Six Sigma Process Improvements and Sourcing Strategies Following Factory Fire

by

Sarah Egan

Bachelor of Science in Industrial Engineering, Northwestern University (1999)

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

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

In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2005

Signature of Author____
Sloan School of Management
Department of Civil and Environmental Engineering
May 6, 2005

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

Certified by____
Donald Rosenfield, Thesis Supervisor
Senior Lecturer of Management, Sloan School of Management

Accepted by____
David Capodilupo, Executive Director of Masters Program
Sloan School of Management

Accepted by____
Andrew Whittle, Chairman, Departmental Committee for Graduate Students
Department of Civil and Environmental Engineering

Six Sigma Process Improvements and Sourcing Strategies Following Factory Fire

by

Sarah Egan

Submitted to the Sloan School of Management and the Department of Civil Engineering on
May 6, 2005 in Partial Fulfillment of the Requirements for the Degrees of

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

Abstract

This thesis addresses Six Sigma process improvements and the supplier management issues resulting from the shift to external suppliers in the aftermath of a fire.

Originally, this thesis was to address a lean implementation in Raytheon's substrate fabrication area. It was intended to build on work done by Satish Krishnan, which focused on a lean implementation in a related area. However, a fire in Raytheon's El Segundo substrate area forced Raytheon to outsource substrate production and brought to the forefront a different set of challenging issues.

The fire shut down production for 21 days, creating pressure to capture lost ground once operations resumed. The increased demand and burden on resources during the recovery uncovered inefficiencies in key processes. One of the areas that increased in importance following the fire was magnet assembly. The first half of this thesis (Chapter 3 through Chapter 6) applies Raytheon's Six Sigma framework to the magnet assembly process in an effort to reduce non-value added work and increase standardization and control.

Six Sigma incorporates many of the principles of lean manufacturing, such as continuous improvement and the elimination of non-value added work. The first half of this thesis focuses on the Six Sigma framework because of Raytheon's strong commitment to the approach, rather than the larger set of issues in lean manufacturing.

Typically, the vertical integration decision is one of the key strategic choices facing a firm. The fire crippled Raytheon's substrate fabrication area and changed this decision from a strategic one to a tactical one. Rebuilding the substrate capability in El Segundo would require close to a year. In the short term, Raytheon was forced to shift substrate production from El Segundo to external suppliers or alternate internal sites.

The second half of this thesis (Chapter 7 and Chapter 8) addresses the issues associated with outsourcing a technically complex product. The initial substrate offload accelerated the timeframe for establishing suppliers and for dealing with concerns like intellectual property, coordination, dependency and the strategic consequences of outsourcing a key technology. This thesis attempts to address these implementation issues as well as the strategic implications of outsourcing substrates.

Thesis Supervisor: Donald Rosenfield
Title: Senior Lecturer of Management, Sloan School of Management

Thesis Supervisor: David Simchi-Levi
Title: Professor of Engineering Systems Division and Civil & Environmental Engineering

ACKNOWLEDGEMENTS

The author wishes to acknowledge the Leaders for Manufacturing (LFM) Program for its support of this work.

I would like to thank Raytheon for its sponsorship of the LFM program. It was a pleasure to work with such a dedicated and supportive group of people. In particular, I would like to thank Robert Chatterson, Richard Johnston, Dennis Coyner, Steve Dowzicky, Rodney White, Brooke Reed and Mark Talcott for their support of my project.

I am also grateful to my LFM advisors, Donald Rosenfield and David Simchi-Levi, and the rest of the LFM community.

(This page intentionally left blank)

TABLE OF CONTENTS

TABLE OF FIGURES

(This page intentionally left blank)

Chapter 1: Project Context

The Fire

On July 6th, a fire started under one of the hoods in Raytheon's Solid State Microwave (SSM) business unit. Solid State Microwave includes substrate and circulator production, which feed the antenna value stream (discussed below), as well as microwave integrated circuit (MIC) production. SSM provides inputs across many of Raytheon's product lines. Because of SSM's upstream position in the value stream, problems at SSM can ripple through the entire organization and lead to employee furloughs, internal schedule slips and even final customer delivery delays further downstream.

The fire added to Raytheon's challenges, but it also created an energy and openness to change. A cross-functional team which cut across the entire organization was pulled together in the immediate aftermath of the fire. The team first stabilized the area, and then catalogued the damage and impact to the business. Although the fire damage was extensive no one was injured and it was contained within the substrate fabrication area, a single room. Production throughout the area was stopped for 21 days and the substrate fabrication area, where the fire started, was taken off-line indefinitely. Secondary water damage from the more than 400,000 gallons of water used to fight the fire caused extensive damage throughout SSM.

The most severe consequences were avoided through the fire recovery team's exceptional efforts, but the fire and subsequent water damage estimates were in the millions of dollars. Photos of the substrate area immediately after the fire can be seen in **Figure 1**.

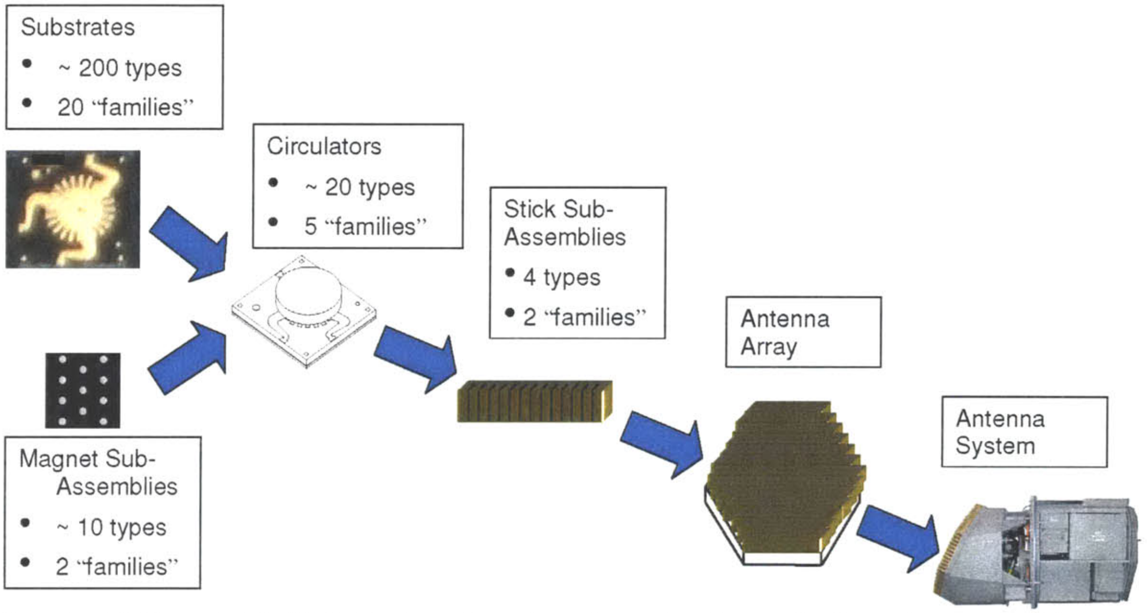
Figure 1: Aftermath of Fire

The Antenna System Value Stream

Raytheon's Space and Airborne Systems (SAS) business designs and manufactures products to enhance space and airborne missions, including active arrays for military aircraft. Active array antenna systems can both transmit and receive beams. These arrays enable pilots to electronically steer portions of the array to simultaneously navigate and track objects. Prior to active arrays, navigation and tracking could not be done concurrently.

The antenna system value stream is shown in **Figure 2**. This thesis focuses on substrates and magnet sub-assemblies, the furthest upstream inputs into the antenna system.

Figure 2: Antenna System Value Stream



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

Value Stream Components

Manufacturing antenna systems is a complex process and spans across locations and business units. In addition to local optimizations within these different areas, recent efforts have focused on the integration across the process. This thesis focuses on substrates and magnet sub-assemblies, which increased in importance following the fire in Raytheon's substrate production area.

Substrates: Substrates provide the basic mechanical structure and interconnects for different kinds of RF circuits. Prior to the fire, Raytheon produced over two hundred types of substrates that fed both microwave integrated circuits (MICs) and RF circuits (circulators). After the fire, substrate production was outsourced to three main vendors, and substrate production for circulators went to a single vendor in the northeast.

Magnet Sub-Assemblies: Magnets are applied to the substrate and help to control the flow of RF energy within a circuit. Magnets impact circulator performance. Magnet discs are sourced from an outside vendor, but magnetization and assembly is done in-house within the circulator area. The simultaneous increase in circulator volumes and the ratio of magnets to circulators has put increasing pressure on the magnet area.

Circulators: Circulators direct the flow of RF energy, allowing the circuit to transmit and receive simultaneously. Circulators are often referred to as the "traffic cop" of the antenna system. Energy is permitted to flow from the transmit port to the antenna port as well as from the antenna port to the receive port. RF energy is prevented from flow from the transmit port to the receive port. Circulators are relatively inexpensive, have low energy loss and importantly require no power or signal to operate.

Stick Assemblies: Stick assemblies are the structural housings for the circulators. Four types of "stick" assemblies exist and can be grouped in two families based on similarities within production methods.

Antenna Arrays and Antenna Systems: Antenna systems built on circulator technology allow a pilot to navigate the aircraft while tracking objects on the air and on the ground.

Chapter 2: Project Summary

Problem Statement (Burning Platform)

Raytheon refers to an identified need for change as a "burning platform". On July 6th, 2004, this metaphor became a reality when a devastating fire at the El Segundo facility crippled the Solid State Microwave (SSM) business. The fire halted circulator production for nearly four weeks and forced Raytheon to outsource substrate production for circulator products, which had previously been done in-house.

The fire exacerbated the key challenges facing the circulator area, which includes magnet assembly.

