BUSINESS EXPANSION AND LEAN TRANSFORMATION FOR HELICOPTER BLADE SHOP

by

S. Neil Bar

B.S. Mechanical Engineering, Columbia University, 1999

Submitted to the Sloan School of Management and the Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

Master of Business Administration
AND
Master of Science in Mechanical Engineering

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2006

Signature of Author ____________________________
May 2006
MIT Sloan School of Management
Department of Mechanical Engineering

Certified by ____________________________
Daniel Whitney, Thesis Advisor
Senior Research Scientist
Center for Technology, Policy and Industrial Development

Certified by ____________________________
Roy Welsch, Thesis Advisor
Professor of Statistics and Management Science
Center for Computational Research in Economics and Management Science

Accepted by ____________________________
Debbie Berechman
Director of Masters Program
Sloan School of Management

Accepted by ____________________________
Professor Lallit Anand
Chairman, Graduate Committee
Department of Mechanical Engineering

BUSINESS EXPANSION AND LEAN TRANSFORMATION FOR HELICOPTER BLADE SHOP

by

S. Neil Bar

Submitted to the Sloan School of Management and the Department of Mechanical Engineering on May 10, 2006 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Mechanical Engineering

ABSTRACT

Sikorsky Aircraft is undergoing a lean transformation as its helicopter blade line is relocated from Stratford to Site B. Value Stream Mapping is a vital tool to eliminate sources of waste in the existing blade shop and to create a vision for the future state production system. This thesis briefly focuses on the enterprise to provide a sound understanding of the business and aerospace industry, describing the flow of information from customer proposal through product delivery. Detailed value stream maps for the main and tail rotor blades are then analyzed from an operations perspective to uncover major time and process delays.

Implementation is a topic of in-depth review within this thesis. As a management tool, Value Stream Mapping does not reinforce roles, responsibilities, and accountability to achieve the future state vision. Therefore, a set of guidelines are followed to coordinate kaizen initiatives. Examples consist of matrices to quantify and prioritize opportunities, charters to organize teams and deliverables, and work plans to track progress and metrics. The introduction of management tools aid in satisfying monthly throughput targets while establishing a precedence for upcoming lean programs.

The thesis concludes with the design of a lean production system, which includes a new cellular layout. The future operating system is intended to align Sikorsky's lean flow philosophy with manufacturing capabilities. Recommendations to further enhance factory operations are evaluated in the final chapters along with an action list for on-going projects. A wrap-up for sustaining change is also discussed through a formal critique of the management organization.

Thesis Advisor: Daniel Whitney
Senior Research Scientist
Center for Technology, Policy and Industrial Development

Thesis Advisor: Roy Welsch
Professor of Statistics and Management Science
Center for Computational Research in Economics and Management Science

ACKNOWLEDGMENTS

I would like to extend my appreciation to the Leaders for Manufacturing Program, the Sloan School of Management, and the School of Mechanical Engineering for their support of my work. Through MIT, I had a wonderful opportunity over the two years to learn from faculty and diverse classmates. I would like to specifically thank my advisors: Daniel Whitney of the Center for Technology, Policy and Industrial Development, and Roy Welsch of the Center for Computational Research in Economics and Management Science.

I would like to acknowledge Sikorsky Aircraft for sponsoring my internship. Many thanks to Neil Crockett, Larry Donohue, Ed Machia, Sue Burzynski, Doug Walker, and the entire operations organization for providing a great experience. My internship would not have been a success without their guidance and knowledge.

A special thanks also goes to Arnie Appleby, Bob Mahmood, Lori James, Bob Smith, and all the line operators for helping me navigate the factory and answering even the simplest of questions to further my understanding of blade manufacturing processes.

Finally, I would like to express my appreciation to my family for their encouragement and faith in me. I hope that I fulfilled your dreams and made you proud.

TABLE OF CONTENTS

APPENDIX A: VALUE STREAM MAPS

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Background and Introduction

Located in Stratford, Connecticut, Sikorsky Aircraft aspires to become the first name of choice in vertical flight. The company, a longstanding division of United Technologies Corporation, has been immersed in an operations transformation after the turn of the century. Such an endeavor led by Chairman and CEO, George David, can be characterized as a business-wide strategy to increase operating margin and inventory turns across all existing factories.

Since the early 1990s, the aerospace industry has been confronted with demand uncertainty and steep pricing pressure, giving way to a bleak competitive landscape. As a result, manufacturers and vendors must minimize lead time and inventory levels by fine-tuning production and supply chain activities. Doing so requires a sound understanding and ability to apply lean manufacturing techniques, which serve as a foundation for UTC's operations transformation. The methodology has been a key contributor towards sustained growth in a volatile economy. Rigorous implementation is therefore a necessity to Sikorsky's continued success.

In this chapter, an overview of United Technologies and Sikorsky Aircraft is provided, including a brief history of lean applications in helicopter manufacturing. Although lean practices were brought into UTC during the 1980s in part by Pratt & Whitney, a comprehensive program was not instituted company-wide until two decades later. Chapter 1 concludes with a general outline of this thesis.

1.1 Background of United Technologies and Sikorsky Aircraft

Named the most admired aerospace company for five consecutive years, United Technologies is a diversified industrial firm headquartered in Hartford, Connecticut with 2005 revenues of $37 Billion. Globally represented in over 62 countries, UTC has a reputation for pioneering innovation in aerospace, aviation, helicopter design, climate control, elevator design, and hydrogen fuel cells. Eight independent business units comprising the corporation are summarized below:

- Carrier Heating and Air Conditioning
- UTC Fire & Security Protection Services
- Hamilton Sunstrand Aerospace and Industrial Systems
- Otis Elevators and Escalators

- Sikorsky Aircraft
- Pratt & Whitney Aircraft Engines
- UTC Power
- United Technologies Research Center

The majority of these subsidiaries share a unique and common bond in that they were founded by the original product inventors.

Sikorsky Aircraft traces its legacy to 1939 when Igor Sikorsky developed and flew the first practical and stable helicopter that could remain airborne for 15 minutes at a time. The VS-300 was a simple machine composed of steel tubing, open cockpit, a 65-horsepower engine, and a belt transmission turning a 3-bladed main rotor. Over the past 65 years, the company has become a world leader in the design and manufacture of advanced helicopters for commercial, industrial, and military applications with major facilities in Connecticut, Florida, Alabama, and Wisconsin.

From a military standpoint, Sikorsky helicopters currently serve roughly 50% of all five branches of the United States armed forces. The Blackhawk and its derivatives continue to remain the core company product, flying various missions for the Army, Air Force, and Marine Corps. Additionally, the company manufactures the Seahawk for the Navy and the Jayhawk for the Coast Guard. Finally, Sikorsky supplies the heavy-lift CH-53 to the Air Force, Navy, and Marine Corps for use in anti-mine warfare and personnel/equipment transport.

In the commercial and industrial arena, Sikorsky provides two types of helicopters. The S-76 is widely flown in 40 countries for executive travel, offshore oil, emergency medical service, and airline missions. The company's civil aircraft line-up also encompasses the S-92, capable of carrying up to 22 passengers per load. See Figure 2 below for an illustration of Sikorsky's <u>general</u> product classification.

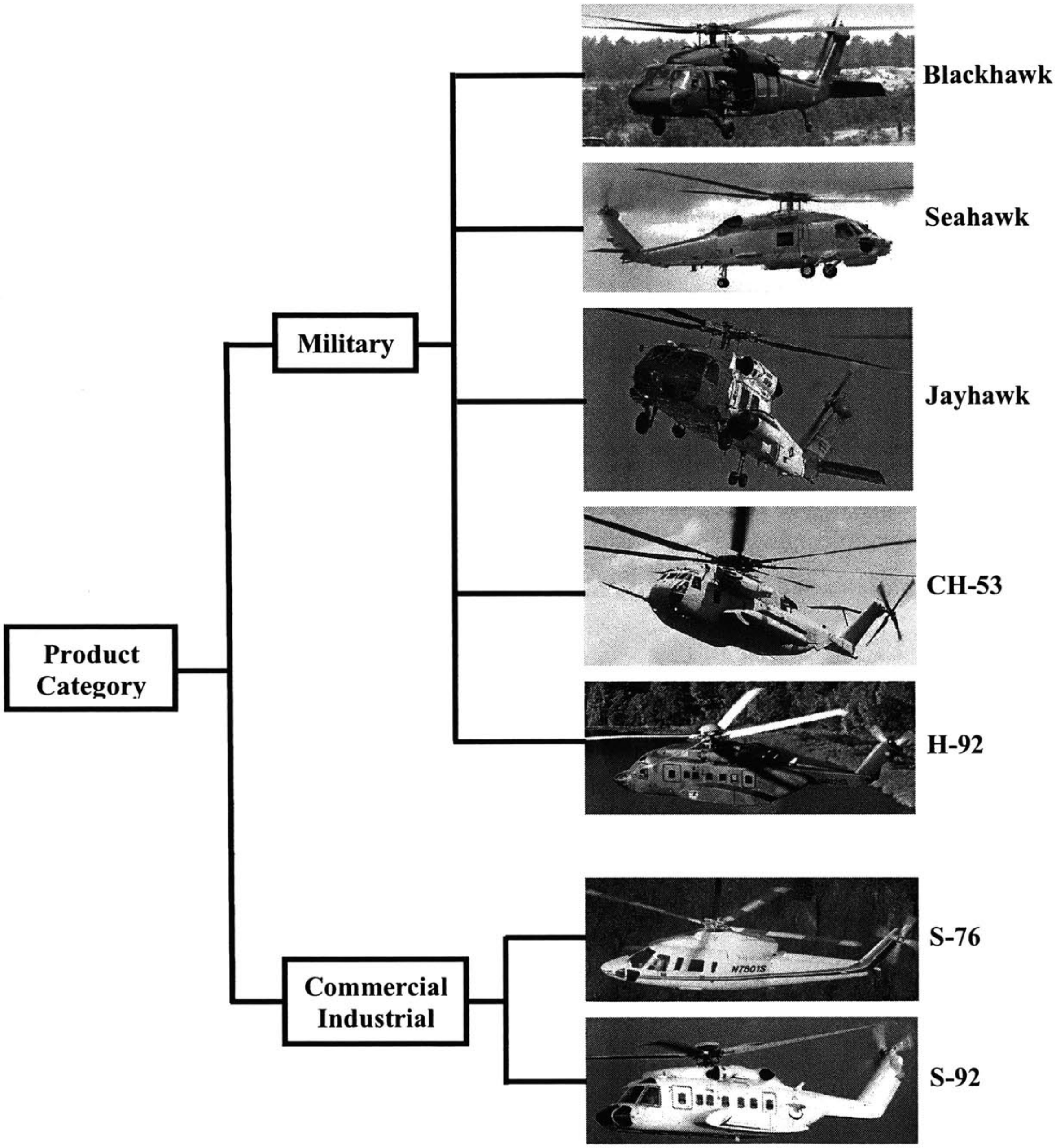


Figure 2. Market Segments and Product Portfolio

Like its sister company Pratt & Whitney, Sikorsky complements its products with a diverse array of aftermarket services designed to minimize operator downtime, improve usability, and reduce cost of ownership. Helicopter Support Incorporated (HSI) is an independent subsidiary that tends to the needs of commercial operators, offering a full range of factory-authorized services. On the military side, Sikorsky acquired Derco Holding, which is a leader in aircraft logistics, component distribution, repairs, and aftermarket program management. The alliance fostered between HSI and Derco combines the strength of a major manufacturer with the flexibility of a small company.

1.2 Lean Manufacturing at Sikorsky Aircraft

American companies during the post war period, extending into the 1980s, had an inclination to emphasize products over processes, ultimately laying the groundwork for economies of scale and standardized products. UTC has parted ways with this norm and embarked on a lean journey, leading a revolution to integrate Japanese production techniques for dramatic process improvements. George David described the mental shift as follows:

"We treated setup times as fixed and established lot sizes accordingly; Japanese methodology eliminated setup times and costs. We drove the manufacturing process by push, relying on extremely complicated scheduling systems; Japanese processes stressed kanban scheduling. We relied on end of line inspection; Japanese practice sought process control at each individual station, working to a philosophy of never building bad product in the first place, and therefore eliminating inspections entirely; We treated our suppliers as adversaries, seeking to maximize our gains at their expense; Japanese methodology sought integration among suppliers and customers, generating value for both parties by doing things better together" (David, 1999).

The ACE (Achieving Competitive Excellence) Program, created by United Technologies in the early 1990s, was the first legitimate effort towards enhancing quality across the business. The initiative itself is not quite lean manufacturing in its purest form. Common lean principles such as specifying and identifying value, creating flow, and using kanban systems are missing from ACE. However, the toolkit reinforces continuous improvement through 6-sigma with elements of 5S, total productive maintenance, root cause analysis, mistake proofing, standard work, and setup reduction.

As mentioned earlier, United Technologies has instituted a broader undertaking termed "Operations Transformation." The program is geared towards increasing operating margins by addressing challenges in four areas: strategic sourcing, low-cost sourcing, design for manufacturability, and leadership. A fifth component of Operations Transformation, Value Stream Mapping (VSM), has been coupled with ACE to strengthen Sikorsky's lean capabilities.

1.3 Thesis Structure

The organization of this thesis is outlined below:

Chapter 1: A brief overview of United Technologies and Sikorsky Aircraft has been provided. The industry environment, corporate history, product classes, and events leading to lean transformation serve as a suitable primer to understand the project framework.

Chapter 2: The motivating force behind the internship as well as the goals, objectives, and hypotheses are covered. A basic approach to identify, analyze, and resolve the critical issues is also revealed.

Chapter 3: This chapter describes traditional elements of lean manufacturing and their application in the helicopter blade shop. A literature review on lean implementations by previous LFM students is included.

Chapter 4: The core of this thesis begins with an enterprise perspective. Chapter 4 essentially captures the informational flow across the business value stream from contract authorization to new product release.

Chapter 5: Chapter 5 transitions to a department level analysis with a deep-dive into rotor blade operations to illustrate product flow through the factory. The value stream maps are used to identify sources of waste in the production process.

Chapter 6: This chapter focuses on the key factors attributed to long lead times and poor monthly blade deliveries. Tools to quantify, prioritize, and implement improvement initiatives are discussed in chapter 6.

Chapter 7: New territory is explored with a future state layout of the factory. In this chapter, a one-piece flow system in a cellular arrangement is proposed and validated through a simulation software package (SIMUL8).

Chapter 8: The final chapter concludes with an evaluation of Sikorsky's management organization and potential plans for sustaining change in a dynamic business.

Appendix A: Current state maps for the main and tail rotor blades document the individual processes, inventory locations, and value-added manufacturing times.

Appendix B: This thesis is written under the assumption that its readers have at least a beginner level knowledge of lean manufacturing philosophy. Data will be evaluated and conclusions shall be drawn where appropriate to aid in the reader's understanding of the material. However, the thesis alone is not thorough enough to sufficiently explain the icons specifically applied in value stream mapping. Although Appendix B contains a legend with symbol descriptions, the workbook Learning to See (Rother and Shook, 1999) is a better resource.

Chapter 2: Problem Statement and Discussion

This chapter presents an introduction to the challenges confronted by Sikorsky Aircraft and the motivation behind the internship. A concise lesson in blade manufacturing practices will shed ample light on the project objectives and methodology to address critical issues observed in the factory. The end of chapter 2 outlines the underlying hypotheses guiding this research.

2.1 Project Motivation

Sikorsky is expecting a doubling in business volume over the next 3 years. Once a vertically integrated company, Sikorsky has revised its strategy by shifting non-core manufacturing to the supply base and transforming batch and queue process villages into lean flow lines. Choosing a low cost, high profit operating model has influenced Sikorsky's decision to concentrate on key competencies, including parts manufacturing.

Given an aggressive demand setting for upgraded aircraft and spares, the parts manufacturing organization is under pressure. Sikorsky must free up factory floor space to accommodate its growing production requirements. To execute this task, the company is transferring the main and tail rotor blade lines for the K200 helicopter to Site B. To maintain confidentiality, the specific site and aircraft model have been masked. With K200 orders on the rise, Sikorsky plans to accelerate blade production in the third quarter to ensure aircraft delivery and avoid contract penalties. Thus, the purpose of the internship is to assist in the relocation, improve throughput at Site B with a temporary plant layout, and propose a lean factory re-design for future main blade operations.

2.2 Short-Course in Rotor Blade Manufacturing

In order to fully grasp the internship direction embedded within Sikorsky's lean transformation effort, the reader should possess a rudimentary knowledge of how composite rotor blades are constructed by industry players. A main blade is typically manufactured in two progressive stages, which are listed as follows:

1. Spar Fabrication
2. Blade Assembly

The spar, or skeleton of the blade, is a composite made up of several layers of textured graphite and glass ply kits. In their collective arrangement, these plies are more advanced and environmentally friendly than titanium, maintaining greater flexibility and requiring little finishing treatment. The disadvantage, however, is that composites are susceptible to defects related to air gaps between successive layers of plies. Figure 3 depicts a spar that is formed around a fixture for its oval shape.

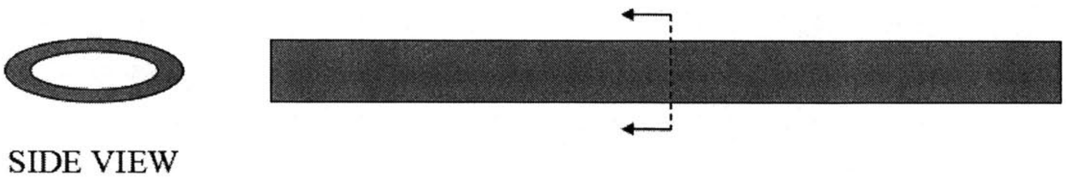


Figure 3. Composite Spar for Main Rotor Blade

During blade assembly, material is compacted onto the spar and cured in a large autoclave. The pocket, composed of a skin with honeycomb core, is primed and bonded to the spar's trailing edge. Counterweights are then mounted to the opposing end of the spar and enclosed by a sheath stretching over the leading edge. The sheath essentially releases heat as a de-icer element and contains a combination of materials including nickel, titanium, and fiberglass. Figure 4 shows the spar progressing towards an aerodynamic profile.

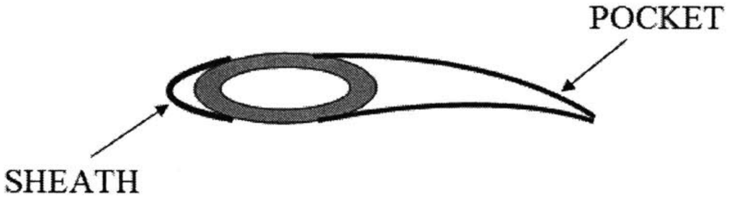


Figure 4. Main Blade Clamshell

After the pocket and sheath are applied, the main blade assembly proceeds to laminate bond, where it receives additional composite layers for strength under dynamic loading conditions. The purpose of this operation is to alleviate high stresses occurring at the root end near the helicopter rotor head. The next step involves milling and drilling holes at a multiple axis machining center. Refer to Figure 5 for a visual.

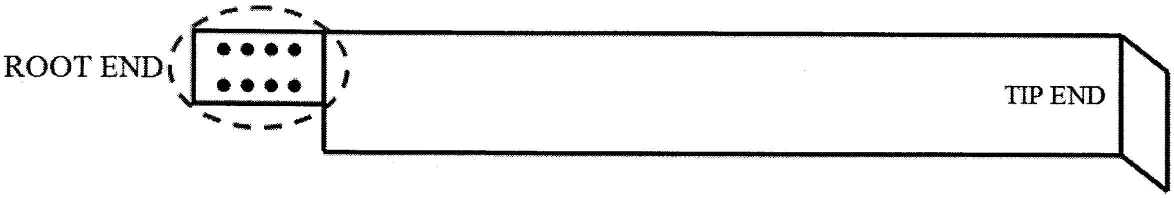


Figure 5. Main Blade Root End

In the finals station, manual detail work is completed on the tip and root ends. The cuff, an interfacing component that connects to the helicopter rotor head, is then fastened to the main blade. Similar to a spar, the cuff is also constructed from layered composites. Figure 6 demonstrates how the main blade and cuff are joined together.

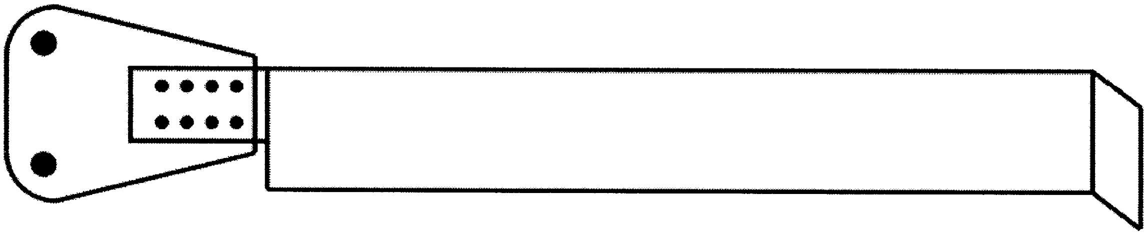


Figure 6. Main Blade Attachment to Cuff

Once complete, the entire assembly is passed on to paint and finishing for a durable coating. Before releasing a main blade to the hangar or spares customer, it is balanced and tested on a whirl stand. See Figure 7 for a view of the completed product.

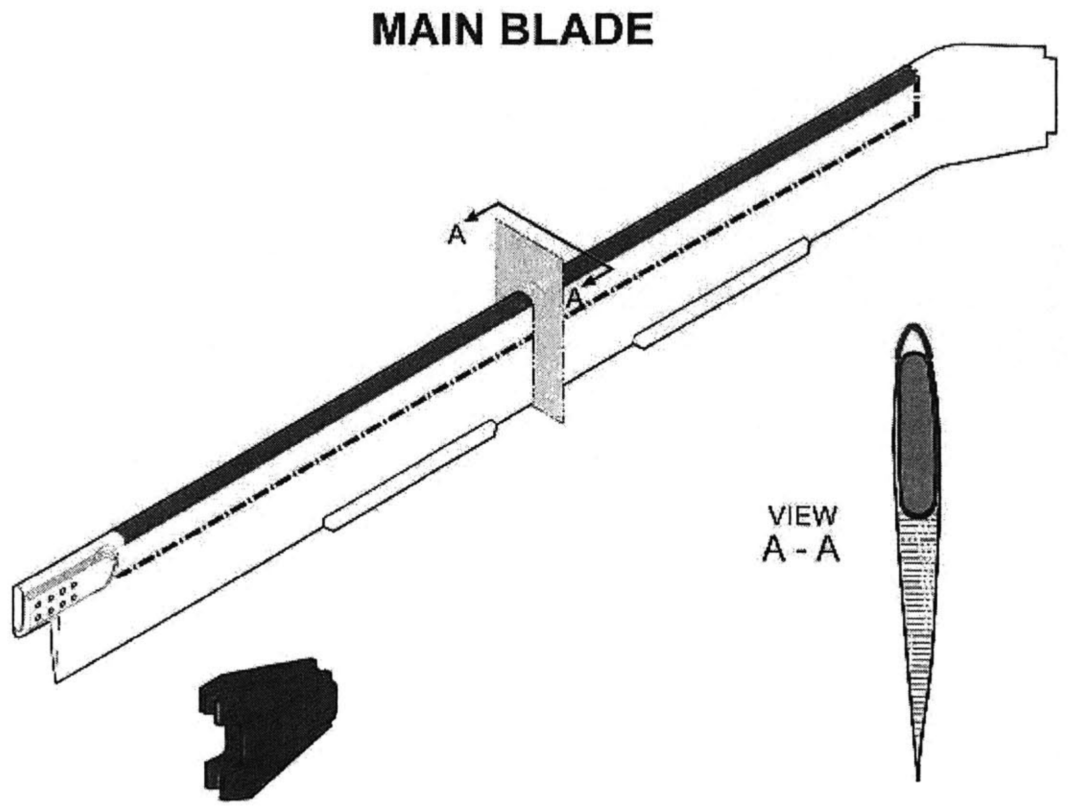


Figure 7. Isometric View of Main Blade

Tail blade manufacturing is slightly different from that of a main blade. While the main blade contains a spar, the tail blade consists of a torque tube similar in material and shape, but much smaller in scale. Instead of using a cuff, technicians install a slender beam to join the blade to the aircraft. The tail blade is also robust in that it does not require a laminate bond.

2.3 Goals, Scope, and Approach

Fabrication for the K200 helicopter commenced in 2004 and transformation of the rotor blade lines followed shortly afterwards. In one year, Sikorsky progressed rapidly along a sharp learning curve to satisfy customer needs and categorized its lean execution into three major stages:

Phase I - Relocate all K200 production equipment to Site B.
Phase II - Establish a temporary layout around existing monuments.
Phase III - Implement cellular arrangement with in-line machines.

This research hinges on three aspects of lean methodology: enterprise and department level value stream mapping, management of improvement initiatives, and the design of a dedicated lean flow line for main rotor blades.

Deliverable 1

Value Stream Mapping is employed during Phase II to assess the current state of the main and tail blade production systems. However, before analyzing material flow, it is important to step back and observe how factory processes fit into the overall context of the business. For example, the purchasing organization may be optimized as a stand-alone department, but could be considered sub-optimal if the total enterprise is not lean (Figure 8). That is why documenting information flow across various cross-functional areas provides a valuable frame of reference.

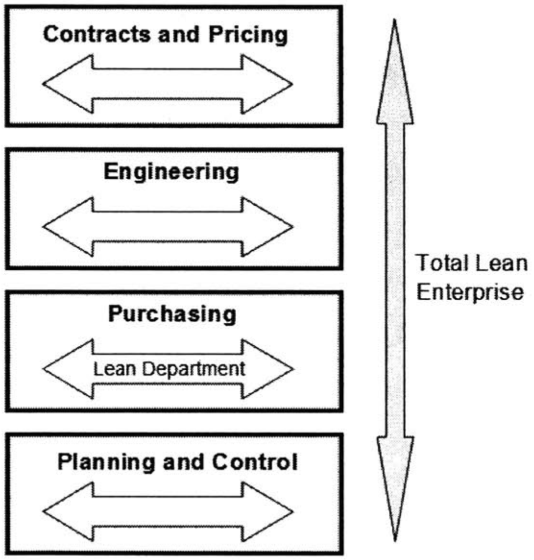


Figure 8. Breaking Cross-Functional Boundaries

Deliverable 2

Using future state value stream maps, several potential kaizen events are identified to reduce lead time and increase monthly blade deliveries. However, as a management tool, value stream mapping by itself does not emphasize team roles, responsibilities, and actions needed to achieve an ideal production system. Therefore, specific guidelines are applied to prioritize the activities, track performance, and audit the changes.

Deliverable 3

Long lead times and poor throughput levels have been logged throughout Phase II. With orders expected to double by 2006, Phase III capital investment plans are under review to ensure that the plant can adequately accommodate the volume. Although most expenditures have been approved, a cellular arrangement will not be finalized within the scope of the internship. Despite the timing issue, a proposed factory layout for the main rotor blade is presented. The challenge in designing a lean flow line becomes evident given the physical constraints of the Site B plant.. A discrete event simulation is included to validate the new manufacturing cell.

2.4 Key Ideas and Hypotheses

In certain instances, companies apply lean to rectify individual processes. While locally patching the problem offers some relief, the result is often times temporary or even negligible over the long haul. Introducing a sustainable solution means that the whole value chain must be examined as a complete entity. One hypothesis of this research is that the presence of "fat" in the upstream activities places pressure on downstream operations. Value Stream Mapping is an excellent tool to detect waste and establish a future vision of the enterprise.

Many production facilities are historic behemoths developed around mass production principles. However, in light of aggressive competition, manufacturers are embracing lean methodology to reduce costs, enhance quality, and accelerate responsiveness to changing customer demands. The disposal of batch and queue processing has brought about greater agility in the market. A second supporting hypothesis is that the introduction of flow in a brownfield site can significantly boost operating metrics and dramatically reduce space requirements. But, a full system redesign is necessary to realize the plant's true potential and benefits of lean.

