Creation and Sustainment of Manufacturing Technology Roadmaps

by

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SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT AND DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF

MASTER OF BUSINESS ADMINISTRATION
AND
MASTER OF SCIENCE IN MECHANICAL ENGINEERING

IN CONJUNCTION WITH THE LEADERS FOR GLOBAL OPERATIONS PROGRAM AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2012

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Abstract

Manufacturing technology roadmaps align manufacturing capability development to product development and the driving business need. Roadmaps allow an executable business strategy to be communicated to all levels of an organization reducing the time and resources required to bring new technology to market. This thesis examines the creation and sustainment of manufacturing technology roadmaps at Raytheon Space and Airborne Systems (SAS). It demonstrates how by using a stakeholder analysis and demonstrating a positive value proposition to all stakeholders agreement and adoption can be created across a large organization.

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Acknowledgments

The author wishes to acknowledge the Leaders for Global Operations Program for its support of this work. I would also like to thank LGO for giving me such an amazing opportunity to have an active role in both the LGO program and in my internship. The great staff was invaluable in their support and guidance.

I would like to thank first and foremost my family and friends for their support of continuing my learning in a structured and time intense environment.

I would like to thank everyone at Raytheon SAS who was a part of this project both directly and indirectly. The input of wide and varied sources was instrumental in completing this project. A special thanks goes to my supervisors and mentors at Raytheon SAS. I would also like to thank the core members of the roadmap team who helped shape this project into what it is.

This thesis could not have been complete without the foundation that Cullen Johnson created during his internship at Raytheon SAS.

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Continuation Internship

This internship was completed on site at Raytheon Space and Airborne Systems (SAS) in El Segundo, CA from June to December 2011. It is a follow-on to the work completed by Cullen Johnson. Cullen Johnson completed his internship on site at Raytheon Space and Airborne Systems (SAS) in El Segundo, CA from February to August 2011. Please refer to the thesis of Mr. Johnson entitled Implementation of a Manufacturing Technology Roadmapping Initiative. This thesis looks to build off of the strong foundation created in Implementation of a Manufacturing Technology Roadmapping Initiative to further improve the method to create and sustain roadmaps at Raytheon SAS.

Due to the nature of this combined effort and shared idea generation some of the initial chapters in this thesis appear in part or in entirety in Mr. Johnson's thesis Implementation of a Manufacturing Technology Roadmapping Initiative. This is so that the reader has the same base of information and can clearly see how the project evolved from a common beginning.

Chapter 3- Technology Roadmaps at Raytheon SAS was written by Lou with input from Cullen Johnson.

Chapter 4- Setting the stage for roadmaps was drafted by Cullen Johnson and edited by Lou Grillon for use in this thesis.

1 Introduction

Raytheon Space and Airborne Systems (SAS) is a large innovative technology company. They have a diverse offering of products that range from airborne radars to satellites to targeting and tracking systems. Raytheon SAS provides products that deliver critical mission capabilities to the warfighter that have never been realized before. Working to develop and deliver cutting edge technology that must function in some of the harshest environments comes with a variety of challenges.

This research effort examines how the process of delivering value to the customer can be improved. This process can be improved at the top level by three major methods; improve the business strategy, improve the actual process by which work is completed, and improve the alignment between the business strategy and its execution through work processes. The focus here will be on investigating and improving the second two methods; alignment between strategy and execution, and improving work processes.

The theme carried out in this thesis is that a shared vision that is written down can be disseminated between different parties and used as a tool to communicate strategy. This paper postulates that this shared vision takes on the form of a roadmap to communicate business strategy. From an understanding of a common shared vision of what the business strategy is, individual work methods can be tailored to achieve the goals of the greater business.

1.1 Opportunity to Excel

With any large organization, even a small change can make a dramatic impact. It therefore follows that since Raytheon SAS is a large organization, there is a lot of opportunity to make a positive impact. As a technology company it is imperative that Raytheon is able to develop new technologies and then execute on the delivery of these products to their customers. For this process to happen efficiently and effectively there must be strategic alignment across the company and corresponding best work practices. SAS must design and develop technologies that can be easily manufactured, assembled, and tested, with the customer in mind. This necessitates a shared strategic vision of where the company is headed and what the customer wants. This vision then must be communicated to all the necessary individuals. Currently this process could be improved, particularly communication between engineering and operations. In a broader sense the communication starting with the customer's need, until the product is delivered and supported in the field, can be improved. The tool examined in this thesis by which to accomplish this improved communication resulting in strategic alignment is roadmaps.

1.2 Research Goals

This thesis is based on work conducted at Raytheon SAS in El Segundo, CA as part of an internship supported in partnership with MIT's Leaders for Global Operations (LGO) program. The goal of the internship was to further develop the method for creating manufacturing technology roadmaps that Mr. Johnson established, document the improved process, and provide recommendations on how to implement and sustain roadmaps.

The intent of this thesis is to examine the specific situation at Raytheon SAS and provide recommendations on how Raytheon can improve their strategic alignment and execution through the use of roadmaps. This thesis also looks to generalize the lessons learned in carrying out this investigation so that they may apply to other technology companies looking to implement roadmaps or change in general.

1.3 Thesis Outline

After a brief introduction chapter the thesis starts with a chapter on strategic technology management and why roadmaps were chosen as the tool to encourage strategic alignment. Chapter three gives a background on the aerospace and defense industry and Raytheon SAS. Chapter four highlights the current state of manufacturing technology roadmaps and how the project was scoped out. Chapter five describes the method used to create and sustain manufacturing technology roadmaps. Chapter six goes through the pilot effort conducted and the observations made. Chapter seven provides recommendations for implementation of manufacturing technology roadmaps at Raytheon SAS. Chapter eight takes the recommendations one level higher and talks about roadmaps in general. The thesis concludes with chapter nine which provides final conclusions and closing thoughts.

2 Strategic Technology Management

Innovation is a powerful tool that companies leverage to achieve a competitive advantage and grow. For innovation to be effective it must solve a customer need and be commercialized. Strategic technology management helps guide the innovation of new technologies so that technology development can be completed effectively. That is, the new technology developed solves a customer need and can be provided at a cost that is equal to or less than the value the customer attributes to it. This chapter talks about different methods to manage technology development focusing on roadmaps.

2.1 Technology Management Methods and Environment

There are two basic approaches to management of technology development. The first is a decentralized technology-push approach where technologists, engineers, and inventors, work on ideas they think are interesting and could be useful in the future. This approach focuses on developing new capabilities based on the inventor's expertise. The second method is a market-pull approach where customer needs are gathered and solutions to the customer needs are developed. This approach focuses on delivering the customer the capabilities they asked for.

In almost all cases neither approach is used alone, but rather a combination of the two approaches is used. A bottom-up capability development approach is coupled with a top down needs identification approach. The bias towards one end of the spectrum or the other is driven by a variety of factors including; industry, economy, maturity of the company, risk tolerance of the company, etc. It is important to note that Raytheon SAS's major customer is the United States government and that budget reductions including DoD budget reductions were under discussion during the 2011 and 2012 time period. This drives Raytheon SAS to want to effectively get all the benefit they can out of internal research and development money so that they can best position themselves to win new business. Under pressing economic times, and times of uncertainty, the focus of development efforts can be shifted to near term lower risk solutions.

This means that with the current economic environment that Raytheon SAS needs a method to effectively communicate what the pressing customer needs are so that new innovative technology solutions can be developed effectively to meet these needs. This requires a shift towards a top down approach where the customer needs are communicated and a lower risk technical solution can be developed. With the current economic environment and Raytheon SAS's position taken into account, technology roadmaps were determined to be the right tool for the job. Technology roadmaps allow for a top down communication of customer needs and what technology will be needed when to meet the customer needs. Technology roadmaps also allow for the bottom-up communication of new capabilities that have the ability to solve a variety of unmet or unidentified customer needs.

2.2 Technology Roadmaps

Technology roadmaps are the output of the method used to create them called technology roadmapping. Sandia National Laboratories describes a technology roadmap by the following statement "It identifies (for a set of product needs) the critical system requirements, the product and process performance targets, and the technology alternatives and milestones for meeting those targets." (Garcia & Bray, 1997) Here the power of technology roadmaps can be seen. They allow a company to layout the critical system requirements they need to achieve in order to meet the customer needs. The technology roadmap then provides a framework to determine lower level product and process targets and what technologies can be used to achieve these. This allows a company to see what technologies they should focus on to meet their customer needs.

Technology roadmaps provide a variety of benefits. Again taking an excerpt from Sandia National Laboratories "The main benefit of technology roadmapping is that it provides information to make better technology investment decisions by identifying critical technologies and technology gaps and identifying ways to leverage R&D investments." (Garcia & Bray, 1997) Here it is clear that technology roadmaps provide many benefits. They identify the current state of technology, needed future state of technology, and the gap between these. They then guide the decision on how to close the gap between current and future capabilities in a way that best leverages a company's resources. In this manner a technology can be developed that closes not just one, but many technology gaps by using technology roadmaps to plan ahead.

Technology roadmaps do not come in just one shape or size. There are a variety of different types that exist. Most technology roadmaps have time on the x-axis and a variety of different characteristics on the y-axis in separate levels. The most basic technology roadmaps have three distinct levels. The top level of a technology roadmap typically consists of the purpose which is the market or customer that the technology being developed will satisfy. The second tier is the delivery, the actual products and required capabilities. The third level is the resources needed to achieve the required capabilities. Resources can range from capital to the actual research projects. (Phaal, Farrukh, & Probert, 2004) Below is a graphic illustrating the basic layout of a three level technology roadmap along a time axis with different activities (grey boxes) linked to show dependency. This graphic is adapted from Customizing Roadmapping. (Phaal, Farrukh, & Probert, 2004)

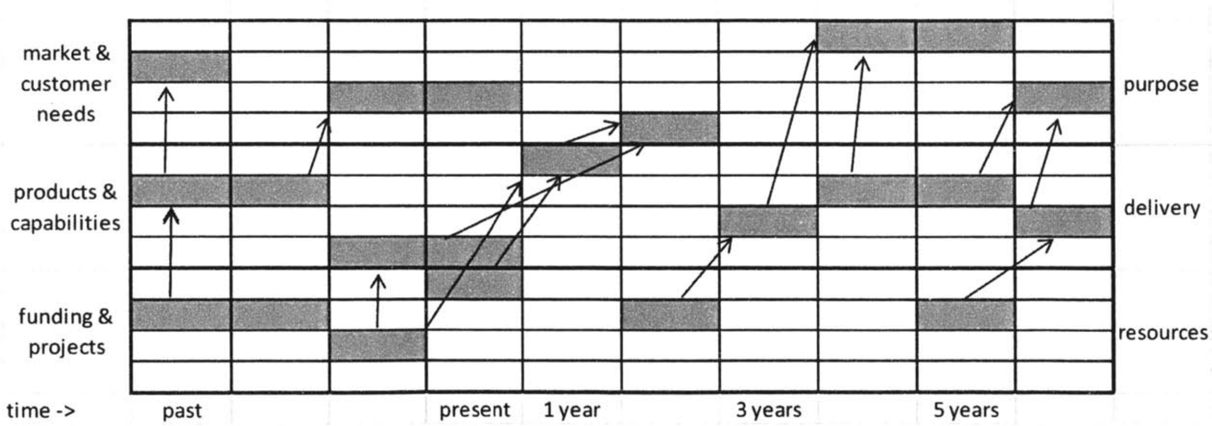

Figure 1Three Level Technology Roadmap Example

There can also be more detailed technology roadmaps that have more than three levels. It is up to the creator and user to determine what information is important and corresponding levels of detail necessary.

This technology roadmap framework can be adapted to a variety of technologies and situations. In the following sections some specific versions of technology roadmaps at Raytheon SAS are discussed.

2.2.1 Technology Investment Roadmaps

Technology investment roadmaps consist of three tiers. The top tier is market opportunities or programs. The second tier consists of products and capabilities that support the pursuit of the market opportunities. The third tier lists the various technologies and types of funding that support the development of the new products and capabilities necessary to meet the customer needs in the top level. The technology investment roadmaps are used to pool investment money to support many different pursuits. In this manner basic research and development money can be leveraged over a variety of different programs. These roadmaps provide the basic information for the product technology and manufacturing technology roadmaps to be built off of. They have detailed timelines with dates of deliverables, such as a product or technology.

2.2.2 Product Technology Roadmaps

Product technology roadmaps consist of three main levels. The first level is market opportunities or programs just like the technology investment roadmaps. The second level consists of products and capabilities that support the pursuit of the market opportunities. The third level differs from the technology investment roadmaps in that it contains the required resources necessary to design and develop the new products and technologies at a more granular level. The product technology roadmaps provide a clear understanding for engineering management on what is necessary to support the new products and technologies they will be working on in the future. This includes new tools, software, and training of staff. A specific example would be an engineering manager seeing that chips are getting smaller and smaller and new software and training is required for engineers to continue to design electronic systems efficiently.

2.2.3 Manufacturing Technology Roadmaps

The manufacturing technology roadmaps consist of three levels. The first two levels are the same as the other roadmaps, market opportunities or programs and products and capabilities. The third level of the manufacturing technology roadmaps consists of the resources required to manufacture the products and technologies. This includes; new capital equipment, process development, and training of staff. The manufacturing technology roadmaps allow for operations management to have a clear understanding of the required resources they will need in the future to support the manufacturing of the new products and technologies that are being designed and developed.

2.3 Technology Management and Technology Roadmaps Summary

This chapter talked about how technology innovation can be managed effectively by the use of technology roadmaps. The different ways to customize technology roadmaps was briefly described. Real world examples of Raytheon SAS customized technology roadmaps were described along with their benefits. The next chapter will provide further background information on defense industry and Raytheon SAS.

3 Defense Industry and Raytheon SAS

This chapter provides background information on the defense industry, Raytheon as a company, the business unit Space and Airborne Systems (SAS) where this project took place, and the department where the project began, Advanced Manufacturing Engineering (AME). The intention is to provide a broad overview of the environment in which the project took place so that the reason why decisions were made can better be understood.

3.1 Defense Industry Background

The defense industry as it is called in the United States is the group of companies that supply products and technologies to the United States Government. The Department of Defense or DoD as it is called has the following mission, "The mission of the Department of Defense is to provide the military forces needed to deter war and to protect the security of our country." (About the Department of Defense (DOD)) DoD is in charge of the United States Government defense budget spending including all money to support national security and the different military branches; The Army, Air Force, Navy, Marine Corps, and Coast Guard. The DoD's proposed defense budget is $671 billion for fiscal 2012. (DOD Releases Fiscal 2012 Budget Proposal, 2011)

The DoD is Raytheon SAS' major customer. Being a supplier to such a large government organization comes with unique challenges. Since the DoD is so large and diverse there are a variety of systems that it has put in place to help manage the procurement of products and services from contractors such as Raytheon. These systems are talked about in further detail in Appendix A. The take away is that there are a variety of systems that are complex and focused on technology development. They require technology maturity to reach a certain milestones for contracts to be won. There was previously not a major focus on the manufacturing maturity of technology being developed by the DoD as visible by many of the acquisition milestones focusing on technology requirements instead of manufacturing requirements.

3.2 How the DoD Acquisition System Influences Companies

Companies in the defense industry typically focus on the technical milestones required to win the next phase of a contract. This is required because the technical requirements are a go, no-go issue. If a program does not meet the technical requirements that are set for it then it will not pass the milestone and will not be awarded a further contract.

Contracts used to be awarded on which company could provide the most advanced technology with little weight given to the actual manufacturing costs. This created the environment where companies were focused on developing a very technically capable technology that would meet or exceed the performance requirements.

"In Defense, practice is often to demonstrate the performance of complex systems, then change the design late in development for production / support." (Gordon, The Need for Manufacturing Innovation and Readiness, 2008) This practice results in costly changes to the system; creating cost and schedule overruns. This is an artifact of the Cold War era when any technical advantage over other countries was worth the required investment.

