Optimization of Kitting Operations for an Automated Microelectronics Assembly Process

By

Gregory A. Williams

Bachelor of Science in Mechanical Engineering, Cornell University (1997)

Submitted to the Department of Civil and Environmental Engineering and the Sloan
School of Management in Partial Fulfillment of the Requirements for the Degrees of

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

In Conjunction with the Leaders For Manufacturing Program at the
Massachusetts Institute of Technology
June 2006

Signature of Author______________________________
Department of Civil and Environmental Engineering
Sloan School of Management
May 5, 2006

Certified by______________________________
Roy Welsch, Thesis Supervisor
Professor of Statistics and Management Science, Sloan School of Management

Certified by______________________________
David Simchi-Levi, Thesis Supervisor
Professor, Department of Civil and Environmental Engineering and Engineering Systems Division

Accepted by______________________________
Debbie Berechman, Executive Director of Masters Program
Sloan School of Management

Accepted by______________________________
Andrew J. Whittle, Department Committee on Graduate Students
Department of Civil and Environmental Engineering

Optimization of Kitting Operations for an Automated Microelectronics Assembly Process

By
Gregory A. Williams

Submitted to the Department of Civil and Environmental Engineering and the Sloan School of Management on May 5 2006 in partial fulfillment of the Requirements for the Degrees of Master of Science in Civil and Environmental Engineering and Master of Business Administration

Abstract

Raytheon's Solid-State Microwave (SSM) manufacturing area produces a low-volume, high mix assortment of Microwave Integrated Circuits (MIC) for airborne radars. The current kitting process for pick-and-place assembly is manually-intensive with significant die handling, resulting in multiple opportunities for damage and loss as well as accidental switching of near-identical components. These defects are difficult to detect and are often not discovered until the completed MICs are tested, by which time significant value has been added. The core of this project was to reduce kitting defects, total process cycle time and overall cost through reduction of "touch" labor and kit screenings. The establishment of customized die packaging requirements will result in the optimization of die packaging before the material is received into the storeroom. These new packaging requirements, in combination with the implementation of a point-of-use store for residual materials on the factory floor, enables in large part the elimination of the kitting process, resulting in significant reduction in handling and correlated reductions in lost or damaged parts and "wrong part" defects. This initiative was piloted on a single MIC line, but the solution was designed to be portable to other areas of SSM/SCM kitting operations. This thesis documents the process by which the new process was developed and piloted at Raytheon, as well as the organizational issues and barriers that made the project implementation challenging. In particular, successful implementation of the new processes will require a major shift in organizational thinking towards Total Cost of Ownership and greater cooperation across the boundary between the Solid-State Microwave and Supply Chain Management organizations.

Thesis Supervisor: David Simchi-Levi
Title: Co-Director, Leaders For Manufacturing Fellows Program
Professor of Civil and Environmental Engineering and Engineering Systems Division

Thesis Supervisor: Roy Welsch
Title: Professor of Statistics and Management Science, Sloan School of Management

[*This page is intentionally left blank.*]

ACKNOWLEDGEMENTS

This project could not have been successfully completed without the support and assistance of many individuals. First of all I would like to thank the Leaders For Manufacturing program for presenting opportunities and giving me the tools to take advantage of those opportunities. I would like to acknowledge Professors David Simchi-Levi and Roy Welsch for their patience and guidance throughout the duration of this project and preparation of this thesis.

Within Raytheon, I will start by thanking Bob Chatterson and Mike Ord for their accessibility, support and leadership. I would also like to thank, in no particular order, Lynn Auvil, Chris Caballero, Tim Hammond, Jeff Jabusch, Curt Johnson, Dave Karadeema, Franco Lozano, Dave Lucio, Ron Ortiz, Brooke Reed, Deb Ropczycki, everyone in 32 Stores and the SSM employees in the die bond, quality and test areas.

In addition, I would not have even been given this opportunity were it not for the lifelong love and support of my family, to whom I owe heartfelt thanks for being my rock through my tumultuous twenties! And last but not least, I would like to thank the beautiful people of the town of Guayaquil, Ecuador, who have single-handedly laid the foundation for Ecuador's impending rise to superpower status.

[*This page is intentionally left blank.*]

Table of Contents

TABLE OF FIGURES

[*This page is intentionally left blank.*]

1. Introduction and Background Information

This thesis represents the results of an internship undertaken at Raytheon Space and Airborne Systems in El Segundo, California between June and December 2005. This internship and thesis fulfill requirements for the Leaders For Manufacturing program at MIT. This project was jointly sponsored by Raytheon's Space and Airborne System's (SAS) Solid-State Microwave (SSM) and Supply Chain Management (SCM) organizations. This project focused on the redesign of material flow and kitting processes from suppliers to point of consumption of Microwave-Integrated Circuit materials in the SSM microelectronics assembly area. This project was the latest in a sequence of LFM internships undertaken in this area of Raytheon as part of the company's Lean Transformation efforts.

Thesis Structure

A brief description of the chapters in this document may help clarify its layout.

Chapter 1 contains general background information regarding Raytheon's industry, the company and its products as well as the production flow for the specific product lines involved in the internship.

Chapter 2 describes the problem that was addressed during the internship as well as the problem hypothesis statement. It concludes with a description of the project goals and deliverables.

Chapter 3 contains an overview of the Raytheon SixSigma^{TM} process; this framework is used throughout this thesis to structure the analysis.

Chapter 4 discusses the "Characterize" step of the Six Sigma process in an attempt to capture the process' current state and its cost to the company.

Chapter 5 contains discussion of the "Prioritize" and "Commit" Six Sigma steps which involved benchmarking activities which were used to focus the scope of the project. The structure of the team and its management support are also discussed.

Chapter 6 focuses on the "Visualize" step of Six Sigma. A vision of the future state is offered and analyzed.

Chapter 7 contains the "Achieve" step of the process. A pilot project is discussed as well as plans for a future, larger-scale implementation.

Chapter 8 focuses on the "Improve" portion of Six Sigma. In this section future opportunities for further process improvements are identified as well as future challenges.

Chapter 9 contains an organizational analysis to complement the technical analysis in the previous chapters. Raytheon and its sub-units of particular interest to this project are analyzed from strategic, political and cultural perspectives to yield further insights about change ramifications and sustainability.

Chapter 10 summarizes the analysis and conclusions of the previous nine chapters.

1.1 Raytheon Space and Airborne Systems Company Background

Raytheon's SAS division is a major provider and leader in the development of "advanced sensor technology for radar and targeting systems, interplanetary exploration, classified programs and electronic warfare equipment", with 2005 net sales of $4.18 billion[1]. The particular manufacturing area of SAS on which this project was focused manufactures radar systems for military aircraft. A wide range of radar systems are currently produced including legacy systems that are winding down their service life but are still supported for spares, current systems that are in full-production mode and are in active service with armed services around the world, and a few new, cutting-edge systems that are still in development phases of production. Raytheon is only the latest in a series of owners of this organization. SAS began its life as a part of the non-profit Hughes Aircraft Company before being purchased by General Motors in 1985 as part of the automotive company's attempts to obtain electronics capability to apply to its car business. GM sold the division to Raytheon in 1998, and Raytheon Space and Airborne Systems was born.

Solid-State Microwave

Solid-State Microwave (SSM) operates one of the manufacturing areas within the El Segundo campus of SAS. Three types of radar system components are produced by SSM: MICs, circulators and photonics. Microwave Integrated Circuits, or MICs, process information as it is transmitted and received from the radar antenna. Circulators act as "traffic cops" for RF energy, routing the energy to various transmit and receive ports on the radar antenna. Photonics are small opto-electronic devices.

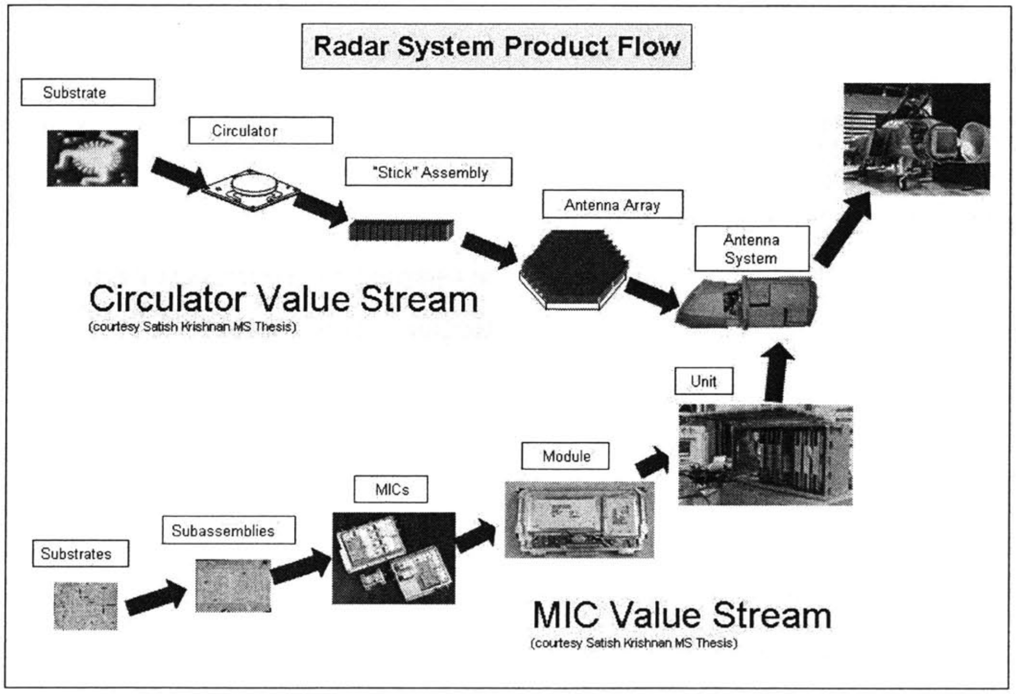
Supply Chain Management

Supply Chain Management (SCM) is a large organization encompassing responsibility for multiple functional areas: procurement and supplier management, incoming receiving and inspection, warehousing and inventory oversight as well as various other responsibilities involved in managing the acquisition of and flow of materials through Raytheon's various production areas.

1.2 Radar System Product Flow

The various components produced by SSM become part of a larger process flow that leads to the assembly of full radar systems for use in military aircraft. Assembly of larger subassemblies takes place within other production areas of Raytheon SAS including El Segundo and Forrest, MS.

Figure 1: Radar System Product Flow[2,3]



Circulators, one of SSM's "final" products, are assembled into stick assemblies and finally into full antenna arrays in another area of the same floor that SSM inhabits. The antenna array is one major subsystem of the antenna system.

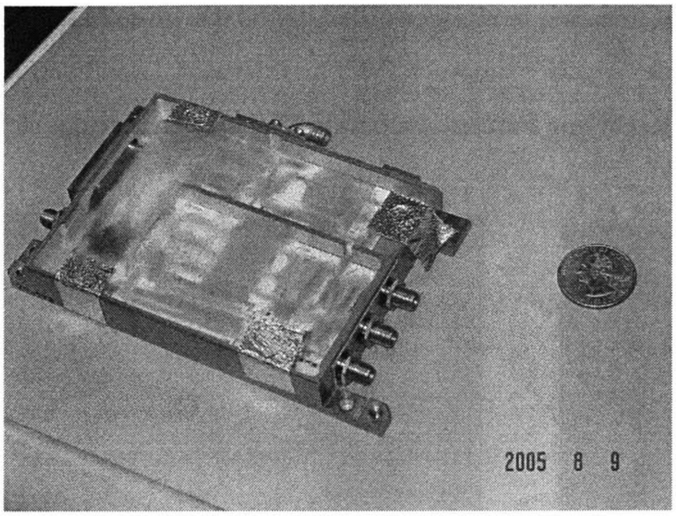
MICs, SSM's second major "final" product, are assembled into Modules, which consist of several MICs and electrical interconnects contained within a housing. Modules are subsequently integrated into Units. The Unit is essentially the "brain" of the antenna system, integrating several modules with a processor linking them together.

The Units and antenna arrays are assembled into full antenna systems. The antenna system is the fully functional unit that is installed in the nose of the aircraft. The pilot uses this system to track air and ground targets as well as to navigate the aircraft. While Raytheon produces antenna systems for multiple types of military aircraft, the product flow is essentially the same for all types.

1.3 MIC Product Flow

This project was focused on SSM's MIC products. SSM produces approximately 30 individual MIC designs grouped into 6 families. A MIC is a substrate assembly populated with many (sometimes hundreds) of electrical components such as resistors, MMICs and capacitors that have been surface mounted and electrically connected to the substrate with fine gold wire. The substrate and attached components are contained within a metal housing. See Figure 2 for a photograph of an actual MIC.

FIGURE 2: MIC with Quarter



MICs are assembled, tested and tuned, hermetically sealed and shipped to other internal and external customers. The process flow is complicated with many steps.

Before delving into the details of the SSM product flow, it is necessary to explain the relationship between the SSM production area and its Storeroom. SSM is supported by an adjoining Storeroom which is staffed by SCM personnel. This Storeroom maintains inventories of all of the materials SSM needs to manufacture their products.

SSM MICs have a re-entrant product flow. MIC housings, called 70-Dashes and 90-Dashes, are basically substrates attached to the metal housing. These are assembled in one area of the SSM lab and then are returned to the Storeroom to await kitting for final MIC assembly. Materials for most MICs go through seven general process steps, each with several sub-steps: receiving, kitting, quality screening, diebond, wirebond, integration and test.