2.5 Chapter 2 Summary

Throughout chapter 2, we touched upon the motivating factors for the internship, an introductory course to rotor blade fabrication, and the hypotheses guiding the author's project objectives. In Chapter 3, relevant lean terms and concepts are introduced to provide a flavor for twenty-first century manufacturing challenges. Some of the tools from this discussion are selectively applied in the later chapters to address the deliverables presented in Section 2.3.

Chapter 3: Key Concepts and Literature Review

3.1 Mass Production Loses Steam

Similar to Henry Ford and the mass production concepts employed under his supervision, many organizations operating in various industries prospered during the early 1900s utilizing identical techniques. Prominent breakthroughs included interchangeability of parts, standard work sequences, and the moving assembly line. However, in the latter half of the twentieth century, mass production fell short of meeting the customer need.

First and foremost, unions despised the repetitive nature of the job and sought to minimize working hours, which indicated a strained partnership between management and its people. Secondly, companies purchased larger equipment to support scale economies, eventually leading to batch production, huge work-in-progress, and soaring finished goods inventories. Quality was directly impacted as operators became less involved, allowing defects to duplicate in any given batch before being detected. Under this reactive system, end-of-line inspection stations were common as completed products were removed for repairs. Lastly, engineers branched into specialized departments in response to the growing complexity of products. The lack in communication not only introduced design problems, but also lengthened overall time to market.

3.2 The Birth of Lean Production

If mass production ideology proved inadequate as mentioned in the previous section, then what type of system would satisfy a diverse customer base? The corporate building blocks, mainly people and machines, must be aligned such that the output (Dennis, 2002):

- Is defect-free with the features and performance the customer expects
- Can be delivered one request at a time (batch size of 1)
- Can be supplied on demand in the version requested
- Can be delivered immediately
- Can be produced without wasting any materials, labor, energy, or other resources (such as costs associated with inventory)
- Can be produced in a work environment that is safe physically, emotionally, and professionally for every employee

This definition is a founding principle of lean manufacturing, where better performance can be expected with less time, effort, equipment, and space. Instituted by Taiichi Ohno and Eiji Toyoda in the 1950s, the Toyota Production System (TPS) was developed and refined to address the driving forces behind today's global challenges: fragmented markets demanding several low-volume products, rapidly changing technology, tough competition, fixed or falling prices, high cost of capital, and greater worker involvement (Dennis, 2002).

Over the past five decades, the Toyota Production System has been perceived more as a "way of thinking" rather than a "list of things to do." Until recently, the tools had rarely been articulated in writing, making it difficult for outside firms to grasp. Although several books currently exist to describe specific TPS practices in isolated pieces, Jim Womack and Dan Jones co-authored a text in 1996 that ties all the methods together into a cohesive implementation guide. Based on their extensive research, lean thinking can be summarized in five steps, which will be discussed further in the following sections: precisely specify *value* by specific product, identify the *value stream* for each product, make value *flow* without interruptions, let the customer *pull* value from the producer, and pursue *perfection* (Womack and Jones, 1996).

3.3 Value Specification and Identification

Lean thinking establishes a complementary relationship between producers and consumers. It must begin with a value proposition that can only be defined according to the end customer. A producer, on the other hand, creates value for the sole purpose of providing a good or service which meets the customer need at a specific price and time.

Identifying the value stream exposes value-creating activities as designs progress from concept to launch, information flows from initial order to delivery, and physical product moves from raw material to customer. Doing so reveals three types of processes along the value stream (Dennis, 2002):

1. Actual Work: Refers to actions that add value to the good or service (i.e. installing a blade on a helicopter rotor head)
2. Auxiliary Work: Unavoidable action supporting actual work (i.e. selecting a blade from storage)
3. Muda: Opposite of value; Any action for which the customer is unwilling to pay (i.e. making more parts than customer demands)

Techniques for value stream mapping and categorizing sources of waste in the blade shop will be covered in Chapter 5.

3.4 Creation of Flow

Creating continuous flow is the second phase in lean transformation and most likely the hardest since today's leaders are evaluated based on their adherence to existing measurement systems. Organizing work into vital steps with no interruptions, excess motion, batches, or queues can have a dramatic effect on operations. But, successfully applying flow calls for managers to challenge the deep-rooted assumptions, obsolete models, and traditional indicators of efficient production.

3.4.1 Design

Product design has always been a batch-and-queue process where work is handed off from one department to another. The marketers translate the voice of the customer to designers who develop a good. After a design is complete, buyers purchase certain parts and arrange delivery from the supplier base. Finally, manufacturing engineers consider tooling and factory requirements to fabricate and assemble components. While this format would suffice for a single initiative, ownership issues surface when simultaneously driving multiple platforms. If something is everyone's problem, it becomes nobody's problem (Spear and Bowen, 1999).

The lean solution is to appoint dedicated product teams with keen proficiency in value specification, design engineering, purchasing, tooling, and production planning. This specialized approach is more responsive, allowing teams to execute with limited rework and effectively transition products from concept to customer.

3.4.2 Order-Processing

Historically, the sales force has taken responsibility for independently securing business from retailers. Once orders are cleared, the information is relayed to the scheduling department which in turn communicates relative ship dates to the customer. If a particular delivery is late, scheduling personnel expedites the request by manually moving idle parts to the front of the queue where they can be immediately assembled.

Repeating this cycle compromises the customer relationship by increasing overall wait time for prior orders.

In a lean environment, the sales and scheduling functions are critical members of the product team, where both parties share a mutual knowledge of production capabilities. Generating a strong sales plan ensures that information contained in each unique order can flow alongside its respective product from sale to delivery. A key to achieving such consistency is the notion of takt time, which synchronizes the rate of production to that of demand. The term will be further explained in chapter 6.

3.4.3 Production

Since the introduction of lean philosophy to American culture, the production setting has received much attention. Even before Jim Womack and Dan Jones published Lean Thinking, J.T. Black wrote The Design of the Factory with a Future in 1991, chronicling the efforts of companies to incorporate critical elements of the Toyota Production System. In his book, Black outlines ten steps to create an Integrated Manufacturing Production System (IMPS), half of which address flow methodology and coincide with Just-in-Time (JIT) innovation pioneered at Toyota in the 1950s (Black, 1991).

3.4.3.1 Manufacturing and Assembly Cells

In a continuous flow scenario, manufacturing cells should be arranged as a group of sequential fabrication steps with one-piece movement of parts and *no* buffer of work-in-process. Equally important, the cells must be organized by product family and contain right-sized machines that can fit directly into the production line. See Figure 9 for an example layout.

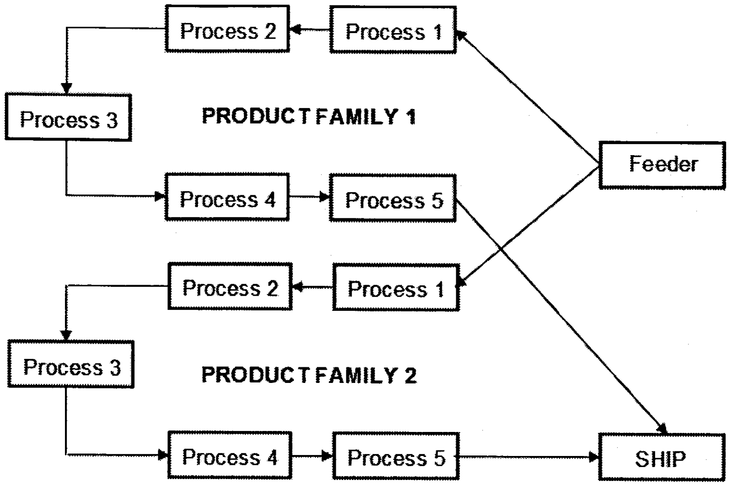


Figure 9. Single Piece Flow Cells by Product Family

The diagram shows greater flexibility because storage disappears, work teams can be adjusted in size depending on cell volumes, and larger machines that were once central to all products are now dedicated to individual families.

3.4.3.2 Setup Times

In a technologically advancing society, many customers demand tailored goods at a price comparable to large volume production and lead time of "instant availability." Thus, providing mixed models without adding changeover time is crucial if companies expect to meet customer needs. Quick changeovers also enable manufacturers to alleviate bottlenecks, lower costs, and improve quality. But, bear in mind, the end objective of flow thinking is to totally eliminate all stoppages in an entire production process (Rother and Harris, 2001).

While Taiichi Ohno had completed some setup reduction at Toyota, Shigeo Shingo revolutionized the factory by developing an approach known as Single Minute Exchange of Dies (SMED). Through his teachings, companies have utilized the methodology to uncover its benefits, cutting changeover times from hours to just minutes (Shingo, 1985).

3.4.3.3 Quality and Preventative Maintenance

The third and fourth steps in creating flow are to integrate quality and preventative maintenance within the cell. In a lean operation, tasks are standardized such that employees assemble every component correctly on the first attempt. Even more so, it becomes vitally important that workers feel empowered to monitor their own work as products move downstream. This can be aided through an inspection technique called poka-yoke, or mistake-proofing, which applies visual control to prevent defective parts from proceeding to subsequent stages (Womack and Jones, 1996). For example, a part with two similar sized holes may be difficult for an operator to distinguish during assembly. However, placing a notch or letter "L" next to the larger hole eliminates potential confusion.

3.4.3.4 Level and Balance

Companies embracing a lean culture strive to facilitate one-piece flow in the factory, but often build to order with a "speed up, slow down" strategy. The monthly variation in demand generates an uneven schedule that encourages operations planners to switch between making substantial and minimal quantities from week to week. While customers are unpredictable, this production mentality fosters high inventory level and poor quality. More importantly, it leads to mismanagement of resources and complicates upstream supplier interactions.

Black's fifth step in regulating flow is to level the work schedule by volume and model mix, otherwise known as heijunka according to Toyota philosophy. Those who employ heijunjka do not build product based on actual customer demand. Instead, they take the total volume of orders in a given period and balance them so that the same amount and mix can be made every day. Figure 10 represents basic shapes as mixed models and visually clarifies un-leveled versus leveled conditions.

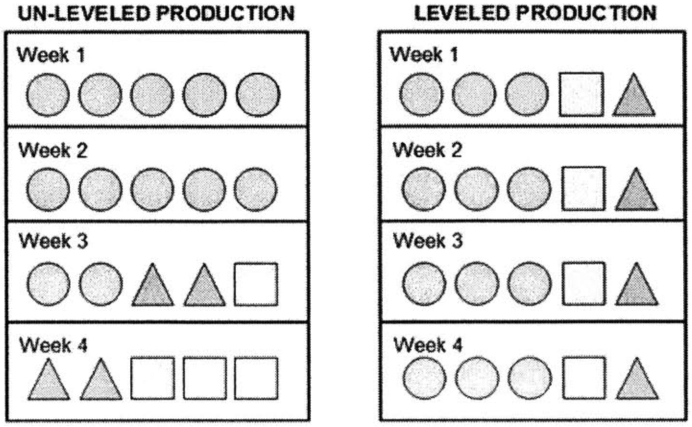


Figure 10. Simple Illustration Exemplifying Heijunka

3.5 Pulling Product

Although any company can apply the framework in Section 3.4 to initiate faster flow in a factory, how does one assure that the right goods are provided at the appropriate time and in the correct amount? The third phase in lean implementation is pull production, which means that nobody upstream should produce an item unless the downstream customer requests it. Communication between downstream and upstream processes usually takes the form of a pull signal, or kanban.

A kanban system maintains an orderly and efficient flow of material across the entire manufacturing chain. It primarily relies on the movement of parts through the use of cards and containers. With this tool, the supplier (or warehouse in some cases) should deliver components to work stations only when they are required. Conversely, each station must only produce when a card and empty bin is received, indicating a need for more components.

3.6 Perfection

The final phase in creating a lean factory is perfection, where business leaders can continuously revitalize operational performance through radical and incremental improvements. In order to visualize and pursue perfection, managers must specify value, identify the value stream, optimize flow, and pull from the customer. Following this sequence of events not only exposes additional wastes to be removed, but also reveals the gap between current reality and the desired future state.

3.7 Lean in the Blade Shop

As knowledge from the Toyota Production System permeates the global marketplace, several LFM theses have emerged within the past decade to address lean business issues. Yuliya Frenkel's research in 2004 centered around dissemination of lean principles on the enterprise level at Northrup Grumman. She created value stream maps for aircraft carrier pipe assemblies that enabled her to identify opportunities to reduce or eliminate time delays, inventory buildups, and rework along the value stream (Frenkel, 2004). In the same year, Matthew Gates developed a set of management tools to organize and facilitate lean initiatives at United Technologies Hamilton Sundstrand. He also employed cellular manufacturing techniques to redesign the factory for efficient mixed-model rotor production (Gates, 2004).

The application of lean in the blade shop invokes some new material while combining Yuliya and Matthew's approaches. Chapter 4 presents a broad enterprise perspective, documenting the high-level flow of information from contract agreement to product release. The author's research then narrows in on manufacturing, where he uses management tools to aid in the physical improvement of current operations. The final part of the thesis focuses on the redesign of a dedicated plant layout for Sikorsky's K200 helicopter blade line.

Chapter 4: The Enterprise Perspective

A full analysis of the evolution of lean thinking urges a broader view of lean, centered on the entire enterprise. Improving parts of a system taken separately is not likely to improve performance of the system as a whole. The majority of product value in aerospace resides in upstream design and development and in downstream sustaining operations. While manufacturing has been the first area of focus in the application of lean thinking in the aerospace industry, it is increasingly clear that a focus across the entire business enterprise is essential. Anything less than a holistic systems approach is bound to result in sub-optimization (Murman, et al, 2002).

4.1 Contracts and Pricing

Sikorsky maintains a balanced customer base by competing in the commercial and military markets - the company has consistently served branches of the armed forces including the Army and Navy. Contracts with Sikorsky do not necessarily relate to new products alone since they can also incorporate aircraft upgrades and even repairs. To initiate an order, the customer must release a statement of work containing specifications, delivery scheduling, and terms and conditions. This is usually completed through a formalized Request for Proposal (RFP).

Although commercial contracts are clear-cut with standard pricing and requirements, military orders are exactly the opposite with rigorous, individualized guidelines. More importantly, there is a tremendous amount of transparency associated with government contracts, where all data and activities are available to the customer upon request. If for example a supplier bid for production is lower than the quantity noted in the original contract, Sikorsky is obligated to reimburse the difference in cost to the government.

When the RFP is submitted, several groups such as engineering, manufacturing, and sourcing review the statement of work and generate a preliminary Bill of Materials (BOM) for estimation purposes. Additionally, the worldwide customer service department prepares technical publications and lists of spares for the new product or aftermarket service. After the RFP is evaluated, Sikorsky and the intended customer negotiate the pricing, which is frequently the most contentious subject. Quite often, there are other concerns that demand equal or greater attention. For instance, socio-economic discussions are very relevant in considering a military order. If the government wants to retain jobs in the United States to protect the economy, then it may be in Sikorsky's best interest to limit outsourcing options and fabricate in-house. The time between RFP submission to successful negotiation can range from a few days to one year.

4.2 Blade Engineering

Once a new product contract is mutually acceptable to Sikorsky and the customer, the blade engineering organization moves forward with aircraft development. The preliminary Bill of Materials examined during the negotiation period can now be refined. Utilizing a skeleton BOM framework reflective of previous generations of blades, the engineering staff is able to further customize the parts list in accordance with specific requirements.

The conceptual design effort for a main rotor blade begins with an aerodynamic profile, which engineers interpret as an empty envelope or shell. Given an exterior shape, they start the design from the outermost surface of a blade and progress inward. Following this methodology, the engineering team conducts cross-sectional analyses along the length of the blade, accounting for changing load stresses at the tip and root ends. The blade is then pieced together one section at time in a manner that can endure dynamic conditions.

When the internal space of the basic shell is filled with structure, engineers must perform a deeper level of detailed design. Determining the correct number of graphite ply kits and selecting the appropriate tool surface are just a sample of activities. Among these tasks, blade designers also interface with their counterparts in the machining and transmissions function to construct mating components. In the verification stage, accelerated life testing is carried out through extensive in-flight simulations and correlated with actual prototype testing. Physical specimens are often obtained through an external provider. While product confirmation is an absolute necessity for long term reliability, the engineering organization places similar importance on the validation of design processes to ensure that they are in control. The overall development lead time spans from eighteen months to several years depending on the maturity of the technology.

4.3 Purchasing

Sourcing personnel coordinate the order and prompt shipment of materials for both new and existing products. This section will not cover the latter responsibility related to design enhancements and daily change traffic.

The purchasing process is initiated when buyers receive a specification from engineering. In the past, requirements from engineering were limited since Sikorsky performed most if not all operations in-house and requested only small items from vendors. However, as the company becomes less vertically integrated, more power and accountability is being shifted to the suppliers.

After reviewing the specification, the sourcing function formulates a Request for Quote (RFQ) and arranges an open bidders conference, where competing vendors offer their best solutions while having access to a shared knowledge network. Thus, a question or concern brought about by one supplier is communicated to all participants. Before issuing a Purchase Order (PO), sourcing specialists perform a comprehensive down-select analysis, measuring and rating each vendor against a set of weighted factors. Example criteria include price, delivery targets, and longest mean time to failure. If the complexity of the part or assembly is high, then additional variables may be considered. In many cases, some suppliers have identical scores, but strengths in different areas of a design. Therefore, it is common on occasion for at least two bidders to join forces. The purchasing lead time from RFQ to material arrival ranges from six to nine months.

4.4 Planning and Control

When the sales group ascertains how many helicopters the company aims to sell, the operations team enters the forecast and engineering Bill of Material into a Material Requirements Planning (MRP) system. With this computerized algorithm, an MRP controller synchronizes the arrival of components from suppliers so that the product can be assembled and available to the end customer on the expected need date.

In general, an MRP report informs supply chain managers what parts or materials to buy, how much to purchase, when to buy them, and when they need to arrive. The database usually invokes a buffer where more parts are ordered than necessary and delivered ahead of schedule to avoid any potential delays or shortages. Perhaps the most significant parameter in MRP context is lead time, which is the time between the day a component or assembly is ordered to the day it is delivered to the factory. Lead time depends on multiple factors such as transportation, minimum order quantity, and design complexity. The turnaround for an order is typically faster if a proficient vendor is located near the facility and produces a commodity in low volume. An un-scaled MRP tree diagram for a blade and its constituents is shown in Figure 11

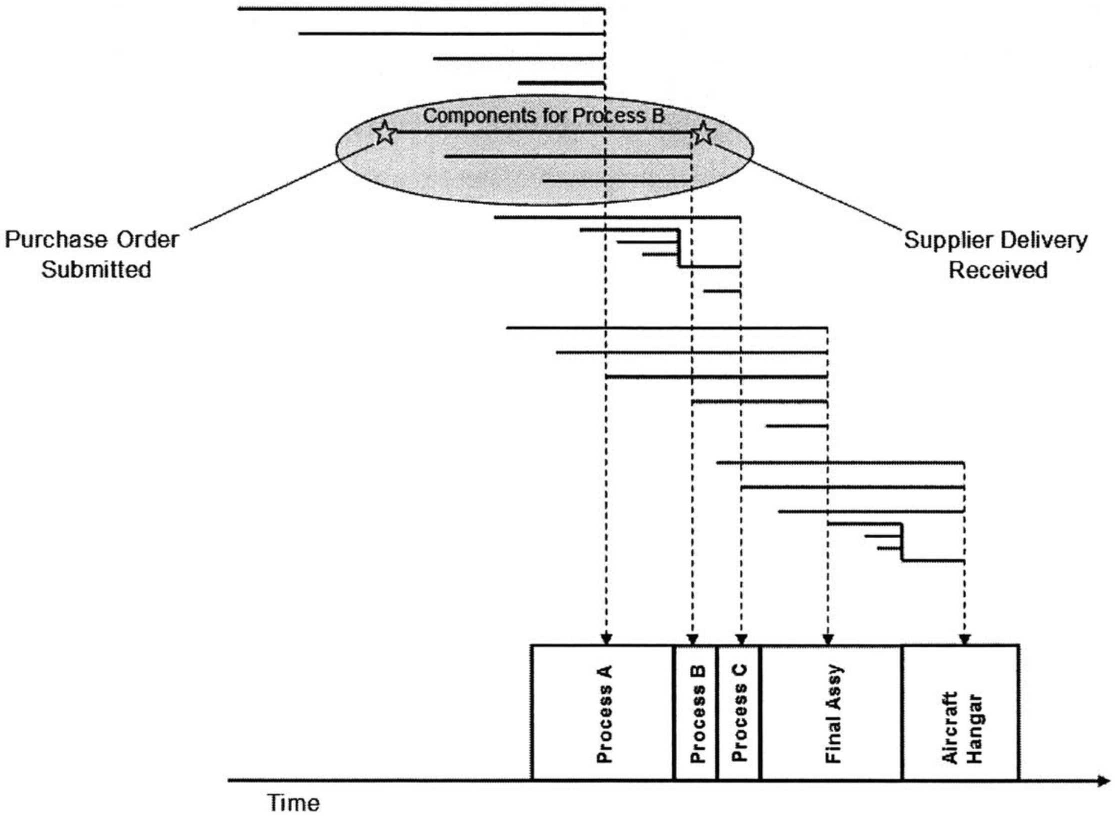


Figure 11. Rough MRP Illustration for Blade Fabrication

4.5 Enterprise Summary

Chapter 4 captures the logical flow of information from contract authorization to manufacturing. Yet, a closer look reveals that the enterprise is not entirely lean. In fact, even the smallest hiccup in upstream processes translates to greater stress on downstream activities. Configuring aircraft is a prime example, where a customer can modify the contract multiple times after an initial agreement is reached. Despite the flexibility, renegotiation hinders engineering if the design is altered, further delaying development progress. Purchasing efforts are compromised as well especially for components with long supplier lead times, which in turn postpones part availability. This case illustrates how uncertainty filters through the value chain, eventually impacting production. Due to the limited scope of the internship, the remainder of the thesis concentrates on lean issues in the factory.

In Chapter 5, we attempt to build on our understanding of the total enterprise by quantifying system performance specifically in the plant. Through the concept of value stream mapping, we intend to diagnose and classify wasteful activities in the existing plant that are tied to long manufacturing lead times. Using this tool, we also establish an ideal plan and set of operating guidelines for the future state factory.

Chapter 5: Value Stream Mapping at Sikorsky Aircraft

As mentioned in Section 3.3, a value stream is all the actions (both value-added and non-value added) required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of the customer, and (2) the design flow from concept to launch (Rother and Shook, 1999). Chapter 5 deals with door-to-door production flow inside the factory from customer demand back through raw material.

Value Stream Mapping is a method to better understand the flow of material and information as a product moves through the value stream. More specifically, it allows one to follow the assembly path and track the steps that transform raw materials into finished goods. The tool helps visualize flow across the entire plant, shows the linkage between information and material, assists with identifying sources of waste, provides a common language for discussing processes, represents a blueprint for lean implementation, and describes qualitatively how a facility should operate to create flow (Rother and Shook, 1999).

5.1 Classifying Waste

The elimination of non-value adding processes lies at the heart of any lean enterprise. Figure 12 breaks down eight general types of waste and shows that nearly 95% of daily activities are governed by muda. True value, as stated by Taiichi Ohno, is literally the size of a plum seed. A brief description of each waste is noted below (Dennis, 2002).

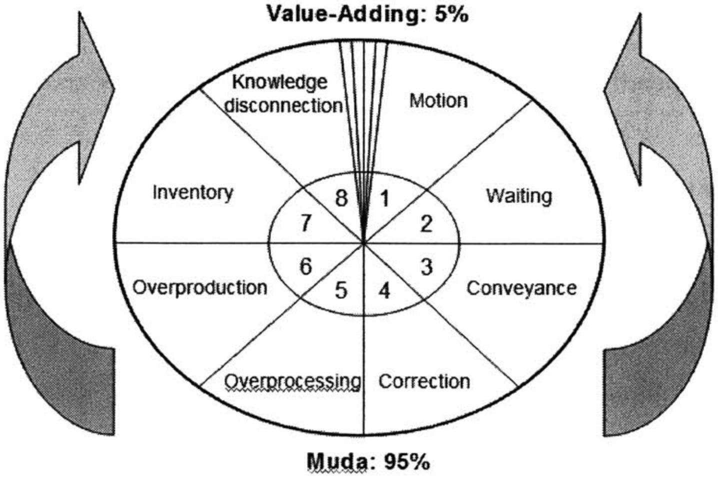


Figure 12. Dissecting and Interpreting Waste

1. Motion – Poor ergonomics related to unnecessary walking, reaching, or twisting
2. Delay – Waiting for material to be delivered or a line stoppage to be cleared
3. Conveyance – Excess movement of parts from one process to another
4. Correction – Fixing defective product
5. Overprocessing – Doing more than what the customer desires
6. Overproduction – Making things that do not sell
7. Inventory – Surplus of raw materials, parts, and Work-in-Progress (WIP)
8. Knowledge Disconnect – Obstructs transfer of ideas and connection between a company and the voice of the customer

5.2 Creating Value Stream Maps

A firm grasp on existing end-to-end rotor blade fabrication begins with an analysis of the current state value stream. The book Learning to See lists a few suggestions for drawing a map (Rother and Shook, 1999):

- Always collect current-state data while walking the actual material and information flows yourself
- Begin with a quick walk along the entire door-to-door value stream
- Begin with the shipping end and work upstream
- Bring your stopwatch and do not rely on standard times or information that you did not personally obtain
- Map the whole value stream yourself
- Always draw by hand in pencil

Please refer to Appendix C and the textbook for additional details and instructions.

5.3 Inter-Plant Overview – K200 Main Blade

For a single plant scenario, the granularity of a value stream map should be on a door-to-door level. However, before pursuing this route, a broader plant-to-plant assessment is recommended due to ongoing Phase I equipment relocation. Figure 13 magnifies the flow of main rotor blades between Stratford and the new facility. When the internship began, only 50% of production capability had been transferred, forcing Sikorsky to ship assemblies back and forth by flatbed truck. The manufacturing lead time for a main blade, from incoming raw material to delivery to the aircraft hangar, was approximately 75 time units (masked for confidentiality). Of this amount, nearly 15% (12 units) was consumed by inter-plant travel, which made transportation an enormous waste and immediate priority for removal. In December 2005, the kit cutting tool was installed at Site B, decreasing total lead time by 4 units. Relocation of final assembly is still in progress, but the paint operation will remain in Stratford.

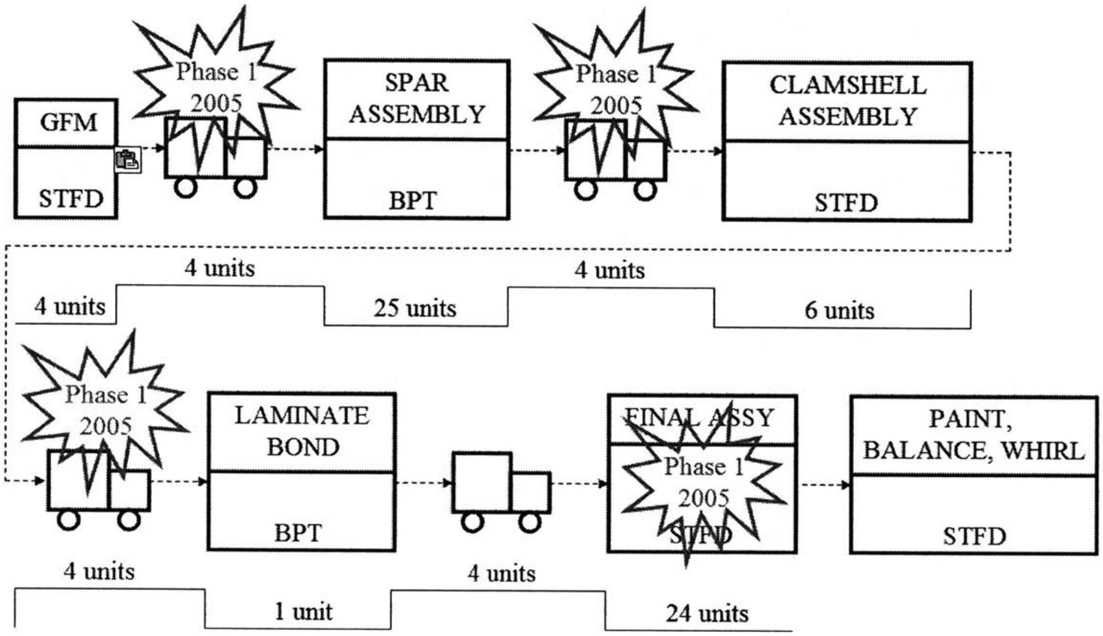


Figure 13. Inter-Plant Value Stream Map for K200 Main Blade

5.4 Current State – K200 Main Blade

The main blade current state map can be found in Appendix A.1. Upon first glance, it is apparent how MRP is being used in the factory to estimate the demand for product. This push system encourages each process to operate independently, disconnected from the true needs of any downstream customer. One may counter that there are no tell-tale signs of MRP such as massive inventory between steps and long changeover times. However, it is arguable that K200 volumes are still too low to see the effects. The symptoms would be more visible when production ramps up four-fold within two years.