"GAO's reviews of weapons over three decades have found consistent cost increases, schedule delays, and performance shortfalls. The nation's growing long-range fiscal challenges may ultimately spur Congress to pressure DoD to cut spending on new weapons and to redirect funding to other priorities." (United States Government Accountability Office, 2007)

As the world changes the needs of our government are changing too. This means that DoD is much more cost conscience in the current environment of increasing national debt and ballooning costs. One way to try and control costs is to move away from cost plus contract to fixed price contracts. There are a variety of different cost plus contracts that exist such as cost plus fixed fee and cost plus incentive fee. Cost plus contracts can create an environment where there is less of an incentive to reduce the manufacturing cost of a product. This is why the DoD is moving away from cost plus contracts to fixed price contracts. (RMS, 2011)

Numerous studies have been conducted to try and determine the cause of schedule and cost overruns. (United States Government Accountability Office, 2007) Below is an illustrative example that applies to the focus of this paper.

Based on 62 programs	Technology Status at Beginning of Development	
	Mature	Immature
RDT&E Cost Increase	2.6%	32.3%
Acquisition Unit Cost Increase	<1%	>30%
Average Schedule Delay	1 month	20 months

Figure 2 Technology Maturity versus Cost and Schedule

(Gordon, The Need for Manufacturing Innovation and Readiness, 2008)

Here it is clearly illustrated that having an immature technology greatly increases the risk of cost and schedule overruns. The immature technology can be at any point along the research, development, test, and evaluation (RDT&E) phase. The DoD is trying to have contractors develop technologies, both design and manufacturing, further along before they are used in programs.

3.2.1 Manufacturing Readiness Levels

The DoD has also begun to try and encourage manufacturing preparedness in hopes of preventing cost and schedule overruns due to manufacturing. They are trying to accomplish this through manufacturing readiness levels (MRLs). MRLs are a measure of a given technology's maturity (and attendant risk) from a manufacturing perspective taking into account design, manufacturing technology and processes. (OSD Manufacturing Technology Program, 2011) The DoD has a similar rating scale for design technology called Technology Readiness Levels (TRLs). For a complete list of the various Manufacturing Readiness Levels and their definitions please see Appendix B - DoD Manufacturing Readiness Level Definitions.

3.2.1.1 Manufacturing Readiness Assessments

Manufacturing Readiness Assessments (MRAs) are a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem. Performed to:

- Define current level of manufacturing maturity (MRL)
- Identify maturity shortfalls and associated costs and risks
- Provide the basis for manufacturing maturation and risk management

MRAs are becoming mandatory on some programs that the DoD funds. This means that the contractors are required to demonstrate that their manufacturing technology is developed to the appropriate point before passing the various milestones. This is verified by DoD personnel that conduct the MRA in similar fashion to an audit.

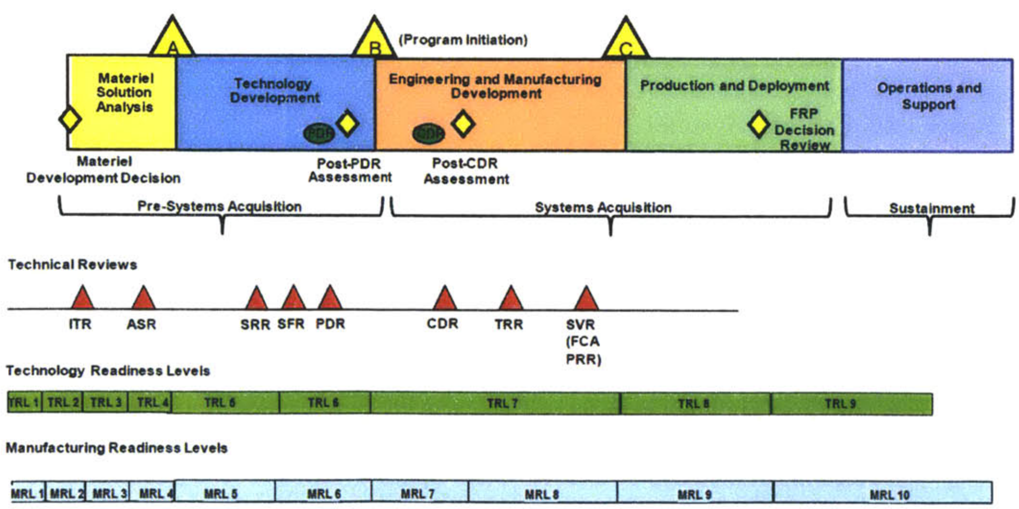

Figure 3 Relationship of MRLs to System Milestones, TRLs, and Technical Reviews

(OSD Manufacturing Technology Program, 2011)

In this graphic it is shown how the manufacturing and technology readiness levels line up with the Defense Acquisition System (DAS) phases and milestones.

"MRLs and MRAs were developed to help succinctly identify manufacturing requirements and risks in a building block approach that can start in S&T (Science & Technology), build throughout the subsequent acquisition phases and culminate in a program that is ready for production, on cost and schedule, and meets performance requirements." (Joint Defense Manufacturing Technology Panel (JDMTP), 2009)

Here it is clearly demonstrated that DoD is trying to help programs achieve cost and schedule targets by helping them to recognize and measure the maturity of their technologies and manufacturing capabilities.

3.3 Raytheon Background

Raytheon (NYSE:RTN) is a technology and innovation leader specializing in defense, homeland security and other government markets throughout the world. (Raytheon, 2011) Raytheon employs 72,000 people worldwide and had 2010 sales of $25 billion. The headquarters are located in Waltham, MA. Raytheon is made up of six business units. Space and Airborne Systems (SAS), Integrated Defense Systems (IDS), Intelligence and Information Systems (IIS), Missile Systems (RMS), Network Centric Systems (NCS) and Raytheon Technical Services Company LLC (RTSC). The project discussed in this paper was completed at Raytheon Space and Airborne Systems.

3.3.1 Space and Airborne Systems

The focus of SAS is on a variety of sensors systems including various radars, targeting products, and space products that operate across the electromagnetic spectrum. SAS has 12,500 employees with 2010 revenue of $4.8 billion. Its headquarters are in El Segundo, CA. (Raytheon, 2011)

SAS is broken up into three main mission areas Tactical Airborne Systems (TAS), Intelligence, Surveillance, and Reconnaissance Systems (ISRS), and Space Systems (SS). In the first quarter of 2011 Raytheon SAS acquired Applied Signals Technology (AST). Now it is called Raytheon Applied Signal Technology. (Applied Signal Technology, Inc. , 2011) Each of these mission areas are in charge of programs that meet customer needs in their area of focus. An example would be that TAS is responsible for the F-18 radar program. Please refer to Appendix C SAS Mission Areas for more information on the specific mission areas.

SAS was created by the acquisition of various aerospace defense companies in the 1990s including Hughes Aircraft Company (1997) and the defense business of Texas Instruments (TI) (1997). These two companies competed with each other in a variety of different markets and had very distinct organizations from each other and from what was Raytheon at that time.

Since SAS was formed by a variety of different companies, the culture of each took a while to slowly get absorbed into the Raytheon culture and each facility to this day still retains some of its original history. Part of the culture of Hughes Aircraft was basic research and development. This focus on research and development led to many new advanced technologies which were successfully commercialized. It was innovation that drove the success of the company.

Due to the nature of the defense industry there are many reasons for information not to be shared between groups internally. This aversion to sharing information carries over to information that can be shared, but is not because it is not habit. This mentality of not sharing information in prevalent throughout the defense industry.

3.3.1.1 SAS Organizational Structure

The organizational structure of SAS is very important to understanding the context of the project. SAS operates in a complex matrix structure. There are functional departments such as engineering and operations. These departments supply the resources necessary for programs to be completed. There are then various programs which are focused on delivering a product to the customer.

The functional department managers are responsible for their specific function. Take the example of engineering, there is a VP of engineering. As you go down the engineering hierarchy, there are more specific engineering centers that focus on an engineering specialty. Lower still are the functional departments, which are responsible for the training and development of their employees. They need to make sure that there are enough trained employees in the right areas to support the business.

There is a program for each contract SAS has with a customer. The programs are responsible to fulfill the contract and deliver the product to the customer. To achieve this they need functionally trained employees. They pull these employees from the functional departments.

Below is a chart that visually depicts this. It shows various functional departments on the left hand side. Across the top are the mission areas and specific programs within each mission area. These programs then pull in the necessary functional employees to complete the work. This is depicted with an X. Functional departments include; engineering, operations, supply chain management, contracts, finance, etc.

	Tatical Airborne Systems (TAS)		Space Systems (SS)		Intelligence, Surveillance & Reconnaissance (ISR)		
	Program 1	Program 2	Program 3	Program 4	Program 5	Program 6	Program 7
Engineering	X	X	X	X	X	X	X
Operations		X	X	X	X		X
Supplay Chain Management		X		X	X		X
Mission Assurance (Quality)		X		X	X	X	X
Functional Area 5				X	X	X	
Functional Area 6				X			

Figure 4 SAS Matrix Organization

It is important to recognize that each functional department, mission area, and program has its own amount of influence. Different programs may have different amounts of influence based on the size (dollar amount) of the program. The same is true for functions; larger functional areas tend to have an easier time driving change when compared to smaller "supporting" functional areas.

There is one more additional layer of complexity to this matrix. Engineering design work does not take place in the same location as manufacturing for some of the products. This is due to the large size of Raytheon SAS with major locations in California, Texas, and Mississippi. This gives rise to an additional reporting structure where there are also site hierarchies and responsibilities.

3.3.1.1.1 Advanced Manufacturing Engineering

Advanced Manufacturing Engineering (AME) was created in 2005. AME was created as a bridge between the design engineers and the factories where manufacturing takes place. The focus of this group was to take manufacturing knowledge and help design engineering incorporate it into their design to create producible products. The vision of AME was as follows, "Advanced Manufacturing Engineering delivers technical & process solutions that enable manufacturing operations to yield high quality, on-time and cost effective products." AME reported up through the VP of Operations.

This role was initially developed for AME, but the department struggled partly due to the matrix structure that exists at SAS. Some programs did not want to fund AME to help the design engineers develop manufacturable products. In a few cases the design engineers did not want to be told how to do their design work. They were not always worried if the product could be manufactured easily, they were focused on the performance characteristics. It was the responsibility of operations to figure out how to manufacture the designed product for the desired cost.

After many years of existence it was decided that AME would be dissolved in 2011. The industrial engineering group, which was tasked with factory improvements, would stay in operations. The rest of AME which supported the development of producible products would be moved over into engineering. The hope was to align the groups in a more efficient manner so that new technologies being developed would be designed to be manufactured easily.

It is important to note that the incentives for engineering can be tuned to more closely align to the current state of the business. Engineering is still incentivized on developing new high performing technologies. This is an artifact of the old defense days when technology performance was priority number one. As the various DoD sources state (referenced previously section 3.1 – Defense Industry Background), this is no longer the case. DoD who is the primary customer for Raytheon SAS and Raytheon as a whole, wants a product that meets performance requirements, but that also meets cost and schedule requirements. This means that manufacturing considerations need to be taken into account during the initial design.

3.3.2 Manufacturing at SAS

Raytheon SAS is in the aerospace/defense industry. As such, many of the products that are developed and manufactured are low volume. This is especially true of the space programs where only one or two instruments or satellites may be manufactured. As a corollary to this, since limited quantities of products are produced, the customer wants the product customized to their specific mission needs. This means that there is a wide variety of different variations of a product.

As a technology innovator SAS does not want to manufacture every piece of every system they make. This means that they must rely on their suppliers to provide components and sub systems to them. SAS then integrates these into final system level assemblies that are then tested. When a new technology is developed in house that provides a competitive advantage SAS will develop the manufacturing processes in house to retain the competitive advantage. This is where manufacturing technology roadmaps can have a real impact on how business is done. They support the development of manufacturing capabilities that are key differentiators, while at the same time make sure that suppliers are capable to support non-strategic manufacturing requirements.

Manufacturing technology roadmaps give Raytheon SAS the ability to see what their existing manufacturing capabilities are, what new manufacturing capabilities they need in the future, and what gaps exists between these. With this information operations leadership can make informed decisions so that new manufacturing capabilities are ready in time to support the customer. They can also determine whether a new manufacturing capability should stay in-house, or if it can be outsourced. This is a key strategic decision that roadmaps seeks to enable. Manufacturing technology roadmaps also allow operations leadership to determine which factory should develop the new manufacturing technology if it is to be developed in-house based on current and future capabilities.

4 Setting the Stage for Roadmapping

This chapter was taken from the draft version of Cullen Johnson's thesis entitled Implementation of a Manufacturing Technology Roadmapping Initiative and adapted to fit into this thesis. The reason why this chapter appears in this thesis is to provide the reader with continuity on how the project was initially started and the importance of the roadmapping process.

4.1 Overview

The process of creating roadmaps is often referred to as roadmapping. Any roadmapping initiative is a time-intensive and difficult process that will undoubtedly require much persistence and support to be successful. It requires a collaborative effort across several functions and business units within the company. In addition to the substantial level of effort required, time is required before the benefits of roadmapping are realized. Therefore, it is imperative that the need for roadmapping is investigated and that its scope and objectives are clearly defined. Stakeholders must perceive a valid and pressing reason for roadmapping, and leadership must communicate a strong commitment throughout the company.

In order to satisfy these initial conditions, numerous interviews, meetings and discussions were held to investigate the motivation for roadmapping and clearly define the scope and objectives for the effort. The goal is to gain consensus on the issues necessitating the roadmaps and how the roadmaps will be used to address these issues. This phase of the roadmapping initiative will help ensure the scope and objectives of the roadmapping initiative are clearly defined and that support from the leadership is obtained.

First, stakeholders were identified and engaged to investigate their perceived needs for roadmapping. The information obtained from these interviews and discussions were then used to perform a root-cause analysis and to define the scope and objectives of the manufacturing technology roadmaps project. Finally, the findings from this phase were used to inform the stakeholders in an effort to obtain their support for the initiative.

4.2 Stakeholder Analysis

A stakeholder analysis was performed to identify all of the stakeholders that will be involved and/or affected by the roadmapping initiative. The goal was to better understand the following:

- What are their interests?
- What is the relationship between each of these stakeholders?
- What does each stand to gain or lose from the project?
- What role should each stakeholder play in the implementation of the project?
- How willing and/or able are they to support the' project?

A stakeholder analysis was performed at the beginning of the project and in as much detail as possible. It is recommended that the initial analysis be revisited later in the project as the stakeholders and their view will change throughout the project. A stakeholder analysis was an effective method to help the roadmapping team identify the stakeholders and to better understand their perspectives on the initiative. It also helped the team understand the network of relationships among the stakeholders and helped determine how to navigate and engage the organization.

The figure below provides an example illustration of the stakeholder analysis. (Thompson, 2012) The stakeholder analysis visually depicts the interest level and power of individual stakeholders and is used to focus on key stakeholders such as stakeholder 1 & 3.

