shows a coefficient of variation of 1.5 which indicates that the process is out of control. Some of the variation may be attributed to operators incorrectly logging hours on the unit. This lack of discipline skews the data and makes it impossible to determine exactly how big the problem is and it hinders meaningful improvement projects. However, personal observations led me to believe that much of this variation exists in reality. Some major causes are equipment failures and inattentive and distracted operators. Both of these can and should be addressed. Process definition and standards should help identify the issues more precisely and assist teams in focusing their improvement efforts.

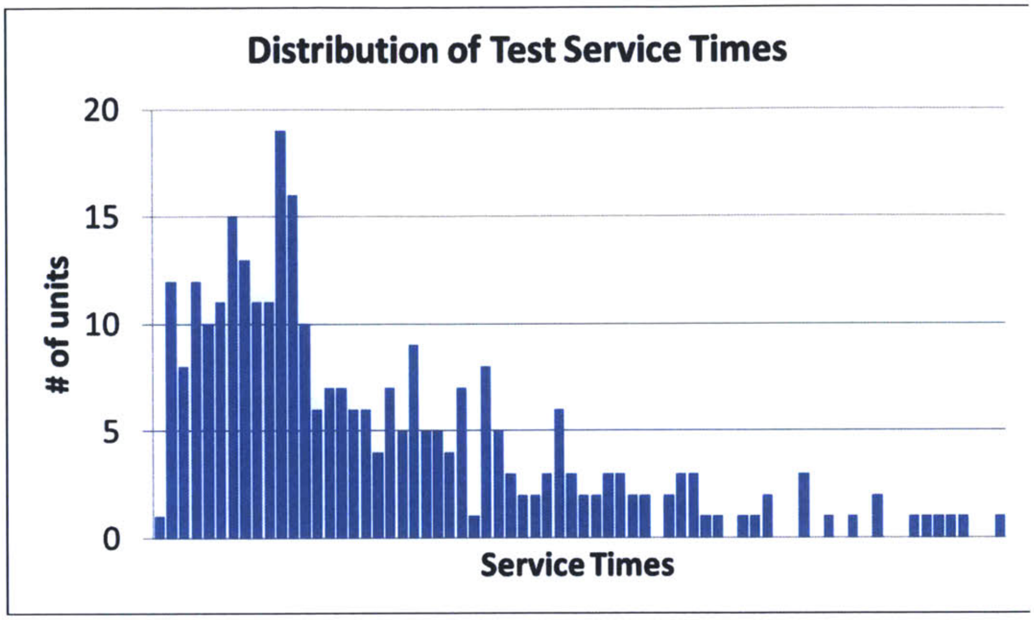

Figure 10: Distribution of Test Service Times

Highly variable operations will not benefit from the same level of process definition, as there is too much expected variation in their work. However, these operations can still map out generic work processes. How do they decide what to work on next? When they pick up a part how do they determine what actions to take? What tools do they need? Where are the tools stored? How do they know when they should get help? How do they know when they should stop troubleshooting and replace an entire card? Part-specific standards can be created for these processes to measure performance at an aggregate level. This type of approach will create expectations and can be used to identify problems. Within these variable operations there are also some sub-processes that are performed frequently that can be well defined. For example, during the repair operation components are regularly removed and replaced. Definition of the removal process and the soldering process can be improved through standard work. This type of increased process definition will allow for some targeted process improvements and sharing of best practices. It will also be useful to help train new employees.

For both routine and variable operations, one of the biggest sources of waste today comes from interactions between groups. Repair will greatly benefit from carefully defining the processes around interactions between groups. The handoff from troubleshooting to the repair operation demonstrates the issue. For the handoff to occur the unit must be physically moved to the repair area and it must be moved electronically, so the IT system shows the unit in the repair queue. When test technicians isolate faulty components during troubleshooting, they order replacements. However, they have no way of knowing when the components will be available. Per the current process, test technicians are expected to move units to the repair area. Most units follow this process but occasionally units are moved to repair in the IT system but then test technicians forget to physically move them or they give them to planners. This causes problems for assemblers who see work in their queue but then have to spend time tracking down the unit.

Moving the unit directly to the repair area without parts creates a mountain of units for assemblers to sort through to find those that are workable. The current process requires that units sit in the repair area for at least four hours before being moved to the provisioning area (special shelves for units awaiting components). Assemblers are responsible to sort through the units and determine which ones do and which do not have the necessary components. Hours are spent during each shift reviewing the units in the repair area, prioritizing those that are workable, handling those that are not, and searching for units that are in the repair operation in the IT system but are not physically there. When assemblers have units that do not have the components required for repair, they then ask the planner responsible for that unit to move it to the provisioning area.

Planners are each responsible for some number of product families and their role is to expedite units through the entire repair process. Planners each have designated shelves in the provisioning area where they store units. Within their designated area there is no way to determine where a part might be. They rely on good memories to find the units quickly. This might work, but space constraints sometimes cause other people to move units around on the shelves making them difficult to find. Also, any time a planner is out, someone else must go and find the unit. If planners are absent, their units are not likely to move out of the provisioning area at all unless management notices parts are ready for a given unit while reviewing units that have been in an operation for a long time.

As components become available, they are released to the shop floor. Planners match up the released components with the related units. Since components are released whenever they are available, a given unit may have 9 of 10 required components sitting with it while waiting on one component that will not arrive for days or weeks. This increases required inventory of replacement components. At the same time, there may be a unit that needs only one specific component for repair and the stock room is out of stock but the required component is one of the nine sitting with another unit. The status of released components can only be checked manually, so it is possible that both units are delayed unnecessarily. It is difficult to determine the impact this has, but simply waiting to release components to the shop until a complete order can be filled eliminates the issue.

The issues observed in the handoff between troubleshooting and repair can be addressed through clearly defined processes designed to reduce unnecessary waste of time and energy. A system could be designed to provide visibility to operators in terms of expected availability of components. If all components are available right away they could wait in a short-term holding area. If components are out of stock, they could go the traditional provisioning area. While units are waiting for components, they should be put in the IT system to the provisioning operation to create a better measure of performance in the repair operation by only tracking time when the units are ready for repair. Implementing an organization method or installing a simple barcode system would allow parts to be quickly retrieved from the provisioning area. In this way, the number of times the unit is handled would be reduced. Time spent by assemblers sorting through units would be eliminated. Other handoffs and interactions between various groups in the repair shop would yield similar benefits and reduce queue time.

4.3 Create Flow

Creating flow is an interesting concept for an existing organization. Ideally, flow should be established at the same time a shop is created. This section explores a variety of aspects of creating flow. Flow creation for Repair, centers on the challenges associated with aligning production with demand, managing constraints, and balancing workflows.

4.3.1 Aligning Production with Demand

Aligning production with demand is a critical step in creating flow. In the current model for repair this is a simple concept because no work should be done that is not requested by the customer. The traditional problem of overproducing because demand forecasts are wrong is not an issue. The problem for repair is how to align the steps of the process to provide a certain lead time.

In a traditional manufacturing environment, one might begin by determining takt time. Takt time is defined as the amount of time available to do work over some period of time divided by the customer demand over the same period of time. Take for example a computer manufacturer. Suppose the company runs a single shift and expects employees to work productively for 400 minutes per day excluding breaks. If they have a total demand of 20 computers per day, their takt time would be 20 minutes (400 minutes/day ÷ 20 computers/day). Thus, a computer should roll off the end of the line every twenty minutes. In *The Toyota Way*, Liker presented the 14 principles of the Toyota Way. Principle 4 is the concept of *heijunka*. To implement *heijunka*, you must review historical demand data and figure out how to create a level-loaded mixed-model schedule that allows you to produce the same thing every day (assuming that you make deliveries on a daily basis). This system provides higher responsiveness and reduces lead times (Liker, 2004). Based on this mixed-model schedule you can ensure that the steps in the process can be completed faster than the takt time including changeovers. The time required for each process step should also be leveled out to increase productivity and reduce down time for that step. Small safety buffers help prevent down time of one step from affecting other steps downstream, although continuous improvement should drive buffer size down as small as possible to improve lead time. Voila! You have created flow that aligns production with demand.

Some traditional concepts for aligning flow with demand apply to repair, and some do not. A detailed representation of the situation in Phoenix demonstrates these concepts and their value. We again start by determining the takt time. For this example we assume that employees work three shifts and cover a total of 18 hours per day five days per week. We also assume a total demand of 100 parts per month (4 weeks per month). So the takt time is 3 hours and 36 minutes (18 hours/day ÷ 5 parts/day). By analogy, one might suppose that the bottleneck must produce one unit every 3 hours and 36 minutes and everything will work perfectly, but this is not the case.

The bottleneck in the repair process is not a single operation, but rather it is the test equipment itself. The test rigs are used for incoming test, final test, and troubleshooting. There is a mix of universal and dedicated test rigs across the shop, but even universal rigs are only compatible with a limited number of parts. So takt time should be calculated for each rig based on expected demand for that rig. The takt time represents the total time allotted to push a part through each of the processes performed including the rework for operations visited repeatedly throughout the repair process.