Based on the map, the process time, otherwise known as the value-added "hands on" time, equates to 20 units. But quite shockingly, the total production lead time shows that one blade takes 38 time units to move through the plant from start to finish, with the exclusion of 12 additional units of plant-to-plant transportation noted in Section 5.2. The ratio of value-added to non-value added work is 0.40, which is better than the aerospace industry benchmark of 0.30. Even so, Womack and Jones firmly declare, "To hell with competitors; compete against perfection by identifying all activities that are muda and eliminating them. This is an absolute rather than a relative standard that can provide the essential north star for any organization" (Womack and Jones, 1996).

5.5 Future State Vision – K200 Main Blade

Figure 14 displays the main blade future state map and represents an ideal, yet realistic manufacturing system that can be attained. The goal for lean experts is to build a chain of production where the individual processes are linked to their customers either by continuous flow or pull, and each process gets as close as possible to producing only what its customers need when they need it (Rother and Harris, 2001). In defining future state concepts, the rotor blade team answered the following crucial questions (Rother and Shook, 1999):

1. What is the takt time, based on the available working time of our downstream processes that are nearest the customer?
2. Will we build to a finished goods supermarket from which the customer pulls, or directly to shipping?
3. Where can we use continuous flow processing?
4. Where will we need to use supermarket pull systems in order to control production of upstream processes?
5. At what single point in the production chain (pacemaker process) will we schedule production?
6. How will we level the production mix at the pacemaker process?
7. What process improvements will be necessary for the value stream to flow as our future state design specifies?

These questions are explored in the order they are listed.

The takt time, known as the heart beat, matches the pace of sales with that of production. It can be numerically computed by dividing the available work time by the

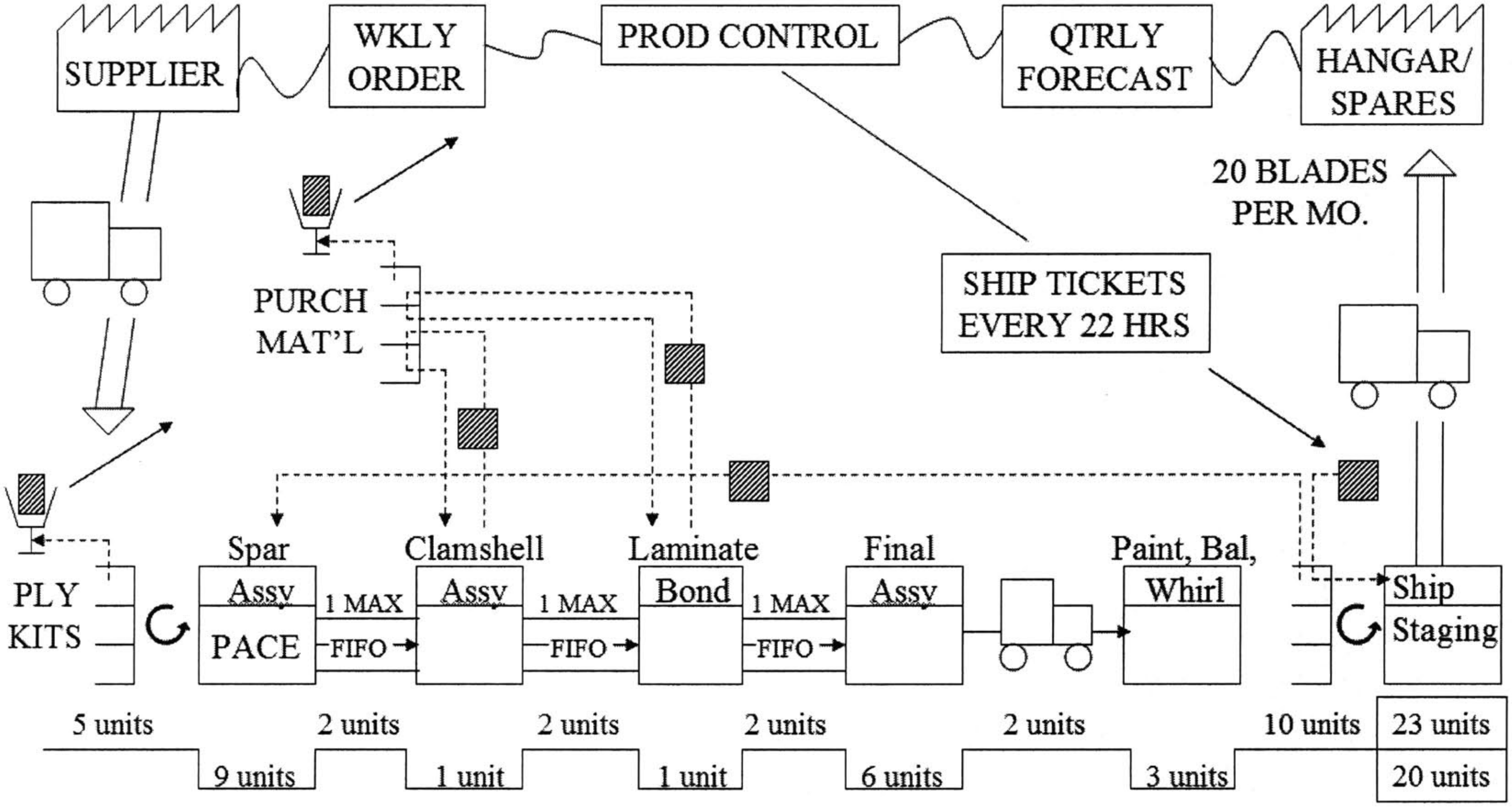


Figure 14. Future State Map for K200 Main Blade

customer demand rate. With the main rotor blade, the equation can be expressed in the format below.

$$\text{Takt Time} = \frac{\text{Available Time}}{\text{Demand}} = \frac{22.5 \text{ hrs / working day}}{10 \text{ blades / } 20 \text{ working days}} = 45 \text{ hrs / blade}$$

This calculation is based on 3 shifts and 20 full work days in a calendar month. Since the plant fabricates ten blades per month, production control must release a ship ticket almost every other day.

Whether to build blades to a supermarket or directly to shipping depends heavily on process reliability and the customer buying behavior. Because K200 manufacturing expertise is still in the emerging stages, product yield is low but expected to improve over the next year. In addition, nearly 90% of scheduled and incoming orders are primarily for aircraft sales. If a greater percentage of the business was driven by spares, then a make-to-order model would be advised. However, a finished goods supermarket is more suitable in light of the main blade characteristics.

Continuous flow refers to producing one piece at a time, with each item passed immediately from one process to the next without stagnation. For the main rotor blade, the spar fabrication and blade assembly steps are combined where possible to minimize accumulation of inventory. But, a few FIFO lanes are incorporated as a precaution to avoid merging all the lead times (and down times). Once process reliability increases, the FIFO lanes may be removed and replaced with single piece flow.

Aside from FIFO lanes, there are often spots in the value stream where batching is necessary (Rother and Shook, 1999). Some processes are far away and shipping one piece at a time is impossible. Others have too much lead time or are too unreliable to couple directly to other steps. The former case applies specifically to the blade shop as Sikorsky embraces the global market. With a growing number of parts being outsourced to external suppliers, the factory should create supermarkets for raw material and purchased components. It is extremely important to install responsive pull signals (kanban) in these locations where continuous flow is interrupted.

The pacemaker process is essentially the scheduling point in the door-to-door value stream. In Figure 14, the final assembly area sets the pace for all upstream processes. Any delays or fluctuations in volume at this station will affect capacity requirements throughout the factory. Also, leveling of the production mix at the pacemaker can be disregarded because the main blade line is solely dedicated to K200 output.

Numerous kaizen initiatives are necessary to achieve the future state and will be the subject of discussion in Chapter 6.

5.6 K200 Tail Blade

The current and future state maps for the tail rotor blade can be referenced in Appendix A.2 and A.3. Unlike the main blade, all production equipment for tail blade fabrication has been relocated to Site B with the exception of final paint, which shall reside in Stratford. Although tail blade manufacturing may appear to have more continuity due to less plant-to-plant travel, production lead time is estimated to be 49 units. However, tail blade process time is 10 units of actual work, roughly half that of a main blade. In constructing a future state vision, similar questions from Section 5.4 were raised to establish a sound operating system.

5.7 Chapter 5 Summary

In Chapter 5, we discussed the basis and criteria for value stream mapping and applied the technique to better understand existing rotor blade processes in the plant. Utilizing VSM, we also crafted a vision for the ideal operating system through flow and kanban methodology. In Chapter 6, the author assesses the current factory and identifies potential improvements to achieve the future state. A set of tools are then developed to prioritize the opportunities and guide implementation for a specific initiative.

Chapter 6: Implementation of Kaizen Initiatives

A future state map conveys a clear image of the various wastes that weaken productivity, but there is no defined methodology on implementing change. While the Learning to See text recommends yearly value stream action plans and even status reviews against proposed goals, the manual falls short of the bigger picture. With dozens of kaizen bursts identified to achieve the future state, there is no information about prioritizing initiatives and enforcing accountability on projects that provide the greatest return on investment to the business. Therefore, an extensive set of management tools is imperative to executing and sustaining enhancements in the factory.

The value stream management guidelines portrayed in Figure 15 were studied by Matthew Gates through a course offered at the University of Michigan (Gates, 2004). These tools support a system where lean teams and management can select a product value stream, pinpoint improvement opportunities, perform the work, and track progress. Moreover, the framework acts as a binding agreement within the operations committee to limit the fire-fighting behavior that is too prevalent in today's manufacturing environment. Since value stream mapping has already been addressed for main and tail rotor blades, Chapter 6 will begin with choosing the right kaizen activities to pursue.

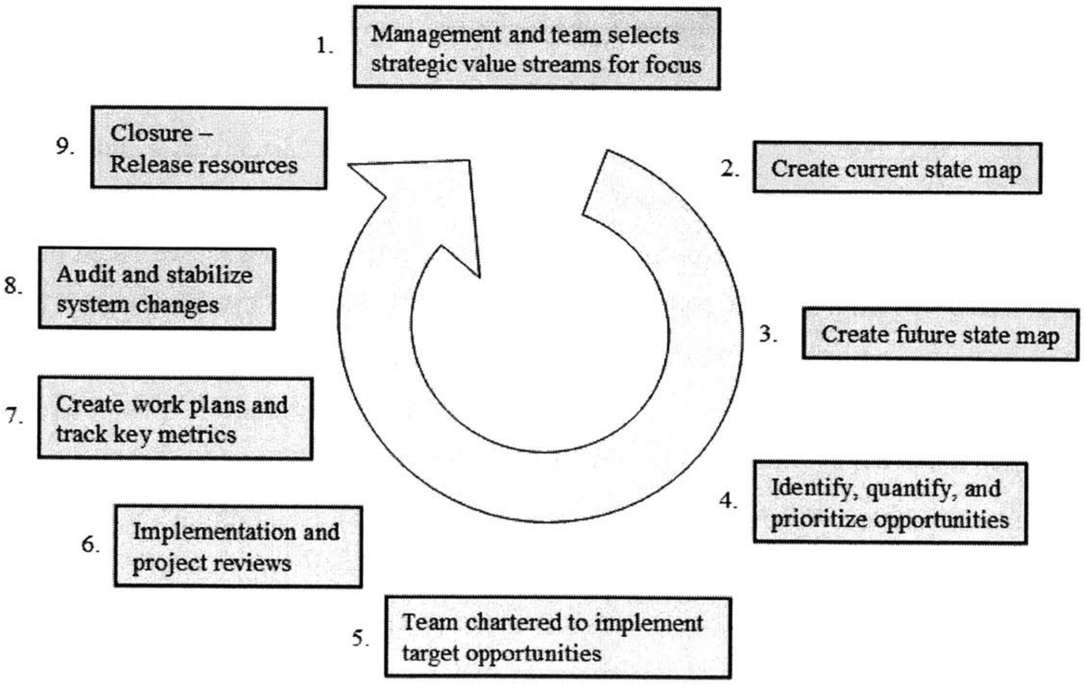


Figure 15. Value Stream Improvement Process

6.1 Prioritizing Kaizen Events

The gap between the current and future state of rotor blade manufacturing lengthens as additional wastes are highlighted. Given the array of opportunities to reduce muda in the factory, there are fortunately two techniques to quantify and prioritize initiatives according to business needs. The first tool is the goal spreadsheet laid out in Table 1, which itemizes the bottom line performance targets for 2005. Notice the anticipated decline in plant-to-plant travel by 75% for main blades and the impact on minimizing lead time. This example emphasizes the relationship among key metrics, where improving one area can benefit another. The high-level document unites lean practitioners with a shared vision and serves as a gold standard when measuring the success of a project.

Table 1. K200 Goal Document

Key Metric	Product	Current State	2005 Goal	% Improvement (Expected)
Lead Time (Days)	Main Blade	61	53	13.11%
	Tail Blade	49	45	8.16%
Monthly Deliveries	Main Blade	8	10	25.00%
	Tail Blade	8	10	25.00%
Inter-Plant Travel (ft.)	Main Blade	232,320	58,080	75.00%
	Tail Blade	N/A	N/A	N/A

The second tool is a detailed method of prioritizing several kaizen bursts and is displayed in Table 2. On the left hand column, a list of possible improvement initiatives were generated by the rotor blade team. Along the top row, there are six weighted factors narrowed down from a larger group of attributes. Each of these criteria were then scored (1, 5, or 9) depending on the relative significance to the organization. For instance, implementation time was critical and assigned a "9" since the author's internship lasted just six months while project complexity was moderately important with a "5."

In the next step, all kaizen events were ranked (1, 3, or 5) to determine how well each initiative stacked up against the designated factors. A grade of "5" indicates the best outcome whereas a "1" denotes the worst case. For example, standardizing work in project I greatly satisfies safety commitments (5), but only has a marginal effect on inventory and lead time reduction (3). Once complete, the individual values from each

		Complexity	Implementation Time	Inventory/Lead Time	Customer Satisfaction	Safety	Cost/Benefit	
	Weight (Stakeholder Priority)	5	9	9	9	5	5	**Total**
A	Eliminate main blade transportation time (total # trips) between Stratford & Site B	1	1	5	5	3	3	134
B	Optimize manpower & equipment utilization to synchronize main spar layup with demand rate	3	5	3	5	1	5	162
C	Determine outsourcing plan for main and tail blade sub-assemblies so that autoclaves can be dedicated to critical path items only	3	1	3	3	3	3	108
D	Analyze autoclave capability and capacity to support part production according to takt time	3	3	3	5	1	5	144
E	Purchase and install right-sized ovens for final assembly area to avoid use of shared resources	3	3	1	1	1	3	80
F	Minimize wait time for items awaiting inspection	3	3	3	1	1	3	98
G	Investigate root causes for delay associated with tail blade flexbeam deliveries	3	3	3	5	1	3	134
H	Reduce accumulating inventory for tail blade torque tubes	5	5	1	1	1	3	108
I	Standardize operator work in the pacemaker processes for main and tail blades	1	1	3	3	5	3	108
J	Coordinate incoming work orders for the six-axis machine to enable flow	3	3	3	3	1	3	116

Priority x Score
5 x 3 = 15

Sum Across Row
5 + 9 + 45 + 45 + 15 + 15 = 134

Table 2. Kaizen Prioritization Matrix

opportunity were multiplied by their respective weighted criteria and summed across the rows, giving a total score in Table 2. As the reader can see, main blade project B possesses a high mark and has been selected for further analysis. It is also tied to the monthly delivery target specified in the goal sheet in Table 1. Although there is some subjectivity in the rankings, the matrix is nevertheless indispensable as a quantitative and comparative tool.

6.2 The Site B Challenge

As stated earlier, Site B has been a location for expansion and consolidation in previous years. The favorable situation is that much of the supplementary tools are already in place to manufacture rotor blades. However, the facility has several monuments which complicate lean methodology and single-piece movement of parts with right-sized equipment. This sentiment is better expressed through the Phase II temporary layout illustrated in Figure 16. The superimposed spaghetti chart displays the general sequence of events and demonstrates how monuments like the massive machining center and stand-alone autoclaves can disrupt product flow. A dotted line between steps indicates an operation that has yet to be transferred to Site B.

The prioritization matrix in the preceding section brought one project to the forefront of Phase II implementation: *Optimize manpower and equipment utilization to synchronize main spar layup with demand rate.* This initiative plays a major role in delivering finished blades to the hangar for final assembly to the aircraft. More specifically, Project B presents a tremendous opportunity to increase monthly throughput because spar fabrication consumes nearly 40% of total main blade processing time. Also, the value stream map from Appendix A.1 reveals a large portion of inventory and work-in-progress (WIP) in the layup stations. The congestion is particularly evident between steps 1 and 2 in Figure 16 as spars are built and loaded into the 50-foot autoclave.

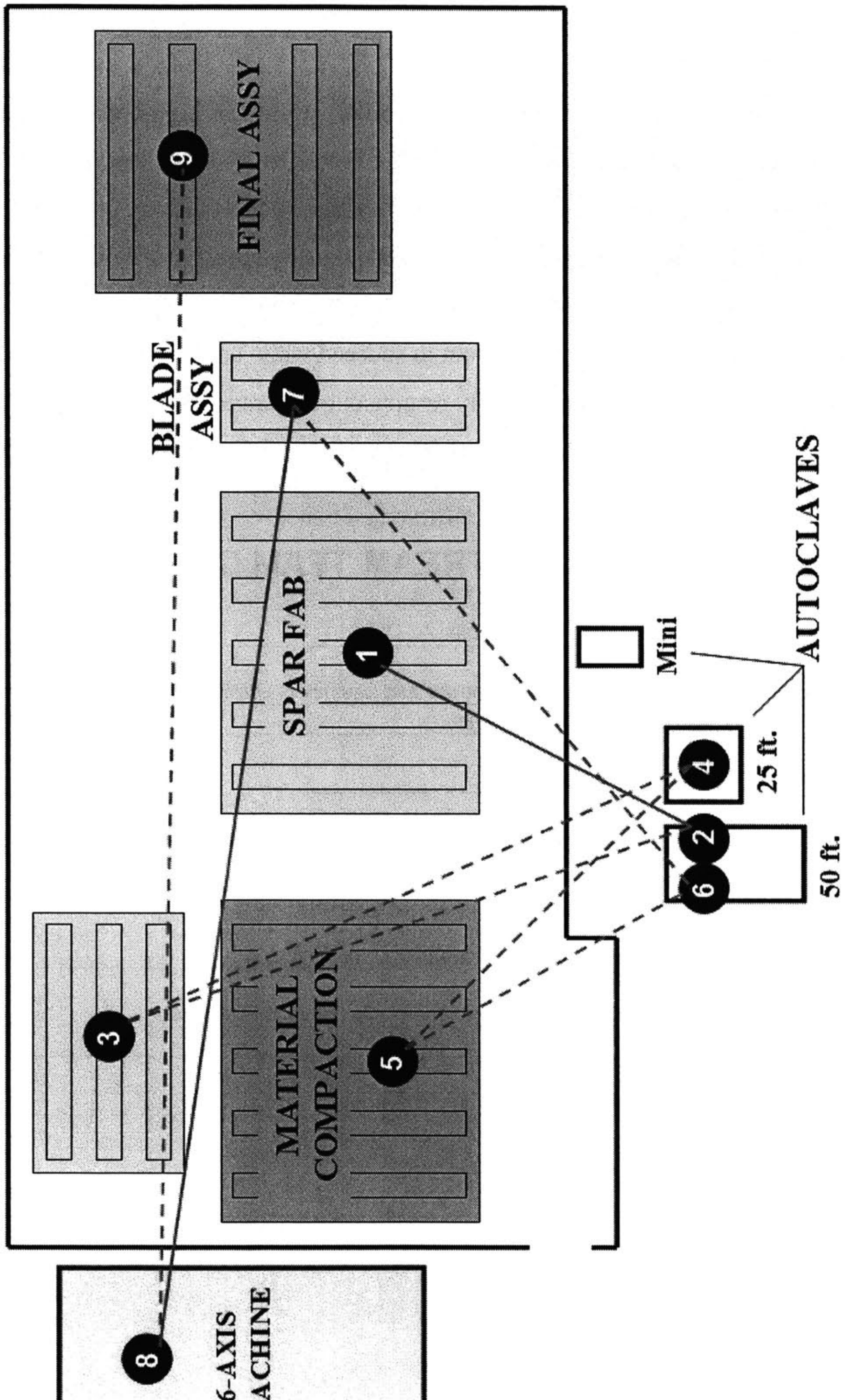
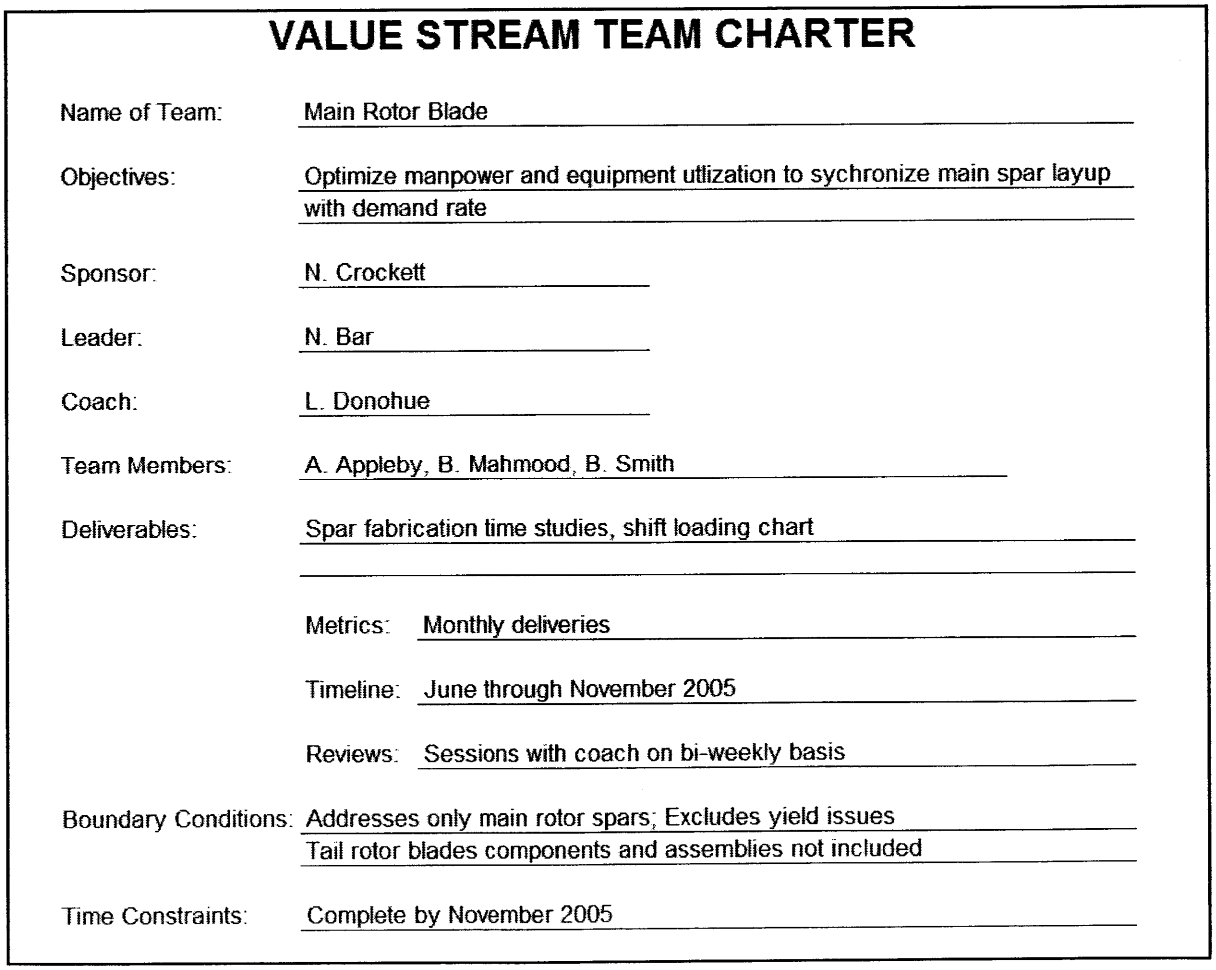


Figure 16. Site B Factory – Phase II Layout (Not to Scale)

6.3 Chartering Teams

The prioritization matrix applied in Section 6.1 quantifies high-leverage projects to achieve the future state production system, but is absolutely worthless without a formalized plan for implementation. A team charter, such as the one portrayed in Figure 17, establishes a framework around key stakeholders by specifying deliverables, metrics, timelines, boundary conditions, and constraints. The sponsor, or lean manager at Sikorsky, invests his efforts for the team to succeed while enforcing accountability. The leader heads the team and is personally responsible for facilitating the process through to completion. Finally, the coach provides educational and directional support to the leader upon request.



VALUE STREAM TEAM CHARTER

Name of Team: Main Rotor Blade

Objectives: Optimize manpower and equipment utlization to sychronize main spar layup with demand rate

Sponsor: N. Crockett

Leader: N. Bar

Coach: L. Donohue

Team Members: A. Appleby, B. Mahmood, B. Smith

Deliverables: Spar fabrication time studies, shift loading chart

Metrics: Monthly deliveries

Timeline: June through November 2005

Reviews: Sessions with coach on bi-weekly basis

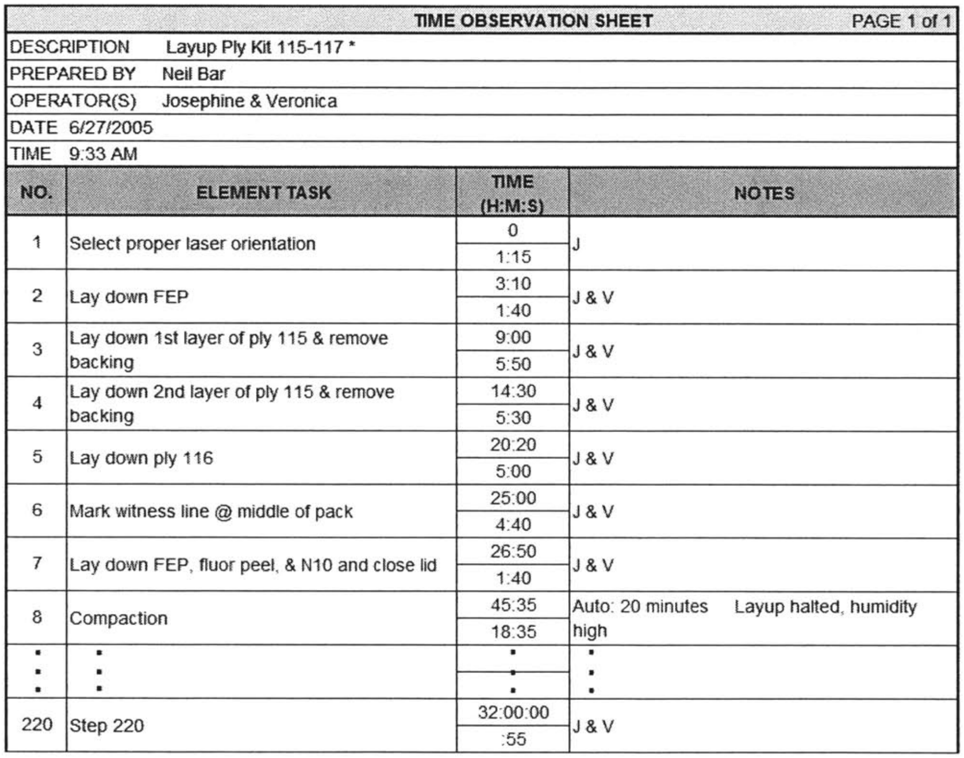
Boundary Conditions: Addresses only main rotor spars; Excludes yield issues
Tail rotor blades components and assemblies not included

Time Constraints: Complete by November 2005

Figure 17. Main Blade Value Stream Team Charter for Project B

6.4 Project B - Work Planning and Metrics

With a takt time of 45 hours, the plant had to manufacture and ship one blade every other day, corresponding to a throughput of ten blades per month. Prior to the author's internship, no data existed to suggest whether this could be achieved since much of the knowledge was based on anecdotal evidence provided by veteran employees. What's more is that the current shop was only producing eight blades per month. As a result, the first part of Project B was to document spar fabrication processes through time observations like the one in Figure 18.