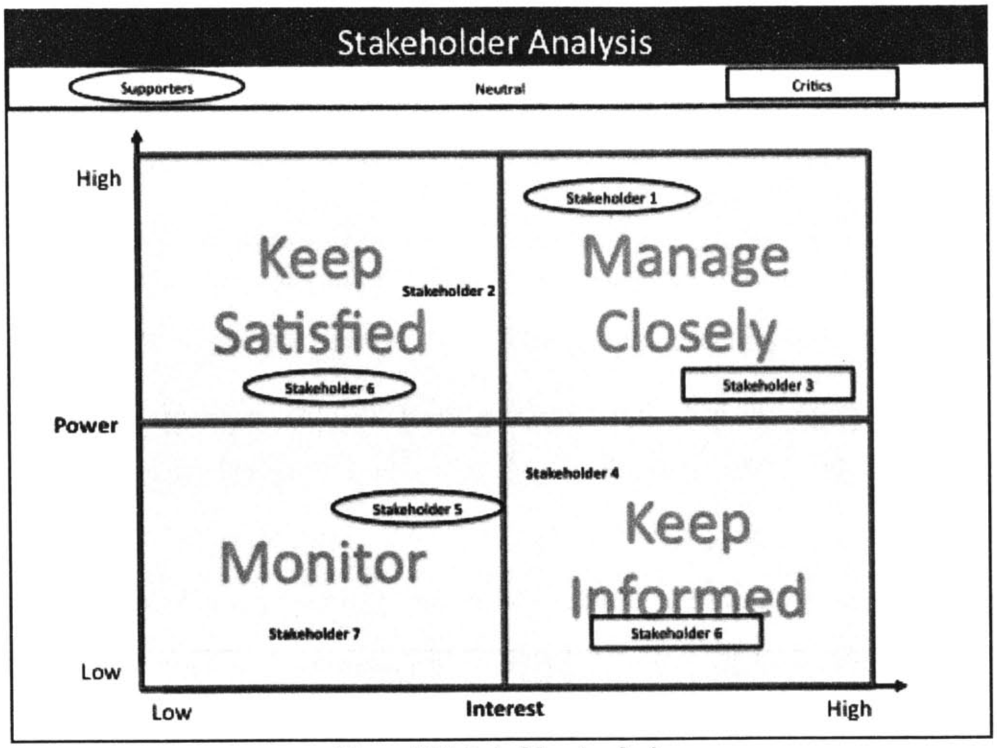

Figure 5 Stakeholder Analysis

(Thompson, 2012)

4.3 Identifying the Need for Roadmaps

After the stakeholder analysis was completed, the stakeholders were engaged to identify the issues driving the need for roadmapping. Understanding the concerns and perspectives of each of the stakeholders was crucial to the success of the roadmapping initiative. It provided the foundation for all of the future roadmapping work, as the roadmaps and the methods to develop the roadmaps are based on the roadmapping team's understanding of the stakeholders' perceived issues. This was an essential step in creating alignment between the stakeholders and in gaining their support.

The perceived need for roadmapping differed between the organizations, and at different hierarchical levels within the organizations, depending on their perspective and responsibilities. At a high level though, most of the issues lead back to one overarching issue; the lack of an effective strategic planning method for manufacturing technology. This has three major effects:

- Production often exceeds budgets and schedules
- Strategic impact of make-buy decisions is not effectively evaluated
- Manufacturing technology is not aligned with product technology

Therefore, the driving need for roadmapping is a method to develop and clearly communicate the strategic vision for Raytheon's manufacturing technology. A method is needed to align investments in manufacturing technology with those in new products and to determine the business's strategic core manufacturing capabilities. Without an agreed-upon method for defining and executing a strategy, investments in new manufacturing technology have been ad-hoc, delayed and sub-optimal. Raytheon SAS needs a method to guide the investments in new manufacturing technologies to insure the necessary manufacturing capabilities (skills, processes, facilities and equipment) are being developed to deliver new products and maintain its competitive advantage.

4.3.1 Manufacturing Technologies

When investigated, it was found that production schedule and budget overruns are often the result of manufacturing being unaware of new products that will enter production and are therefore unprepared. A lack of information about the production timelines and volumes are two aspects of this unpreparedness. Immature manufacturing technology is another aspect, and is of particular importance due to its impact and the long lead times required to develop new manufacturing technologies. Some of the reasons for immature manufacturing technologies in order of importance include:

- Manufacturing is not engaged during the early product development phases of a program
- Internal manufacturing capabilities do not significantly factor into new product development
- Funding is not available to mature manufacturing technologies

- Factories are not aware of new products until they are scheduled for production

In general, manufacturing technologies are not being developed concurrently with the new product technologies. The need for the development and/or improvement of manufacturing technologies is driven by two factors; 1) the development of new product technologies and 2) the natural evolution of products require tighter tolerances and better control, both resulting in the need for new and improved manufacturing technologies.

Most often, manufacturing technologies are not matured past the ability to make a small number of units in a laboratory environment. In fact, factories are often not aware of new products being developed and are therefore unable to develop or acquire the necessary manufacturing technologies. When the new product enters production, the manufacturing technologies are not production-ready. In most cases, the factories deal with immature manufacturing technology either by reactively investing time and money in the required manufacturing technology or by starting production with immature manufacturing technology. The result is delayed schedules and budget overruns, either from upfront investment of time and money to develop the required technologies or caused by low yields and excessive rework when using immature technologies. In other cases, factories deal with this issue by anticipating the future production needs and proactively investing in new manufacturing technologies. Although this prepares the factories for production in the cases that they correctly anticipate the new product technology needs, this practice exposes the factory to the risk of making unnecessary investments. Whether the factories choose to react or anticipate, the result is less than optimal and can be improved. Therefore, a method to strategically align the development of new manufacturing technology with new product development is critical to being able to effectively invest in new technologies.

In addition to the development of new manufacturing technologies is the improvement of existing technologies. While it may not make sense to improve a particular manufacturing technology for any one program, it may make sense to improve it if it will be used for multiple programs. There are opportunities to improve existing manufacturing technologies to raise yields, reduce scrap and rework, and reduce costs. For this to be possible however, manufacturing must be informed of the strategic direction of new product development so that they can align the development of new manufacturing technology accordingly. A method to effectively identify gaps in manufacturing technologies and close these gaps prior to the start of production is a key challenge facing Raytheon SAS today.

4.3.2 Make-Buy-Where Decisions

The decision to make a part internally or to outsource it to an external supplier is another critical issue that has proved challenging. Operations and supply chain management for each program are responsible for making the make-buy decision and has historically chosen to outsource the part for a couple of reasons. The first reason is based on cost. Because suppliers are incentivized to bid low for new business, development teams are able to obtain quotes for parts below the cost that the part can be made internally. In reality, the actual cost of the parts from suppliers often exceeds the supplier-quoted cost, as well as the cost to produce internally. The second reason is that suppliers are eager to confirm that they are capable of making complex parts to win business when in fact they are often not capable without additional investment and learning. The result is two-fold; opportunities to develop strategic manufacturing capabilities internally are missed and outsourced parts often exceed budgets and delay schedules.

Of particular importance to this project is the strategic decision of whether or not to maintain control over manufacturing capabilities. The ability to look across the entire business to define and invest in strategic manufacturing capabilities of the company is important for Raytheon SAS to maintain its competitive advantage.

4.3.3 Total Cost of Product Development

Investments in new technologies, both product and manufacturing, is a critical strategic decision that defines the future of the company. When evaluating a new business opportunity, the total cost of winning that business must be considered. With production constituting a large portion of the total cost and time, it is imperative that it be considered in the decision process. Because production is toward the end of the development lifecycle however, it is often not given the proper consideration. It was found at Raytheon SAS that the investment in new product technologies and those in new manufacturing technologies are not evaluated together, but as separate decisions.

The ability to evaluate business opportunities on the total cost of winning the business is important for the success of Raytheon SAS for two reasons. First, the company needs to have a good understanding of the total cost of new products to be able to prioritize the investments in new technology. Second, the customers need assurance that the company can deliver products according to the budget and schedule set forth. As the trend toward fixed-price contracts continues, the importance of evaluating the production costs will also continue to increase. Raytheon SAS needs a method to effectively evaluate the total investment required to deliver new products and prioritize accordingly.

4.3.4 Root Causes

The issues described above are symptoms of more fundamental underlying issues and it is important to be aware of and address these root causes.

In the defense industry, business is awarded through a series of contract awards. Historically, product performance has been the most influential factor in the decision to award contracts. With decreasing defense budgets however, cost and schedule are becoming increasingly important in the decision process. This changing priority is resulting in a shift of contract awards from the best performing product to the best total value. Therefore, it is increasingly important in an effort to win business that manufacturing considerations are considered early and often. The current incentive structure was designed to reward superior product performance and as a result, manufacturing engagement during the early phases of product development was not considered a priority. The current incentive structure does not reward manufacturing engagement nor does it reward manufacturability. This incentive structure has led to a communication gap between engineering and manufacturing that leads to the issues described in the previous sections. This root cause analysis is depicted in the figure below.

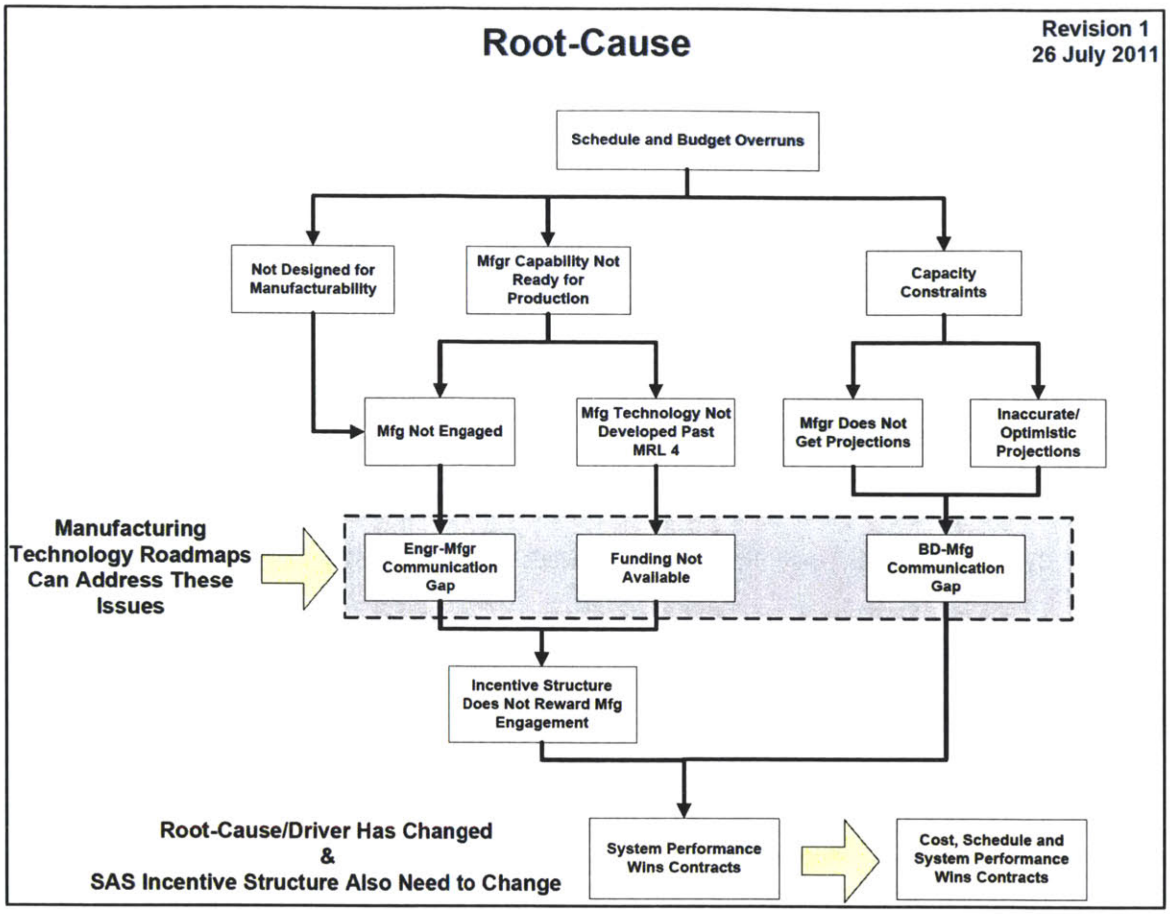

Figure 6 Root Cause Analysis

The Department of Defense has identified production schedule and budget overruns as a fundamental challenge that must be corrected and has placed much more emphasis on awarding contracts on the basis of performance, cost and schedule. In order to satisfy its customers, Raytheon SAS should continue its efforts to improve transition to production and also continue to place emphasis on the manufacturability of its products in order to produce products efficiently.

4.4 Defining the Scope and Objectives

By investigating the issues driving the need for roadmapping, it is apparent that a clearly defined strategy for manufacturing technology must be developed and communicated throughout the business. But this is not enough. In order to succeed at roadmapping and develop this strategic vision, the underlying root causes must be addressed. The incentive structure must drive early manufacturing engagement and communication gaps must be closed.

Initiatives are in progress at Raytheon SAS to address the root causes. Integrated product development teams are being formed to conduct Manufacturing Readiness Assessments on new development programs. A new corporate Technology Network for manufacturing collaboration across the company was setup in the end of 2011. Manufacturing roadmaps are being added as part of Raytheon SAS' strategic planning and advancing new manufacturing technologies is becoming part of SAS' overall investment strategy. It is believed that these initiatives will help drive early manufacturing engagement and close the communication gap between engineering and manufacturing at the program level. The success of these initiatives is critical to the success of manufacturing technology roadmapping, as it will provide the collaboration and detailed knowledge of the new products that is necessary to understand the manufacturing implications. This collaboration will positively impact both the design and the manufacture of new products, and will greatly facilitate manufacturing technology roadmapping. With this information, manufacturing technology roadmaps will be able to focus on the collection and synthesis of this detailed knowledge into a strategy and investment tool for manufacturing technology.

To effectively roadmap manufacturing technology, manufacturing must be informed of the strategic direction of the company and of the new product developments to be able to set the strategic direction of manufacturing technology. A strategic planning method to guide the investments in new manufacturing technologies across Raytheon SAS' factories was determined to be the overall goal of roadmapping. Roadmapping will serve to strategically align the investments in manufacturing technologies with those in new products to insure that Raytheon SAS develops and maintains the manufacturing capabilities that will set it apart from its competitors. The scope and objectives for Raytheon SAS' manufacturing technology roadmaps include:

- Strategic technology plan with a five year outlook
- Strategically align manufacturing technology with product technology and business strategy

- Identify new manufacturing technologies required and their drivers
- Identify internal and external critical manufacturing capability gaps/ risk areas and determine the time-phased investments to close the gaps
- Show the total investment in new manufacturing technology (IR&D, Capital, CRAD (customer research and development), ManTech) required to deliver new products/ programs
- Guide the investments in new manufacturing technologies to optimally allocate investments
- Identify strategic manufacturing capabilities and guide decisions to control or outsource manufacturing intellectual property
- Identify synergies in manufacturing technologies across Raytheon SAS
- Benchmark against other Raytheon businesses, competitors, and industry
- Facilitate communication across Raytheon SAS
- Provide a feedback loop to engineering

The roadmapping objectives above present the strategic vision for Raytheon SAS' manufacturing technology roadmaps. It should also be noted that manufacturing technology roadmaps can be used to effectively communicate with customers and suppliers on the current state and capabilities of manufacturing. Roadmaps are a powerful tool to use in the proposal process so that SAS' capabilities and plans for the future can be concisely communicated.

4.5 Leadership Support

Perhaps one of the most important aspects to successful roadmapping within a corporation is the strong and visible support of the leadership. Without leadership support, roadmapping will not be successful or a valuable use of resources.

Roadmapping requires input from across the company and at all hierarchical levels within the company. It requires both strategic and tactical knowledge from across the entire company, which can only be obtained with cooperation from all of the organization and hierarchical levels. Top leadership from engineering, technology development, strategy & business development and operations organizations must be involved to provide the overall strategic direction of the company. The people responsible for developing the new products and technologies and the manufacturing processes must also be involved to provide the detailed knowledge. Finally, the end users of the manufacturing technologies, the factories, must also be involved. Without leadership support, it is unlikely that the manufacturing technology roadmapping team will receive cooperation from all those who must be involved.

Roadmapping also requires a substantial upfront investment of company resources before the benefits can be realized. After the initiation of a roadmapping process, the participants will need time to begin to expand their time horizons and develop the communication channels and knowledge to become successful contributors to the roadmapping effort. In a world where companies think about the next quarter or year, the delay between the initial effort and resulting benefit leads many companies to abandon the effort before the full benefit can be realized. With each successive roadmapping iteration, the task becomes easier and the benefits greater. Therefore, leadership must continue to provide support for manufacturing technology roadmapping until the full benefits can be realized.

Another factor that makes manufacturing technology roadmapping challenging is the fact that the most important contributors are often not the ones who receive the benefits. This disconnect between the contributors and beneficiaries must be overcome through leadership's commitment to improving the company as a whole, which in return will benefit the contributors.