- Circulator demand was forecasted to growth four-fold over two years, increasing the burden on operators and equipment. The growth in magnet sub-assembly demand would be even greater as the ratio of magnets to circulators was also forecasted to increase. The circulator and magnet assembly processes needed to eliminate waste and optimize the use of current resources.
- The fire forced Raytheon to outsource substrate production. In addition to production work, Raytheon relied on the substrate area for developing substrate prototypes, a key part of the circulator design process. The co-location of design engineers, substrate production and circulator production allowed for the free flow of ideas and quick turn around on prototypes. In additional to managing substrate supplier production, Raytheon needed to develop a plan for maintaining innovation without an on-site substrate facility.
- Problems with the outsourced substrates and other inputs like carriers and magnet sub-assemblies led to cost overruns and schedule slips on a number of programs.

Project Definition

Magnet sub-assemblies and substrates are important inputs in to the circulator process. The impact of magnet assembly inefficiencies and the substrate offload on circulator production and the antenna value stream is a recurrent theme in this thesis.

Magnet Assembly

The first half of this thesis applies the Six Sigma process improvement framework to magnet assembly. Circulator production and magnet assembly are done in the same room and share equipment and personnel resources. Although circulator and magnet assembly are deeply linked, the management of these areas lacks continuity. The process for circulator assembly is standardized, but the magnet assembly process is less clearly defined and requires significant engineering supervision. Because of this, operations management takes the lead on scheduling circulator lots and engineering takes the lead on magnet assembly scheduling. The disconnect between the heavily interdependent circulator and magnet assembly areas leads to many problems, discussed in detail later.

At the time of the internship, circulator costs on several key programs were running over budget. The higher costs were attributed to an increase in labor expense caused by damaged raw material that increased inspection and rework time. This thesis proposes that there were also substantial hidden costs within the magnet assembly process. Magnet assembly was generally viewed as filler work. An operator typically worked on magnets in conjunction with a circulator assembly task and allocated labor costs to the circulator task. Because of this it was difficult to really understand the true cost of magnet assembly. The discussion in the following chapters proposes that the growing inefficiencies in the magnet area were also contributing to labor cost overruns and uses the Six Sigma framework to propose improvements.

Substrate Offload

Raytheon produced substrates for circulators and microwave integrated circuits (MICs) at its El Segundo site. The second half of this thesis focuses primarily on the outsourcing of circulator substrates and the impact on circulator development and production.

Raytheon recognized the need to outsource a portion of substrate production prior to the fire. A technical team within Raytheon had begun benchmarking the capabilities of the supplier base. Raytheon had also been working to understand the costs of producing different substrate types in-house, in order to better compare costs by substrate type with outside suppliers. The El Segundo site produced more than 200 substrate varieties, with a wide range of complexity and technical sophistication. The intention was never to outsource all of substrate production, but to select commodity substrates for outsourcing while maintaining newer, propriety technologies for in-house production.

For the circulator based products, substrates are an integral part of development and the key driver of performance of the overall antenna system. Circulator substrates are a highly customized product and the supplier base for these types of substrates is very limited. Although the fire necessitated the outsourcing of substrates in the short term, reestablishing at least some circulator substrate capability internally is an important strategic consideration for Raytheon. This thesis examines the initial implementation of the substrate offload as well the strategic considerations for outsourcing substrates.

Project Goals

The goals of this project are to:

- Eliminate inefficiencies in magnet assembly by applying the Six Sigma process improvement framework (Chapter 4 through Chapter 7)
- Provide a framework for making longer term substrate outsourcing decisions (Chapter 8)
- Understand and develop tools for mitigating the risks associated with the circulator substrate offload for both production and design work (Chapter 9)

Chapter 3: Six Sigma – Visualize, Commit & Prioritize

Six Sigma Framework

The Six Sigma process was originally implemented at Motorola in the early 1980s in an effort to improve quality measurement. It was aimed at minimizing waste and producing identical product with extremely low defect rates.[1] Like many companies, Raytheon has adopted its own version of the Six Sigma process, which is based on benchmarking with Allied Signal and General Electric. It expands on the Motorola Six Sigma process, which focused on design and manufacturing, and includes all organizational processes and functions.

Raytheon Six Sigma is essentially a roadmap for implementing change. It involves six steps: Visualize, Commit, Prioritize, Characterize, Improve and Achieve. Although Six Sigma incorporates many of the ideas of lean manufacturing it differs in its objective. Six Sigma is a method for implementing change, while lean manufacturing defines the nature of the changes.

The Six Sigma method attempts to define value in terms of the customer, identify the value stream, eliminate waste and variation, make value flow at the pull of the customer and continuously improve. All of these ideas are attributes of a lean manufacturing system. The Six Sigma framework provides a method for identifying and implementing various aspects of lean.

Visualize

The first step in the Six Sigma process is to define the clear and pressing need for change and create a vision for the future.

Magnet Sub-Assembly Process

Magnets are an often overlooked component in the antenna value stream. The low cost of magnet discs can be misleading and result in underestimating the total cost of the

---

[1] Source: http://www.isixsigma.com/library/content/c020815a.asp accessed on April 2, 2005

magnet sub-assembly process. Magnet assembly is an ad-hoc and poorly defined process, which requires significant labor and engineering supervision to ensure it is done correctly. Also, there is a disconnect between the management of magnet production and the management of circulator production. Both magnets and circulators utilize the same personnel resources and share the same physical space, making it essential for there to be clear communication and coordination between the two areas. Problems with magnet assembly highlight several clear needs:

- To simplify and standardize the magnet sub-assembly process
- To monitor and track magnet assembly costs
- To integrate magnet sub-assembly with downstream circulator demand
- To develop an inventory control system for magnets

In addition to these tactical improvements, a value stream analysis throws in to question the amount of value being added by the magnet sub-assembly process. The majority of steps performed in magnet assembly are done to prepare the magnets to interface with circulator assembly robots downstream and do not add any value to the end customer. An entire shift might be spent positioning the magnets for further processing, without making any meaningful impact on the magnets themselves. Value is defined by the ultimate customer (Womack & Jones, 2003, p. 20). Although there are legitimate reasons for many of the magnet sub-assembly steps, shifting magnets between plates does not create value for the end customer.

Commit

The second step in the Six Sigma process is to commit. No project is successful unless the vision of the project is aligned with the vision of the people responsible for implementing and maintaining its results. Across the circulator area and its inputs, aligning the vision of key stakeholders can be a difficult task. Over the past two years, Raytheon has been transitioning the management of circulator production, which includes magnet assembly, from its engineering to its operations organization.

Thanks in part to the work done during Satish's internship there has been significant progress in aligning the vision for circulator assembly, but the vision for magnet assembly has lagged behind. The impact of inefficiencies within magnet assembly is often overlooked. The support of the Director of the area as well as several key members of the operations and engineering staff has helped draw more attention to the growing cost of magnet assembly as well as the impact magnets have further up the value stream. Quantifying the cost of schedule delays, equipment failures and increased labor generated by magnets has also created a greater willingness to improve the process.

Raytheon has a strong commitment to the Six Sigma process and the culture of continuous improvement. Raytheon has worked hard to disperse Six Sigma process knowledge through all ranks and businesses. At the time of the internship, 100% of salaried and more than 50% of bargaining unit employees in SSM had been certified as Six Sigma specialists. Areas for improvement are openly discussed at weekly meetings with the engineering and operations organization. Daily meetings at the beginning of each shift are also used to brainstorm potential improvements and communicate changes.

Prioritize

The third step in the Six Sigma process is to prioritize. To successfully complete a large project it is necessary to set and prioritize goals. This defines the project scope and identifies resource needs. Without a clear plan of action it is difficult to know when you have veered off-course.

The action plan for implementing Six Sigma in the magnet sub-assembly area includes the following goals:

- To understand and measure the costs associated with magnet assembly. Identify inefficiencies within the process.
- To simplify, standardize and document magnet assembly processes.
- To develop a visual inventory control system for assembled magnets.

- To develop tools for integrating magnet assembly in to the circulator production tools. Magnet assembly shares resources with circulator assembly and should be reflected in circulator resource planning.

Chapter 4: Six Sigma - Characterize

Characterize is the fourth step in the Raytheon Six Sigma process. Data was gathered through interviews and time studies. Manufacturing metrics, present and future value stream mapping and six sigma training tools like identifying undesirable effects were used to analyze and identify problems.

Magnet Sub-Assembly Process

Magnet assembly is a very simple process. Metal discs are magnetized, stabilized through temperature cycling and dealt out on plates in order to interface with the automated machinery in the circulator assembly process. The magnet assembly process varies depending on two attributes: (1) whether or not magnets have pre-attached spacers and (2) whether magnets require screening.

Pre-attached Spacers: For a small number of product lines, spacers are attached to magnets during magnet assembly. The resulting magnet sub-assembly is then attached to the substrate in one step during circulator assembly. For product lines without pre-attached spacers, the spacers and magnets are attached separately during circulator assembly, in two steps.

Screened versus Unscreened: A more meaningful difference in processing can be found between screened and unscreened magnet products. The strength of each magnet in a given magnet lot is not identical. Magnets are screened where necessary to meet circulator performance requirements with high test yields. This is not required on all programs. For programs where the circulator design is sufficiently robust to handle the normal magnet variation screening is not required. Because the process for screening magnets is still being developed, products requiring screening have more than double the processing time and significant support from the engineering organization.

