Implementing a New Organization to Manage Manufacturing Technology Innovation

By

Annabel Flores

B.S. Mechanical Engineering, Massachusetts Institute of Technology 1999

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

Master of Science in Mechanical Engineering
And
Master of Business Administration

In conjunction with the Leaders for Manufacturing Program at the Massachusetts Institute of Technology June 2003

Signature of Author..
Department of Mechanical Engineering, Sloan School of Management
May 9, 2003

Certified by..
Deborah Nightingale, Thesis Advisor
Professor of the Practice
Department of Aerospace and Aeronautical Engineering
& Engineering Systems Division, MIT

Certified by..
Roy E. Welsch, Thesis Advisor
Professor of Statistics and Management Science
Sloan School of Management, MIT

Certified by..
Warren Seering, Thesis Reader
Weber-Shaughness Professor of Mechanical Engineering
Department of Mechanical Engineering, MIT

Accepted by..
Ain Sonin, Chairman Graduate Committee
Department of Mechanical Engineering

Accepted by..
Margaret Andrews, Executive Director of Masters Programs
Sloan School of Management

Implementing a New Organization to Manage Manufacturing Technology Innovation

By

Annabel Flores

Submitted to the Department of Mechanical Engineering and the Sloan School of Management on May 9, 2003 in Partial Fulfillment of the Requirements for the Degrees of Master of Science in Mechanical Engineering and Master of Business Administration

Abstract

The purpose of this research is to provide an academic, external perspective to facilitate the implementation and development of a new internal organization for Raytheon Missile Systems (RMS) with a focus on strategy and the organization. The new organization, named the Advanced Manufacturing Development Center (AMDC), is chartered to work concurrently with the design community to develop state-of-the-art manufacturing technology to compliment the next generation engineering designs. .

This thesis documents the efforts of a company implementing change detailing the specific challenges they faced. The principle lessons learned during the course of this project are (1) that effectively introducing change is very difficult and depends largely on thorough planning and understanding the culture and (2) that manufacturing innovation and development is a critical step to improving the manufacturing capabilities and providing a competitive advantage to a company.

The defense industry is undergoing a lean transformation that focuses on "Better, Faster, Cheaper" defense systems demanding better products within a faster development timeframe at cheaper development and production costs. Defense companies have an external push to improve their manufacturing capabilities. In the context of the defense industry, adapting to change is a slow process given the industry's clockspeed and historical development. Making the challenge of effective implementation even more difficult is the lack of urgency at RMS's due to their success in the marketplace.

Benchmarking and organizational studies specific to the industry and the company were conducted to identify best practices to provide a basis for the development of the AMDC. This project uses academic research to identify existing theories on manufacturing innovation and organizational change to overcome the socialization and cultural issues that ensued from implementing change and to improve the potential sustainability and impact of the AMDC. An implementation roadmap and operational model were generated that combined the best practices found in industry and academic theories that would help meet the objectives of the AMDC.

Thesis Supervisors

Deborah Nightingale
Professor of the Practice, MIT Department of Aerospace and Aeronautical Engineering & Engineering Systems Division

Roy E. Welsch
Professor of Statistics and Management Science, MIT Sloan School of Management

Warren Seering, Reader
Weber-Shaughness Professor of Mechanical Engineering, MIT Department of Mechanical Engineering

Acknowledgements

The research described in this thesis was possible through the efforts of many people and I would like to take this opportunity to thank some of the people that gave of their time and experience.

I would like to acknowledge the Leaders for Manufacturing Program (LFM) for its support of this work. In addition, my two advisors, Professor Deborah Nightingale and Professor Roy Welsch have been key contributors to this research. Both were not only fully engaged throughout the project and the writing of this thesis, but they also provided key insights from their personal experience that added to my research.

The LFM network consists of a number of stakeholders, current students, alums, partner company representatives and the administration, each of which deserve my gratitude. My classmates, aside from providing moral support and their friendship, were there as a sounding board for my ideas, work and frustrations. They also shared their previous work experience that added to the benchmarking studies and went so far as to edit portions of my research. I owe many thanks to the LFM alums who shared their time and experiences as they were invaluable in getting this research started. I would also like to thank the LFM administration and numerous professors that also shared their experience and provided additional contacts. Similarly, partner company representatives were not only receptive to speaking with me but also provided vital contributions and insights regarding their respective companies.

Raytheon Corporation has been central, not only in this research but also in the pursuit of my graduate edcation. I would like to thank my manager, Mike Liewald, for supporting my educational goals and granting my sponsorship for the LFM program. In addition, I would like to thank the employees of the Raytheon's Corporate Knowledge Transfer and Benchmarking Office for their efforts in performing a portion of the benchmarking included in this research.

I owe much of this research to Raytheon Missile Systems and its employees for all of their support and help throughout the internship. Many employees and managers opened their doors and shared their beliefs, perceptions, and insights regarding the culture and business practices of the company. Specifically, I would like to thank Kevin McDonald for helping with the logistics of this research project and as well as participating in Raytheon's Six Sigma training. Also, my project supervisor, Dennis Kox, deserves my gratitude for facilitating and being receptive to my work and research. Finally, I would like to thank my project champion, Pat Caldwell, for believing the contributions of an academic would be useful in industry and for his forward thinking in redefining manufacturing and operations.

Finally, and most importantly, I would to thank my family, Roy, Juanita, Maribel and Christa, for the constant support, help and level-headedness they provide and for letting me know that no matter where I go and what I do, they'll always be a phone call away.

Table of Contents

List of Figures

List of Tables

This page intentionally left blank.

Chapter 1 Introduction

This thesis is the culmination of a six-month internship project within the Operations Organization of Raytheon Missile Systems (RMS) and the subsequent work of the author at MIT as a part of the Leaders for Manufacturing Program. The project scope was to facilitate the implementation and development of a new organization, the Advanced Manufacturing Development Center, within Operations. The new organization's charter is to develop new manufacturing capabilities that would match the needs of advanced product technologies currently in development, thereby creating a competitive advantage for RMS. The premise behind this research is that transferring knowledge from academia and existing research would provide a framework to effectively introduce change within an organization. The key research topics in this investigation are to understand the importance of (1) identifying and compensating for the socialization issues that arise when introducing change into an organization, (2) manufacturing innovation in building a competitive advantage, and (3) creating a learning organization for increased effectiveness in the development and sustainability of new manufacturing capabilities.

This thesis will seek to characterize the defense industry and detail the forces driving companies to change and the specific challenges faced in attempting to implement change. Also, this research will attempt to characterize the culture of Raytheon Missile Systems to identify leverage areas to successfully implement the new organization. Published literature describes a model for the dynamics of innovation in both product and process development as it relates to a product's life cycle. Using this model, this thesis will assess a company's product and characterize it within its lifecycle to determine the need and opportunity for continued manufacturing and process innovation. In addition, this research will seek to identify operational parameters for effective manufacturing innovation.

1.1. Defining the Business Problem

Currently, design engineers within advanced research and development labs at Raytheon Missile Systems (RMS) are isolated from manufacturing. Often, the design engineers have developed a state-of-the-art product but the existing manufacturing technology is inadequate for production. The disconnect between engineering and manufacturing can result in a myriad of problems such as longer development time, more difficult transition from development to production, longer ramp-up time, lower manufacturing yields, higher rework ratios, and longer extensive test cycles to validate the performance of each product. All of these problems lead to higher unit costs and a damaged reputation for developing and delivering new systems to existing and potential customers.

More importantly, the defense industry is currently undergoing a lean transformation. Customer expectations of cost and time for new system development will soon exceed current capabilities. Also, military and defense needs are shifting and are redefining the requirements and skills needed for companies to deliver new products. To be responsive to these changing customer needs, a company should be flexible and adapt to the new nature of the industry. A company's ability to develop and deliver new systems to meet new customer needs within their requirements will determine their competitive standing. However, the effective development of new products is hampered by engineering's existing practice to "throw the design over the wall" to manufacturing. In general, this concept describes the end of requirements and responsibilities from one entity to the other with little to no accountability linking the overall process.

Ideally, companies that are facing this environment such as RMS should modify their entire product development cycle by eliminating the ivory walls that have traditionally separated product development from the rest of the enterprise. By having the engineering and manufacturing communities working together to fulfill the same purpose, they can more efficiently deliver high quality advanced products and systems to the customer. This vision, however, requires a massive realignment of the existing organizations and culture. In addition, this requires the elimination of the silo mentality that prevents collaboration across boundary lines as well as the introduction of accountability from initial concept development to system delivery.

Unfortunately, breaking down the existing barriers between engineering and manufacturing has troubled both academics and enterprises. Combining the two communities is a challenging endeavor given the diametrically opposed cultures and sometimes adversarial relationships that exist between them. "Since most dominant orientations incorporate implicit, if not explicit, judgments as to the relative importance of various functions and their roles in achieving a competitive advantage, they establish strong mind-sets within an organization as to the role that manufacturing should play in its competitive strategy."[1] A complete redefinition of a company's existing business practices is an extremely risky undertaking. The time required for the enterprise to reach a steady state could be prohibitively long. There are also no guarantees that the change will be successful and that effective coordination will result. Drastically shocking the existing system could result in an enterprise whose performance is significantly inferior to before the shock was introduced.

A more manageable undertaking could involve the implementation of accountability and ensuring that product development efforts span the entire process. Adding accountability throughout the process would require programs to identify and address the manufacturing technology needs and mitigate the manufacturing risks early in development. Being able to develop new manufacturing technologies and processes would result in an expansion of the internal manufacturing capabilities with the potential to affect the rest of the supply chain at a later date. Building new manufacturing capabilities would create a competitive advantage for RMS. Subsequent sections of this thesis will outline the additional benefits of manufacturing innovation.

However, in the context of the defense industry, adapting to change of any magnitude is difficult. Making the challenge even more difficult within RMS is the lack of urgency or

---

[1] Robert H. Hayes and Steven C. Wheelwright, *Restoring Our Competitive Edge: Competing Through Manufacturing*. (New York: John Wiley & Sons, 1984), pg 38.

a "burning platform" to encourage effective implementation of any change let alone such a drastic one as described above.

In order to innovate manufacturing processes and technologies, RMS leadership has decided to create an Advanced Manufacturing Development Center (AMDC) with the goal of minimizing the organizational shock. In the past, RMS had a research organization devoted to developing manufacturing technologies. However, this organization was disconnected from the product development research and the manufacturing technologies that ensued were not applicable within the business. To prevent the same scenario, the AMDC is chartered to create practical, low-cost solutions for the next generation engineering designs. The role of the AMDC is to work concurrently with the design groups and develop state-of-the-art manufacturing technology to compliment their designs.

1.2. Manufacturing Innovation

Manufacturing innovation is the research, development and application of new manufacturing tools, processes and techniques. A fair amount of research has been undertaken by academics to understand how changes in the competitive environment are affecting American manufacturing companies. With this research comes a historical perspective that attempts to explain the factors that drove companies to their current state. The research results largely dictate the change needed of these companies to remain competitive.

1.2.1. U.S. Manufacturing - a Historical Context

The state of American manufacturing companies has undergone a significant amount of scrutiny particularly with the increase of international competition in the 1980's.

> "U.S. manufacturing companies [chose] to compete primarily on dimensions other than manufacturing ability. The United States thought it had [overcome any production problems]. Therefore, attention and resources have been directed toward mass distribution, packaging, advertising, and the development of incremental new products to round

> out existing product lines or attack specific market segments, instead of toward improving manufacturing capabilities."[2]

The globalization of many different industries creates a direct competition amongst the different policies. "Managers of competitively successful technology-based German and Japanese firms have identified a strong pattern of commitment to the development of advanced process technology. Most of these firms designed and built critical elements of their own process equipment, and they have gained competitive advantage from unique products that depend upon proprietary developments in process technology."[3] Henderson et al. believe "that inadequate attention to process development may be an important factor in the failure of many U.S. firms to respond effectively to heightened foreign competition."[4]

In describing the competitive environment of the 1980s and beyond, Hayes and Wheelwright believe

> "For many [US] companies the issue had become one of simple survival. The "secret weapon" of their international competitors was not superior product designs, marketing ingenuity, or financial strength, but manufacturing superiority – the ability to 'make it better'...[US companies under attack] came to realize that they had been systematically neglecting their manufacturing organizations...The skills required to compete effectively against world class competitors had atrophied."[5]

"Too often companies have acted as if they were driven by market and competitive forces alone, and as if manufacturing's role was simply to respond to those forces by enlisting and coordinating the adjustments and resources provided by suppliers of parts and equipment."[6] The competitive environment for most companies is changing the existing manufacturing system from meeting the new industry needs. Developing new products without taking into account their manufacturability or the diversity of demands they

---

[2] Hayes & Wheelwright, pg 20
[3] Hayes & Wheelwright, pg 19
[4] Rebecca M. Henderson, Jesus Del Alamo, Todd Becker, James Lawton, Peter Moran and Saul Shapiro, "Perils of Excellence: Barriers to Effective Process Improvement in Product-Driven Firms," *Production and Operations Management* 7, no. 1 (Spring 1998), pg 3.
[5] Hayes & Wheelwright, pg viii
[6] Hayes & Wheelwright, pg 21

placed on manufacturing often led to unfocused facilities that tried to be 'jack of all trades' – and ended up being master's of none."[7]

Conversely, the Japanese have a better grasp of not only a vast array of manufacturing technologies and capabilities but also the skills needed to develop new manufacturing technologies. "The Japanese pattern [of innovation] would support the popular stereotype of American firms as innovators and creators of new industries and the Japanese as skillful at applying their considerable talents of automated production to product refinement and manufacture."[8] Their mastery and understanding of manufacturing can be applied to easily imitate products developed by their competitors; reducing the manufacturing costs and improving the product design effectively eliminating any advantage from those that initially developed the product.