Manufacturing technology roadmapping has been demonstrated to be an extremely valuable tool but implementing it is a substantial challenge that necessitates a strong commitment from the top leadership of the company. Therefore, it is imperative that leadership is behind the effort and communicates this to the rest of the organization.

4.6 Summary of Roadmapping

This chapter talked about the challenges to implementing roadmapping and the benefits it provides. It explained the objectives for manufacturing technology roadmaps at Raytheon SAS that were established at the beginning of this project. The challenges, including gaining leadership support and improved communication between engineering and manufacturing, to implementing manufacturing technology roadmaps were also discussed

5 The Method to Create and Sustain Roadmaps

A method or process to create a product is necessary so that people can be trained and the output is standardized independent of who creates it. In this case the product is a roadmap. The previous sections of this paper talked about defining what a roadmap is, and the information it should contain. Here the method to create a roadmap will be further elaborated upon. How does a creator of a roadmap go from a blank sheet of paper to a completed roadmap that communicates a strategic vision? This chapter will answer just that question.

5.1 Objectives of the Method

There are two main objectives of a method to create roadmaps. The first is that a standardized output is produced. The second is that the method to create roadmaps fosters communication and collaboration between different working groups. These are the general objectives for a method to create roadmaps; specific examples relating to Raytheon SAS will now be discussed to provide further insight.

At Raytheon SAS the objective of creating a roadmap for this project was to produce a shared representation of strategic pursuits and what specific actions are required to accomplish them. This shared vision allows all the different stakeholders involved in delivering value to the customer to be aligned. A common language that everyone involved understands must be used to communicate the vision for this to work. In this specific example the common language is a set of agreed upon definitions and standards. Below is an example of a manufacturing technology roadmap which shares a common set of standards with other roadmaps at Raytheon SAS.

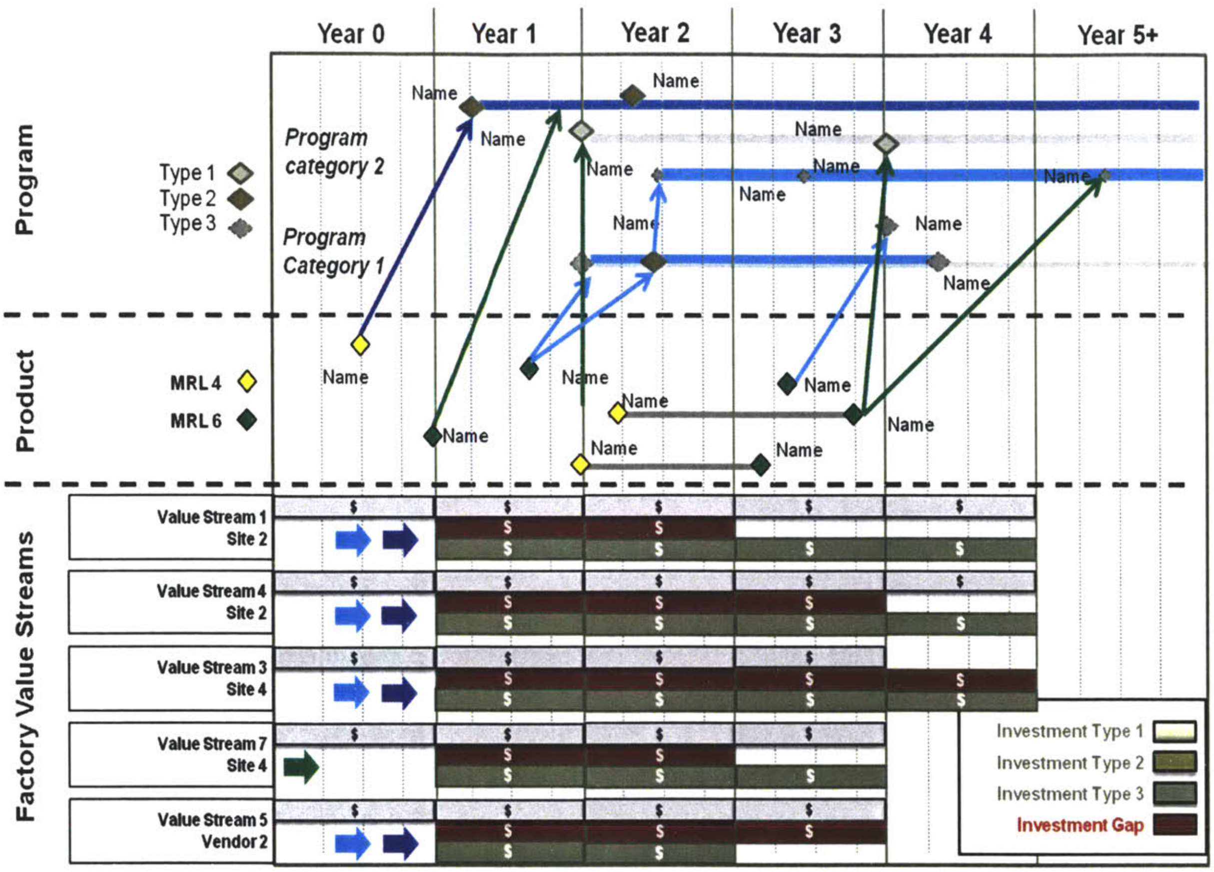

Figure 7 Manufacturing Technology Roadmap Example

The manufacturing technology roadmap shown above consists of three main layers, the first layer consists of business opportunities, programs in this case. There are three main categories of programs, each with its own specific definition and color coding. In the product layer there are standard MRLs with definitions from the DoD. These have a common color coding scheme that is easily recognized. In the third layer there are factory value streams. Each value stream has a common naming convention that is understood and followed. To the right of each value stream is required funding to support manufacturing. This funding can be of four standard types, these types of funding and their associated color coding are standardized. All these different features are common across all Raytheon SAS roadmaps. This allows for easy recognition and understanding of all roadmaps, regardless of familiarity with a specific one.

As previously stated, the second main objective of having a method to create roadmaps is to encourage communication and collaboration between different groups of people. The manufacturing technology roadmaps at Raytheon SAS require cross site and cross department collaboration both by design and necessity. Collaboration between groups is very important when working on projects. Raytheon SAS has a matrix organizational structure as stated before. One of the main strengths, but also a challenge of a matrix organization is to make sure there is sufficient communication between functional groups (Ford & Randolph, 1992). Roadmaps were designed to require communication between different groups to strengthen this lateral communication between functional groups. It is also necessary that different groups and sites collaborate to complete the manufacturing technology roadmaps at Raytheon SAS due to the size and diversity of the company.

The goal of any technology development company is to quickly and seamlessly transition technology from R&D to production. Whether the product is ultimately manufactured at a supplier or internally, the capability to manufacture it is still required. This is one of the main reasons why it is so important for engineers working on developing a new technology to be closely aligned to the manufacturing team that will ultimately make the product. This also allows the manufacturing team insight into what they need to do to be prepared to make the product in the future. This further enables the designers to consider a myriad of important considerations such as design for manufacturing, design trade studies, design for test, etc. This is a widely known benefit of designers and manufacturers working closely together. For further reading on this topic please refer to the book <u>Product Design and Development</u> by Ulrich and Eppinger.

The specific example at Raytheon SAS is that to complete a manufacturing technology roadmap in one technology focus area there needs to be collaboration between all of the Raytheon SAS manufacturing sites. This is because different components of the technology are manufactured at each site. There is required collaboration and information sharing between the different engineering functions, operations (manufacturing at each site), supply chain management, and strategy and business development. Strategy and business development provide the programs or business pursuits with dates in the top layer of the roadmap. The technology management team provides the products with dates and maturities in the second layer. Process engineering, manufacturing engineering, operations, and supply chain then work collaboratively to fill in the third layer, factory value streams, with the necessary actions so that products can be delivered to the customer on time, with an acceptable cost and quality level.

5.2 Sources of Information

A broad overview of the sources of information was reviewed in the previous section to demonstrate that many different people are involved in the creation of a roadmap. This section will go into further detail on who provides what information to whom. It will detail the current information flows.

Manufacturing technology roadmaps did not previously exist at Raytheon SAS in a complete unified form. This meant to create the desired manufacturing technology roadmaps a new method would have to be developed. Mr. Johnson created this method during his internship. The following graphic depicts the outline of the method that was created and piloted. This graphic was created by Mr. Johnson.

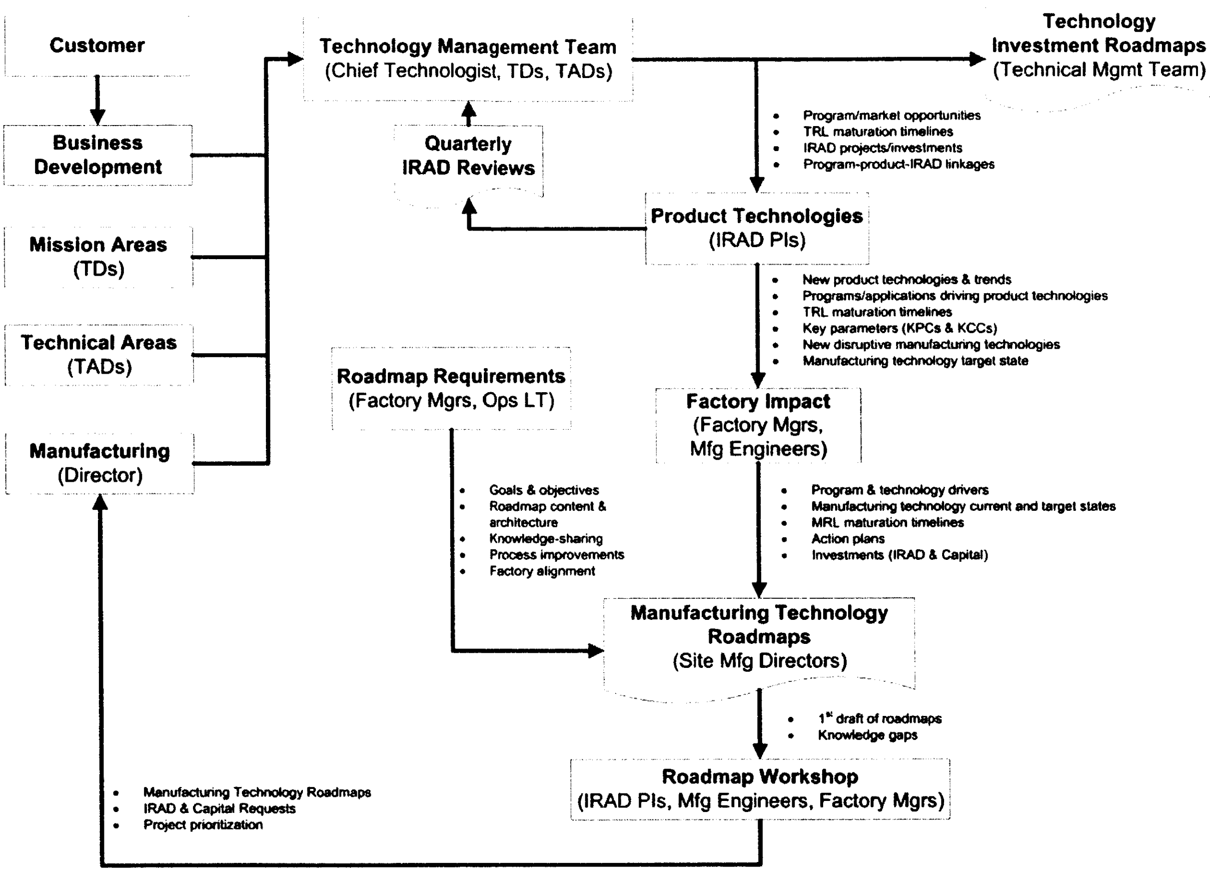

Figure 8 Roadmap Creation Initial Method

This was the first time this method was used so it had to be encouraged and led. The project lead for each technology focus area had to pull the required information from each resource along the path. The information did not naturally flow between blocks, and in some cases there was resistance to the flow of information. The technique of having one person in charge pulling information from the required resources was necessary in the beginning to collect everything and establish a method to be followed in the future. The method described above is time consuming, and only begins to establish information flows between the necessary groups that should be communicating with each other. To make sure that the necessary information flows were established a value proposition was created for each stakeholder, and if necessary the approach was adjusted so that everyone involved had a positive value proposition.

5.3 Value Propositions for the Stakeholders

A stakeholder analysis was conducted at the beginning of the project to determine the value proposition for everyone that would be impacted by the manufacturing technology roadmap project. The stakeholder analysis was continually updated as the project progressed and buy-in was formed. This provided a powerful tool to adjust the roadmap method to ensure all stakeholders received maximum value from the project, while at the same time reducing any unnecessary effort required of them.

As an example the initial analysis looked at both the implementation and future sustainment. Each stakeholder was ranked on a scale of one to five for the effort required of them and the associated benefits they would receive from the manufacturing technology roadmap project. Below is the ranking and graphic for implementation of the manufacturing technology roadmap project. Here it is clearly visible that most of the stakeholders have a positive value proposition, they are above the line. There is however one stakeholder, principal fellow, who has a negative value proposition as shown in the figures below.

Stakeholder	Benefits for Stakeholder	Effort Required for Project Implementation
Operations Leadership Team	5	2
Business Development and Strategy	4	3
Technology Management Team	4	4
Operations Project Team	5	3.33
Factory Manager- 1	4	4
Factory Manager- 2	4	4
Factory Manager-3	4	4
Factory Manager- 4	4	4
Principal Fellow-1	3	4
Division Level Engineering 1	4	4
Division Level Engineering 2	4	4
Section Level Engineering 1	4	4
Section Level Engineering 2	4	3

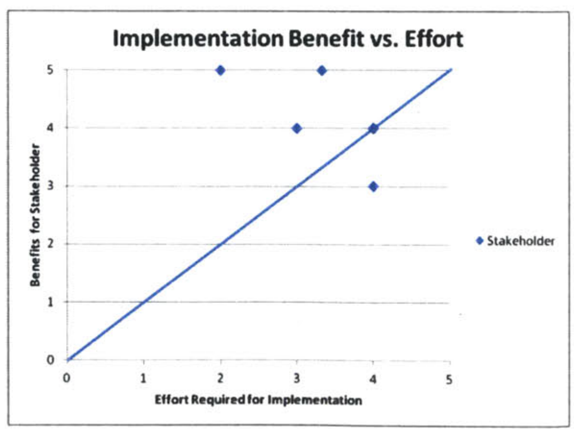

Figure 9 Stakeholder Implementation Rating

Figure 10 Stakeholder Analysis Implementation Graph

This allowed special care to be taken with this stakeholder and for the method to be adjusted so that they could have a positive value proposition. This can be seen below in the stakeholder analysis performed for sustainment of the manufacturing technology roadmap project.

Stakeholder	Benefits for Stakeholder	Effort Required for Project Sustainment
Operations Leadership Team	5	2
Business Development and Strategy	4	2
Technology Management Team	4	3
Operations Project Team	5	3.33
Factory Manager- 1	4	4
Factory Manager- 2	4	4
Factory Manager-3	4	4
Factory Manager- 4	4	4
Principal Fellow-1	3	3
Division Level Engineering 1	4	3
Division Level Engineering 2	4	3
Section Level Engineering 1	4	3
Section Level Engineering 2	4	3

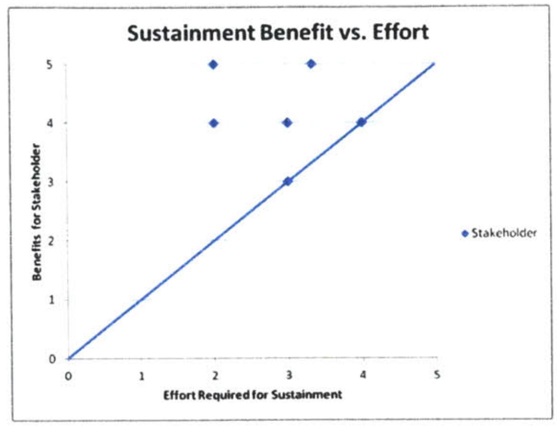

Figure 11 Stakeholder Sustainment Rating

Figure 12 Stakeholder Analysis Sustainment Graph

Additional stakeholder analysis was performed ranking the stakeholders on their influence to the project and their commitment or buy-in to the manufacturing technology roadmap project. The data for one specific technology area where a roadmap was created is shown as an example below.