As noted earlier, the repair process is organized by function. Since takt time makes the most sense in this context when talking about each test rig, it also makes sense to organize the shop into cells centered on the rigs. Operators from all non-test operations should be divided and relocated to support the value-stream focused cells. The benefits of moving from a functional organization to a cellular organization are well documented in lean case studies. Spear (2009) asserted that functional organization with poor linkage between tasks is an attribute of low-velocity operations. Research done by Correa (2011), estimated the following results in response to becoming a cellular organization for one product family: "a 73% reduction in inventory, an 84% reduction in lead time, a 40% reduction in staffing levels, and a 62% reduction in part travel" (p. 11). However, there are some challenges to achieving this type of cellular configuration. For example, there are a number of test rigs in Phoenix dedicated to only a few parts so there would be a large number of unique cells. To create flow, roles and responsibilities of the operators would need to be adjusted to fit the takt time for each individual cell. Additionally, the new cellular organization would require a significant change to the layout of the entire plant. Production still owns most of the test equipment and their local management would never consent to these types of changes as it would be highly disruptive and detrimental to their own process and flow.

An effective solution to these challenges fits nicely with Repair's plan to purchase test equipment and operate independently from Production. Repair has the option to purchase universal test rigs capable of testing a majority of the parts that pass through the shop with a test adapter that can be moved between test rigs. This would enable them to limit the Repair process to a few cells and relocate the entire process to a concentrated block of space within the shop dedicated entirely to Repair. This setup leverages knowledge of the existing functional silos. Each cell would be capable of supporting most products and employees could be shifted between cells as necessary. It would require significantly less redesign of roles and responsibilities since cells would not need to be considered individually. This solution aims to provide a significant amount of flexible capacity that allows the shop to be very responsive to changes in demand and facilitate single-piece flow. While it does not follow the traditional *heijunka* methodology, it does produce the same desired effect. But for this solution to work most effectively, the variability of the process steps must still be considered. This issue is addressed in the following section.

4.3.2 Managing Constraints

Managing constraints is important in any process but it is especially important when variability is high. Capacity can have an impact on the speed at which work can be accomplished, but in our case, it may also impact the flow. The flow can be affected when there is an influx of parts at final test and there is insufficient capacity to move other parts through early test-related stages of the process. If parts are not moving through the earlier stages of the process it has the potential to disrupt flow as downstream operations run out of inventory. To illustrate the challenges we can look at a specific test cell. Figure 11 shows the distribution of demand for that test cell. The demand represents the number of units moved into a test-related operation each day including units moving back through the process for rework. This captures the external variability of demand and internal variability caused by unpredictable rework. We still must consider further internal variability based on the processing times for the test operations. Variability in the actual test procedures is minimal, but the variability of troubleshooting is enormous. Figure 12 shows the combination of all internal and external variations for demand in this cell.

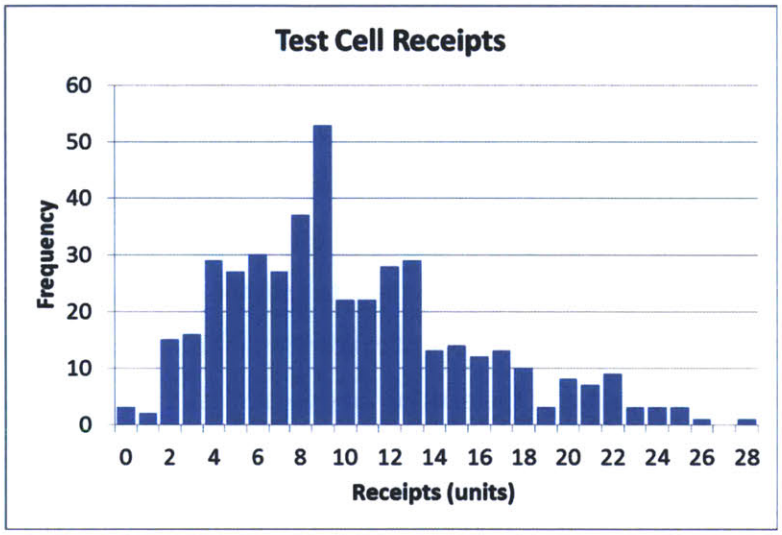

Figure 11: Distribution of Demand for a Single Test Cell (Parts)

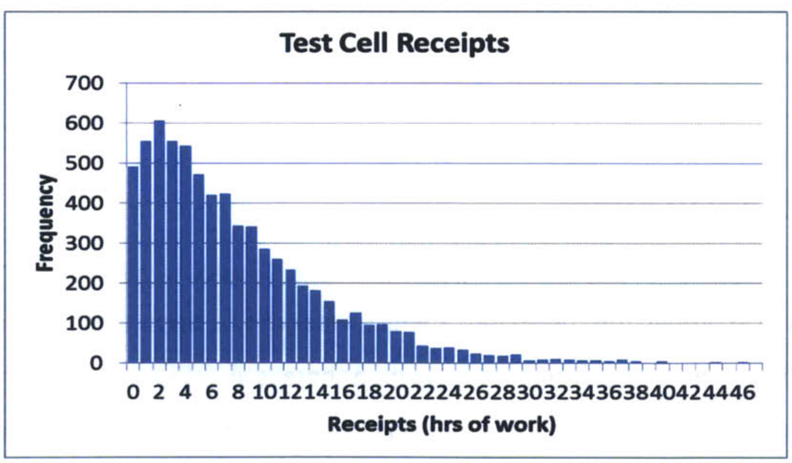

Figure 12: Distribution of Demand for a Single Test Cell (Hrs.)

Capacity planning needs to account for the variability to ensure that flow is not interrupted or that the level of disruption is acceptable. For example, say that we want to be able to handle all the work that comes in each day. If we have exactly enough capacity to meet the average demand, then we would be providing all parts received to the next process step with a 50% service level. Given that a part passes through the test rig a minimum of three times it makes more sense to plan for a higher service level from the test and troubleshoot operations. Figure 13 shows the required capacity against the desired service level. For this example, providing a 99% service level from test requires about 24 hours of test rig capacity each day. Given that each test rig will only operate productively for about 18 hours this means that we would need two test rigs to provide a service level this high. However, test equipment is very expensive. If the shop is willing to live with a 93% service level and the impact that has on the overall TAT, then they would only need one test rig.

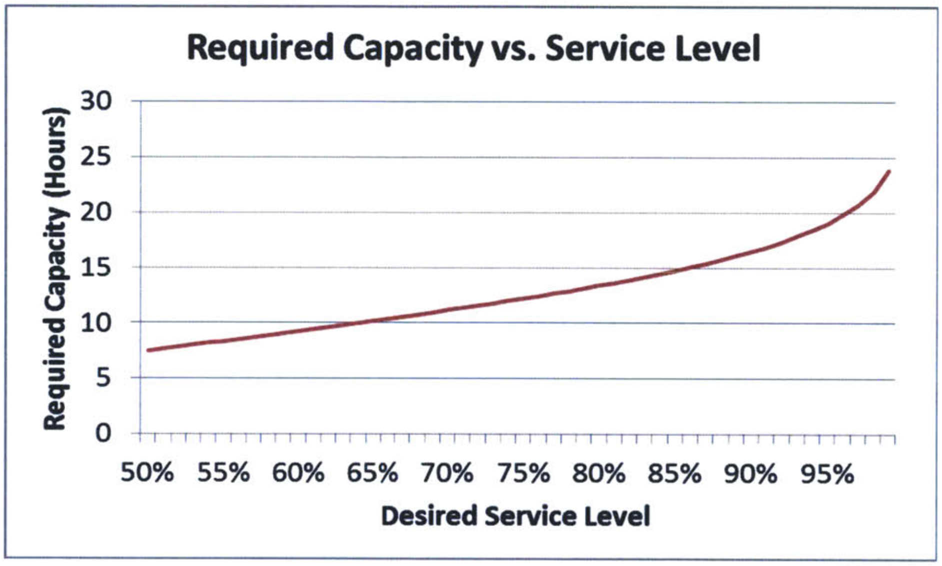

Figure 13: Test Equipment Capacity Planning

A capacity planning perspective provides more justification for Repair to purchase new test equipment. Currently, Repair uses many dedicated test rigs. A shift to universal test rigs will result in reduced capacity required to meet the same service level. The concept is similar to one commonly applied to inventory planning and optimization. The square root law states that, "total safety inventory required to provide a specified level of service increases by the square root of the number of locations in which it is held" (Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel, 2006, p.189). A common problem posed in regard to inventory reduction is how to determine the desired number of distribution centers for a supply network. In these types of problems, the amount of inventory required to deliver at a given service level varies as the square root of the number of distribution centers assuming that demand is not correlated. Our scenario involves either many dedicated test rigs or a few universal test rigs. The test capacity required to provide the same service level from test increases as the square root of the number of test rigs. So if the shop is providing a 99% service level and using four dedicated test rigs to do it and then decides to move to a universal platform, they can expect that the capacity required for the same performance would be half as much. In other words they would only need to invest in two universal rigs.