1.2.2. Innovation through the Development Cycle

"An innovation's changing competitive impact is driven by ongoing innovation development, emerging complimentary technologies, and the innovation's widening use."[9] William Abernathy and James Utterback contributed a significant amount of research to the field of innovation. Together, they have developed a model describing the rate of product and process innovation through the different phases of development, shown in Figure 1.

---

[7] Kim B. Clark and Takahiro Fujimoto, *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry.* (Boston: Harvard Business School Press, 1991), pg 54.
[8] James M. Utterback, *Mastering the Dynamics of Innovation.* (Boston: Harvard Business School Press, 1996), pg 48
[9] Dean M. Schroeder "A Dynamic Perspective on the Impact of Process Innovation Upon Competitive Strategies," *Strategic Management Journal* 11, no. 1 (Jan 1990), pg 37

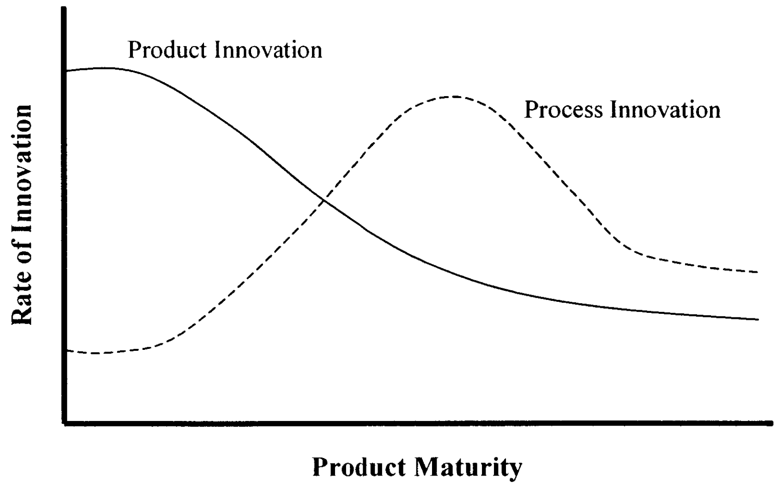

Figure 1 Innovation through Product Maturity[10]

Typically, the rate of product innovation is high in the preliminary stages of development where all facets of the system need to be defined. This phase of development is termed the fluid phase due to the ever changing nature of the product design. A large amount of resources are expended during this early stage focusing on defining product standards, architecture, etc.

In the course of their research, Utterback and Abernathy "observed that this flurry or radical product innovation eventually ends with the emergence of a dominant design."[11] A dominant design, in their terms, refers to the development of standard customer expectations on product performance, aesthetics, and capabilities; parameters that determine a product's competitive standing in the market. This phase of development is named the transitional phase as the myriad of technologies begin to shift toward the dominant design. The graphical representation of the Abernathy-Utterback model depicts the high rate of product innovation for a new product followed by a sharp rate decrease once a dominant design emerges. Once a design becomes dominant, there are relatively fewer areas of a product's design that require innovation and product design efforts shift

[10] Utterback, pg 91
[11] Utterback, pg 81

to incremental development. "As obvious improvements [to product design] are introduced, it becomes increasingly difficult to better past performance."[12] The last phase of development is the specific phase since most product development efforts converge on one dominant design. An industry with a dominant design, such as the automobile, is considered mature.

Abernathy and Utterback similarly characterized the historical rate of process innovation to the product's maturity level. In the fluid phase of development, minimal product definition precludes the ability to innovate new processes. "During the formative period of a new product technology, the processes used to produce it are usually crude [and] inefficient."[13] As the product design stabilizes, it facilitates the ability to identify specific areas of process innovation to target. The transitional phase is characterized largely by advancements in process technology. As customers begin to accept a new product or technology, they grow to expect a certain level of performance from this product. The formation of a dominant design changes the nature of competition. Companies cannot rely solely on product differentiation to remain competitive. Customer preferences shift to issues of quality and price driven largely by manufacturing and process advancements. "Manufacturing skill shows up in many areas that customer notice in one way or another: quality of fit and finish, the rate at which new models come out, the time it takes for a custom order to be built and delivered and product durability and reliability."[14]

It is in this transitional phase of development that product innovation and process innovations become tightly linked. As products reach maturity in the specific phase of development, the opportunity for advancements in process technology decreases and the rate of process innovation stabilizes. In this latter phase, product and process technologies are closely integrated and it is prohibitively expensive to drastically alter either one. "Changes in process technology can have a significant impact on product characteristics. Conversely, minor changes in product design specifications can require

---

[12] Utterback, pg 82
[13] Utterback, pg 82
[14] Daniel H. Whitney and Charles Fine, "Is the Make-Buy Decision Process a Core Competence?" MIT Center for Technology, Policy, and Industrial Development (1996), pg 6.

the development of completely new process technologies."[15] However this interdependence allows for firms not only to maintain product innovation-based competitiveness, but also to improve its product innovative abilities in the future.[16] One of the major critics of the Abernathy-Utterback model is that it limits high rates of process innovation to the transitional phase of development.[17] There is a large potential for process innovation to positively impact the product innovations during the fluid phase, without the constraints of established product characteristics. A subsequent section on process innovation will discuss the number of benefits that companies can achieve

Abernathy and Utterback extend their model of product and process innovation. Table 1 summarizes how a variety of factors shift from the fluid to the transitional to the specific phase.

Product	From high variety, to dominant design, to incremental innovation on standardized products
Process	Manufacturing progresses from heavy reliance on skilled labor and general-purpose equipment to specialized equipment tended by low-skilled labor
Organization	From entrepreneurial organic firm to hierarchical mechanistic firm with defined tasks and procedures and few rewards for radical innovation
Market	From fragmented and unstable with diverse products and rapid feedback to commodity-like with largely undifferentiated products
Competition	From many small firms with unique products to an oligopoly of firms with similar products

Table 1 Enterprise Level Shift through Phases of Development[18]

[15] Gary P. Pisano, "Learning-Before-Doing in the Development of New Process Technology," *Research Policy* 25 (1996), pg 1099.
[16] Masaaki Kotabe and Janet Y. Murray. "Linking Product and Process Innovations and Modes of International Sourcing in Global Competition: A Case of Foreign Multinational Firms" *Journal of International Business Studies* 21, no. 3 (1990), pg 389.
[17] Gary P. Pisano, *The Development Factory: Unlocking the Potential of Process Innovation.* (Boston: Harvard Business School Press, 1997), pg 7-8.
[18] Utterback, pg 91

Abernathy and Utterback use their research to describe how a company can use this framework to manage the innovation of technology across the enterprise through the changes of innovation. Subsequent sections of this thesis describe enterprise level changes necessary at Raytheon Missile Systems to effectively manage manufacturing innovation.

Historically, it is rarely the leading firm in one generation of technology to develop the next generation. "Most industry-shattering innovations do not spring from the established competitors in an industry but from new firms or from established firms entering a new arena."[19] Utterback's main premise is that the leader in one generation of technology focuses intently on further developing that technology that they are unprepared for the next leap in technology.

> "The most obvious explanation for the demise of established leaders in an industry would be that they have skills in the old product or process technology, while the entrepreneurial firms have a base in the new...[however] the differences in technological resources do not much discriminate between invading and traditional firms in an industry. Most threatened firms do participate in the new technology and often have preeminent positions in it. The basic problem seems to be that they continue to make their heaviest commitments to the old."[20]

It is also possible for a leading firm to be hesitant and wary of developing new technologies in-house that will cause their core technology to become obsolete.

In addition, "the lethargy of well-established competitors in a product market in the face of potentially disruptive innovation is that they face increasing constraints from the growing web of relationships bringing product and process change together."[21] Increasing the challenge for existing leaders to generate new technology, "Christiansen has shown that customer for entrenched products can influence a firm not to change when change is called for, increasing [the company's] resistance and vulnerability to

---

[19] Utterback, pg xxvii
[20] Utterback, pg 194
[21] Utterback, pg xxvii

technological progress."[22] The leading firm is caught unprepared and is forced to scramble to catch up. "Innovations shift competitive advantage when rivals either perceive a new way of competing or are unwilling or unable to respond."[23]

1.2.3. Innovation in a Manufacturing Context

Academic research on manufacturing innovation is fairly recent. The manufacturing environment has not seen much new, widespread, technological advancement. One of the leading researchers of manufacturing innovation, Gary Pisano, has studied manufacturing development within the pharmaceutical industry and generalized his theories to apply to other industries.

Table 2 details the different emphasis that manufacturing development acquires depending on the rate of product and process innovation.

---

[22] Utterback, pg 29
[23] Michael Porter, *Competitive Advantage: Creating and Maintaining Superior Performance*, (New York: Free Press, 1985), 45-47

Rate of Process Innovation		
High	**Process Driven** • Commodity Chemicals • Steel • Paper Process development focuses on cost reduction.	**Process Enabling** • Pharmaceuticals/Biotechnology • Specialty chemicals • Semiconductors • Advanced materials • High-precision, miniature electronic goods Process development focuses on solving complex technical problems, rapid time to market, and fast ramp-up.
Low	**Mature** • Apparel • Processed food • Shipbuilding Process development focuses on cost reduction.	**Product Driven** • Software • Entertainment • Workstation computers • Assembled products Either little process development or a focus on design for manufacturability.
	Low	High
	Rate of Product Innovation	

Table 2 Relationship between Product and Process Innovation[24]

The design of products and systems that face a low rate of product innovation has reached the stable phase of development. Pisano labels these types of products as material and process driven. Manufacturing developments in these types of products typically entail incremental improvements of existing manufacturing tools, processes and techniques to reduce production costs. Of products and systems with a high rate of product innovation, there are those with a low rate of process innovation. These product driven industries have stable and well-known manufacturing processes.

Process development is focused in the design phase of development to improve, modify or simplify the design to match the existing manufacturing capabilities. Further development of these products and system typically involve design for manufacturability

---

[24] Pisano (1997), pg 10

tools suited to making product designs compatible with current process capabilities.[25] "Research aimed at finding ways to improve manufacturability has led to greater understanding of the power of the design and development processes to affect manufacturing performance."[26]

The final category of products and systems are labeled as process enabling. These have a high rate of both product and process innovation. As new products are designed, they are continually in need of new manufacturing capabilities and require a high degree of process development and innovation to be able to produce the system. The focus of this research involves an industry that requires process-enabling technology. Even with a reduced rate of product innovation, "the appearance of a dominant design shifts the competitive emphasis in favor of those firms – large or small – that are able to achieve greater skills in process innovation and integration and with more highly developed internal technical and engineering skills. Once the dust has settled on the contest for *product* innovation, then competitive engagement shifts to a new battleground: *process* innovation."[27]

Process-enabling products require a new model for the role of manufacturing within the product development cycle and throughout the life of the product. Traditional development engages manufacturing near the end of the design phase and is known for the design teams throwing the design "over the wall" to the manufacturing teams. "Experience in a variety of industries suggests that a significant fraction (as much as 80 percent in some cases) of total product cost is established during the product engineering stage of development."[28] Pisano focused his research on process enabling products and created the following chart to detail the major differences between the traditional model and a new model for manufacturing development within a company.

---

[25] Pisano (1997), pg 9
[26] Clark & Fujimoto, pg 3
[27] Utterback, pg 30
[28] Clark & Fujimoto, 3 as a reference to the following articles: L. Soderberg, Facing Up to the Engineering Gap, The McKinsey Quarterly (Spring, 1989) & R. Jaikumar, Postindustrial Mfg, HBS (11 to 12/1986).