Stakeholder	Influence (Power)	Commitment (Interest)
Operations Leadership Team	5	3
Business Development and Strategy	4	3
Technology Management Team	5	4
Operations Project Team	5	3.33
Factory Manager- 1	4	4
Factory Manager- 2	4	2
Factory Manager-3	3	3
Factory Manager- 4	4	4
Principal Fellow-1	5	3
Division level Engineering 1	4	4
Division level Engineering 2	4	4
Section Level Engineering 1	4	4
Section Level Engineering 2	3	3

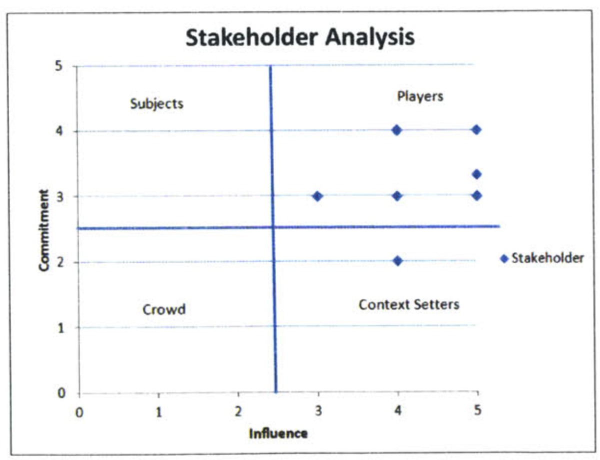

Figure 13 Stakeholders Influence and Commitment Rating

Figure 14 Stakeholders Influence and Commitment Graph

Here it is clear that most of the parties involved with this particular technology focus area are both influential and committed to the project. The technique of analyzing the various stakeholders based on commitment and influence and then categorizing them in the four categories; crowd, subjects, context setters, and players, is a widely accepted technique. (Bryson, 2004) This stakeholder analysis technique was used for all the different technology focus areas where a manufacturing technology roadmap was completed. It was also used to determine where effort should be focused on generating buy-in.

5.4 The Method Piloted

The method piloted during the internship of Mr. Grillon has the same flow of information as the method piloted during Mr. Johnson's internship. The revised method encourages information flows to happen without requiring as much attention of a leader having to pull the information, but instead by having the different groups openly share the information with each other. This is depicted in the graphic below which was collaboratively created by Mr. Johnson and Mr. Grillon.

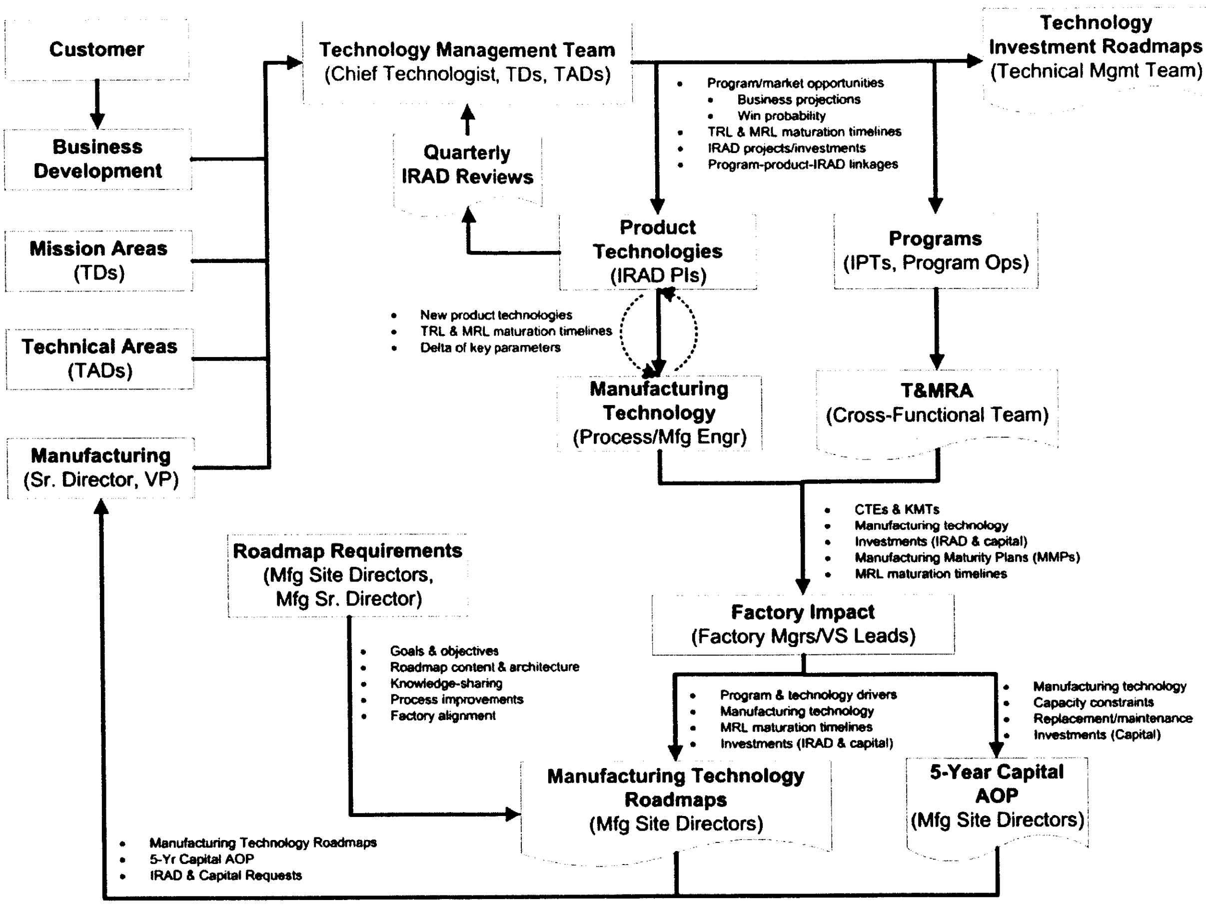

Figure 15 Roadmap Creation Revised Method

For this method to be followed and work effectively there must be a variety of changes to the current system. These changes range from the organizational support down to the processes and methods used to complete work. These are discussed in more detail in the section that follows.

5.5 Big Picture Changes

It was clearly recognized at the beginning of this effort that the current system in which manufacturing technology roadmaps were piloted in was not supportive to the creation or sustainment of these roadmaps. Since the ease of creating the roadmaps along with their sustainment is crucial to the success of this project these necessary changes were encouraged throughout the project. This section talks about the plan to influence changes in the system that roadmaps exist within at Raytheon SAS.

First let us examine and understand why the current behavior is happening, then an informed plan can be developed on how to encourage the desired future state. As stated previously Raytheon SAS has a matrix organizational structure. At times this can lead to functions operating in their own silos and not communicating as much as they could with other functions. An example of this is during the design process manufacturing engineering and the factories that will build a product are not always involved early on. This can lead to issues such as not considering design for manufacturability and not having the right processes to manufacture the product at production volumes.

The second organizational characteristic is that since Raytheon SAS was created by the acquisition of Hughes Aircraft Company and Texas Instruments defense division, among other companies, there still exists internal competition. This internal competition is increased because the different manufacturing sites falsely believe they compete with each other for the right to build new products. This fosters an environment where manufacturing and engineering information is closely held at the site level.

The two major challenges to continued success of manufacturing technology roadmaps are thus information sharing between departments and information sharing between sites. It is necessary that information is shared across departments for roadmaps to be successful. The need to share information across sites can be mitigated by putting in place certain restrictions on what information is shared with whom. Another approach to mitigating the challenge of sharing information across manufacturing sites is to have an agreed upon process by which it is determined where a new product will be manufactured. This would allow sites to know exactly what their core competencies are and where they should focus their efforts.

The first hurdle is the most challenging, how to get different departments sharing the required information so that the business strategy can be effectively executed. This is where the majority of time was spent trying to influence the current state. This project was tasked with developing a method to create manufacturing technology roadmaps. This in itself can be accomplished by looking at literature and implementing a customized method at Raytheon SAS. The challenge is how to sustain manufacturing technology roadmaps without having numerous full time project managers supervising it.

The stakeholder analysis discussed previously highlighted areas where buy-in and change of thinking or mental models would be required. It was also noted that top level alignment would be required for the proper information to flow freely between departments and sites. The graphic below illustrates the current independent organization at Raytheon SAS which leads to separate roadmap efforts within each functional organizations and to some degree even within functional organizations.

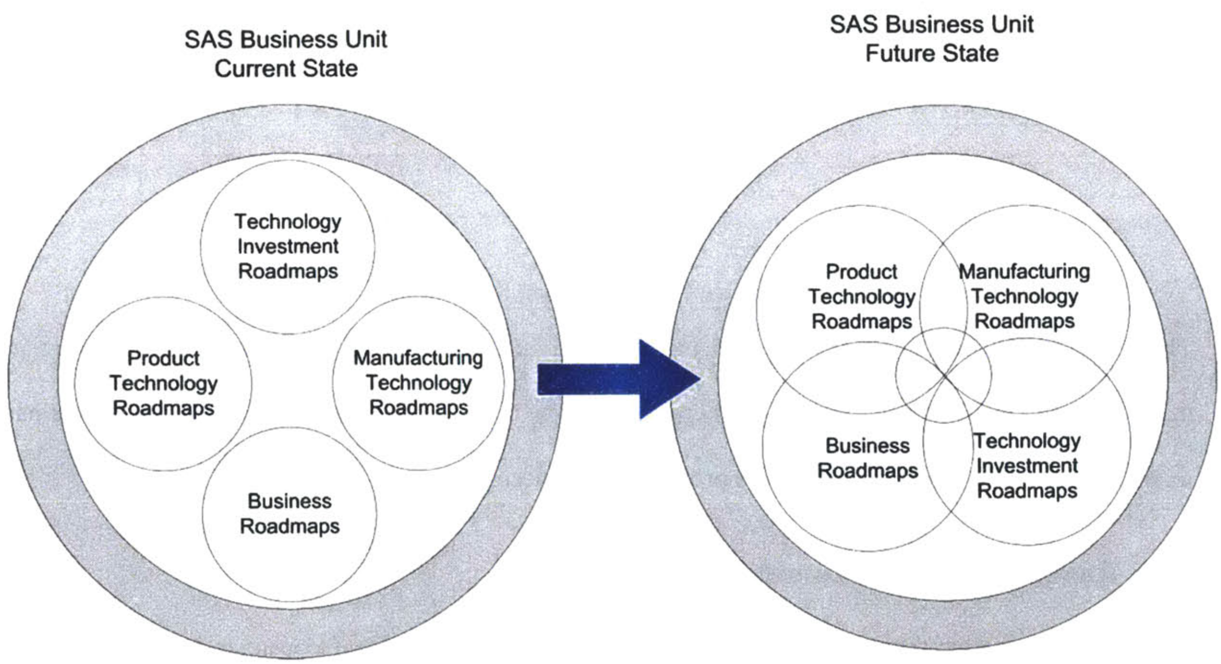

Figure 16 Raytheon SAS Roadmaps Current and Future State

With this idea in mind a strategy to create this top level alignment was enacted. The method was to engage with each function starting at the working level to sell the idea and tailor it to provide maximum benefit. Special focus on engineering and technical management was necessary because both these organizations hold key knowledge necessary for the completion of the manufacturing technology roadmaps. As working teams were formed and buy-in was accomplished at the working level the idea of collaborating and the benefits gained were shared with higher and higher levels of the organization. The graphic below shows a general view of the Raytheon SAS organizational structure.

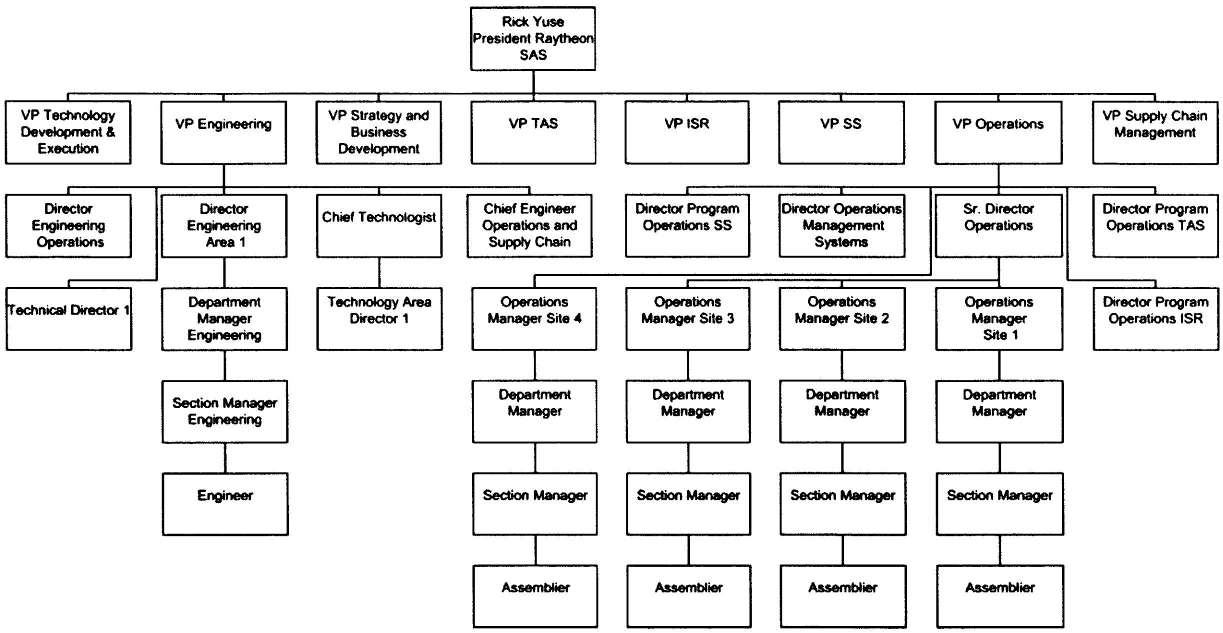

Figure 17 Organization Structure

The above graphic is in no way a complete picture of Raytheon SAS's organizational structure. There are many roles and positions missing. It is only meant to show the important functions and positions that had to embrace the idea of roadmaps for this project to be a success.

5.6 Roadmap Method Summary

This chapter discussed the method piloted at Raytheon SAS to create manufacturing technology roadmaps. It described the flows of information and different functions that must collaborate for roadmaps to be successful. A step back and examination from a higher level was also taken to see what is required for manufacturing technology roadmaps to sustain at Raytheon SAS.

6 Piloting the Method to Create and Sustain Roadmaps

6.1 Executing the Method

The focus of this chapter is on how the method was executed to make sure that manufacturing technology roadmaps could be created and more importantly how they will be sustained going forward. The previous chapter highlighted the stakeholder analysis and the method to build buy-in starting at the working level. This plan was executed on throughout the project.

6.2 Engagement

6.2.1 Contact Plan

The first step in developing a plan of who to inform was to survey the organizational structure of the company in which this project took place. Raytheon SAS has a matrix organization, and it was thus determined that the best way to generate buy-in was to start at the working level in the major departments the project focused on, engineering and operations. This would allow relationships and buy-in to be generated in the independent functions of engineering and operations separately. Then at each level where buy-in existed in both organizations, the teams could be brought together to collaborate on creating manufacturing technology roadmaps.

It was also important to consider the structure of the organization when developing the contact strategy. Care had to be taken to make sure to talk to the right people who were seen as having influence in the organization. This included many key engineering thought leaders and manufacturing managers who were recognized as subject matter experts. This required leaning on the senior management supporting the project that had this knowledge and these contacts.

