

**LEAN IMPLEMENTATION ACROSS VALUE STREAM
IN MAIN ROTOR BLADE AREA**

by

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B.S. Civil Engineering, United States Military Academy, 1996

Submitted to the MIT Sloan School of Management and the Department of Civil and Environmental Engineering on May 11, 2007 in Partial Fulfillment of Requirements for the Degrees of

**Master of Business Administration
AND
Master of Science in Civil and Environmental Engineering**

In Conjunction with the Leaders for Manufacturing Program at the
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May 2007
MIT Sloan School of Management
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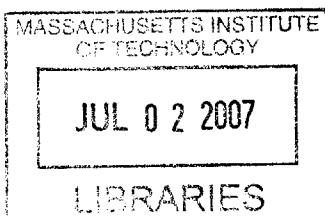
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ABSTRACT

The primary goal for this project was to help expand the existing capability of Sikorsky's main rotor blade business from raw material (titanium) through final assembly. The project helped to facilitate the ongoing lean transformation as the factory makes the journey to single-piece flow. During the internship, monthly kaizen events were used to help focus efforts on different areas of the value stream. These activities resulted in changes in the following areas: decrease in cycle times and lead times, reduction in inventory, procedural changes, and a future plan to physically change the factory floor to improve flow.

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NOTE ON PROPRIETARY INFORMATION

In order to protect proprietary Sikorsky information, the data presented throughout this thesis has been altered and does not represent the actual values used by Sikorsky Aircraft.

The cycle times have been disguised, altered or converted to percentages, names have been changed and part numbers and supplier data have been omitted in order to protect competitive information.

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CHAPTER 1: Introduction

Companies today are being confronted with new competitive pressures that mandate increased efficiencies irrespective of their specific industry or market segment. At stake in many cases is the very survival of the organization or enterprise. Unfortunately, the operations team of most companies is a major contributor to the inefficiencies and tensions that plague the firm. This is predominantly due to the fact that in most cases the organization and processes that represent the foundation of the company have evolved in an unplanned and essentially haphazard fashion as the technology and the diffusion processes have matured.

This thesis shall examine one particular company in the aerospace industry. The subject company, Sikorsky Aircraft, shall be analyzed using a lean production concept along with value stream mapping. The ultimate goal of this thesis shall be the demonstration of the utility of a variety of small operational changes in support of a lean transformation. We will position this paper with a broader history of lean as it pertains to aerospace industry. There will also be a discussion about incremental versus more revolutionary changes as well as the decision to spend time improving the existing process compared with the outsourcing option. This work shall illustrate the effectiveness of lean organizational structure and processes, and to support the subsequent transition to lean principles and single piece flow. Further, these methodologies shall be employed to substantiate the advantages of a lean transformation relative to the existing processes.

Due to increased competition, Sikorsky has embraced lean methodologies to reduce costs, enhance quality and increase responsiveness to customer demands. The disposal of batch and queue processing has brought about greater flexibility in the marketplace. The primary hypothesis in this work is that the introduction of single-piece flow (or just flow) to a brownfield manufacturing site can greatly improve operational metrics and reduce space requirements. However, an entire system redesign is required for the plant to realize its true potential. This work will attempt to answer the question about whether these small changes to the process are worth the efforts. The following

paragraphs will provide insight into the company's current state of affairs by examining Sikorsky and its parent company, United Technologies Corporation (UTC). While the analysis contained herein shall be presented from the perspective of Sikorsky Aircraft, the basic issues that exist are not peculiar to the subject or its industry. It is clear that similar motivating factors universally exist in competing markets and environments.¹

1.1 Background

Sikorsky aircraft is a world leader in the design and manufacture of advanced helicopters for commercial, industrial and military uses. Located in Stratford, Connecticut, Sikorsky strives to be the customer's first choice when the need is rotary flight. Sikorsky is a division of United Technologies Corporation (UTC), which used to be United Aircraft until 1975, and is also a leading defense contractor. UTC has continued to transform their operational effectiveness over the years to keep pace with increased competition in this aerospace sector. Earnings results illustrate that they have chosen the right strategy to lead them into the current millennium. Their cumulative shareholder return during this period is an astounding 1083% increase, five times that of the S&P 500 and three times that of the Dow Jones Industrial Average. This tremendous success is attributed to their diversified business strategy and a willingness to change when the market dictates such a move.

Most recently there is even more of a need to increase operating margins and inventory turns across all factories. Due to the increased military operational tempo and the uncertainty of demand fluctuations, the defense part of the business is being tested. The understandings of lean manufacturing techniques as well as the ability to implement them continue to be critical to the ongoing operations transformation. Lean thinking has promulgated throughout the organization and Sikorsky has embraced the challenge to help UTC maintain its success.

This chapter will give an overview of Sikorsky and UTC as well as describe the history of lean applications in similar environments. Lean manufacturing revolutionized

¹ Cocuzzo, Millard. 1984. The Applications of System Engineering Methodologies in Support of the Lean Enterprise Transformation. Master's Thesis, Massachusetts Institute of Technology.

the automobile industry for some time, but Womack, Jones, and Roos' 1990 publication of The Machine that Changed the World is what helped to popularize the Japanese techniques to the western world.² Lean practices made their way into UTC in the 1980s via Pratt & Whitney, but only in the last decade have they been widely used across all companies.

1.2 Background of United Technologies and Sikorsky Aircraft

United Technologies is a diversified, multinational corporation and industrial firm headquartered in Hartford, Connecticut with 2006 revenues of \$47 billion. As stated above, over the last 10+ years UTC has been on a tremendous growth trajectory and is currently the 20th largest U.S. manufacturer. They are the 47th largest employer in the world with 220,000 employees (2005) and were named “Most Admired” aerospace and defense company (2001-2006 lists, *Fortune*). The company researches, develops, and manufactures products in numerous areas, including aircraft engines, helicopters, heating and cooling, fuel cells, elevators and escalators, fire and security, building systems, and industrial products. Their international presence is significant with over 4,000 locations in approximately 62 countries and with business contact in approximately 180 countries.

UTC is comprised of eight independent business units listed here and illustrated below:

- Hamilton Sundstrand
- Sikorsky Aircraft
- Carrier Heating and Air Conditioning
- Otis Elevators and Escalators
- UTC Fire & Security Protection Services
- Pratt & Whitney Aircraft Engines
- UTC Power
- United Technologies Research Center

² Womack, Jones, and Roos. *The Machine That Changed the World*. New York, NY; Harpercollins Publishers, 1990.

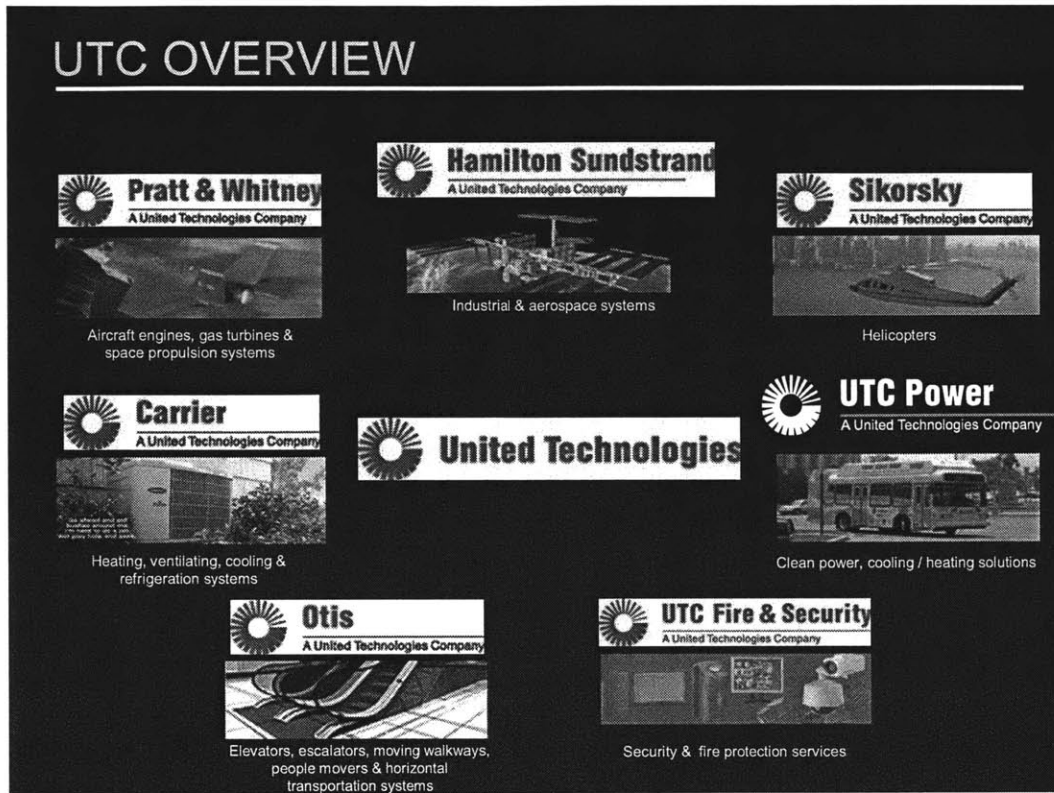


Figure 1: UTC Business Units

Their history goes back to 1853 when Elisha Graves Otis established his elevator factory and proved at the New York World’s Fair that his contraption worked safely. UTC has certainly made progress through the years demonstrated most recently by Rocketdyne being acquired from Boeing and added to Pratt & Whitney’s space propulsion business in August 2005.

Sikorsky Aircraft’s heritage starts with the man the company is named for, Igor Sikorsky. He founded it in 1923 and made the first stable, single-rotor, fully-controllable helicopter to enter large full-scale production in 1942. It was this prototype that the majority of subsequent helicopters were based. The company became a part of United Aircraft in 1934 (which is now UTC) and remains one of the leading helicopter manufacturers, producing such well-known models and the UH-60 Black Hawk and SH-60 Sea Hawk (See Figure 2), as well as experimental types like the Sikorsky X-Wing (See Figure 3). Sikorsky was also a proud supplier of the President of the United States,

Marine One since 1957 (this changed in January 2005). Sikorsky primarily concentrates on medium and large rotorcraft and is used by all 5 branches of the U.S. armed forces (Army, Navy, Air Force, Marines and Coast Guard). Their main plant and administrative offices are located in Stratford, Connecticut, but they do have other facilities in Shelton and Bridgeport Connecticut; West Palm Beach, Florida and Troy, Alabama.³



UH-60 Black Hawk



SH-60 Sea Hawk

Figure 2: Common Aircraft Types at Sikorsky

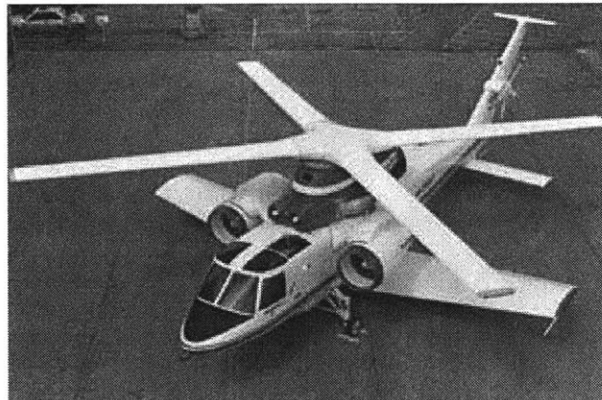


Figure 3: Sikorsky X-Wing

Militarily, Sikorsky helicopters currently serve roughly half of the needs of all five branches of the United States armed forces (Army, Navy, Air Force, Marines and

³ www.sikorsky.com

Coast Guard). However, the Blackhawk has proved to be an extremely versatile aircraft and the true “workhorse” of the Army, Air Force and Marines Corps. In fact, this aircraft is able to support many different types of missions including troop and equipment transport as well as air assault missions. They also provide a heavy-lift capability to the Air Force, Navy and Marine Corps in the CH-53 (although this is a low volume product).