	Conventional Model	New Model
Primary Goals	Reduce manufacturing costs of existing products	Proactive support of timely, efficient, and high-quality launches of new products
Technical focus	• Incremental process improvement • New capacity/ equipment/automation • Troubleshooting • Product modifications for enhanced manufacturability	• Exploration/development of new process architectures needed for new product designs
Product Development Role/Influence	Peripheral	• Central • Process developers as core members of product development teams
Customer	Plant	• Plant • R&D
Key Capabilities	• Process Engineering • In-depth knowledge of current manufacturing environment • Minimize product disruptions	• Process science • Ability to anticipate future manufacturing requirements • Responsiveness to project level uncertainty
Learning	Maximize learning curve *within* product/process generations	Capture learning *across* product/process generations
Metrics of Performance	Improvements in yield, cost, quality, and capital over the life of a product	• Improvements in *initial* yield, cost, quality, and capital across products • Lead time, efficiency, quality

Table 3 Two Models of Process Development[29]

Table 3 differentiates between the status quo and the direction that companies should be headed in to develop new manufacturing capabilities. "Evidence is mounting that effective design and development of new products have a significant impact on cost,

---

[29] Pisano (1997), 290

quality, customer satisfaction, and competitive advantage."[30] Particularly important to note is the development of new manufacturing technologies results in improvements across the entire product development cycle as well as through the production and delivery of the product. "The challenges and opportunities [for process development] run deeper than ensuring compatibility of product and process design, or achieving manufacturability. Process development represents a technically difficult and organizationally complex undertaking in its own right."[31]

1.2.4. Purpose of Manufacturing Innovation

This section attempts to explain the importance of developing new manufacturing capabilities and attempts to itemize and justify investment in manufacturing innovation. "Real leverage comes from an aggressive pursuit of process technology changes rather than a simple focus on operating existing technology better to increase volume and boost capacity utilization."[32] Many industries are exposed to a multitude of different factors that support and drive the adoption of new models of development. There is an increasing complexity of product technology, minimal sustainable competitive advantage and shorter product life cycles. By investing in manufacturing innovation early in the product development cycle, a company can generate a number of competitive benefits:

- Difficult to copy manufacturing technologies
- Longer more sustainable competitive advantage
- Develop sophisticated technical problem-solving capabilities
- Capability to push the envelope of both product and process technology
- Decreases time to market
- Faster manufacturing ramp-up
- Reduces risk and complexity of development
- Provide technical degrees of freedom for product design benefits[33]

[30] Clark & Fujimoto, 1
[31] Pisano (1997), 9
[32] Gary P. Pisano and Steven C. Wheelwright, "The New Logic of High Tech R&D," *Harvard Business Review* 73. no. 5 (1995), pg 101.
[33] Pisano (1997), 17

In addition, "although superior process development can reduce manufacturing costs, in itself an important dimension of competition, the power of process development more often lies in how it helps companies achieve accelerated time to market, rapid production ramp-up, enhanced customer acceptance of new products, and a stronger proprietary position."[34]

Unfortunately, many companies are blindly following a policy to outsource different components as well as the manufacturing equipment used to build products in house. While outsourcing components could potentially result in the loss of a key link to control the product design and supply chain[35], outsourcing the manufacturing equipment results in the loss of internal skills to develop manufacturing processes. More damaging is that if other companies in the same industry are also outsourcing their manufacturing equipment, competitors end up with the same 'cookie cutter' technology available to everyone else. Hence, it becomes much easier and faster for competitors to imitate a product if the process technology used is readily available.[36] "Proprietary processes are just as formidable competitive weapons as proprietary products, and more enduring competitive barriers are created when a firm couples product innovation with process innovation."[37]

1.2.5. Challenges in Manufacturing Innovation

Manufacturing innovation can be a difficult and challenging concept to understand, let alone to use as a competitive advantage. "The barriers to using process development as an effective competitive weapon in companies that have been primarily product driven are subtle, complex, and deeply embedded in both the formal and the informal structure

---

[34] Pisano (1997), pg 11

[35] Charles H. Fine, *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. (Reading, MA: Perseus Books, 1998), refer to clockspeed and the "Intel inside" dilemma that started with IBM and began outsourcing all components, including those that resulted critical in today's market forcing IBM to lose power in the industry.

[36] Pisano (1997), pg 18

[37] Hayes and Wheelwright, pg 18

of the organization."[38] In their study of the automotive industry, Clark & Fujimoto outline the seemingly different environments within manufacturing and research & development. The traditional argument to explain those differences is that "effective production management [requires] stability, efficiency, discipline, and tight control whereas effective R&D management requires dynamism, flexibility, creativity, and loose control."[39] This argument underlies why different groups manage the two different functions in diametrically opposed ways. "Lacking balance and integration among all essential factors means that by investing heavily in one area, a firm could allow its competitors to exploit the new product or process technology first."[40]

Coordination and collaboration between the two major communities requires a close understanding of their new roles and responsibilities. "Product engineering must comprehend implications of their designs for manufacturability, and process engineering must clarify constraints and opportunities in the process and develop a good measure of flexibility to cope with the changes inherent in the product design process."[41] The push for manufacturing innovation requires early involvement in the product development stages. "The effects of process development are cumulative – the earlier a company undertakes process development, the greater the total financial return. Conversely, the longer a company waits to initiate process development, the less incentive there is to do so."[42]

It is important to note that the development of new manufacturing technologies typically has a longer development time. Companies that are pursuing manufacturing innovation should be conscious of the process development cycle and begin manufacturing innovation early in the development of the product design to be able to deliver both the product and the process. This extended development cycle time can be attributed to a number of factors. Primarily, most companies have a limited degree of experience in

---

38 Henderson et al, pg 3
39 Clark & Fujimoto, pg 168
40 Utterback, pg xxi
41 Clark & Fujimoto, pg 123
42 Pisano and Wheelwright, pg 101

developing new manufacturing processes and conducting manufacturing research. There is an inherent lack of skills to quickly and efficiently develop new processes. In addition, there is higher complexity in manufacturing innovation, in part due to the constant shift of the product design.

A number of issues regarding effective manufacturing innovation require significant changes to the organization and culture that surrounds development work within a company. Subsequent sections will detail the challenges faced in promoting organizational change.

1.3. Organizational Change

Research on organizations and their ability to change spans many decades and covers a myriad of theories. Often researchers focus their efforts on specific aspects of organizational change such as teams, stakeholders, leadership skills, culture, etc. While many different aspects of implementing change are studied and just as many possible solutions are offered, there is one definite conclusion: change is difficult and there is no magic formula to guarantee effective change. "Change is extraordinarily difficult, and the fact that it occurs successfully at all is something of a miracle. Change is furthered, however, if and when an organization can strike a delicate balance among the key players in the process."[43]

1.3.1. Implementing Change

One of the biggest challenges researches face in studying organizational change is the inability to prove their theories since it is impossible to isolate the organization and the different factors an organization is exposed to while undergoing change. "We are not yet, in this field [of corporate culture], at the stage of having hard hypotheses to test, and

[43] Ancona, et al, module 8, core pg. 12.

perhaps we never will be."[44] Even from the organization's point of view, the process of implementing change is difficult to apply in isolation. "No matter how carefully the leaders prepare for change, and no matter how realistic and committed they are, there will always be factors outside of their control that may have a profound impact on the success of the change process. Those external, uncontrollable, and powerful forces are not to be underestimated, and they are one reason why some researchers have questioned the manageability of change at all."[45]

Research on organizations implementing change is fragmented and includes a multitude of theories and schools of thought with a multitude of case studies and different suggestions for effective implementation. Difficulties in implementing change involve the organization, its culture, the stakeholders and the leaders involved in the process. However, "any action that disturbs the organizational status quo or represents a threat to an individual's habitual way of doing things is likely to provoke defensive, and often counterproductive, behaviors."[46] To implement change effectively, it is not only important to identify what within an organization should be changed but also to identify who will be affected by the change and whose support will ultimately be critical in its diffusion and its success.[47] Identifying the stakeholders and "understanding how recipients perceive the change and how they experience it"[48] is a critical step to effectively implementing change.

In implementing change, "culture matters because it is a powerful, latent, and often unconscious set of forces that determine both our individual and collective behavior, ways of perceiving, thought patterns and values."[49] The effectiveness of a company's culture is largely dependent on the competitive environment and whether or not the

---

[44] Edgar H. Schein, *The Corporate Culture Survival Guide: Sense and Nonsense about Culture Change*. (San Francisco: Josey-Bass, 1999), pg xvi.
[45] Ancona, et al, module 8, core pg. 14-16.
[46] Ancona, et al, module 8, core pg. 14.
[47] Ancona, et al, module 8, core pg. 17
[48] Ancona, et al, module 8, core pg. 19
[49] Schein, pg 14

culture is aligned with the company's strategy.[50] "The essence of culture [is] jointly learned values, beliefs, and assumptions that become shared and taken for granted as the organization continues to be successful."[51] However, as the environment changes, the same assumptions and culture may not be successful. In an older company, the organization's culture has stabilized and changing involves having to unlearn a portion of the old culture to learn about the new one. Additionally, in a more mature organization, "it is more difficult to decipher the culture and make people aware of it because it is so embedded in routines."[52]

The challenge in dealing with change on an individual level is that people prefer familiar environments. They "do not like chaotic, unpredictable situations and work hard to stabilize and 'normalize' them. Any prospective culture change therefore launches massive amounts of anxiety and resistance to change."[53] Edgar Schein, researcher on organizational culture, believes that while people "can be coerced into changing their overt behavior, [it] is not stable unless the deeper levels undergo some kind of transformation."[54] A subsequent section will address a number of steps that can be taken to overcome this individual resistance to being changed.

1.3.2. The Learning Organization

Very closely tied to the need for manufacturing innovation are studies of the environment that would best suit innovation. "Today, when competitiveness hinges on the ability to develop or adapt new technologies in products, services, and processes, understanding the dynamics of industrial innovation and change is essential for survival and success."[55] For innovation in manufacturing to occur, a radical shift in thinking is required to overcome the current mindset of manufacturing as a support function. "The organizations that will truly excel in the future will be the organizations that discover how to tap people's

---

[50] Schein, pg 24
[51] Schein, pg 20
[52] Schein, pg 143
[53] Schein, pg 26
[54] Schein, pg 115-116
[55] Utterback, pg xiv.

commitment and capacity to learn at *all* levels in an organization."[56] It is that spirit of enthusiasm and commitment that will establish manufacturing innovation and create a competitive advantage for a company.

"To avoid the grim reaper that has carried off so many proud and prosperous firms over the past century, modern managers must develop and nourish organizational capabilities that will carry them successfully from one generation of product and process technology to the next. This may be the ultimate managerial challenge."[57] Senge believes that 'in the long run, the only sustainable source of competitive advantage is your organization's ability to learn faster than its competition."[58] By learning faster, a company is able to respond and adapt to changes quickly. To garner these learning benefits, he believes a company should transform themselves into a learning organization. Senge has focused his research on learning organizations and defines these as organizations "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together."[59]

In defining a learning organization, Senge identifies five major disciplines that will create an organization that is capable of learning. The five disciplines are systems thinking, personal mastery, mental models, building shared vision, and team learning. Systems thinking is a high level understanding of system dynamics, a relatively young field of study that attempts to describe and understand entire systems and interactions of multiple different factors. System Dynamics hopes to provide additional perspective to decision makers to allow them to see the long-term consequences and repercussions of their actions. A subsequent section in this chapter describes in further detail the concept of System Dynamics and systems level thinking. Personal mastery refers to "continually clarifying and deepening our personal vision, of focusing our energies, of developing

---

[56] Peter M. Senge, *The Fifth Discipline: The Art & Practice of The Learning Organization.* (New York: Currency Doubleday, 1990), pg 3-4
[57] Utterback, pg xix.
[58] Senge, front flap
[59] Senge, front flap

patience, and of seeing reality objectively."[60] Senge believes that a commitment between an organization and an individual is necessary to engender growth and learning for the individual that is gradually transferred to the organization.[61]

The term, mental models, is also obtained from system dynamics. A mental model is an individual or group's perception of their environment. In Senge's words, "mental models are deeply ingrained assumptions, generalizations or even pictures or images that influence how we understand the world and how we take action."[62] Building a shared vision is a straightforward concept. Its application within the learning organization refers to uniting people to pursue a common goal and share the same destiny.[63] Finally, team learning is crucial in a learning organization to ensure that the whole is greater than the sum of its parts.

> "We know that teams can learn; in sports, in the performing arts, in science, and even, occasionally, in business, there are striking examples where the intelligence of the team exceeds the intelligence of the individuals in the team, and where teams develop extraordinary capacities for coordinated action. When teams are truly learning, not only are they producing extraordinary results but the individual members are growing more rapidly than could have occurred otherwise."[64]

In other words, teams have the ability to learn above and beyond their individual capabilities, generating additional benefits for a learning organization.