TIME OBSERVATION SHEET PAGE 1 of 1

DESCRIPTION Layup Ply Kit 115-117 *
PREPARED BY Neil Bar
OPERATOR(S) Josephine & Veronica
DATE 6/27/2005
TIME 9:33 AM

NO.	ELEMENT TASK	TIME (H:M:S)	NOTES
1	Select proper laser orientation	0 1:15	J
2	Lay down FEP	3:10 1:40	J & V
3	Lay down 1st layer of ply 115 & remove backing	9:00 5:50	J & V
4	Lay down 2nd layer of ply 115 & remove backing	14:30 5:30	J & V
5	Lay down ply 116	20:20 5:00	J & V
6	Mark witness line @ middle of pack	25:00 4:40	J & V
7	Lay down FEP, fluor peel, & N10 and close lid	26:50 1:40	J & V
8	Compaction	45:35 18:35	Auto: 20 minutes Layup halted, humidity high
⋮	⋮	⋮ ⋮	⋮
220	Step 220	32:00:00 :55	J & V

Figure 18. Partial Time Study for Process 1 of Spar Fabrication

There are essentially five sequential components that make up spar fabrication:

- Process 1 ---- 32 hours
- Process 2 ---- 12 hours
- Process 3 ---- 8 hours
- Autoclave --- 24 hours (Automatic Machine Cycle)
- Process 5 ---- 4 hours

Of these processes, the 50-foot autoclave is the most important because it is a miniature pacemaker helping to regulate the flow of preceding activities. Given the overall times above, a shift loading chart was created to coordinate spar production (Table 3).

SHIFT LOADING CHART - K200 SPAR

DAY	M			T			W			R			F			S			S			M			T			W			R			F			S			S		
SHIFT	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Process 1	225			226			226			227			227									228			228			229			229			230								
Process 2				225						226												227						228						229								
Process 3		224						225						226												227						228										
Autoclave [24 Hours]				224						225												226						227						228								
Process 5	223						224						225												226						227											

Table 3. Initial Shift Loading Chart for K200 Spar

In Table 3, a shift is equivalent to eight hours and every spar is numbered to track progress. An immediate conclusion can be drawn regarding the series orientation of individual operations. Because each process has one tool or machine, certain steps become dependent on one another, eventually restricting output. Process 3, for example, cannot be initiated unless Process 5 is complete. Despite the limitation, this configuration feeds five blades into the autoclave every two weeks, leading to ten blades per month.

At the start of the fourth quarter, demand spiked to twelve blades per month. In order to accommodate the need, the lean team added flexibility to the spar fabrication stations with the intent of testing the maximum capability of the system. First, a spare tool was introduced to Process 1, cutting its time from 32 to 24 hours while keeping operator headcount the same. Secondly, management approved weekend labor and readily incorporated third shift resources to perform Process 5 during the off-hours. Table 4 shows a follow-up draft of the "train schedule." By loading the autoclave on Sunday evenings, six blades could be cured every two weeks. Between June and October 2005, throughput increased nearly 50%. However, in retrospect, Project B signified more of a lesson in change management than tactical planning.

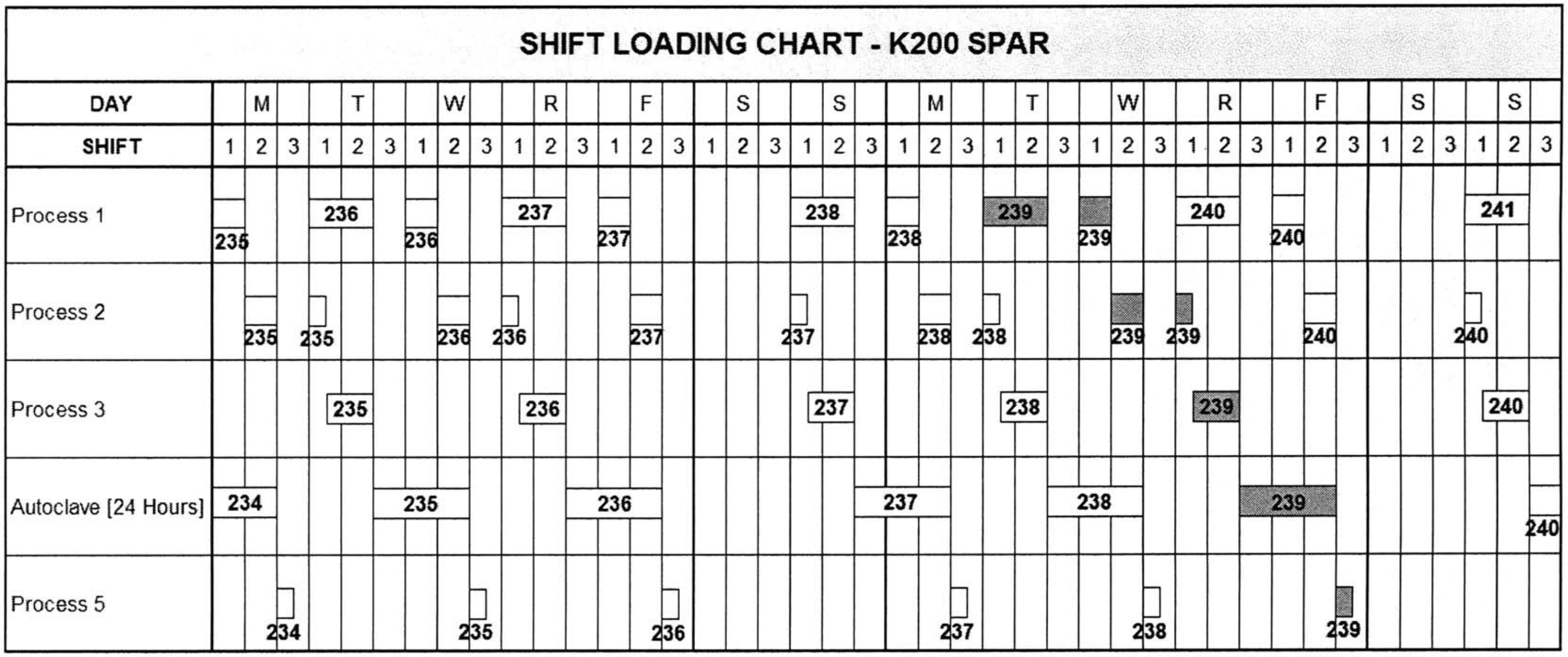


Table 4. Modified Shift Loading Chart Due to Demand Spike

6.5 Auditing

An audit sheet is a formalized mechanism to monitor manufacturing performance and prevent kaizen bursts from turning into a flavor-of-the-day initiative. Figure 19 displays the number of blade deliveries to the aircraft hangar by month. Although the throughput target for the third quarter of 2005 was 10 blades every 4 weeks, the lean team missed the goal in August. Failure to comply with the customer requirement exposed a major flaw in the factory that had been neglected for some time.

The problem was not related to equipment or processes, but rather the people. With production quickly ramping up, there was a deficiency in transferring skilled labor to Site B. The primary cast of operators could complete their duties without hitches. However, when these first string employees took vacation for example, throughput was severely impacted as the plant did not have a knowledgeable reserve of alternative workers. Because blade assembly is manually intensive, back-up operators with little familiarity of the process finished tasks at a slower pace as they progressed along the learning curve. Through this experience, lean experts have assigned supplementary resources to the K200 line and even emphasized cross-training the staff.

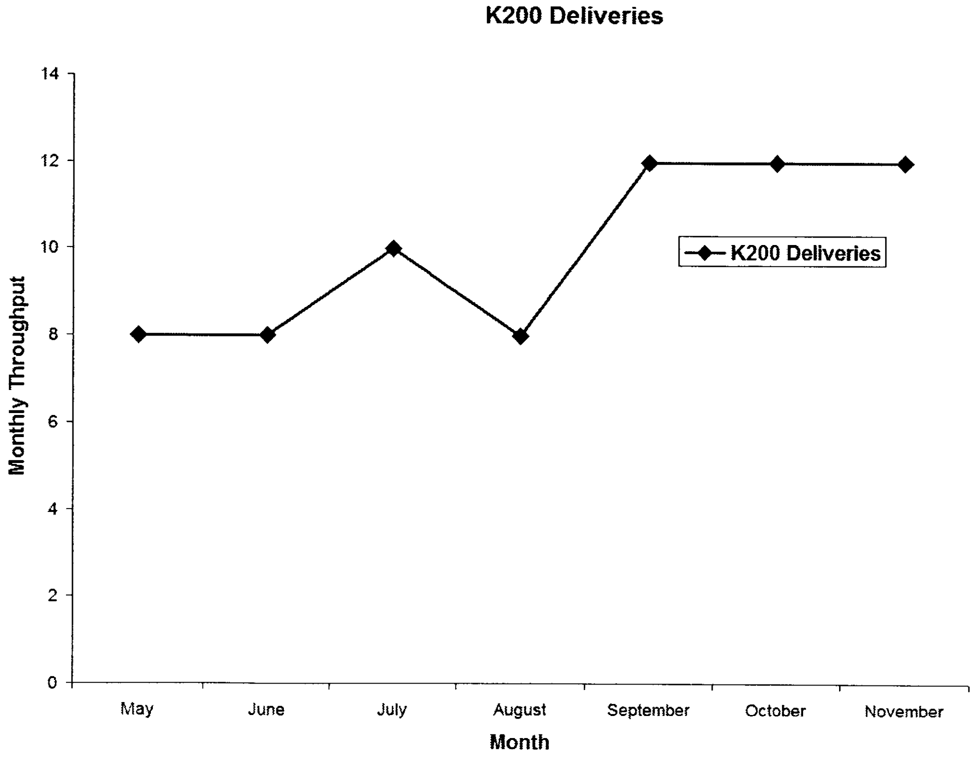


Figure 19. K200 Monthly Throughput

6.6 Chapter 6 Summary

In Chapter 6, we presented a step-by-step approach to identify and prioritize a range of multiple kaizen opportunities. On the back end, we followed through with project implementation to increase monthly blade throughput in the spar fabrication area. In Chapter 7, the author transitions from improving current production efforts to optimizing operational performance for the future factory. A re-designed plant layout with dedicated, right-sized equipment is considered and evaluated through a discrete event simulation and capacity analysis.

Chapter 7: Achieving Phase III

In the preceding sections, there is much discussion about Sikorsky's MRP-driven operation and single-piece "push" production system. While the temporary plant layout in Chapter 6 could suffice under a constant year-over-year demand scenario, it will not be fundamentally sound to satisfy customers when the need for spares exceeds 20 blades per month in 2006, decreasing takt time to 22.5 hours. This is primarily due to the lack of dedicated equipment such as right-sized autoclaves and machining centers.

But, holistically speaking, the importance of Phase III extends well beyond throughput alone. It draws attention to the fact that sixty days between incoming raw material and delivery of a blade to the hangar leaves room for improvement. Although transportation between sites is the chief contributing factor, the core issue is centered around the sub-optimal layout of the existing factory. As can be seen in Figure 16, work stations are not arranged intuitively to promote efficient movement of material from one process to another. Thus, the purpose of Chapter 7 is to design a lean facility that can accommodate peak demand, enhance product flow, and shorten lead time to market.

7.1 Cellular Arrangement

Three important assumptions were made in constructing a cellular layout for Site B. Because the facility is only 225 feet long by 80 feet wide (see Figure 19 dimensions) and rotor blades are approximately 25 feet in length, building the entire end-to-end manufacturing line within the allotted space is impossible. Due to this constraint, the author has chosen to exclude spar fabrication from in-house operations. Secondly, since spar production would be outsourced, the upstream vendor network must be capable of reliably supplying goods depending on customer needs. Thirdly, despite the resource deficits mentioned in Section 6.5, the author presumes that both people and equipment will be available to support the proposed system.

As shown in Figure 20, incoming raw material (spars) arrives on the left and the process hooks around at each end of the plant such that flow occurs in the shape of the letter "S". Given the large product size, main blades may in few cases have to exit a station from the side as opposed to the front or rear. Movement from one step to the next

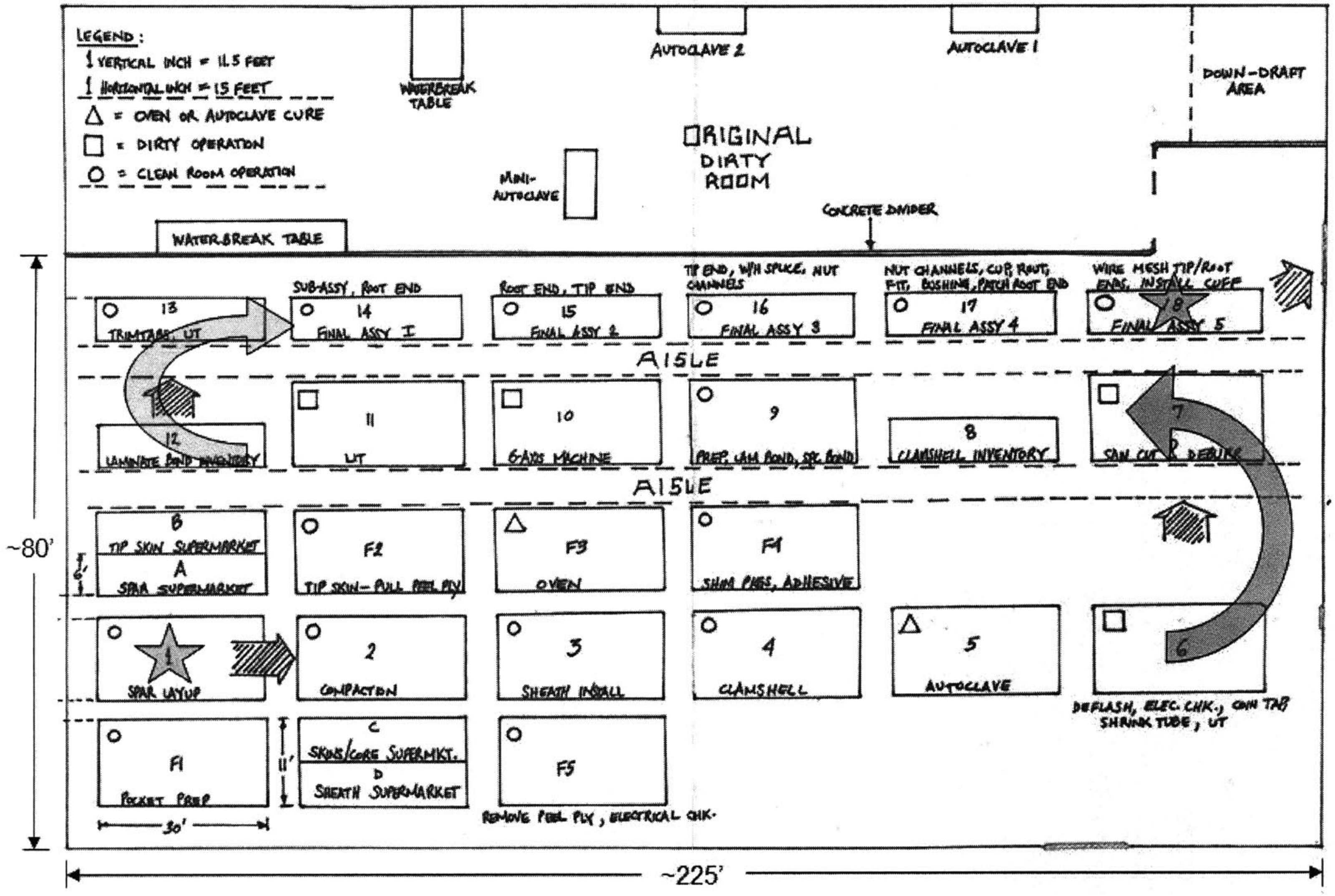


Figure 20. K200 Main Blade Cellular Layout for Site B

would be handled with a mechanical cart that can lift and lower blades with a manual foot crank. Table 5 provides a detailed break down of how the facility can be organized.

Table 5. Orientation of Processes for K200 Future State

Station(s)	Description
1,2,3,4,5,6,7	Material Compaction and Blade Curing
8	Inventory Location
9,10,11	Strengthening and Machining of Blade Root End
12	Inventory Location
13,14,15,16,17,18	Final Assembly
A,B,C,D	Part Supermarkets
F1,F2,F3,F4,F5	Supporting Processes to Feed Material Compaction

The feeder lines and many of the critical path stations are eleven feet by thirty feet, providing enough room for operator mobility, tools, and machines. Inventory locations, part supermarkets, and final assembly areas are about six feet by thirty feet. In addition, there are four lengthwise aisles six feet in width along the walls and in the center of the factory to promote easy access and visibility. It is also important to note that nearly 55% of the stations listed in Table 5 require a modular clean room to separate them from the remaining dirty operations and prevent contamination.

7.2 Simulation Modeling

With the physical layout known, several process variables have been entered into a software package (Simul8) to model the future factory. Examples of input parameters include supermarket material arrival rate, operation time characteristics for individual stations, and inventory limits. A key inference of this simulation is that management will exercise three shifts, excluding weekends, where each shift is comprised of 7.5 hours plus a 30-minute break. Another generalization addresses the nature of workers. Since many of the non-automated steps are manually intensive and people-dependent, there is an issue related to repeatability and reproducibility. In other words, the concern is how consistently an operator can complete a task on time and whether others can duplicate the results. Due to the high degree of uncertainty, all processes are assigned a normal operation time (as opposed to fixed) distribution.

Upon running a one-month trial, presented in Figure 21, the strategic inventory levels (stations 8 and 12) were found to be at reasonable levels with three or four rotor blades.

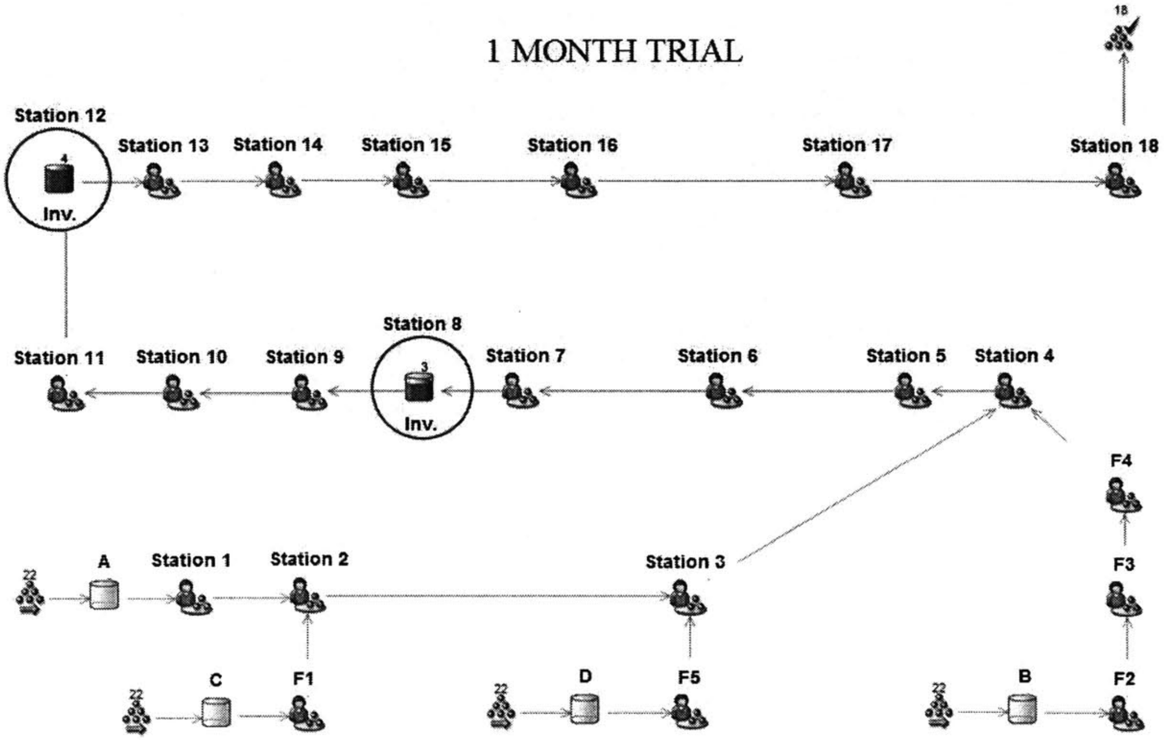


Figure 21. One-Month Production Simulation

However, after allowing the trial to resume for a full quarter (Figure 22), the inventory locations spiked and would have exploded had they not been capped. Even worse, the "traffic jam" slowly crept upstream to partially clog the supermarkets feeding the material compaction stations. Now, the fact that three months passed before these problems emerged demonstrates that the factory has close to enough capacity. The simulation actually predicts a lead time of 17 days and throughput of 18 blades per month, barely shy of the 20 blade commitment. Section 7.3 takes a further look into what exactly is causing the system to falter.

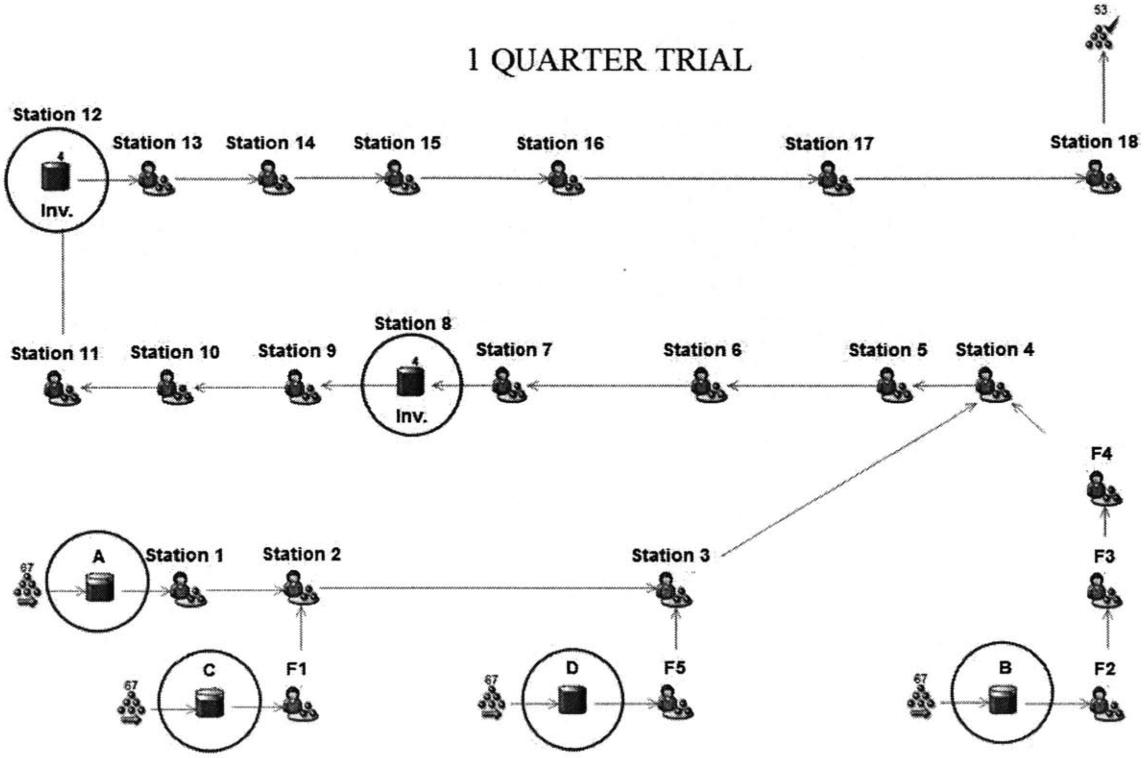


Figure 22. One-Quarter Production Simulation

7.3 Discussion

Through the simulation tool, we determined that our proposed cellular design will have difficulty fulfilling the anticipated monthly demand of 20 blades. In this section, we seek to answer why. According to Ravi Anupindi, if we observe a given resource during the period in which it is available, we will notice that it alternates between periods in which it is utilized, or busy processing flow units, and periods during which it is idle. Machines, for instance, may be out of service (maintenance or breakdown), occupied for setups (changeovers), or interrupted by other activities. Any one of these events will reduce the time period during which a resource is available (Anupindi, et al, 1999).

Idleness aside, the theoretical capacity of a resource pool is its maximum sustainable flow rate if it were completely utilized during its scheduled availability. Table 6 contains a capacity analysis for each of the critical path and supplementary work stations. The calculation can be derived as follows:

$$\text{Th. Cap. of Resource Pool} = \frac{1}{\text{Unit Load}} \times \begin{matrix}\text{Load}\\\text{Batch}\end{matrix} \times \begin{matrix}\text{Sched.}\\\text{Availability}\end{matrix} \times \begin{matrix}\text{Working Days}\\\text{Per Month}\end{matrix} \times \begin{matrix}\text{\# of Units in}\\\text{Resource Pool}\end{matrix}$$

In our scenario, load batch and total number of units in resource pool are both equivalent to 1 due to a single-piece pull manufacturing system and equipment shortages. Also, there are 20 working days to every month, corresponding to 22.5 hours of daily scheduled availability as mentioned in Section 7.2.

If the reader may recall from *The Goal*, two types of resource pools co-exist in manufacturing: bottlenecks and non-bottlenecks. A bottleneck is a resource that defines the effective capacity of a plant and is equal to or less than the demand placed upon it (Goldratt, 1992). In the text, Eli Goldratt stresses balancing the floor by controlling flow through the bottleneck and into the market. For the main blade line, the final assembly area (stations 14 to 18) is an obvious bottleneck and establishes the pace of production, taking at least twice the time to complete when compared to upstream operations. The factory could theoretically deliver 20 blades per month, but the inherent variation in each of the processes is collectively bringing the system under water.

Table 6. K200 Main Blade Capacity Analysis

THEORETICAL CAPACITY ANALYSIS FOR K200 MAIN BLADES					
Resource Pool	**Unit Load** (hrs/blade)	**Load Batch** (blades/batch)	**Th. Capacity of Resource Unit** (blades/mo)	**# of Units in Resource Pool**	**Th. Capacity of Resource Pool** (blades/mo)
1	3.58	1	126	1	126
F1	4.74	1	95	1	95
2	0.82	1	549	1	549
3	2.00	1	225	1	225
F5	2.00	1	225	1	225
F2	0.66	1	682	1	682
F3	1.50	1	300	1	300
F4	2.48	1	181	1	181
4	1.75	1	257	1	257
5	7.00	1	64	1	64
6	10.69	1	42	1	42
7	0.75	1	600	1	600
9	11.75	1	38	1	38
10	4.00	1	113	1	113
11	1.00	1	450	1	450
13	4.45	1	101	1	101
14	22.50	1	20	1	20
15	22.50	1	20	1	20
16	22.50	1	20	1	20
17	22.50	1	20	1	20
18	22.50	1	20	1	20

7.4 Recommendations

With a keen understanding of the limitations discussed in Section 7.3, there are a couple options for Sikorsky to ensure that blades are delivered in unison with the rate of sales. From a short-term perspective, the factory could artificially maintain process reliability by installing a supermarket after final assembly to absorb some of the system variation (Figure 23). A harder solution involves standardizing the content and flow of activities in the final assembly stations where main blades would spend up to 53% of their time. Since the distribution of work is lopsided with greater labor focus at the tail-end of production, this particular scenario favors cross-trained operators who can easily rotate to support downstream operations.

Eventually, customer demand will climb to 40 blades per month, cutting takt time to 11.25 hours. Looking ahead, the business could employ a pair of tactics to soften the impact. With the right amount of capital, the factory can strengthen production capability by increasing capacity in final assembly as depicted in Figure 24.