Commercially, Sikorsky provides two types of helicopters. The S-76 is widely flown in 40 countries for executive travel, offshore oil, and emergency medical service and airline missions. The company’s civil aircraft line-up also encompasses the S-92, which is capable of carrying up to 22 passengers per load. The following are Sikorsky’s market segments and aircraft types.

Commercial: S-76 and the S-92

Military: UH-60 Blackhawk, SH-60 Seahawk, HH-60 Jayhawk, CH-53 Super Stallion and the H-92 SuperHawk

1.3 Lean Manufacturing at Sikorsky

Like its partner companies Pratt & Whitney, Hamilton Sunstrand and others, Sikorsky Aircraft has continued to attempt to improve their operations. They have undergone a lean journey on much of the manufacturing floor in an attempt to emulate the Japanese production techniques for dramatic process improvements.

UTC’s current CEO, George David, explained the importance of lean operations in an address to the University of Yale in 1996:

“The reason is kaizen, lean production, process re-engineering or whatever similar term we choose. This is the single most powerful force in corporate America and in our economy today, no qualification, no question. And I believe I am in a position to speak persuasively about this. The facts are that United Technologies has reduced employment by about 15%, a total of 30,000 positions, and manufacturing space by another 15%, or 10 million feet, over the last four years [as output has increased during this same time period].” He continued, “The principles [lean] are straightforward. First, make something only when you need it and never early. Make it in the smallest possible

quantity and make it again when you next need it, which of course requires set-up time and cost minimization, which is kaizen's most basic initiative. Third, minimize the numbers of separate operations, and therefore hand-offs and therefore opportunities for inventories and delays, and minimize travel distance within the manufacturing process. Fourth, measure quality at every intermediate step and eliminate rework per operation rather than reject parts at final inspection."⁴ It is interesting to note that the current definition that Sikorsky uses for lean is: *The elimination of waste in a process, resulting in improved cost, quality, delivery, lead time and asset utilization.* George David was discussing this more than ten years ago in much the same terms as the company sees it today.

This illustrates UTC's firm commitment to lean over its history. In fact, they instituted a wider definition through their Achieving Competitive Excellence (ACE) Program. They started this program in the early 1990s and its goal was to ensure a quality standard across the organization. This program provided tools that could then be used in lean manufacturing such as root cause analysis, mistake proofing, standard work, setup reduction and total productive maintenance. Figure 4 shows how ACE supports the traditional path toward improvement.

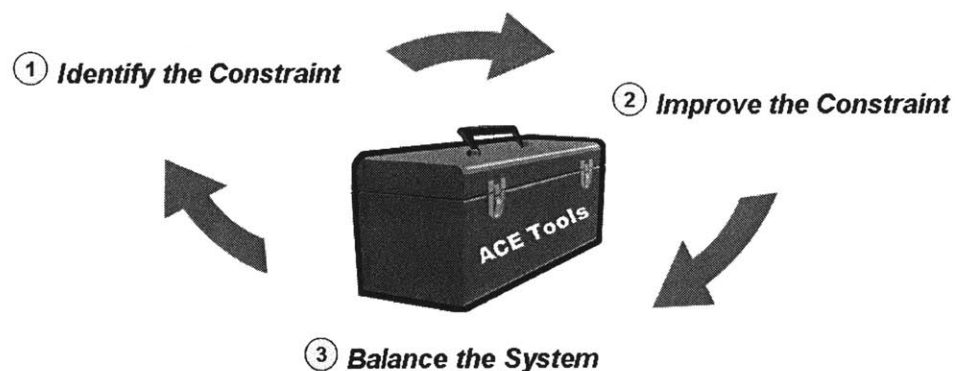


Figure 4: ACE Tools Integration

⁴ David, George, *Technology and the American Economy*, the University of Yale, 1996

1.4 Thesis Structure

The organization of this thesis is outlined below:

Chapter 1: This chapter is a brief overview of United Technologies and Sikorsky Aircraft is included. Also, we set the stage for the need for the internship project as well as some information about the competitive landscape in the aerospace industry. Lastly, we offered a theory as to what is essential to grasp the full benefits of lean.

Chapter 2: This chapter is a description of the challenges at Sikorsky and the impetus behind the internship. Also, it contains a complete description of the main rotor blade process.

Chapter 3: This chapter summarizes the basic tenets of lean and its history.

Chapter 4: Included in this chapter is a case study which helps answer the stated hypothesis. The internship project was the medium used for this study. It defines kaizen events and describes in detail the areas of interest and recommendations for improvements. It also lists the primary anticipated results for recommendations set forth from the internship project.

Chapter 5: This chapter gives organizational perspectives involved when implementing lean by providing an in-depth analysis of the company from a strategic, cultural and political perspective.

Chapter 6: The final chapter concludes with some closing thoughts and remaining questions for the future. In addition, it provides the author's stance on how Sikorsky is currently performing and where it can look for improvements.

CHAPTER 2: PROBLEM STATEMENT AND DISCUSSION

This chapter discusses the challenges that Sikorsky is facing and the impetus behind the internship. Also, a description of the main rotor blade manufacturing process is included.

2.1 Project Motivation

Sikorsky has had a doubling of demand over the last few years. This is primarily due to the increased military operational tempo around the world (Iraq and Afghanistan). Couple this with the fact that Sikorsky also went through a strike in the first quarter of 2006 and it becomes clear why a more efficient process has become extremely critical to success. The method chosen to move down this critical path was (and has been for many years at Sikorsky) a lean implementation. The lean concepts are firmly ingrained into the minds of most management executives and, therefore, many resources are allocated to foster an environment that embraces lean. This project was in this spirit and continued the ongoing work in the main rotor blade area.

The primary goal for this project was to help expand the existing capability of the main rotor blade business from raw material (titanium) through final assembly. The project helped to facilitate the ongoing lean transformation as the factory makes the journey to single-piece flow. Monthly kaizen events (defined and discussed in detail later) were used to help focus efforts on different areas of the value stream. These activities resulted in changes in the following areas: decrease in cycle times and lead times, reduction in inventory, procedural changes, and a future plan to physically change the factory floor to improve flow.

2.2 Main Rotor Blade Manufacturing Process Overview

The process the internship focused is the initial steps in creating a main rotor blade out of a raw sheet of titanium. Appendix B shows the blade shop visual process in detail. Essentially, a main rotor blade is produced in two successive stages: blade and

spar assembly. About half of the steps in the study looked at the blade while it was a tube (basically just a flat sheet of titanium that has been formed into a hollow cylindrical shape). The other half of the process involves a spar, or a skeleton of the blade (See Figure 5).

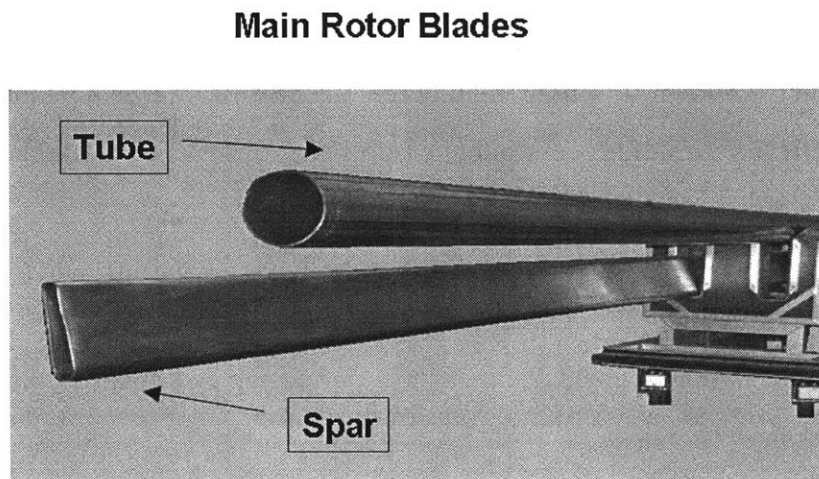


Figure 5: Main Rotor Blade (Tube and Spar)

2.2.1 Detailed Description of the Blade Process

Tube

- Brakeform – Flat sheet of raw titanium is pressed into a round cylindrical tube
- Etch/Moment – Series of chemical processing tanks that etch the titanium to the desired thickness and moment
- Sanding – Series of sanding operations to prepare the tube for future follow-on processes and to inspect the product for deficiencies
- Slot Weld – Welding operation that makes the tube a full cylinder
- Boroscope – Inspection step that looks at the inside of the tube (specifically at the weld bead) for any deficiencies

- X-Ray – Inspection step to ensure there are no cracks or deficiencies
- Saw – Cut off the excess titanium needed for the welding step
- Cone Weld – Fabricated conical pieces are welded onto the tubes for future oven process
- Turco – Paint booth step
- Air Cure – Time allowed for curing prior to going to the oven

Spar

- Hot Form and Cooldown – 11 hour heating process that transforms tube into a spar
- Scribe/Cut/File – Series of processes that ensures spar meets specifications
- Kolene – Series of chemical tanks needed for additional strength
- Machine/Hand Sand – More sanding operations to prepare for follow-on processes and to inspect the product for deficiencies
- Case and Moments – Additional chemical tank processing as a spar to ensure desired thickness and moment
- Final Sand – Final sanding operations to ensure no deficiencies
- Wall Readings – Inspection step to ensure desired thickness
- Blacklight/Whitelight – Inspection step for quality assurance purposes
- Shot Peen – Shot is fired at the blade to give it the desired finish and to meet specifications
- Contour Check – Inspection step to meet specifications
- Milling and Deburring – Inspection step to meet specifications
- Picatinney – Chemical processing tanks to ensure desired strength of spar
- Oven Dry – Spar is dried in the oven prior to leaving the titanium main rotor blade area

The lead time for the entire process currently takes, on average, 50 days from beginning to end. As shown in Chapter 4, this lead time can be reduced to approximately 10 days with a corresponding reduction in inventory.