To create a learning organization, a number of changes are required to encourage learning. "Traditionally, organizations attempt to surmount the difficulty of coping with the breadth of impact from decisions by breaking themselves up into components. They institute functional hierarchies that are easier for people to 'get their hands around.'"[65] Now, there is a basic need for coordination to raise the level of awareness and optimize

---

[60] Senge, pg 7
[61] Senge, pg 8
[62] Senge, pg 8
[63] Senge, pg 9
[64] Senge, pg 10
[65] Senge, pg 24

everyone's efforts across the entire enterprise. "When people in organizations focus only on their position, they have little sense of responsibility for the results produced when all positions interact."[66] In this new competitive environment, a company can remain competitive by finding systematic "ways to bring people together to develop the best possible mental models for facing any situation at hand."[67]

Also, a new type of environment is required that engenders explorations and innovation. Trying new things to find creative solutions often means traveling out of a comfort zone and it is important to create a challenging and nurturing environment that is safe for people to think differently and make mistakes along the way without fear of repercussion.

1.3.3. System Dynamics

Systems level thinking is a systematic attempt to view and understand the world as a complex system where everything is interrelated. System Dynamics is a management tool used to identify major sources of conflict in the system, to effectively implement change by identifying high leverage points and to design better operating policies with both the short term effects and long term consequences in mind.

> "We each have a 'learning horizon,' a breadth of vision in time and space within which we assess our effectiveness. When our actions have consequences beyond our learning horizon, it becomes impossible to learn from direct experience. Herein lies the core learning dilemma that confronts organizations: we learn best from experience but we never directly experience the consequences of many of our most important decisions."[68]

System Dynamics provides a way to overcome that learning horizon and lows practitioners to see the "interrelationships rather than linear cause-effect chains, and [see]

---

[66] Senge, pg 19
[67] Senge, pg 181
[68] Senge, pg 23

processes of change rather than snapshots."[69] Additional descriptions to understand system dynamics and causal loop diagrams are included in Section 4.4 and Appendix A.

"The bottom line of systems thinking is leverage – seeing where actions and changes in structures can lead to significant, enduring improvements. Often, leverage follows the principle of economy of means: where the best results come not from large-scale efforts but from small well-focused actions."[70] Senge warns change agents and leaders to "beware of the symptomatic solution. Solutions that address only the symptoms of a problem, not fundamental causes, tend to have short-term benefits at best. In the long term, the problem resurfaces and there is increased pressure for symptomatic response. Meanwhile, the capability for fundamental solutions can atrophy.[71] Often, "it is much easier to draw on the strengths of the culture than to overcome the constraints by changing the culture."[72]

1.4. Thesis Organization

Chapter 1 provides an introduction to the internship project and details the academic research applicable to the key thesis topics. Chapter 2 is an effort to define the defense industry characteristics and the external driving forces to validate the need for manufacturing innovation. Chapter 3 describes the Raytheon Company, including its history, to understand the entire enterprise. The specific business unit in this study was characterized using various tools – Three lenses, System Dynamics – to identify and prepare to overcome the socialization challenges that arise from implementing change. Chapter 4 defines the vision and goals of the new center, the Advanced Manufacturing Development Center, and includes a more detailed account of the current operating culture and procedures of RMS to understand how efforts to develop new manufacturing capabilities will affect the organization.

---

[69] Senge, pg 73
[70] Senge, pg 114
[71] Senge, pg. 105
[72] Schein, pg 87

Chapter 5 describes the benchmarking efforts undertaken to understand how other companies manage manufacturing innovation. Chapter 6 details the operational model developed for the AMDC, including the operation of a Manufacturing Technology Strategy Committee and of the teams that will be developing the new manufacturing technology. Chapter 7 describes the progress of the implementation and development of the AMDC into the organization with recommendations for improvement and conclusions drawn throughout the research project. In addition, suggestions for additional avenues for research both in an academic sense as well as in the practical application of research ideas within the company. Although the research is specific to the defense industry, generic problems and conclusions are drawn that are applicable to other industries.

1.5. Chapter Summary

This first chapter introduces the project that served as a basis for this thesis. The majority of the chapter focused on presenting the academic research to define and validate the need to (1) effectively manage the change process, (2) innovate within the manufacturing environment and (3) create a learning organization for effective innovation. The research presents a basis to effectively implement change by thinking strategically about the change process, taking the organizational context into consideration and identifying the critical socialization issues that ensue. The results of this research are basic awareness of the fact that change is difficult. Viewing the enterprise as a whole permits a global-level understanding of the needs and benefits of manufacturing innovation. Finally, the management of technology and innovation is complex and requires an appropriate environment for optimal effectiveness.

This page intentionally left blank.

Chapter 2 Defense Industry

This chapter describes the defense industry to provide a general context of the competitive environment and describe the unique challenges that companies in this industry face. Researchers believe that to implement change in the product development cycle, "it is essential that we understand the linkages of product technologies with manufacturing process, corporate organization and strategy and the structure and dynamics of an industry."[73] This chapter also identifies the changes occurring within the defense industry that are external driving forces for companies to adopt manufacturing innovation research in their product development efforts.

For the purpose of this research, the defense industry includes companies that manufacture guided missiles, defense electronics, military aircraft, naval vessels, and corresponding parts, and other related defense components and systems, as well as companies that provide services such as military system integration, repair, and maintenance.[74] This thesis focuses primarily on the major US defense companies and their presence within the local US environment while including their product sales to international customers. The major US defense companies are those that produce large systems and are often primary contractors.

2.1. Porter's Industry Dynamics

Michael Porter presents a systematic framework to evaluate an industry by taking a closer look at the strength or power yielded by the various existing and potential players and factors. Porter created this framework to think about the five major forces that affect industry dynamics. He believes that understanding the dynamics within an industry will allow existing competitors to evaluate their position in the industry, determine if they are able to remain competitive, and evaluate the supply chain to determine if there are other

---

[73] Utterback, pg xxi
[74] Hoover's On-line – Aerospace & Defense Sector Description paraphrased to include only defense (accessed December 2002); available on www.hoovers.com.

profitable areas to pursue within the industry. In addition, an analysis of the Five Forces allows members of the supply chain to evaluate their competitive position as well as to allow potential entrants to determine the probability of successfully entering a particular area of an industry. Finally, characterizing the forces can help determine how an industry will respond to the introduction of a new product or a new business model. The five forces, Competitors, Customers, Suppliers, Threat of Entry and Substitutes, are illustrated in Figure 2 below.

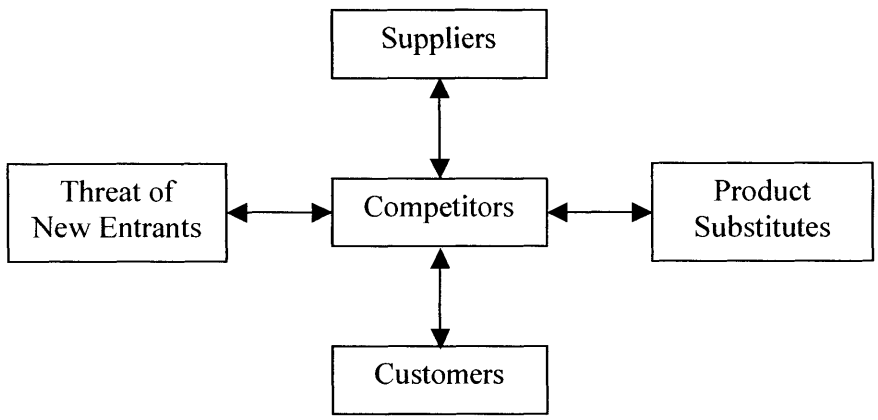

Figure 2 Porter's Five Forces

To begin the analysis, a definition of the defense industry is required and is described earlier in the chapter. The five forces of the industry were identified and the dynamics that defense companies face were characterized.

2.1.1. Customers

The primary customers in the defense industry are the US government and the major military branches: Army, Navy, and Air Force. For this analysis, international customers are not considered as a separate entity since all international sales are subjected to the approval and authorization of the US government and therefore have a similar, albeit more complicated, relationship.

The customers of the defense industry exert a large amount of control on all of the stakeholders. Multiple facets of the US government affect all aspects of product acquisition from new product and technology development to the purchase of available products to the creation of policies that determine the number and type of suppliers that must be involved. "The funding of U.S. government programs is subject to Congressional authorization and appropriation. While Congress generally appropriates funds on a fiscal year basis, major defense programs are usually conducted under binding contracts over multiple years, which provides a level of continuity uncommon to many industries."[75]

As mentioned earlier, the customer controls all sales, foreign and domestic, effectively controlling the fate of every defense company in their decisions. The customer has recognized the disadvantage they are in when compared to customer expectations in other industries. To rectify the situation, the customer is working with defense companies to implement lean principles to reduce both development and production costs of defense systems.

2.1.1.1. Lean Efforts

The Lean Aerospace Initiative (LAI)[76] is a collaborative effort comprised of MIT, representing the academic institution, industry representatives, as aerospace product design representatives, and U.S. military officers representing the interests of the customer. LAI is a forum for discussing industry changes and addressing the problems facing the different stakeholders to find common, practical solutions for all stakeholders.

One major initiative undertaken by LAI during the course of this research was a commitment by the U.S. Air Force to apply lean principles to the acquisition process. Their primary objectives are to simplify the acquisition process and reduce costs both

[75] Raytheon Company 2002 Annual Report, (accessed March 2003); available on http://www.raytheon.com/finance/annrpt.html, pg 2.
[76] MIT Lean Aerospace Initiative (accessed October 2002); available on http://lean.mit.edu/.

inherent in the process and in development. In addition, leaning out the process should reduce the amount of time currently required to make development and production decisions as well to reduce the product development timeline.

2.1.1.2. Acquisition Process

Defense is a highly regulated industry. As its primary customer, the U.S. government has a detailed Defense Acquisition Management Framework through which all acquisitions are managed. The framework is shown graphically below in Figure 3.

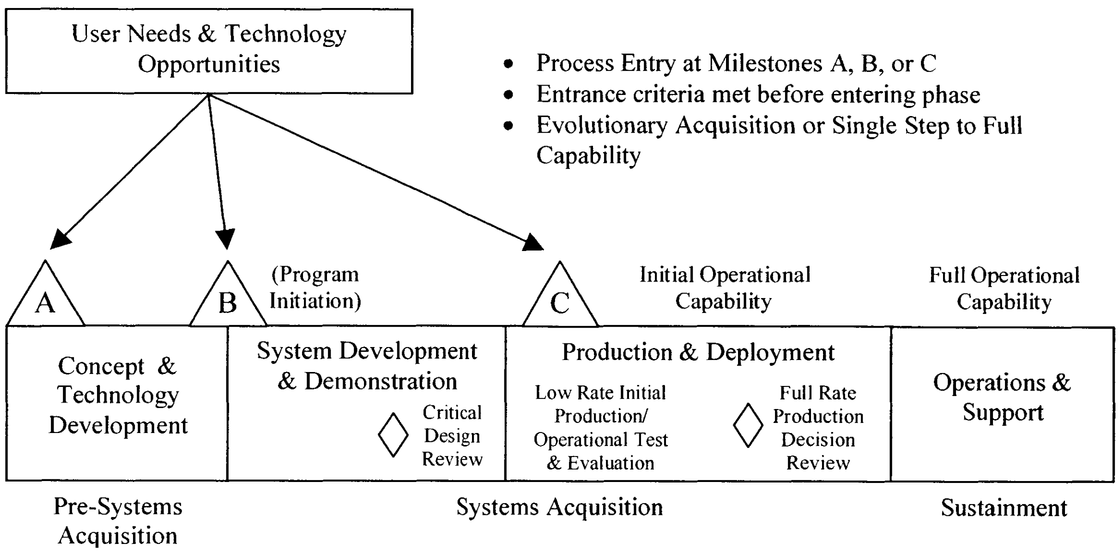

Figure 3 Defense Acquisition Management Framework; The 5000 Model[77]

The framework provides a high level overview of the different types of programs the government can fund. There are three major points where the customer can begin a new acquisition, denoted above as Milestones A, B, and C. From the customer's point of view, acquisition begins with either the identification of customer needs or of new technology opportunities.

---

77 Department of Defense, "Operation of the Defense Acquisition System," *Defense Acquisition University*, October 30, 2002 (accessed on November 2002); available on http://dod5000.dau.mil/ (Note: all government personnel involved in the acquisition process must be certified by the Defense Acquisition University.)

Typically, the government can notify defense companies of their needs at each milestone. Each company decides whether or not to submit a proposal for development or production work as requested by the customer. Once a bid is submitted, the government evaluates each proposal based on a set of entrance criteria and the company's credibility in meeting the system requirements. The customer then awards the contract to either one or multiple companies.

Milestone A, shown above, initiates the Pre-System Acquisition process. During Pre-System Acquisition the customer funds concept and technology development. At this point, defense companies primarily create top-level designs, define the overall system performance requirements and identify major technologies that will be used. In addition, companies perform trade studies to validate a particular technology or its application to meet the customer's needs. Particularly when granting funds for early development work, the customer is likely to fund several companies in parallel through the earlier phases of development.