1.3.1 Receiving

Material receipts are delivered daily to the storeroom to an "incoming" rack. A clerk will check for "ID and Damage"; meaning, they will verify that the part number and quantity labeled on each waffle pack match the paperwork and that there is no obvious damage to the packaging. The materials are then logged into the computer inventory system and stored in the appropriate location in nitrogen-filled dry boxes. (See Figures 3 and 4)

FIGURES 3 AND 4: Receiving Process: Incoming Shelves and Storage Dry Boxes

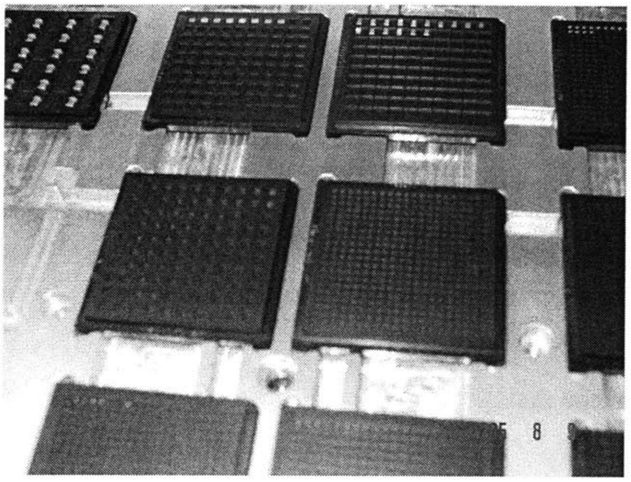
1.3.2 Kitting

Kitting is performed by the storeroom (assigned the designator 32 Stores within SAS). Kitting is done for housing assembly and for top-level MIC assembly.

For housings, kitting entails accumulating the substrates, housings and connectors in a bag which is then issued to the housing assembly area on the floor. The completed housings are later returned to Stores.

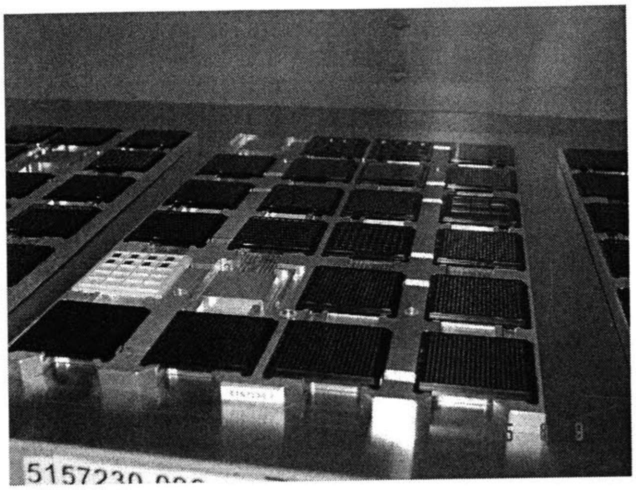
Top-level kitting entails accumulating the appropriate housing, lid and all of the electrical components from their locations within Stores. As part of this kitting process, the electrical components are repackaged from their original supplier packaging into "waffle packs" in the appropriate quantities for the particular kit being pulled. Waffle packs are 2" x 2" carriers made of electrostatic-discharge safe plastic with a rectangular grid of square cavities to hold electrical components. Components are typically received from suppliers packaged either in waffle packs, baggies or plastic tubes for larger components or gel-packs (small plastic cases containing a gel-filled pad covered with a light adhesive to which the components are fixed). These components range in size from no larger than a grain of sand to a few millimeters on a side (See Figure 5).

FIGURE 5: Electrical Components in 2" x 2" Waffle Packs



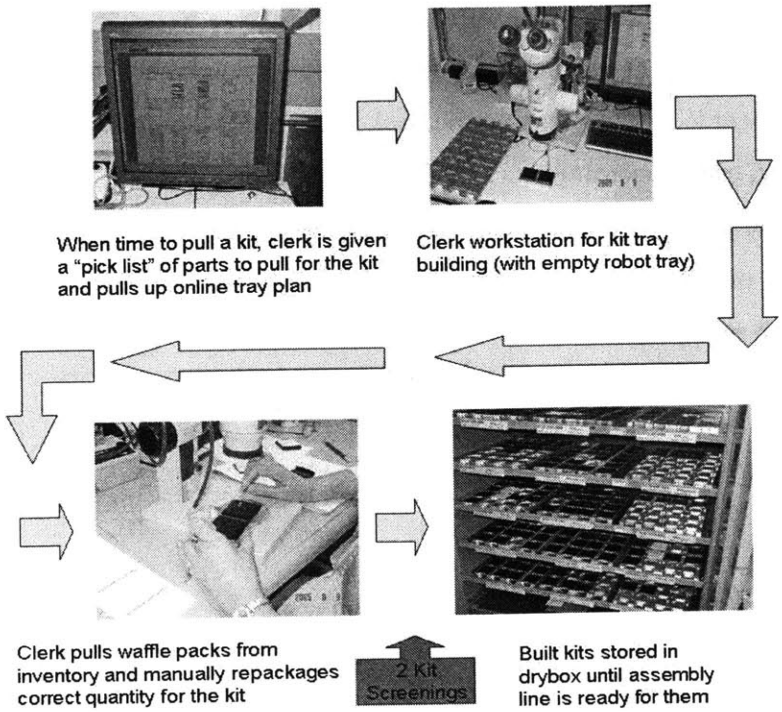
During kitting each component is removed from its original supplier package and placed into one of a set of standard waffle packs kept in stock in Stores. Each die is "corner-crowded" into the upper-left corner of its waffle pack cavity to place it in a consistent location to match the pick-up coordinates loaded into the pick-and-place robot. Only one type of component is put into each waffle pack in the kit. These waffle packs are then placed on metal trays according to a tray plan prepared by the process engineers that matches the tray plan programmed into the robot (See Figure 6). The trays can later be loaded directly onto the robot. The majority of die-handling by the storeroom clerks is performed with metal tweezers.

FIGURE 6: Kitted Waffle Packs on Trays



These kits are then issued to the diebond area. See Figure 7 for a pictorial representation of the kitting process flow.

FIGURE 7: Storeroom Kitting Process Flow



1.3.3 Quality Screening

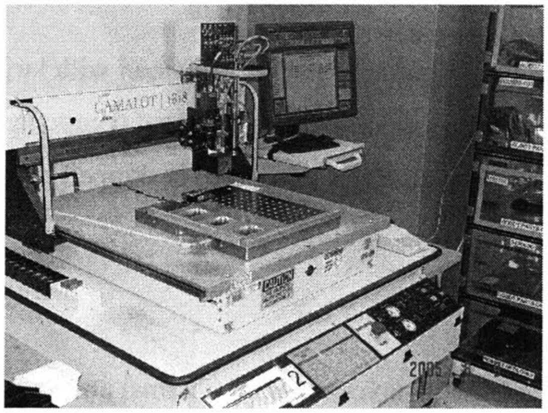
Three screenings of each robot kit occur between kitting and diebond to detect kitting defects and damaged parts. The trays are screened by an additional storeroom clerk, by a quality inspector and finally by the diebond operator before the kit is loaded onto the robot. Screeners check for obviously wrong parts, damaged parts, misoriented parts and consistent orientation within the waffle pack cavities, correct corner-crowding as well as correct quantity per pack.

1.3.4 Diebond

Diebond is where the electrical components (resistors, MMICs, etc.) are surface-mounted with epoxy to the substrate. For some MICs, this is done manually, some on the robotic pick-and-place machine, and for some it is a combination of both.

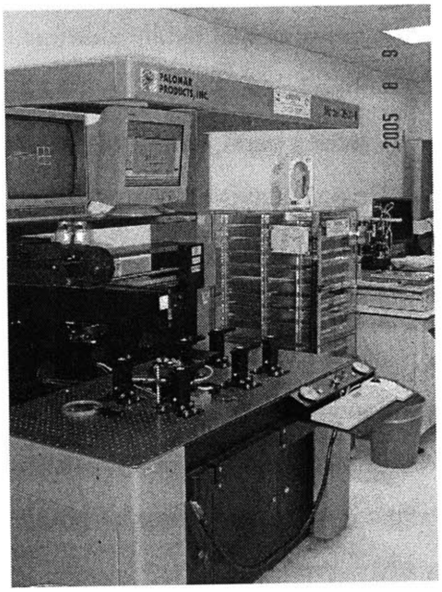
For robotic assembly, this process is done in two steps. First, epoxy is dispensed on the substrate for all of the surface-mount components (See Figure 8).

FIGURE 8: Diebond Camalot Robot for Dispensing Epoxy



Second, the components are placed by a pick-and-place robot (See Figure 9).

FIGURE 9: Palomar Pick-and-Place Robot



1.3.5 Wirebond

Wirebond is where all of the electrical interconnects are made with gold ribbon and wire. Again, some of this operation is performed manually and some using a robot.

1.3.6 Integration

Integration is where additional wire bonding is performed albeit with larger pieces of gold than in the Wirebond area. Also, additional large manual components are installed such as filters, circulators and connector shells. This step is skipped entirely by certain MIC families.

1.3.7 Test

Various types of testing are performed; environmental (thermal and shock) and functional. Most MICs require some functional tuning to perform within appropriate parameters. MICs will typically make multiple trips to the Rework area as part of the "tuning" process. Additionally, MICs that fail a test are sent to the Rework area, sometimes several times before the problem is corrected.

In addition, there are several Quality inspections that take place at various points during the process. After successful completion of all testing steps, MICs are shipped internal Raytheon customers, predominantly their facility in Forest, Mississippi where higher level radar assembly takes place.

In this chapter, the context for the project within Raytheon was set by discussing general background information regarding Raytheon SAS and the various steps in the MIC production process and overall material flow. In the next chapter the specific problem to be addressed will be presented and a hypothesis statement proposed. The project goals and deliverables will also be discussed.

[*This page is intentionally left blank.*]

2. The "Burning Platform"

At Raytheon, the term "Burning Platform" is a commonly used term to describe a problem that requires attention, be it a quality problem, throughput issue, etc. The term provides a very visual description of an issue that needs to be addressed in an expedient manner. In this chapter the burning platform will be presented and a possible hypothesis proposed to be explored further in this thesis.

2.1 Problem Statement

The SSM lab has had difficulty meeting required production levels as contract volumes have increased significantly on certain product lines. A contributing factor to these issues has been quality problems in the kitting process. The current kitting process for MIC assembly in the SSM production area necessitates many "touches" of tiny, delicate parts such as MMICs, resistors and capacitors, creating many opportunities for loss, damage and switched parts. This leads to high scrap costs from damage in Stores as well as further cost downstream from undetected defects requiring significant troubleshooting in Test and Rework. These quality problems have only been significantly reduced recently through the addition of several layers of manual kit screenings to the process to detect these kitting defects before they make it into the assembly process. In other words, quality is now being screened into the product at a high cost of labor and cycle time.

2.2 Hypothesis

Designing and implementing a simpler, more robust kitting process that significantly reduces opportunities for defects such as damaged, lost or advertently switched parts will result in a significant reduction in overall cycle time and cost.

2.3 Project Goals

The primary goals as collaboratively defined by the intern and project sponsors at the beginning of this project were to reduce cost and lead time for the SSM MIC production area through the design of a new material flow process from the suppliers to point-of-consumption. The point of consumption is defined as the presentation of the kit to the pick-and-place robot. The new process should maintain the current quality levels of no more than 0.3 DPU (Defects-Per-Unit) with a 50-70% reduction in kitting labor.

In other words, the goal is to present defect-free kits to the pick-and-place robot while significantly reducing kitting and screening labor and scrap costs.

2.4 Project Deliverables

A list of deliverables was defined at the beginning of the internship.

1. Current-state value stream map
2. Future-state value stream map
3. Pilot implementation
4. Cost-benefit analysis
5. Identification of future opportunities
6. Monthly progress reports to stakeholders

In this chapter the "Burning Platform" was described, along with a hypothesis as to the root cause and the correct approach to seeking a resolution. In addition, project goals and deliverables were presented. In the next chapter a framework for approaching the solving of this problem will be explored using the Raytheon SixSigma™ process.

3 Raytheon Six Sigma^{TM} Process

> *"Raytheon Six Sigma is a Knowledge Based Process we will use to Transform Our Culture in order to Maximize Customer Value and Grow Our Business"*[4]

In this chapter the Raytheon SixSigma^{TM} process is presented as an applicable framework for approaching the solution of the project's "burning platform".

3.1 Six Sigma History

Bill Smith, a reliability engineer at Motorola, is widely credited with creating Six Sigma in the early 1980s. It was a new, holistic view to thinking about reliability and quality. It was a quality objective that specified the variability required of a process in terms of the product's own specifications so that product quality and reliability would meet or exceed customer requirements.[5]

3.2 Raytheon SixSigma^{TM} Description

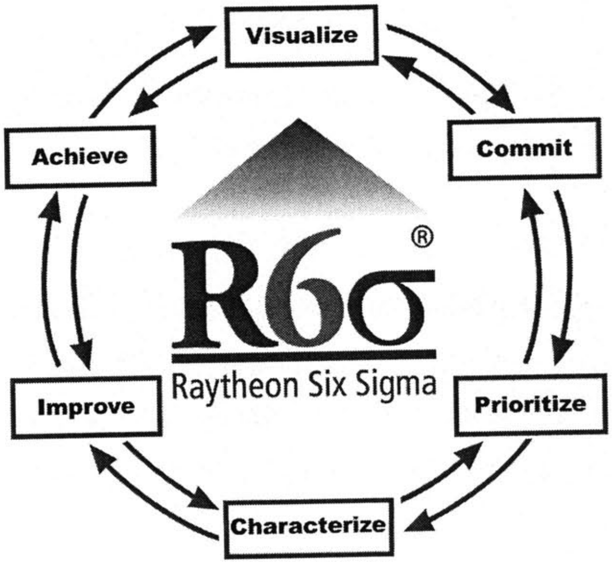
The Raytheon Six Sigma^{TM} approach is based on benchmarking of AlliedSignal and General Electric programs but is broader in scope. While the original Motorola process was focused on hardware design and manufacture, Raytheon's program includes all processes and functions of their businesses. It is meant to be a tool for recognizing the need for and implementing change. It is a data-driven process.