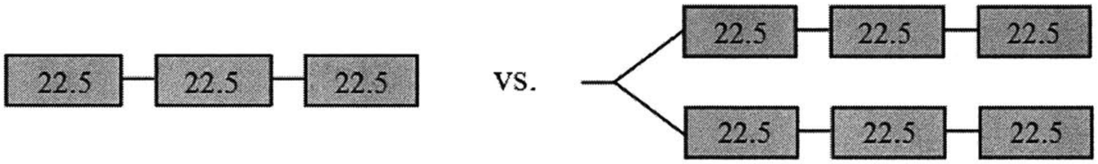


Figure 24. Shift from Series to Parallel Processing

For example, instead of having three stations at 22.5 hours a piece, one could build a second set of stations to operate in parallel, thus doubling output from twenty to forty blades per month. Based on Figure 25, Sikorsky also has an opportunity to maximize throughput by "bite-sizing" its bottlenecks.

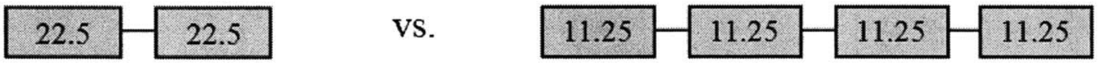


Figure 25. Simplifying Bottlenecks in Final Assembly

In this case, for instance, the plant can divide final assembly work into smaller chunks such that transfer of product from station to station is synchronized with takt time. While both of these solutions are flexible to market fluctuations, space is a critical constraint for Site B. As a result, management will more than likely opt for a larger facility to house the additional equipment and expand operations.

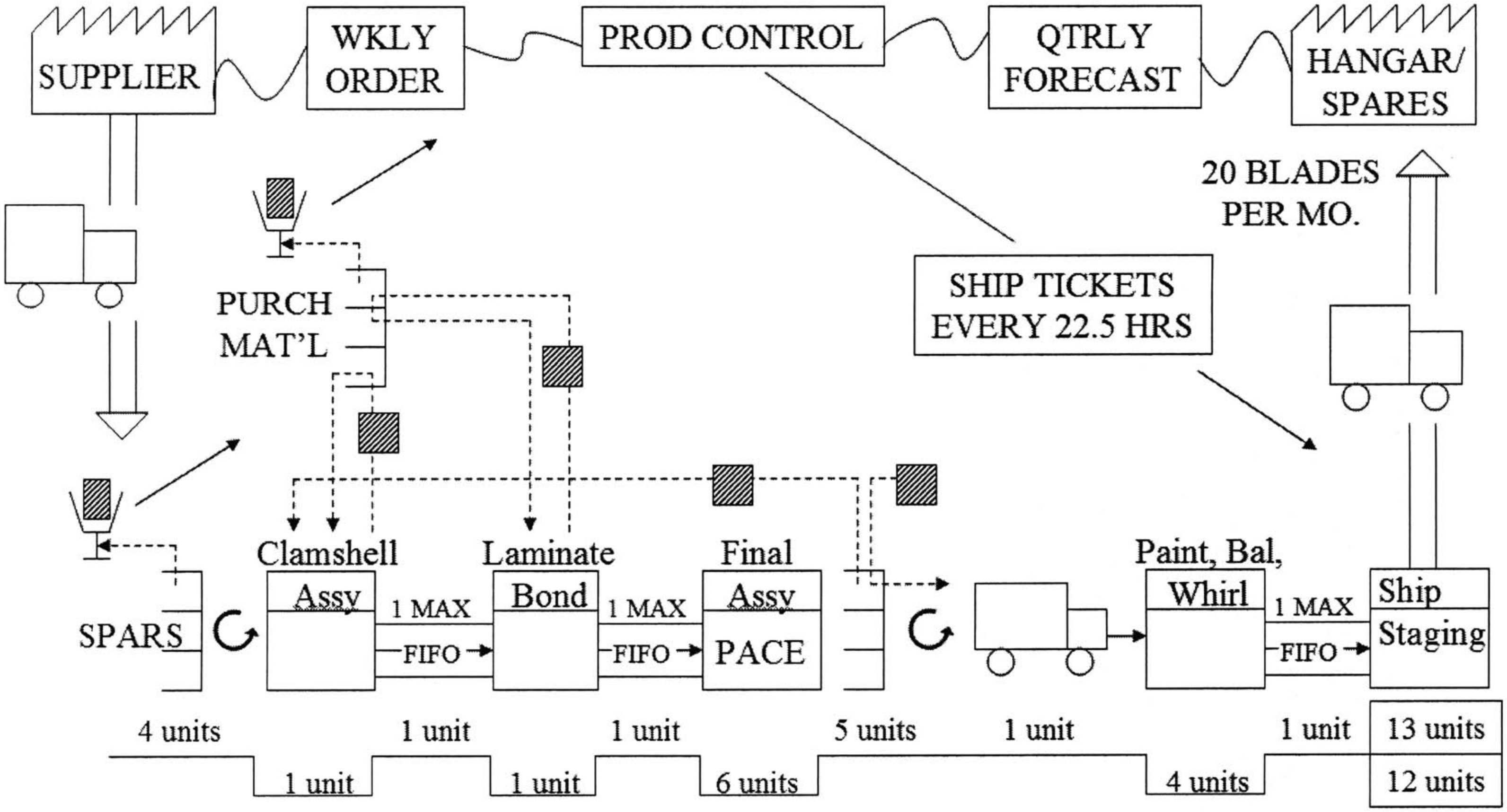


Figure 23. Revised Hypothetical Future State Map for K200 Main Blade

Chapter 8: Leadership and Organizational Change

This chapter is a stand-alone paper, extending beyond the author's internship experience to describe personal leadership in the midst of organizational change. It specifically captures the context of the research and stakeholder alignment surrounding the project. In tying these elements together, Chapter 8 concludes with a reflection on the author's lessons learned, professional strengths, and development needs.

8.1 Project Background and Description

As part of my 6-month internship, I joined Sikorsky Aircraft in Connecticut to drive lean transformation initiatives in the rotor blade shop while supporting business expansion efforts. In June 2005, the company was planning for a doubling in production volume over the next three years. Once a vertically integrated company, Sikorsky has revised its strategy by shifting non-core manufacturing to the supply base and converting batch and queue process villages into lean flow lines. Choosing a low cost, high profit operating model influenced Sikorsky's decision to concentrate on key competencies.

Sikorsky's core military platform, the Blackhawk, has always been a mature and long-standing source of revenue. In fact, the need for spare blades continues to reach record highs in light of the ongoing war in Iraq. As a result, management set aside additional capacity in the Stratford facility to accommodate the rise in demand. However, by reserving extra floor space in the existing factory for this purpose, business leaders decided to relocate the K200 program (masked for confidentiality) to an alternate site. Compared to the Blackhawk, K200 manufacturing proficiency is still in its infancy, functioning much like a job shop. This is not the desired state especially when orders are expected to quadruple by 2007.

Shortly after commencement of K200 helicopter rotor blade fabrication, transformation of the rotor blade lines followed. In one year, Sikorsky progressed rapidly along a sharp learning curve to satisfy customer needs and categorized its lean execution into three major stages:

Phase I - Relocate all K200 production equipment to Site B.

Phase II - Establish a temporary layout around existing monuments.

Phase III - Implement cellular arrangement with in-line machines.

Given the business objectives, my internship focused on three aspects of lean methodology: enterprise and department level value stream mapping, management of improvement initiatives, and the design of a dedicated lean flow line for main blades.

Deliverable 1

Value Stream Mapping was employed during Phase II to assess the current state of the main and tail blade production systems. However, before analyzing material flow, I took a step back and observed how factory processes fit into the overall framework of the business. For example, the purchasing department may be internally optimized, but could be considered sub-optimal if the total enterprise is not lean. Thus, documenting information flow across various cross-functional areas provided a valuable frame of reference as illustrated below (Figure 26).

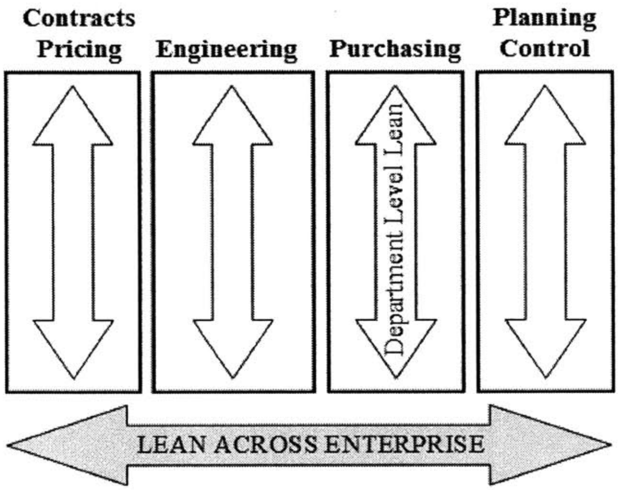


Figure 26. Enterprise Versus Department Level Lean

Deliverable 2

Using future state value stream maps, I identified several potential kaizen events to reduce lead time and increase monthly blade deliveries. Though, as a management tool, value stream mapping by itself did not emphasize team roles, responsibilities, and actions needed to achieve an ideal production system. Therefore, specific guidelines were applied to prioritize the activities, track performance, and audit the changes.

Deliverable 3

Long lead times and poor throughput levels have been logged throughout Phase II. With orders expected to double by 2006, Phase III capital investment plans were under review to ensure that the plant could adequately accommodate the volume. Although most expenditures received approval, a cellular arrangement could not be finalized within the scope of the internship. Despite the timing issue, I completed a proposed factory layout for the main rotor blade. The primary challenge in designing a lean flow line became evident given the physical constraints of the Site B plant.. A discrete simulation was also created to validate the new manufacturing cell.

8.2 Three Perspectives on Organizational Processes

"Businesses are changing rapidly in response to economic, social, political, and technological forces. Companies have flattened their hierarchies in order to be flexible and to cut costs. More companies have global reach and diversity of people and ideas to match the diversity of their customers and stakeholders. Companies are networked internally and externally to gather information and combine resources for emerging opportunities. The idea that companies or firms are the central actors in economic life is yielding to teams, projects, joint ventures, supply chains, and other structures that cut across traditional boundaries" (Caroll, 1995). This section offers various insights on organizational behavior from a strategic, political, and cultural perspective.

8.2.1 Strategic Design

The strategic design of an organization encompasses the mission of a company based on rational analysis of opportunities and capabilities. Guided by a vision, senior leaders recruit knowledgeable individuals and group them by expertise to execute on corporate objectives. Considering Sikorsky's goals, the business is expanding its presence in the military and commercial helicopter space for greater market penetration. To capitalize on the increase in aircraft demand, Sikorsky has focused on profit margins, shifting non-core manufacturing to its supply network and re-grouping employees into various distinct departments including Contracts/Pricing, Engineering, Purchasing, and Planning/Control. Of course, some of these functions are further categorized according to product family (i.e. Blackhawk, CH-53, S-76, etc.) and competencies mentioned in Section 8.1.

From a Planning/Control standpoint, both production output and proficiency continue to ramp up significantly for K200 rotor blades. In terms of customer profile, 90% of blades currently service complete aircraft sales while the remaining 10% fulfill requests for spares. Though, as the product matures, the percentages will eventually become more balanced. Due to high volume forecasts and the desire to minimize internal operating costs, the business has developed a strategy to integrate lean methodologies within the factory through single-piece flow and cellular manufacturing. Many believe the adoption of Toyota Production System (TPS) principles will improve responsiveness to the customer and shorten lead time to market.

During my internship, I was directly exposed to the lean transformation initiative. My stretch goal was to help relocate the entire K200 line (Phase I), but I was primarily responsible for meeting product delivery targets with equipment that had already been transferred to Site B (Phase II). As part of my second deliverable, I led a focused team to increase monthly throughput by enhancing the flow of activities in the rotor blade fabrication area. This kaizen project fit well with the overall need to demonstrate system capability and satisfy volume expectations.

8.2.2 Political Perspective

The political viewpoint assumes that an organization is a diverse collection of stakeholders with different and sometimes conflicting interests (Caroll, 1995). Individuals and/or coalitions with "power" does not mean exercising control over others. Rather, it suggests the ability to get things done or thwart progress through persuasion, access to resources, special alliances, and knowledge. Since my assignment was closely linked to factory performance, key stakeholders included the operations manager, plant foreman, and line workers. Figure 27 portrays the nature of these relationships with respect to my project in addition to external participants having a vested interest in the outcome. A plus (+) implies that the initiative is favored whereas a negative (-) denotes resistance.

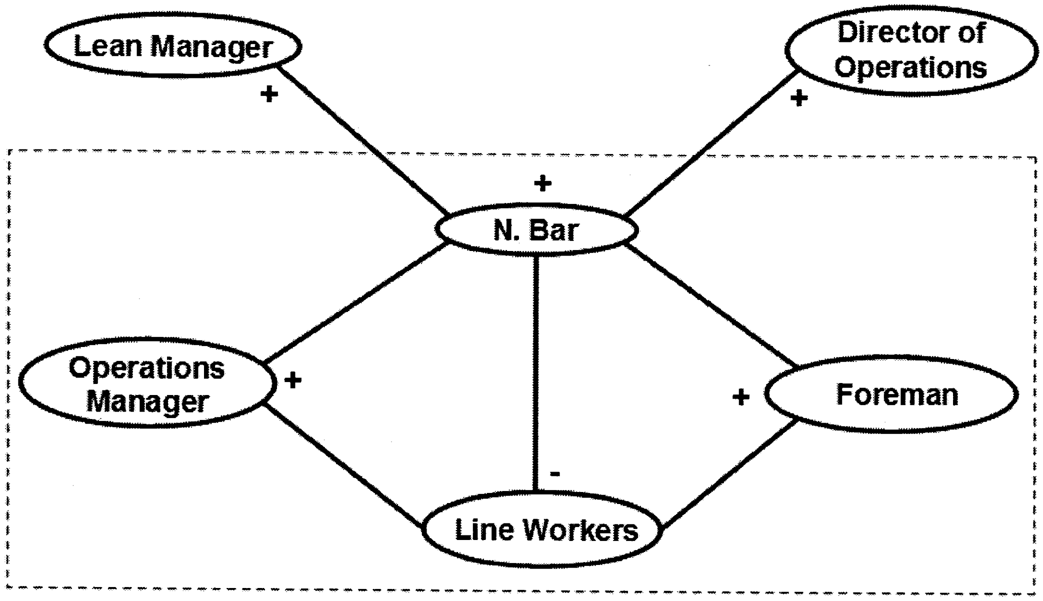


Figure 27. Project Stakeholder Map

In evaluating the reasons for support and disagreement, I realized that each of the stakeholders had something to gain or lose with the throughput project. On the top-most level, my lean manager and the director recognized that the business would eventually take a hit and lose money if aircraft assembly did not march to the beat of increasing sales. Both the foreman and operations manager understood that blade deliveries to the hangar were rising sharply, but did not have an instant solution to match supply with demand. Standing in opposition were the line workers who are adroit in their trade and have mastered the intricate manufacturing processes for years. Because Sikorsky is off-loading parts to competing vendors, line operators' concerns about their livelihood continue to grow. Learning from them or documenting how they work was initially perceived as a threat because their expertise (knowledge) is a main source of power and losing it would make them expendable.

8.2.3 Culture

Underlying the visible aspects of culture are a set of articulated attitudes and beliefs, shaping a "way of life" for how and why things are done in a particular fashion. Prior to the 21st century, Sikorsky operated as a traditional batch and queue manufacturer with large inventories and long lead times to market. With only a small number of competitors, the business was once complacent in its position as the dominant player in vertical flight. However, increased customer expectations and the management decision to pursue a lean philosophy described in Section 8.2.1 truly challenged the existing culture by rocking the foundation of a historic mental model.

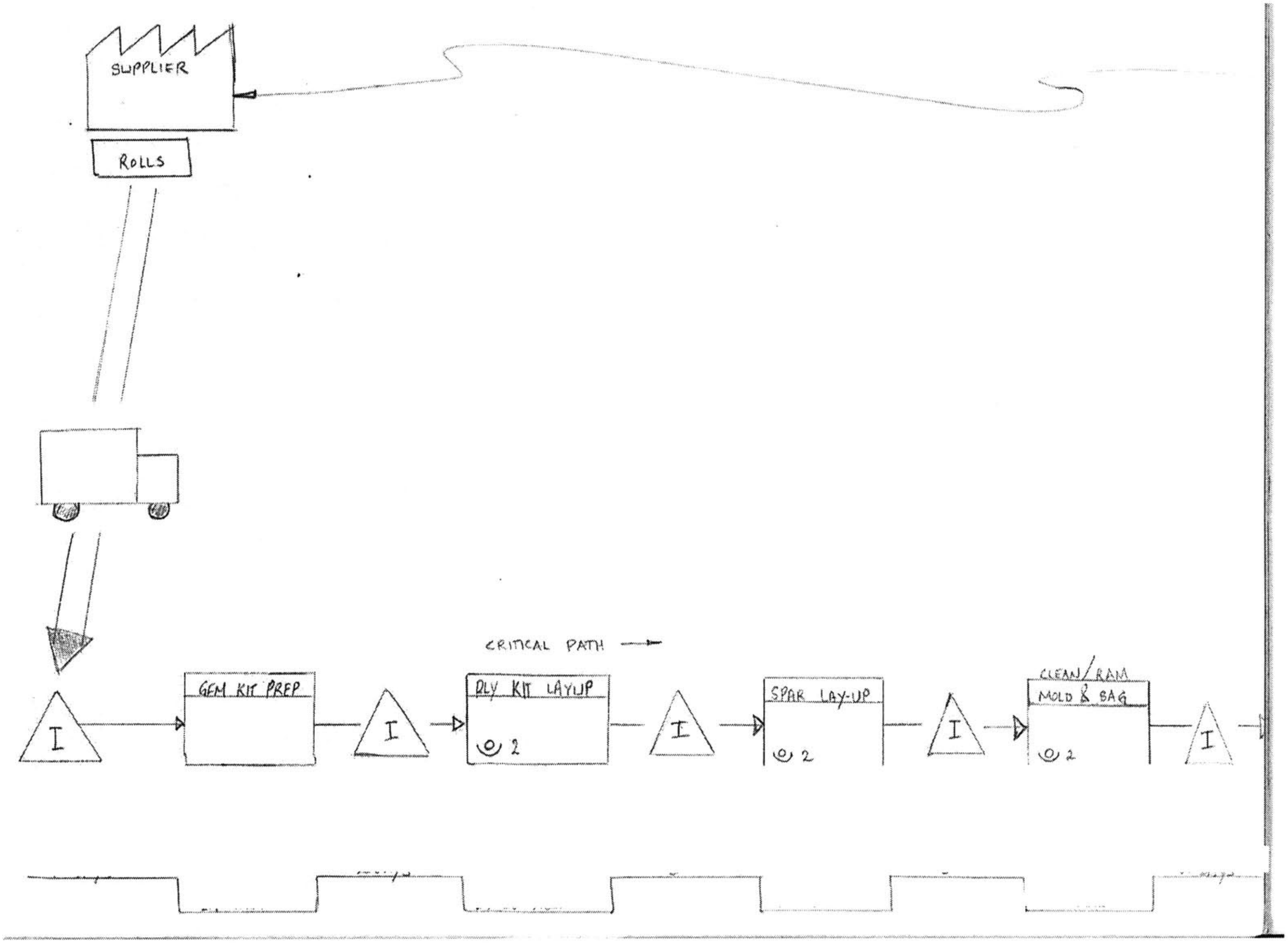
8.3 Evaluation and Recommendations

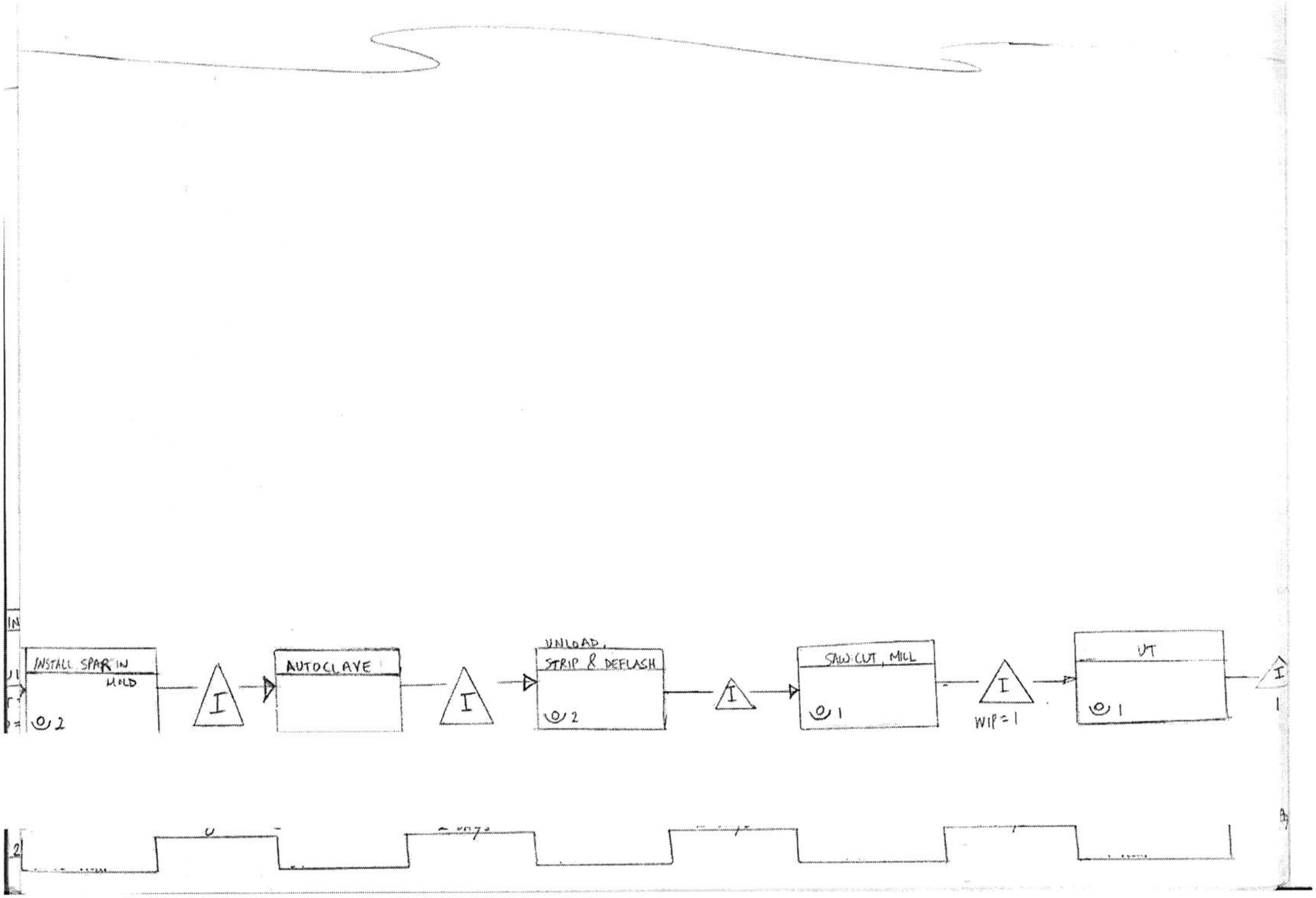
Although the full production relocation effort was not completed within a six month period, I was still successful in increasing blade throughput by roughly 50% for a specific set of fabrication stations. During my internship, the idea of implementing a shift-load chart eventually evolved into a standard sustainable solution for tracking deliveries to the aircraft hangar. However, the impact of my project was equally significant from an organizational perspective as well. I was amazed to see how a data-driven, team-oriented mindset could simultaneously improve operational metrics and overcome the age-old paradigm of "don't fix it if it isn't broken."

While at Sikorsky, I had a terrific manager and mentor who instructed me on the lean principles and values of leadership. I would like to pass on three of his mantras that are meaningful to me and may be helpful in guiding others engaged in similar situations:

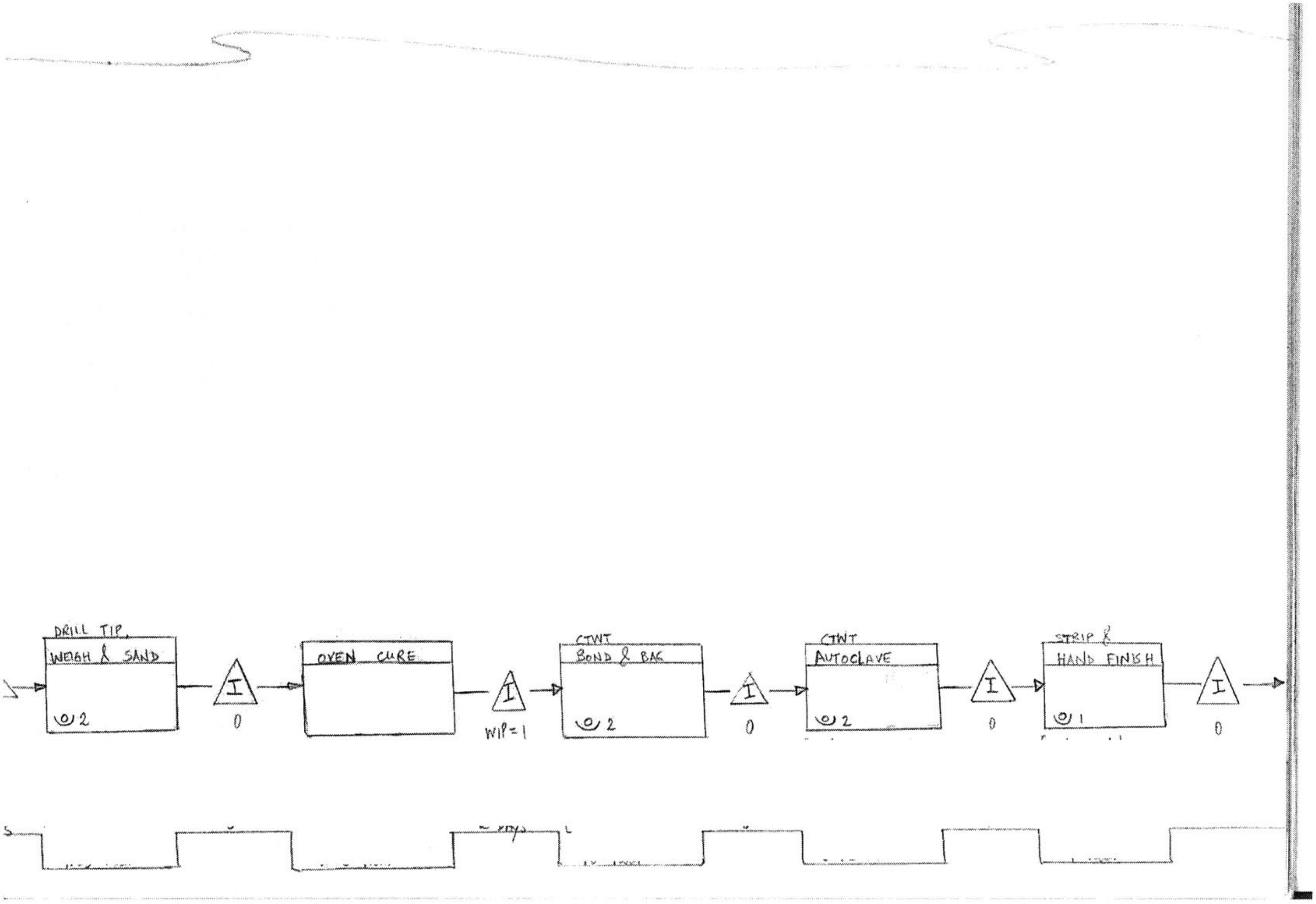
1. *"A great leader must have solid interpersonal skills, the passion to learn and acquire knowledge, and the ability to initiate change."*
2. *"It is easy to manage through fire-fighting because the choices are simple: you either turn left or right. The true challenge is one of proactive management."*
3. *"A capable leader must manage the appropriate amount of tension to enforce accountability. In a short assignment, pushing the envelope for change among team members is just as important as building relationships and establishing credibility. Maintaining the right balance separates the good from the great."*