Milestone B is the official program initiation. A contract that begins at Milestone B is either a continuation of work done in a previous contract or uses proven, existing technology for product or system development. This phase of the process is considered the beginning of Systems Acquisition. A company that is granted a System Development and Demonstration contract undergoes a critical design review where they must demonstrate the technology and current design meet the customer's requirements. Only if the critical design review is successful will the program enter the next phase: Production and Deployment.

Milestone C continues the System Acquisition portion of the process but requires companies to demonstrate the initial operational capabilities of the system. Programs in this phase begin low rate initial production, primarily to conduct operational tests and evaluate system performance. In addition, a major review of this phase determines whether or not a company can begin full rate production of the system. The final phase of the acquisition process is termed sustainment. Products or system design in this phase have been developed to their full operational capability. Contracts that begin at Milestone C typically involve an order for the delivery of existing systems with minimal if any design changes. Because the system and technology are proven, there is no need for additional reviews in this case. Aside from additional production volumes, sustainment contracts involve customer service and support, spare parts and repair.

Due to the nature and funding of development contracts, the government effectively owns all development work. The customer has the ability to fund a company to develop a design and then pass it on to another company for manufacturing. For example, the customer can grant Company X a research contract to develop a design using a new technology and then grant a production contract to Company Y using the work of Company X as a blueprint. The resulting competitive environment means that having the capability to design great products does not guarantee that the contract to manufacture and deliver the products will be awarded to that company. It is important to note that defense companies generate a majority of their profits through the sale of hardware rather than its development. Therefore, "the ability to make things rapidly and efficiently – to transform materials into parts, components, and assemblies – is a critical source of advantage in product development."[78]

2.1.1.3. Better Faster Cheaper

The aerospace and defense industry is caught up in a wave of Better, Faster, Cheaper, a term coined in the early 90's to describe a shift in the development requirements within the industry.[79] For several decades, the Cold War largely shaped the environment for defense companies. Globally, this era was "characterized by technologically sophisticated superpowers dominating the world's geopolitical forces."[80] The result

---

78 Clark and Fujimoto, pg 167.
79 Earll M. Murman, Myles Walton and Eric Rebentisch, "Challenges in the Better, Faster, Cheaper Era of Aeronautical Design, Engineering and Manufacturing," *Lean Aerospace Initiative*, September 2000 (accessed August 2002); available in http://lean.mit.edu, 2.
80 Murman, et al, pg 1.

during this era of competitive development was a dominant emphasis on pushing product performance "Higher, Farther, Faster" than ever before with little regard to the development costs or timeline. Consequently, "improvements to design, development and manufacturing were given lower priority".[81]

The end of the Cold War brought about a new paradigm to the defense industry of "Better, Faster, Cheaper" summarizing the increasing demands of customers within the industry. "Better, Faster, Cheaper" pushes defense companies to continue to create *better* products by pushing the envelope in their technology and performance while at the same time developing and delivering those products at a *faster* rate and *cheaper* development and production costs. This need for improved development and production is especially critical in generating flexible organizations that can respond to changing customer needs. The threats facing today's military are transforming from a single known threat that characterized the Cold War era to a myriad of terrorist groups with a minimal information available to characterize the threat.

2.1.2. Competitors

The push for Better, Faster, Cheaper represents a shift in the capabilities required for defense companies to remain competitive. Companies cannot rely on their product and technology development capabilities as their sole source of competitive advantage. Better, Faster Cheaper summarizes the customer's high level requirements and drives defense companies to excel at rapid product development and technology innovation at a competitive cost.

Massive consolidation in the last decade within the industry has formed giant players, the top four being: Lockheed Martin Corporation, The Boeing Company, Northrop Grumman, & Raytheon Company. Lockheed merged with Martin Marietta and acquired General Electric's aerospace unit. Boeing merged with McDonnell Douglass and purchased the satellite division of Hughes Electronics. Northrop merged with Grumman,

[81] Murman, et al, pg 5.

recently acquired Litton Industries and Newport News and is in the process of acquiring TRW's aerospace and defense units, the fifth largest defense company. Raytheon acquired Hughes Electronics' defense unit, E-Systems, and the defense and missiles division of Texas Instruments.

As mentioned earlier, the customer takes into account a company's reputation and track record in awarding a contract. The major defense contractors have established their reputation through years of developing and delivering products to the customer. There is a large incentive for the existing players to keep others out of the defense industry. The industry giants have the resources to protect their position within their markets.

Major defense products are sold as entire systems where the customer commits to the entire system architecture. Upgrading subsystems to include the latest technology is significantly more economical than switching to a new system since the costs to switch from an established system to another are exorbitantly high. High switching costs are incurred in having to change the existing mounting architecture, provide new user training and develop new software systems to name a few. Subsystem upgrades create product families that reinforce incremental development.

In addition, major systems such as fighter planes remain in use for decades. For example, the F15 made by McDonnell Douglas now Boeing, had its maiden flight in 1972.[82] The basic architecture of the F15 has expanded the product family to include five models, from A to E for the US Air Force. The latest version, the F15E Strike Eagle, was first delivered in 1988 and current contracts schedule production to continue through 2004.[83] The U.S. Air Force and Boeing have a plan to sustain the F-15 at least through 2030.[84] In addition, development of the F15J is under a licensing agreement to Japan[85] and Boeing

---

[82] US Airforce Fact Sheet, F15E Strike Eagle (accessed February 2003); available on http://www.lakenheath.af.mil/Mission-history/F-15E.htm.
[83] Boeing F15K Fact Sheet (accessed February 2003); available on http://www.boeing.com/defense-space/military/f15/f-15k/f15kfacts.htm.
[84] Boeing F15K Fact Sheet (accessed February 2003); available on http://www.boeing.com/defense-space/military/f15/f-15k/f15kfacts.htm, accessed February 2003.
[85] Boeing F15 Fact Sheet (accessed February 2003); available on http://usfighter.tripod.com/f15.htm.

is developing the F15K for the Republic of Korea[86]. This extremely long product lifetime results in additional revenue opportunities for defense companies as they can offer system upgrades for the life of the product. Conversely, this also requires that companies provide support to the customer over the product's useful life.

While the government places stringent requirements on defense companies it also provides a high degree of insulation from external forces. One of the main drivers for the resurgence of manufacturing within US manufacturing companies was intense international competition, particularly notorious in the automotive industry. However, there exists a strong need, based on national security concerns, for the US government to purchase its defense needs from US companies. An underlying belief that the United States military forces should maintain its superiority in weapons and defense technology leads to the continual funding of US defense companies to develop state of the art systems. "Sustained government investments were made [during the Cold War] in aerospace research, development and technology to assure that the technological capability of the country was superior to the enemy's capability."[87] US defense contractors are effectively sheltered from foreign competition within the US market. However, foreign defense companies compete with US defense products and systems in the international market.

New threats to national security require new types of systems to be developed. Because those new systems are yet to be fully defined, a defense company must be responsive to those needs and be able to adjust their product development efforts. "A firm's ability to sustain its success is most likely a result of constant innovation to adapt to changing circumstances."[88]

---

[86] Boeing F15K Fact Sheet (accessed February 2003); available on http://www.boeing.com/defense-space/military/f15/f-15k/f15kfacts.htm.
[87] Murman, et al., pg 1-2.
[88] Porter, pg 65

2.1.3. Suppliers

Suppliers within the defense industry are defined, for the purpose of this research, as all those companies that supply components or relatively smaller systems to the primary contractors described above. Because of the complexity of most defense systems, hundreds to thousands of different subsystems and components are needed to deliver the final product. Consequently, many primary contractors carry a myriad of suppliers; Raytheon Missile Systems is currently working with a supply base of 10,000 companies.

The structure of the defense industry presents a number of challenges to the supply chain. Typically low volumes within defense results in low profit margins for suppliers. Technologies or components are often specific to defense and provide little opportunity for suppliers to benefit from economies of scale. However, suppliers often provide the same component to a number of different industries. Technology progresses at a faster clockspeed in most other industries compared to defense. It is likely that a component may become obsolete in the general market but is still needed within defense. Circuit card technology, for example, progresses very rapidly in the consumer electronics industry. Because production volumes and consequently profit margins are higher for suppliers who cater to commercial electronics, they are likely to phase out the components needed by defense companies that require the older technology. Making the matter of technology obsolescence more complicated is that customers prefer and often require products to use proven technology. Upgrading systems also requires that companies validate performance.

The low production volumes dictate a minimal production capacity requirement within the supply chain; leaving room for a limited number of suppliers. This reduces the ability for primary contractors to force price wars among different suppliers. One of the larger problems within the supply chain is that suppliers become sole source suppliers for certain components. Also, primary contractors become highly dependent on them since they can starve production further downstream. Even more hazardous to defense companies is that parts become obsolete as suppliers phase parts out of their product lines if their profitability declines, as new technology advances or as suppliers advance their technology to keep up with customers outside of the defense industry.

One of the more complicated aspects of managing the defense industry's supply chain is that primary contractors compete against each other for one program often supply subsystems to these same competitors on other programs. For example, Lockheed Martin supplies Raytheon with the canister and launcher for the Patriot missile and performs final assembly and test of the missile, canister, and launcher.[89] Conversely, Raytheon is developing three radar systems for Lockheed for the Theater High Altitude Area Defense program.[90] In addition, competing companies are sometimes forced to create a single development team. Development of the F/A-22 is a partnership between Boeing and Lockheed Martin.[91]

2.1.4. Threat of New Entrants

Given the size of the primary defense companies, there are extremely high barriers to enter the defense industry at the major system level. A vast amount of resources are required to be able to compete for large programs. Because the acquisition decision-making process takes a company's reputation and credibility into account, a new entrant has neither to compete with the established defense companies. However, a company could potentially fulfill a niche market by supply high tech components with potentially less competition and higher margins.

There are multiple different market segments within the defense industry that not all of the major competitors are currently in. An existing defense company can more readily attempt to enter a market segment new to their portfolio. In addition, defense consolidation and acquisition allows companies easier access to different market

---

[89] Lockheed Martin Patriot Product Fact Sheet (accessed November 2002); available on http://www.lockheedmartin.com/factsheets/product187.html.
[90] Hoover's on-line – Raytheon Company profile (accessed December 2002); available on www.hoovers.com.
[91] Boeing F22 Fact Sheet (accessed February 2002); available on http://www.boeing.com/defense-space/military/f22/f22_back.html.

segments. Due to the changing customer needs, it is possible that new defense markets open where there are no entrenched players. For example, one of the newer threats to national security is biological warfare. There are currently a multitude of companies, from start-ups to existing defense companies, racing to develop products that can detect and counter biological threats. It will be several years before any company can establish a reputation for developing these types of systems and can grow to dominate the new market segment.

2.1.5. Substitutes

Although missiles are a relatively mature industry, changes in customer needs means that current weapons could be phased out and substituted by new products. Defense companies need to respond by fulfilling current needs through new products. "The United States faces a new imperative: It must both win the present war against terrorism and prepare now for future wars – wars notably different from those of the past century and even from the current conflict."[92] The events of September 11th highlight the vast changes in the type of threats that the US must be prepared to defend against. "Contending with uncertainty must be a central tenet in U.S. defense planning."[93]

If the nature of wars and conflicts that are being fought are changing, for example, to biological/chemical warfare, existing defense companies have limited experience to adapt to this radical shift in technology. A shift in customer needs could also be driven by increased use of non-lethal methods to win. Substitutes open the field of competition since no dominant companies have emerged thus far. Currently, there are a myriad of companies, both within the existing defense industry and outside it, that are looking to address the changing military needs.

---

[92] Donald Rumsfeld, Secretary of Defense, *Annual Report to the President and the Congress*, 2002, 1.
[93] Rumsfeld, pg 10

2.1.6. Summary of Porter's Dynamics

Customers exert a high degree of control throughout the industry and are driving drastic changes not only in the needs but also in the process by which companies fulfill those needs. The massive consolidation of defense companies has created massive defense entities that increase the barriers for others to enter. The defense industry has a fragmented supply chain although suppliers have the potential to control development and production efforts if they supply critical components and specific technology.

2.2. Clockspeed

The term "clockspeed" was coined by Charles Fine and is defined as the rate of evolution of an industry.[94] Fine believes that "each industry evolves at a different rate, depending in some way on its product clockspeed, process clockspeed, and organization clockspeed."[95] His studies discuss how an industry's clockspeed is the rate of changes that the entire industry undergoes and the responsiveness required from different companies to adapt to changes in their industry. "Observers often note that some industries – telecommunications, computers, and the like – undergo changes with astonishing rapidity, whereas others seem to mosey along at a leisurely pace, scarcely bothered by changes elsewhere in the business environment."[96]

Industries that face fast clockspeeds are constantly redefining their business model and are often exposed to turbulence in organizational dynamics. Companies within the information-entertainment industry face one of the fastest clockspeeds as new processes and services are rolled out every few months. At a relatively slower clockspeed, the semiconductor industry measures changes in years rather than months and products have a market life of two to four years before becoming obsolete. According to Fine, "at the slowest end of the clockspeed scale…are the manufacturers of aircraft [who measure] a

[94] Fine, pg 6
[95] Fine, pg 6
[96] Fine, pg 7

product's clockspeed in decades.[97] Consequently, Raytheon and the rest of the defense industry are in a relatively slow clockspeed when looking at the overall system. New products, depending on the complexity of the system, can take years to develop from concept to production and their market life can span decades. Subsystems of defense products, such as electronics and processors, can have significantly greater clockspeeds, adding additional complexity to the design.