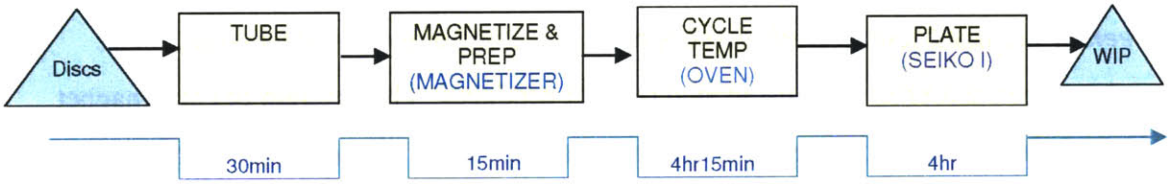
Magnet Process Flows

Magnets are processed and stored on steel plates measuring fifteen inches by nine inches. Each plate stores approximately 1,000 magnets and magnets are between 100 and 300 mils in diameter. The number of each type of magnet needed for an antenna system varies by program from less than one hundred to close to twenty thousand.

Unscreened Magnets

The magnet process flow for unscreened magnet products is shown below in Figure 3. Equipment utilized is shown in blue text in parentheses and estimated process times per 1,000 magnets (one plate) are shown below. The process for unscreened magnets is very straightforward and involves a limited number of steps and only three pieces of equipment. Metal discs are put in to plastic tubes (TUBE) and magnetized. The magnetized discs are removed from the tubes and placed in stacks on a metal plate in preparation for stabilization in the oven (MAGNETIZE & PREP). Once stabilized (CYCLE TEMP), magnets are dealt out one by one on to a fifteen by nine inch magnet storage plate (PLATE).

Figure 3: Unscreened/No pre-attached Spacer Process flow



Note: Times are standard estimates for a magnet plate of 1,000 magnets

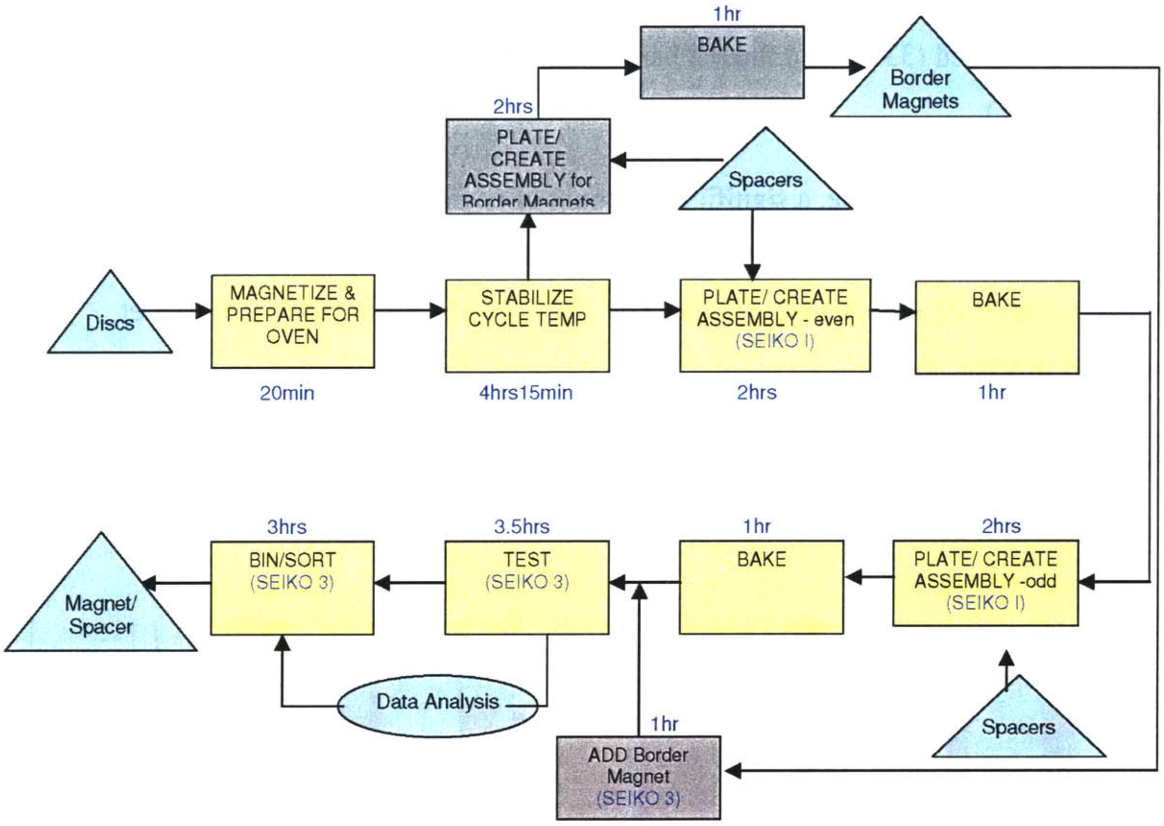
Screened Magnets

The process for screened magnets is more complex than the unscreened process. The primary loop (processes in orange) includes the steps for unscreened magnets in addition to the testing (TEST) and binning (BIN/SORT), where acceptable magnets are identified and grouped together on designated plates.

The process flow in **Figure 4** is for a screened magnet product which uses pre-attached spacers. The interaction between magnets is a problem for magnets with pre-attached spacers. Spacers are attached using epoxy, which must be baked in order to cure the seal. When magnets with pre-attached spacers were placed in close proximity prior to curing, the magnets would shift and alter the position of the spacer. To overcome this problem, magnets for even and odd positions on the plate are dealt out on the plates separately and the plate is baked in between to fix the seal between the magnets and spacers.

The secondary loop (processes in gray) was also put in place to overcome the magnet interaction discussed above. In order to have a balanced force on each of the magnets on the plate, approximately 65 border magnets were manually added to each plate later in the process.

Figure 4: Screened/Pre-attached Spacer Process Flow



Note: Times are standards estimates for a magnet plate of 1,000 magnets

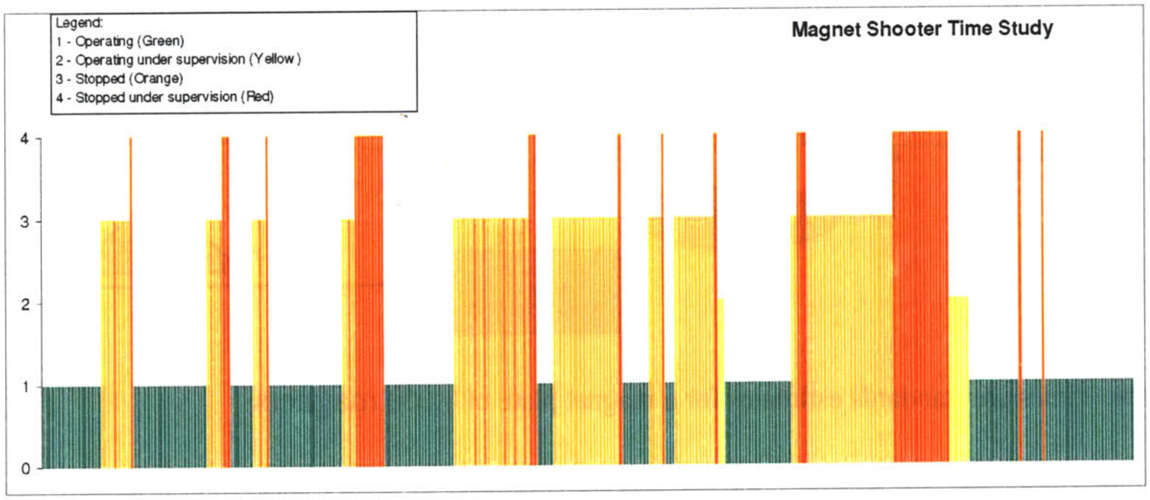
True Cost of Magnet Assembly

As described in previous chapters, magnet assembly is an often overlooked process. Because labor is not directly allocated to the process, the true cost is not understood. Based on time studies done over two days, operators spent an average of 15% of their time on magnet assembly while billing their labor to other processes. Because the magnet assembly costs are hidden, there is limited incentive to address inefficiencies in the process.

The machine for dealing magnets out on plates was designed to be able to run for more than three hours with no operator assistance. Currently, even under ideal conditions it runs for at most 30 minutes uninterrupted and can stop as frequently as every few minutes. A graph showing machine downtime and required operator supervision can be seen in Figure 5. The green bars represent when the machine is running unaided (53%), the yellow bars when the machine is running under supervision, the orange bars when the machine is stopped (33%), and the red bars when the machine is both stopped and being serviced (12%).

In addition to operator time, a significant amount of engineering supervision was needed to ensure that the non-standardized process was performed correctly. Based on this data, magnets contribute significantly to labor costs that are not attributed to the magnet assembly process.

Figure 5: Magnet Shooter Time Study



Value Creation

When evaluating a process for improvement opportunities it is important to focus on the contribution each process makes to the value of the product. Womack and Jones classify actions in to three categories based on the value they add to a product: (1) those which create value to the customer; (2) those which create no value but are required by the process (Type I muda); and (3) those that don't create value or aid the process and can be eliminated immediately (Type II muda) (Womack & Jones, 2003, p. 39).

Type I Muda

The basic role of the magnet assembly process is to prepare the magnets for loading on to a machine further downstream. The tubing of magnets and the dealing out of magnets on plates adds no value to the end customer and they act solely as enablers of the current production process (Type I muda). Together these to steps represent fifty percent of the processing time for unscreened magnet products. Within the unscreened magnet process only magnetization and stabilization through cycling temperature make a fundamental change to the end product.

The screened magnet process creates more value for the customer because the testing of magnets has an impact on the performance of the product, but it still contains many process-enabling, non-value added steps such as dealing the magnets out on plates.

Type II Muda

In addition to the Type I muda discussed above, the magnet assembly process has a number of steps that add no value to the customer or to the process and can be classified as Type II muda. A key tool in the Raytheon Six Sigma process is the identification of undesirable effects in the current state. Undesirable effects are direct observations of key problems in the process. Several such conditions existed for the magnet process and are identified below.