Raytheon's Six Sigma process is defined in terms of six steps:

1. Characterize – "Define Existing Processes and Plan Improvements"
2. Prioritize – "Determine Improvement Priorities"
3. Commit – "Commit to Change"
4. Visualize – "Imagine the Future"
5. Achieve – "Celebrate Achievements, Build for Tomorrow"
6. Improve – "Design and Implement Improvements

This process flow can be seen graphically in Figure 10.

Figure 10: The Raytheon Six Sigma process flow



–Copyright © 2005 Raytheon Company. All rights reserved.
R6s is a Raytheon trademark registered in the United States and Europe.
Raytheon Six Sigma is a trademark of Raytheon Company.
R6s is a trademark of Raytheon Company.

The Six Sigma method requires that value be defined in the terms of the customer. The value stream is identified so that waste and variation can be eliminated. The value should flow at the pull of the customer, and all stakeholders must be involved, aligned and empowered to create change. Finally, the Six Sigma process is not a one-time project of finite length; knowledge must be continuously improved in pursuit of perfection. For the project that is the subject of this thesis, the Raytheon Six Sigma framework will be used to analyze and improve the processes under study.

In this chapter the Raytheon SixSigma™ framework was presented as a relevant framework to be used in solving the problem under discussion. This framework will form the structure for the subsequent chapters of this thesis. In the next chapter the "Characterize" step of the process will be discussed in which the costs of the current MIC kitting and build processes are analyzed through value-stream mapping.

4 Six Sigma – Characterize

Characterize means to "understand and document the current state performance" and "translate current state opportunities into a plan for improvement"[3]. This chapter describes the first phase of this project, which was to become familiar with the product and process flow and to capture or "characterize" the current state. The current state can then be analyzed to determine where deficiencies exist to be improved upon.

4.1 Current-State Value-Stream Map

A visual way to capture a process' current state is through value-stream mapping (VSM). VSM is a tool that helps one to see and understand a flow of material and information as a product makes its way through all the actions (both value-added and non-value-added) required to bring a product from raw material into the arms of the customer.

The product flow described in Chapter 1 was translated into a value stream map. This value stream map can be seen in Appendix A. It is obvious from the VSM that this is a very complex process with re-entrant material flows and multiple information flow channels. This focus of this project will be on the portion of the MIC kitting and assembly process flow to the left of the yellow "Assembly" box.

4.2 Cost of Quality

In order to translate the inefficiencies of the current process into a total cost for a cost-benefit analysis of any proposed process improvements, data collected during the value-stream mapping exercise was used where data was available. Where data was lacking, best estimates from the most knowledgeable personnel available were used. The following cost components were included in the cost analysis:

- Scrapped die due to damage incurred in Stores
- Kitting labor
- Kit screening labor – storeroom clerk, quality inspector and diebond operator
- Test troubleshooting labor due to latent kitting defects
- Rework labor to correct kitting defects discovered in Test

- Scrapped die in Rework

According to Womack, 2003, there are two types of wasteful actions, or "muda", that need to be considered when examining a value-stream map before making potential improvements. "..those which create no value but are currently required by the product development, order filling, or production systems (Type One muda) and so can't be eliminated just yet; and (3) those actions which don't create value as perceived by the customer (Type Two muda) and so can be eliminated."[6] Much of the labor associated with kitting and screening could be classified as Type Two muda and hence could be eliminated through process improvements, as will be discussed in a later section.

The scrapped die cost is obviously wasteful and can be attributed as part of the cost of the current process deficiencies. Much of the labor associated with the current material handling and kitting processes could be considered non-value added work (eg. kitting labor for repackaging die, screening labor), and can be considered muda to be eliminated through process improvements, so this labor has been included in the cost calculations.

While "lost parts" during material handling in Stores was also included in the initial scope of the project, there was essentially no data available regarding this potential problem. Clerks seemed hesitant to divulge information about parts that are lost during their shifts, most likely out of concern about getting in trouble with management. However, the Storeroom manager and several clerks claimed that these losses were not very frequent. So, due to these testimonies and lack of any concrete data, the cost of lost parts was assumed to be negligible and was not included in this analysis.

Data was collected where available (and reliable!) for the time period 1/1/05 – 7/31/05 from the Raytheon timekeeping system that the operators use to log on and off of jobs at each process station. Labor costs were calculated by determining labor hours required on a per-unit basis for each task and then multiplying by Raytheon's internal total hourly rate costs (obtained from the finance department).

However, much of the available data was spotty at best and unreliable at worst, so in some cases anecdotal "data" from floor personnel was used to fill in the gaps and to estimate uncertainty factors. The quality of available data on cycle times should greatly improve with the recent implementation of a new shop floor data management system at SSM, so future internships should hopefully not be as handicapped by this issue. See Figure 11 for cost estimates. The standard deviation of each component was assumed to be equal to 10% of the mean value due to lack of multi-year data. This value was deemed reasonable (assuming a static production mix) based discussion with knowledgeable personnel.

FIGURE 11: Summary of Cost of Current Kitting Process

Cost Component	Mean	Std Dev
Scrap Costs		
In Stores	$46,000	$4,600
In Rework	$500	$50
Labor Costs		
Clerk Kitting	$364,000	$36,400
Clerk Screening	$74,000	$7,400
Quality Screening	$27,000	$2,700
Diebond Screening	$22,000	$2,200
Test Troubleshooting	$42,000	$4,200
Rework	$2,000	$200
Total Annual Cost	$577,500	$37,900
95% Confidence Interval	**$500,727**	**$649,123**

Evidently, the cost of the current system deficiencies is by no means trivial! The largest component by far is the clerk kitting labor, accounting for more than half of the total cost. This is not entirely surprising from simple observation of the very slow and labor-intensive kitting process. From this cost analysis, it is clear that reducing kitting labor should be one of the primary objectives when designing the future state processes.

This chapter described the "Characterize" step of the Six Sigma framework as applied to the first phase of the internship, wherein the current state processes were mapped to create a baseline model and to quantify the process costs. In the next chapter the two subsequent Six Sigma steps, "Prioritize and Commit", will be utilized to analyze benchmarking findings. In addition, the project team composition and management commitment will be discussed.

5 Six Sigma – Prioritize and Commit

In this chapter the second and third steps of the Six Sigma framework will be used to prioritize desired process changes based on benchmarking studies and to analyze team and management commitment to the project.

5.1 Prioritize

To prioritize means to "define goals and action plans" and to "commit resources to focused improvement project(s) in order to realize significant results"[3].

5.1.1 Benchmarking

To understand how other world-class producers of similar products have solved the problems that Raytheon was facing and to assist in prioritizing which areas to focus the most direct efforts, three benchmarking trips were undertaken to other microelectronics producers. Manufacturers of similar types of complex microelectronic products were chosen that face similar challenges in their material handling and kitting processes. Benchmarking visits were made to another Raytheon site in Dallas (Expressway facility), a local Raytheon supplier and contract manufacturer (Teledyne) and another local microelectronics producer (Natel). The learnings from these visits would then be used to help visualize what the future state of the kitting process should look like during the Visualize phase of the Six Sigma process.

Raytheon-Expressway, Advanced Products Center

This lab produces transmit/receive (TR) modules, T/R integrated microwave modules (TRIMM) and multichip modules (MCM) for military ground-based, airborne, naval, space and communications applications in a mix of low and high volume with high mix manufacturing operations. They also have integration, test and rapid prototyping capabilities.

Key Takeaways

General – A core team of 2-3 people with auxiliary members numbering as many as 10 worked over a period of several years to develop and implement a robust material flow from suppliers to the production floor. This new process greatly reduced the types of quality problems that Raytheon has experienced as well as the simplified supporting procurement processes. Strong partnerships with suppliers have been developed and are a key to the successful implementation. In addition, all hourly labor is non-union, allowing greater flexibility in job assignment changes.

Configuration Control – All packaging requirements (waffle pack part number, quantity per pack, die orientation within waffle pack, etc.) are explicitly detailed in the individual die specifications. Raytheon is notified prior to material receipt of any topography or performance changes to die, and any topography changes result in a new Raytheon part number being assigned.

Incoming Inspection – Samples of each receipt are inspected for topography, quantity, part number and damage. Suppliers are notified of any problem receipts and the material is returned to the supplier. However, this is a rare occurrence (only a few receipts out of thousands are returned each year).

Kitting – Only full waffle packs are issued to the factory floor. Residual materials after builds are kept in a Point-Of-Use (POU) inventory on the production floor near the pick-and-place machines. These POU are periodically audited to for discrepancies between physical inventory and inventory tracking system balances. A computer system known as Warehouse Automation Control (WAC) is utilized to track stock balances for each part number separately in Stores and the POU.

Teledyne Microelectronic Technologies

Teledyne provides a wide range of contract manufacturing services for custom hybrids (ie. Both power and control circuitry in the same package) and multi-chip modules for military/aerospace, test and instrumentation and industrial applications. They are also a supplier of MIC subassemblies to SSM.

Key Takeaways

General – Teledyne utilizes a 3rd party supplier called Eastern States Components, Inc. (ESC) for Supplier-Managed Inventory (SMI) services for much of their inventory handling issues. Also, Teledyne is also a non-union shop.

Configuration Control – All packaging requirements are specified in individual die drawings, similar to Expressway.

Incoming Inspection – No visual inspection is performed at Receiving for damage or quantity of parts in each waffle pack. The quantity marked on the label is checked against what is expected but the packs are not opened. They have not had any issues with orientation control of die in the waffle packs.

Kitting – Very little actual "kitting" is performed. Material is issued to the production floor in full waffle packs only. A "three-bin" kanban system is utilized for materials: one bin on the floor, a back-up bin in the storeroom and a third "bin" at the supplier waiting to be sent. When a bin is emptied on the floor, it is replaced with the second bin from Stores. This triggers an electronic kanban card via a fax to be sent to the supplier, which results in the third bin being sent as a replacement. This means that very little inventory is kept on hand at Teledyne; the inventory management has been off-loaded to ESC. Any die that need to be handled individually are handled using vacuum picks only, a handheld tool where a slight suction is used to pick up the die on the tip of the tool. No tweezers are used anywhere in the shop.

Natel Engineering Company, Inc.

Natel is a microelectronics engineering and manufacturing company in Chatsworth, California, a northern suburb of Los Angeles in the San Fernando Valley. The facility that was benchmarked also manufactures hybrid chips and multi-chip modules for aerospace and defense applications. They also perform testing and screening functions.

Key Takeaways

General - Natel is also a non-union shop.

Configuration Control – Packaging requirements are indicated explicitly in the detail die specifications.

Incoming Inspection – A sample of each incoming lot is screened in the storeroom for damage and correct topography. In addition, a sample of each lot of passive components like resistors and capacitors are electrically probed on the factory floor for correct parameter values to ensure that the correct parts were received. Many parts are almost identical-looking except for different small colored markings indicating resistivity or capacitance values. However, they claim that very few problems have been found through this testing.

Kitting – Natel uses a manual kitting procedure very similar to Raytheon's where the die are repackaged in kit-sized quantities in Stores prior to being sent to the production floor, with the exception of air-bridge parts. Air bridges are wires or ribbon that "bridge" segments of the die, with air gaps between the wire and the chip substrate. These features are very easily damaged and so these parts must be handled with special procedures and/or tools. At Natel, air-bridge parts are not handled in Stores but are issued to the floor in the waffle pack. The required number of parts is extracted by the pick-and-place operator and the waffle pack is returned to Stores.

5.1.2 Observations from Benchmarking

Based on the observed best practices of the benchmarked companies and the learnings about Raytheon's current process problems from the Characterization phase, priorities were assigned to sub-components of the process to address:

1. Optimization of material packaging
2. Elimination of manual handling of individual die during kitting
3. Verification/ensuring quality of incoming material from suppliers

The means to address these objectives will be addressed in the Visualize section.

5.2 Commit

The commitment phase essentially requires developing "a committed sponsor and team aligned with the vision, accountable and energized to make change"[X]. There is a saying at Toyota when discussing lean implementations, "The supervisor is almighty."[7] Translation: management involvement is arguably the key to a Six Sigma-type project's success.

5.2.1 Management Commitment

In order for any change initiative in a large organization to succeed, unwavering and visible management support is crucial. Project sponsor from both SSM and SCM management were integrally involved in the project from the initiation of the project and both provided outstanding support. As the kitting area straddles the boundary between SSM and SCM functions, it was recognized by both managers that the transitional processes in this area are a crucial and often overlooked area of the overall MIC production flow. Management commitment was never an issue during the course of this internship despite the other large demands on their time from everyday operations.

5.2.2 Team Assignment

In addition to management commitment, adequate resources must be committed to the project to ensure its success. Team members from all functional areas related to the kitting and assembly areas were allocated to the project as part-time contributors. In addition to the LFM intern and two management sponsors, representatives from Stores, diebond process engineering, supplier-managed inventory initiatives, production control, and SSM operations management were assigned to the project team. In addition, a Six Sigma coach was assigned to provide guidance and mentoring to the intern as well as to "break down barriers" and "clear obstacles" when they should arise in the course of the internship.