Fine believes there are two primary drivers of clockspeed: technological innovation and competitive intensity. "When an industry is subjected to an important innovation, that industry typically feels a significant uptick in the overall clockspeed. The jet engine with its effect on the transportation industry provides one example."[98] In his research, Fine lists reasons for changing clockspeeds in industry – shocks to the business environment, economic shocks, technological shocks, shocks from competitor's breakthrough products and services, and shock of a new and newly dominant business model.[99] Changes in technological innovation or competitive intensity have historically had a local effect where "such effects would not usually strike an industry all at once."[100]

Underlying this concept is that fast clockspeed industries are readily exposed to changes and must be able to respond quickly to those changes to remain competitive. Companies within slower clockspeed industries are insulated from immediate changes and have a longer time period to adjust and respond to those changes. Consequently, the decision-making process occurs at a relatively lower rate within industries that have slower clockspeeds. Theoretically, Fine believes that the challenges that are facing industries with faster clockspeeds will eventually affect all other industries and force them to respond and change accordingly.

For example, the evolution of US auto manufacturers was spurred largely by the dramatic increase in global competition. Initiatives to improve the manufacturing environment and

---

[97] Fine, pg 7
[98] Fine, pg 26
[99] Fine, pg 30-31
[100] Fine, pg 28

apply programs, such as lean and agile, have become staples within that industry. At a slower clockspeed, Boeing has recently been faced with global competition and the need to drastically improve their operation to remain competitive. Consequently they have chosen to adopt lean principles and create a moving assembly line for the final assembly of the 777 commercial aircraft.

"The faster an industry evolves – that is, the faster its clockspeed - the more temporary a company's advantage. The key is to choose the right advantage – again and again."[101] Companies must exploit their current capabilities and competitive advantages while at the same time building new capabilities to prepare for the obsolescence of the old ones. The prevailing efforts are to create a sustainable competitive advantage and effectively block the competition out. For a relatively slow clockspeed industry, such as defense, a competitive advantage can seem to be sustainable as changes occur more slowly. However, the aggressive push of technology should be an indication that change will come increasing in the clockspeed and decreasing in the amount of time that a capability will remain a point of competitive advantage.

2.3. Chapter Summary

This chapter analyzes the dynamics of the defense industry using Porter's Five Forces and discusses a number of changes occurring within the industry. The concept of industry clockspeed is introduced and defined as the rate at which change occurs in an industry. In addition, this chapter details the general business environment defense companies face that provides a context for the remainder of this research. More specifically, background information about the competitive environment as well as the challenges and constraints Raytheon faces is provided. Finally, this chapter includes an impetus for defense companies, particularly the shift to Better, Faster, Cheaper, to recognize the industry changes that are driving change in how companies do business. New requirements and demands are being placed on competitors and those companies

[101] Fine, pg 29

that can continually develop better products within a faster timeframe and at a cheaper cost will have a competitive advantage.

Chapter 3 Raytheon Company

The basis of this thesis is a research project at Raytheon Missile Systems (RMS); it is necessary to understand the environment within the company. To better understand the culture and organization, this chapter describes the corporation, its history and the general business practices of Raytheon Company. In addition, this chapter describes the business markets in which RMS competes.

3.1. Background Information

Raytheon is a leading edge technology company that provides electronic systems in both the commercial and defense sectors. Raytheon produces and develops a range of products from radar to business jets. Founded in 1922, achievements in the company's history include the solution for mass-producing magnetrons for radar in World War II, the invention of microwave cooking, the development of the first guided missile able to hit a flying target and the computer that guided the Apollo astronauts in their historic journey to the moon.[102]

Raytheon is divided into a matrix organization by function & product technology. Figure 4 describes their corporate organizational structure.

[102] Boston History Collaborative on awarding Raytheon Company with 2002 History Makers Award (accessed November 2002); available on http://www.raytheon.com/feature/hma/index.html.

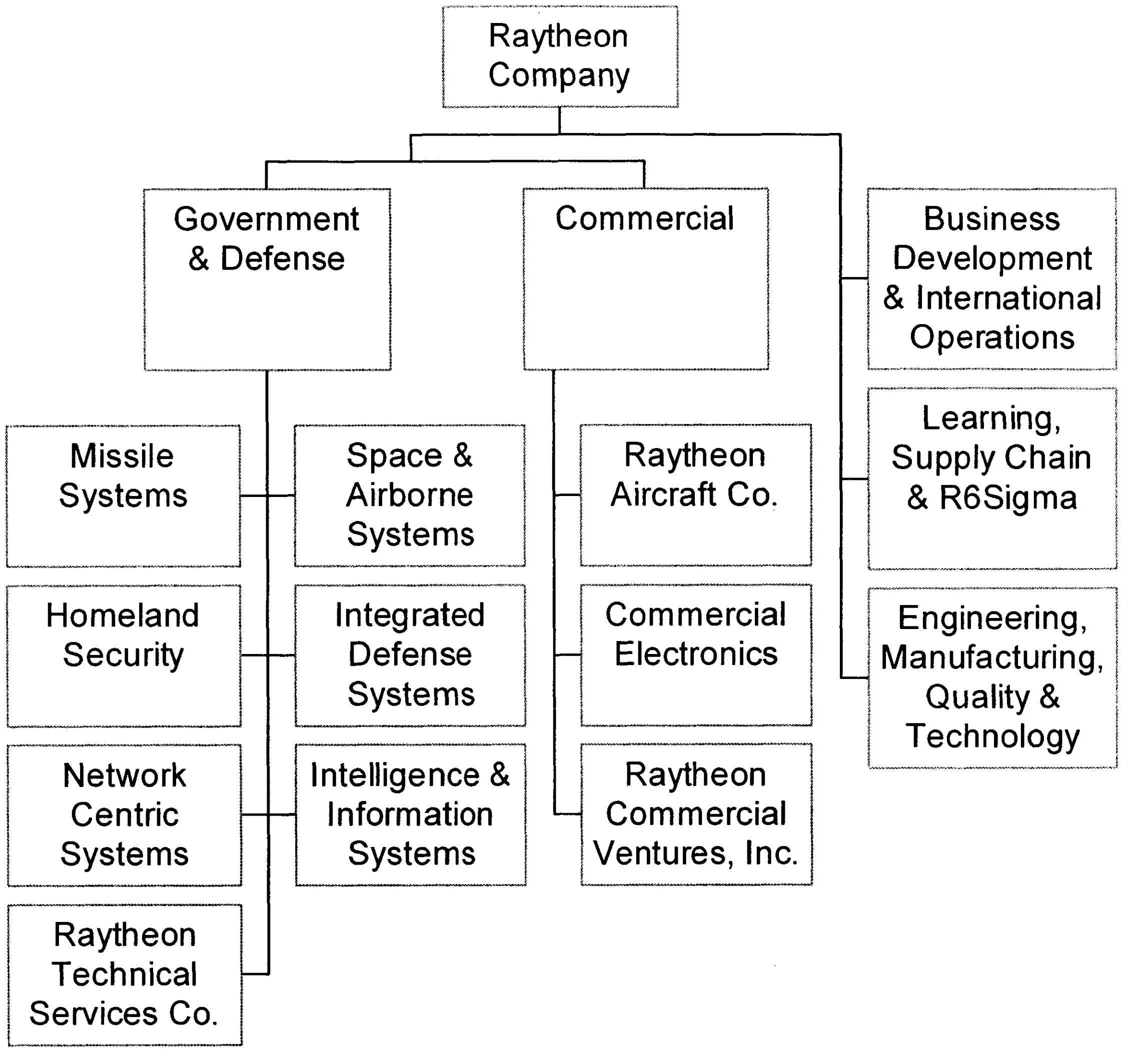

Figure 4 Raytheon's Corporate Organizational Structure[103]

Within the Government & Defense sector, there are seven different business units that directly address different customer needs. With corporate sales of $16.8 billion for 2002,[104] the U.S. government accounts for 73% of sales, including international defense sales. The U.S. Department of Defense constituted 62% of sales for Raytheon in 2002.[105]

[103] Raytheon Company (accessed November 2002); available on http://www.raytheon.com/businesses/.

[104] Raytheon Company 2002 Annual Report, (accessed March 2003); available on http://www.raytheon.com/finance/annrpt.html, pg 2.

[105] Raytheon Company 2002 Annual Report, (accessed March 2003); available on http://www.raytheon.com/finance/annrpt.html, pg 2.

"Raytheon's commercial electronics businesses leverage defense technologies in commercial markets. Raytheon Aircraft is a provider of business and special mission aircraft and delivers a broad line of jet, turboprop and piston-powered airplanes."[106]

Raytheon, as well as other major defense companies, have been successful thus far by providing cutting edge technology to the customer. The customer historically demanded defense products and systems that push the limits of technology. The companies that succeeded required bright engineering talent that could innovate products that went higher, farther, and faster than ever before. Within an organization, this technology push resulted in the creation of ivory towers for product technology research and development groups and consequently the marginalization of all other functions such as manufacturing.

Product development leaders at Raytheon are typically grown from the engineering and research communities. With a career foundation within the ivory towers, the status quo incentive in development is to go higher, farther and faster than ever before. Given additional funds, investments are more likely to be made to push the technology "one iota further" instead of to address other functional needs, i.e. evaluating the design for manufacturability or identifying and developing new manufacturing capabilities.

Given that a majority of defense sales involve the same customer, it is important to understand the customer's business strategy and be able to develop a strong working relationship. The primary customers, the government and armed forces, drove the defense companies to mimic their culture of command-and-control, hierarchical structure.

3.2. One Company Tools

As mentioned earlier, Raytheon recently acquired a number of different sectors in the late 1990's: Hughes, Texas Instruments and E-Systems. The rapid growth at Raytheon was

---

[106] Wall Street Journal profile of Raytheon Company (accessed November 2002); available on www.wsj.com.

followed by a number of reorganizations as overlapping work was consolidated and different areas were reorganized, restructured and relocated to better align the entire enterprise. For example, Centers of Excellence were formed to combine the production of their commodity type products to reduce overhead costs, increase production volumes and thus achieving economies of scale. However, given the difficulties of merging different companies and cultures after an acquisition there are many areas that are still working as distinct entities. Raytheon is still striving to work as one company. To that end, a number of tools were developed using both internal and external best practices to standardize basic processes across the company. This section describes two tools pertinent to this research: the Integrated Product Development System, and Raytheon Six Sigma.

3.2.1. Integrated Product Development System (IPDS)

IPDS is a template for managers and employees of Raytheon to follow throughout a product's development cycle. IPDS is available on Raytheon's intranet where it is accessible to all employees with a computer terminal. This system mirrors the DAU's acquisition model shown in Figure 3. Refer to Table 4 to view the IPDS phases and gates.

Phase 1: Business Strategy Execution	
	Gate 1: Interest/no interest
	Gate 2: Pursue/no pursue
	Gate 3: Bid/no bid
	Gate 4: Bid/proposal review
Phase 2: Project Planning, Management and Control	
	Gate 5: Start up review
Phase 3: Requirements and Architecture Development	
	Gate 6: Internal system functional review
Phase 4: Product Design and Development	
	Gate 7: Internal preliminary design review
	Gate 8: Internal critical design review
Phase 5: System Integration, Test, Verification and Validation	
	Gate 9: Internal test/ship readiness review
Phase 6: Production and Deployment	
	Gate 10: Internal production readiness review

Phase 7: Project Control	
	Gate 11: Transition and shut down

Table 4: Integrated Product Development System Overview[107]

Each gate is further developed to include major tasks that should be completed by all of the different stakeholders, from program managers to facilities personnel. Each program is encouraged to use IPDS although they are allowed to tailor the standard process to suit their specific development needs. Different programs use different systems of to plan their product development efforts and may not use IPDS at all.

Recall from the government's acquisition model that a contract can span different phases of development. Contracts can span different portions of the IPDS from development contracts such as trade studies to the delivery of additional products with no further development. Phase 1 occurs each time the customer chooses to begin the acquisition process, i.e. Milestones A, B, or C. If the contract is awarded to Raytheon, Phase 2, 3, and 4 of IPDS begin. Phase 5 and 6 coincides with the customer Production and Deployment phase of acquisition as well as sustainment. Phase 7 encompasses the latter portion of sustainment and determines Raytheon's plan of action for facilitating the destruction of obsolete systems.