- ***Magnet Tooling:*** The process for dealing magnets out on plates was designed to be automated. The original goal of the tooling was to have it operate uninterrupted for up to three hours. Age and problems with the software for the tooling has resulted in the machine operating unaided for at most 30 minutes, even under ideal conditions. On many occasions it runs for only a few minutes before requiring operator attention.

The unreliable machines require large amounts of operator attention. Data gathered over a two day period found that operators spent an average of 15% of their time on magnet assembly (see Figure 5).

- ***Dirty/Discolored magnets:*** The machine that deals magnets out on plates relies on optical sensors to locate the magnets. During the stabilization process, certain magnet metals become discolored, making it difficult for them to be "seen" by the magnet sensor. Unseen magnets are skipped and can cause additional complications for the already finicky magnet tooling.

  In response to the dirty magnets problem, operators clean the magnets by pressing them to tape to remove the dirt. Because of the small size of the magnets this process can take an entire shift for a single plate of magnets.

- ***Magnets too large for tooling:*** Several programs use magnets that are too large for the existing magnet tooling. In this case, operators must manually load each magnet on to the machine that deals out magnets. Not only does this require more labor, it also is more likely to result in mistakes like incorrect polarity.
- ***Single Points of Failure:*** Because the magnet assembly process is not codified or documented, it is highly reliant on the localized knowledge and input of the engineering staff. Many "single points of failure" can be seen throughout the process. Often, if the person needed to answer a magnet related question is not available, production halts until they can be tracked down.
- ***Pre-attached spacers:*** The use of pre-attached spacers contributes unnecessary complexity to the process. Pre-attached spacers require the dealing out on plates to occur in two steps and it creates the need for "work-arounds", like the use of

border magnets. Also, when too much epoxy is used or the epoxy is not applied exactly on center, magnets with pre-attached spacers can get glued to the plate, increasing attrition and process time and possibly causing quality problems.

- ***Unnecessary steps:*** Many steps, like the time consuming processing of border magnets, require significant resources, but add no value to the customer or to the product. Border magnets were put in place to overcome the problems caused by magnet interaction while maintaining the 1,000 magnets per plate. Border magnets can be eliminated simply by allowing for plates with fewer than 1,000 magnets. Eliminating the use of pre-attached spacers should also be considered. Without pre-attached spacers, both border magnets and the need to plate odd and even magnet positions in separate steps disappear.

- ***Disorganization:*** Both empty and full magnet plates are stored in a series of shelves in the magnet storage unit (See **Figure 6**). Many of the plates contain unique magnet plate numbers, but approximately a quarter are unlabeled. Usable and unusable magnets are stored next to one another and someone "in the know" often needs to direct operators on which plates to use and which lots to process.

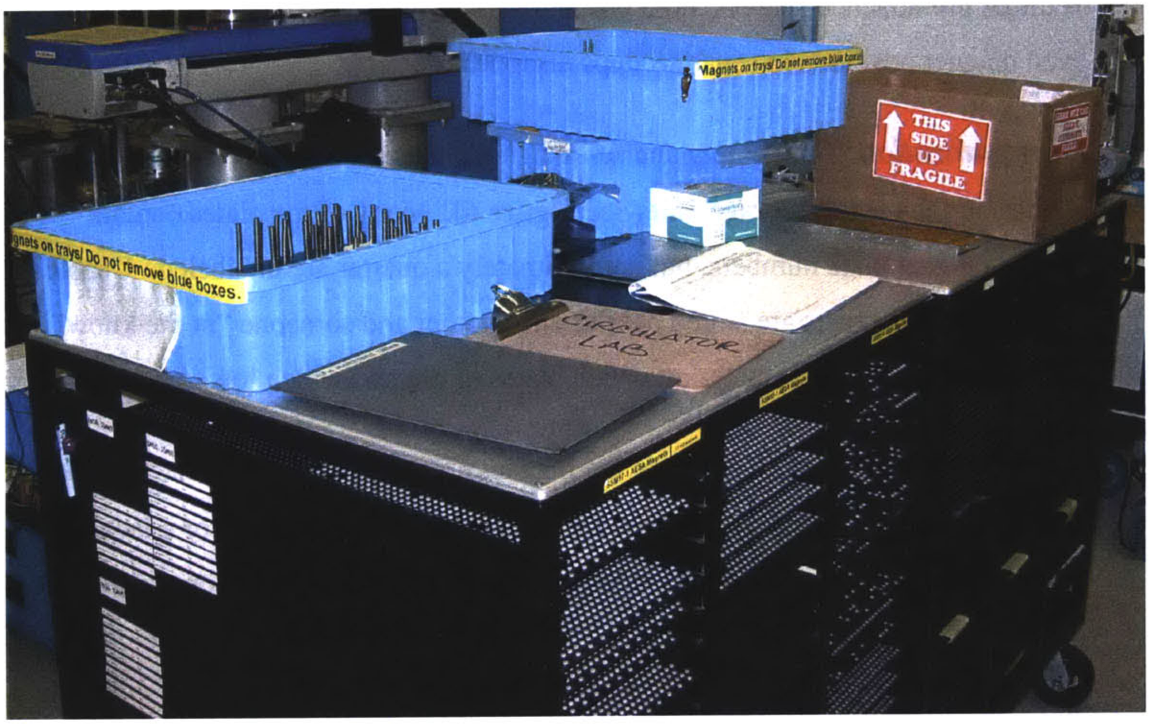
- ***Unnecessary Rework:*** Rework in the magnet process can often be traced back to the lack of organization. Magnets are placed on the wrong plates or a lack of documentation that a step has been completed leads to steps being done more than once or on the wrong plates.

- ***Poor Communication:*** Although magnet assembly feeds circulator assembly and the areas share resources and equipment, there is limited coordination between them.

- ***Raw Material Problems:*** Circulator inputs, like carriers, arrive damaged and operators are spending time inspecting each part prior to processing. Inspection also occurs at other points in the process and there is not a clear boundary between identifying quality problems and potential over inspection.

- ***Developing Process for Screening Magnets:*** The method for screening magnets is not fully developed. The measurement tools and tolerances around this process are still being defined. Due to magnet strength distribution differences across lots, unique bin ranges are currently created for each lot. With the establishment of uniform bin ranges, the testing and sorting steps could happen simultaneously, saving two to three hours for each plate of 1,000 magnets.

Figure 6: Magnet Storage Unit



Impact on circulator production

When volume through an unstable process increases, problems become more visible. The simultaneous increase in both the number of circulators produced and the number of magnets per circulator brought to light previously hidden challenges in the magnet area. Although at the time of the internship there was sufficient capacity in the magnet area to meet circulator needs, the projected increase in multiple magnet circulators could rapidly lead to magnet assembly becoming the process bottleneck. Also, true magnet capacity is overestimated because unreliable magnet tooling cannot run at theoretical rates.

In addition to the lack of standardization and high cost of magnet assembly, problems in the area have impacts further down the value chain. Circulator production is put on hold when magnets are not ready in time. Because magnets enter the circulator line in the middle of production, scheduling slips can cause a circulator lot to be stopped in the middle of its run, greatly increasing cycle time and delaying production of other lots in the queue.

As volumes increase, magnet assembly is taking up more operator time. Operators are often pulled away from circulator assembly in order to deal with magnet problems. Circulator operators work on magnet assembly as filler for downtime. While the intention was to utilize operators during automated parts of the circulator assembly process, the practice often pulls operators away from concentration intensive tasks, such as inspection. The decreased reliability of the magnet tooling with age and increased use has made this problem more severe.

Chapter 5: Six Sigma - Improve

The fifth step in the Raytheon Six Sigma framework is to improve. During the improve phase, data that is gathered and analyzed during the Characterize and Prioritize stages is synthesized and applied to create positive change.

Magnet Sub-Assembly Improvements

As a result of the analysis discussed in Chapter 5, many areas of improvement were identified and implemented. While some improvements are relatively simple to put in place (Quick Fixes), others require more fundamental change and were not completed by the end of the internship (Longer Term Solutions). For each of the changes described below the undesirable effects addressed are listed in parentheses.

Quick Fixes

- **Elimination of Border Magnets** *(Unnecessary Steps)* – Border magnets are used solely to have 1,000 magnets on each plate. Although this does reduce the need for magnet storage plates since approximately 65 more magnets can be stored on each, it does not add any true value to the process. Creating and placing border magnets around the edge of the plate adds approximately two hours of labor for each magnet plate. At current volumes this adds up to twenty hours per month.

- **Pre-tubed Magnets** *(Unnecessary Steps)*: For a couple of programs, magnets from the supplier are provided in tubes at no additional cost. There is no reason why all programs should not be using pre-tubed magnets, eliminating a non-value added operator step.

- **Schedule Linking Circulator and Magnet Production** *(Single Points of Failure, Poor Communication)* - The planning tool used to schedule circulator lots was expanded to include magnet assembly status, improving coordination and reducing schedule slips. Magnet and circulator production are now scheduled using the same tool allowing for better resource allocation and improved information on upcoming magnet needs. The visual circulator production chart, which shows the status of current lots on the floor, was expanded to include magnet assembly status.

- **Organization of Magnet Storage Unit** *(Disorganization, Unnecessary Rework, Single Points of Failure)* – Labels were created to enforce an "every plate has its place" rule and aid in controlling and tracking magnets through the system. Each magnet shelf has a unique code that corresponds to the same code on a magnet plate. Colored electrical tape was used to divide the storage area in to product line specific sections and magnet plates were coded by program. Since different plate finishes are used for programs with pre-attached spacers and programs without pre-attached spacers, identifying the plates by program eliminates costly mistakes and associated rework. The new organization gives operators a better understanding of what needs to be done and makes them less reliant on direction from the engineering staff. It also gives a quick view of magnet inventories, highlighting shortages before they hold up production.