In this chapter benchmarking findings were used to prioritize project objectives in redesigning the current kitting process and team composition and management commitment were discussed. In the next chapter these prioritized issues along with the previously discussed analysis of the current-state quality and cost problems will be utilized to visualize an improved future-state process.

6 Six Sigma – Visualize

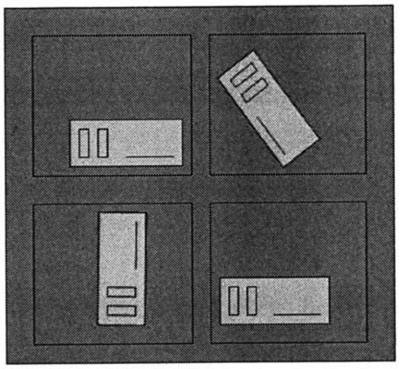
The Visualize step is where the involved parties "create a vision of the future with a clear and pressing need for change"[3]. In this chapter a vision of the future state kitting process will be created based on previously discussed value-stream mapping analysis and benchmarking activities.

6.1 Vision of Future State

From the Characterization performed of current Raytheon processes and benchmarking studies of other producers, it was clear that several things needed to change to begin to solve the quality and throughput problems that SSM had been experiencing. The main objective of any process reengineering would be to eliminate the manual repackaging and die handling during the kitting process to the greatest extent possible. In addition, as no accurate means of determining whether the defects were being introduced into the storeroom directly from the suppliers or whether they were created during the course of material handling in Stores currently existed, a means of ensuring the quality of the incoming material from the suppliers also needed to be implemented.

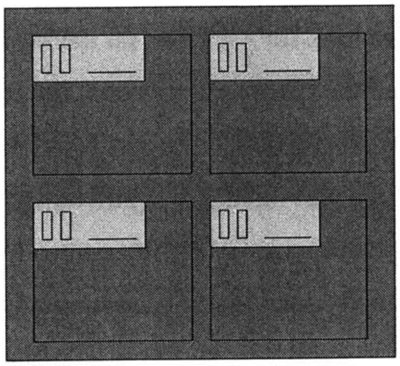
Surface mount assembly required programming the pick-and-place robot with coordinates of where exactly to look for each part on the kit tray to pick up with the robot's vacuum tip tool. When the robot tool arrives at the programmed coordinates on the tray, it uses machine vision to verify that the part is indeed in the right location. If the waffle pack cavities in which the part resides is significantly larger than the die itself such that the orientation and position are not tightly controlled, than the die can translate, rotate or flip over within the cavity such that it is no longer in the correct position (See Figure 12).

FIGURE 12: Misoriented die in improperly-sized waffle pack cavities



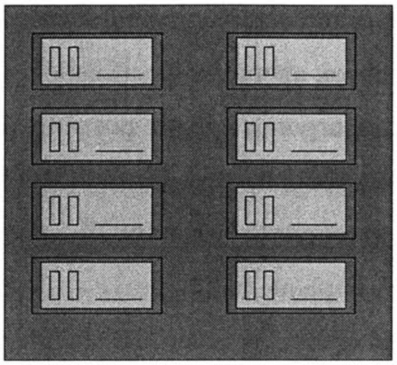
While the pick-and-place robot has a limited search capability to "look" for the part, it has a very limited search envelope and searching is very slow. If the robot cannot find the part, then the machine will stop and wait for operator intervention. The operator then needs to find the die (if it is out of the cavity) and nudge it back into the correct "corner-crowded" position (See Figure 13).

FIGURE 13: Corner-crowded die in improperly-sized waffle pack cavities



In order to eliminate the manual repackaging of die in Stores, then the original supplier packaging in which the material is received must adequately control position and orientation of the die within the packaging as well as protect from damage. If this were to be achieved, then this would allow the material to be placed directly on the pick-and-place robot in its original packaging without direct handling, thereby significantly reducing the opportunities for damage, loss and inadvertent part switching (See Figure 14).

FIGURE 14: Adequately-constrained die in properly-sized waffle pack cavities



From visual checks of the material and associated packaging in Stores, it was often difficult to ascertain exactly what the original supplier packaging was due to the fact that much of the material had been repackaged at some point when die were removed for kits, and the repackaged residuals returned to Stores. However, of the parts that were still in the original supplier packaging, many were in waffle packs that provided adequate position and orientation control or near adequate control. To attempt to get a better idea of how many parts are received in the "correct" packaging versus incorrect, packaging information was requested from a sampling of the supplier pool. From the visual checks of material in stores and information from suppliers, it appeared as though at least 50% of the material received from suppliers was actually in adequate packaging. However, the current kitting process negated this opportunity by repackaging all material individually into one of about 12 standard waffle packs that were stocked in Stores, in most cases providing a very poor cavity-die fit. This necessitated the "corner-crowding" action.

The fact that many of the suppliers were already shipping material to Raytheon in adequate packaging was encouraging, as this meant that the goal of receiving all material in optimal packaging was actually much closer than originally thought!

To fully realize this objective, a means of standardizing packaging requirements, conveying them to suppliers and enforcing conformance with them needed to be created.

6.1.1 Packaging Specification

A "generic" packaging specification was created to serve as this vehicle for formalizing material packaging requirements and communicating them to the supplier base as part of the procurement process. Feedback about the specification was obtained from a sampling of suppliers and this feedback incorporated where possible. Raytheon's purchasing group was also included in discussions about the specification and how it would be used. This specification will be attached to purchase orders for all AESA material purchases going forward, and should the AESA implementation prove a success, then it will be more broadly utilized across material orders for other MIC families.

6.1.2 Sample Inspections of Incoming Material

To ensure that the material received from the supply base is not introducing quality defects into the kitting and assembly process at the start, a sample of each lot of material received at Raytheon's Receiving, Inspection and Test (RIT) facility, which is the initial delivery point for all of SSM's incoming material, will be inspected for three criteria to assure compliance with the packaging specification:

1. Proper packaging (waffle pack part number)
2. Die orientation within the waffle pack cavity
3. Quantity of die within the waffle pack

The equipment and trained personnel are already on-site, but some set-up of a new inspection station will be required.

6.1.3 Issuance of Full Waffle Packs to the Floor

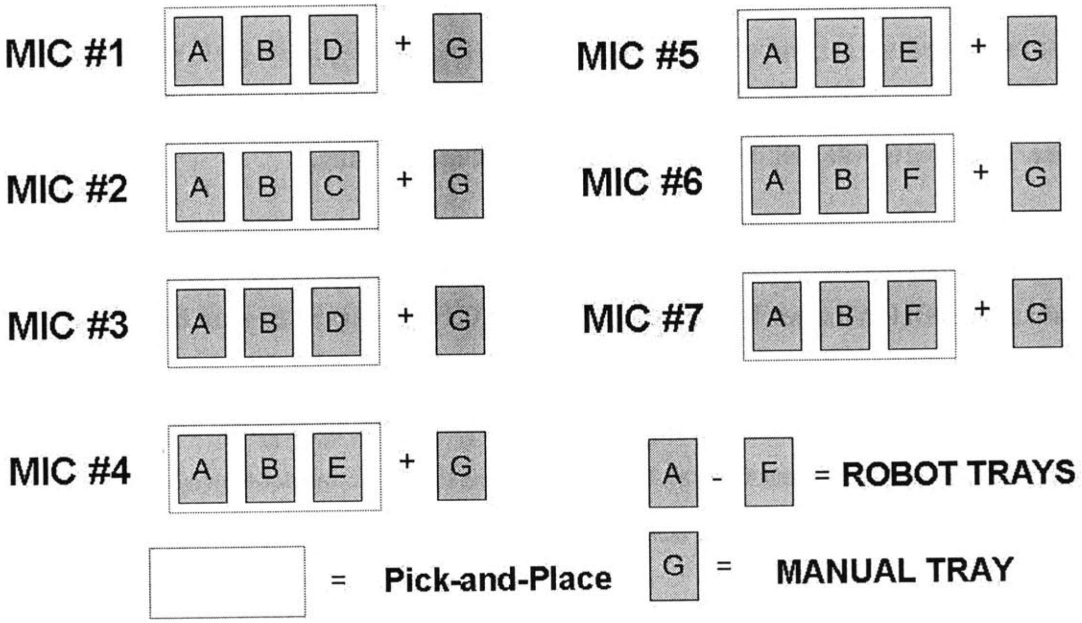
For most components, only full waffle packs will be issued from Stores to the production area on an as-needed basis, to be further explained when the "standing tray" system is detailed in the next section. Only components with air bridges (less than 10% of the parts) will continue to be repackaged manually in the storeroom. These parts cannot be shipped in waffle packs from the suppliers because of the delicate nature of the features on the chip upper surfaces. They are typically shipped in gel-packs to prevent damage of the air bridge which might occur from contact with the pack lid if the parts were shipped in a waffle pack. Gel-packs cannot be put directly onto SSM's pick-and-place machine. Hence, these parts will still need to be repackaged during kitting.

6.1.4 Point-Of-Use and "Standing Tray" System

Residual material in the waffle packs after each MIC build will be kept on trays in a point-of-use (POU) in the production area near the pick-and-place robot. Each program or MIC family will have its own set of trays, as the procurement budgets are separate for each program and the material cannot be co-mingled (due to contract segregation requirements imposed on defense contracts), with the exception of certain low-value inventory.

To illustrate how the standing tray system will work, the AESA program will again be used as an example. There are 7 unique MIC designs within the AESA family and approximately 120 unique surface mount component parts in the bill-of-materials. By strategically allocating a set of waffle packs across 7 trays (6 trays of robotic parts and 1 tray of manual parts) that are kept in the POU such that each part number resides on exactly one tray, each MIC design can be built from a particular combination of three robot trays and the single manual tray. (See Figure 15).

FIGURE 15: Illustration of Standing Tray Point-of-Use System



When a MIC is "released" to the floor to be built, WAC (Warehouse Automation Control), the computerized inventory management system used at Raytheon, will automatically cross-check the BOM for that particular MIC against what is currently held in the POU. Any parts that will run short during the build will be flagged, and a pick list will be generated. The inventory levels in the POU for each part number in the build will be debited appropriately, and the new material issued to the line with the kit will be credited to the POU balance. A storeroom clerk will pull fresh waffle packs of only these "shortage" parts from inventory, and this material will be issued to the line along with the housing and any air bridge parts that need to be repackaged for that particular kit. The appropriate trays will be pulled by the diebond operator from the POU and placed on the pick-and-place robot. As the build progresses and the expected shortages occur, the operator will remove the empty waffle pack and replace it with the full pack issued with the kit, and then resume the build. When the build is complete, the trays will be returned to the POU.

With this process, manual touching of the die will be largely eliminated, along with the necessity to build the kit trays each time with waffle packs from the POU (per the Raytheon Expressway process observed during benchmarking), saving significant time.

6.1.5 Utilization of 3rd Party Supplier For Repackaging Services

The final component of the envisioned future state is the utilization of a 3rd party inventory services supplier for material repackaging. Feedback was solicited from suppliers about the packaging specification to determine how many suppliers would be willing to comply with the new specification at no cost versus for additional cost (or not at all). A few of the suppliers used by Raytheon are only distributors and they have no repackaging capabilities, so they would be unable to comply with the new requirements. In these cases, a process has been devised whereby those suppliers will ship their material directly to the 3rd party supplier. This organization will inspect the material to confirm that it is correct and defect-free, and then they will repackage the material to conform to Raytheon's packaging specification and then ship the material to Raytheon.

6.2 Simulation

Before carrying out an extensive implementation of any new process it is often helpful to create a simulation model upon which various configurations can be tested and from which to collect data to build a business case for capital investment in new equipment and training for personnel.

6.2.1 Simul8© Model

A baseline simulation model of the current MIC fabrication process was built using Simul8© software. Material flow from kitting in Stores through shipping after completion of testing was modeled. Current shift schedules and labor allocations, cycle times from previously collected data and current defect rates were incorporated into the model. See Appendix B for a screen shot of the model. This model was calibrated to output realistic end-to-end and testing phase cycle times based on current SSM metrics.

A simulation model of the envisioned future state MIC kitting and fabrication process was then built using cycle times and defect rates based on estimated changes from the current process. See Appendix C for a screen shot of this model.

6.2.2 Simulation Results

The resulting cycle times and variabilities from the two models can be compared to understand potential benefits to the overall value stream. See Figure 16 for a comparison table of the outputs from the two models for three key SSM metrics; end-to-end cycle time, diebond-to-ship cycle time and test cycle time.

FIGURE 16: Comparison of Baseline and Future State Simulation Models

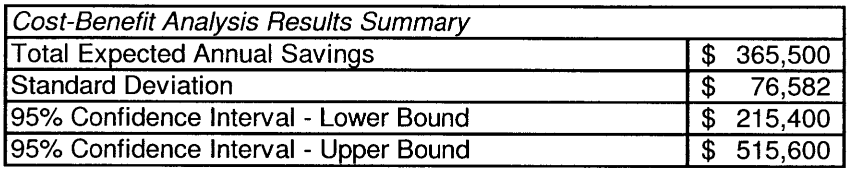
(All times in days)	Lwr 95% Conf	Mean Value	Max 95% Conf
Current State			
End-to-End	22.4	23.2	24
Diebond-to-Ship	18.4	19.1	19.9
Test	6.3	6.9	7.6
Future State			
End-to-End	17.9	18.6	19.3
Diebond-to-Ship	17.5	18.2	18.9
Test	5.6	6.2	6.8

As can be seen from the simulation results, transitioning to the "future state" should result in a significant reduction in the total MIC build cycle time, primarily due to kitting and screening cycle time reductions but also due to reduced test troubleshooting and rework times.