This process was executed over the six month internship. The graphic below shows the same Raytheon SAS organizational structure with the key positions to win over for manufacturing technology roadmaps listed. Here boxes are highlighted in green for positions that were informed of the manufacturing technology roadmap project and voiced their support of it. This clearly depicts how within operations and engineering the project was sold and bought in at each level, culminating with a presentation to the vice presidents of engineering, operations, and technology development.

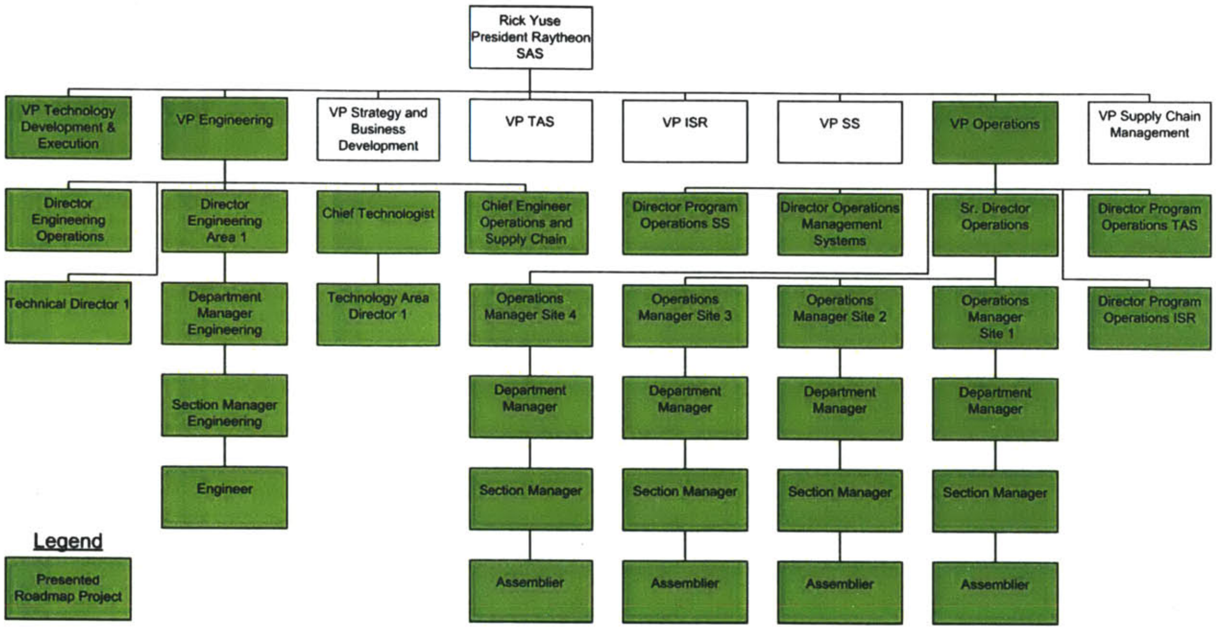

Figure 18 Organizational Structure and Contact List

This strategy worked effectively and allowed growing buy-in to be generated. Once the VPs of engineering, operations, and technology development understood the roadmap project they agreed to support the project in 2012. This provided more incentive for the team to continue with the project next year, and was a key factor to making sure that the roadmap project sustains going forward.

6.2.2 Changes to Plan

As with any plan, there are always unexpected bumps along the way. This was true for the manufacturing technology roadmap project. There were a variety of minor challenges along the way where more time and effort was required to get certain individuals to buy-into the project. Sometimes many meetings were required, and four or five other individuals would have to be brought on board to win over just one key influencer. The positive part was that a plan existed and following the major milestones allowed for successful execution, even if it may have taken a little longer than initially scheduled. These were the minor bumps along the way. There were some major bumps along the way which required a larger reexamination of the plan that are discussed below.

The major challenges for the manufacturing technology roadmap project stemmed from the re-organization of Advanced Manufacturing Engineering (AME) during the middle of the project. One of the supporting directors had to move on from supporting the roadmap project to a new role. This along with much uncertainty about what employees' positions were and would be going forward initially slowed the sense of urgency that the project had been gaining.

This challenge was viewed as an opportunity to cement the relationship between engineering and operations. The opportunity was taken to branch out and make a wider section of employees aware of the roadmap project and its benefits. This organization change allowed changes in support for the better that formerly did not exist. A new director level position, chief engineering of operations and supply chain management, was created. This created the high level focused support that would be required to champion the roadmap project forward. A solid working relationship was created with this position to make sure that the knowledge gained thus far could be transitioned over to the team taking the roadmap project forward next year.

6.3 The Revised Process

The revised process closely mirrors that of the initial pilot executed by Mr. Johnson and the revised method depicted in chapter 5. The key to the revised process is simplified ownership. The initial pilots had a project leader who lead a team and made sure all the pertinent information was collected from dispersed sources. The new process follows the same steps and uses the same information, but the key is that information flows are beginning to be enabled. Where policy or culture before did not allow the sharing of certain information, especially between departments and sites, this information is now beginning to be shared. The most powerful part is that at least these groups know the information exists and can go out and ask for it. There are now, at least on paper, owners of the individual roadmaps who are responsible for their completion and update. These roadmap owners know it is their responsibility, and their management knows it too. This allows for review and follow-up.

6.4 Manufacturing Technology Roadmaps

Manufacturing technology roadmaps have now been piloted across Raytheon SAS in a few key technology areas. They still need to be implemented across all of the various technology areas in which Raytheon SAS does business. This will be no small task, but a standardized method exists, and through the different pilots it has been shown that it can be done and that doing so is beneficial to the company. One can look back into the past and determine which manufacturing challenges could have been avoided by the use of manufacturing technology roadmaps and then say that roadmaps could have fixed the issues 20% of the time to get a cost savings. It is important to note that the effort required to make the initial manufacturing technology roadmaps was high for a variety of reasons, the first being organizational inertia. Employees were used to working in their individual functions, and not collaborating at such a high level on new products and manufacturing technologies. The second reason was that this was a learning process. As the pilots were executed knowledge was gained and feedback was used to improve the method. This required deep analysis and constant search for feedback.

The third major reason for the amount of effort needed was because the product technology roadmaps did not exist in a complete standardized form. Product technology roadmaps are supposed to break down the systems level needs of customers to actionable product level capabilities. These roadmaps should show the same programs at the top level, then link to products and technologies in the middle level. Here they have associated dates of when a new technology is needed to meet the customer's needs. The third layer of the product technology roadmap is the detailed action plan that will allow Raytheon to design and deliver the new technologies and products to the customers when they want them. Without all this information standardized and in one place, it was required to create it in order to make the manufacturing technology roadmaps as robust as required.

Manufacturing technology roadmaps provide an actionable plan for Raytheon SAS and the factory value stream owners. They show where the current manufacturing capabilities are, where the future manufacturing capabilities need to be, and identify the gaps that exist between the two of these. This information is then visually displayed on a timeline showing when these new manufacturing capabilities need to be developed by to meet the customers' needs. This is a very powerful tool since it links required investments in capital and new manufacturing capabilities to the customers. The one missing part is that the manufacturing technology roadmaps do not say what the best way is to acquire the new manufacturing capabilities that are necessary to support the customer. To determine this, a framework was developed to analyze how to acquire new manufacturing capabilities. This framework is called the strategic capability acquisition framework and is elaborated on in the next section.

6.5 Strategic Capability Acquisition

The strategic capability acquisition framework takes identified new manufacturing capabilities from the manufacturing technology roadmaps and then analyzes them to determine what the best method is to acquire these new manufacturing capabilities. It is composed of two major pieces, an excel spreadsheet which determines whether the manufacturing capability is strategic or not to Raytheon SAS and a decision tree that leads the user to an actionable outcome based on if it is strategic or not.

6.5.1 Strategic Capability Spreadsheet

The strategic capability spreadsheet determines if a new manufacturing capability is strategic to Raytheon SAS or not. It considers a variety of factors that make a new technology strategic, both qualitative and quantitative. It then assigns a dollar value to both the qualitative and quantitative factors so that a comparison can be made and easily understood by the user. Clear definitions are given on how to rate qualitative data. Key inputs include the following factors; required capital, market size, probability of win, change in probability of win, risk, a factor for learning from manufacturing internally (not a learning curve factor), a factor for disruptive technologies that require spiral development, and a factor for impact on manufacturing base. These variables are entered into the strategic capability spreadsheet and an output is created. This output is a green, yellow, or red, ranking. These colors correlate to the manufacturing technology being strategic (make), the manufacturing technology being somewhat strategic (a judgment call by senior management), or the manufacturing technology not being strategic (buy). This provides an easy to understand interface for the user. Please see Appendix D - Strategic Capability Spreadsheet for an example of the strategic capability spreadsheet. This information is then taken, the new manufacturing technology is strategic or not, and used as an input to the strategic decision tree.

6.5.2 Strategic Decision Tree

The strategic decision tree begins with the knowledge of whether a new manufacturing technology is strategic or not. From here the user follows the decision tree that leads them through what issues to consider and thus what the appropriate approach to acquire the new manufacturing capability is. The basic outputs of the decision tree are described below. Develop the manufacturing technology internally if it is strategic and no one else is currently manufacturing it. Consider acquiring a company if the technology is strategic and only one manufacturer currently exists. Buy the product from a supplier if the technology is not strategic. If no suppliers exist and the technology is not strategic, then help develop a supply base for the technology. If the technology is strategic and Raytheon SAS cannot acquire the company or more than one supplier exists, develop more suppliers so that the technology becomes commoditized reducing any temporary advantage competitors may have had. Please see Appendix E - Strategic Capability Acquisition Decision Tree for an example of the strategic decision tree.

6.5.3 Strategic Capability Acquisition Conclusions

This framework was developed with a cross functional team at Raytheon SAS and meshes seamlessly with the manufacturing technology roadmaps. Together the manufacturing technology roadmaps and the strategic capability acquisition framework tell Raytheon SAS what new manufacturing capabilities they need when and how to acquire them. This is a very powerful toolset that can help drive Raytheon's future business. It allows for new manufacturing capabilities to be considered on their strategic merit to the entire business unit instead of on a project by project basis. This allows for a higher level optimum to be achieved instead of maximizing at lower level of individual projects or programs.

6.6 Piloting the Method Summary

This chapter discussed how buy-in was generated throughout the project by following the contact plan and slowly moving up the organizational structure getting support for the project. It described how challenges were overcome when individuals did not at first agree with the manufacturing technology roadmap project by showing those individual how the roadmaps benefited them and finding more supporters who could help bolster the effort. This chapter also examined the value manufacturing technology roadmaps provide and how they seamlessly fit with the strategic capability acquisition framework. Together manufacturing technology roadmaps and the strategic capability acquisition framework tell Raytheon what new manufacturing capabilities are needed when, and how to acquire them. Chapter seven looks to describe how manufacturing technology roadmaps can be fully implemented across all of Raytheon SAS.

7 Recommendations for the SAS Wide Implementation

Manufacturing technology roadmaps provide a large benefit to Raytheon SAS when implemented by showing what new manufacturing capabilities are required when. They allow for planning to take place so that manufacturing capabilities can be developed in time for when production must start to meet customer requirements. Manufacturing technology roadmaps allow factories to show how new market changing technologies fit with the overall company strategy by placing these technologies on a roadmap and showing what programs it could support. The benefits of manufacturing technology roadmaps are only realized if the roadmaps are created and updated regularly. This is why it is so important that manufacturing technology roadmaps sustain after the internships that began their pilot. The next section details how manufacturing technology roadmaps can be implemented so that they sustain at Raytheon SAS.

7.1 Sustaining Manufacturing Technology Roadmaps

Manufacturing technology roadmaps have only been piloted thus far at Raytheon SAS and a full scale implementation is required for them to be standardized across the entire business unit. The next step required to do this is to create the appropriate governance structure to standardize and control the roadmaps. Once the governance structure is in place, the piloted method must be implemented and supported cross functionally by engineering, operations, and supply chain management. The roadmaps must provide clear utility to the users, such as allowing them to receive necessary funding to close manufacturing capability gaps. The roadmap project must also be clearly supported by senior leadership by both providing the necessary resources to complete the roadmaps and by following up to make sure the roadmaps are being completed in a comprehensive manner as part of the planning process.

7.1.1 Manufacturing Technology Roadmaps Governance

There are a variety of different governance models that would be sufficient to support manufacturing technology roadmaps. Based on the stage that the effort is currently at and the organizational structure of

Raytheon SAS the most likely to succeed approach is suggested below. A supervisory committee of vice presidents that meets biannually to provide the roadmap team direction and verify that the roadmaps produced are of sufficient detail and updated regularly so they provide working level actionable data. The supervisory committee also verifies that all roadmaps are standardized and align to the company strategy. This roadmap governing board should include the following VPs; engineering, operations, technology development, supply chain management, and strategy & business development.

A director level position, such as the chief engineer of operations and supply chain management, should be placed in charge of the working coordination of the roadmap team. They will be the one responsible for the creation and update of the manufacturing technology roadmaps. They will also be the person to remove any roadblocks during the initial implementation. The roadmap team should consist of a full time employee from each department involved in the process including; engineering, operations, business development, and supply chain management. These employees will report to a senior manager in charge of roadmaps who reports to the chief engineer of operations and supply chain management. There also needs to be a designated point of contact from each engineering center and manufacturing site, who can act as a point of contact. The point of contact's position does not have to be fulltime. This team can then drive the cross functional creation of manufacturing technology roadmaps. They can as necessary support department managers and value stream managers in the completion of their manufacturing technology roadmaps. The technology roadmap structure is depicted below.

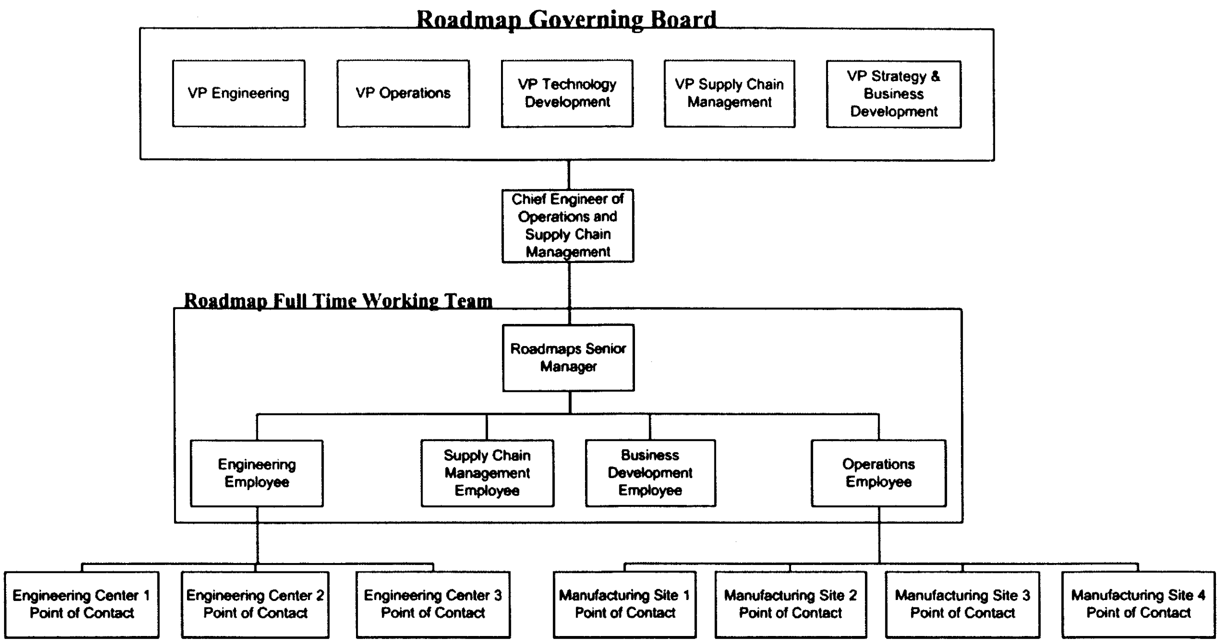

Figure 19 Technology Roadmap Governance Structure

7.1.2 Manufacturing Technology Roadmap Support and Utility

As stated earlier the manufacturing technology roadmaps must be supported and provide utility to the user. The governance structure above provides the necessary cross-functional support. It is still necessary for individual departments and sites to support the effort of their employees in creating and updating the roadmaps they are involved with. Working level employees must be given time and resources to meet and generate the roadmaps.