As will be discussed in Chapter 4, the process was studied through the facilitation of numerous kaizen continuous improvement events. Each of these events had a cross-functional team involved in the planning, execution and the eventual implementation of the results of the events.

This chapter gave a detailed description of the titanium main rotor blade process. Also, it has given a motivation for the lean framework that was used in the internship.

CHAPTER 3: KEY CONCEPTS AND LITERATURE REVIEW

3.1 History Prior to Lean

Lean manufacturing, as it is known today, grew out of craft production and then from mass production with Fred Winslow Taylor and Henry Ford. Taylor laid the foundation for mass production because he was the first to systematically apply scientific principles to manufacturing. By investigating how to do any particular job better, he invented industrial engineering. His ideas today are not thought of as true because his basic premise was that the workforce lacked the literacy to plan the work. However, despite its drawbacks, his innovations include standardized work, reducing cycle times and the idea of time and motion studies.

It was Henry Ford who finally fully implemented much of the ideas in existence with his 1908 Model T. He brought the idea of mass production to the forefront of manufacturing. Despite the popular belief that it was the assembly line that was at the heart of mass production, it was actually the interchangeability of parts and ease of assembly. His innovations produced enormous savings and paved the way to lean manufacturing. However, Ford's system had systemic problems such as design problems, quality problems due to batching and worker unrest.

3.2 The Need for Lean Manufacturing

It all started in 1950 when Eiji Toyoda visited Ford's Rouge plant in Detroit. Legend has it that this visit inspired him to improve on the traditional mass production processes at Toyota Motors in his native Japan. Over the next 50 years this improvement would grow into the Toyota Production System (TPS), or lean production. This system made Toyota one of the most successful companies in the world and continued to reaffirm these ideas year after year. It took the Toyota management thirty years to perfect the system and manufacturers all over the world constantly attempt to emulate TPS.

3.3 What is Lean Production

Lean Production, or TPS, really just means doing more with less (less time, less space, less human effort, less machinery, less materials) while giving customers what they want. The reason this system is so important in today's world is the fact that in many industries today the price is relatively fixed or falling. In this environment, the only way to increase profit is to reduce cost. The goal with lean production is reducing cost without reducing quality --- not an easy task. However, the tenets of TPS give us the framework to draw upon when looking for opportunities to decrease cost.

The core goal of TPS is to provide the highest quality, at the lowest cost, in the shortest time by continually eliminating muda or waste.

The basic foundation of lean production consists of the following

- Standardization
- Stability
- Just-in-Time delivery of parts and products
- Jidoka, or automation with a human mind

The overall goal of the system is customer focus or delivering the highest quality to the customer, at the lowest cost, in the shortest lead time. The true power of TPS is the continuous reinforcement of these concepts.

Womack and Jones, in Lean Thinking, further clarify this point by talking a lot about value and how it can only be defined by the ultimate customer. This is a counterintuitive perspective, but one that must be accomplished for long-term success in today's global economy.⁵ They summarized the lean approach into five key lean principles:

1. Specify value. This element can only be defined by the customer
2. Identify the value stream. The core set of actions required to produce a product.

⁵ Womack, James P. and Jones, Daniel T., Lean Thinking: Banish Waste and Create Wealth in your Corporation, New York: Simon & Schuster, 1996.

3. Make the value flow. The method of aligning the processes to facilitate the critical path.
4. Let the customer pull. The customer should begin to 'pull' product on an 'as needed' basis.
5. Pursue perfection. Develop and amend the processes continuously in pursuit of perfection.

They believe that this five step approach can help a company respond to any business issue.

3.4 Types of Waste

There are eight different kinds of muda: Motion, waiting, conveyance, correction, over processing, overproduction, and inventory and knowledge disconnection.

A discussion of each follows:

- Motion – Wasted motion can be both human and machine. It is related to workplace ergonomics and affects productivity and safety.
- Waiting – This occurs when there is excess Work-in-Process (WIP) or when people stand around waiting to process a part.
- Conveyance – This waste is caused by inefficient workplace layout, overly large equipment, or traditional batch production.
- Correction – This is related to making and having to fix defective products. Quality costs associated with correction are large.
- Over processing – Related to doing more than what the customer desires.
- Overproduction – This involves making things that do not sell. Essentially, the goal is to meet customer demand, but not to exceed this level.
- Inventory – The keeping of unnecessary WIP is the condition of inventory waste.

- Knowledge disconnection – These disconnects can be horizontal, vertical, or temporal. They inhibit the flow of ideas and result in missed opportunities and frustration.

3.5 Stability

One key tenet of lean production is the 5S system:

- S1 – Sort – This basically just means to sort out what is not needed. Prioritize what is needed for the job and what is not.
- S2 – Set in Order – Here we need to ask ourselves how to place machines, tools, storage shelves, etc. to reduce the muda of motion.
- S3 – Shine and Inspect – Make the work area a clean well-ordered workplace.
- S4 – Standardize – This step supports S1 through S3 because it will provide a framework to know if these are acceptable or not.
- S5 – Sustain – This is the overarching support to ensure that each step continues to be important in the organization.⁶

3.6 Standardized Work

Standard work is when an operator follows a prescribed method, with a proper workstation and proper tools, and is able to perform the amount of work required in the same amount of time, with perfect quality, without risk to health or safety. The main purpose of this is to allow any operator to perform the work to the same acceptable standard. This minimizes the need for cross-training, but gives the supervisor greater flexibility in scheduling. For example, at any given time, the amount of work-in-process should always be the same. The result is a smoother running operation and one that gives the supervisor a different role (explained more in chapter 4).⁷

⁶ Dennis, Pascal, Lean Production Simplified: A Plain Language Guide to the World's Most Powerful Productions System, New York: Productivity Press, 2002.

⁷ Duggan, Kevin, Created Mixed Model Value Streams, New York: Productivity Press, 2002.

3.7 Just-in-Time Production

The Just-in-Time (JIT) system makes value flow so that the customer can pull. Essentially, the JIT concept is to replenish the operation with inventory at a time no earlier than the time it can actually be processed. This results in a lower level of WIP throughout the system. Achieving this level of sophistication takes a disciplined approach to operations that depend on many factors. These factors are much of what has been discussed (standard work, 5S, stability, eliminating waste) in addition to quick machine changeovers. The inherent secret behind TPS is that all of these issues need to work in tandem to successfully implement a true lean system.⁸

3.8 Toyota Production System

Much has been written about TPS, while very few companies have been able to match their efficiencies. The main reason for this is because true lean operations is more than just about flow or pull production. TPS in Toyota has been primarily concerned with making a profit with the lowest cost and shortest lead-time, while developing the skill of its workforce through rigorous training. This result focused approach is one of the main reasons they have outperformed many U.S. manufacturing competitors over the last 20 years. They continue to drive all work toward making a profit as the ultimate goal. The TPS tools (some of which are discussed in this thesis) are just ways to see problems, and are not the solutions themselves. The key lesson to extract from their process is to fully understand the problem at hand prior to applying the tools.⁹

3.9 Lean in Aerospace

Although the principles of Lean manufacturing are now well established, especially in the automotive industry, it faced initial reluctance in the aerospace industry.

⁸ Dennis, Pascal, Lean Production Simplified: A Plain Language Guide to the World's Most Powerful Productions System, New York: Productivity Press, 2002.

⁹ Smalley, Art. 2005. TPS vs Lean and the Law of Unintended Consequences, Superfactory

Much of this can be attributed to much longer lead times and, therefore, not as great a sense of urgency as with the automotive industry. There are many examples and ample evidence that lean principles are a powerful enabler when applied effectively.¹⁰

This chapter summarized the basic tenets of lean and its history. The next chapter will illustrate the implementation of a lean concept called kaizen. These kaizen events were used as the case study to help learn how much value incremental change can bring to an established industry at a brownfield site.

¹⁰ Haque, Badr and James-Moore, Mike. Applying Lean Thinking, Journal of Engineering Design

CHAPTER 4: IMPLEMENTATION OF KAIZEN EVENTS

4.1 What is a Kaizen Event

The word kaizen is a Japanese term meaning “continuous incremental improvement.” Therefore, a kaizen event is nothing more than a specific amount of time (in our case one week) that is dedicated to a particular area on the manufacturing floor. Its goal is to produce steady results of improvement (i.e. reduced cycle times, reduced lead times, fewer inventories, less congestion) along the path to perfection

4.2 Value Stream Mapping

The motivation for doing the value stream mapping of the main rotor blade process was to give us a clear understanding of what the problems were. We needed to confirm our suspicions of where the bottlenecks were, better understand the information flow and to help us determine potential areas to target reduced inventories.

4.3 Eliminating Waste

Value stream maps (VSMs) are extremely important tools to help a manager (or anyone studying the organization) understand a process. A value stream is all the activities, both value-adding and non-value-adding, currently required to bring a product through the production flow and the design flow (Rother and Shook, 1998). The ultimate goal is to work out a lean value stream, reduce non-value-adding iterations, avoid wasting resources and achieve time compression. In fact, Parry and Turner go further to say that any manager who cannot draw their process on a single piece of paper is unlikely to be able to manage it.¹¹

4.4 Creating Value Stream Maps

¹¹ Parry G.C. and Turner C.E. 2006. Application of lean visual process management tools, University of Bath, School of Management.

The reason we wanted to a value stream map was to better help us understand where the opportunities for improvement were located. Furthermore, it helped to guide us toward the areas that were a priority and could be improved upon in the shortest amount of time. The process helped us make strides out of a complex process. It is not intuitive to look at a process from a holistic view. In fact, it is much more common to observe a system at an individual time and location and then infer, or make assumptions, about other parts of the system. The building of the value stream maps raised our consciousness and helped us look for methods to permanently eliminate waste. It is especially important here to form the cross-department and cross-company team to better focus on the product.¹² Shown in Appendix B is the value stream map of the titanium main rotor blade system. This shows multiple turn backs of product as well as outside entities that are involved in the process. The major results of this exercise are shown in chapter 7.

4.5 Prioritizing Kaizen Events

Kaizen events were prioritized by the general manager of the blade area. He listened to other's recommendations for what was most critical to the success of the business, but ultimately he was the final decision on what portion of the value stream we would study.

4.6 Selecting Team Members

For each kaizen event we had a cross functional team involved. Those team members included, but were not limited to the following:

- Team leaders
- Business unit manager
- ACE
- Design Engineering

¹² Womack, James P. and Jones, Daniel T., Learning to See, Brookline: The Lean Enterprise Institute, 2003.

- Industrial Engineering
- Maintenance

All team members played a vital role in the pre-work activities and the entire event. In addition, the entire team was encouraged to provide ideas and feedback to management and to the consultant from outside the organization.

4.7 Kaizen Events

These continuous improvement events covered a range of processes in every study. The normal progression for investigation was followed such that we looked at the beginning of the process (raw material titanium) first and then continued downstream (as material flows). This method of analysis made the understanding of the value stream, discussed in Chapter 5, easier to grasp.