- **Magnet Inventory System** *(Disorganization, Single Points of Failure)*: The reorganized storage unit provides a visual indicator of current magnet inventories, enabling a continuous review inventory model. Magnet re-order points and lot sizes were established for each program based on available storage space and demand.

  There are many motivations for holding inventory including economies of scale, logistics and protecting against uncertainties in demand and lead time. For magnets, the most important of these factors is the protection against uncertainties in lead time. As described above the magnet process lacks predictability. Unreliable equipment and lack of information lead to highly variable process lead times. Without inventory protection, longer than expected lead times can lead to schedule slips further down the value stream.

  There are also costs associated with inventories, including holding costs, order costs and shortage costs. Holding costs include the cost of the physical space to store the items, breakage, obsolescence and the opportunity cost of alternative investments. Order costs include set up costs for internally produced inventory and receiving, handling and explicit vendor charges for externally procured inventory.

The Economic Order Quantity (EOQ) Model

EOQ is the simplest inventory model and provides the basis for more complex models. By assuming a known and constant demand, no shortages, no order lead time and known set up cost, order cost and holding cost, the model predicts the optimal order quantity Q* for each product (Nahmias, 1997, p. 213).

$Q^* = \sqrt{2K\lambda / h}$ (Equation 1)

Variables for each product i are defined as:

$Q^*(i)$ = economic order quantity
$K(i)$ = fixed order cost
$\lambda(i)$ = demand per period
h = holding cost per unit per period

The simplest version of EOQ does not include order lead time or constraints imposed by budget or space limits for inventory, both of which are important factors for magnet sub-assembly inventories and are addressed below.

Variability in Lead Time

The Continuous Review Model expands EOQ to include lead time uncertainty and assumptions of service level. (Simchi-Levi, Kaminsky, Simchi-Levi, 2003, p. 62). The previous EOQ model assumed no lead time and Q* was ordered when inventory reached zero. A positive lead time requires a reorder point greater than zero to accommodate lead time demand. Also, because there is uncertainty in the magnet assembly process, there is variability in the lead time and therefore the demand over the lead time.

For each product the following variables are defined and used to determine Q* and the optimal reorder point, s:

$K(i)$ = fixed order cost
$\mu demand(i)$ = average demand per day
$\mu lead\_time(i)$ = average lead time (days)
$\sigma lead\_time(i)$ = standard deviation of lead time
$\sigma demand\ (i)$ = standard deviation of daily demand
h = holding cost per item per unit time
α = service level with probability of stocking out equal to $1 - \alpha$

The reorder level, s, consists of two components, the average inventory required during lead time and the buffer inventory or safety stock that accommodates any variations in lead time demand.

The second component, safety stock, depends on the safety factor, *z*, derived from the targeted service level. The safety factor, which protects against lead time shortages, is chosen to ensure that the probability of stockouts is exactly $1 - \alpha$. A z-value of 1.29 assumes a 10% probability of stockout and a z-value of 2.05 assumes a 2% probability of stockouts. Magnet assembly lead time is based on internal production and is not dependent on an external supplier so management has some ability to expedite essential orders. Because of this, a lower service level of 90% is probably acceptable.

The reorder level for each product, *i* is calculated as follows:

$$s = \mu demand \times \mu lead\_time + z\sqrt{\mu lead\_time \times \sigma^2 demand + \mu^2 demand \times \sigma^2 lead\_time}$$

(Equation 2)

In reality, the demand is known, but there is significant demand variability. The *σdemand* term is used to represent demand variability and not uncertainty.

Constraints on Magnet Storage

The Continuous Review Model does not take in to account potential constraints on budget or physical space available to store inventory. The magnet storage unit has a finite capacity and for product lines with with Q* plus safety stock exceeding available capacity. EOQ should be calculated incorporating these constraints, which can be done through the use of Lagrange multipliers.

- **Improved Documentation** *(Disorganization, Poor Communication, Single Points of Failure)***:** The addition of magnet lot numbers to the circulator process routers provides a mechanism for measuring the impact of magnets on high level assembly performance. Previously there was no way to trace what magnet lots went in to what antenna systems.
- **Process Changes** *(Magnets too Large for Tooling)***:** Magnets for several programs are manually loaded on to the magnet plates. Later, during circulator assembly they are removed from the plates and applied to the circulator substrate. With a simple coding update these magnets could be manually loaded during circulator assembly. Although this would still be more labor intensive than the traditional automated process it would reduce cycle time by approximately four hours for every 1,000 magnets. Instead of manually loading the magnets on to plates, where they would then need to be picked for circulator assembly, the magnets could be manually loaded to circulator assembly.

Longer Term Solutions

Many of the problems with the magnet process can be attributed to Type I muda, actions that add no value, but are currently required for the production process and Type II muda, actions that add no value and can be immediately discontinued. The improvements discussed above mainly address Type II muda. Because eliminating Type I muda requires changes to the production process, these improvements are often more difficult and timely to implement.

- **Elimination of Dealing Out Magnets on Plates:** As mentioned in previous chapters many of the magnet assembly steps add little value to the end consumer. Raytheon should investigate easier ways for magnets to be prepared for future circulator assembly, such as using stacks or tubes of magnets for circulator assembly and eliminating the need to put magnets on plates. This is particularly appealing for unscreened magnet products, which do not require any additional testing or grouping once they are magnetized and stabilized.

  Eliminating magnet plates offers other advantages in addition to significant savings in process and operator time. Right now, a very small volume of product takes up a huge footprint within the circulator lab. If circulator assembly was configured to interface with stacks instead of plates of magnets, the large storage bin shown in **Figure 6** could be removed, freeing up much needed floor space. Also, the dealing out of magnets on plates utilizes large, expensive equipment that could be adapted to other uses within Raytheon or sold.

- **Limited Tracking of Magnet Assembly Costs:** There is a trade-off between the cost of inaccurate cost data and the cost of measurement (Cooper & Kaplan, 1999, p. 216). By not allocating the true resource costs to magnet assembly, Raytheon is getting a skewed picture of the expense. However, the cost of monitoring and tracking technician and engineering labor costs of the area could be extensive. Raytheon should seek a balance between the cost of inaccurate information being used to make decisions and the cost of measurement. Simple tools to get a ballpark figure on operator time based on the number of equipment stoppages and average time to service would be relatively inexpensive to implement and shed light on the hidden costs of magnet assembly.

- **Combining Testing and Binning in to One Step:** Right now the information to create screened magnet subgroups is done separately from the actual physical grouping of the magnets. Because the parameters for the magnet subgroups are not standardized across lots, the magnet strength for each magnet in a lot must be recorded before parameters for that lot are defined. During physical testing magnets are lifted off the plate for testing and replaced in their original position. After all magnets are tested, they are then lifted off the plate and moved to a designated plate based on the pre-recorded magnet strength.

The engineering staff is currently working towards pre-defined strength parameters that would enable the simultaneous testing and physical segmenting of magnets, potentially cutting process time for each plate of magnets by three to four hours. There are several complexities that might make this difficult. First, the variability in magnet strength across lots makes it difficult to define magnet grouping parameters ahead of time. Also, the change would require a significant investment in rewriting the software that currently runs the process.

- **Consider Magnet Outsourcing:** Raytheon should consider whether it should be processing magnets at all. Although testing and binning of magnets do have an impact on performance, the tubing, magnetization, stabilization and organizing of magnets are not core capabilities for Raytheon. At least some parts of the magnet assembly process might be pushed back to the metal disc providers.

Chapter 6: Achieve

Achieve is the final step in the Six Sigma process. Once improvements have been identified they must be implemented, measured and sustained in order for changes to have a lasting impact on the organization.

Among the steps that must be completed to ensure that achievement is sustained are:

- Defining responsibilities and support for the revised process
- Training, education and communication of the new process
- Measurement to track results and compare against expectations
- Maintaining focus on continuous improvement

Metrics and Measurement

In order to ensure that changes to the magnet assembly process actually improve performance, several metrics should be used to track progress. Right now various statistics are kept for circulator production such as lead time, yield, on-time delivery percentages and labor costs. There is very limited data collection for magnet assembly, which be contributing to the tendency of management to overlook problems with the magnet assembly process.

Any time metrics are proposed there is a trade-off between the amount of time and resources needed to track information and the amount of value that can be captured from that information. The following measures would provide valuable insight in to the predictability of the magnet process with minimal investment on the part of management.

- ***Lead time:*** The lead time for magnet assembly is difficult to predict. Equipment problems and the use of magnet assembly as filler work contribute to lead time variability, increasing the schedule risk for the overall value chain. A better understanding of the lead time can also be used to more closely estimate the required inventory for magnet sub-assemblies.

- ***Magnet-related Circulator Delays:*** Magnet assembly is often overlooked because the impact on the process further up the value chain is not fully realized. Recording the number of circulator schedule slips stemming from magnet sub-assembly delays will help highlight the importance of this process to the overall system.

- ***Operator Labor Estimate:*** Allocating direct labor cost to the magnet assembly process would likely require a greater investment than the anticipated gains the new information would bring. However, some insight in to the time operators are spending assembling magnets is needed. Without any information on magnet labor, management may overestimate circulator labor and make inappropriate decisions.

  A couple of simple tools can be used to estimate magnet assembly labor with minimal added expense:

  - *Record Magnet Tooling Maintenance:* Combining a simple tally of the number of times operators service the magnet equipment and an estimate of standard service time can provide a rough approximation of magnet related labor.

  - *Operator Survey:* Asking operators to asses the percentage of time they spend working on magnets each week can also be used to estimate direct magnet assembly labor.