Managing constraints through this system of capacity planning will have a significant impact on TAT though the actual benefits are difficult to calculate. Some sampling of test cells using this approach shows that the test-related contribution to TAT could be reduced by about 80%. However, the 80% reduction cannot exclusively be attributed to this method. Only the portion of the TAT caused by existing capacity constraints can be claimed. The pervasiveness of capacity constraints is hard to determine because Production currently does capacity planning and scheduling for all of their test equipment. However, Repair will benefit from renegotiating expected capacity needs with Production by following this methodology.

4.3.3 Balancing Operational Workflows

Aligning production with demand and managing the constraints creates the drumbeat within the shop to which other operations should be realigned to more closely match the pace of work across operations and create the most consistent flow possible. Figure 14 shows a representation of the various capacities of the functional groups today. The graph seems to indicate very poor balancing of operations. However, not every unit visits every operation and some units visit an operation multiple times during their visit to the shop. So to get a clearer picture we should normalize the data over demand for each operation. Figure 15 shows the capacity of each operation normalized over demand and over the capacity of the test and troubleshoot operations.

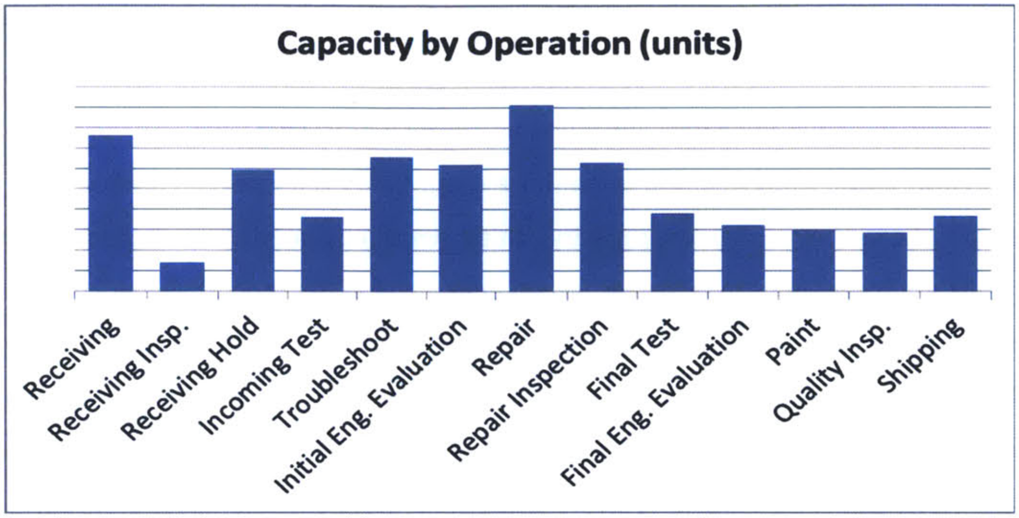

Figure 14: Capacity Comparison by Operation

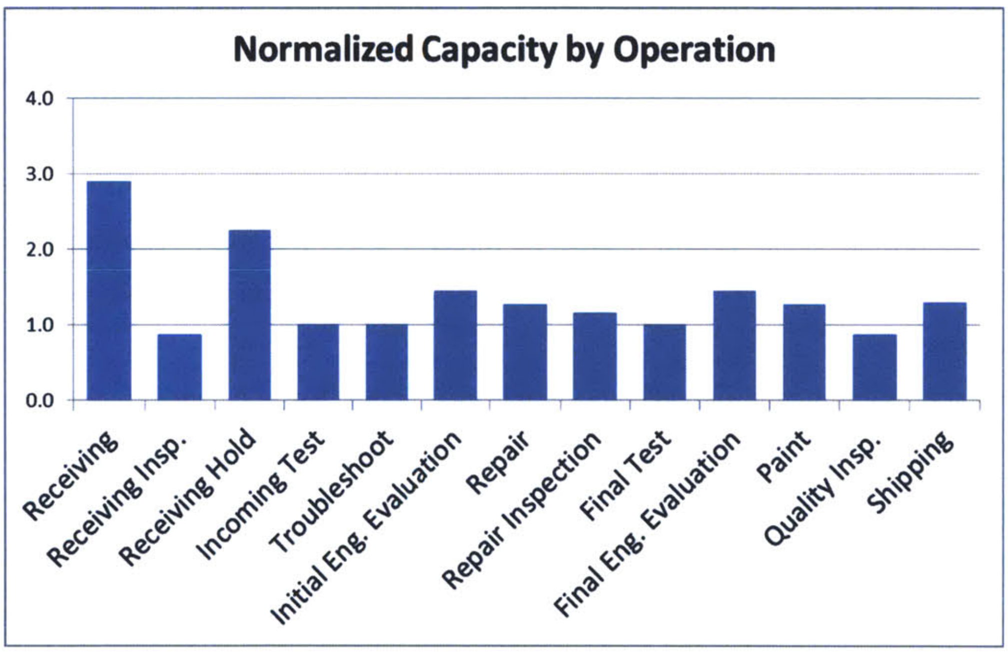

Figure 15: Normalized Capacity by Operation

Looking at each operation relative to the test and troubleshoot operations, we expect to see at least slightly higher capacity everywhere else since test rigs are the bottleneck. The picture that emerges shows the quality team has a lower capacity than the bottleneck. This is masked by the fact that Production does not balance the scheduling of Repair units well and units pass through the test rigs more than any other operation. As scheduling issues are resolved, either through collaboration with

Production or purchasing new test equipment, the lack of capacity in the quality operation will become visible. Quality makes up for their lack of capacity by working overtime, but management must consider that planned overtime will have a negative impact on employee morale over time.

Figure 15 also shows a few operations that have much higher capacity than is necessary. The receiving operation shows the most excess capacity. This is amplified due to a lack of data related to time requirements to process units in receiving. When units arrive in the shop, they have not been entered into the IT system so it does not track labor hours spent working on each unit in receiving. No other time studies have been done to completely capture the length of time required to receive units. This is indicative of the fact that receiving actually spends much more time per part than what they estimate. Receiving hold as shown here is representative of the work order administrators perform during this operation. The excess capacity is an accurate reflection of the situation. However, order administrators perform a number of other supportive tasks that are not represented here. Their time is fully utilized with these other tasks. Finally, engineers have excess capacity. This may be a result of poor data. Engineering time is not tracked on a per unit basis. As discussed previously, engineering involvement in the process should be reduced which will increase their availability for other tasks. Engineers can use their additional capacity to improve test procedures and processes and provide training for test technicians. The net effect will be an increase in the capacity of the test and troubleshoot operations.

Another consideration that should be made towards creating better balanced workflow is the priorities for functional groups. The greatest complications for priorities occur for individuals who work on parts in more than one operation. In many cases, priorities are not well established in regard to what work needs to be done and in which operation. For example, a member of the quality team is needed for incoming inspections, repair inspections, and final quality inspection. A few members of the team work in quality inspection during first shift. Another member of the team works in repair inspection for half of the first shift and then switches to quality inspection for the second half of the shift. Another member of the team works on repair inspections the first half of second shift and then works on incoming inspections for the second half of first shift. The scheduling may change from time to time but priorities have not been set to allow team members to move back and forth between tasks prioritizing the units in a way that promotes single-piece flow. Even if priorities were appropriately set, the areas where these tasks are performed are spread out throughout the plant which dramatically increases non-value added time to walk back and forth between operations. This can be resolved through the creation of cells created around the value-stream. Within the cells the priority must be to achieve single-piece flow.

4.3.4 Benefits of Creating Flow

Creating flow increases the shop's responsiveness. This step allows the team to appropriately consider the variation in their processes and assess their needs in terms of human resources and equipment. As they plan sufficient capacity to handle the expected variability they can reduce backlog.

The backlog of parts in the Phoenix repair shop is nearly two months' worth of work. It is important to note that not all of this backlog will be easily eliminated. Some of the backlog is due to parts shortages which could be reduced through optimizing the supply of parts on hand, but that is outside the scope of this document. Another source of backlog comes from poor customer responsiveness. The shop has agreements with its customers that it will not do anything without the approval of the customer. In some ways it is like taking your car to a mechanic. You expect them to evaluate what is wrong and then let you know what it is going to cost to fix it. Based on this information you decide if you can afford the repair and if you trust the mechanic's competency and diagnosis of the problem. If so, you would approve repair and the mechanic would move forward. Due to this type of arrangement with customers, the shop often waits for days, weeks, or even months in the worst cases, to hear from unresponsive customers. The shop needs to work on relationships and agreements with customers to help reduce the WIP that accumulates while waiting for responses from customers. If they can improve their performance, they should have more leverage with customers to press them to be more responsive. Note that the shop does not count any time waiting for responses from customers against its TAT.