4.7.1 Visual Tools

In each of the kaizen events we made improvements in factory visuals. These changes support the discussion of 5S in chapter 3.5. The benefit of each of these changes was to assist the operators in following a consistent method for each product at each station. They provided the ability to get a good sense of the status of the production process from a quick glance. These were simple additions to the area that provided significant operational awareness to both the hourly workers and the management team. The only challenge we faced with this implementation was ensuring that the visuals were updated. Consistent follow up and supervision were required for the continued success of these visual aids.

4.7.2 Chemical Processing of Tubes (Pre-Spars)

The first area we investigated was the chemical processing of tubes.

Description of process:

There are a series of five chemical tanks positioned side-by-side in the work station. The operator moves the part between these tanks using a crane that is attached from the roof and submerges the part in each tank for a specified amount of time. There are three *different* operations that use the chemical tanks at subsequent times in the overall process which are named below:

- 1) Cleaning for tube moment (We call this Process A)
- 2) Cleaning for slot weld (We call this Process B)
- 3) Cleaning for the paint booth (We call this Process C)

The individual tanks are situated on the shop floor as follows (from south to north):

- S-TE180 Brulin Alkali (Soap)
- S-TE181A Hot Water Rinse
- Nitric Hydros Flouric Acid (Etching process)
- Cold Water Rinse A
- Cold Water Rinse B

Each of these processes requires a different amount of time in each of the tanks.

Depending on the process (A, B, or C) the part is required to stay in the etching tank for an undetermined amount of time. This is based on many factors such as: the strength of the acid on the day of interest, the ambient air temperature and the thickness of the part.

All of these factors can vary at once or individually, which can make this process extremely difficult to predict. Also, primarily Process A is an iterative process because it requires a moment measurement that must be within specifications prior to moving to the next step in the process.

Analysis

After observation of the area, the most significant issues were: an increased level of inventory, lack of standardized work (in general and across different shifts), suboptimal procedures and inefficient material handling.

The main reason we decided to focus on the chemical processing is illustrated in Figure 6. The blade processing in the chemical tanks actually exceeds the TAKT time. Initially, this observation was not clear because during this section of the process the product passes through the tank station a total of four times. This information told us that

the chemical tanks were shared resources, and therefore, the cycle times for each process step needed to be added.

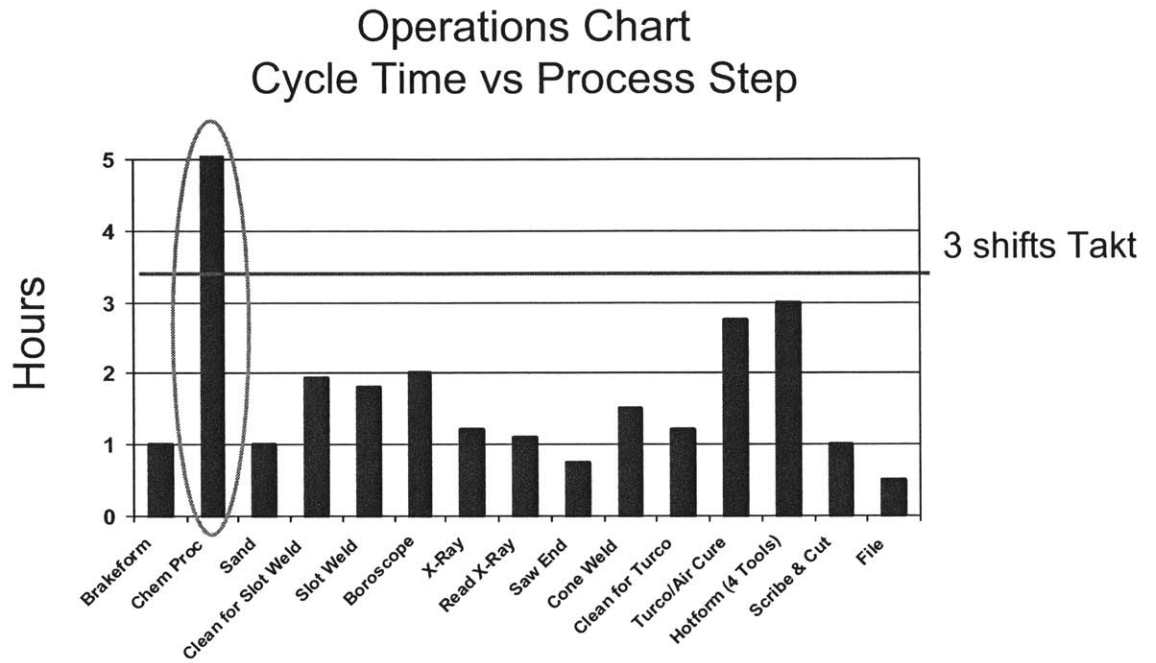


Figure 6: Tube Operations Chart

This finding led us to focus on each of the processes to determine where there was room for improvement. One of the first solutions we implemented was by completely eliminating the last process step. The quality assurance department agreed that the final step was unnecessary so long as we instituted a more thorough quality inspection after the third chemical process step. This allowed for a reduction in inventory in the chemical area as well as a smoother flow due to the decreased congestion (only three steps versus four).

Another area that we improved on was the cycle time. This was an obvious choice considering the TAKT time issue discussed above, however, it proved to be a significant area for improvement. As previously discussed, the primary constraint in this area is the

crane attached to the rafters used to transport the WIP blades between chemical tanks. Given that this was not going to change in the near future, we directed our attention to getting more processing time out of the existing process. One of the best ideas that we used were the dwelling arms that we had fabricated and installed in a few of the appropriate chemical tanks (See Figure 7). As discussed previously, prior to this event the blades were moved one at a time from tank to tank. However, no more than one tube was ever put into a given tank at the same time. These arms essentially capitalized on the automatic time that the operator was not required to be present physically working on the product.

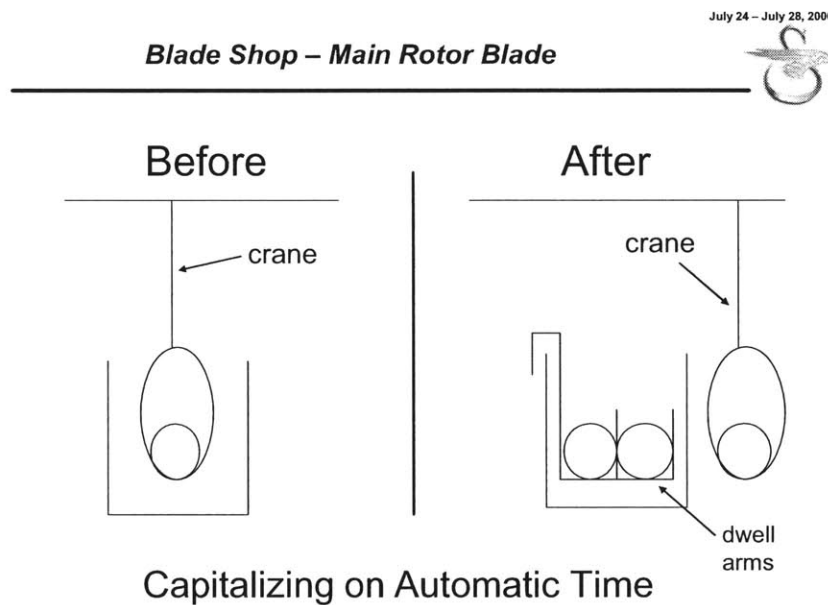


Figure 7: Dwelling Arms

With these dwelling arms the crane could be used in a more efficient manner (i.e. the crane would not have to loiter with a part attached in a tank while another part could have been introduced into the process. This resulted in a decrease in cycle time overall and a higher utilization of the tanks. To accomplish this we proposed a set of work instructions with new process steps for the operator to follow in order to take advantage of the dwelling arms. For example, here is our proposed list of instructions to optimize the three processes:

Process Needed to Utilize Arms

1. Place Etch & Moment tube onto scale.
2. Place Clean/Etch for Slot Weld tube into Brulin tank arm. (Detach from crane)
3. Pick up Etch & Moment tube from scale and drop into Brulin tank arm. (Detach from crane)
4. Pick up Clean/Etch for Slot Weld tube and brush, drop back into arm. (Detach from crane)
5. Continue Etch & Moment Process till complete.
6. Continue Clean/Etch for Slot Weld process till complete.
7. REPEAT STARTING WITH STEP 1

We anticipated these instructions to yield a decrease in cycle time of 20% for a given blade.

One of the most difficult problems that these chemical tanks presented was the acid etch tank. This was the process in which the tube would be etched in an acid mixture in order to attain the proper moment for the tube. Inherent in this process was a tremendous amount of variation due to the following issues: strength of the acid at any given time, ambient air temperature, operator technique, variation of incoming tube. The strength of the acid was particularly tricky because of all the variable inputs mentioned. About once a month the inspectors would test the strength of the acid and then add the appropriate amount of acid. Therefore, during this month the acid's strength would continue to decrease as blades were processed through. All of this combined to make this process step vary from a minimum time period to a maximum of five times the minimum. Obviously, it was critical to stabilize this process before continuing to make additional improvements. One of the primary reasons for this variation was because of the experience level of the operators. An operator with a lot of experience would tend to minimize the number of times the tube was weighed. This would usually result in a minimum number of iterations (less time), but would occasionally require more iterations due to the perceived ability of the operator (more time). The end result of this was an

unstable system requiring a procedure and a decision framework for the operator. The way the team approached this is included in Figure 8. Here is the result of the engineer analysis of the incoming tube and the time it is generally required to dwell in the acid etch tank to arrive at the appropriate thickness.

July 24 – July 28, 2006

Blade Shop – Main Rotor Blade



Etch Rate
vs
Moment

Initial Moment [in*lbs]	Etch Rate [in/min]									
	0.00005	0.0001	0.00015	0.0002	0.00025	0.0003	0.00035	0.0004	0.00045	0.0005
18150	3.0	1.5	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3
18175	6.8	3.4	2.3	1.7	1.4	1.1	1.0	0.8	0.8	0.7
18200	10.5	5.3	3.5	2.6	2.1	1.8	1.5	1.3	1.2	1.1
18225	14.3	7.1	4.8	3.6	2.9	2.4	2.0	1.8	1.6	1.4
18250	18.0	9.0	6.0	4.5	3.6	3.0	2.6	2.3	2.0	1.8
18275	21.8	10.9	7.3	5.4	4.4	3.6	3.1	2.7	2.4	2.2
18300	25.5	12.8	8.5	6.4	5.1	4.3	3.6	3.2	2.8	2.6
18325	29.3	14.6	9.8	7.3	5.9	4.9	4.2	3.7	3.3	2.9
18350	33.0	16.5	11.0	8.3	6.6	5.5	4.7	4.1	3.7	3.3
18375	36.8	18.4	12.3	9.2	7.4	6.1	5.3	4.6	4.1	3.7
18400	40.5	20.3	13.5	10.1	8.1	6.8	5.8	5.1	4.5	4.1
18425	44.3	22.1	14.8	11.1	8.9	7.4	6.3	5.5	4.9	4.4
18450	48.1	24.0	16.0	12.0	9.6	8.0	6.9	6.0	5.3	4.8
18475	51.8	25.9	17.3	13.0	10.4	8.6	7.4	6.5	5.8	5.2
18500	55.6	27.8	18.5	13.9	11.1	9.3	7.9	6.9	6.2	5.6
18525	59.3	29.7	19.8	14.8	11.9	9.9	8.5	7.4	6.6	5.9
18550	63.1	31.5	21.0	15.8	12.6	10.5	9.0	7.9	7.0	6.3
18575	66.8	33.4	22.3	16.7	13.4	11.1	9.5	8.4	7.4	6.7
18600	70.6	35.3	23.5	17.6	14.1	11.8	10.1	8.8	7.8	7.1

33

Figure 8: Acid Etch Rate vs Moment

This table is a tool that the operator can use to give them a greater predictability for determining etching times. It is a standard way for operators to perform the process while relying less on trial and error and experience. An operator enters this table with the etch rate for the day and the initial moment measurement. The intersection of the row and column give him the amount of time he should leave the blade in the etch tank. We anticipated this tool to reduce the iterations from an average of two to the goal of one.