6.3 Cost-Benefit Analysis

To build a business case for change at Raytheon, it is necessary to put a monetary value on the change for the organization. A cost-benefit analysis was performed whereby the total annual cost of the current process was compared to the estimated total annual cost of the redesigned process to calculate the potential annual savings for the project. The total cost analysis of the current process was already discussed in Section 4.2. The annual cost of the new process was estimated using data from the simulation as well as data from the pilot implementation which will be discussed in Section 7.1. Some uncertainties for future state cycle time/labor uncertainties had to be estimated based on lack of sufficient data. See Figure 17 for a summary of the analysis results.

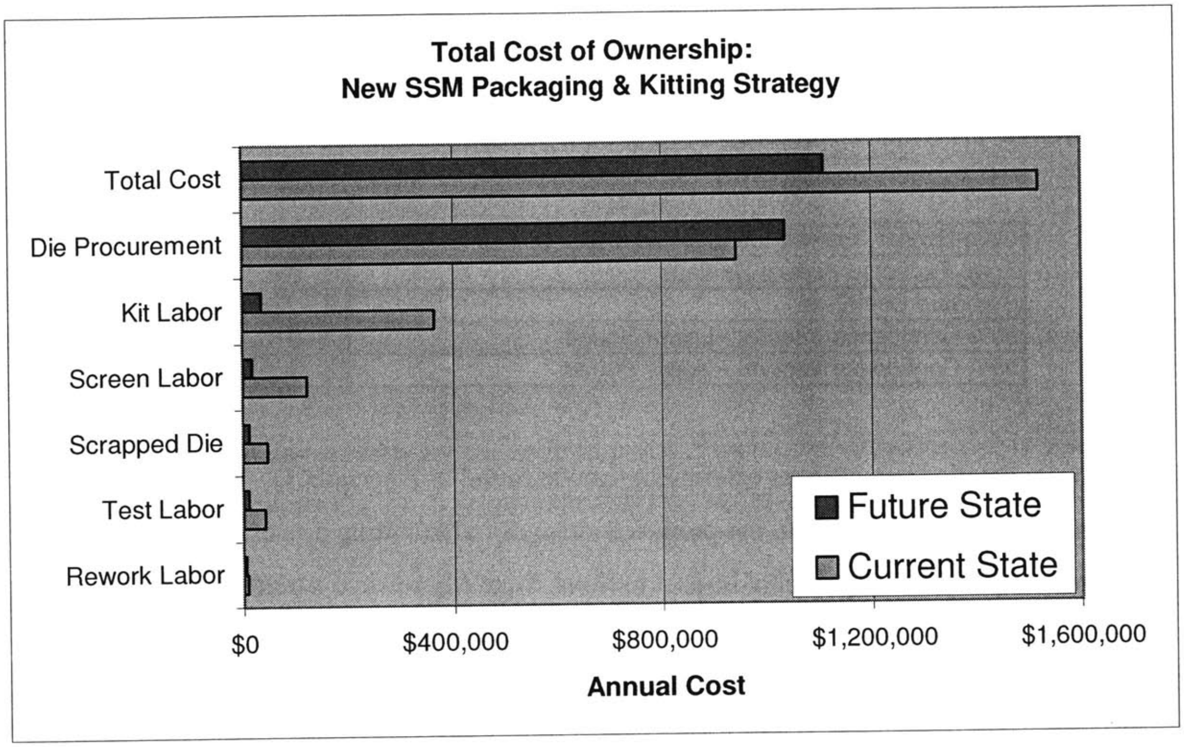
FIGURE 17: Results Summary Table for Cost-Benefit Analysis



Cost-Benefit Analysis Results Summary	
Total Expected Annual Savings	$ 365,500
Standard Deviation	$ 76,582
95% Confidence Interval - Lower Bound	$ 215,400
95% Confidence Interval - Upper Bound	$ 515,600

A more detailed spreadsheet calculation can be found in Appendix D. With an expected annual savings of $365,500, the proposed changes to the kitting process have the potential to make a significant impact to Solid-State Microwave's bottom line. While the cost of material procurement is estimated to increase slightly due to the additional repackaging effort that will be required by some suppliers and the third-party repackaging house, one needs to take a Total Cost of Ownership (TCO) perspective and look at the cost of the entire value stream from material procurement to shipping of the MICs to see the true value of the change. With this perspective, this material cost increase is more than compensated for by savings from significant reduction in labor primarily in the kitting and screening areas. This change is more clearly seen in a graphical format in Figure 18.

FIGURE 18: Total Cost of Ownership – Resultant Savings from Process Changes



In this chapter a future state was visualized based on analysis of the current process deficiencies and findings from benchmarking studies. This future state model was simulated to assess performance and a cost-benefit analysis was performed. In the next chapter the "Achieve" step in the Six Sigma framework will be applied to a small-scale pilot implementation to test the simulation model and prove the concept. A plan of action for going forward with a full-scale implementation will also be discussed.

7 Six Sigma – Achieve

"Achieve" means to deliver measurable results that create change and build momentum for continuous success, as well as to get people excited about participating in Raytheon Six Sigma repeatedly. This chapter documents the implementation and results of a small-scale, proof-of-concept pilot study for comparison to future-state model predictions. A plan to execute a wider implementation will also be developed.

7.1 Pilot Implementation

While simulation models provide a good discussion tool, they can only go so far in convincing skeptics that theory can be turned into practice. A pilot implementation was created in order to test the new process and prove its potential "real world" benefits.

7.1.1 Pilot Scope

Initial planning called for the pilot to include all seven of the SSM-built AESA MIC designs and run for one month to collect 4 full sets' (28 MICs) worth of cycle time and defect rate data. However, during detailed planning it became clear that there would be a considerable amount of pre-pilot robot reprogramming time required, on the order of 20-30 hours per MIC design. Then, late in the planning stages of the pilot, SSM Operations was informed by design engineering that one of the MIC designs would be eliminated entirely and another 4 would be completely redesigned in mid-2006 to fix performance and manufacturing issues. This would necessitate another major reprogramming effort on the part of process engineering at a later date. As a result, the pilot was down scoped to include only the two MICs that were not slated for elimination or redesign. In this way the large number of initial reprogramming hours required would not have to be repeated a year later. Based on the production schedule it was determined that a total of 10 MICs would be built as part of the pilot over the course of a month. The "standing tray" system would not be part of the pilot due to the large number of reprogramming hours required and a shortage of available time from process engineering. Instead, a POU similar to that seen at Raytheon-Expressway would be used because of this time constraint.

7.1.2 General Description

Since most of the material for the next several months' worth of MIC builds was already in-house, a "bulk kit" of repackaged material was created for the pilot. All of the material needed for the 10 MICs was pulled from Stores and repackaged into new waffle packs that were selected to be as close to optimal in terms of cavity size as could be found on short notice (certain custom waffle packs require as much as 10-12 weeks lead time). The repackaged material was then inspected by Quality to ensure that the initial kit was completely free of defects and correct in terms of die orientation and quantity per pack. By starting with an "optimally" packaged and defect-free kit in this manner it would be representative of SSM having received properly-packaged and inspected material straight from the supplier, as it would be in the future. The bulk kit was then kept in a POU cabinet in the manufacturing assembly area to be accessed by the die bond operators as needed. The pilot process then ran as follows:

When it was time to release a kit to the assembly area for a build, Stores would issue the kit to diebond. In this case, the kit now just consisted of a housing, a lid and some large manually installed filters and other large components. The diebond operator would then get the necessary waffle packs from the bulk kit in the POU and arrange them on the tray per the online tray plan. The trays would then be placed on the pick-and-place. The operator would then need to "status" the machine, or in other words, tell it where the first die in each pack was located since the location would be changing from build-to-build. The MIC would then be built as usual. At the build completion, the residual material waffle packs would then be returned to the POU.

In the kitting and diebond areas, data was to be collected on tray build time, tray screening time, robot status time and tray tear-down time. Diebond-to-ship and test cycle times and defects found in test would also be collected to characterize the effects of the kitting process changes on the whole MIC build process flow.

7.1.3 Pilot Results

The pilot data collected is summarized in Figure 19.

FIGURE 19: Pilot Data Summary Table (in hours)

Data Collected	Pre-Pilot		Pilot		Percentage Change
	Mean	Std Dev	Mean	Std Dev	
Kitting Cycle Time	15.4	11	0.5	0.1	-97%
Kit Screening Cycle Time	5.2	2.1	0.3	0.1	-96%
Robot Programming Cycle Time	0	0	0.1	0.1	N/A
Kitting-related Defects Found	1		0		-100%

While diebond-to-ship and test cycle times were also collected, production and test issues related to non-pilot MICs in the pipeline resulted in skewed data being collected due to excessive queue times between process steps that were not related to the pilot. However, the data seen in Figure 19, while not as extensive as originally planned, does support the results from the simulation, suggesting that significant cycle time reductions can be achieved while maintaining very low defect rates.

7.2 Go Forward Plan

After it became clear that a full implementation across SSM's product lines would not be realistic during the short timeframe of the internship, efforts were focused in three areas; implementing the previously-discussed pilot, the development of the required infrastructure to enable a full implementation and the creation of a detailed implementation plan to be followed after the intern's departure from Raytheon.

7.2.1 Infrastructure Development

The LFM internship project in SSM from the previous year was initially a great success by any measure. However, it fell apart within a few months of the intern's departure and is no longer in use. The primary reason for this was the lack of a clearly-identified person at Raytheon to "carry the torch" and to bear primary responsibility for the project's continued success and growth. Identification of a successor became a major focus of the last portion of this internship. In the end, a capable and committed "point man" was found to move the project forward after the intern's departure. Ironically (and fortunately), it is the LFM intern from the previous year who had since accepted a full-time position at Raytheon SAS.

In addition to identifying a successor, other areas of focus were releasing the previously-mentioned packaging specification, developing a relationship with the recommended third-party supplier for repackaging and creating a dialogue with a large portion of the supplier base regarding the proposed packaging changes.

7.2.2 Definition of Timeline and Process Maps

To further enable a timely implementation, a timeline with required milestones was created for reference by the team. See Appendix E for a graphical timeline.

In addition, to capture the required steps required to implement and sustain the future state process, process maps and decision trees (with responsible parties identified for each step) were created to guide the team moving forward. See Appendix F for an example of one of these process maps and Appendix G for a stakeholder map.

In this chapter the specific steps necessary to "Achieve" kitting process change implementation were discussed; these included a pilot study to prove the future-state concept and collect data for comparison to the simulation model and planning for a full-scale implementation across all product lines. In the next chapter, "Improve", other future opportunities for continual improvement of the new process are identified along with future challenges that will need to be addressed to sustain the change.

8 Six Sigma – Improve

The "Improve" step in the process is where integrated improvements and control systems are designed to maximize value. In this chapter future opportunities for additional process improvement are identified and discussed and potential future challenges are described.

8.1 Future Opportunities

During the course of this project, other related opportunities for further process improvement were identified. It is recommended that they be investigated further by the remaining team as they could result in significant further quality improvements and cost savings.

8.1.1 Elimination of tweezers from kitting process

Based on initial benchmarking activities, it is clear that most world-class producers of microelectronic products do not handle their die with tweezers. They instead use vacuum picks for kitting and handling operations. Storeroom personnel have been trained in the proper use of vacuum picks and have the appropriate equipment at their workstations. This is a change that needs to be made to cut down on the amount of damage that is inflicted on these sensitive die during handling. While there is resistance to this change on the part of the clerks, this is not surprising as they are used to the tweezers. While it has been suggested to the clerks by their direct supervisor that they should try to use the vacuum picks, it has never been made into an enforced "run rule". While there will be a transition period where their speed will suffer a bit, after a short time they should be able to handle die as quickly as before and more gently.

It should be noted that this change will not apply to certain air bridge parts whose topographies do not allow vacuum pick-safe zones. This small number of parts will still need to be handled with tweezers. However, improvement in damage rates might still be attainable using plastic-tipped tweezers instead of metal.

8.1.2 Supplier-Managed Inventory for Low-Value Inventory

"Shift inventory or inventory ownership to suppliers" was listed as one of the top seven effective inventory reduction strategies in a survey of materials and inventory managers[8]. A supplier-managed inventory system similar to the system observed at Teledyne for the SSM storeroom's low-value inventory (LVI) would provide significant benefits. These benefits would include reduced inventory levels in Stores and, as a result, increased agility to phase in design changes, as well as reduced ordering and administrative costs associated with the procurement and management of these parts. Eastern States Components already provides these services for Teledyne with great effectiveness, and SSM could benefit from implementing a similar system. A two-bin kanban system could be used whereby two bins of waffle packs are kept in the storeroom; one bin for replenishment of the waffle packs on the standing trays on the line and the other as a spare. When the 1st bin is depleted and the 2nd bin opened, a faxed "kanban" signal would be sent to ESC. ESC would then automatically send a replacement bin directly to the storeroom without having to go through RIT. This system should result in increased inventory turnover and reduced inventory levels, decreasing the risk of obsolescence and required investment in inventory[5].