Parts shortages and customer responsiveness are only two of the problems that will prevent Repair from eliminating their entire backlog. As performance improves and the backlog decreases they will run into other issues that are currently masked by the backlog. This idea is often conveyed as the water and rocks analogy depicted in Figure 16. The ship in the figure represents incoming work. The water represents the backlog. As the backlog goes down we start to see the rocks which represent issues that can stop the flow of work. As issues are identified teams will need to eliminate them to restore flow and allow the backlog to continue to decrease.

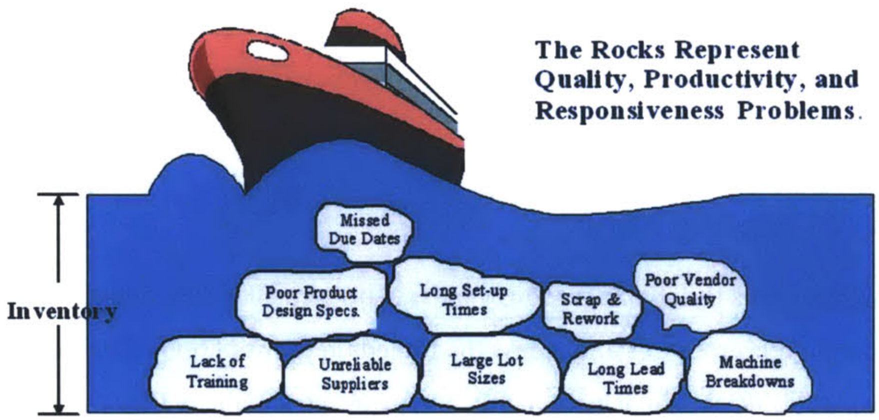

Figure 16: Water and Rocks Inventory Analogy (Harrison, 2009)

A graph of process touch time versus queue time is shown in Figure 17. Parts spend over 97% of the entire flow time waiting to be worked on. If we exclude units waiting for parts and units waiting for a customer response, there is still over a month's worth of backlog in the shop. This backlog accounts for about 68% of the total remaining queue time.

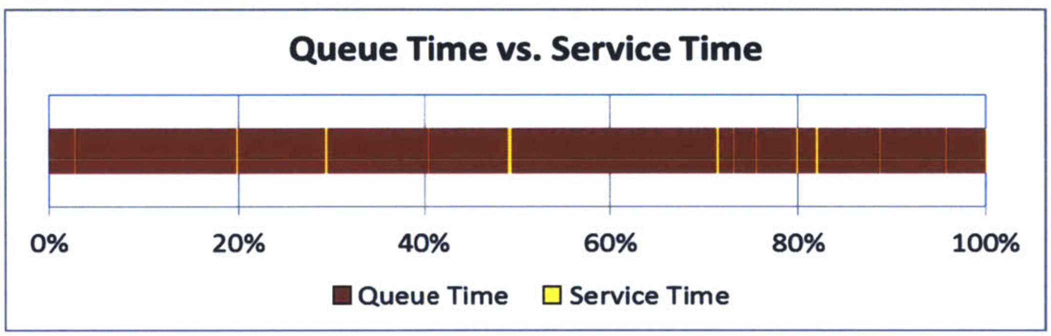

Figure 17: Repair Process - Queue Time vs. Service Time

Repair needs a strategy to reduce the backlog and associated queue times. Current planning methods attempt to follow traditional methods of establishing a takt time. If a takt time is set according to the incoming demand, the shop could handle demand over the course of the year. But this approach ignores the need to eliminate backlog. Even without a backlog, this strategy does not make sense given the variability in of demand. Figure 18 shows the average demand by month over the last three years. Demand is not predictable by month, but similar stochastic variation is expected from month to month. The static takt time goal will actually create a backlog during the peak months that will not be eliminated until the months of lower demand. Figure 19 shows the contribution to TAT based on the backlog building and subsiding from month to month following a static takt goal. Over the course of the year the average backlog would account for 10% of today's total TAT and 37% of the end TAT goal.

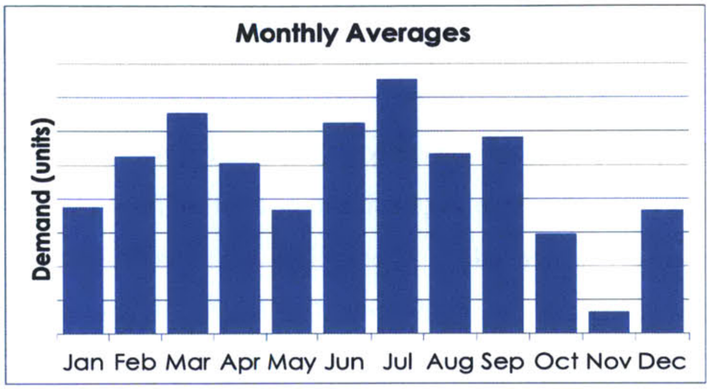

Figure 18: Repair Monthly Average Demand

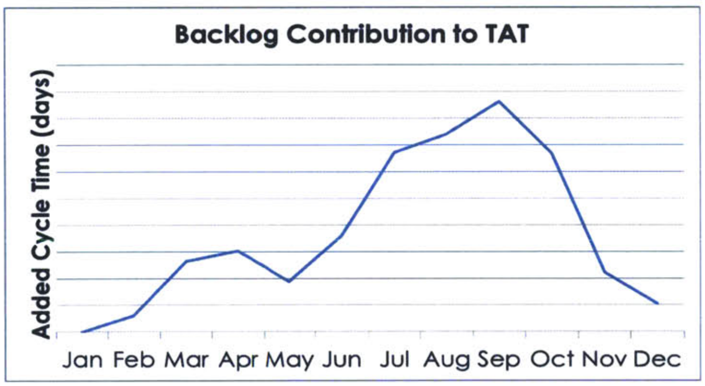

Figure 19: Static Output Backlog Contribution to TAT

A static output goal can be used to eliminate the backlog if the goal is set high enough. However, it does not provide means for handling the variability in a way that does not contribute to total TAT. A more effective strategy for repair is a variable output goal. For example, you can draw a line 20% above the average demand and ensure the shop has sufficient capacity to handle this level of demand. Then whenever daily demand is higher than this line you plan to handle the input for the day using overtime. Whenever daily demand is lower than this line you plan to output 20% above the average demand. This way you plan for the variation in a way that eliminates the backlog. Using this plan, the backlog would be eliminated in about 10 months.

4.4 Seek Perfection

Once value has been specified, the value-stream has been identified, and flow has been created, a company must embark on a lifelong goal to seek perfection. They must continue to improve to maintain a competitive advantage. Seeking perfection is where many of the tools from the lean toolbox become useful. It is at this point that a clear baseline has been established from which to begin improvements. Developing flexible processes will allow quick adjustments. Well defined processes and standard work will keep everyone on the same page and can be a forum for knowledge transfer about best practices as well as process experimentation. 5S organizes work and facilitates an environment of visual management wherein mistakes are easy to identify. The list of tools goes on and on.

A common strategy for driving improvement is based on the theory of constraints. The concept of managing constraints was first introduced by Goldratt in his 1984 novel, *The Goal*. The Goldratt Institute (2009) explained that the philosophy is founded on the notion that in every system there is a single constraint and that by focusing on the constraint, performance will continue to improve. Furthermore, this process of ongoing improvement consists of the following steps:

1. Identifying the constraint
2. Deciding how to exploit the constraint
3. Subordinating and synchronizing everything else to the decisions above
4. Elevate the performance of the constraint
5. Repeat the process each time the constraint changes

The theory is great for identifying the issue that will have a measureable impact on performance. The key flaw with focusing only on the constraint in the system is that it does not engage everybody. If the constraint in the repair shop is test, it will not require the help of everyone on the shop floor to understand how to improve performance for test. Each member of the team should be engaged in improving their processes in meaningful ways to drive down TAT. This can most easily happen as operational boundaries are realigned to match the capacity of each step in the process with the constraint. Furthermore, if all operations are not improving while the constraint is being improved, it stands to reason that the shop will eventually see a new constraint and will have to begin focusing on it. There is no reason to wait until a certain function becomes the constraint to start improving its processes.

Teams should follow the Shewhart cycle to improve their processes. The Shewhart cycle was popularized by Dr. W. Edwards Deming and involves four steps. The steps are plan, do, check, and act (PDCA). In the planning stage teams must assess the current state and generate a plan for improvement. With a plan in place teams must move forward to implementation. Following implementation, teams should monitor the results of the change to see if they match up with expectations. Even if the first plan produces the expected results, there is always room for improvement. The act phase is for making adjustments based on the results of the check phase. This cycle of incremental improvement helps adjust the mindset of individuals away from the idea that there is one "silver-bullet" solution. It also helps avoid analysis paralysis, wherein teams get stuck in the planning phase trying to come up with the perfect solution only to find that six months later things did not work out as originally planned.