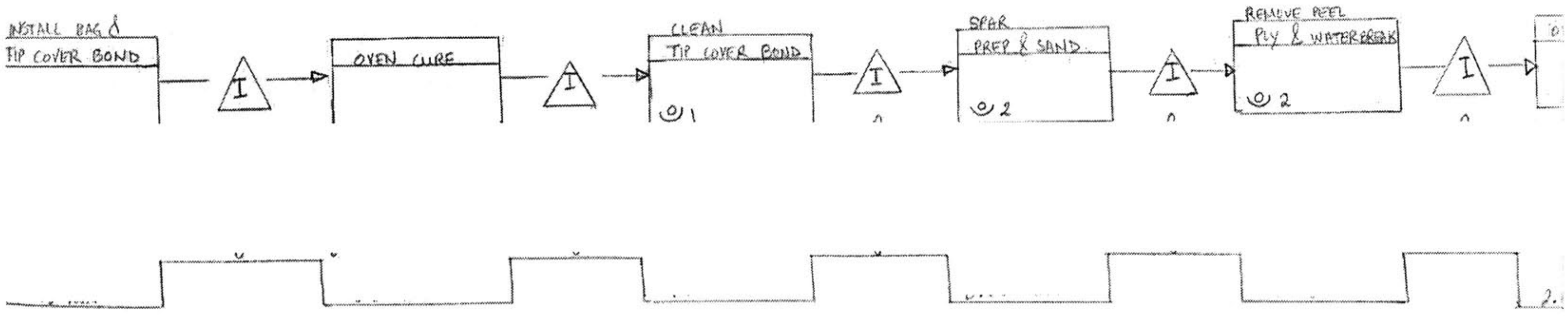
APPENDIX A.1 – K200 MAIN BLADE CURRENT STATE MAP

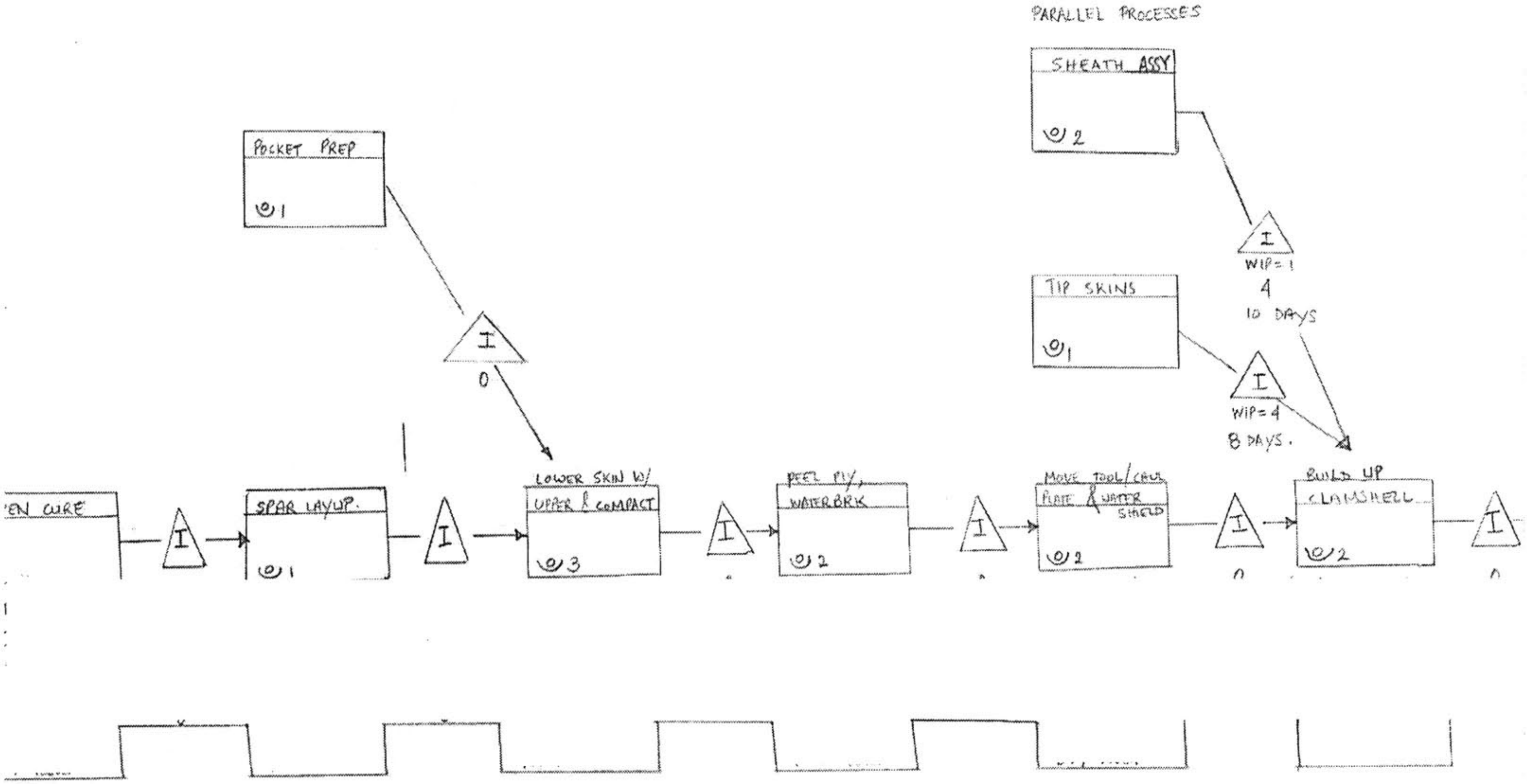


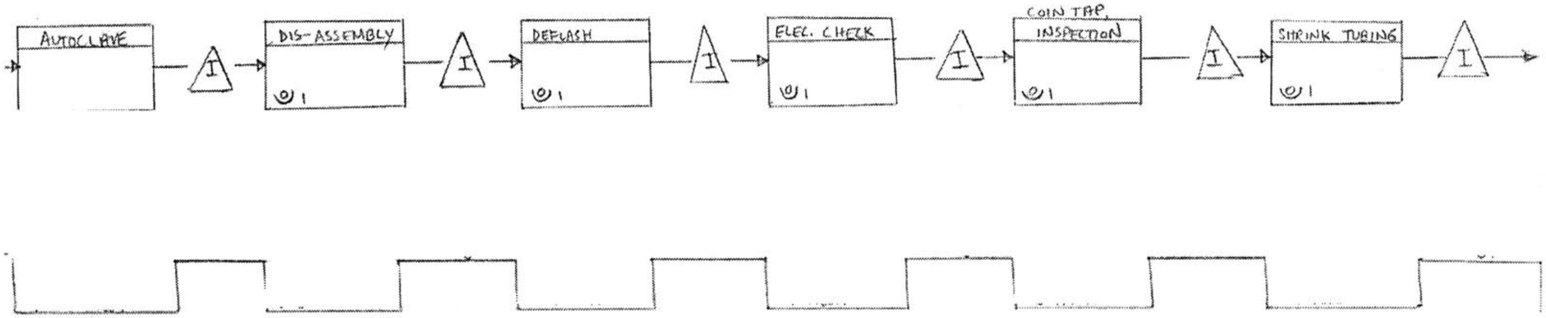


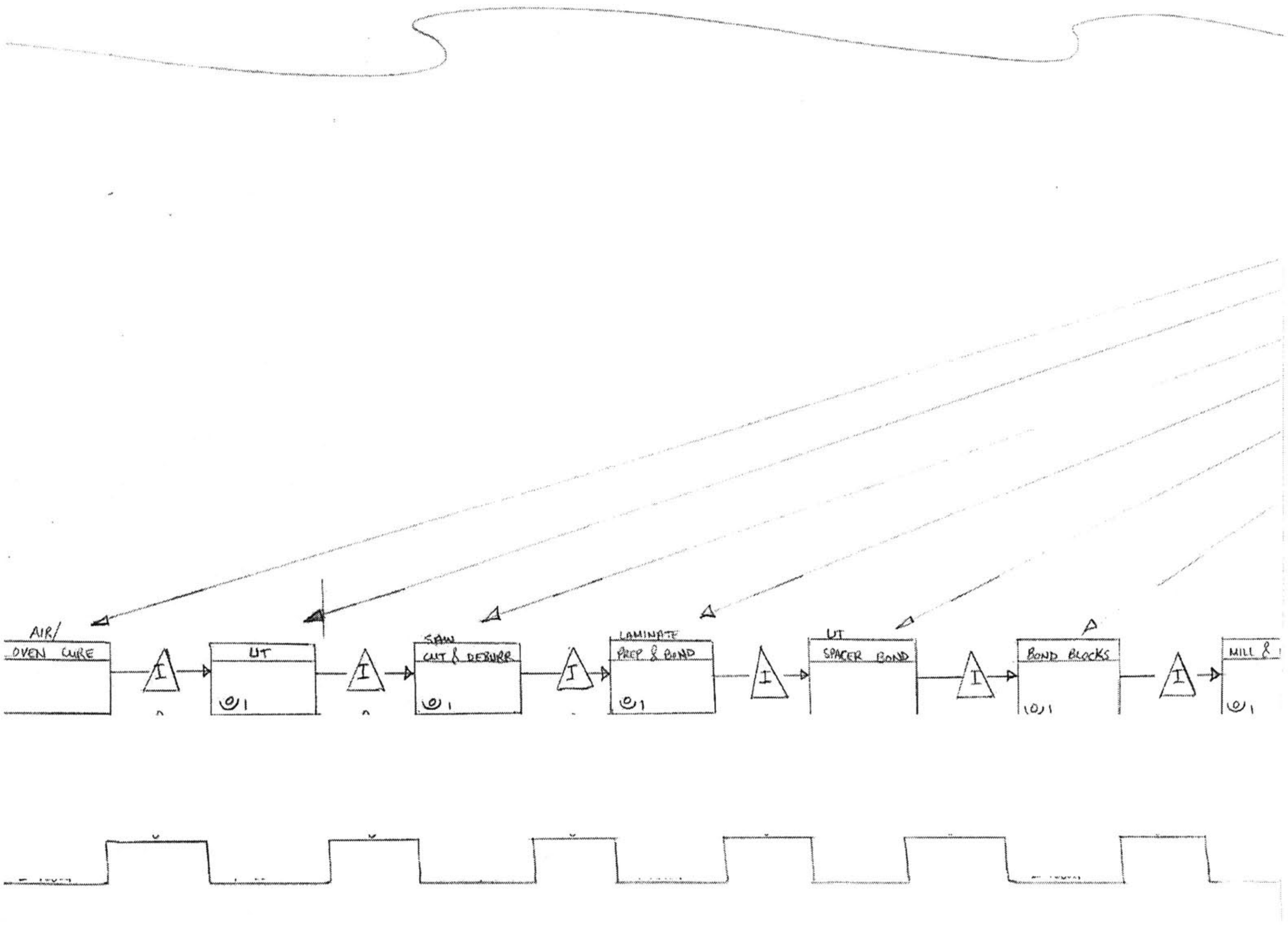
INSTALL SPAR IN MOLD
2
I
AUTOCLAVE
I
UNLOAD, STRIP & DEFLASH
2
I
SAW CUT, MILL
1
I
WIP = 1
UT
1
I
1
2

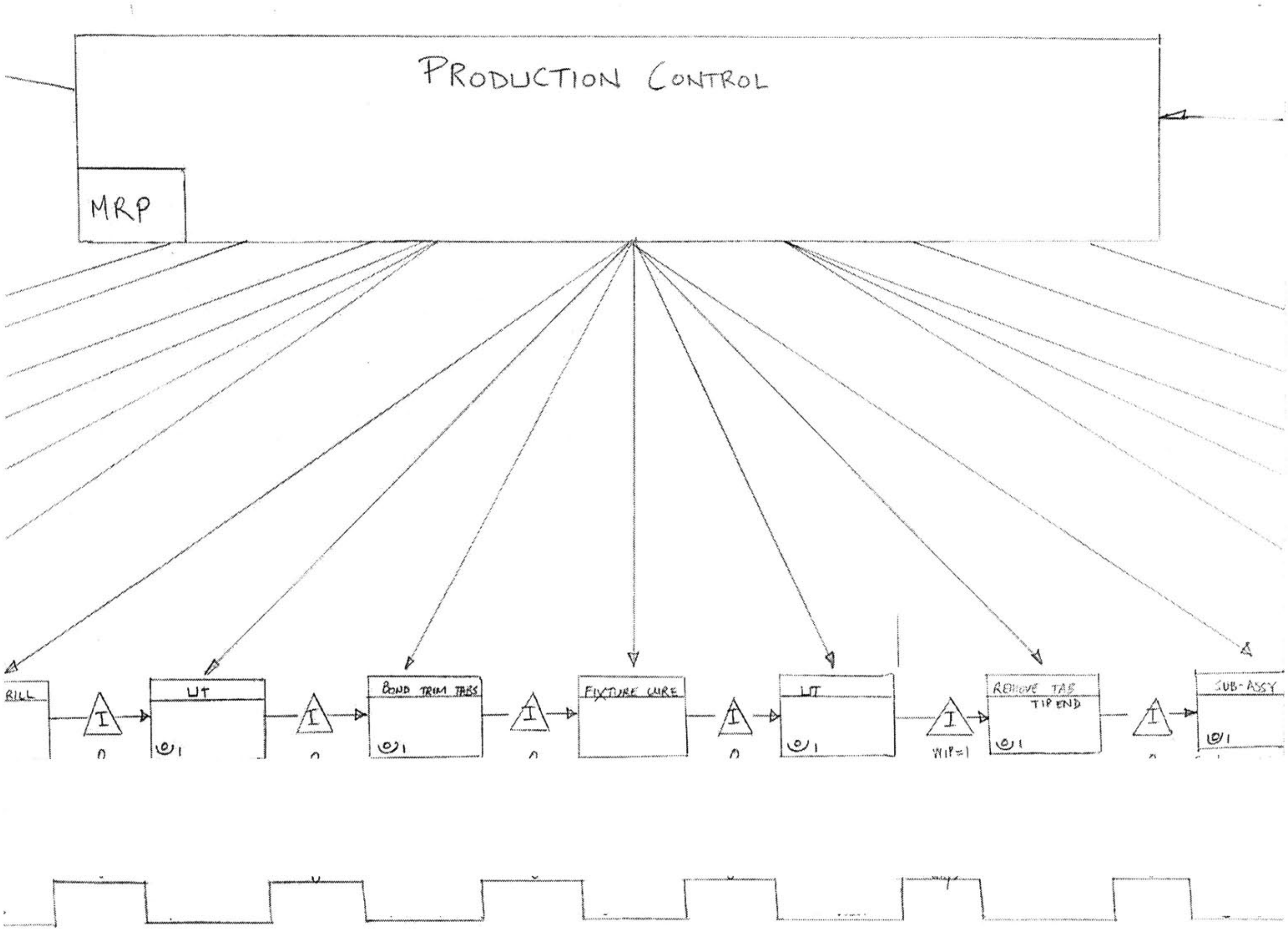

DRILL TIP,
WEIGH & SAND
2
0
OVEN CURE
WIP=1
CTWT
BOND & BAG
2
0
CTWT
AUTOCLAVE
2
0
STRIP &
HAND FINISH
1
0

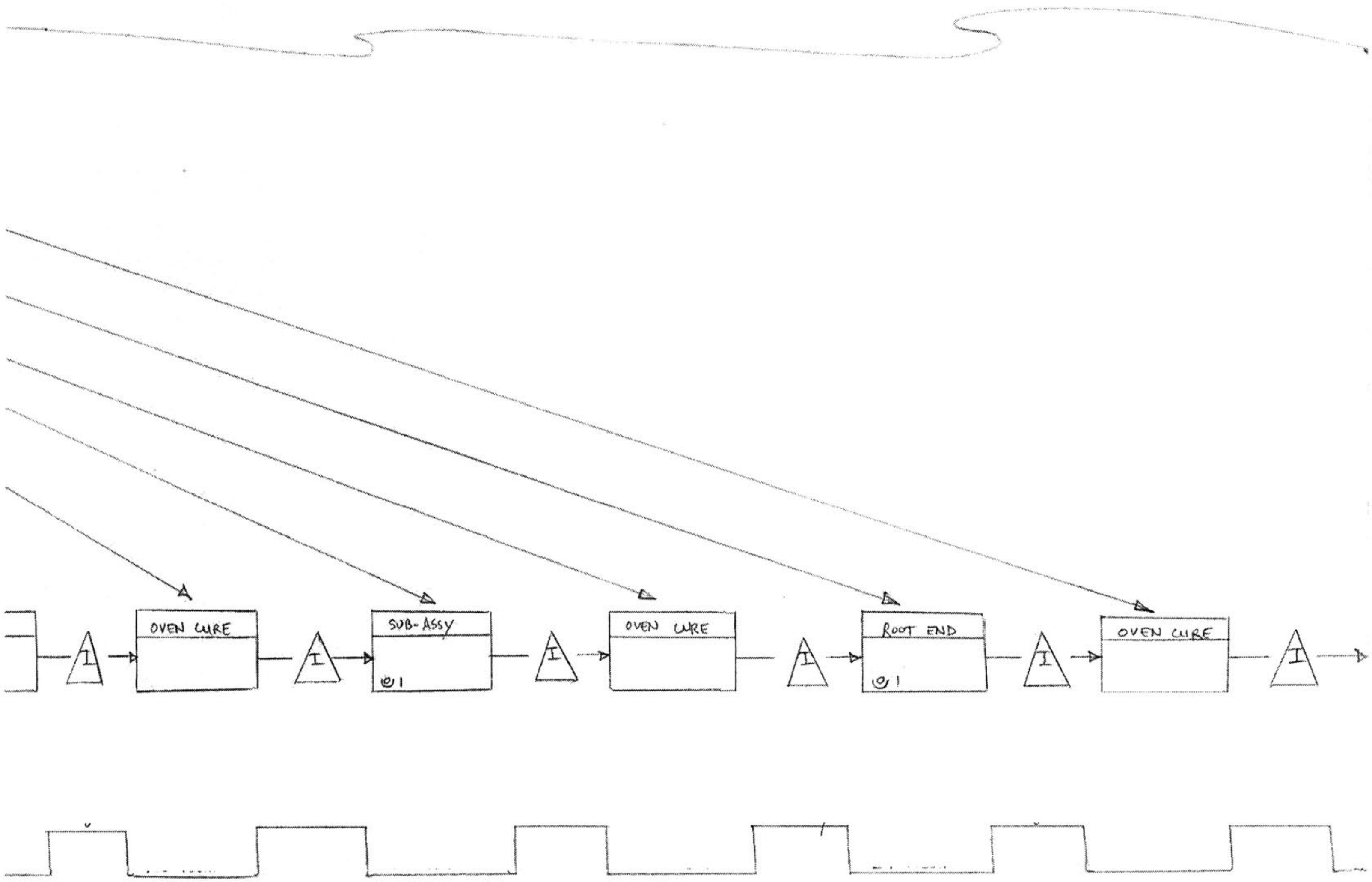

INSTALL BAG &
TIP COVER BOND
I
OVEN CURE
I
CLEAN
TIP COVER BOND
1
I
SPAR
PREP & SAND
2
I
REMOVE PEEL
PLY & WATERBREAK
2
I
2.

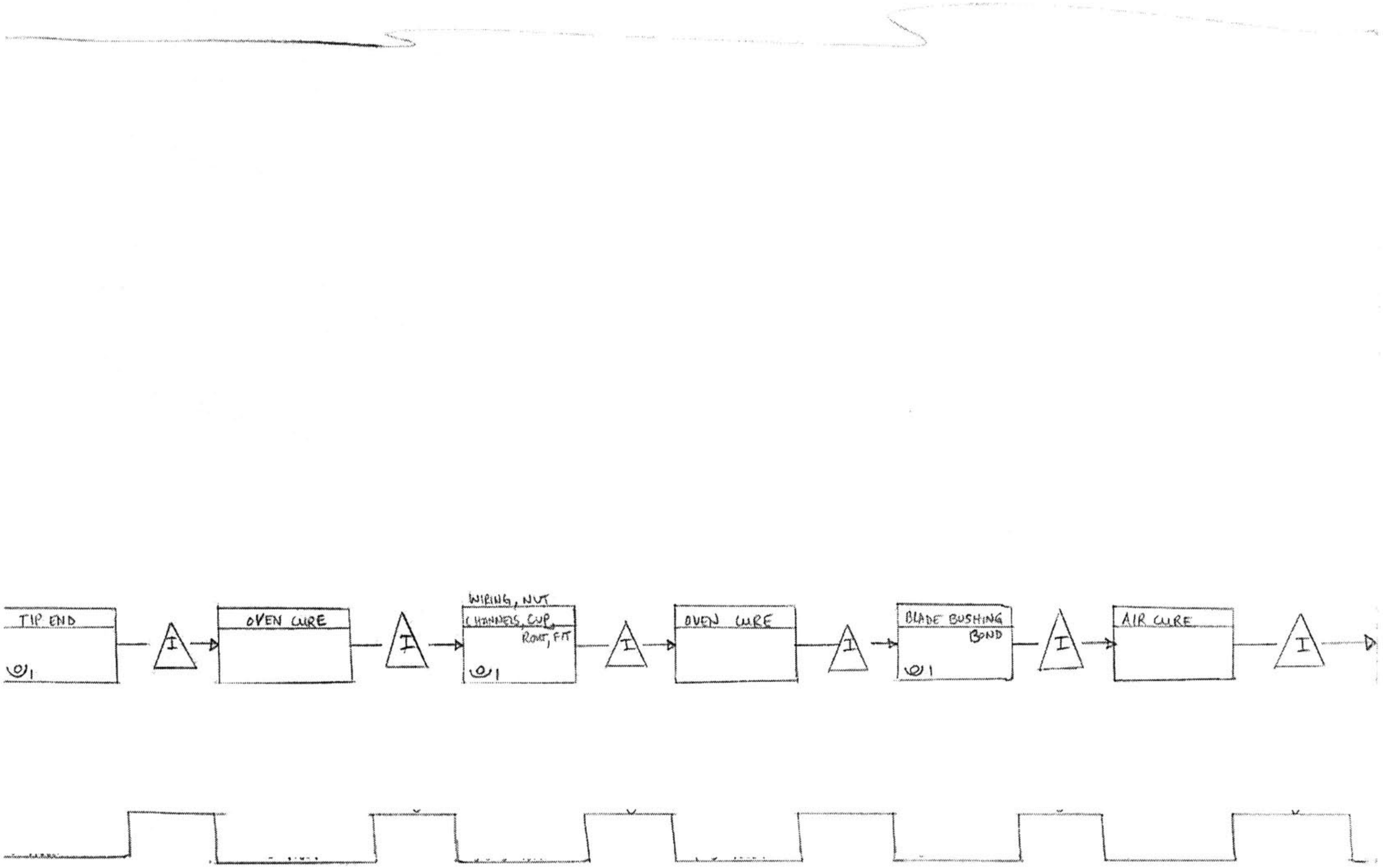

PARALLEL PROCESSES
SHEATH ASSY
2
I
WIP = 1
4
10 DAYS
TIP SKINS
1
I
WIP = 4
8 DAYS.
POCKET PREP
1
I
0
'EN CURE
I
SPAR LAYUP.
1
I
LOWER SKIN W/
UPPER & COMPACT
3
I
PEEL PLY,
WATERBRK
2
I
MOVE TOOL/CAUL
PLATE & WATER
SHIELD
2
I
BUILD UP
CLAMSHELL
2
I