8.1.3 Unique Part Numbers for Unique Component Topographies

Under the current configuration management system in place at SSM, it is possible to have several different components with the exact same part number but each with a completely different topography in inventory simultaneously. These topographies are actually different enough that they cause problems for the pick-and-place and wire bond machines due to different fiducial feature and electrical pad locations. This has been a major headache for the personnel in these areas with the result that significant time is spent troubleshooting on the robots. In addition, the different sizes and shapes make it impossible to select a single waffle pack that fits multiple topographies correctly, which means that in the new system, each time a different topography is put on the robot, time will have to be spent to "status" the machine as to where to look for its references.

There are several reasons for the multiple topography problems. In general, buyers within the SCM organization will purchase a batch of material from the source with the lowest cost. This results in using multiple suppliers for the same part number over a period of time. Many of these parts are common, widely used commercial parts such as resistors and capacitors which will be redesigned over the course of their service lives. Since they are used by many different customers, the manufacturer does not provide prior warning of the changes to all of their customers (especially small volume shops such as SSM). So one Raytheon supplier will stock one version while another stocks a different version, resulting in SSM purchasing multiple topographies under the same part number.

In order for Raytheon to realize the full potential benefits of the new kitting system, this problem needs to be addressed. One potential solution would be to limit the procurement of each part number to one topography only. This would place some restrictions on the freedom of the buyers to go to the cheapest bidder, but it would fix the problem on the manufacturing side. Another potential solution would be to assign each topography a unique part number so that the different topographies could be tracked within inventory. Regardless of how it is addressed, the current configuration management system is unacceptable and will continue affecting SSM's production costs and cycle times until it is resolved.

8.2 Future Challenges

While much of the infrastructure required for full implementation of the proposed new processes was laid during the course of the internship, there are obstacles still to be overcome by the implementation team.

8.2.1 Hardware Designs in Flux

The aforementioned MIC design changes slated for late 2006 are not necessarily the last ones that will occur before the designs reach maturity. Major design changes will result in BOM changes, possibly necessitating procurement of new material, reallocation of waffle packs on the standing trays and associated robot reprogramming time. These changes and their effects on material packaging should be tracked carefully.

8.2.2 Job Responsibility Changes for Bargaining Unit Employees

In order to implement the new kitting system, certain responsibilities of the hourly workers in Stores and the die bond area will be changed, others will be transferred to other personnel and yet others will be eliminated. This presents challenges on two levels: One, many of the BU personnel are set in their ways and will resist the idea of changing jobs at which they have become proficient and comfortable; Two, the union has had a history of filing grievances over changes in established job responsibilities. To circumvent some of these issues, every attempt was made to include the hourly workers in the development process of the new process flow such that their input was solicited and incorporated and they were educated about changes coming in the future. However, despite these efforts there are sure to be bumps in the road from unforeseen problems during implementation. The BU workers must be treated as part of the implementation team and their input and feedback continually solicited.

8.2.3 Reallocation of Labor to Realize Cost Savings

Finally, as can be seen from closer inspection of the estimated total cost savings discussed in Section 6.3, much of the proposed savings result from the reduction in labor content during kitting in Stores. Since it is a union shop, laying people off is not really an option. These savings cannot be realized unless this idle labor capacity can be reallocated to another area of need. Fortunately, SAS is currently in growth mode and this should not prove excessively difficult.

In this chapter future opportunities for additional process performance improvements were discussed and a few important challenges to be overcome for long-term process sustainability were identified. In the next chapter the organizational implications of the changes initiated by this project and their ramifications for process sustainability are discussed using a high-level organizational analysis of strategic, political and cultural issues.

9 Organizational Analysis

Change implementations within organizations cannot be approached from a strictly technical or mechanical point-of-view, even if the problem being solved appears to be purely technical or process-oriented in nature. Changes affect people's job responsibilities, their standing within the organization as well as the performance of business units, which in turn can affects employee and management compensation. As a result, organizational analysis can be as crucial as engineering or operations analysis in determining the likelihood of a change's ultimate success or failure and the broader ramifications of the change on the organization. This chapter discusses Raytheon's organizational design, incentive systems and some political and cultural issues as applied to the recommended kitting process changes.

9.1 Introduction

Raytheon SAS produces a wide range of high-performance, complex products. The complexity of the product line is in some respects mirrored by the complexity of the organization that produces these products. As a large, hierarchical company with multiple divisions and many functional groups, SAS has a unique cultural identity and deeply-ingrained social norms and established processes that must be considered when analyzing the effectiveness of various change management techniques. Carroll's Three Lenses model[9] is useful in understanding organizational behavior and in crafting strategy for effecting change within the organization. The strategic, political and cultural lens perspectives will be applied to SSM and SCM to better understand the role of the organization in creating and sustaining change.

9.2 Strategic Lens Analysis

The strategic lens views the organization as a logical organization, assuming that individuals are rational and that organizations can be structured to achieve a goal. This view of an organization focuses on intrinsic characteristics like organizational groupings and linking mechanisms as well as alignment mechanisms such as metrics and incentives.

9.2.1 Structure – Grouping and Linking

Solid-State Microwave

Operations and Engineering report to separate vice presidents within SAS. Engineering creates and develops new products. Operations provides support for the development of these products and bears primary responsibility for their production. SSM is an operational division of Raytheon SAS. SSM serves two purposes: One, SSM manufactures circulators, MICs and photonics for their downstream customers. Two, engineering development work is performed concurrently in the same production facilities, utilizing their specialized equipment to prototype and test new designs. It is a unionized shop. SSM is organized such that development and production of each product group is overseen by one of a group of project managers who report to both the director of SSM Operations and the Vice-President of SAS Operations. Each of these projects is typically part of a large, fixed-price, long-term military contract. The director of Operations is responsible for allocating required resources to the various projects.

Supply-Chain Management

SCM is a functional organization of SAS whose purpose is to support their various operational, engineering and product divisions. Functions within SCM include purchasing, sourcing, receiving and inspection, warehousing and supplier-managed inventory coordination. Hourly workers are unionized. Customers of SCM are charged a material handling rate for their services which is based on the dollar value of material received by SCM each month for each particular business unit. This method of charging their customers results in a situation whereby if an internal Raytheon customer of SCM has need of a high level of service but has relatively little material needs, they will essentially receive a discounted price for SCM services. SSM is one of these types of customers.

SSM's resident storeroom (32 Stores) is run by Warehousing, a subgroup of SCM. This storeroom maintains SSM's inventory. They also provide additional support for SSM in the form of kitting operations. Another subgroup of SCM, Production Control, is responsible for controlling the release of kits to the SSM production floor per the MRP schedules of the various product lines. Production Control is essentially the traffic cop that controls the flow of material into the manufacturing pipeline.

9.2.2 Metrics and Incentives

Solid-State Microwave

SSM performance is judged primarily according to one key metric: output per month for each product line. The ability to keep up with the scheduled demand from the downstream customer is tantamount and this metric dominates discussions in meetings and billboards where metrics are posted.

Individual metrics are somewhat less clear. Operators are tracked according to quality and individual output. However, within the unionized workforce in SSM, operators are assigned seniority and a labor grade as well as the distinction of being a "certified operator" if they have completed training. Seniority is the number of years that the operator has been with the company (the company being Raytheon, GM or Hughes; seniority from each prior company is transferable to Raytheon). Seniority is the determinant of who is laid off first during times of downsizing. Certified operators are allowed to both perform and inspect shop floor operations. These are operators that have consistently produced high quality work. These certifications are a prerequisite for advancing in labor grade. Labor grades determine the potential pay rates for employees, and are an indicator of general skill level. Most operators are within one of three or four labor grades; there are actually few distinct labor grades. Most of the operators have been working at the company for many years and have "maxed out" their labor grades, meaning that they are not eligible for further pay raises without being bumped to the next higher labor grade.

Managers can also issue "On the Spot" awards to operators for outstanding or "above and beyond" performance. These are small monetary awards ($25 to $200) that provide public recognition for hard work.

Supply-Chain Management

SCM is judged primarily on the level of service that they provide to their internal customers within Raytheon SAS. There are also metrics specific to each functional area within SCM.

Employees involved in procurement of parts from outside sources are judged primarily on the per-part prices of these purchases. This focus on lowest purchase price often results in very large buys at discounted prices. In fact, an accepted practice within Raytheon is to make "lifetime buys", or to purchase as much material is needed to fulfill the life of the current contract. As a result of this practice there are often high levels of inventory and little focus on the holding costs of these inventories.

Warehousing is judged according to their ability to provide a ready source of parts to the factory floor. Individual stock clerks within the storeroom are judged mostly according to the accuracy of the kits that they prepare, with defects related to wrong parts, wrong quantities of parts or damaged parts tracked carefully. A key point to be noted is that both the stock clerks in SCM and the operators in SSM are part of the same labor union, resulting in a set of very similar incentives for both groups of employees.

9.3 Political Lens Analysis

The political lens fosters a view of the organization in which stakeholders with different goals and interests struggle for power with one another. This lens helps us understand the dynamics of power within an organization and how people form more informal coalitions when they share common interests as opposed to the more formal groupings seen through the strategic lens.

Solid-State Microwave

Within SSM, the director of Operations wields significant influence and power as the person bearing primary responsibility for meeting MRP production requirements for SSM's products. SSM provides key components to downstream internal customers. If these products are delivered late then the delivery of finished products to the end customer (military) will also be delayed, resulting in significant negative visibility to

SSM. Within Operations, certain project managers (members of the Director's staff) have also accrued significant levels of influence as the single-point of responsibility for development and production of those specific projects. The project managers of the newest, most cutting-edge products have the highest visibility within the organization and as a result wield the greatest level of influence, for better or for worse.

The SSM Operations director has been a very vocal and visible supporter of lean initiatives and promoter of change within his area of responsibility. The assignment of several LFM interns to SSM over the past several years is testament to his influence within SAS and his desire to implement world-class manufacturing practices within his group. This visible promotion of LFM projects by such an influential person within the organization ensured that access to senior members of his staff was available to the intern when necessary. In addition, when roadblocks were encountered, the director was available and willing upon request to provide the necessary clout to get things moving forward again.

Supply-Chain Management

Within the context of this project, SCM's position as the provider of services to SSM results in a clear provider-customer relationship, and SCM is accordingly fairly responsive to the demands of SSM. The influential position of the director of Operations within SSM has resulted in SCM providing services above and beyond those provided to other production areas. For example, robot kitting was initially performed by SSM operators. This work was transitioned to the storeroom to be performed by storeroom clerks despite resistance from the bargaining unit workers there who claimed that this work was outside of their job descriptions. As a result, SSM was able to get SCM to provide additional services at no extra cost, reducing SSM's workload.

This project has the potential to significantly reduce the workload for SCM associated with these kitting operations. While the SCM sponsor of this project was equally enthusiastic about it as the SSM sponsor and equally committed to implementing lean, world-class supply chain practices in their organization, the visibility of SCM management within was less prevalent. While the Storeroom supervisor was fully supportive and very enthusiastic about providing whatever resources he could to create a successful project, the storeroom clerks more or less view him as "one of their own" as opposed to upper management. As a result of this situation, his level of influence over their daily actions and behavior is somewhat reduced. This resulted in the intern benefiting less from the visible support of upper management (in terms of the intern's own level of influence) with the hourly workers in the Storeroom than within the SSM production area.

9.4 Cultural Lens Analysis

Organization culture develops over time as groups share common situations and problems and pass on traditions. The cultural lens views the organization as a social system in which people must co-exist together and in which actions are driven by the meanings people assign to situations.

General Raytheon SAS

Much of SAS's culture was inherited from Hughes Aircraft when it was acquired by Raytheon. Hughes' culture stressed superior technical performance; innovation was highly prized and the organization thought of itself as more of a research and development enterprise than a manufacturing organization. As a result, operations and industrial engineering functions were in a sense relegated to second-tier status. This perception has changed significantly over time as the operations organization has grown in importance as a source of advantage in a competitive marketplace, but elements of this culture remain entrenched throughout the company.

Solid-State Microwave

SSM builds complex, high performance, state-of-the art products. This is a source of pride for all employees. In addition, a recent corporate initiative within Raytheon has stressed "Mission Assurance"; since the lives of warfighters are dependent upon Raytheon's products working the first time, every time, they shoulder a great responsibility to assure that their products can complete their missions effectively and reliably. Management has successfully levered this sense of mission into an additional source of pride in their work.

Supply-Chain Management

Supply Chain is in the midst of a Raytheon-wide initiative called "Supply Chain Transformation", which is an effort to transform the organization from a collection of functional groups with silo mentalities to a more cross-linked, effective organization that can provide its customers with additional value and Raytheon with a source of competitive advantage. As a result, the culture is in a transitional period and there is an occasional sense of conflicting identity within the organization. Members of the organization sometimes do not seem to think of themselves as members of a team called SCM that is working towards a common goal, but more as Buyers, Warehouse Managers, etc. with occasionally conflicting incentives and distinct goals.

Within 32 Stores, there is a considerable amount of tension between the hourly workers and management (and sometimes even between different shifts of hourly workers). Union grievances are not uncommon and a great deal of skepticism exists of management intentions. Part of this discontent seems to stem from the lack of visibility of management above the storeroom supervisor on a daily basis. The clerks do not feel as though their contributions are particularly valued by their managers and at least one stated that they feel like they are "treated like children". The hourly workers seem to look back on Hughes as "the good old days" compared to the current Raytheon environment, and grumblings of miscontent are frequently heard upon visiting the storeroom.