Chapter 5: Overcoming Cultural and Organizational Challenges

Merely having lean tools and understanding their value will not suddenly make an organization lean. The organizational structure and culture must be aligned to take advantage of the tools and drive improvement. Based on his conversations with leaders from Toyota, Liker (2004) noted that most talked more about the Toyota culture than about the tools associated with TPS. Gary Convis, the first American President of Toyota Motor Manufacturing in Kentucky, showed Liker (2004) the diagram found in Figure 20 and told him, "JIT, *jidoka*, [and] *heijunka*... are just technical tools and they can be effective only with the right management and the right philosophy – the basic way of thinking. At the center of TPS is people" (p. 175). Chapter 4 focused on the value of the principles of lean. In this chapter, focus shifts to the people related issues. All recommendations, while broadly applicable, are those deemed most valuable for the challenges faced by Repair.

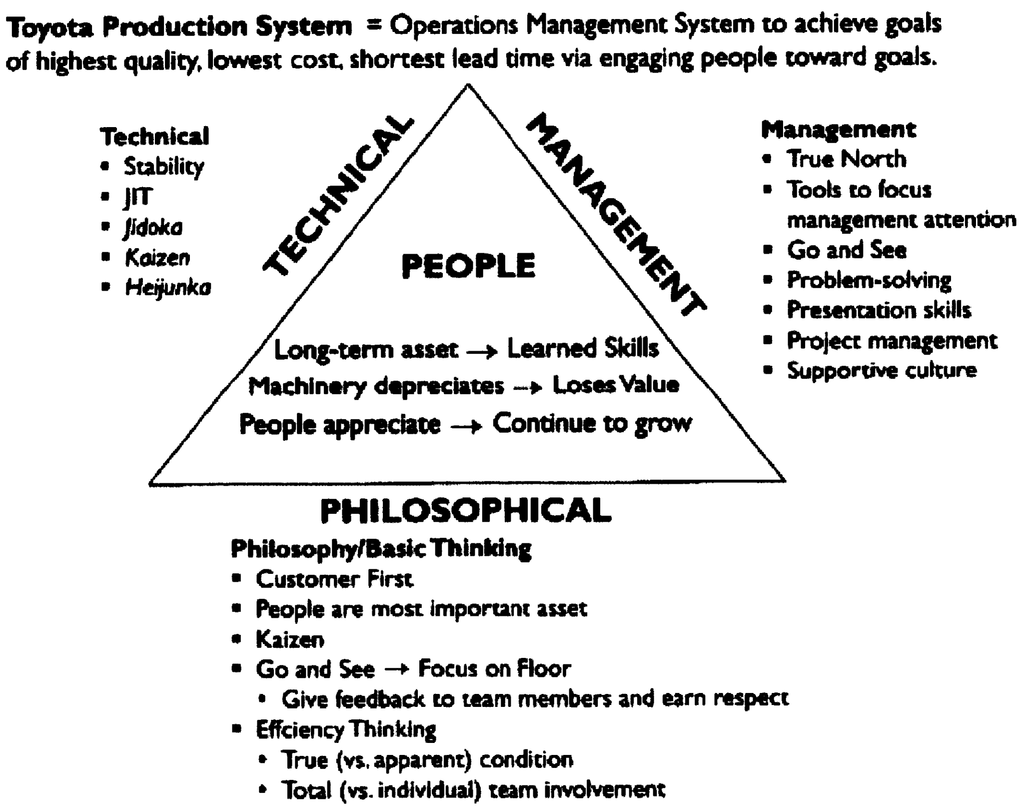

Figure 20: Gary Convis' Depiction of TPS (Liker, 2004, p.176)

5.1 The Role of Shop Management

"Juran claimed that most breakthrough analyses found that over 80% of the problems (e.g. defect rates, scrap rates) were under management control and fewer than 20% were caused by operators" (March, 1990). A closer look at the management team in Phoenix gives some insight into this statistic. It also yields a path for managers to get out of their own way.

Management in the Phoenix repair shop is typical of what you would find in companies across the USA. The system is a command and control type model with managers making decisions and setting daily priorities. They are a group of bright individuals, with good ideas about how to get the work done. The administration manager is diplomatic and is fantastic at working with customers to resolve their issues. The quality manager has helped Phoenix become a leader in overall repair quality. The operations managers know how to get units pushed through the system quickly. The general manager is a good overseer and holds people accountable for moving parts forward from day to day. So if everybody is competent and capable what is missing?

The Toyota leadership model is a great place to start. Figure 21 is a model for classifying leaders at Toyota. Toyota looks for leaders who are mostly in the top right quadrant. Repair managers fall into the top left and bottom right quadrants in their management styles.

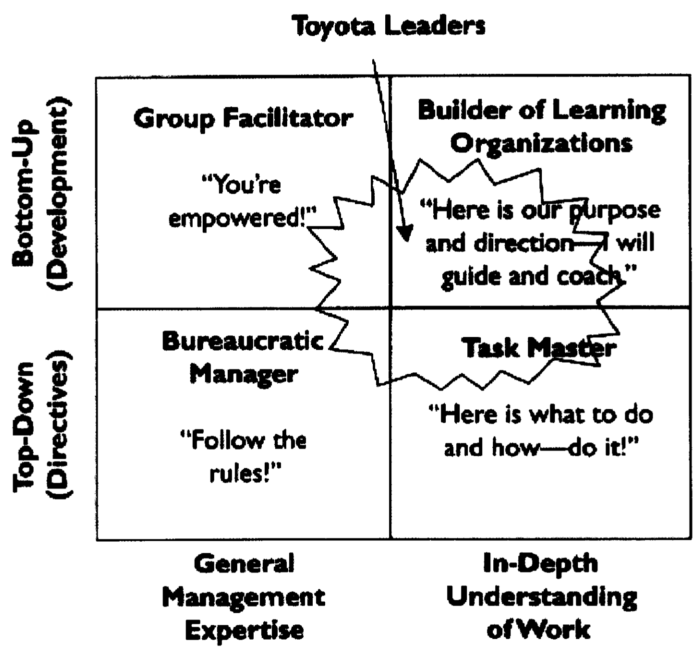

Figure 21: Toyota Leadership Model (Liker, 2004, p. 181)

I do not have enough data to say why Repair managers fall into these categories but I do have a few thoughts that typify people who fall into these quadrants. First, someone with the characteristics of the top left quadrant is well described as a "people person". This is someone who has been successful in their career by being able to connect with others and to coordinate projects involving groups of people who do not usually interact. Managers in this category continue to use these same skills to keep their teams moving forward.

Next, we look at those whose managerial style is more in the bottom right quadrant. The managers that fall in this category are people who have been groomed to believe that being decisive and assuming the role of task master is what is valued at the company. They have risen through the ranks because of hard work and have been promoted for their technical abilities. Even though they are now in a managerial role, they continue to do things the way they always have and use their technical competence to make sure that the work gets done. These people are micromanagers who like to be involved in every decision. As long as they do not get stretched too thin, they can achieve impressive results working this way.

Provided that projects are going well, there is no reason for managers to change or do anything differently. We expect managers to take responsibility for the success of an organization and often assume they have all the "answers". Spear (2009) pointed out that, "We celebrate celebrity and fuel the myth of the leader as supreme architect, engineer, and pilot." American culture does not help the matter as we do not like to expose or discuss our weaknesses. We believe that admitting our weaknesses somehow makes us less fit to lead. Argyris (1991) argued that professionals are great at learning until it is centered on their own performance. One reason for this is that professionals are not accustomed to failure (Argyris, 1991) and have a hard time dealing with situations when their organization underperforms. They do not like to take any personal responsibility for the group's performance. Another reason is that while they have a core set of values, often their behaviors fail to live up to those values (Argyris, 1991).

Management must lead in a way that encourages high employee involvement. Each manager must lead by example through their commitment to teaching, learning, and continuous improvement at a personal level as well as at the organizational level. Managers in the top left quadrant stand to gain great technical understanding from the people they manage. Toyota does not like to bring in outside managers because they expect their managers to be intimately familiar with the work done by those they supervise (Liker, 2004). One tactic these Repair managers can borrow from Toyota is *genchi genbutsu*, which essentially means managers should spend time on the shop floor carefully observing the processes and involving themselves in the day to day work at a much deeper level. By gaining a deeper understanding of the work on the floor, these managers will become much more effective in teaching people to solve problems.

Managers in the bottom right quadrant have the opposite problem; they need to find a way to rely on others to do their jobs without micromanaging or being demanding. This sentiment has been captured by numerous researchers. For example, Spear (2009) took the position that:

> High-velocity managers are not in place to command, control, berate, intimidate, or evaluate through a contrived set of metrics, but to ensure that their organizations become ever more self-diagnosing and self-improving, skilled at detecting problems, solving them, and multiplying the effect by making the solutions available throughout the organization (p. 26).

Recardo and Peluso (1992) further suggested:

> ...the first change that is required is also the most difficult for management to make: management must accept and demonstrate a new attitude, one in which workers are important as human beings. Management must believe that employees have a high degree of ability (p. 42).

The challenge for these managers is not technical in nature. Rather they must exhibit a degree of self-awareness to accept their management style and within themselves find the motivation to change it.