It is great if manufacturing technology roadmaps are created, but unless the information they provide is actionable and is acted upon they do not provide much utility. There must be funding sources to close the manufacturing capability gaps that the roadmaps highlight. Management needs to support the projects that the roadmaps highlight as being of necessity for the business to grow and be successful in the future. One example of how to do this is to require new capital requests to have a roadmap supporting the need for the new capital. If each year during the capital AOP process manufacturing technology roadmaps are required or highly encouraged to receive funding then employees will realize the importance of manufacturing technology roadmaps and will be encouraged to create and update them.

Another forcing function to make sure manufacturing technology roadmaps are created and sustained is to require all internal research and development to have a manufacturing strategy for the technology that is being developed which requires at least one complete manufacturing technology roadmap. This manufacturing strategy and corresponding manufacturing technology roadmap can be reviewed during internal research and development quarterly reviews to make sure that it is completed in a satisfactory manner.

7.2 Enterprise Wide Scalability

Manufacturing technology roadmaps can be used across the entire Raytheon enterprise at each business unit. This would allow each business unit to leverage the methodology developed at Raytheon SAS and in so doing have visibility of the required new manufacturing capabilities they need to have along with the associated timelines. This would allow Raytheon to deliver on customer commitments in the most efficient manner. It is quite possible that one business unit may already have a manufacturing capability, but the other business units do not know about it. In this case knowledge can be leveraged across the entire company to deliver products more efficiently to the customer.

If each business unit at Raytheon completed their own manufacturing technology roadmaps and shared this information across the enterprise a second benefit would be that synergies between business units could be recognized. A global optimum could be attained for the entire company instead of each business unit being a local optimum. Synergies could then be exploited. Different business units could collaborate on the same new manufacturing capabilities. Decisions could be made if as an entire company Raytheon wanted to focus resources for one location to become the manufacturing process expert, or for critical manufacturing capabilities it would prefer multiple internal sources. Manufacturing technology roadmaps provide the opportunity to have a shared vision stated in a common language. They would facilitate communication across the business units, so learnings at one business unit could be shared with the appropriate employees at another business unit doing similar manufacturing.

7.3 Manufacturing Technology Roadmaps Conclusions

This chapter examined how manufacturing technology roadmaps can be fully implemented across all of Raytheon SAS. It provides a governance structure to sustain manufacturing technology roadmaps. Specific examples were given of how manufacturing technology roadmaps can be supported going forward. It also takes a step back and examines how manufacturing technology roadmaps can be expanded across all business units at Raytheon and the benefits this would provide. Chapter 8 studies roadmaps in general, not just manufacturing technology roadmaps, but a host of different types of roadmaps and how they are connected to each other.

8 Roadmaps at SAS

This project focused on manufacturing technology roadmaps at Raytheon SAS. Manufacturing technology roadmaps require information from a variety of other functions such as engineering and strategy & business development. It is important to take a step back and see that in business many different investments are made over time to develop new or improved capabilities. Engineering must think about how they will design new products. Business development must know what customers will want, and when they will want it. Roadmaps in general provide a clear shared representation of advancements over time and can be made for any type of technology or growth opportunity.

Roadmaps other than manufacturing technology roadmaps exist at Raytheon SAS. Some functions and sites have their own roadmaps. Sometimes a program or an initiative will have its own roadmap. These roadmaps exist in many places and in many forms. There is a large opportunity if the roadmap governing board described in chapter 7 could bring together all these disparate roadmaps and align them to the overall business strategy. A unified business strategy flow down could be organized that happened each year where the business strategy was flowed down and roadmaps updated accordingly. This would provide a very powerful tool to communicate the strategy and make sure each department and site was aligned and knew what they had to execute on.

The framework to achieve this exists and has been piloted, the example being the manufacturing technology roadmaps taking information from the technology investment roadmaps that already exist and breaking it down into actionable projects for the different manufacturing sites to execute on. All that is required to make this happen is a lot of coordination and communication between all the parties involved. In the following sections the different types of roadmaps that exist at Raytheon SAS are discussed, who their owners are, what state they currently are in, and what information they provide.

8.1 Manufacturing Technology Roadmaps

Manufacturing technology roadmaps were piloted in 2011 across Raytheon SAS. Each manufacturing site was involved with the pilot process. There are currently detailed manufacturing technology roadmaps in the piloted technology areas. The manufacturing technology roadmaps are owned by both an engineering department manager and an operations manager. They provide actionable information on what new manufacturing capabilities are required at what time to support future production needs. This includes but is not limited to; new capital, new manufacturing process, new skilled employees and additional training required, new test processes and procedures, along with new suppliers.

8.2 Product Technology Roadmaps

Product technology roadmaps are owned by their respective engineering department managers. They currently exist in a non-standardized, not always up-to-date form. The product technology roadmaps should provide actionable information on what new engineering capabilities are required at what time to support future business needs. This includes but is not limited to; new capital, new design tools and software, new skilled employees and additional training required.

8.3 Technology Investment Roadmaps

Technology investment roadmaps currently exist for each different technology area at Raytheon SAS in a standardized, updated form. The owners of the technology investment roadmaps are the technology management team, consisting of technical directors and technology area directors. The technology investment roadmaps are linked closely with the business development roadmaps where they pull the customer needs from. The technology investment roadmaps show what technical capabilities are required by when. They also show how these capabilities will be developed and what types of funding will pay for that development.

8.3.1 Business Development Roadmaps

Business development roadmaps currently exist for the different mission areas at Raytheon SAS. These roadmaps show where the market is going, competitors, and areas of opportunity. They are owned by the different mission areas and business development. They provide the necessary time phased capabilities that Raytheon needs to win new business. Information from the business development roadmaps currently flow into the technology investment roadmaps.

8.4 Roadmap Integration at the Business Unit

As stated above there are a variety of different roadmaps that exist at the business unit level. They all share certain information. Each roadmap needs information from the other roadmaps to provide the most value to its users. The goal of each roadmap is to show a time phased progression of steps that needs to be taken and how these discrete steps link together to deliver an overarching strategy.

If Raytheon SAS links together all these roadmaps they can have a powerful method to flow down business strategy to the different departments and sites, so that it can be executed on. Roadmaps are powerful when integrated at the business unit level, but become even more powerful when they are integrated at the enterprise level.

8.5 Roadmap Integration at the Enterprise

If each business unit executes the roadmap method starting with creating business development roadmaps, flowing this information to the technology investment roadmaps, then flowing this information to product technology and manufacturing technology roadmaps, then these roadmaps can be shared at the enterprise level. The same benefits would apply as talked about in section 7.2 Enterprise Wide Scalability. Raytheon as an entire company could optimize its pursuit of new business. It could optimize its technology and capability development by leveraging resources across the company. Business units could share learning and best practices with each other. A corporate wide strategy could be communicated from the corporate headquarters and shared with each business unit which could then execute on it. Knowledge from the working level of the business units could be communicated back up to the top through roadmaps to show where new market shaping possibilities exist with new technology.

8.6 Roadmaps Closing Remarks

Chapter 8 outlined the various types of roadmaps that currently exist at Raytheon SAS. These roadmap types include; manufacturing technology roadmaps, product technology roadmaps, technology investment roadmaps, and business development roadmaps. For each of these major types of roadmaps the current state and benefits were described. The integration of all these roadmaps along with additional benefits was discussed at the business unit level and then at the enterprise level.

9 Conclusions

This final section of the paper wraps up all the ideas and recommendations stated throughout this thesis. It first provides Raytheon SAS clear actionable steps that can be taken to increase the probability of success for manufacturing technology roadmaps, and the wider set of roadmaps that exist at Raytheon SAS. After specific suggestions are provided, generalized recommendations are given for any technology company that is looking to implement manufacturing technology roadmaps, or any form of roadmaps.

9.1 Success of Roadmaps at Raytheon SAS

Manufacturing technology roadmaps have been piloted at Raytheon SAS. A formal documented method exists on how to create manufacturing technology roadmaps. The key inputs to the process are known. For manufacturing technology roadmaps to be fully implemented across the entire business unit in every technology area, there is still much work to be done. Below is a list of actionable steps to increase the success rate of the manufacturing technology roadmap project.

9.1.1 Establish Roadmap Project Charter

First a formal project charter must be established so that there are clear objectives. The project charter at a minimum should include; scope of the project, responsibilities, a schedule with key milestones, the team, and specific allocated funding. This will provide the framework on which to drive the project forward and make sure that it is completed in a satisfactory manner. Key steps that should be included in this step are; present the project charter to the vice presidents of engineering, operations, technology development, supply chain management, and strategy & business development. The purpose of this meeting is to generate buy-in and support of the project from the top level. This meeting also serves to solicit the further support of these individuals to create the roadmap governing board.

9.1.2 Create Roadmap Governing Board

The creation of the roadmap governing board is critical to the success of roadmaps at Raytheon SAS. Roadmaps are very cross functional and require the collaboration of many different functional departments. There needs to be visible top level support for this cross functional collaboration to flourish. The roadmap governing board should be composed of the vice presidents involved with the creation and sustainment of roadmaps to include the vice presidents of engineering, operations, technology development, supply chain management, and strategy & business development. This review board will approve the roadmap project charter, and biannually monitor the progress of the project and content of individual roadmaps. They will help direct how the business strategy is broken down into executable projects through the roadmaps and make sure these align with changing business needs.

9.1.3 Announce Roadmap Project Business Unit Wide

An organizational wide announcement should be sent out to all employees publicizing the roadmap project. This is to include a link to a short presentation brief which describes why the roadmap project is necessary, what is involved, along with a high level overview and timeline. This business unit wide announcement serves two main purposes. The first is to inform all employees of the project, why it is needed, and the high level support that exists for it. The second is to make a public commitment on behalf of the VPs and the roadmap team to deliver on making the manufacturing technology roadmap project a success.

9.1.4 Set Goals and Verify Progress

The goals of the roadmap project need to be carefully considered so that the desired outputs are achieved. There should be two main types of goals, objective output based goals and behavioral process based goals. Objective goals might include making sure each technology area and each manufacturing value stream have manufacturing technology roadmaps completed by August. An example of a behavior goal would be that cross functional teams composed of engineering, operations, and supply chain management meet at least once a month to develop and update manufacturing technology roadmaps. Output based goals allow for progress to be monitored and the output to be verified and rated. Behavioral goals make sure a process that can lead to success is being followed and the right behaviors are being established and encouraged. Both sets of goals need to be verified regularly by seeing actual results not just hearing a verbal update on progress.

9.1.5 Use a Database for Data Integrity and Management

Roadmaps generate very powerful actionable data. This data needs to be kept secure and its integrity ensured. To support the creation and continual update of roadmaps it is suggested that a relational database be used to store all the information and linkages. This provides one shared repository for all information, and makes sure when a change happens it is communicated to all those affected. A database can also limit the content that specific users can access. This is important since the roadmaps are an executable form of the business strategy. They must be shared throughout the company, but they must also be managed so that the information does not end up in the wrong hands.

9.1.6 Align Incentives to Enable Roadmaps

To drive end to end process thinking, the first step is to understand the business process by which value is delivered to the customer. This requires mapping the entire value chain from customer request to product delivery and support. This allows for clear responsibilities and handoffs to be understood and communicated. With the big picture in mind incentives can be re-examined to make sure they support a global optimum. It is a powerful tool when departments are incentivized on profits of the products that they design, develop, and deliver. For example if engineering were incentivized on profits of the products they develop this would encourage them to work closely with manufacturing to reduce the costs of the product. It would also encourage them to collaborate with business development so that customer value could be increased, allowing for a higher selling price. Manufacturing could incentivize their employees on profits of the products they produce too with a focus on reducing costs through cross site collaboration and sharing of best practices.

9.2 General Recommendations for Roadmaps

This paper discussed how roadmaps can be a powerful tool to help communicate a business strategy and break it down into actionable projects. It examined some of the challenges associated with implementing manufacturing technology roadmaps at a large aerospace and defense company, Raytheon SAS. Specific challenges and methods to overcome these were discussed in detail. Some broad generalizations can be drawn from these specific examples which can hopefully provide insight to others looking to embark on similar endeavors. This section looks to describe some of those broad generalizations that apply to change and to manufacturing technology roadmaps.

9.2.1 Results are Important, Process is Key

Manufacturing technology roadmaps, or roadmaps in general, require cross functional collaboration to generate and update. Through this process ideas and priorities are discussed. Information on where the business is heading and how to get there are weighed in on. Relationships are built, and a common vision is developed. The world is always changing, and with this comes changing strategies. The important thing that roadmaps provide is a method to evaluate alternatives and share this information with the relevant people. The connections that roadmaps establish and strengthen are a key benefit besides their actual output.

9.2.2 Shared Representations Align Stakeholders

Communication is key in a matrix organization. Roadmaps allow for focused communication to take place in order to create a shared representation on which the entire team agrees upon. They provide a common language by which different functions can communicate and easily see how their work influences others, both upstream and downstream from them. This shared representation allows for a common understanding of the goals and how they will be achieved. Key technology components and associated timelines are given; it is then up to the stakeholders involved to figure out how best to close the gaps between current state and the future state capabilities.

9.2.3 Roadmaps are Cross Functional, Support Must Be Too

Roadmaps require a cross functional team to be generated and updated; this requires the same cross functional support at the top level to sustain roadmaps. No one department can create and sustain roadmaps on their own, it is a collaborative task. There must be support from each individual department so that its employees have the time and resources necessary to devote to roadmaps. These individual departments must then make their support public so that roadmap teams can work together effectively.

9.2.4 Building Support by Showing Value

Any time the way something is done is changed, for it to be sustained; life should be easier for the person doing the action after the change. Support can be created if you can make people's work easier for them to complete. All you have to do is lead them to see how the change will make their work easier and prove it with examples and pilots. This thought is what drives the power of a stakeholder analysis. To gain support, demonstrate the value of the proposed method to those that must accept it.

9.3 The Vision and the Ideal State

The vision for roadmaps is to provide a technology company, large or small, the necessary tools to communicate an executable strategy to all of its employees. An unknown strategy cannot be executed on, although more often than not this is what is expected in business today. Roadmaps provide a clear shared representation of what the business strategy is, and how to get there. It allows a strategy to be communicated without becoming diluted. The strategy instead becomes stronger and stronger as it reaches the working level with an executable plan in the shape of a roadmap.

The ideal state will vary from company to company, based on size, industry, and needs. The ideal state will have a standardized format showing time phased investments required to support the business strategy that can be executed at each level of the organization from VPs to working level contributors. As in life nothing of meaning comes easily, it is a journey that must begin now, but will never truly end. As W. Edwards Deming once said "It is not necessary to change. Survival is not mandatory." Roadmaps are just one tool that can be used to plan, execute, and verify a comprehensive business strategy so that a business can survive and grow.

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Appendix A DoD Acquisition System

11.1 DoD Acquisition System

DoD acquisition system is depicted below from a 2006 DoD report. Here we see that "Big "A"" is the total acquisition process encompassing; requirements, budget, and acquisition. It is known as a system of systems. Each one of these is run semi- independently of the other.