- ***Engineering hours/week:*** One of the biggest hidden costs associated with magnet assembly is the amount of engineering support required to monitor the process. Much of the work that engineering does for magnet assembly is not related to innovation, but rather to process management and should be transitioned to Operations Management within the circulator area.

Sustaining Achievement

Sustaining improvement is equally important to the initial achievement and must be worked on throughout the Six Sigma process. From as early on as the vision statement it is important to gather support from throughout the organization, particularly among the people responsible for managing change on a day to day basis. In order to ensure that the improvements generated by the Six Sigma process would be institutionalized it was essential to involve key stakeholders from the beginning. Ideas were generated from the broad group working in the circulator area, including Operators, Operations Management, Process Engineering and Design Engineering.

Although buy in from stakeholders is important, additional steps also need to be taken. Some of the process changes put in place can be understand implicitly. The new organization of the magnet storage unit is an example of this type of change. Other changes, like the inventory management system require training and documentation to ensure the improvements are adopted. In an effort to support the changes in the magnet area, a set of run rules was drafted and is posted in the magnet assembly area. Operators were involved in developing various process improvements and training on revisions to the process were communicated during the daily morning meeting.

Conclusion

Six Sigma process change attempts to examine all aspects of a process in an effort to define the value stream, specify value in the eyes of the customer, eliminate waste and variation and continuously improve in the pursuit of perfection. The Six Sigma framework gives employees a common language to discuss and implement change.

Several important lessons came out of applying the Six Sigma framework to the magnet assembly process. First, it highlighted the necessity of looking at a problem from more than one point of view. Incorporating information from the diverse group of stakeholders impacted by magnet assembly gave a deeper knowledge of the underlying drivers of the current process. Also, it is essential to understand what is important to key stakeholders to successfully sell change. Finally, focusing on a small, often overlooked process like magnets highlighted that seemingly simple processes can hide significant costs.

Chapter 7: Supplier Management – Vertical Integration Decision

The decision about what to outsource is one of the most crucial that a firm can make. This chapter analyzes the choice to outsource circulator substrates independent of the fire, which made outsourcing, at least in the short term, unavoidable.

Beckman and Rosenfield lay out a framework for making a vertical integration or disintegration decision by examining four dimensions: strategic factors, which focus on the criticality of the function to the firm's core business, market factors within the industry such as the available supplier base, product and technology factors and economic factors, which consider the cost trade-offs between outsourcing and retaining ownership (Beckman and Rosenfield, Chapter 2). In an ideal world, companies would own only activities within its core capabilities and would outsource others. However, the decision is more complex when evaluated in the context of capacity needs, potential business disruptions, such as the fire, quality of the supplier base and economic considerations.

Strategic Factors: Core Capabilities Screen

Although in some applications substrates can be viewed as a commodity product, circulator substrates are integral to circulator design and antenna system performance. Much of the innovation in the antenna systems takes place at the substrate level. The critical and integral nature of substrate design to circulators makes it core to Raytheon's business.

Capacity/Capability Factors

Charles Fine discusses the role of dependency, which would be a subset of strategic factors within the Beckman and Rosenfield framework. The need for outsourcing may result from two categories of dependence: dependency for knowledge and dependency for capacity (Fine, 1998, p. 166). Raytheon's internally produced substrates fed several product lines, including microwave integrated circuits (MICs) and circulators. Prior to the fire, Raytheon was independent for knowledge, but recognized its growing dependence for capacity as volumes increased. One of the reasons the substrate area was chosen as the initial target for this project was Raytheon's desire to explore the use of lean to increase substrate production capacity without a large capital investment. While Raytheon wanted to evaluate how lean manufacturing techniques could be used to increase capacity, it had begun to prepare for the inevitability of outsourcing.

Market Factors

Beckman and Rosenfield address three major market factors: market reliability, aggregation of demand and market structure. Market reliability refers to the ability of the supplier base to meet cost, availability, quality and feature needs. Aggregation of demand affects the ability of suppliers to achieve economies of scale. Market structure identifies relative market power and interdependencies across the supply chain.

External Suppliers

In anticipation of additional substrate outsourcing, a significant amount of work had been done to benchmark suppliers in the months leading up to the fire. The supplier base for the garnet-based substrates used in circulators was very limited and consisted of a few small, specialized players. There were few suppliers with the capability to produce them and all available suppliers would need some training and technical support in order to become operational. Even the raw materials used for circulator substrates are only provided by a few specialized suppliers. The overall supply chain for antenna systems is shown in Figure 2. A more detailed look at the value chain for circulators is shown in Figure 7.

Only two of the major defense contractors are large players in circulator development. The potential substrate suppliers for the circulator industry are highly fragmented and typically specialize in a technology or material type. Although several suppliers had the equipment and capacity to produce substrates, the specialized technical knowledge required for circulator substrates was difficult to find. Raytheon chose to outsource circulator substrates to an East Coast supplier that had previous experience on one of the less complex circulator products. The supplier had more than sufficient capacity, but required significant technical support from Raytheon's design and process engineers prior to beginning production.

Internal Suppliers

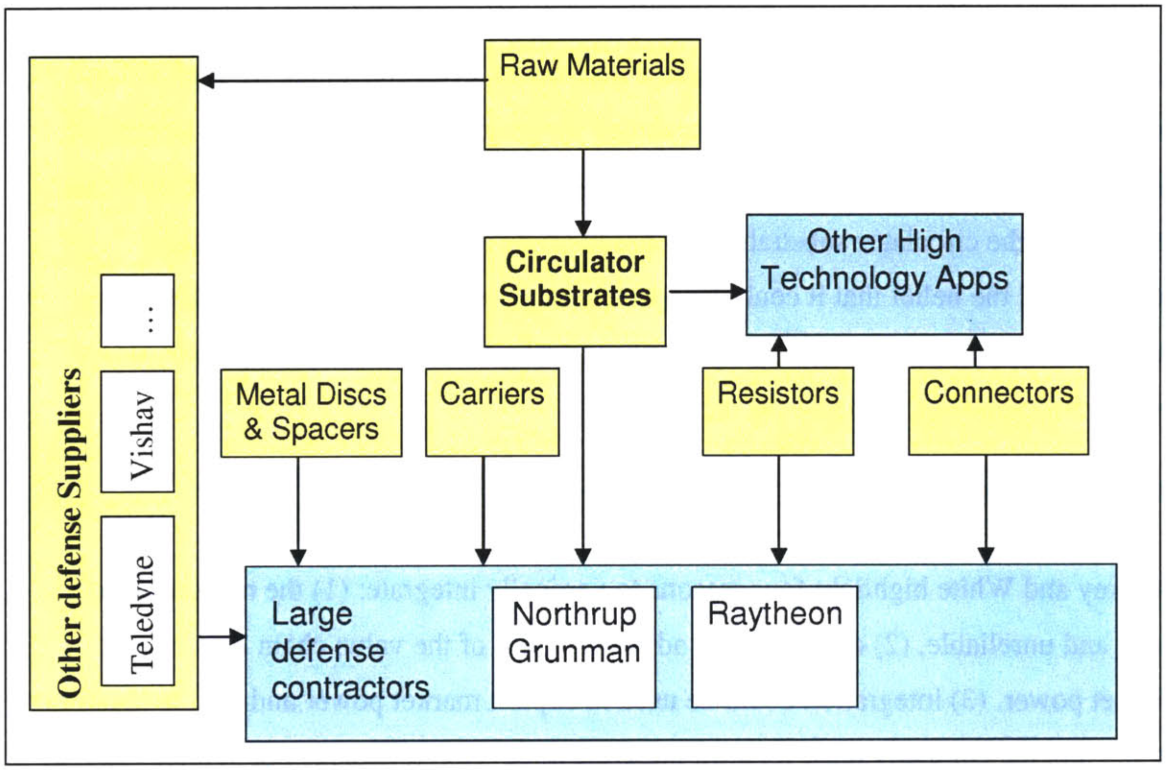
Raytheon's Texas facility had an advanced substrate fabrication suited for high volume production. Raytheon El Segundo outsourced the majority of its microwave integrated circuit (MIC) substrates to Texas following the fire. The decision to use the East Coast supplier for the circulator substrates was based on its previous work on circulator products and the belief that it could be operational in less time. The role of the Texas facility is important when evaluating whether to rebuild El Segundo's capability or to extend the capability of the Texas facility.

Vertical Market Failure

Stuckey and White highlight four reasons to vertically integrate: (1) the market is too risky and unreliable, (2) companies in adjacent stages of the value chain have more market power, (3) integration could be used to exploit market power and (4) the market is young and the company must forward integrate to develop it (Stuckey & White, 1993, p. 71). The most important of these reasons for Raytheon is the first one, which can lead to Vertical Market Failure (VMF). VMF would be considered under the market factors category in the Beckman and Rosenfield framework.

The typical features of a failed vertical market are (1) a small number of buyers and sellers; (2) high asset specificity and (3) frequent transactions. Each of these conditions holds for the circulator substrate market, increasing the risk for vertical disintegration. Circulator substrates are an evolving technology and there are a small number of fragmented providers. There is also a high degree of technical specificity. Like auto assemblers and their component suppliers, who can be locked together by a component that is specific to a make and model, each circulator substrate is unique and can only be used by its designated product line. Finally, the high volume of circulator substrate product required frequent transactions although longer term price contracts can be established.