A barrier managers from the lower right quadrant may face is figuring out how to get employees to take greater responsibility and ownership of their work. Employees who work for these types of managers are not used to having decision making authority and as a result are not well trained to take ownership of their own work processes. They will not wake up one morning and decide that a process needs to be improved and they are going to take the lead in doing it. These managers will need to transform themselves into teachers, capable of showing employees how to identify problems and correctly address them.

The process of developing managers and changing from the top down will not be easy and it will take a significant amount of time. It will require everyone in the organization to be more open to allowing others to fail. Individuals must take more personal responsibility and acknowledge their own shortcomings. Managers need room to grow into their new management styles. Employees need time to become consistently engaged in leading improvement projects and educate management about their processes.

5.2 Role of Employees on the Shop Floor

The Toyota Way has two main pillars: respect for people and continuous improvement (Toyota North America, 2008). Respect for people will be shown as managers relinquish process control to the individuals who perform those processes. A primary tenant of lean is to ensure process ownership and the responsibility and authority for change is pushed to as low a level as possible (Womack, Jones, & Roos, 2007). Everyone across the entire organization must be empowered to take action and actively become involved in the problem solving process. This will have a multiplying effect on the rate of change. In essence, engagement of every employee is what makes lean special. Other companies rely on superstars to drive their improvement. But unless a company is filled with superstars they would be hard pressed to match the impact of employees in an organization where everyone contributes to continuous improvement.

"Responsibility means freedom to control one's work – a big plus – but it also raises anxiety about making costly mistakes" (Womack, Jones, & Roos, 2007, p. 12). Employees will need significant support to embrace these changes. Managers will need to be careful not to penalize employees who experiment with process improvements that fail. For each successful idea, there will be some number of ideas that fail. But learning by doing will ultimately drive higher performance.

In addition to support, employees need a commitment from management to stop firefighting and start investing in improved capabilities. Figure 22 shows the dynamics of the situation.

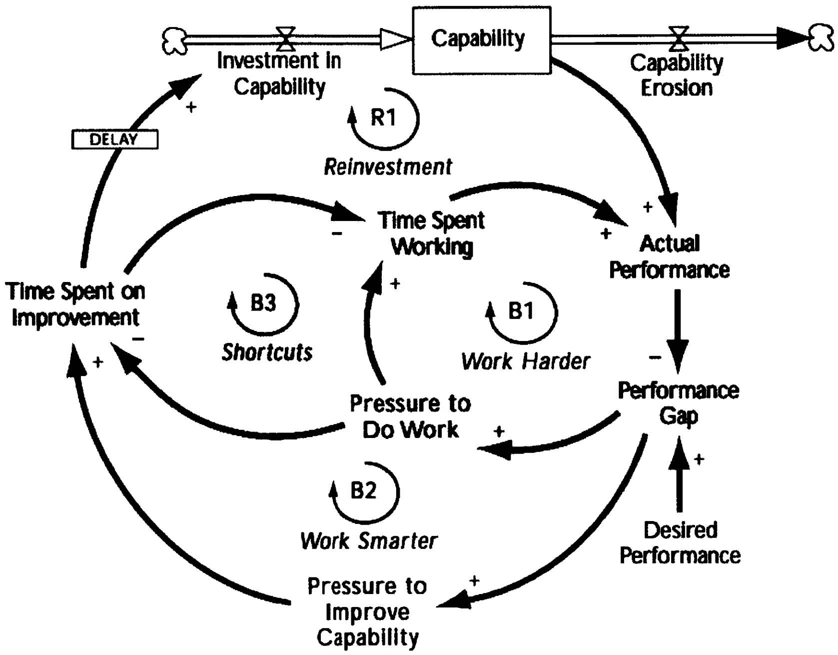

Figure 22: System Dynamics of Improvement (Repenning & Sterman, 2001, p. 73)

One primary obstacle to improvement in any company is the day to day work. Whenever performance lags, there is a tendency to push people to work harder to close the gap and catch up. As more time is spent doing the daily work, less time is spent on improvement projects. The reverse is true as well. That is, when a company begins an improvement initiative, they spend less time doing "normal" work. This tends to cause a gap to develop between output and desired output. It is this gap that usually has managers screaming for people to work harder. A long-term commitment must be made to working smarter with the expectation that while short-term performance will suffer, productivity will be higher in the long run. The expected effect is shown graphically in Figure 23. While this effect may seem somewhat obvious, Repair consistently pushes for end-of-the-month heroics, which seems to be indicative of their deference to short-term results. Senior management must push against this tendency and ensure incentives also support their commitment to increased capabilities and long-term success.

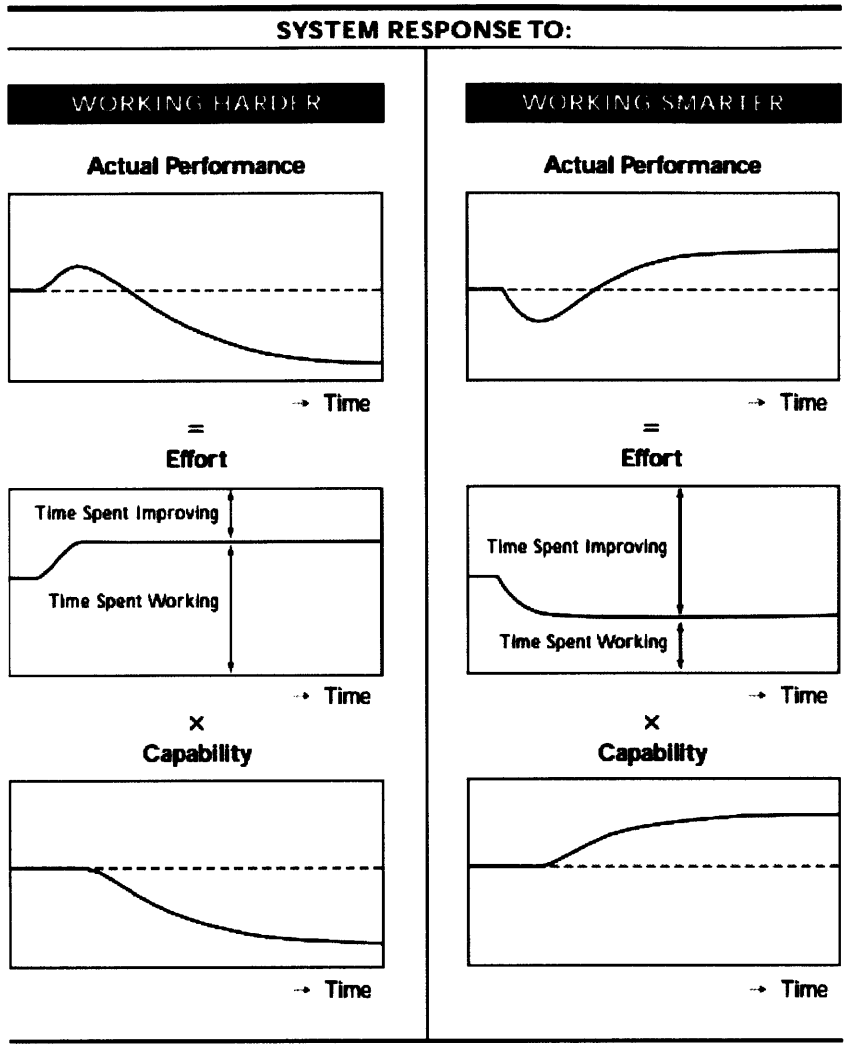

Figure 23: Impact of Working Harder vs. Working Smarter (Repenning & Nelson, 2001, p. 74)

In support of becoming a problem-solving culture, creating work teams responsible for improvement efforts will be valuable. The recommendations around team structure and the benefits are discussed in the following section.

5.2.1 Teams

The benefits of improving processes as a team are undeniable. Collaborative efforts produce higher quality solutions than individual efforts. Currently, Repair employees are grouped into functions, but the functional grouping only means that employees sit together and work on the same operations. There are also QCPC teams consisting of people from many of the different functional groups. QCPC teams meet on average about once a week during *kaizen* events. The sporadic effort towards continuous improvement has not produced the results Repair requires.

In the early phases of their lean transformation, Repair should utilize functional groups to drive improvement within each operation. This makes sense because there is a lot of work to be done towards defining and mapping processes, creating metrics, standards, and standard work procedures. Because of the complexity of the repair work and the lack of cross-functional training, working with people in other functional groups on these types of tasks would not be fruitful at this stage of maturity in the transformation effort.

When Repair adopts previous recommendations to create value-stream based cells centered on the test rigs, they should create cell-based work teams focused on continuous improvement. However, functional work teams should remain in place so as to continue to create value across the value-streams. The cell-based teams would be responsible for maintaining flow and redefining operational boundaries as necessary. They would need to promote cross-training which creates an enormous amount of flexibility and aligns well with the high variability of demand. On the topic of value-stream based work teams, Womack, Jones and Roos (2007) found that,

> It is the dynamic work team that emerges as the heart of the lean factory… workers need to be taught a wide variety of skills – in fact, all the jobs in their work group so that tasks can be rotated and workers can fill in for each other. Workers then need to acquire many additional skills: simple machine repair, quality-checking, housekeeping, and materials-ordering. Then they need encouragement to think actively, indeed proactively, so they can devise solutions before problems become serious (p. 99).