While IPDS details the steps that should be taken for effective product development planning, the culture of Raytheon rewards individuals who can effectively save a program in crisis. The underlying incentive is that heroes can only be formed if programs are in crisis. Effective program planning is not necessarily valued since this would generally prevent programs from running into major obstacles. This may be one of the reasons why the culture does not reinforce the use of planning tools such as IPDS.

[107] Raytheon Company Intranet – Integrated Product Development System (accessed October 2002); not publicly available.

3.2.2. Raytheon Six Sigma

Raytheon Six Sigma is a continuous process improvement program that empowers employees at all levels to improve how they work. The program is based on W. Edwards Deming's improvement cycle of "Plan, Do, Check, Act." Raytheon's Six Sigma model is illustrated in Figure 5.

Figure 5 Raytheon Six Sigma Model[108]

The six different phases of the program are Visualize, Commit, Prioritize, Characterize, Improve, and Achieve. Visualize involves picturing the ideal state of affairs and creating a vision for changing an area. Commit refers to obtaining upfront commitment from leaders and stakeholders involved in the change process. Prioritize requires that the goals of the project be defined and prioritized. This phase of Six Sigma plans high-level action and serves as a check and balance stage for aligning leaders with the project. Characterize characterizes the source of the problem, identifies a solution and metrics for change. Improve involves the design and implementation of the solution as well as control systems to verify the impact and success. Achieve is the final step of the process where the success of the Six Sigma project is celebrated. The entire process is intended to be iterative to allow project members to review and reevaluate any step of the process until the ideal state is reached. [109]

[108] Raytheon Company Intranet - Six Sigma (accessed October 2002); not publicly available.
[109] Raytheon Company Internal Benchmarking Handbook, ed. September 2002, pg 2.

Employees are trained in the different phases of Six Sigma as well as in basic tools required in the process such as statistics and affinity diagrams. Once their training is completed, employees are tasked to apply Six Sigma to their every day tasks as either individuals or groups. Once a project is completed, the project efforts are documented and made available on the company's intranet for the entire enterprise to access. Employees are then certified as Six Sigma Specialists and encouraged to continually apply Six Sigma. As of 2002, Six Sigma projects have "achieved a cumulative gross benefit of some $1.8 billion in its first four years."[110]

This internship research project fell under the auspices of Six Sigma. The involvement of Six Sigma was beneficial to the implementation effort at RMS because it gave the author access to a number of individuals who are familiar with the culture of the organization and can provide an enterprise level view of the entire company. In addition, by documenting this effort as a Six Sigma project, the research findings can be easily disseminated and transferred throughout the company.

3.3. Raytheon Missile Systems

Raytheon Missile Systems (RMS) is one of the business units within Raytheon Company designing, developing and producing missile systems for critical requirements, including Air-to-Air, Strike, Surface Navy Air Defense, Land Combat, Guided Projectiles, Exo-atmospheric Kill Vehicles, and Directed Energy Weapons. The product portfolio for RMS includes the Tomahawk, Maverick, AMRAAM, and Standard missiles to name a few. RMS is located in Tucson, Arizona with net sales in 2002 of $3 billion.[111] The manufacturing facility predominantly assembles and integrates systems as a large percentage of components are outsourced.

[110] Raytheon Company 2002 Annual Review, (accessed March 2003); available on http://www.raytheon.com/finance/annrpt.html, pg 2.
[111] Raytheon Company 2002 Annual Report, (accessed March 2003); available on http://www.raytheon.com/finance/annrpt.html, pg 6.

3.3.1. Historical Context

Originally, this facility belonged to Hughes Aircraft Company, founded by Howard Hughes in 1936.[112] The company was originally founded as a non-profit technology research organization and was often referred to as Howard Hughes' personal labs, providing him with research grants and space to tinker and play with new technologies. As with most start-ups, "the personal beliefs, assumptions, and values of the entrepreneur or founder are imposed on the people he or she hires, and – if the organization is successful – they come to be shared, seen as correct, and eventually taken for granted."[113] As a non-profit, the emphasis was to continually research new technologies instead of delivering hardware. The price on the products that were developed and produced was extremely high since minimal consideration was given to reduce costs. An aura of eliticism surrounded the products leading to the prevailing belief that pushing the envelope on technology is the most important aspect of product development.

General Motors (GM) acquired Hughes Aircraft in 1985 and lost its non-profit status. In 1992, General Dynamics sold its Missile Systems to Hughes Aircraft. Under General Motors' leadership, Hughes Aircraft became an entity within a newly formed Hughes Electronics.[114] Additional changes occurred with the influence of General Motors, primarily the formation of Knowledge Centers, similar to the one created in GM's corporate headquarters as repositories of knowledge. As part of reorganization, numerous General Dynamic's facilities were relocated to Tucson. The final acquisition of Hughes Electronics by Raytheon led to further reorganization. Tucson, in particular, houses legacy programs from Hughes, Texas Instruments and E-Systems; employees from each bringing their own processes and culture.

---

[112] Hughes Aircraft History (accessed on February 2003); available on http://www.shanaberger.com/hughes.htm.

[113] Schein, pg 91.

[114] US Centennial of Flight Commission – The Hughes Companies (accessed on February 2003); available on http://www.1903to2003.gov/essay/Aerospace/Hughes/Aero44.htm.

Research on the formation of organizational cultures has found that "the culture that the organization acquired during its early years is now taken for granted."[115] Within Raytheon, it is the legacy Hughes business units that are more emphatic in their quest to push the capabilities of product technology. The consolidation of Raytheon has been slow, as leaders have grappled with honoring the heritage and successes of the legacy companies and forming one entity. To this day, people identify themselves and differentiate each other with the company or facility from which they were originally hired.

3.3.2. Organizational Structure

Like the parent organization, RMS is structured in matrix form divided by function and product and research families. Figure 6 displays the organizations relevant to this project.

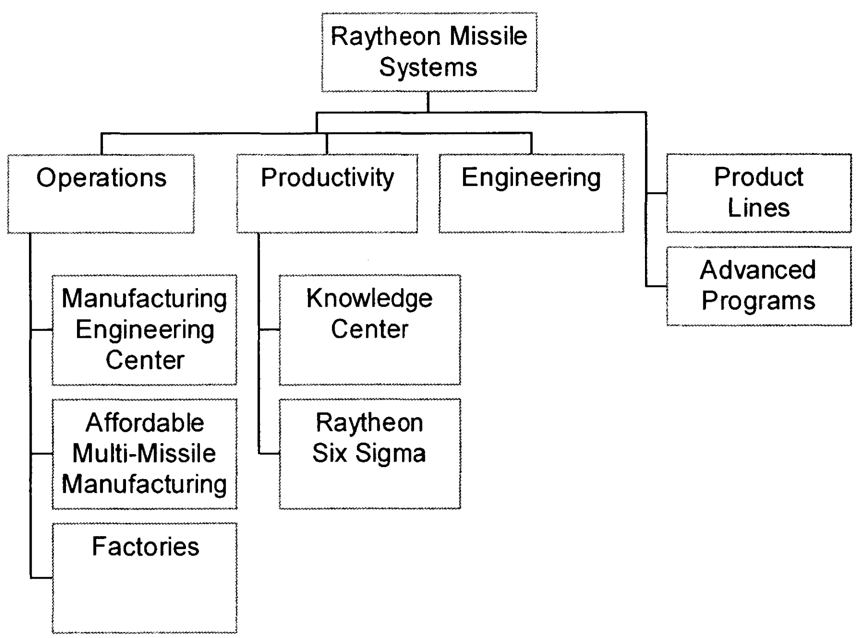

Figure 6 RMS Organizational Structure

[115] Schein, pg 143.

The primary functional organizations affected by the outcome of this research are Operations, Engineering, and Productivity. The Operations organization is responsible for all production issues such as manufacturing and supply chain management as well as the management and maintenance of facilities. The Manufacturing Engineering Center (MEC) is a supporting organization providing development and production programs with project engineers, assembly engineers and manufacturing engineers to develop manufacturing processes and generate step-by-step instructions for line workers. The MEC has traditionally focused on project engineering from a manufacturing viewpoint and on resolving manufacturability issues that arise while in production. Their improvement skills can be characterized as focusing on design for manufacturing and assembly (DFMA) and in incremental improvements to existing manufacturing processes.

The Affordable Multi-Missile Manufacturing organization (AM^3) is the result of a customer effort to facilitate and encourage flexible manufacturing practices such as design reuse and component commonality across different missile programs. This organization was established to match the efforts of the Defense Advanced Research Program Agency (DARPA)[116], the government's primary research agency, as well as other government agencies that are needed to provide additional funding support to help reduce manufacturing costs.

The factories are considered the end users of any new capabilities developed within the AMDC. Factories within RMS fall into two distinct categories: those dedicated to specific product lines and those that are shared throughout the business unit. The latter set of factories provides similar components or subsystems to the product lines. Common factories include the Ultra Precision Machining, Composites and the Electro-Optical Sensors and Precision Assembly. While the initial focus of the AMDC is to impact internal development, once the center is proficient at developing new capabilities, the emphasis can shift to impact supplier capabilities. Productivity is responsible for all

[116] Department of Defense - Defense Advanced Research Program Agency, DARPA, (accessed July 2002); available on www.darpa.mil.

efforts that increase the productivity of RMS. The Knowledge Center and Raytheon Six Sigma are both within the Productivity organization. The Knowledge Center is primarily viewed as a repository of information and provides training and workshops on existing tools such as design for manufacturing. In addition, the Knowledge Center has some prototyping capabilities, particularly with the use of stereo-lithography equipment. Raytheon Six Sigma has thus far focused on improving the manufacturing environment and hopes to use manufacturing innovation as a leverage to break into the engineering and research environment.

Engineering provides the engineering staff needed for all development programs from many different disciplines. Product lines include all missile systems currently in production. All research and development efforts are housed within Advanced Programs. These are typically early phase contracts that are several years away from production. Once a program completes development it is transitioned from Advanced Programs to Product Lines. Advanced Programs also consist of pure product technology research conducted by RMS Technologists. These technologists form a link throughout the corporation to ensure they are connected to pure research centers that focus exclusively on pushing the existing bounds of technologies.

3.3.3. Product Maturity Analysis

RMS has a broad number of missile programs that meet a variety of customer critical requirements. A large number of missile programs have been in production for several decades as product families have proliferated. New designs continually evolve the family architecture by updating the technology. Other missile programs are entering the early phases of development. These programs are working to implement the latest technology into a new missile system to meet new customer needs. While technologies are continually evolving, the basic architecture of missiles has stabilized and the major subsystems are shown in Figure 7.

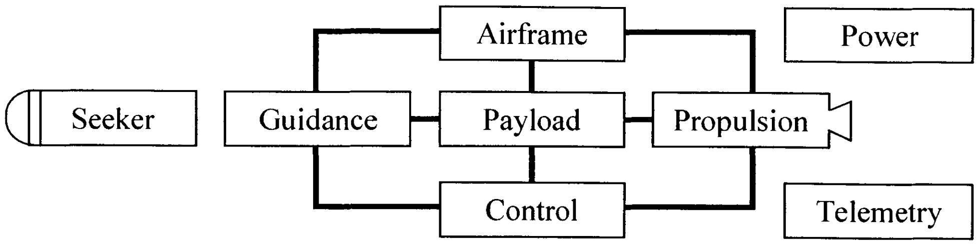

Figure 7 Missile Architecture[117]

The technologies used within those subsystems are continually evolving to match the customer's requirements as new technologies are developed. The existence of a standard missile architecture mirrors the dominant design theory espoused by Abernathy and Utterback. Maturity of RMS products can be characterized using this model and is depicted in Figure 8 below.

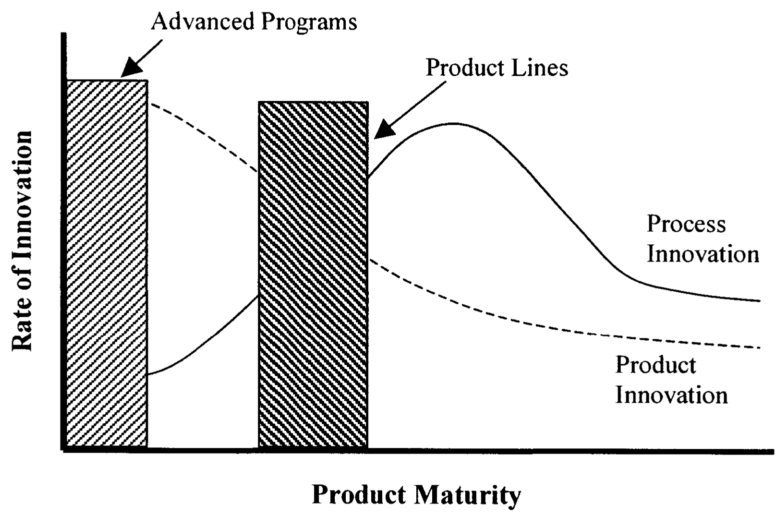

Figure 8 Product Maturity of Missile Systems

Existing product lines at RMS are in the transitional phase of development. These products have been in existence for a number of years and undergo incremental design improvements. Continuous manufacturing improvement projects, led primarily through

---

[117] Robert A. Nicol 'Design and Analysis of an Enterprise Metrics System,' MSM & MSCE, Massachusetts Institute of Technology, 2001, pg 14.