Figure 7: Circulator Value Stream



Product and Technology Factors

Vertical integration decisions require an understanding of the relationship among technology knowledge, products or services that apply that technical knowledge and the operations needed to produce and deliver those products or services (Beckman and Rosenfield, Chapter 2). In Raytheon's case, the technical knowledge required for circulator substrates was proprietary. Although there were multiple substrate suppliers, the product is not standardized and Raytheon would need to share information and best practices to get a supplier operational. Circulator substrates are integral to the performance of the larger system, making it difficult to substitute alternative technologies. On the operations front, outsourcing risks the knowledge that is gained from refining a technical process. When manufacturing knowledge needs to be captured and codified there is always a risk that the "know how" will be maintained, but the "know why" will be lost (Fan, Russell, Lunn, 2000, p. 17). An integrated technology for which limited capabilities exist outside supports a decision to vertically integrate.

Economic Factors

The economic considerations for outsourcing were very different before and after the fire. Prior to the fire many of the traditional cost benefit trade-offs were examined to determine the desirability of outsourcing a subset of substrate products. Raytheon tried to determine the internal cost of producing different substrate types in order to compare external quotes with in-house production. This information could be used in conjunction with analysis of which products utilized the most proprietary technology to selectively outsource a subset of substrates.

While transportation costs are often a key economic factor when making an outsourcing decision, the small size and light weight of substrates made transportation less of a concern. There is some risk of product damage, however, since substrates are fragile and require specialized packaging for protection.

After the fire, economic impact was still relevant, but the need to keep product going out the door increased in importance. Raytheon still cared about the relative cost of producing in-house versus purchasing from the outside. However, the decision became whether to rebuild the substrate capability and where, instead of which substrates to outsource if any. Also, the decision about whether to invest in internal capacity changed significantly. No equipment from the substrate area was salvageable and to re-create the previous capability would require a significant investment. Instead of evaluating whether an updated or second machine might offer a sufficient return on investment, Raytheon needed to consider whether it should rebuild its El Segundo substrate capability at El Segundo or an alternate site or whether it should expand its capability in Texas.

Vertically Integrate

In the absence of the fire, Raytheon should choose to maintain control of circulator substrate production. Strategic concerns, market factors, product and technology and economic factors all point to a vertically integrated strategy.

If the fire had not occurred, Raytheon's outsourcing decision would be easier. The substrate capability already existed. Instead of being forced to outsource all products on a very short time frame, Raytheon would have had the luxury to pick and choose what to outsource from the more than 200 substrate types, outsourcing commodity substrates and retaining newer, proprietary technologies, like garnet based substrates, in-house.

Following the fire, Raytheon has a very different choice. Instead of choosing to maintain garnet based substrates in-house, it must decide whether or not to recreate the capability internally. If it decides to recreate the capability, it must decide whether to do that at an existing site, like Texas, or whether to build a new facility at El Segundo or another site.

Chapter 8: Supplier Management – Substrate Offload Implementation

When dealing with suppliers, companies typically focus on increasing speed and cost effectiveness. Hau Lee contends that this increased efficiency does not give companies a meaningful edge over competitors. Instead, his research identifies three very different qualities as essential for top-performing supply chains: (1) agility, (2) the ability to adapt to changing market structures and strategies, and (3) the alignment of the interests of all firms across the supply chain (Lee, p. 104). These three elements together contribute to the robustness of the supply chain, allowing an organization to respond to unforeseen events, like the fire that disabled Raytheon's substrate production.

Agility has become even more critical in the past few years because there have been frequent and severe shocks to the global supply chain, such as the September 11th terrorist attacks in New York and Washington, D.C., the SARS epidemic in Asia and the dockworkers' strike in California. Lee focuses on several ways companies can build agility into supply chains, including sharing information, developing collaborative relationships, designing for part commonality, maintaining inventory on inexpensive, small components, utilizing logistics systems and putting together a team that knows how to invoke a backup plan.

The agility of Toyota's supply chain was evident in its fast rebound to a fire at its main source supplier of a crucial brake valve (Wall Street Journal, May 1997). Most Toyota plants kept only a four-hour supply and shortages of the $5 valve forced Toyota to shut down all of its 20 auto plants in Japan, which built 14,000 cars per week. However, by incorporating many of the methods suggested by Lee and described above, Toyota was able to restart production in just five days. Toyota moved quickly to share information and leveraged the strong collaborative relationships it had fostered with suppliers. After the fire, Toyota executives were more convinced that using a small number of suppliers with aligned incentives is the right approach. The fire did highlight some areas for improvement and Toyota began an effort to trim the number of parts variations and build contingency plans for sole-source suppliers.

Implementation: Initial fire off-load

After the fire, Raytheon moved quickly to shore up relationships with key suppliers to ensure that product continued to flow. The vast majority of unplanned substrate outsourcing across all products was allocated to three key suppliers, two of which were external and one of which was internal at Raytheon's Texas facility. All of the substrates for circulators went to an East Coast supplier, with whom Raytheon felt it had a strong working relationship.

This chapter focuses on the implementation challenges of the initial circulator substrate offload.

Because of the intense time pressure created by the fire, Raytheon required a supplier that would require little support to become operational. Based on this requirement, Raytheon chose to go with an East Coastsupplier that had been used on a previous circulator product.

The ramping up of production at the circulator substrate supplier on the East Coast differed from Raytheon's usual process in a couple of critical ways. Firstly, the time frame was accelerated. It can take months to choose a supplier for a major off-load and it typically requires various formalized process steps and check points. The East Coast supplier was chosen based on prior experience and preliminary technical benchmarking, but the choice was made less than a week after the fire. Also, Raytheon shared more information, materials and even in some cases equipment than is typical for an outsourcing relationship.

Understanding the Risks

As a result of the fire, Raytheon needed to outsource its immediate substrate needs and adapt its design process to work with an external rather than internal provider. The supplier base for advanced substrates is very limited. It consists of one large supplier, which supplies a broad spectrum of aerospace parts, and a number of fragmented smaller players specializing in a specific technology. Raytheon always planned on outsourcing some of its substrate production to accommodate increasing volumes, but wanted to maintain control over proprietary and developing technologies. Prior to the fire, Raytheon had begun benchmarking suppliers in the field. The fire accelerated this process and eliminated Raytheon's ability to discriminate what it wanted to outsource by product type. It also required that the supplier(s) chosen needed to be up and running almost immediately.

Proximity Risks

Proximity across the supply chain can be measured across four dimensions: geographic, organizational, cultural and electronic (Fine, 1998, p. 136). Prior to the fire, Raytheon's design team was in close proximity across each of these dimensions. The design engineers, substrate production and circulator production were all housed under the same roof in the same organization and utilized the same electronic data tools. Following the fire, Raytheon's design engineering, substrate and circulator units were forced from being geographically close (co-located) to being on opposite coasts.

The importance of being close on at least some of these dimensions is increased the more integral the design and the less easily parts can be swapped out and substituted. Substrates are the heart of the circulator design and the level where the majority of product innovation takes place. While Raytheon outsourced the production of the substrates, the design responsibility remained in-house. Post-fire, Raytheon needed to develop a process for sharing design files, prototyping and validating results with an external supplier. Raytheon also needed a method for remotely communicating demand needs and potentially shifting priorities.

Product and Technology Risks

In order for the supplier to begin production there was a significant amount of technical knowledge that needed to be shared. Previously, Raytheon's design team and production team were housed at the same facility within the same organization. The fire forced the separation of design and manufacturing. In order to transfer the required knowledge, Raytheon's key technical personnel went to the East Coast to facilitate the transition of production.

In addition to sharing personnel and their knowledge, Raytheon also shared its engineering drawings and production tools and materials not destroyed in the fire. Although this made sense in the immediate aftermath of the fire, if the outsourcing relationship was to continue long term, Raytheon would prefer to transfer some of these functions over to the supplier.

Dependency Risks

Outsourcing increases dependency on the supplier, particularly when dealing with a non-standard product like circulator substrates. Raytheon's risk was exacerbated by the fire. In a few hours, Raytheon went from being able to supply itself to having no choice other than to outsource. Obviously, this sudden change shifted the balance of power towards the supplier during the accelerated supplier selection immediately following the fire. The fact that Raytheon is a huge player in the aerospace industry mitigated this risk somewhat. Raytheon outsourced circulator substrates to a small subsidiary of a medium sized micro-electronics company. Raytheon's circulator substrate business made up a meaningful percentage of the substrate subsidiary's revenue.

Although its large relative size gave Raytheon some leverage during the initial negotiations, working with a small supplier has its own risks. The East Coast subsidiary, which focused only on substrates, had roughly $11 million in annual revenues. When its larger parent decided to divest the business, it was bought by a major aerospace supplier looking to expand its substrate business. The East Coast facility where Raytheon personnel had spent so much time transferring technical knowledge and completing first articles would be closed and incorporated in to the purchasers much larger facility in Rhode Island. Raytheon had chosen the East Coast supplier specifically for its unique technical capability and personal service. That specialized capability, which is dependent on human technical knowledge as well as equipment, is put at risk with a factory shut down and relocation.

Mitigating the Risks

There are several strategies that Raytheon can take in order to mitigate the risk of outsourcing its circulator substrates. However, there is no way to prepare for every possible permutation of events. The outsourcing of a product decreases your direct control and increases your exposure to certain risks. The buyout of the circulator substrate supplier is a good example of how outsourcing can expose you to new and unexpected risks.

Partnership versus Arms Length Transaction

The initial relationship between Raytheon and the East Coast supplier was more of a partnership than an arms length transaction. This strategy was used to increase proximity across a number of dimensions, including electronic, geographical and cultural.

Raytheon dispatched several engineers, product line managers and supply chain professionals to the East Coast supplier in order to assess the amount of technical knowledge required to begin production and establish a workable production schedule. This week long session was the first of many visits to the East Coast site during the initial stages of the substrate offload. These visits helped to close the geographical proximity gap.

During the initial East Coast site visit, a communication process was established. To give Raytheon and the supplier a common reference for sharing and verifying information, a spreadsheet cataloguing each product type, required materials, technical specifications and desired quantities was created. A single point of contact was established at each company to further facilitate the flow of information and the spreadsheet was maintained solely by the supplier point of contact to ensure data integrity. Following the initial visit, weekly conference calls were held to go over any outstanding issues.