Phoenix is in the ideal state right now to pilot cell-based teams. They have a test cell with two universal test rigs that they own and operate. Using these test rigs they can create a cell complete with team members from each operation. This will allow them to figure out the best cell arrangement and resolve unforeseen issues that arise with implementation. By doing this, they will be better prepared when they have equipment to create additional cells.

Work teams should foster a learning environment. Learning happens best through experimentation. Ulrich, Von Glinow, and Jick found that experimentation is the type of learning that improves performance and an organization's ability to change the most (Rheem, 1995). Through trial and error, teams will find increasingly effective and efficient ways to perform their work. This also encourages teams to quickly attack problems and learn from them while the issues are still fresh in their minds. The entire shop environment should be designed around fostering learning and increasing the pace at which people learn.

Spear's (2009) research showed that, "High-velocity organizations multiply the power of their new knowledge by making it available, not only to those who discovered it, but also throughout the organization" (p. 25). In this spirit, Phoenix can leverage the work of each team to contribute to the learning of the entire organization. Once each month the Repair team meets in an all-hands meeting. This is the perfect forum for teams to present the projects they have undertaken to reduce TAT. It would help focus the teams on projects that have the most impact as they will want to impress their peers. During these meetings they could explain their thought process in project selection, plans, and expected results. They could then show what happened as a result. This process should spark new ideas for those listening to presentations and should also give them an opportunity to ask insightful questions or share helpful feedback.

Chapter 6: Overcoming Implementation Challenges

Lean tools can be extremely useful and facilitate remarkable increases in performance. Individual managers and highly motivated work teams can have a tremendous impact on performance. However, for a shop to become lean and remain lean, senior managers, middle managers, and employees must all support the principles and commit to continuous improvement in a way that aligns with the direction of the company. Throughout any change effort, there are vast arrays of obstacles that prevent progress or that cause regression. One of the most common problems is incentives.

At the lowest level, employees tend to form habits and establish routines that simplify their own work. Why should they change what they are doing? What is in it for them? All employees from the top of the organization to the bottom tend to focus their efforts on whatever they are personally evaluated on (Bicheno & Holweg, 2009). If they are measured on quality they may take their time and do their job to the best of their ability. If they are measured on speed, it is likely that they will work faster even if it decreases quality and yield. Lean transformations often highlight headcount reduction as a key benefit. If employees sense that headcount reduction is the goal of the lean initiative, they will not become willing participants. Nobody will want to improve their way out of a job.

Middle managers' behavior generally conforms to what they perceive will get them noticed and promoted. A long-term initiative like a lean transformation could take years. In the early phases, performance most likely will get worse. Managers who are not looking to stay in a single position for more than a couple years may find that they can gain more by using brute force methods to produce results. Where this is the case, employees are likely to view initiatives as the program of the month. Employees then become jaded and less likely to accept changes that come and go with each manager. Managers may also fear that lean requires them to relinquish control to employees such that the trajectory of their career is subjected to the performance of others.

Senior management incentives are usually somewhat well aligned with lean initiatives as they are more likely to receive some portion of their compensation in stock and so they are more driven to do what is best for the company. Although, to some extent, they may still have similar incentive issues as seen with middle managers. They must be careful to ensure that short-term results are not rewarded over long-term success. Senior management involvement is critical for the long-term success of an initiative. They will need to align the organizational structure, the reward systems, choose managers, and provide necessary human and capital resources to achieve desired results.

The incentive issues discussed here can be addressed by methodically aligning these internal stakeholders. A model for doing this is presented throughout this chapter.

6.1 Hoshin Model

A lean transformation needs the support of all internal stakeholders. The Hoshin model is used for policy deployment and is a good representation of the linkages between stakeholders. The Hoshin model is shown in Figure 24. It is geared towards aligning the efforts of people at all levels of the company. The model should not be used to exclusively define roles. Rather, it should be used as a guide for evaluating the connections between stakeholders and ensuring that everybody in the company is properly linked.

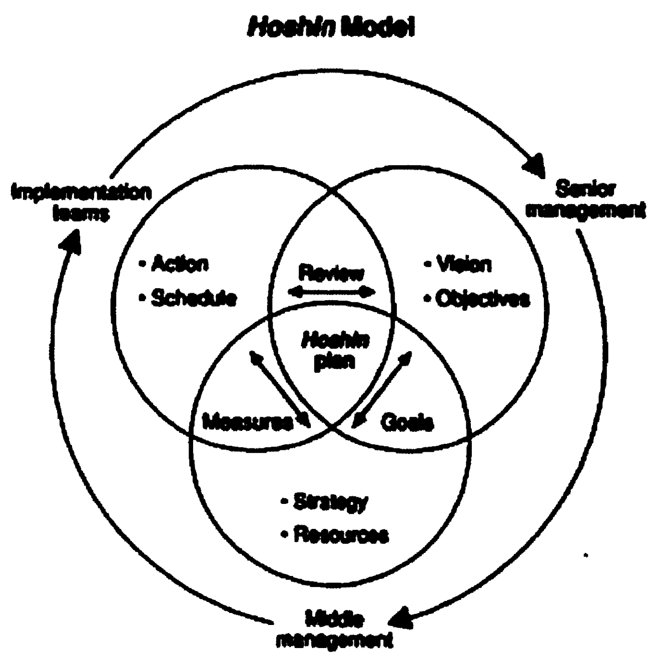

Figure 24: Hoshin Model (Akao, 1991, p. xxv)

The following sections use this framework to provide recommendations intended to increase the probability of a successful lean transformation in Phoenix. Primary emphasis is placed on measurements as I spent a significant amount of time during my internship working on these issues.

6.1.1 Vision

One reason transformations fail is because the vision is undercommunicated (Kotter, 1995). Presenting the vision in a single meeting or mass email is a surefire way to guarantee it will fade away and die. Senior managers must use all available means to get the message across and to keep the pressure up. This includes daily meetings, emails, quarterly reports, websites, newsletters and so forth. Hamilton Sundstrand's senior management has a clear vision which includes improving the performance of the repair shop. However, conversations with employees revealed that they only have a vague understanding of that vision. Senior management should increase the level of communication to employees at all levels regarding their vision. They must also stand ready to provide any support required from middle management and implementation teams to demonstrate their commitment to the vision.

6.1.2 Goals

When I began my internship, I was told the target TAT and CSL for Repair. However, I was never told how those specific goals were determined. In conversations with many operators, nobody could tell me why they were targeting a specific TAT. Since part of the vision is for repair TAT to become a competitive advantage which brings in new business, this requires knowing competitors TAT to understand what really constitutes a competitive advantage. If possible, it would also be good to assess how fast units must be repaired in order to persuade customers to switch from a competitor's system to Hamilton Sundstrand for their next airplane program. If this approach was not followed then goals should be reevaluated. If this approach was followed then it should be communicated along with the vision to increase employee buy-in.

6.1.3 Strategy

The primary strategic issue I observed was the need to come up with a plan to reduce backlog quickly. This issue was already addressed in Section 4.3.4. One other strategic issue faces Repair is their involvement with Production. Repair is on the right path to improving performance by purchasing new equipment and beginning to operate independently of Production. However, that transition will take years to complete. In the short-term, Repair will be better off providing their own people to staff Production test rigs. This avoids the issue of test technicians receiving conflicting priorities and having to learn and regularly apply processes from both organizations. Repair needs to negotiate a schedule with Production to use the test rigs. Unfortunately, Production does not want to relinquish control of the equipment they own in any way. This is an instance where the vision should be a guiding factor in determining which decision is best aligned with the overall direction of the company. It is one area where senior management responsible for repair can work with their counterparts in production to reach an agreement about what is best for the company as a whole and in the process demonstrate their commitment to the vision.

6.1.4 Measures

Measurement systems are one area that Repair still needs a significant amount of work on. For example, the clock for the TAT calculation only starts ticking after a box is opened and a work order is created. If there is an influx of demand, a part may sit on the dock for a week or more before being opened. This is clearly an instance of one of Hammer's (2007) seven deadly sins, narcissism. Hammer defines narcissism as measuring from an internal point of view instead of a customer point of view. The end customer is less satisfied with performance and management is totally unaware of the reason because the measures they look at do not show the whole picture.

Not only are there measuring inaccuracies, there are also numerous measurements that have not even been attempted. For instance, no time measurements are taken at the operation level. Nobody knows how long jobs should take and so nobody knows how they are doing from job to job. Some operations keep a tally of parts they complete each day but that does not account for the fact that some parts are inherently more complex than others. It also does not account for varied staffing levels. Without this type of information it is impossible to use the data to spot problems as they occur. If problems cannot be identified, what is the point in collecting the data?