9.5 Recommendations

The primary takeaway from this internship related to organizational issues is that in order for change initiatives that cross organizational boundaries to succeed, there needs to be a shift in metrics and incentives across the company to focus on Total Cost of Ownership (TCO). Without this shift in incentives, misalignment of metrics makes it very difficult to "rally the troops" around a particular change initiative that could provide benefits to the overall organization. For example, the focus of the buyers in SCM on attaining the lowest possible price on a per-part basis resulted in hesitance to embrace new packaging requirements. The change could result in an increase in their key metric even though this change would enable even greater savings downstream in the process in an area whose key metric is maximizing number of units produced to keep up with an MRP schedule. This type of mindset change is an easy thing to preach but a very hard thing to do in practice. However, this ability will become even more crucial going forward as Raytheon strives to better integrate Operations and Supply Chain as well as their supplier base to increase operating efficiencies, lower costs and take full advantage of the synergies that these cross-organizational partnerships can provide.

9.6 Concluding Remarks

While use of the three lenses does not guarantee that we will develop the perfect diagnosis of an organization, it does allow us to build a more comprehensive model than any one viewpoint alone. The complex interdependencies of the organization and, most importantly in the context of this thesis, the difficulties of implementing change are revealed more completely through this holistic approach. Such an analysis can suggest more ways to bring change, overcome possible resistance and achieve the desired results: to help Raytheon achieve Mission Assurance and provide the best possible support to the Warfighter who depends on their products.

10 Thesis Summary

This thesis presented the results of a six-month LFM internship that focused on improving kitting operations within a division of Raytheon SAS. SSM had been suffering quality and throughput problems in their MIC product lines for some time, troubles which had recently received more visibility due to late deliveries of product to customers. This internship began by value-stream mapping the current processes of material handling from supplier to the manufacturing area. Benchmarking of other producers of similar products was utilized to generate ideas of what an improved future-state kitting and material handling process might look like. A conceptual process model was created and simulated to test its affects on the overall process flow. A small-scale pilot operation was run to collect data to check the simulation model and to build a business case for a wider implementation. A cost-benefit analysis was performed and dialogue was initiated with suppliers and a third-party inventory services supplier that would be critical partners in a full-scale rollout. Results suggested the possibility of significant savings on the order of \$300,000-\$500,000 /yr as well as significant reductions in cycle times resulting from further implementation.

"..all advantage is temporary. No capacity is unassailable, no lead is uncatchable, no kingdom is unbreachable."[10]

If an organization is to survive and thrive in today's ultra-competitive market, they must make continual change part of their culture and never stop looking for ways to improve all aspects of their business. The positive attitude and open mind with which Raytheon's management approached this internship project and the concept of change in general suggests that Raytheon will continue their journey towards a lean enterprise into the future.

[*This page is intentionally left blank.*]

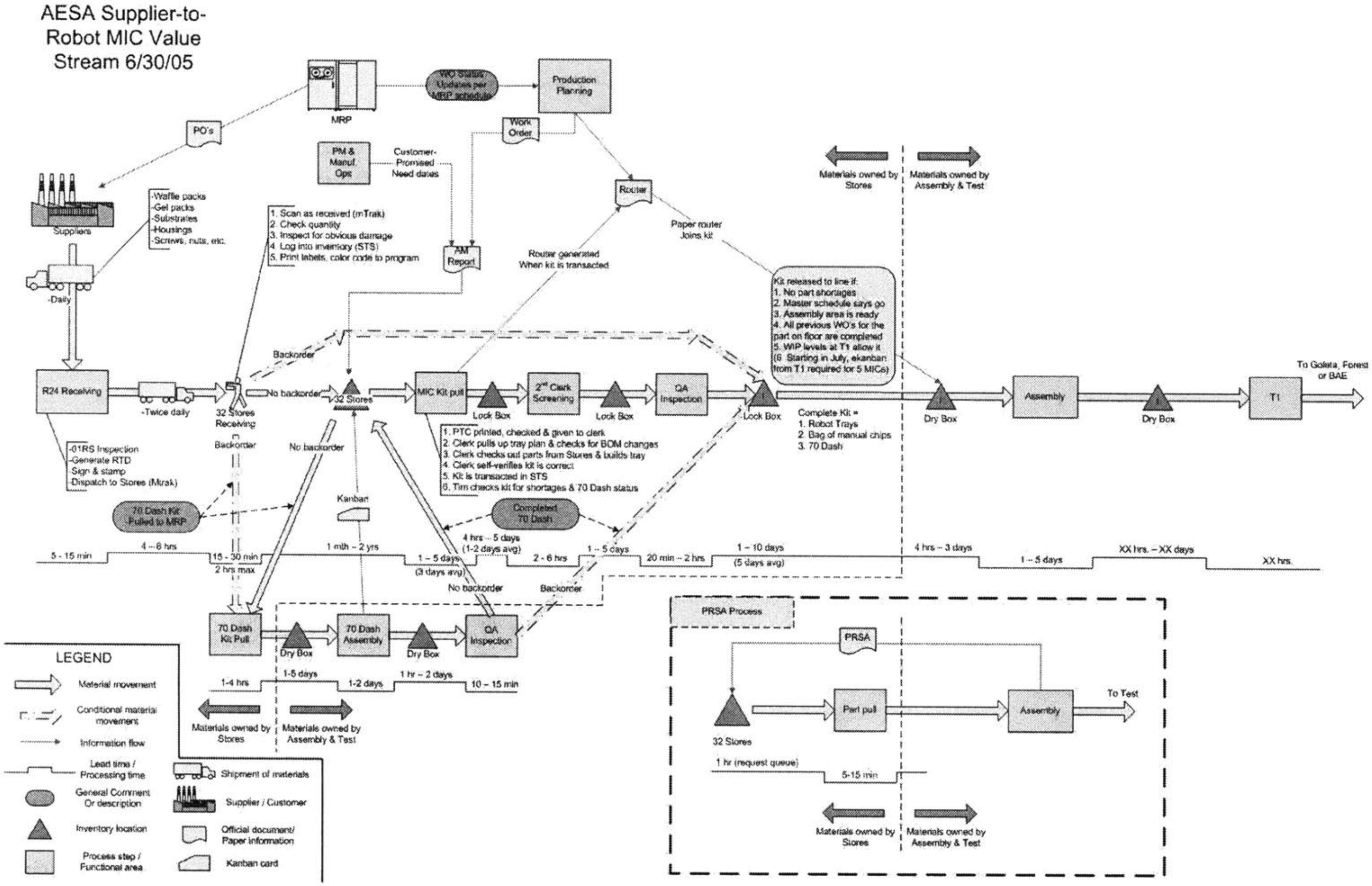
Acronyms

BU = Bargaining Unit
DPU = Defects-Per-Unit
ESC = Eastern States Components
LVI = Low-Value Inventory
MIC = Microwave Integrated Circuit
POU = Point-Of-Use
SAS = Space and Airborne Systems
SCM = Supply-Chain Management
SMI = Supplier-Management Inventory
SSM = Solid-State Microwave
TCO = Total Cost of Ownership
WAC = Warehouse Automation Control

[*This page is intentionally left blank.*]

Appendices

Appendix A Current-State Value Stream Map



AESA Supplier-to-Robot MIC Value Stream 6/30/05

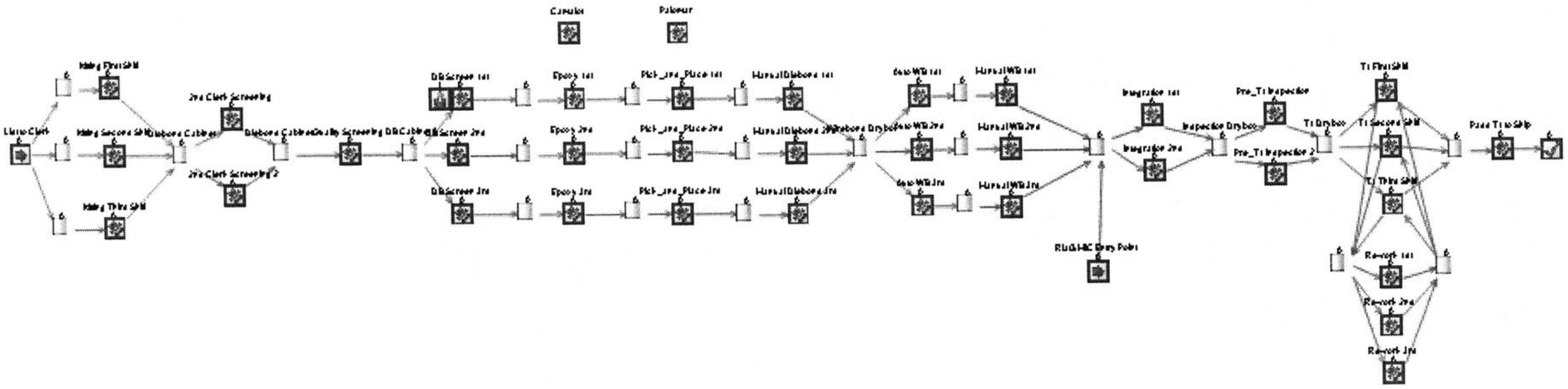
1. Scan as received (mTrak)
2. Check quantity
3. Inspect for obvious damage
4. Log into inventory (STS)
5. Print labels, color code to program

1. PTC printed, checked & given to clerk
2. Clerk pulls up tray plan & checks for BOM changes
3. Clerk checks out parts from Stores & builds tray
4. Clerk self-verifies kit is correct
5. Kit is transacted in STS
6. Tim checks kit for shortages & 70 Dash status

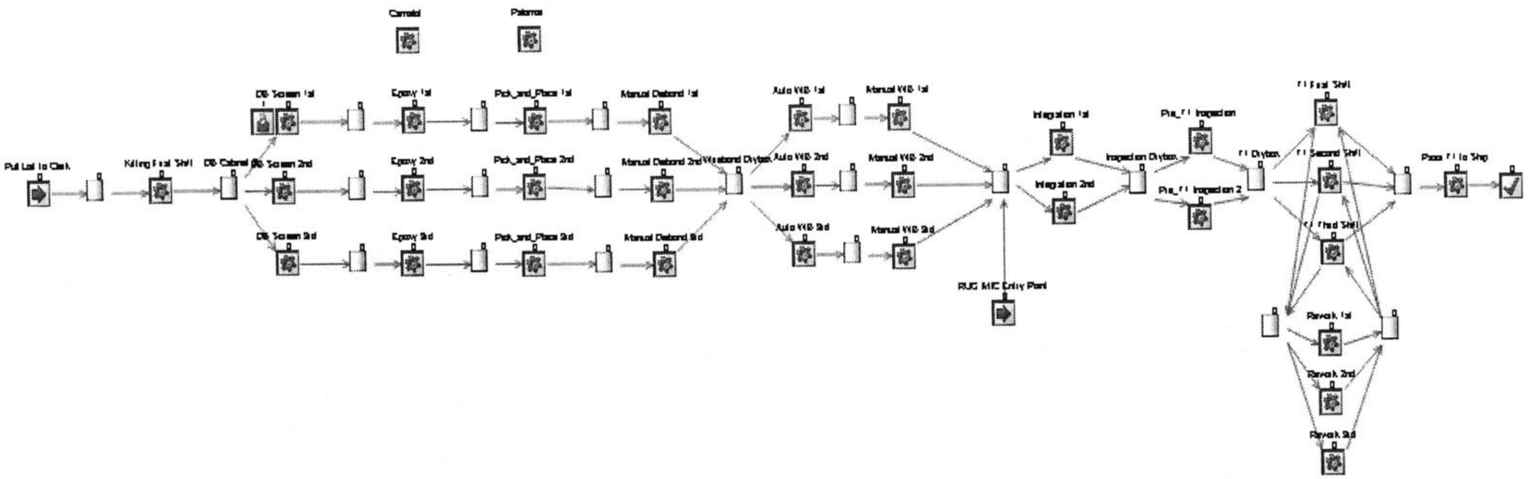
Kit released to line if:
1. No part shortages
2. Master schedule says go
3. Assembly area is ready
4. All previous WO's for the part on floor are completed
5. WIP levels at T1 allow it
(6. Starting in July, ekanban from T1 required for 5 MICs)