Finally, we did some initial research on better ways to move the product between tanks (instead of the existing crane). The research yielded some good ideas, but ultimately did not result in a proposed plan for getting away from the crane use.

Throughout the internship, the team brainstormed different methods that we felt would be appropriate and user friendly. The material handling question is a very important project that another internship could analyze and one that would make an enormous impact. Also, while we felt that moving toward a better material handling system would be beneficial, it would also be costly and take a lot of time. Instead, we focused our efforts on simple solutions (such as the dwelling arms and the table in Figure 8) that we could implement in the short term and show immediate results.

4.7.3 Chemical Processing of Spars

The chemical processing of spars was the next area of interest our team investigated. The process is identical as was described above for tubes, with some minor differences in the amount of time that the spars remain in a specific tank. As seen below in the operations chart for a spar (Figure 9), this side of the business also has shared resources in the form of the chemical process tanks.

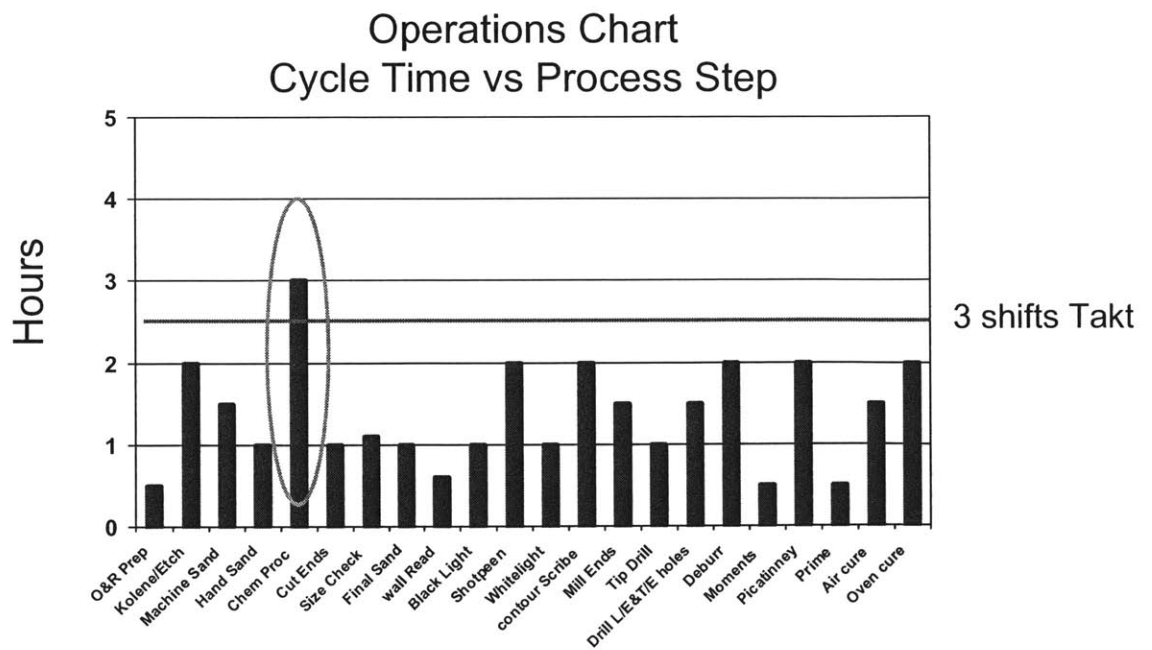


Figure 9: Spar Operations Chart

Many of the same improvements were implemented in this area. However, this area required a different analysis due to the type of products that are processed. Here, not only are the “virgin” blades (blades made from raw material) processed, but the overhaul and repair blades are as well. This increased the required demand, thereby decreasing the TAKT time on the factory floor by 40%. We needed to verify that the overall existing process (using the cranes) was capable of meeting this increased demand. By using a simple simulation seen in Figure 10 we were able to verify this metric.

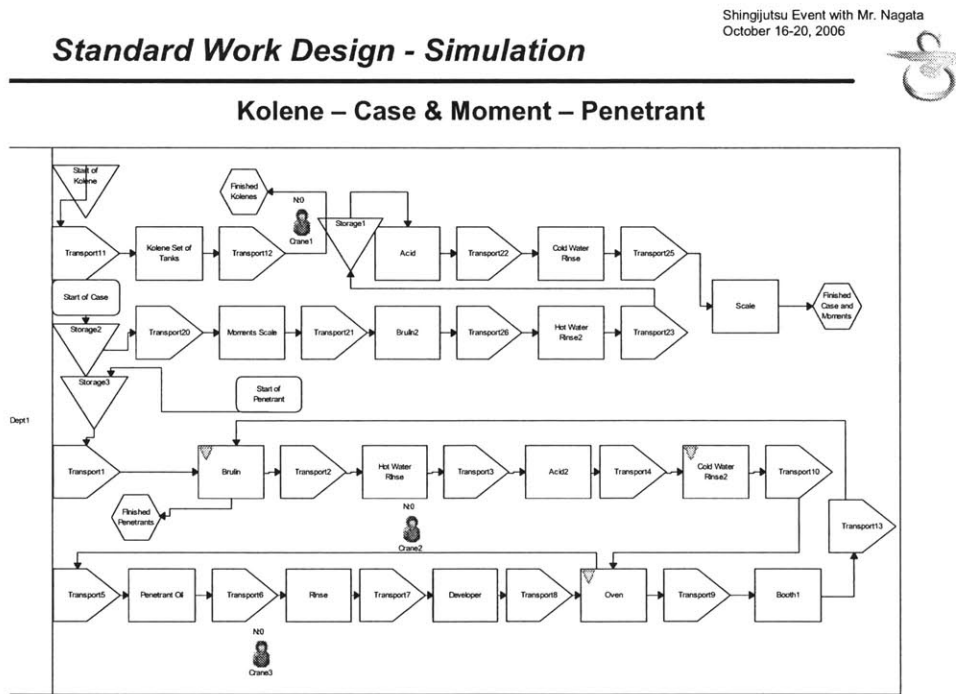


Figure 10: Spar Chemical Tank Simulation

However, the results of the simulation gave us the information shown in Figure 11. It is clear that the current system is extremely sensitive to any variability that may occur. This finding gave us further evidence for the need to find ways to decrease overall cycle time in the chemical processing and to work toward single piece flow.



Standard Work Design Simulation - Results

#	Activity Name	Result Type	Value	SD = 5% of Mean
1	Kolene Crane	Utilization %	65.78	66.62
2	C&M Crane	Utilization %	96.47	99.19
3	Penetrant Crane	Utilization %	79.23	73.89
4	Black Light Booth	Number of Completed Jobs	13	9
5	Finished Kolenes	Number Completed	18	19
6	Finished Penetrants	Number Completed	10	6
7	Finished Case and Moments	Number Completed	11	11

- **Validates our intuition about the ability to meet TAKT time**
- **Crane utilization is a concern – Automation would reduce process variation**
- **Extremely sensitive to any deviation**
- **Findings: IS possible to meet customer demand, BUT need to change process**

Figure 11: Utilization Results

The spar process flow was another example of where we could implement standard work. An example of a standard work sheet is shown in Figure 12.

Standard Work

Shingijutsu Event with Mr. Nagata
October 16-20, 2006



Standard Work Sheet

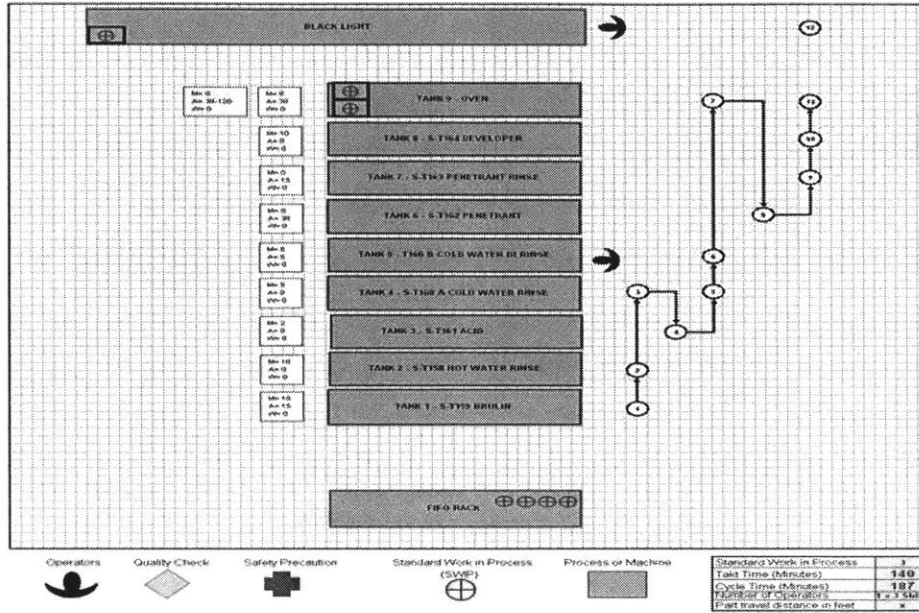
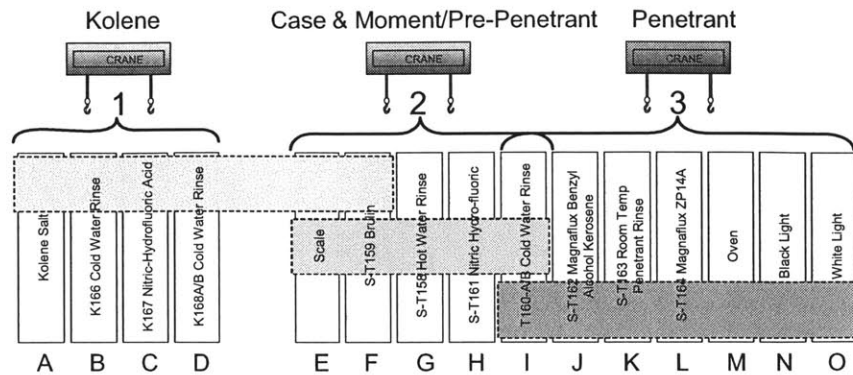


Figure 12: Standard WorkSheet

This worksheet is a standard ACE tool that Sikorsky uses and is a great way to better understand the system as well as a nice visual for the operator to follow.