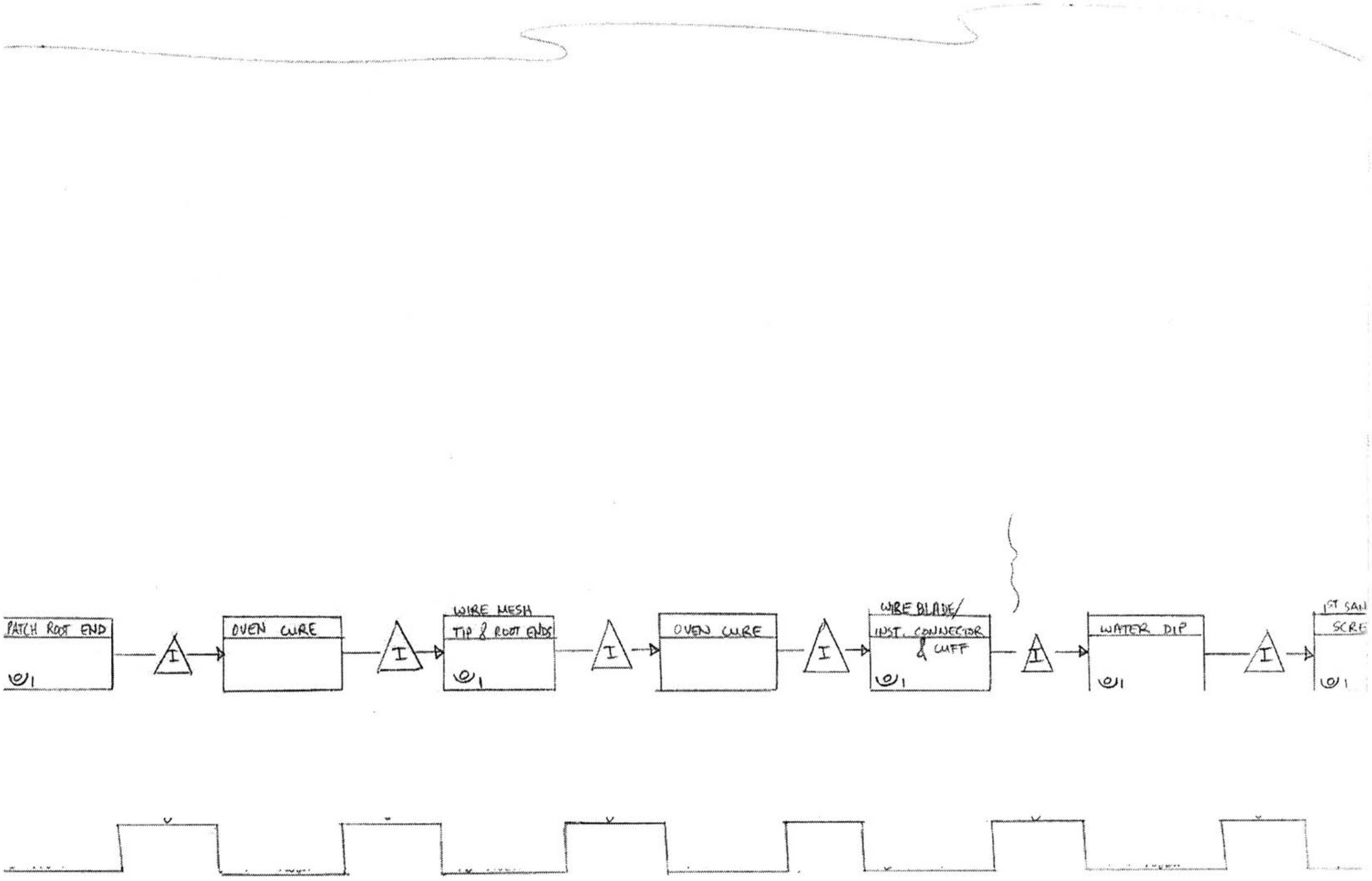

AUTOCLAVE
I
DIS-ASSEMBLY
1
I
DEFLASH
1
I
ELEC. CHECK
1
I
COIN TAP, INSPECTION
1
I
SHRINK TUBING
1
I

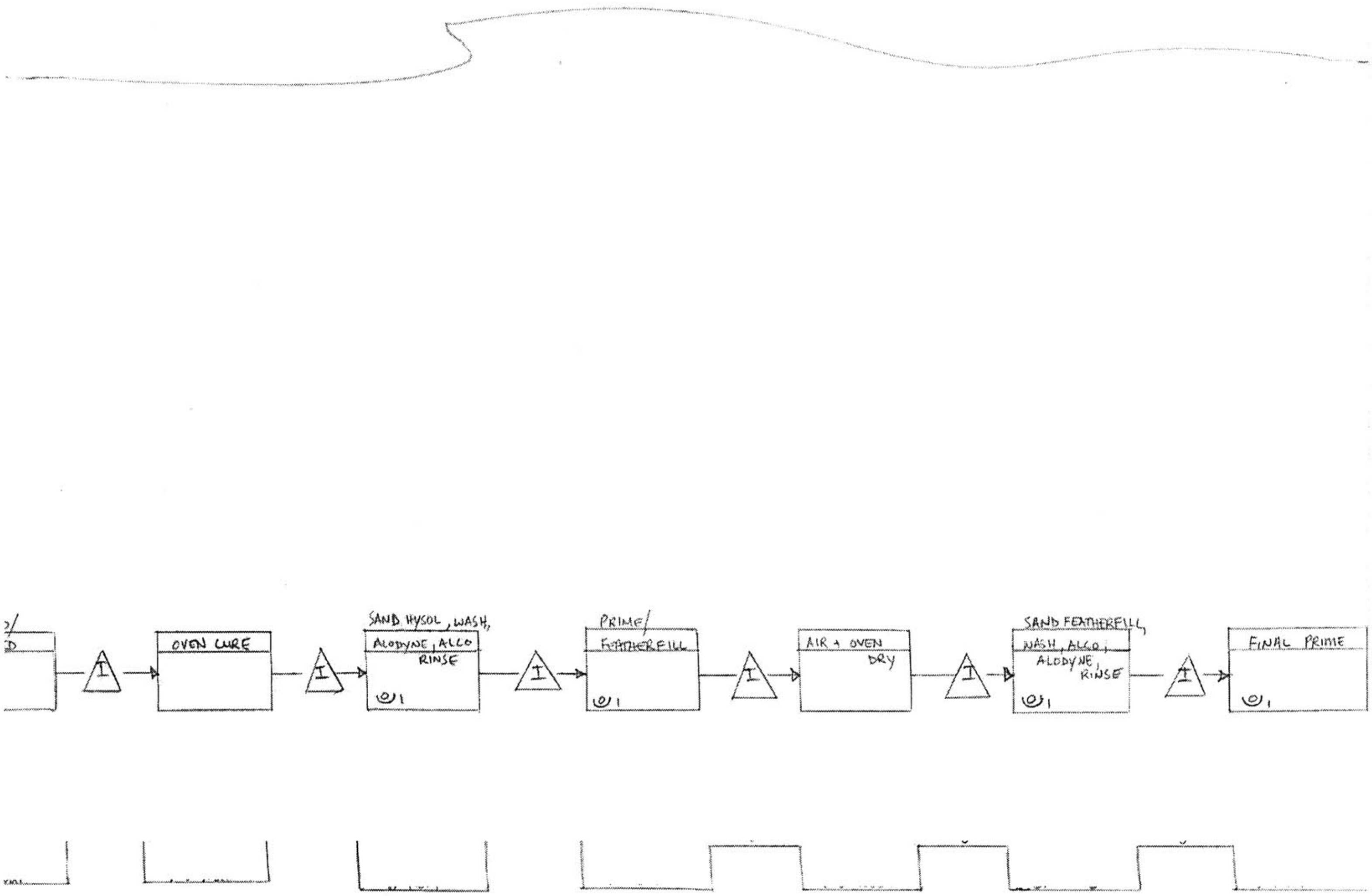

AIR/
OVEN CURE
I
UT
@1
I
SAW
CUT & DEBURR
@1
I
LAMINATE
PREP & BOND
@1
I
UT
SPACER BOND
I
BOND BLOCKS
(0)1
I
MILL &
@1

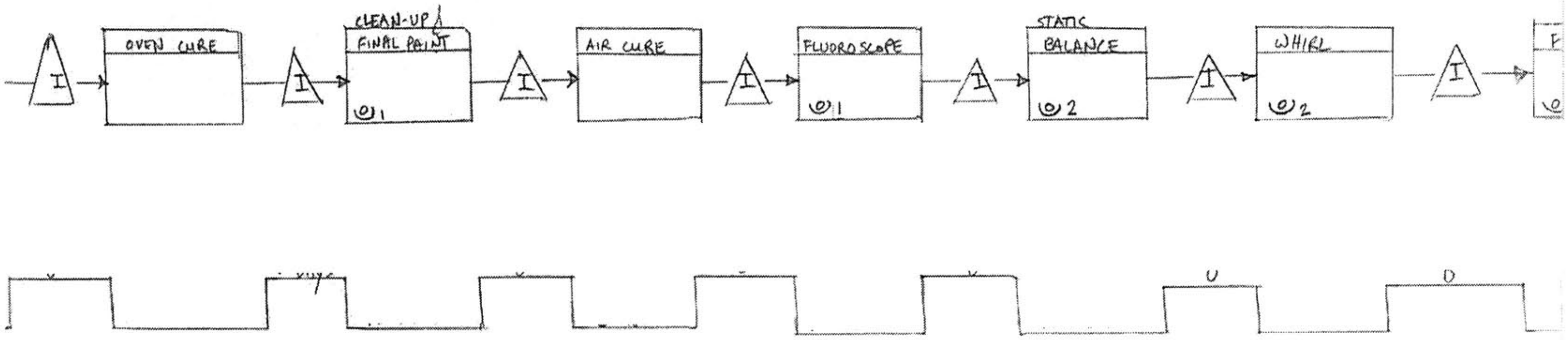

PRODUCTION CONTROL
MRP
RILL
UT
BOND TRIM TABS
FIXTURE CURE
UT
REMOVE TAB
TIP END
SUB-ASSY
I
I
I
I
I
I
WIP=1

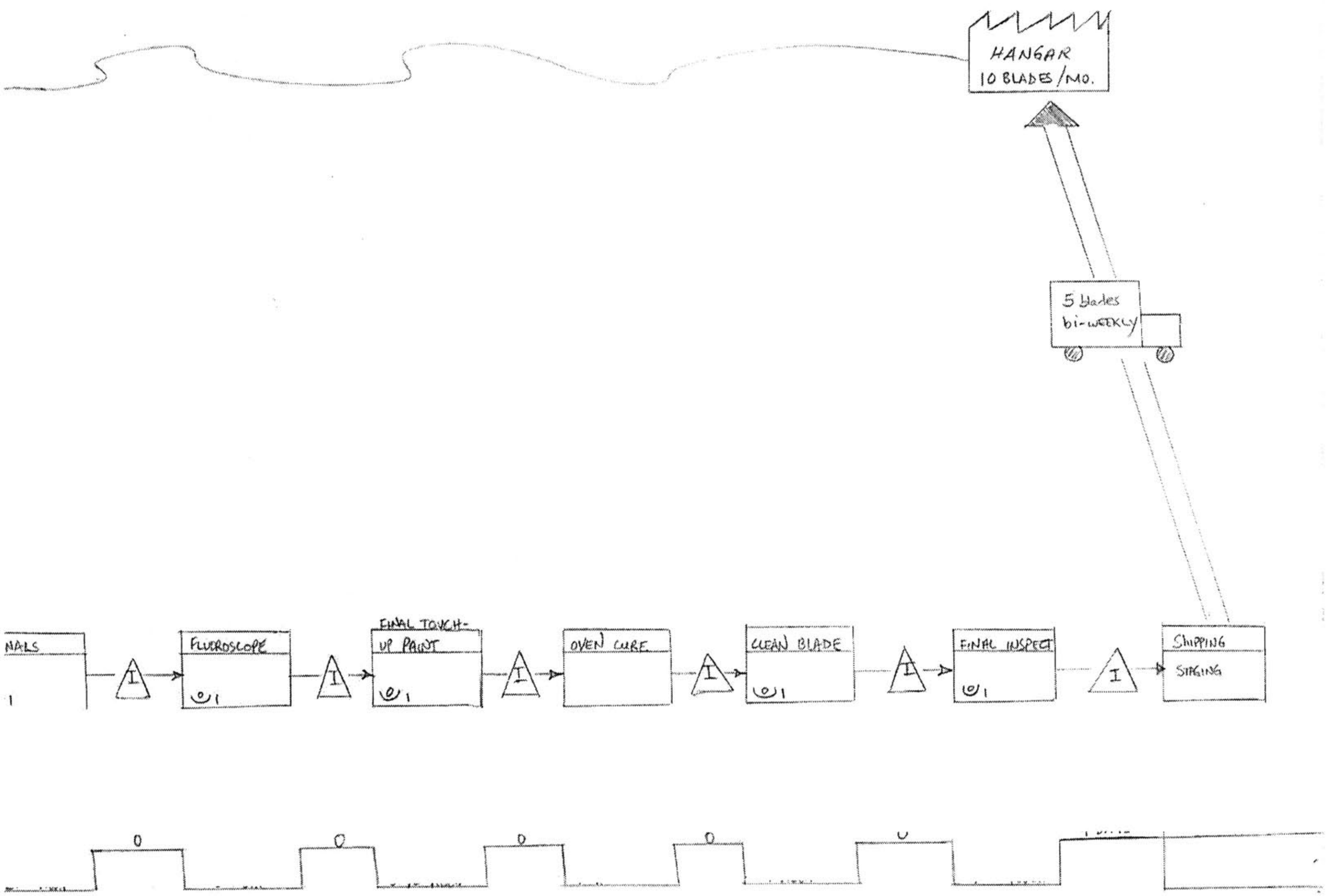

I
OVEN CURE
I
SUB-ASSY
1
I
OVEN CURE
I
ROOT END
1
I
OVEN CURE
I


TIP END
1
I
OVEN CURE
I
WIRING, NUT
CHANNELS, CUP,
ROUT, FIT
1
I
OVEN CURE
I
BLADE BUSHING
BOND
1
I
AIR CURE
I

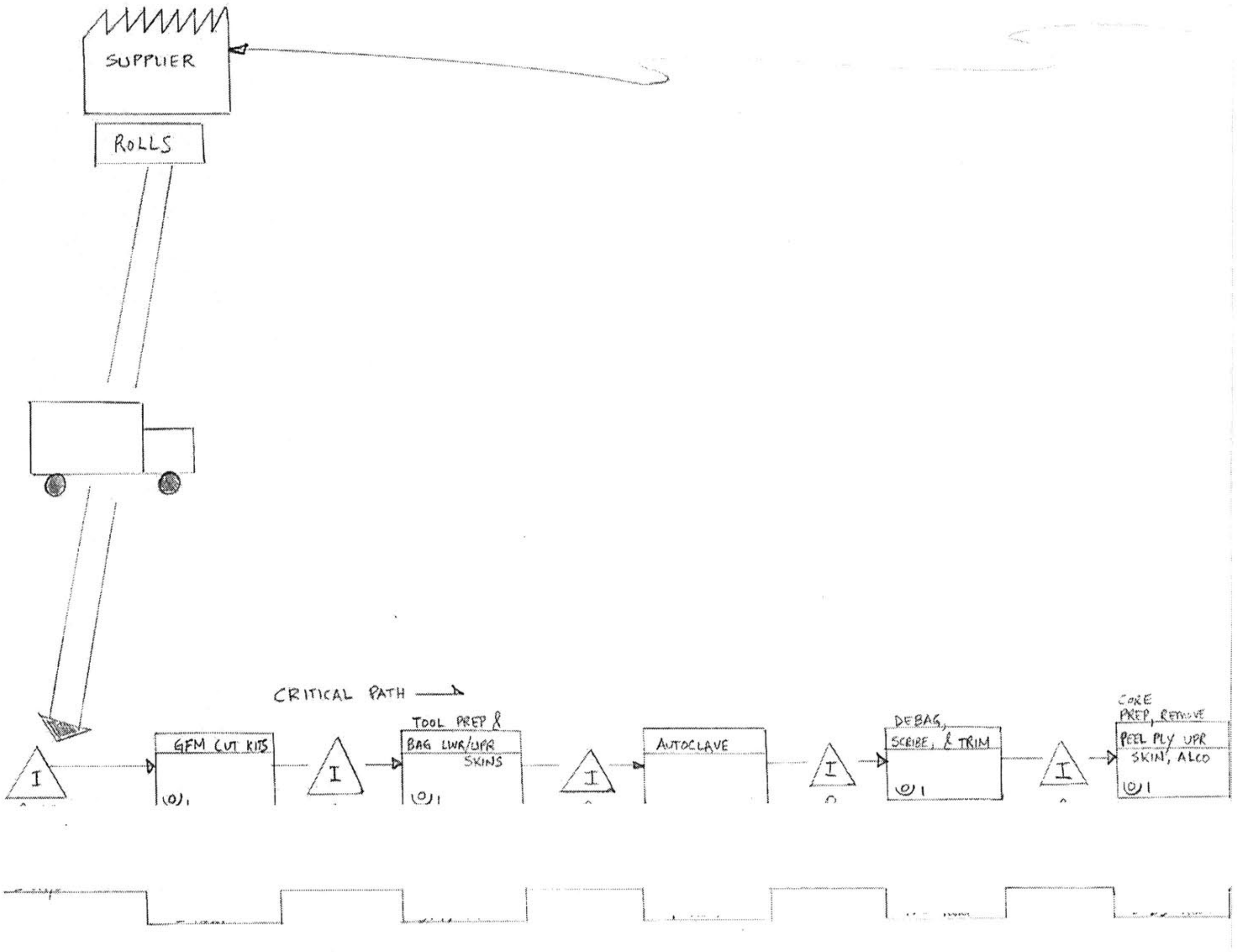

PATCH ROOT END
I
OVEN CURE
I
WIRE MESH
TIP & ROOT ENDS
I
OVEN CURE
I
WIRE BLADE/
INST. CONNECTOR
& CUFF
I
WATER DIP
I
1ST SAN
SCRE

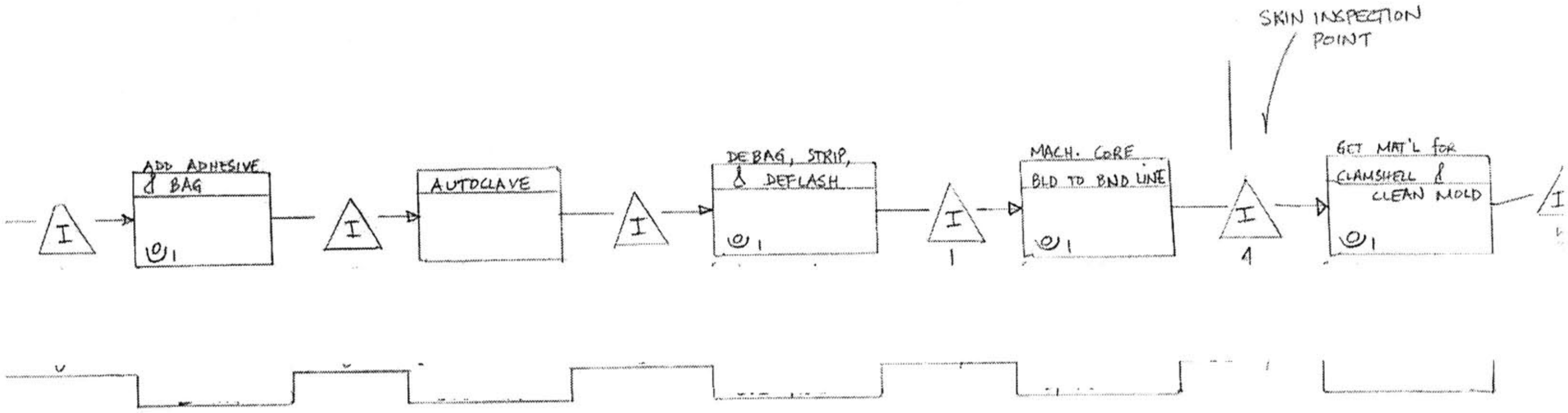

I
OVEN CURE
I
SAND HYSOL, WASH,
ALODYNE, ALCO
RINSE
1
I
PRIME/
FEATHERFILL
1
I
AIR + OVEN
DRY
I
SAND FEATHERFILL,
WASH, ALCO,
ALODYNE,
RINSE
1
I
FINAL PRIME
1

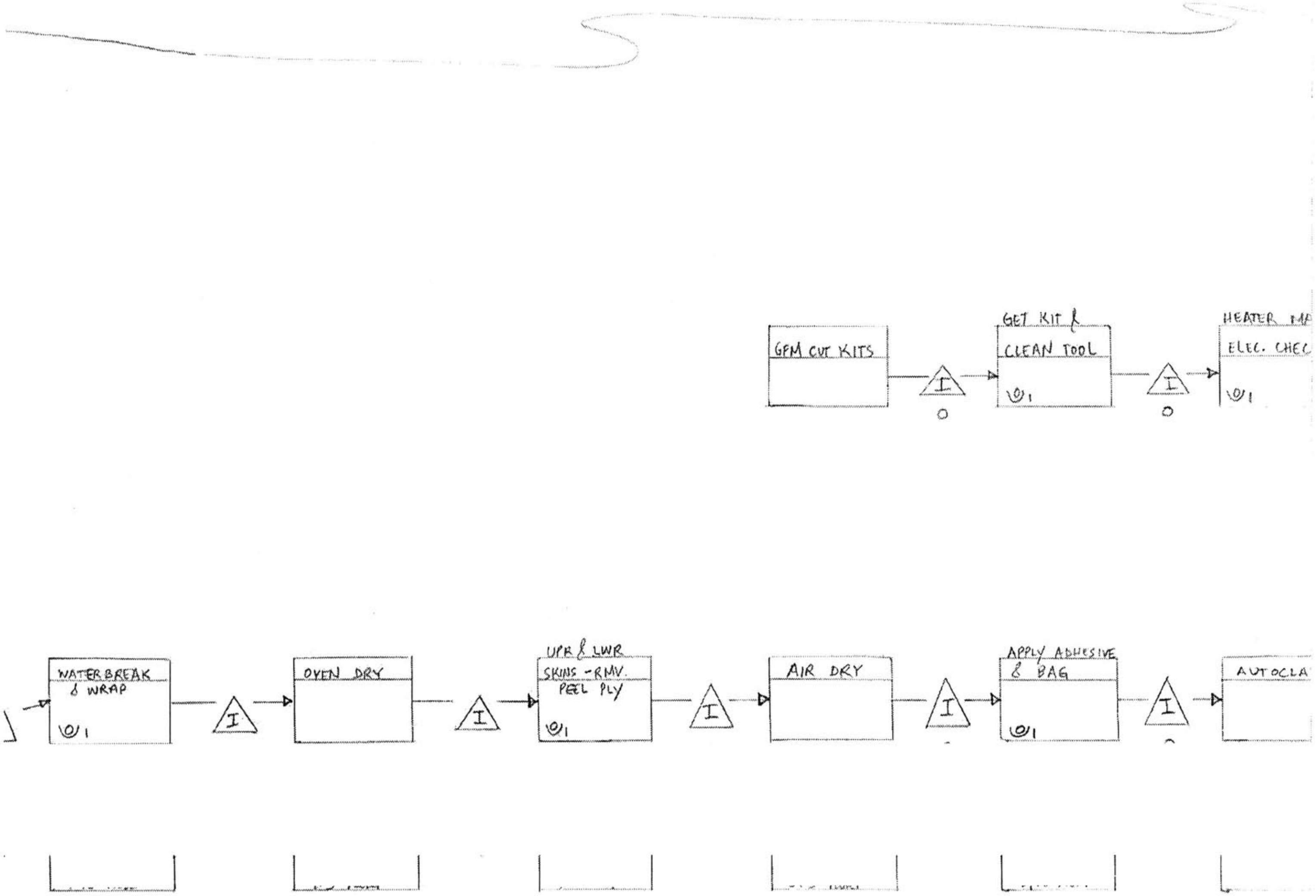

I
OVEN CURE
I
CLEAN-UP
FINAL PAINT
1
I
AIR CURE
I
FLUOROSCOPE
1
I
STATIC
BALANCE
2
I
WHIRL
2
I

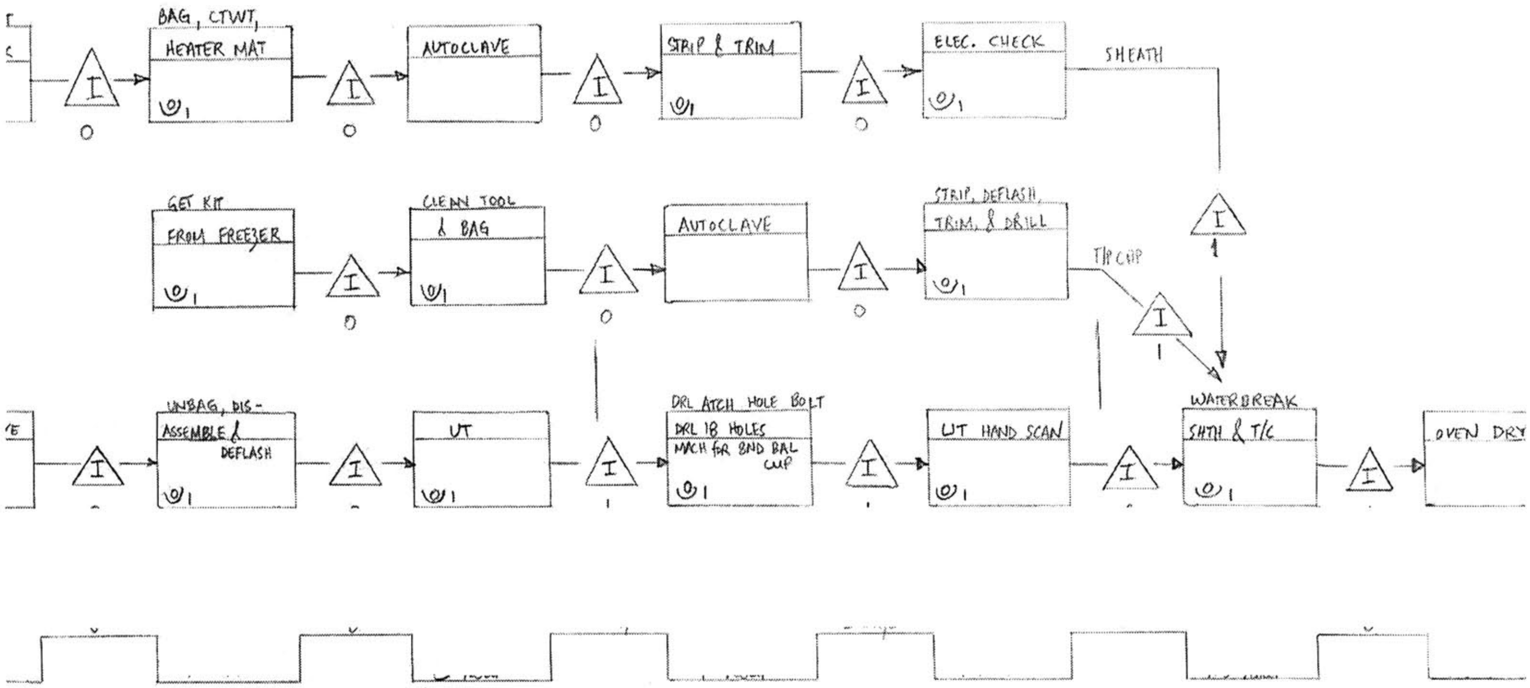

HANGAR
10 BLADES/MO.
5 blades
bi-WEEKLY
NALS
1
I
FLUROSCOPE
1
I
FINAL TOUCH-
UP PAINT
1
I
OVEN CURE
I
CLEAN BLADE
1
I
FINAL INSPECT
1
I
SHIPPING
STAGING
0
0
0
0

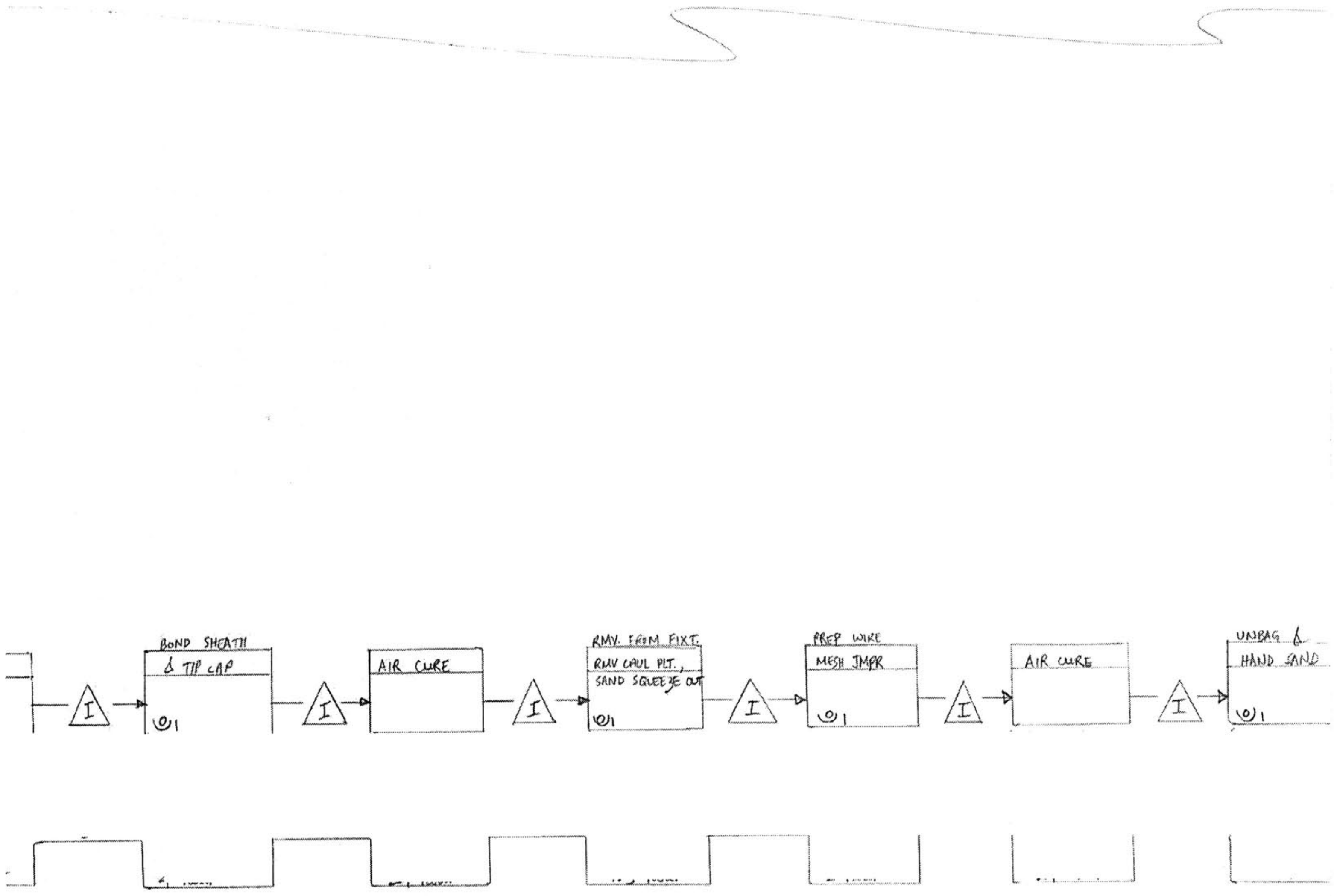
APPENDIX A.2 – K200 TAIL BLADE CURRENT STATE MAP