The IT systems track a significant amount of data in Phoenix, but only limited subsets of data are accessible and formatted in a comprehensible way. Without access to key performance metrics for each operation, it is impossible to decide what to change from a theory of constraints perspective. Of course, most people in the shop have a sense of where the biggest problems are, but as improvements are made, that is not likely to last. Furthermore, there is no accuracy guarantee on employees' gut feel and it cannot tell you how much you are improving. Improvement is visible at the shop TAT level, but a lot of learning and experimentation will come from using the localized metrics.

During my internship, I addressed some of the measurement issues by designing a real-time measurement tool that provides targets and visual cues for individual jobs and tracks the movement of units through the shop. For each work order, it provides a target completion time. The target times are based on historical data and are set aggressively because of the high variation within each operation. However, if the target time is missed, the tool provides visual cues intended to drive behaviors like asking for a team leader's help and entering a turnback for a unit that takes longer than average. The system also tracks live status for operational input, output, expected input, expected output, TAT, backlog, and service times. The expectation is that team leads will be primarily responsible to know what their operation needs to accomplish each day and what new work they should receive. This tool should increase accountability and expectations. All of the historical data is stored in the tool and can be graphically represented so that a team can use it to focus their improvement efforts and easily monitor the impact of any projects they undertake.

Even with a measurement tool in place, Repair still needs a system for improving visibility and making sure both management and shop floor workers are aware of their daily performance. This type of awareness can create motivation to change behaviors, improve planning, and most importantly identify problems as they are happening. My tool was designed with the intention of using it as a dashboard. The dashboard could go on computer monitors or large LCD screens within each cell to ensure everyone sees the same data. To help identify and solve problems, the tool was equipped with a virtual andon capability. Because of the size and layout of the shop, traditional andons do not work well. The virtual andon allows operators to send automated email and text messages requesting help from team leaders, operations managers, or anyone else in the shop at the click of a button.

Previously, employees had not seen their performance in terms of labor hours per unit. In response, I created individual performance reports. The reports are intended to be publicly distributed so that each individual can see how they stack up against their peers. This will expose training opportunities and can also be used to identify high-performing individuals and determine what unique techniques or methods they use that could be incorporated into standard work procedures.

The measurement system is necessary for the shop to move forward with continuous improvement efforts. "As Taiichi Ohno noted, 'without standards there can be no *kaizen*.'" (Womack, Jones, & Roos, 2007, p. 290). The tool's time standards are part specific. They provide clarity and definition in this highly variable process and increase employees' ability to identify problems.

To unify the shop, the measurement tool maintains the data from all the operations in one place. This allows individuals to see the entire repair process and how they are contributing to the team's overall performance. Employees begin to realize how efficient they must be if the team is to achieve its goals. This is only a first step towards helping people look at the repair process more holistically. Employees would also benefit from spending time shadowing people in other operations to better understand what happens throughout the repair process.

6.1.5 Implementation Teams

If goals, strategies, and measures are all aligned with the vision, then implementation should be relatively straightforward. However, the issues I observed with implementation often occurred because work was being done the way it was deemed most efficient by individuals.

One simple case where this was evident was at receiving. While analyzing the receiving process I learned that dock workers unpack a bunch of boxes at the same time before processing any of them into the system. The workers get dirty unpacking the boxes and do not like to touch the computer with filthy hands. So they unpack a number of boxes, wash their hands, and then enter related data into the system. This is not a significant problem but it is an example where mindset conflicts with goals. Dock workers believe they are more efficient when they unpack a few boxes at a time, but their methods do not account for what is important to the customer. The most important thing for the customer is to get the unit back quickly. By creating a batch-and-queue system at the unpacking station, they miss an opportunity to reduce cycle time through single-piece flow. This could be solved by issuing gloves and easy cleaning solution. It could also be resolved by creating stations where one person is responsible for unpacking and another is responsible for data entry to keep units flowing into the system. Whatever the resolution, the goal should be single-piece flow and efficiency of the shop as opposed to efficiency of individuals. All processes need to be similarly evaluated to ensure they line up with the transformation efforts and goals.

Through the early phases of lean transformation, teams will require substantial support and training in lean principles and tools. Lean experts should be brought in to fill this role and guide the effort. Providing this support will offload the operations managers and allow them to focus on reducing the backlog and other day to day issues. However, managers should spend time with the lean experts so that they can begin to fill this role on a long-term basis.

6.1.6 Review

Review is the final link in the Hoshin model. Review connects what is happening on the shop floor to the strategic vision. Review is most effective when there is a good working relationship between senior management and the people on the shop floor. Senior managers must commit to spending time with Repair on a regular basis. They should review metrics to check that the shop is improving and that the improvement is aligned with the overall vision. Senior managers should talk to shop floor employees to make sure that they understand how their work ties back to the vision. They should also observe behaviors on the shop floor to verify that what they see matches the results in the metrics and what people are telling them. Shop floor employees should use time with senior management as an opportunity to understand the direction of the company and to become comfortable with the competence of the senior managers. They should also express any concerns about disconnect between what they are asked to do and the perceived direction of the company.

Chapter 7: Conclusion

7.1 Summary of Recommendations

This section provides a brief overview of recommendations made throughout the paper. It is broken down into recommendations based on the tools and principles of lean, cultural and organizational changes, and suggestions for embarking on a lean transformation.

The ACE operating system has all the elements necessary for Repair to achieve productivity goals. Repair should start with the basic lean principles and apply them systematically to their processes. The application of lean principles and tools should begin at a high-level but then be applied to the most mundane tasks in the repair process. Repair should realize great improvement by reevaluating roles and responsibilities across the shops with an emphasis on engineers, dock workers, and members of the quality team. To create flow Repair needs to have consistent support through the test and troubleshoot operations. This can be achieved by purchasing new test equipment. When the equipment arrives, value-stream based cells should be created to maintain a process focus within the shop. A single cell should be created with the test rigs Repair currently owns to work out the bugs and issues that may arise from the new work arrangement. Cross-training will prepare employees to support one another within these cells and it will help reduce misunderstandings between the functional groups. Repair should attempt to gain test support consistency in the short-term by evaluating their capacity needs using the inventory management techniques presented in Chapter 4. Based on their assessment they should work with senior management to negotiate additional test support with Production. They should also make variable output goals to reduce backlog.

Cultural and organizational changes are necessary to support a lean transformation. Managers should assess their style of management. Managers that are "group facilitators" should work to develop a deeper understanding of the work processes. Managers that are "task masters" should focus on developing people and accomplishing tasks through the collective abilities of team members. Both types of managers should begin to evolve to become teachers. Shop floor employees must be willing to take on an increased role in improving processes. To help employees take on the increased role, Repair should bring in lean experts to lead the transformation effort and coach employees on the principles of lean. Managers must learn from the lean experts so that they can fulfill this role in the long run. A commitment should be made by all levels of management to allow shop performance to suffer in the short-term while employees spend more time improving processes. Functional teams should be utilized to define processes and drive improvement within each operation. As value-stream based cells are created, cell-based teams should become formed and take on improvement projects for the cell. Teams must be encouraged to experiment and failures should be viewed as valuable learning experiences. All-hands meetings should be utilized as a forum for knowledge transfer between teams to increase accountability, employee engagement, and to stimulate learning. To allow improvement to happen managers must commit to stop firefighting and spend more time building capabilities and improving processes. Senior management must make sure that incentives for all employees, especially middle managers are aligned with the long-term goals and not focused so heavily on short-term performance.

The Hoshin model yields some guidance to make the lean transformation successful in Phoenix. Senior managers should commit more time to Repair instilling employees with the vision and creating stronger relationships and better understanding the specific issues that can be observed on the shop floor. They should also make sure the goals meet the intent of the vision and show employees the linkage to increase buy-in. Middle managers should evaluate data collection methods and metrics to ensure they are accurate and customer-centric. They should also ensure everybody is looking at the same set of metrics. This can be achieved by utilizing the measurement tools and performance reports that I created. The measurement tool should drive improvement efforts, turnback entry, training plans, goal setting, and incentives. Shop floor employees should examine their processes and verify that the way they work is consistent with the concept of single-piece flow and that shop efficiency is prioritized over individual efficiency. They should also apply the scientific method to improving their processes.

If these recommendations are taken and applied conscientiously, Repair should easily surpass their productivity goals.

7.2 Final Words

> American companies seem intent on managing their businesses [expecting problems to be solved by a single action]. Rather than sweat out many small successes, with all the players, we wait for that meatball pitch the hero can belt out of the park for the game-winning run... Somehow we think that success is sweeter if we have to overcome adversity to get it. (Recardo & Peluso, 1992, p. xv)

Repair must overcome this notion and implement lean. They must look to their employees to each make small incremental improvements to the processes that will eventually lead to the achievement of phenomenal results.

Charles Darwin's evolutionary theory was first presented in relation to animals. But survival of the fittest is a concept that is not unique to the natural world. Businesses must be willing to change and adapt to the business environment in which they find themselves. Those that are willing to drive for improvement where others have not are bound to be successful in the long run. This dynamic can be achieved through consistent and sustained application of lean principles.

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