1. The Joint Capabilities Integration and Development System (JCIDS) – the requirements system
2. The Planning, Programming, Budgeting, and Execution System (PPBE) – the budgeting system
3. The Defense Acquisition System (DAS) – the acquisition system

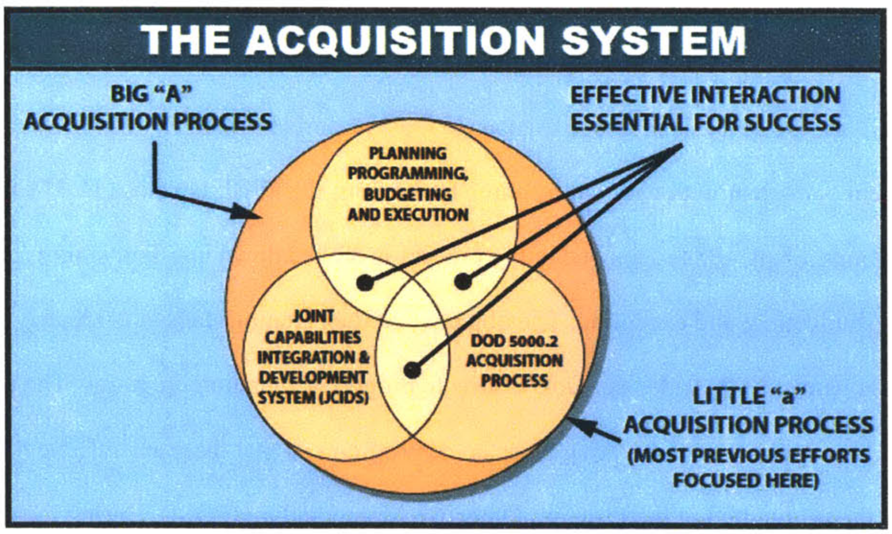

Figure 20 The Acquisition System

(Kadish, 2006)

These different interdependent systems will be elaborated in the following sections. It is important to remember that they all interact with each other, so a change to one will impact the others, and the entire DoD acquisition process as a whole.

11.1.1 The Joint Capabilities Integration and Development System (JCIDS)

JCIDS is the process by which DOD identifies, assesses, and prioritizes what capabilities the military requires to fulfill its mission. (Schwartz, 2010) This is a capability based approach as opposed to the older threats based approach. The JCIDS will identify the capability that the warfighter needs. For a solution to be approved it must meet the following requirements.

1. Capabilities required to perform the defined mission
2. Gap in capabilities required to perform the mission
3. Need to address the capability gap.

Once approved the program enters the Defense Acquisition System (DAS). (Schwartz, 2010)

11.1.2 The Planning, Programming, Budgeting, and Execution System (PPBE)

According to DoD, the PPBE is intended to manage DoD resources effectively for successful mission accomplishment consistent with national resource limitations; the PPBE develops DoD's proposed budget for all acquisitions. (Taft, 1984) This budgeting process is broken down into four stages; planning, programming, budgeting, and execution. The objective of the planning stage is to identify the needs of the combatant commands. This guides the DoD efforts to propose acquisition programs. The programming stage is next. This consists of elaborating on selected programs so that there are sufficient details. These programs are then submitted in the Program Objective Memorandum (POM). During the programming phase the budgeting phase is happening at the same time. This phase involves the budgeting for programs. The execution stage is the last one, during this time programs are evaluated on their ability to execute. This process runs on a year cycle, where planning and programming occur every other year and budgeting and execution occur each year. (Schwartz, 2010)

11.1.3 The Defense Acquisition System (DAS)

The Defense Acquisition System (DAS) is quoted as the following excerpt from DoD directive 5000.1.

"The Defense Acquisition System exists to manage the nation's investments in technologies, programs, and product support necessary to achieve the National Security Strategy and support the United States Armed Forces. " "The primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price." (Paul Wolfowitz , 2003)

The operation of DAS is explained in directive 5000.2. The various programs are managed by a program manager. The primary tool used to manage and track the programs is milestones. For a program to enter the DAS it must be authorized. To receive authorization a program must meet all the criteria for entering into the milestone phase they are entering and pass through a Materiel Development Decision (MDD) review. The various milestones are detailed in the following graphic. (DoD, 2008)

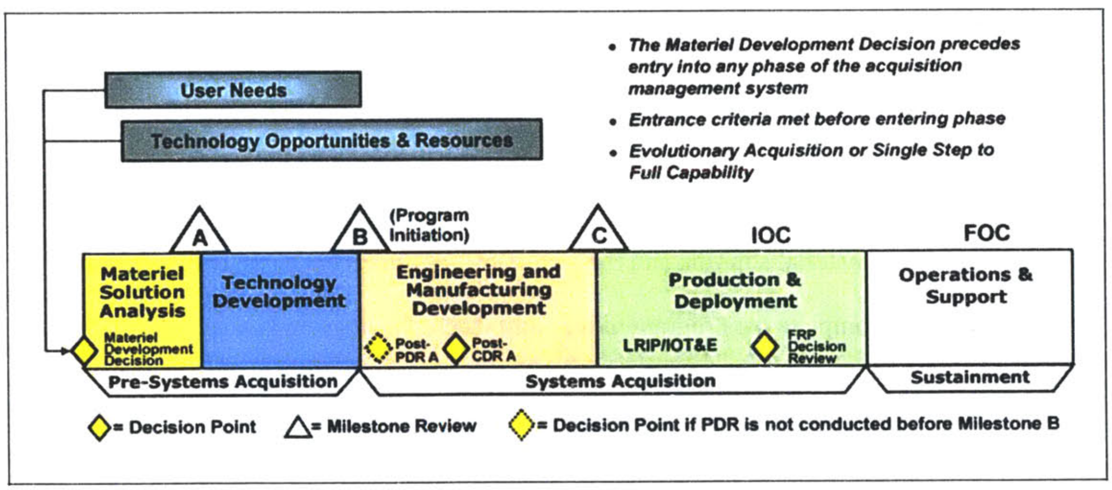

Figure 21 DoD Milestones and Phases

Before going into detail of the DAS and various phases and milestones it is important to note that the three systems; JCIDS, PPBE, and DAS each have their own objectives that are not always perfectly aligned. This causes many different organizational values to be displayed within the process as a whole. These values pull in different directions causing instability. The instability of the system itself is magnified by the ever increasing changing environment that it has to react to.

The defense industry has greatly changed over the past 25 years. Threats used to be well-known and well-defined. This allowed for large production volumes of weapon systems, and thus a large contractor base of over 20 prime contractors. Now the security environment is unpredictable with difficult to define threats. This means that weapon systems need to be developed quicker to meet the current needs. Production volumes have dropped by at least 2/3 and only six prime contractors remain. (Kadish, 2006) Now further elaboration will continue on the various phases and milestones of the DAS.

11.1.3.1 Material Solution Analysis

The major objective of the Material Solution Analysis phase is to determine what options exist to achieve the necessary requirements and to develop a technology development strategy. An Analysis of Alternatives (AoA) is conducted to determine the various options to meet the needs and which are best suited to do this in a cost effective manner with minimal risk. Once a material solution is recommended and the other requirements for milestone A are met, the program moves onto the Technology and Development Phase.

11.1.3.2 Milestone A

Milestone A requires that a program submit a cost estimate to complete the material solution that was the output of the AoA. The material solution and the technology development strategy must then be approved. Once this is complete the program moves into the Technology and Development Phase.

11.1.3.3 Technology and Development Phase

The Technology and Development Phase involves the program determining what specific technologies are required to develop the material solution that was generated from the Material Solution Analysis phase. The technologies are required to be demonstrated by prototyping and also to be affordable. Both the technology and the manufacturing process must be developed in a production relevant environment. In addition to an actual prototype, a Capability Development Document is created which details the operational performance parameters that the system is targeting to achieve. A Reliability, Availability, and Maintainability (RAM) strategy is also developed for the system as a whole. (David Duma and

Kenneth Krieg, 2005) Once all this is completed the program has to pass Milestone B to enter the Engineering and Manufacturing Development phase.

11.1.3.4 Milestone B

Milestone B requires that the Acquisition Strategy, the Acquisition Program Baseline, and the type of contract that will be used to acquire the system are approved. (Schwartz, 2010) This is the milestone where most programs are formally initiated.

11.1.3.5 Engineering and Manufacturing Development

The Engineering and Manufacturing Development phase consists of two sub phases; Integrated System Design and System Capability & Manufacturing Processes Demonstration. During Integrated System Design the various sub systems are assembled into a complete system or prototype. For a program to move to the next sub phase it must pass a Post-preliminary Design Review (PDR) which makes sure the system meets the requirements. It must also pass a Post-Critical Design Review (CDR) Assessment which verifies that the system meets the required design maturity.

System Capability & Manufacturing Processes Demonstration involves various testing of the system to make sure that it can provide military usefulness. It is also verified that the system can be supported through the manufacturing process at this stage. For the system to complete the Engineering and Manufacturing Development phase and move onto Production and Deployment phase it must pass Milestone C, meet performance requirements as demonstrated by a production-representative article in an intended environment, and show that the manufacturing processes work and can produce the intended system.

11.1.3.6 Milestone C

To pass Milestone C a program must meet the following; passed developmental testing and operational assessment, demonstrated interoperability and operational supportability, demonstrated affordability, and be fully funded. (Schwartz, 2010) Once it has passed Milestone C a program begins low-rate initial production (LRIP).

11.1.3.7 Production and Deployment

LRIP is the initial stage of the Production and Deployment phase. Here manufacturing and quality can prepare for higher rate production. Parts from this phase go through operational test and evaluation (OT&E). Once testing is completed and the necessary control over the manufacturing process is demonstrated, the approval for full rate production can be given. The last phase is Operations and Support. Here the program supports the systems in the field.

Appendix B DoD Manufacturing Readiness Level Definitions

This entire section is taken directly from the following source. (Gordon, Manufacturing Readiness Levels)

MANUFACTURING READINESS LEVEL DEFINITIONS

There are ten MRLs (numbered 1 through 10) that are correlated to the nine TRLs in use. The final level (MRL 10) measures aspects of lean practices and continuous improvement for systems in production.

MRL 1: Basic Manufacturing Implications Identified

This is the lowest level of manufacturing readiness. The focus is to address manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (i.e., funded by budget activity) begins in the form of studies.

MRL 2: Manufacturing Concepts Identified

This level is characterized by describing the application of new manufacturing concepts. Applied research (i.e., funded by budget activity 6.2) translates basic research into solutions for broadly defined military needs. Typically this level of readiness in the S&T environment includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging.

MRL 3: Manufacturing Proof of Concept Developed

This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in the S&T funding categories of Applied Research and Advanced Development (i.e., funded by budget activity 6.3). Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.

MRL 4: Capability to produce the technology in a laboratory environment

This level of readiness is typical for S&T Programs in the budget activity 6.2 and 6.3 categories and acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.

MRL 5: Capability to produce prototype components in a production relevant environment

This level of maturity is typical of the mid-point in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete.

Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.

MRL 6: Capability to produce a prototype system or subsystem in a production relevant environment

This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes completion of S&T development and acceptance into a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design of critical components has been completed and producibility assessments of key technologies are complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. A cost analysis has been performed to assess projected manufacturing cost versus target cost objectives and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been completed. Long-lead and key supply chain elements have been identified.

MRL 7: Capability to produce systems, subsystems, or components in a production representative environment

This level of manufacturing readiness is typical for the mid-point of the Engineering and Manufacturing Development (EMD) Phase leading to the Post-CDR Assessment. Technologies should be on a path to achieve TRL 7. System detailed design activity is underway. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments are underway. The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets. Unit cost reduction efforts have been prioritized and are underway. The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place. Production tooling and test equipment design and development have been initiated.

MRL 8: Pilot line capability demonstrated; Ready to begin Low Rate Initial Production

This level is associated with readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is essentially complete and sufficiently stable to enter low rate production. All materials are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. The engineering cost model is driven by detailed design and has been validated with actual data. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established and stable.

MRL 9: Low rate production demonstrated; Capability in place to begin Full Rate Production

At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes.

Major system design features are stable and have been proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.

MRL 10: Full Rate Production demonstrated and lean production practices in place
This is the highest level of production readiness. Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing. Although the MRLs are numbered, the numbers themselves are unimportant. The numbers represent a non-linear ordinal scale that identifies what maturity should be as a function of where a program is in the acquisition life cycle (as described in Section 3). Using numbers is simply a convenient naming convention.

Appendix C SAS Mission Areas

Tactical Airborne Systems (TAS) (Raytheon, 2011)

Tactical Airborne Systems is a world-leading provider of sensors and systems integration expertise, offering superior technologies such as advanced fire control radars, avionics, electronic warfare systems and processor technologies. Our products deliver enhanced capabilities and performance for both manned and unmanned platforms across all operational mediums: air, land, sea, space, and cyberspace. Our mission is to provide integrated air dominance solutions, resulting in actionable information and mission assurance for the warfighters of today and the future.

Key TAS Capabilities:

- Advanced Fire Control Radars
- Electronic Warfare Systems
- Airborne Processors and Avionics

Intelligence, Surveillance & Reconnaissance (ISR) (Raytheon, 2011)

Providing the joint warfighter with actionable information from an unblinking eye across the battle space.

- Air-to-ground and Maritime Surveillance Systems
- Active and Passive Electronically Scanned Array Radars
- Electro-Optical/Infrared Sensors
- Integrated Sensor Suites
- Multi-Platform Integrated Mission Solutions
- Performance Based Logistics and Lifecycle Mission Support

Space Systems (SS) (Raytheon, 2011)

Leading the industry in space-enabled information solutions.

- Intelligence Gathering and Ground Surveillance
- Earth Observation and Climate Monitoring
- Advanced Missile Warning
- Space Protection
- Rapidly Deployable Payload Technologies

Raytheon Applied Signal Technology (AST) (Applied Signal Technology, Inc. , 2011)

We provide expertise in the areas of broadband communications, signals intelligence, cyber security, and sensor surveillance, with a common core competency in digital signal processing. SIGINT capabilities include the collection and exploitation of communication signals and the interception of electromagnetic signals, such as radar and weapons systems, for electronic intelligence. Cyber security capabilities include network monitoring, intrusion detection, and countermeasures. Remote sensing capabilities include processing information from sonar, radar, magnetic, electromagnetic, infrared, electro-optical, hyperspectral, and visible light sensors to detect abnormalities of interest and increase situational awareness. We have experience in space, airborne, terrestrial, and undersea environments.

Appendix D Strategic Capability Spreadsheet

This is an example of the strategic capability spreadsheet. The spreadsheet is used to help guide the user into making an informed decision on whether the new manufacturing capability under investigation is strategic or not. Both qualitative and quantitative data is used. Inputs include factors such as; capital required, risk, estimated market size, probability of winning the contract, change in probability of winning the contract from investments, a realization or learning factor, impact to manufacturing base, and a disruptive technology/ spiral development factor.

Quantitative values are used when possible. When qualitative information is more appropriate it is used and ranked on a 0 to 1 scale with clear definitions explaining the ranking and the reasoning documented. All the factors are then combined with qualitative data being converted into a dollar equivalent. A ratio is then calculated showing what is the most likely, worst case, and best case scenarios. This allows an estimate to be made with some degree of confidence concerning the upper and lower bounds. This ratio then determines if the technology is strategic (make) or not strategic (buy). There is also a range in ratio values where further discussion is encouraged.

inputs	value (most likely)	value (worst case)	value (best case)
capital	$2,000,000	$2,000,000	$2,000,000
risk	0.15	0.3	0.05
market size	$100,000,000	$100,000,000	$100,000,000
P(win)	0.7	0.6	0.75
delta P(win)	0.15	0.1	0.2
Realization Factor (RF)	0.4	0.2	0.5
base	0.213	0.175	0.238
Disruptive Technology, spiral development factor	0.4	0.4	0.4
upside	$3,018,750	$1,775,000	$4,275,000
downside	$2,300,000	$2,600,000	$2,100,000
ratio	1.313	0.683	2.036

1.331		1.331
1.331		1.331
1.331	fulcrum	1.331
Make		Buy

Set Values		
	low	high
yellow	0.9	1.1

function
1.331

Appendix E Strategic Capability Acquisition Decision Tree

This decision tree walks the user through a series of questions that help explore the various options for acquiring a new manufacturing capability, based on whether the new capability is strategic or not. A new manufacturing capability is determined to be strategic or not with guidance from the Strategic Capability Spreadsheet, example in Appendix D.