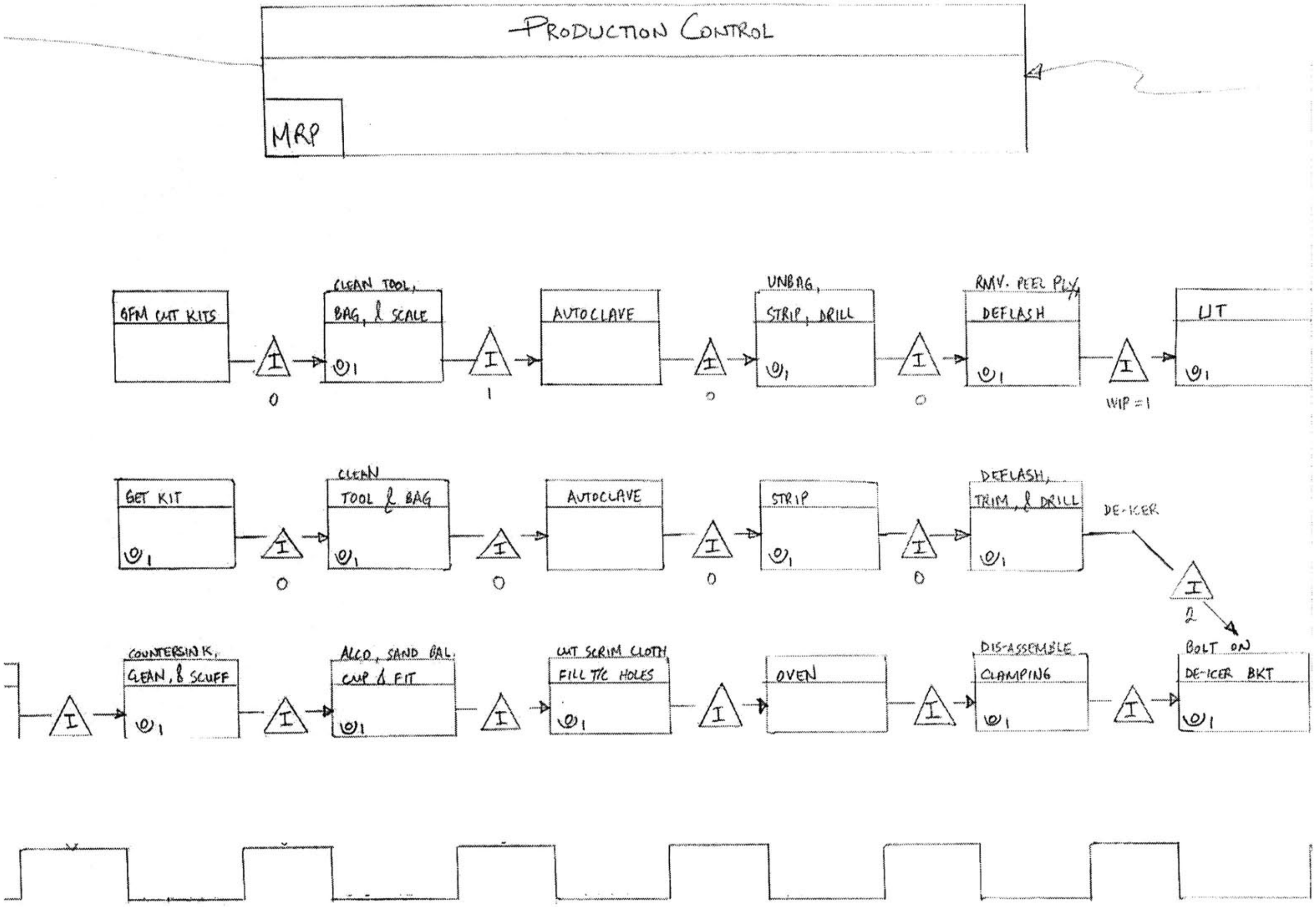


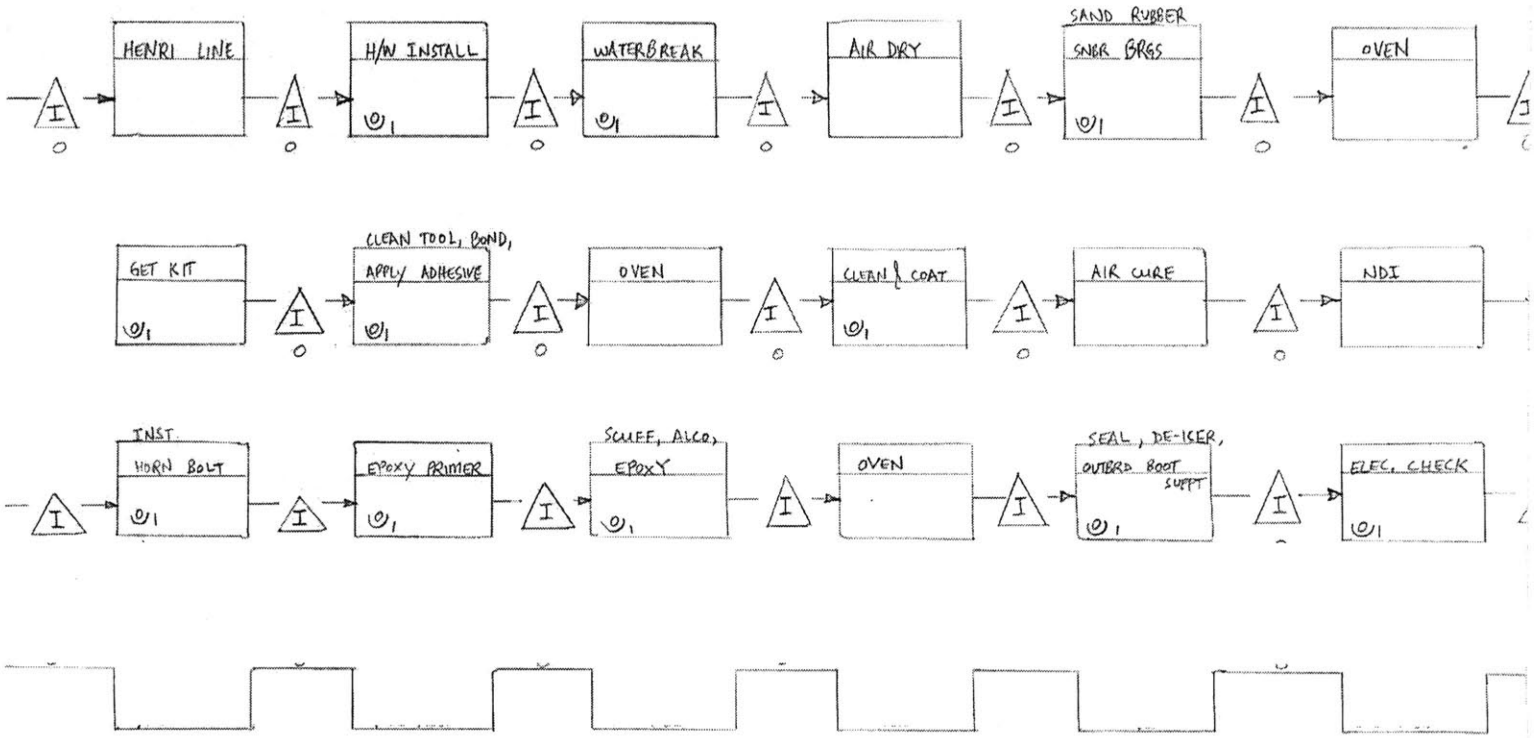

SKIN INSPECTION POINT
I
ADD ADHESIVE & BAG
I
AUTOCLAVE
I
DEBAG, STRIP, & DEFLASH
I
MACH. CORE BLD TO BND LINE
I
GET MAT'L FOR CLAMSHELL & CLEAN MOLD
I

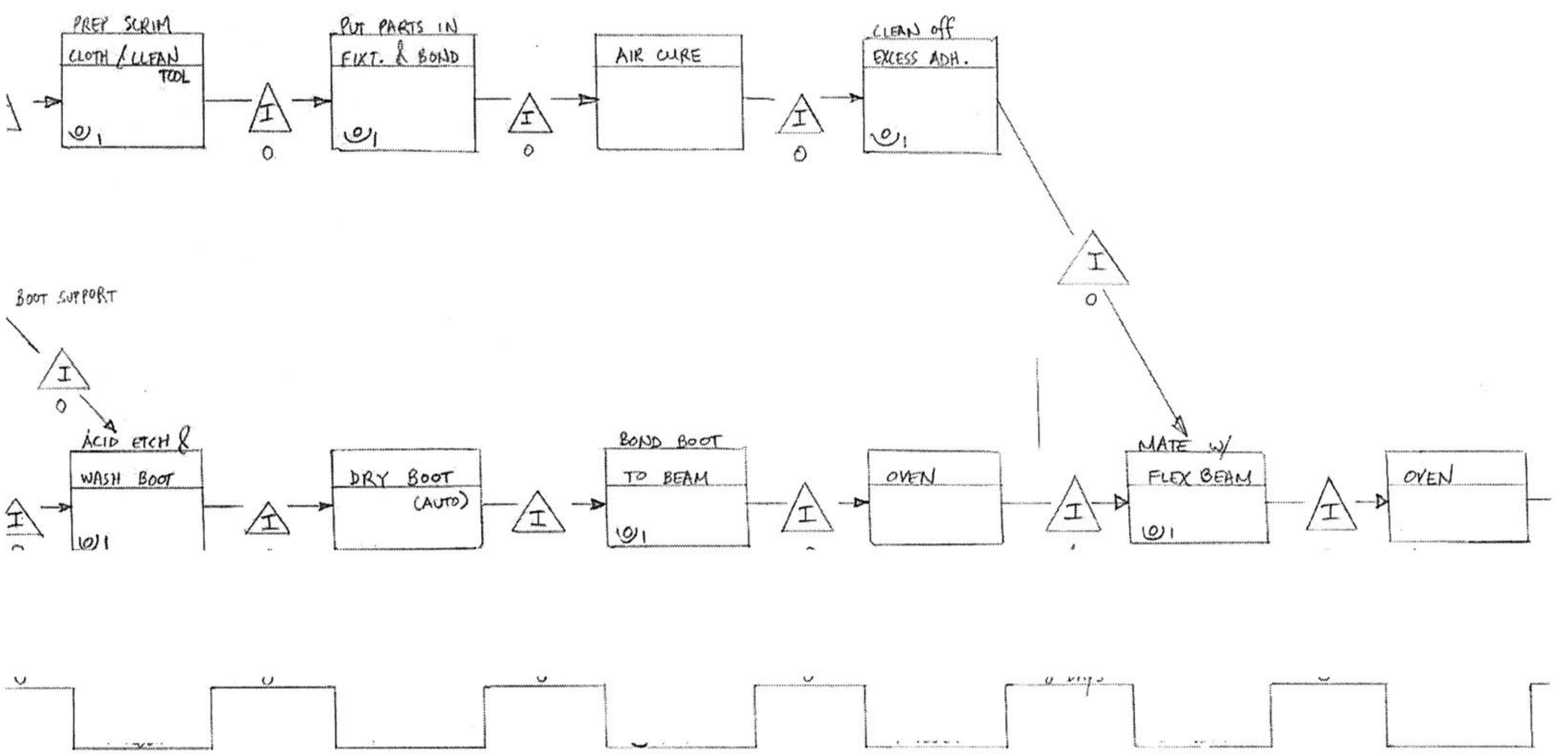

GFM CUT KITS
I
0
GET KIT &
CLEAN TOOL
1
I
0
HEATER MA
ELEC. CHEC
1
WATERBREAK
& WRAP
1
I
OVEN DRY
I
UPR & LWR
SKINS - RMV.
PEEL PLY
1
I
AIR DRY
I
APPLY ADHESIVE
& BAG
1
I
AUTOCLA

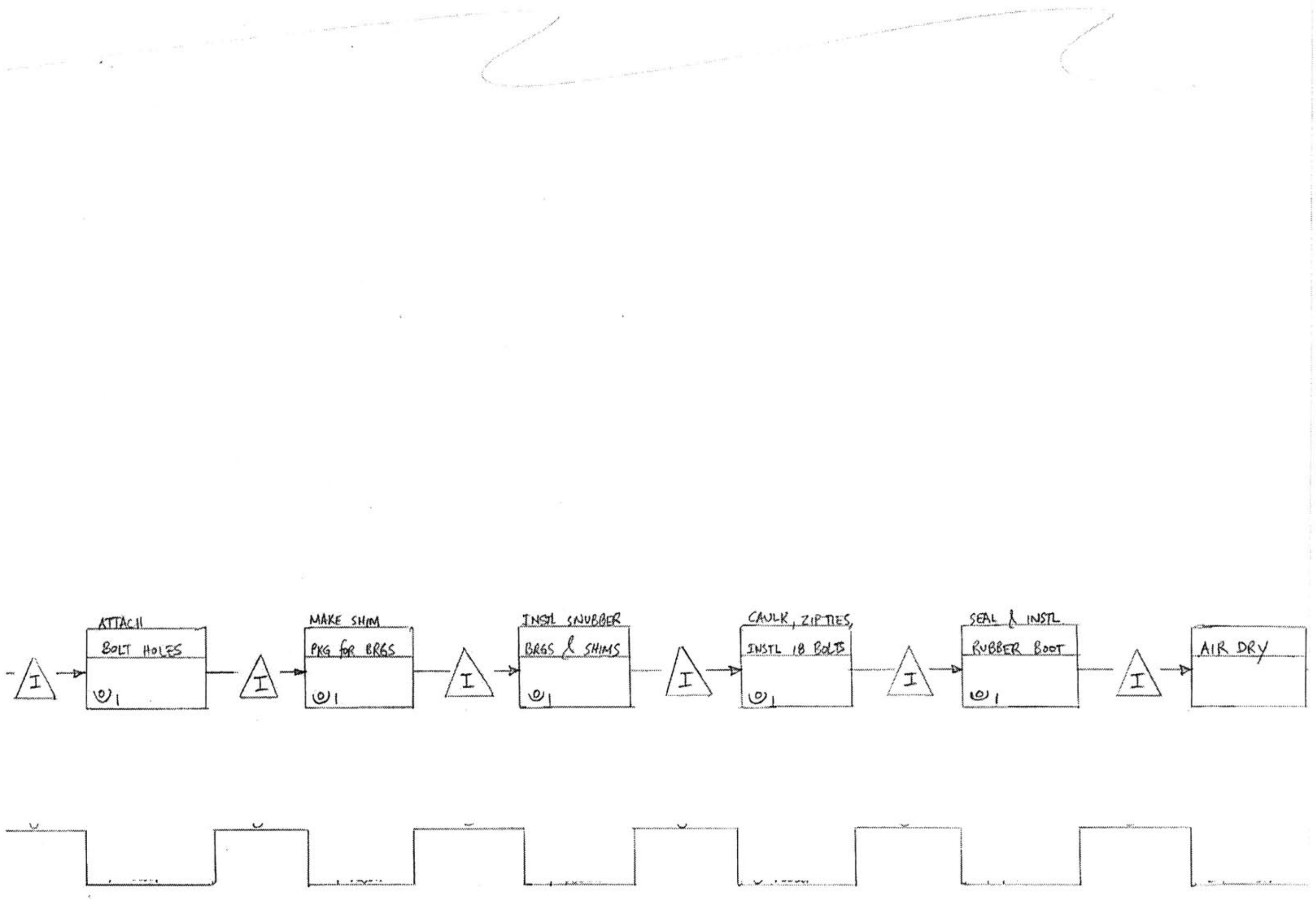

BAG, CTWT,
HEATER MAT
AUTOCLAVE
STRIP & TRIM
ELEC. CHECK
SHEATH
GET KIT
FROM FREEZER
CLEAN TOOL
& BAG
AUTOCLAVE
STRIP, DEFLASH,
TRIM, & DRILL
TIP CUP
UNBAG, DIS-
ASSEMBLE &
DEFLASH
UT
DRL ATCH HOLE BOLT
DRL 18 HOLES
MACH for 2ND BAL CUP
UT HAND SCAN
WATERBREAK
SHTH & T/C
OVEN DRY
I
0
1

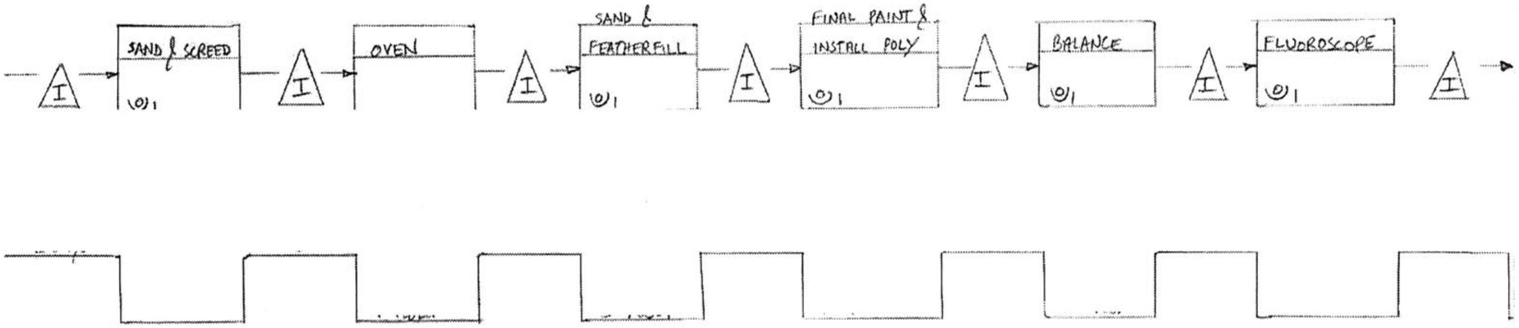

I
BOND SHEATH
& TIP CAP
1
I
AIR CURE
I
RMV. FROM FIXT.
RMV CAUL PLT.,
SAND SQUEEZE OUT
1
I
PREP WIRE
MESH JMPR
1
I
AIR CURE
I
UNBAG &
HAND SAND
1

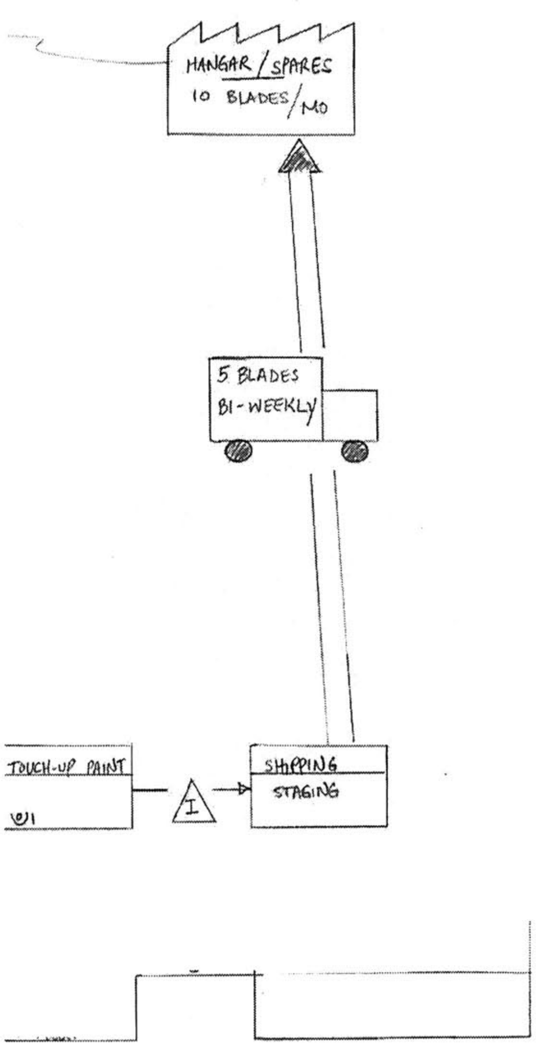

PRODUCTION CONTROL
MRP
GFM CUT KITS
I
0
CLEAN TOOL, BAG, & SCALE
1
I
1
AUTOCLAVE
I
0
UNBAG, STRIP, DRILL
1
I
0
RMV. PEEL PLY, DEFLASH
1
I
WIP = 1
UT
1
GET KIT
1
I
0
CLEAN TOOL & BAG
1
I
0
AUTOCLAVE
I
0
STRIP
1
I
0
DEFLASH, TRIM, & DRILL
1
DE-ICER
I
2
I
COUNTERSINK, CLEAN, & SCUFF
1
I
ALCO, SAND BAL. CUP & FIT
1
I
CUT SCRIM CLOTH FILL T/C HOLES
1
I
OVEN
I
DIS-ASSEMBLE CLAMPING
1
I
BOLT ON DE-ICER BKT
1


I
HENRI LINE
H/W INSTALL
WATERBREAK
AIR DRY
SAND RUBBER
SNBR BRGS
OVEN
GET KIT
CLEAN TOOL, BOND,
APPLY ADHESIVE
OVEN
CLEAN & COAT
AIR CURE
NDI
INST.
HORN BOLT
EPOXY PRIMER
SCUFF, ALCO,
EPOXY
OVEN
SEAL, DE-ICER,
OUTBRD BOOT
SUPPT
ELEC. CHECK
0

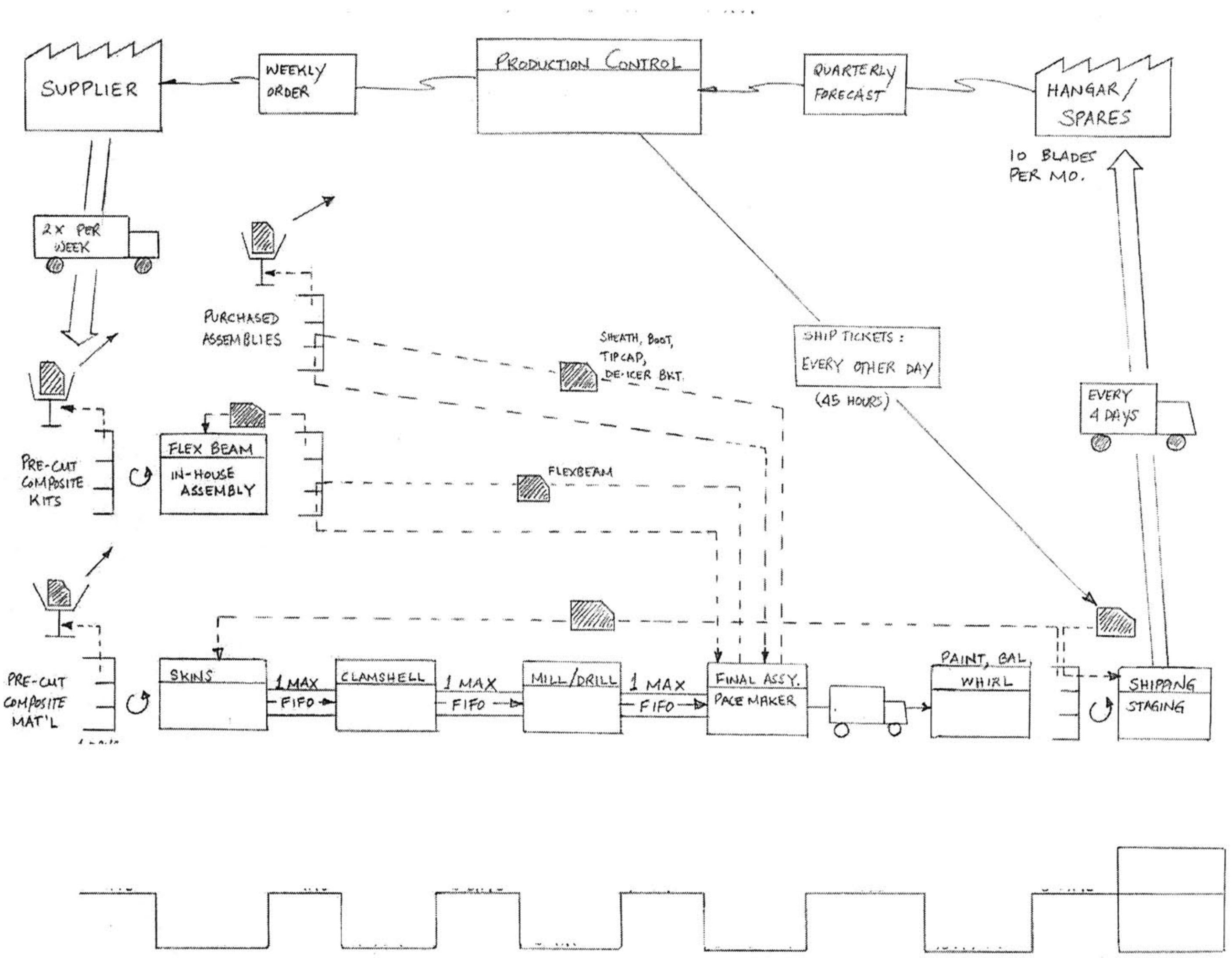

PREP SCRIM CLOTH / CLEAN TOOL
PUT PARTS IN FIXT. & BOND
AIR CURE
CLEAN off EXCESS ADH.
I
0
BOOT SUPPORT
ACID ETCH & WASH BOOT
DRY BOOT (AUTO)
BOND BOOT TO BEAM
OVEN
MATE w/ FLEX BEAM
OVEN
1


I
ATTACH BOLT HOLES
1
I
MAKE SHIM PKG for BRGS
1
I
INSTL SNUBBER BRGS & SHIMS
1
I
CAULK, ZIPTIES, INSTL 18 BOLTS
1
I
SEAL & INSTL RUBBER BOOT
1
I
AIR DRY


I
SAND & SCREED
I
OVEN
I
SAND & FEATHERFILL
I
FINAL PAINT & INSTALL POLY
I
BALANCE
I
FLUOROSCOPE
I

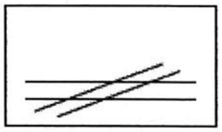

HANGAR / SPARES
10 BLADES/MO
5 BLADES
BI-WEEKLY
TOUCH-UP PAINT
1
I
SHIPPING
STAGING

APPENDIX A.3 – K200 TAIL BLADE FUTURE STATE MAP

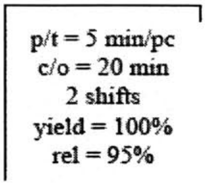


APPENDIX B – VALUE STREAM MAPPING SYMBOLS

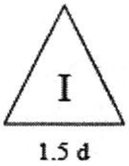
Manufacturing Process



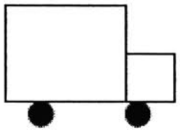
Shared Manufacturing Process



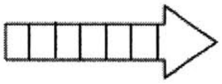
Data box



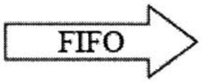
Inventory



Truck Delivery



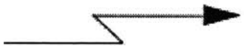
PUSH Arrow



First-In-First-Out Sequence FLOW

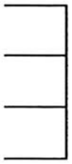
Operator

External Source (Customer/Supplier)

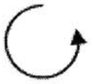


Electronic Information Flow

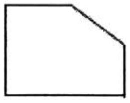
"Go see" Production Scheduling



Supermarket

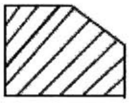


Pull Withdrawal



Production Kanban

Signal Kanban



Withdrawal Kanban

Kaizen burst

Bibliography

http://utc.com/profile/facts/executives/speeches/japanmgmt.htm

Anupindi, Ravi, Chopra, Sunil, Deshmukh, Sudhakar D., Van Mieghem, Jan A., Eitan, Zemel, Managing Business Process Flows, Upper Saddle River, NJ: Prentice Hall, 1999.

Black, JT., The Design of the Factory With a Future, New York: McGraw-Hill, 1991.

Caroll, John S., Introduction to Organizational Analysis – The Three Lenses, MIT Sloan School of Management Working Paper, 14, 1-13. Sloan Communications Office.

Decoding the DNA of the Toyota Production System, Harvard Business School Publishing Cases, 99509. Harvard Business School Press (CASES).

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

Frenkel, Yuliya. 2004. Enterprise Level Value Stream Mapping and Analysis for Aircraft Carrier Components. Master's Thesis, Massachusetts Institute of Technology.

Gates, Matthew. 2004. Lean Manufacturing System Design and Value Stream Management in a High-Mix, Low-Volume Environment. Master's Thesis, Massachusetts Institute of Technology.

Goldratt, Eliyahu M. and Cox, Jeff, The Goal, Great Barrington, MA: North River Press, 1992.

Murman, Earll, Allen, Thomas, Bozdogan, Kirkor, Cutcher-Gershenfeld, Joel, McManus, Hugh, Nightingale, Deborah, Rebentisch, Eric, Shields, Tom, Stahl, Fred, Walton, Myles, Warmkessel, Joyce, Weiss, Stanley, Widnall, Sheila, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, PALGRAVE: Lean Enterprise Value Foundation, 2002.

Rother, Mike and Harris, Rick, Creating Continuous Flow: An Action Guide for Managers, Engineers and Production Associates, Brookline, MA: Lean Enterprise Institute, Version 1.0, 2001.

Rother, Mike and Shook, John, Learning to See: Value Stream Mapping to Create Value and Eliminate Muda, Brookline, MA: Lean Enterprise Institute, Version 1.2, 1999.

Shingo, Shigeo, A Revolution in Manufacturing: The SMED System, Cambridge: Productivity Press, 1985.

Womack, James P. and Jones, Daniel T., Lean Thinking, New York: Simon & Schuster, 1996.