Complete Kit =
1. Robot Trays
2. Bag of manual chips
3. 70 Dash

Appendix B: Baseline Simul8 Process Simulation Model



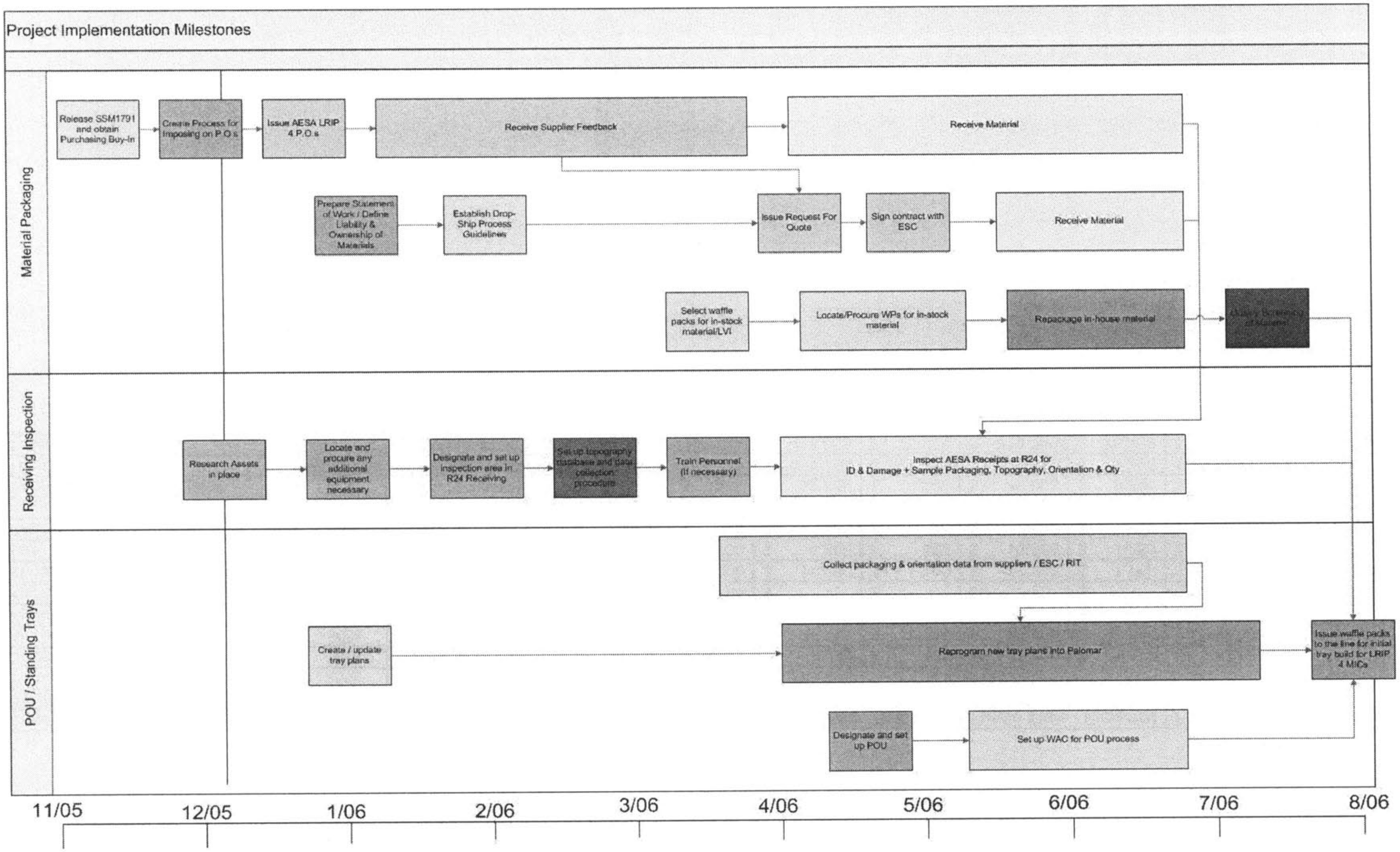
Appendix C: Simul8 Simulation Model for Redesigned Process Flow



Appendix D: Cost-Benefit Analysis Spreadsheet

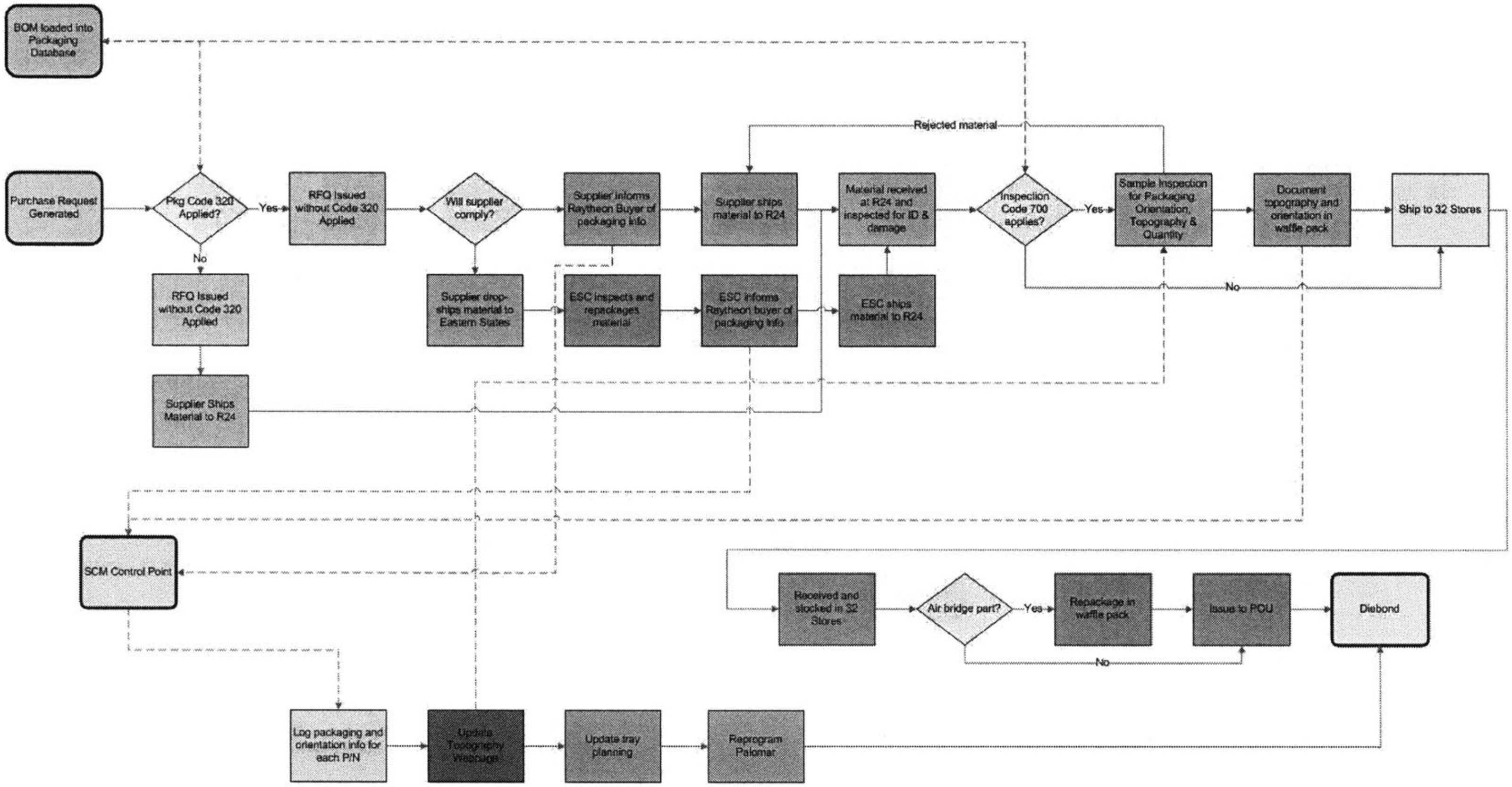
Total Annual Savings Calculation				Current State		Future State - Best Case		Future State - Expected		Future State - Worst Case	
	Best Case	Nominal	Worst Case	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Probability of Scenario Occurrence	25%	50%	25%								
Scrapped Die	-90%	-75%	-50%	$ 47,000	$ 4,700	$ 4,700	$ 470	$ 11,750	$ 1,175	$ 23,500	$ 2,350
Kit Labor	-90%	-90%	-75%	$ 364,000	$36,400	$ 36,400	$ 3,640	$ 36,400	$ 3,640	$ 91,000	$ 9,100
Kit Screening Labor - Clerk	-100%	-100%	-100%	$ 74,000	$ 7,400	$ -	$ -	$ -	$ -	$ -	$ -
Kit Screening Labor - Quality	-100%	-100%	-75%	$ 27,000	$ 2,700	$ -	$ -	$ -	$ -	$ 6,750	$ 675
Kit Screening Labor - Diebond	-50%	-20%	-10%	$ 22,000	$ 2,200	$ 11,000	$ 1,100	$ 17,600	$ 1,760	$ 19,800	$ 1,980
Test Troubleshooting Labor	-90%	-75%	-75%	$ 42,000	$ 4,200	$ 4,200	$ 420	$ 10,500	$ 1,050	$ 10,500	$ 1,050
Rework Labor	-90%	-75%	-75%	$ 2,000	$ 200	$ 200	$ 20	$ 500	$ 50	$ 500	$ 50
Annual Procurement of Die	5%	10%	15%	$ 890,843	$44,542	$ 935,385	$ 46,769	$ 979,927	$ 48,996	$1,024,469	$ 51,223
Incoming Inspection of Mat'l	N/A	N/A	N/A	$ -	$ -	$ 32,903	$ 3,290	$ 32,903	$ 3,290	$ 32,903	$ 3,290
Total Annual Cost				$1,468,843	$58,443	$1,024,788	$ 47,043	$1,089,580	$ 49,298	$1,209,422	$ 52,235
Total Annual Savings						$ 444,055	$ 75,024	$ 379,263	$ 76,459	$ 259,421	$ 78,384

Appendix E: Project Implementation Timeline

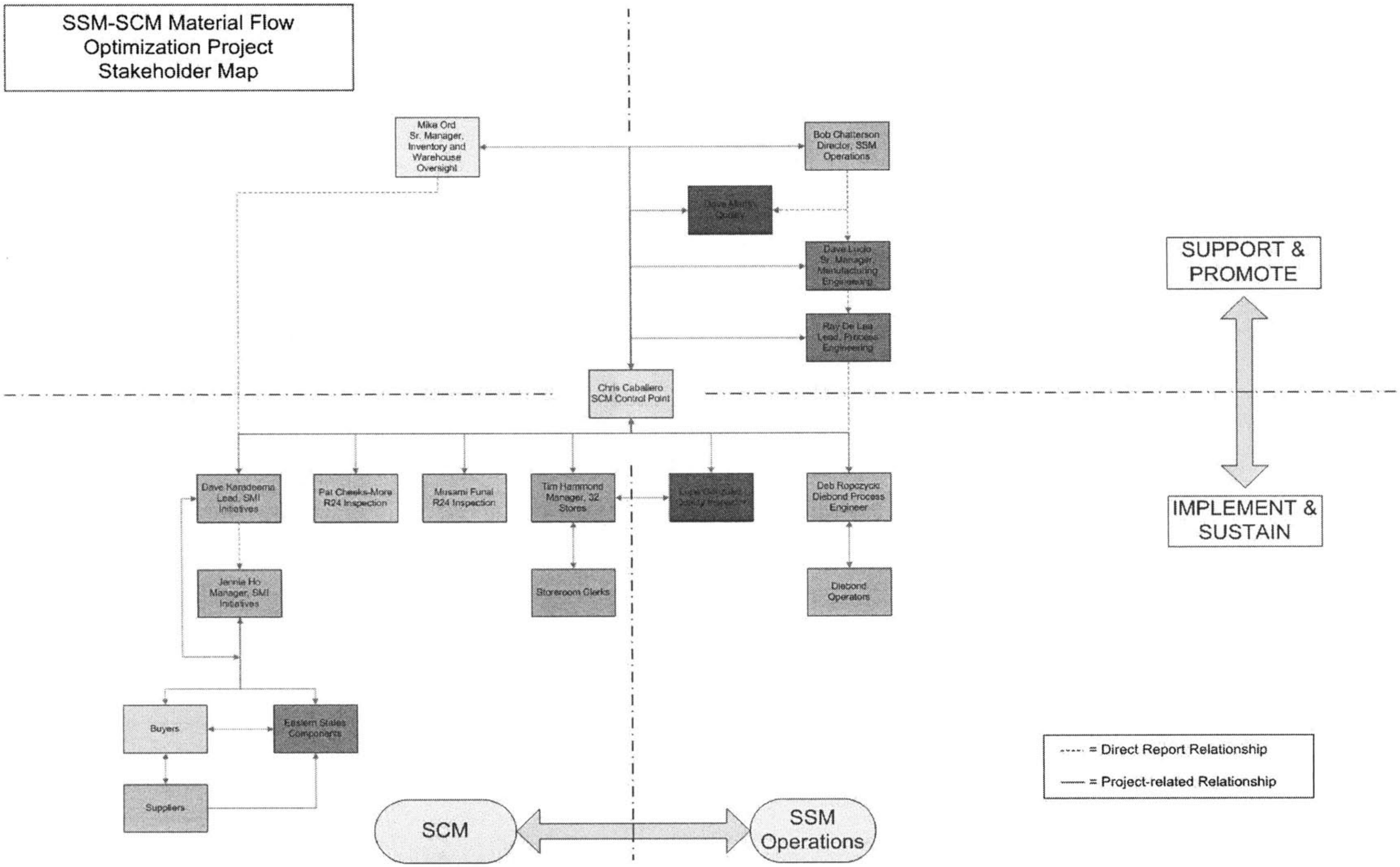


Appendix F: Sample Process Map for Full Project Implementation

Process Map:
Steady-State Process



Appendix G: Stakeholder Map



References

---

[1] 2004 Raytheon Annual Report

[2] Krishnan, Satish, 2004. *Driving a Lean Transformation Using a Six Sigma Improvement Process*, Mechanical Engineering and Management Program Thesis, Massachusetts Institute of Technology.

[3] Caballero, Chris, 2005. *Leading a Lean Transformation in the Wake of a Disaster*, Mechanical Engineering and Management Program Thesis, Massachusetts Institute of Technology.

[4] *Raytheon Six Sigma Two Day Specialist Training Guide*, 2000. Raytheon Learning Institutes.

[5] http://www.qualitydigest.com/may00/html/sixsigmapro.html (Accessed on 1/19/06)

[6] Womack, James P., Jones, Daniel T., 2003. *Lean Thinking*, New York: Free Press.

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

[8] Simchi-Levi, David, Kaminisky, Philip, Simchi-Levi, Edith, 2003. Designing and Managing the Supply Chain, 2nd ed., rev, Chicago: McGraw-Hill/Irwin.

[9] Carroll, John S., 2001. *Introduction to Organizational Analysis: The Three Lenses*, MIT Sloan School.

[10] Fine, Charlie, 1998. *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, Reading: Perseus Books.