Finally, Raytheon worked with the supplier to develop a process for prototyping and design work. Because the type of work required is not known in advance, the supplier created a general menu, which accommodated a variety of material types and processing steps. In this way, Raytheon had a general price guide to work from prior to knowing all the details about a specific project. The supplier committed to a five day turnaround for prototypes. Although this is significantly longer than one day required when the substrate capability was internal it was much quicker than the typical lead time for a new substrate order.

Decreasing Dependency

One strategy for decreasing dependency on an external supplier is to develop the capability internally. Prior to the fire, Raytheon was independent for capability, but expected to become dependent for capacity as volumes increased. After the fire, Raytheon became dependent for capability. Raytheon still maintained the technical knowledge through its engineering personnel and technicians, but that knowledge was no longer housed in a facility with the required equipment.

Although dependence for capability is acceptable for some products, the supplier base for circulator substrates is very limited, increasing the risk of market failure. Circulator substrates are a customized product and require high asset specificity. Also, most of the innovation that takes place in circulator based antenna systems happens at the substrate level. Design and engineering will continue to be housed within Raytheon, but Raytheon decreases its innovation capability by outsourcing substrate production and prototyping.

Conclusion

If Raytheon decides against outsourcing, it has several options for developing the capability internally, including:

- Rebuilding the capability at the El Segundo site
- Expanding the capability at the Texas site
- Creating the capability at another alternate site

Each of these options offers different costs and benefits. Rebuilding in El Segundo returns the proximity advantage for the circulator area by housing engineering, production and downstream assembly in the same facility. Expanding the capability at the Texas site requires less capital investment and mitigates many of the risks associated with using an external supplier. Creating the capability at another internal site makes the least sense as it requires a large capital investment and does not provide the proximity advantage of rebuilding in El Segundo.

Chapter 9: Organizational Considerations

The ability of an organization to implement change is heavily influenced by organizational factors. Unfortunately, organizational behavior is highly complex and difficult to predict and control. In an effort to provide insight in to organizational behavior, John Carroll proposes the Three Lenses model, which looks at an organization from several angles. Each lens provides a different perspective on the underlying drivers of behavior at the institutional and individual level.

The three lenses are the:

- Strategic Design Lens
- Political Lens
- Cultural Lens

Below, the Three Lenses model is applied to Raytheon's Solid State Microwave business in order to better understand how the role of the organization in the ability to create and sustain positive change (Carroll, 2001, p. 3).

Strategic Design Lens

The strategic lens views the organization as a highly rational system. The strategic lens perspective assumes that a firm's strategy is crafted and carried out based on a rational analysis of opportunities and capabilities. People who take the strategic view of an organization focus on company structures like organizational groupings and hierarchy as well as alignment mechanisms like bonuses, raises, stock options and promotions.

Strategic Groupings

Strategic groupings within an organization segregate clusters of tasks and activities. Raytheon's Solid State Microwave business creates functional groupings such as Engineering, Operations, Finance and Supply Chain. Each of these groups focuses on a specific skill that supports Raytheon's Space and Airborne Systems overall goal of designing and manufacturing products to enhance space and airborne missions. By dividing people in to groups focused on these tasks, Raytheon hopes to achieve economies of scale and deepen the specialized knowledge within each of these areas. For example, by grouping supply chain together, Raytheon can reduce the number of contact points with key suppliers and consolidate demand across products.

Linking Mechanisms

Although grouping specialties together within an organization offers advantages, it also creates the need to build bridges across specialized function. The overall goals of the organization can not be reached without coordination between functional groups.

Various linking mechanisms are used to facilitate work between groups. These are particularly important when addressing complex problems that span across the organization. For example, the fire in Solid State Microwave's substrate area had implications for many functions and product lines. In order to address the problems stemming from the fire, Raytheon pulled together a cross-functional team with key members from Finance, Supply Chain, Operations and Engineering. Each of these functional areas had a key role to play in fire recovery.

In addition to sharing information across groups, linking mechanisms are important for feeding information up and down the organizational hierarchy. Solid State Microwave's Operations organization holds daily meetings to communicate what is happening on the production floor to the management team. Information systems, like Materials Resource Planning (MRP) software, act as a linking mechanism by sharing information that is used across functional groups. One of the roles within a functional area might be to facilitate information flow across groups, as is the case with Finance and Project Managers. In addition to the formal linking mechanisms discussed above, informal routines develop, such as carpools and lunches, which further disseminate information across groups.

Alignment Mechanisms

Alignment mechanisms are used to ensure that the efforts of diverse functional groups and the individuals that make up these groups are synchronized with the overall organizational strategy. By tying incentives to metrics that require input from more than one functional area, the goals of seemingly separate groups can be aligned. However, identifying appropriate metrics and tracking them over time is not a simple task.

Issues in aligning incentives can be seen in the magnet assembly process. Operations incentives are typically linked to lower costs and predictability. Design Engineers are rewarded for innovative products. Innovation and lower costs are achieved through very different means. Because the magnet assembly process fills both the production needs managed by the Operations organization and the design and prototyping needs of the Design Engineers there is significant potential for conflict. Design Engineers want to design a flexible process that allows for experimentation. Operations managers want a standardized process that allows for predictability and potentially lower costs.

Raytheon invests heavily in its Six Sigma program to provide incentives for continuous improvement. Raytheon employs its own version of the Six Sigma approach, based on benchmarking with Allied Signal and General Electric. The Raytheon Six Sigma framework provides a common language to discuss and attack problems and is supported by a network of trained Six Sigma experts. Raytheon has worked hard to disperse Six Sigma process knowledge through all ranks and businesses. At the time of the internship, 100% of salaried and more than 50% of bargaining unit employees in SSM had been certified as specialists, the first step to becoming an expert. In order to further motivate employees, Raytheon offered gift certificates at various retailers for employees that completed the first round of training.

Political Lens

The political lens views the organization as a struggle for power among stakeholders with different goals and underlying interests. Power within an organization can come from a variety of sources including formal management authority, unique knowledge or skills, or expertise and relationships that are generated over a long career in the same industry or company.

Following the fire there were many discussions within Raytheon about whether or not to rebuild the substrate production capability at the El Segundo site. There were several different positions within the company, many motivated by how rebuilding the site might shift power around the organization.

Former employees of the substrate area, including technical personnel and operators, were interested in seeing the substrate capability rebuilt in El Segundo. Prior to the fire, the responsibilities of this group revolved around producing substrates. In the immediate aftermath of the fire, the day to day work of the technical personnel shifted from producing substrates to getting suppliers established and determining the cost and timeline of a potential rebuild. The nature of these new responsibilities was short term. If a decision was made not to rebuild, the roles of these employees would be uncertain. Many would likely be redeployed in new functions or products. Change is almost always a threat to those who were valued and successful in the old system. A decision to rebuild would reestablish the need for the pre-fire technical and operations roles.

The design engineers would also benefit from a reestablishment of the El Segundo site. Having the substrate fabrication capability collocated with the design engineers allowed for quick turnarounds and frequent communication. By shifting to an external supplier, design engineers would have a minimum five day turnaround on prototypes and decreased access to the people building their designs.

On the other hand, management at the Texas site was in favor of expanding the capability of their substrate fabrication to include the former capabilities of the El Segundo site. Increasing the volume and capability at the Texas site would increase its relative power within the organization. The new technical knowledge Texas would obtain from manufacturing the circulator substrates could also potentially open the door for future business.

Cultural Lens

The cultural lens addresses the meanings that people within an organization assign to situations. Based on past history, analogies, metaphors and observations, people assign unspoken meanings to the world around them.

Solid State Microwave (SSM) was originally part of Hughes Aircraft and much of its culture can be traced back to these roots. Hughes, like Raytheon, places significant value on technological innovation. Raytheon has a long history of innovation, including the invention of the microwave and important contributions to the Mars Rover project. Because of the value put on technical advances, the design engineer and other technical professionals have a highly respected place in the organization.

Magnet sub-assemblies are not viewed as an innovative even though they are a component of the technically complex and innovative active array systems. Because they are a simple, low cost component, magnets do not receive a tremendous amount of attention. Magnet assembly was sometimes overlooked by operations managers and it was often difficult to get operations managers energized to attack problems in the process.

Putting the Lenses Together

The three lenses are not meant to work directly together, but rather to provide a framework for looking at an organization from multiple perspectives. No single view of an organization can capture all of the complexity and multiple forces working to influence decision making and behavior. Even combining the strategic, political and cultural views does not give a complete understanding of the way an organization functions.

BIBLIOGRAPHY

Beckman, Sara, Rosenfield, Donald. Vertical Integration. Chapter 2 of *Operations Leadership*, to be published by Irwin/McGraw Hill.

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

Cooper, Robin, Kaplan, Robert, 1999. *The Design of Cost Management Systems* Ed 2, New Jersey: Prentice Hall.

Fan, Ip-Shing, Russell, Steve, Lunn, Richard, 2000. Supplier Knowledge Exchange in Aerospace Product Engineering, *Aircraft Engineering and Aerospace Technology*, Volume 72.

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

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

Lee, Hau L., 2004. The Triple-A Supply Chain. *Harvard Business Review*, January.

Nahmias, Steven, 1997. *Production and Operations Analysis, 5th Edition.* Boston: Irwin/McGraw-Hill.

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

Stuckey, John, White, David, 1993. When and When Not to Vertically Integrate. *Sloan Management Review*, Spring.

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

To the Rescue: Toyota's Fast Rebound After Fire at Supplier Shows Why it is Tough. *Wall Street Journal*, May 8, 1997.