- Operator Responsibilities:**
 1 – Kolene Tanks Only.....(A - D)
 2 – Case & Moment/Pre-Penetrant Tanks.....(E - I)
 3 – Penetrant Tanks.....(I - N)
- Daily Operator Requirements (Completed Parts):**
 1 – 10 Kolene + 5 Case & Moment
 2 – 5 Case & Moment + 10 Pre-Penetrant
 3 – 10 Penetrant

Figure 13: Crane Responsibilities

Figure 13 shows an interesting way that we found to visualize what the optimal responsibilities were for each crane in the spar chemical processing area. This assigned whose responsibility it was to accomplish which tasks. The change in procedure outlined here was for the operators to stay in their area of operations rather than have them stay with a particular process. This gave greater flexibility for the product, especially given the inherent variation in the chemical etching procedure.

4.7.4 Improvement of Inventory

As mentioned, an issue that was of particular concern was the large amount of inventory that existed throughout the entire titanium line. In addition to improving operator knowledge and fostering a more “lean” thinking approach, we employed a couple of solutions that drastically cut down on WIP. The first solution was the use of First-In-First Out racks as seen in Figure 14.

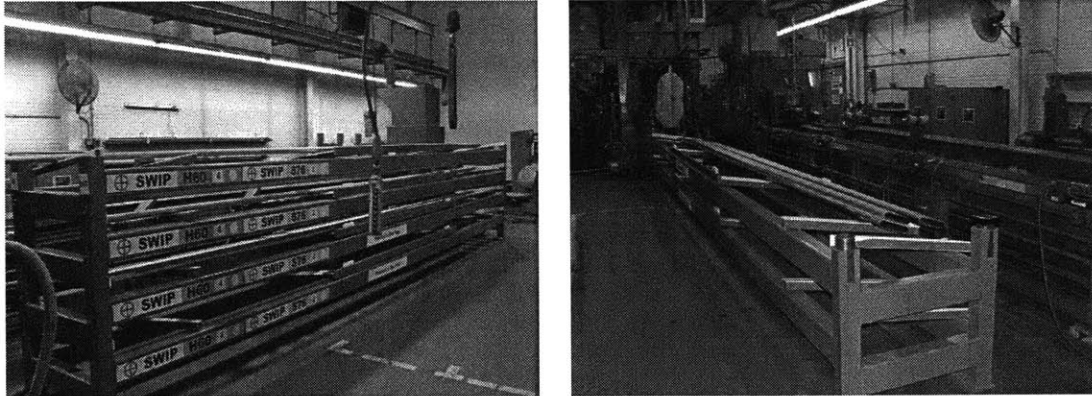


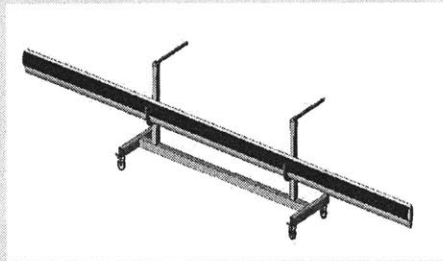
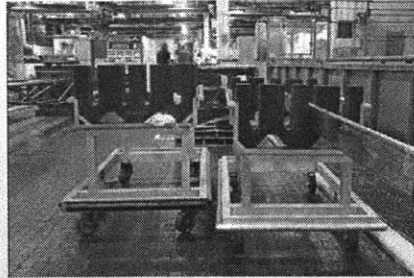
Figure 14: FIFO Racks

Prior to the implementation of these racks, the inventory was organized in somewhat of a chaotic fashion. It was usually stationed on a four-piece dolly, but there was really no set protocol on where inventory should be positioned. One effect that this lack of organization caused was the increased waiting time for a given blade. The finished blades were placed back in a four-piece dolly and were not moved until all four pieces had been processed. The batch of four would then move to the next station when all blades were completed. It is clear to see how this system is sub-optimal and needed to be improved. The FIFO racks effectively created order on the shop floor and gave supervisors an easy visual tool to help them ensure that the appropriate product was being processed at the appropriate time.

A second improvement the team recommended was single-piece dollies. The benefit of this, as compared to the four-piece dollies currently being used is clear (See Figure 15). The pre-existing method for moving the product throughout the process was to batch the inventory on these multiple space dollies prior to movement to the next step in the process. In addition, a common practice was to use these dollies as a virtual holding area. The single piece dolly can solve both of these problems because it will expedite movement of finished product from one step to the next as well as eliminate the temptation of holding more inventory than an individual operator can handle.

Titanium Spar Improvement Plan Summary

Process Kaizen Activity and Improvement Summary



One (1) - Piece Dolly

- Current Process:
 - Three (3) & four (4) piece non-standard dollies.
 - Parts moved by operators.
- Future Process Target:
 - One (1) piece dolly.
 - Ergonomically designed dolly.
 - Parts moved by Pitch person.
- Implementation:
 - Prototype - 9/4/06.
 - Remainder - 9/29/06.

16

Figure 15: One - Piece Dolly

4.7.5 Tooling Improvements

There were a few individual tools that we felt we could improve upon. One that we will discuss here is the T-20 contour gap machine (See Figure 16). This machine measured the contour of the blade in six different locations. Each one of the measuring locations is positioned with a c-clamp and its location is verified with the naked eye. This illustrates how the tool has variability built into the process because of the human error involved with the measuring of the gaps.

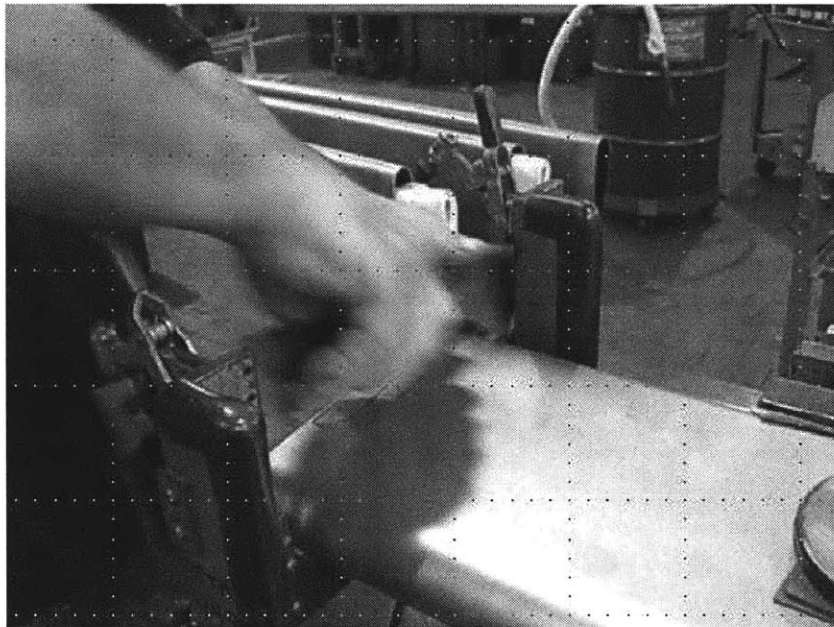


Figure 16: T20 Machine

However, there was not data being compiled on the trends occurring over time. If the tool showed that the blade was out of specification, then it went into a rework loop. There was no process that helped an operator predict if the tool was trending out of specification. This directed us to look at Statistical Process Control (SPC) in order to help improve the accuracy of the tool in a preventative manner rather than a diagnostic one. Some example data and an SPC chart are shown in Figure 17.



Statistical Process Control - Example

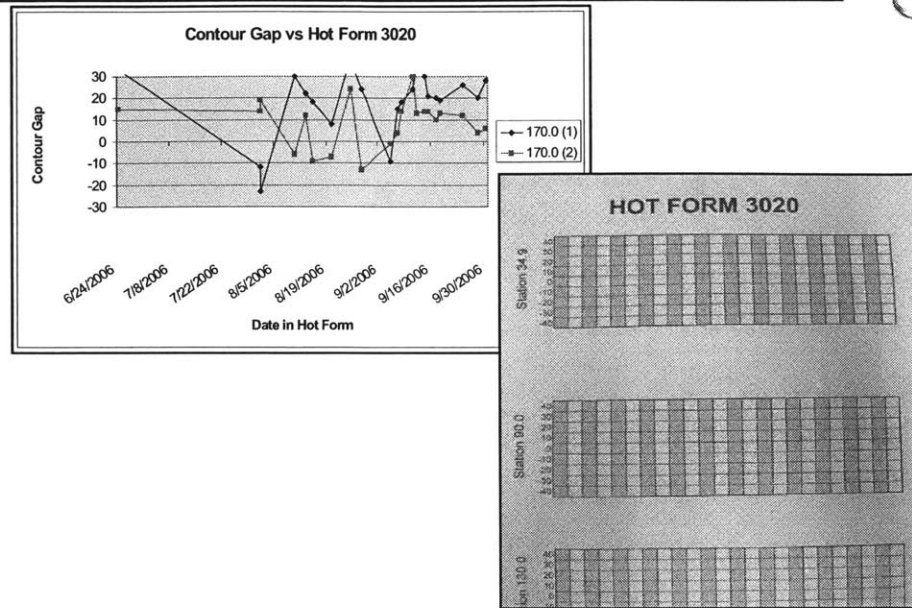


Figure 17: SPC Chart

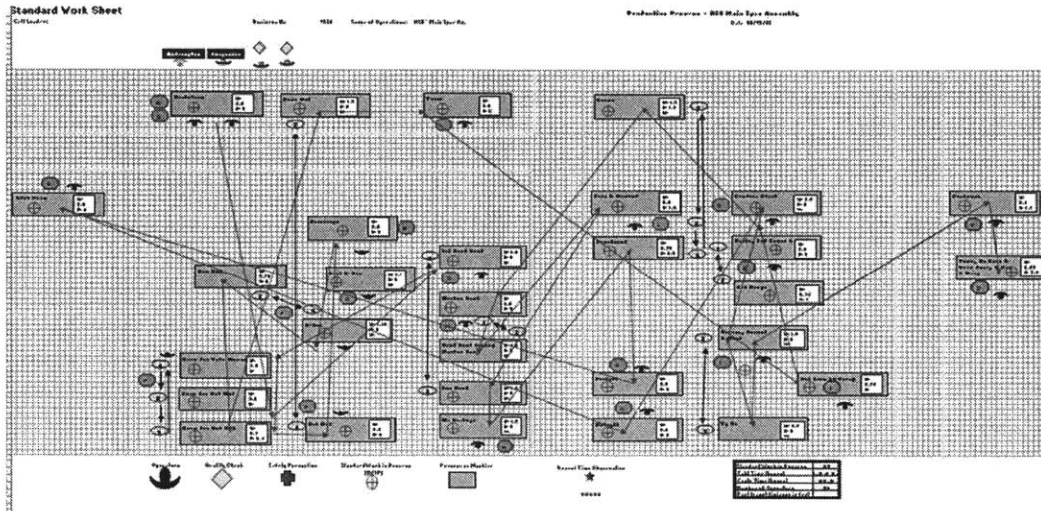
We recommended the use of this chart to improve the T-20's accuracy going forward. However, this was not implemented at the time that the project was completed.

4.7.6 Pitch Route

A common problem on any factory floor is the issue of material handling. At Sikorsky, much of the operator's time is taken up moving equipment to the next process step or retrieving material to process from a previous step. One way we recommended to eliminate this waste was to create a pitch route and identify a person who is responsible. This alleviates the operator from having to do this and also ensures that the product is moving in a given TAKT beat. The part flow with and without the proposed pitch route is shown in Figure 18. The part travel distance using the old part flow path is 3850 feet while the new proposed pitch route is 2750 feet. This translates into an anticipated 1.5 hours of time savings for an individual part throughout the titanium process. However, the real benefit stems from our recommendation to have another person handling the parts while they are in transit. This frees up the workers that are at an individual station

to accomplish their work and it reduces the time that parts are waiting to move to the next station. We also proved that the entire pitch route could be accomplished in less than one TAKT beat (or the time it takes for a customer to demand a part).

Standard Work Sheet – Part Flow



Standard Work Sheet with Pitch Route

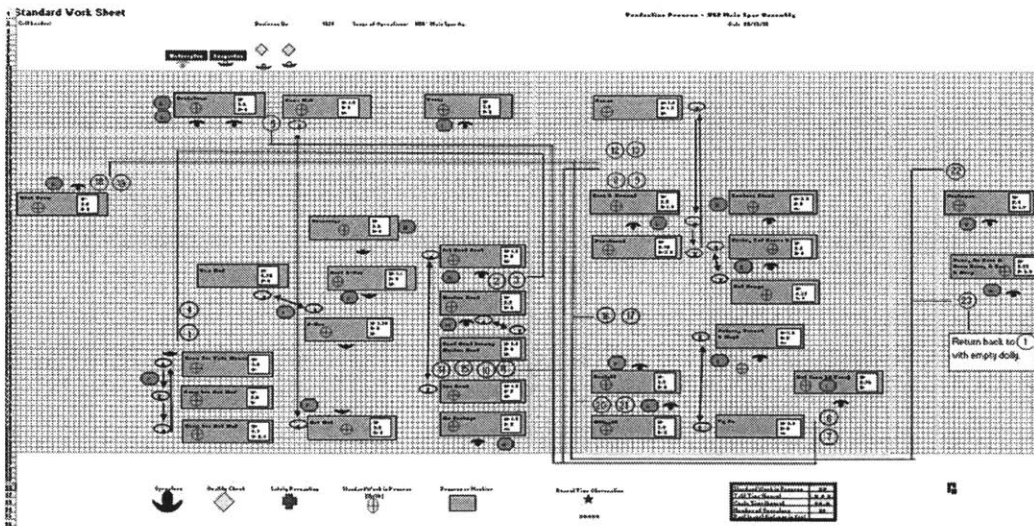


Figure 18: Part Flow without (top) and with (bottom) Pitch Walk

4.8 Predictions from VSM

After finishing the VSMs, the following results emerged:

	Current		Future	
	<u>Hours</u>	<u>%</u>	<u>Hours</u>	<u>%</u>
Lead Time	1,093	95%	232	80%
Process Time	60	5%	60	20%
Total	1,153	100%	292	100%
WIP (pcs.)	188 pcs.		88 pcs.	

As we expected, the value-added time was only 5% of the overall time it took to process a main rotor titanium spar from raw material. Despite this low number, it was a typical characteristic of aerospace manufacturing. The VSM also showed us the dramatic improvement we could make by reducing inventory as shown above and increasing value-added time to 20%. This result was not yet realized by the end of the project, but the organization was trending toward this stated goal.

4.9 Anticipated Results

The recommended improvements should result in significant efficiency increases on the factory floor. These include:

- Standard work across most processes
- Inventory reduction of 50%
- Lead time reduction of 20%
- New plant layout recommendation
- More flexibility

4.10 Supervising and Following Up

The success of each of these improvement implementations and recommendations require consensus, buy-in and perseverance. This is true for no one as much as it is for the supervisor. He must continue to follow up with the operators on the floor to ensure that the change in practice is actually maintained to the point it becomes a habit. This job is not easy, in fact, it is something that the supervisor struggles with everyday. He must juggle this responsibility with all the day to day tasks of running his operation. However, as discussed in chapter 4, when these types of changes are instituted and practiced the supervisor's role should change to one of a manager for abnormal situations as opposed to a firefighter.

This chapter walked through the framework of the internship project. We made the case that a single improvement in the area will not make a significant impact. Rather, only with a concerted effort across the value chain with many different activities all complementing each other will substantial results be achieved. Although we analyzed a large portion of the value system, there are additional areas that we would want to investigate if given more time. These kaizen events were used as the case study to help us learn how much value incremental change can bring to an established industry at a brownfield site.

CHAPTER 5: ORGANIZATION PERSPECTIVES OF LEAN

5.1 Findings

Our finding is an optimistic one since we observed some real results during the time spent with Sikorsky. The majority of the results involved the reduction of inventory (WIP) and the implementation of standard work. However, much of this as well as the recommendations for cycle time improvements were not fully put into practice prior to the completion of the internship. Much of this will require a continued concentrated effort by the supervisors to have success with any of the above recommendations. The supervisors are the critical piece to obtain lasting change. Below is an analysis that will better explain this reasoning.

5.2 Three Lens Analysis

The analysis used here is a framework that is helpful when attempting to better understand the dynamics of a company from differing perspectives. We argue that there are differing managerial levers available to influence the functioning of an organization. It is these levers and perspectives that we notice when we analyzed Sikorsky through the strategic, cultural and political lenses.

5.2.1 Strategic Lens

When looking through the strategic lens one must take the perspective that an organization is designed to achieve goals by carrying out tasks. Sikorsky's goals are to make quality aircraft to meet and exceed their client's needs and to give employees an environment that makes this possible. Specifically, the primary goal of this project is to expand the existing capability of the main rotor blade titanium line. The project has helped to facilitate Sikorsky's lean transformation to single-piece flow.

The current organization for the area of interest is referred to as Integrated Product Teams (IPTs). These refer to the way the product teams interact on a daily basis and are a relatively recent change within Sikorsky's structural makeup. They are the way the team is physically located in the office area in the manufacturing plant. For example,

now the design engineer, manufacturing engineer, supervisors, industrial engineer as well as the business unit manager work in the same proximity. Prior to this change the different areas of the plant were a silo-type structure (i.e. the engineers all worked in one area or the manufacturing personnel were all located in a specific area). This type of organization did not allow for much information flow and increased the overall time for all relevant parties to have the proper information. The transformation to IPTs has improved the information transfer between appropriate departments; however Sikorsky's historically strict hierarchical composition continues to lead to a stifling creative environment. This being said, the IPT structure provides a real value to Sikorsky. It allows for a good cross-functional platform for information to flow. It is here where the majority of middle management resides in a given departmental area. This is the conduit to the factory floor: the place that the organizational strategies are communicated between the vice president level and the supervisor level. It is a great first-step toward a fully integrating the staff.

This internship project is directly in line with the overall needs of the environment of the organization. The IPT's primary goal is to meet customer demand by producing the required number of titanium main rotor blades. Overall, the project is designed to address challenges from the corporate and the hourly worker perspective. The corporation needs the blade area to increase output while maintaining a safe working environment. The hourly worker wants to keep the status quo in process, procedure and chain of command. These two points of view are opposing and to overcome this difference will call for a critical mass of external change-agents who have successfully navigated the political landscape. It requires a delicate balance of various approaches, conducted simultaneously, to meet the goals of both groups.

An area for improvement concerns the assembly of the key team participants during kaizen events. These events are opportunities for process improvement and are valued highly by upper management. Despite their supposed importance, we have seen little weight given to the team selection. Instead, it is a last-minute compilation of employees that are available during the given time with little thought as to each person's capability or job function. This is a critical misstep since these events are given a great deal of visibility and are a great opportunity to institute lasting change.

The structure of the organization is essential to a successful lean implementation. Although the IPTs are a great way to organize, the crucial roadblock to an effective structure is a lack of communication. The most important changes that I recommend are for senior management to spend more time with supervisors to gain their perspective and for there to be a more formal kaizen team member selection process.

5.2.2 Cultural Lens

The symbolic meaning that the project has on the blades area of Sikorsky is simple: fundamental change. The lean transformation is helping to facilitate what is directly in battle with the culture of the organization. Much of the hourly workforce is senior (25+ years) and many of them do not even like to hear the word 'lean' mentioned because of the connotations that the word brings. For example, many hourly workers told us that they associate lean with the aforementioned kaizen events, which don't have lasting impact. This is not an uncommon viewpoint, especially from the most experienced workers. The vast majority of the hourly workers view lean as a necessary evil that comes around every so often to disrupt their daily lives, after which they can go back to business as usual. This is the cultural hurdle that the project's recommended changes must overcome.

Although there is quite a bit of pushback during the implementation, it does not come from the entire workforce. There are a small percentage of hourly workers (mostly new hires or lateral hires from other lean organizations) that see the benefits of lean and are very cooperative. Also, most of the salaried workers understand the value of lean with the exception of a few (very vocal) people. The General Manager (GM) of the blade area is extremely passionate about making the transformation and has successfully convinced most of the salaried employees that it is essential to make the changes.

The project is against much of what the organization has valued historically. For example, in the recent push to increase output the management has made it a practice to approve overtime on a regular basis. In fact, this is so pervasive that many of the hourly workers have come to rely (and basically expect) overtime hours and the lifestyle that it

allows. New workers then come in willing and able to complete more than what has become the standard production of parts. This goes against the current culture because it shows that some of the overtime is inflated and not required. The next step is when veteran workers convey the idea that their 'efficient' work will eat into all of their overtime and, therefore very little changes. This mindset is very difficult to overcome, especially with a union, and one which Sikorsky management has allowed to slowly develop.

Another cultural assumption that is present is the role of the supervisor on the manufacturing floor. Traditionally, the foreman is the person who decides what is going to get processed each day, each shift and sometimes even every hour. The lean project has altered this role because now the inventory is lower and there is a strict protocol on what process to accomplish and in what order. This seemingly minor improvement is a huge cultural change because of the change in responsibility of the supervisor. Before the changes, the foreman was a firefighter all day running around correcting problems and essentially being a crisis manager. This job gave the foreman a hero mentality and respect amongst the hourly workforce because of his problem-solving ability. The huge inventory before each operation also gave the hourly workers a sense of security knowing that no matter how fast they worked, they would never run out of supplies. Now the foreman is mostly only called upon if there is an abnormal event. This has been difficult for the veteran supervisors because they have much more idle time during the course of a day. Similarly, the hourly workers now have occasional inactive time during their shifts. These are all cultural norms and assumptions that the project has questioned and hopefully will change.

Upper management fully supports the project and has communicated this throughout the organizational structure. The GM has repeatedly discussed the importance and the urgency of supporting the recommendations resulting from the project. The internship project team has had access to the appropriate people required to accomplish tasks and they are usually aware of why assistance is being requested. The environment created by the GM and others has helped to improve the possibility of lasting change upon project completion.

Another reason that we believe that the resistance to recommended changes will continue involve the basis for legitimacy. Sikorsky is definitely an experience-based culture that uses seniority, age and company tenure as a basis of determining an employee's worth and knowledge. Job titles and seniority are extremely important factors at Sikorsky. A background in the military and experience flying can give someone instant credibility to both the salary and the hourly workers. Much of the cultural 'inside' information obtained by the team was due to the background of team members rather than anything else. The basis for relationships at Sikorsky is difficult to categorize. There have been situations that are both lateral and hierarchical. The project primarily focuses on the factory floor which is mostly a lateral network. Workers from one area often get questions answered from peers in another area before ever bringing the question to an official superior on an organizational chart. We observed that Sikorsky is a merit based system since small changes are often tried out prior to getting permission from a supervisor. Most workers with at least a few years at the company feel empowered to try something new without feeling the need for approval first. This has caused unintended problems since the IEs are sometimes evaluating a process that is not operating as they believe. Despite this potential waste, it does seem to be a culture that wants employees to improve processes.¹³

5.2.3 Political Lens

Looking at Sikorsky through the political lens reveals self interest groups and alliances. One of these alliances is, not surprisingly, the hourly workers and some of the veteran salary employees. Many of them have progressed through the ranks of the organization and have developed strong relationships. Not only are they professionally connected, but they are also personally and socially involved. This results in a strong coalition and confirms actions that have traditionally been successful.

The power in this organization is firmly held between the Business Unit Manager and the supervisor. They are the ones that drive the change and get the hourly workers to

¹³ Klein, Jan, True Change: How Outsiders on the Inside Get Things Done in Organizations, San Francisco, CA: Jossey-Bass, 2004.

understand why we are recommending the changes. Due to their long relationships with most of the employees (and the fact that they recently were on the line themselves) they have the credibility needed to foster teamwork. We believe that this power will change dramatically once the changes are accepted. However, the power will more than likely be distributed more to the IEs because of their increased participation and excitement to drive process improvements.

This chapter analyzed the results from our case study and summarized our examination of Sikorsky through the described three lens framework. In addition, we added evidence to our earlier notion that lasting change will only occur if the floor supervisors fully participate in the process. We further explained how some of the information disconnects are clearly linked to the organization structure of the department (IPTs). Next, we examined the group both culturally and politically. These two perspectives illustrated to us that the department's power clearly rests with the supervisors and the business unit managers. The impact of this analysis is that it leads us to a better understanding of why supervisors are the most important person on the shop floor. We believe the only way for them to understand this and make good decisions for the entire department is through additional upper management support. Upper management and staff have to change their priorities to focus on the supervisors first, before examining the individual processes.

CHAPTER 6: CONCLUSION

The lean project at Sikorsky was a great learning environment for everyone involved with the transformation. During the internship, many of the ideas of lean were discussed and implemented to improve processes and eliminate waste. Although all the recommendations were not implemented in a six month timeframe, it was a valuable experience. The team dynamics and collaborative learning were key takeaways from the time spent at Sikorsky. Our hope is that future change agents will benefit from some of the topics discussed in this thesis.

Specifically, the primary learning from our time spent at Sikorsky was the role of the supervisors. We believe that this position is the critical piece in the journey toward a world class manufacturing facility. As we argued throughout this paper, the supervisor's role must adapt as continuous improvement is embraced by upper management. There will simply be no place for a supervisor that wants to keep the status quo and believes that the methods used in the past will continue to be successful in the future. Frankly, we did not expect to discover this about the role of the supervisor. Rather, our initial hypothesis was that a brownfield site required a tremendous amount of capital expenditure to make significant improvements. On the contrary, we quickly learned that simple solutions executed by passionate people, supervised by motivated leaders could generate significant results.

We learned some key lessons during this lean implementation. Much of the difficulty around actually getting proposed ideas on the shop floor was bureaucracy. A large organization will never be completely void of official procedures, but improvements are possible. We believe that removing some of the administrative duties from the responsibilities of the supervisor will help him focus on what he should be doing. Also, the level of integration between departments is extremely intricate and confusing. We found procedures quite different between departments, which often delayed a proposed improvement recommendation from being executed. A full standardization of inter-departmental procedures would be a great step forward to a more productive improvement program.

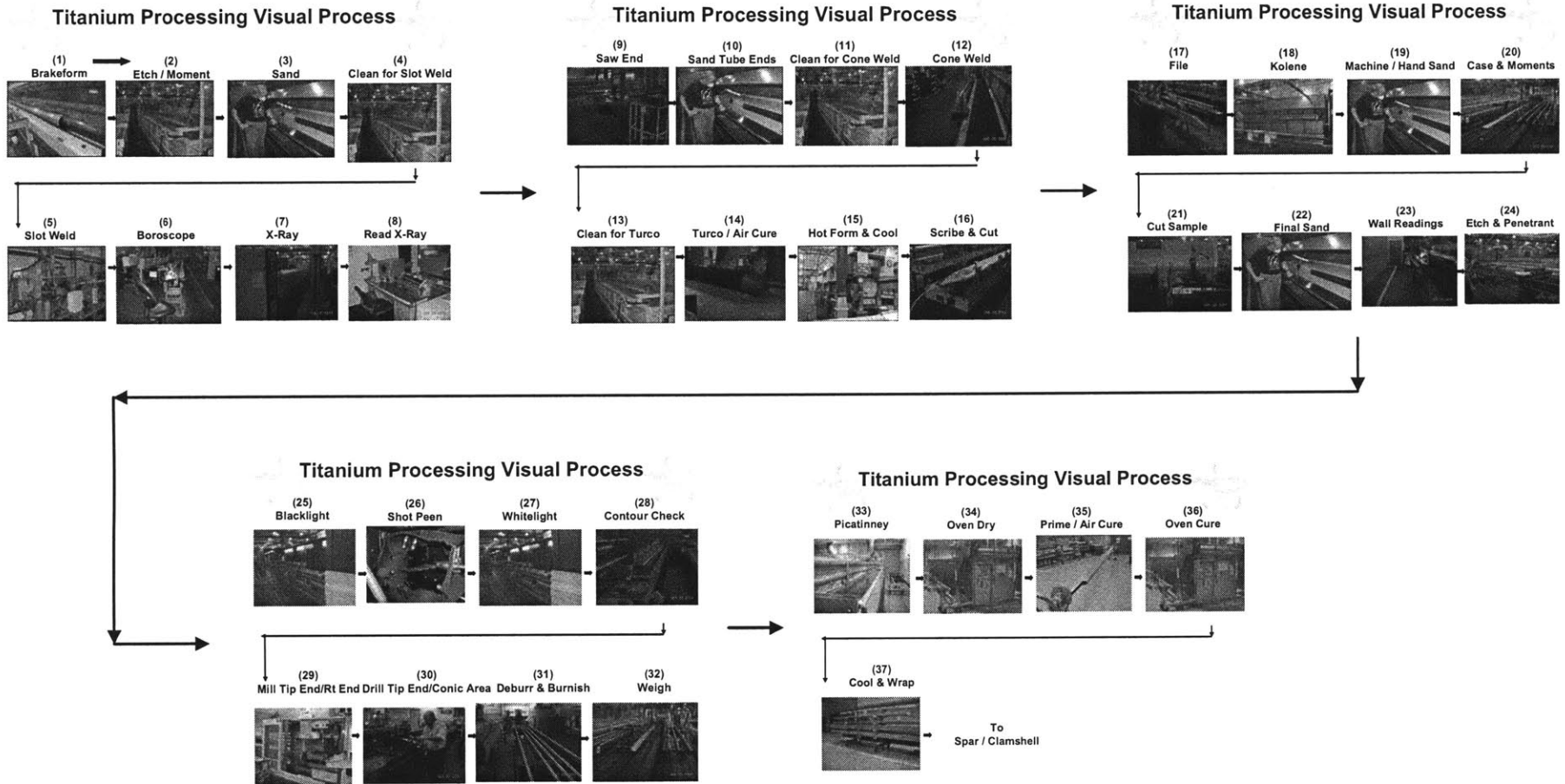
The implications for other manufacturing organizations are clear. The manner in which supervisors have historically been born may not be optimal for a company. Traditionally, supervisors are those that have had significant work experience on the line in many different capacities and job functions. This leads to a supervisor that is competent at the tasks of the job, but not fully interested in thinking about the process globally. In turn, each process functions sub-optimally, while the supervisor believes that they are leading an efficient process. We recommend altering the career development path of a supervisor. Management should more often look outside the organization to fill the supervisor role in order to help fill the information void.

Other organizations can also learn from this work that incremental change to a mature manufacturing process at a brownfield site is worth the effort. Too many organizations refuse to enter into a continuous improvement program because they feel that there will be little impact. This is normally tied to a lack of funds to make major changes in equipment, personnel, etc. However, we have found that minor changes in process and understanding can surpass the expectations of most managers. We hope that this discovery is welcome news to other mature manufacturing firms in similar situations.

As UTC and Sikorsky continue their relationship with the MIT Leaders for Manufacturing (LFM) program, they may have additional interns. In the near future, the following three topics would be appropriate for LFM intern projects:

- Continuing study of other areas in the main rotor blade process post titanium.
- Stabilizing equipment performance and optimizing availability of personnel.
- Developing WIP management strategies for multiple processes and determining how to manage multiple priorities.
- Developing a tool to coordinate WIP management and PM scheduling activities.

APPENDIX B: BLADE SHOP VISUAL PROCESS



APPENDIX C: ACRONYM LIST

TAKT Time – Customer demand rate

$$Takt = \frac{\textit{Effective Working Time}}{\textit{Sum(Demand)}}$$

TPS – Toyota Production System. Otherwise known as lean manufacturing and its main tenet is to create value while eliminating waste.

WIP – Work in Process. Inventory that is undergoing production steps prior to being a finished good.

ACE – Achieving Competitive Excellence. UTC's framework to standardize processes across the organization.

IPT – Integrated Product Team. Organization of Sikorsky's departments.

JIT – Just in Time. An inventory strategy implemented to improve work in process and associated costs.

VSM – Value Stream Map. Tool that helps visualize the current condition and identify improvement opportunities.

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