Six Sigma projects at Raytheon, are largely focused on improving production on the existing product lines. Development within Advanced Programs focuses largely on designing new systems or products using radical new technologies. The rate of product innovation within Advanced Programs is extremely high – characteristic of products within the fluid phase of development. Typically, the rate of process innovation within Advanced Programs is limited.

In addition, RMS products can be characterized using the framework that Pisano developed on product types depending on the required rate of product and process innovation, shown in Table 2. According to this framework, defense systems within RMS have a relatively high rate of product innovation. Product Lines can be characterized as Product Driven using Pisano's terminology as they are primarily assembled products that primarily use established manufacturing processes. Process innovation required by the Product Lines is relatively low. Process improvements focus on incremental improvements or modifying the design to better adapt to established manufacturing processes, i.e. design for manufacturability.

Advanced Programs consist of a blend of assembled subsystems but include advanced materials and high precision electronic subsystems as well. Pisano would characterize products within Advanced Programs as Process Enabling. A high degree of process innovation is required for these products since there are no existing manufacturing processes available to build the product. Pisano's framework validates the assumption that the AMDC should focus primarily on Advanced Programs as the primary customer since there is a high degree of alignment between the manufacturing innovation needs of Advanced Programs and the services the AMDC will provide.

Advanced Programs are in the early phases of development allowing the AMDC time to develop new manufacturing technologies and to influence the design. Product Lines should be considered second tier customers, at least initially, since they may be able to use AMDC solutions to improve their existing products. The additional challenge in targeting Product Lines is the difficulty in modifying the existing design to make better use of new manufacturing technology.

3.4. Chapter Summary

This chapter describes the corporate environment and organizational structure of Raytheon Company with a particular emphasis on correlations between the parent company and the business unit. The RMS organizational structure was also presented as well as an analysis of the maturity of product within their portfolio. The culture at RMS brought about by its historical evolution is somewhat fragmented due to the many acquisitions but is dominated throughout by product development.

Chapter 4 Advanced Manufacturing Development Center

With increased competition and pressure from the "Better, Faster, Cheaper" environment surrounding aerospace and defense companies, product development is a key competitive factor. Product development encompasses the design and production of new systems from identifying customer needs to deliver the system. However, "since firms buy most new technologies for manufacturing operations, it is difficult for them to use these technologies to achieve competitive advantage because it is difficult to protect them from imitation and circumvention."[118] While traditionally the ability to innovate and design new products is at the core of their competitive advantage, a company's ability to also manufacture products is becoming a competitive advantage. In this new environment, companies not only have to continually innovate new products at a faster rate but also be able to produce them faster and cheaper than the competition. Soon, companies will be reaching the limits of their own development capabilities to meet the customer's needs.

The Director of Operations has identified this need and determined one solution for RMS is to establish an Advanced Manufacturing Development Center (AMDC). The AMDC will be responsible for developing new manufacturing technologies by providing low-cost solutions to the next generation engineering designs with a practical application within RMS factories.

The main premise of this project is to use academic research to provide a new perspective to facilitate the implementation of the AMDC. In implementing change, a number of issues must be considered, such as how to introduce change into an organization, understanding the potential responses of the stakeholders using different perspectives or lenses, as well as understanding the dynamics of the culture and identifying the cultural driving forces of an organization.

---

[118] John E. Ettlie and Ernesto M. Reza, "Organizational Integration and Process Innovation," *The Academy of Management Journal* 35, no. 4 (Oct 1992), pg 795.

4.1. AMDC Description

The Advanced Manufacturing Development Center is the functional homeroom within RMS of new manufacturing processes, technologies and skills. The AMDC will create, validate, and assist in the deployment of new processes and technologies associated with new product design, development and production. The new center will also support the pursuit of additional funds for use on innovation technology development from external entities such as DARPA, the Department of Defense Manufacturing Technology Program (ManTech),[119] and the National Institute of Standards and Technology (NIST).[120]

Along with the AM^3 (Affordable Multi-Missile Manufacturing organization), the AMDC will facilitate customer involvement, both internal and external to Raytheon in the development of new manufacturing technology and processes. Similarly, the center will support collaborative relationships with internal and external customers. The AMDC will validate advanced processes via assembly and test of representative hardware and ensure the use and reuse of processes, technologies and tooling across the enterprise.

4.2. AMDC Implementation

A small team was commissioned to create the new center and introduce change to RMS. As change agents, the team had to be aware that "implementing a major and lasting change requires skills akin to a juggler's...striking a delicate balance between individual and collective actions, paying attention to the content as well as the process of change, and pursuing both short-term and long-term goals."[121] Primarily, the short-term goals of the center were to establish itself within the existing organizational framework to add value to the enterprise. The long-term goals focus on the operational infrastructure of the new center and on efficient process development and innovation. Academic research, as previously discussed, has studied organizations that have attempted to introduce change

---

[119] Department of Defense Manufacturing Technology Program, ManTech, (accessed November 2002); available on www.dodmantech.com.
[120] National Institute of Standards and Technology, NIST, (accessed January 2003); available on www.nist.gov.
[121] Ancona, et al, module 8, core pg. 11

both successfully and unsuccessfully. These research efforts provide an additional perspective for the implementation team to effectively introduce change. For example, identifying and involving the stakeholders early in the decision process will facilitate their acceptance and generate support for the AMDC. By influencing the efforts and policies of the new organization, stakeholders will have a stake in the change process and be more compelled to help it succeed.

In the context of this effort, the customer is a critical stakeholder. The underlying purpose of the AMDC is to add value to the customer thereby giving RMS a competitive advantage. Building a relationship between AMDC and the customer is critical not only to increase their awareness of RMS' capabilities but also to help fund manufacturing innovation efforts that will, in the long term, improve their products. Subsequent changes will explore how to introduce change into an organization, particularly given the cultural environment.

The AMDC should also focus on creating a strong alliance with Advanced Programs, the primary customer.

> "Recent work on innovation and technology implementation suggests the importance of closeness between collaborating parties for the successful development and adoption of new technologies. 'Closeness' is used here both in the literal sense, as allowing more frequent, effective, often unplanned interaction, and more broadly, to encompass common language, modes of communication, customs, conventions, and social norms. Such relationships are said to be particularly important in the case of production process innovations."[122]

Physically collocating the two major entities involved in manufacturing innovation will help form a stronger alliance between the two. Research indicates "the frequency of communication is strongly related to project success."[123] In addition, the ease with which

---

[122]Meric S. Gertler, "'Being There': Proximity Organization, and Culture in the Development and Adoption of Advanced Manufacturing Technologies," Economic Geography, volume 71, Issue 1, Collaboration and Competition in Geographical Context (Jan., 1995) 1-26.
[123] Yar M. Ebadi, and James M. Utterback, "Effects of Communication on Technological Innovation," *Management Science* 30, no. 5 (May, 1984), pg 579.

the two entities can communicate with each other will improve coordination and collaboration on all joint product development efforts.

More daunting to the task of introducing change is that scholars believe the change process requires some form of survival anxiety or a burning platform to catalyze action.[124] Raytheon has adopted this belief requiring each Six Sigma project to determine the burning platform to implement change. Not only is RMS a leader in the missile defense market but also there are also minimal indications that their current practices are inadequate. RMS product development efforts currently meet customer needs, sell their products and systems, prove new technologies, and win new contracts among other things.

The president of RMS, Louise Francesconi, believes the biggest challenge for RMS is to avoid becoming complacent in the face of success. "The more successful an organization is the more difficult it is to trigger peoples' action."[125] RMS leaders recognize that there is currently no burning platform and it is easy to stagnate and become overly confidant in their position. The lack of a burning platform does not necessarily prevent change from occurring but introducing and implementing change will be a more challenging endeavor because of it. Effectively implementing change will require time and dedication to follow through with the implementation of the center and in essence with a new ideology to develop products.

One of the methods for trying to overcome this initial challenge is through a strong leader. Schein believes a charismatic leader can "get employees' attention to avoid a complacent reaction that the bosses are only crying wolf." The leader can trigger survival anxiety or guilt and make employees believe the organization is in trouble and needs to change.[126] The dedication and charisma of the Director of Operations can go far in overcoming the lack of urgency. His reputation as a proactive leader, along with an

---

[124] Schein, pg 117
[125] Andrew H. Van de Ven, "Central Problems in the Management of Innovation," *Management Science* 32, no. 5 (1986), pg 591.
[126] Schein, pg 120

engineering background, gives him the credibility with both the engineering and operations communities. Both the Director of Operations and the Director of Engineering are working together to improve the product development process at RMS. In addition, they are attempting to resolve some of the organizational differences that prevent collaboration between their respective communities. This solidarity and collaboration from the leadership is a clear signal to all employees that RMS leadership is committed to change.

4.3. Business Lenses

There are a wide number of issues to consider in establishing a new center within an existing organization. The theory of Organizational Processes suggests characterizing the organization and the changes that a new center will create through three different lenses: strategic, political and cultural. The strategic lens addresses issues of how the center fits within the greater context of the organization and how the center will meet its requirements and goals. The political lens focuses on the bureaucracy involved in an established organization and attempts to identify supporters as well as adversaries to be aware of to ensure the success of the center. The final lens, cultural, develops an understanding of the norms of the organization: the manner in which people relate to each other.

4.3.1. Strategic Lens

In introducing change into an organization, it is important to consider the strategic implications of the change. There are two main issues in the implementation of the center that must be given particular strategic consideration: the organizational fit and meeting the challenge of manufacturing innovation.

Organizational fit corresponds to how well the AMDC can be integrated into the existing enterprise. To do so, it is necessary to obtain buy-in from multiple levels of the organization. In a hierarchical organization such as Raytheon, the acceptance of senior leadership is crucial to generate support for the AMDC. The start-up costs associated with the implementation and development of the new center are significant. The initial investment of resources, in terms of laboratory facilities, staffing as well as initial funding, must not only be justified but must also be supported by the leadership team. In addition, the potential impact of the AMDC encompasses many levels of the enterprise, from the engineering communities that design new systems to the factories that will use the new manufacturing technology in production, and eventually to the suppliers' efforts to develop and produce subsystems. For the center to be able to influence other organizations, they need the support of the different leaders.

To be successful, the AMDC requires the support of customers, both internal and external, that will benefit from the center's innovations. Like other internal organizations that provide a service or add value to product development, the AMDC is considered a cost center. As such, internal organizations must fund development work at the AMDC if they choose to benefit from the center's capabilities. Therefore, the AMDC must not only validate the importance of their capabilities and the service they provide but they must also convince customers to pay for their services. Under existing development contracts, programs are given a small amount of discretionary funds to invest in indirect development, i.e. outside of contractual development obligations. However, there are multiple internal organizations vying for the same pool of discretionary funds, including the same programs that manage those funds that wish to invest in pushing technology forward.

If the AMDC can generate support for its development efforts from external customers, then additional investments can be generated to fund manufacturing innovation. There are two distinct avenues to generate manufacturing research funds from external customers. First, research grants may be obtained from external research agencies that are funded by the government, i.e. DARPA, ManTech, NIST, etc. These agencies were established to help fund innovation within the private sector. The underlying assumption is that these agencies have no direct stake in any particular technology and can optimize research investments from a more global perspective.

Second, the initial proposal submitted to the customer can include a financial budget dedicated to manufacturing innovation that will mitigate manufacturing risks during development. For the AMDC to have input in the proposals submitted requires a high level of collaboration before the start of internal research programs. Approval of the manufacturing innovation budget requires that customer's value manufacturing development. More importantly, the AMDC needs to build credibility and prove that they can mitigate manufacturing risks by developing new manufacturing capabilities. In addition, AMDC collaboration during development improves the system design, and reduces production costs without impacting the overall development budget and schedule constraints of the program.

To establish the AMDC, coordination and collaboration is required throughout the enterprise to garner the benefits of manufacturing innovation. It would be useful to create incentives to encourage other organizations to coordinate with the AMDC by modifying their current efforts or to collaborate by actively participating in identifying and addressing manufacturing risks. Development programs that are underway have a limited source of funds to invest to direct towards manufacturing innovation, particularly if the capabilities of the AMDC are unproven. To overcome these challenges, senior leaders could implement incentives that encourage the acceptance of the need for the AMDC.

One of the main requirements of the AMDC is that all development efforts focus on practical applications of manufacturing innovation. This limits the center's ability from initiating research projects for the sake of research, thereby wasting resources on development projects that are not implemented. Development projects require that a customer pull manufacturing technology development from the AMDC. The requirement for practicality encourages customers to invest in the AMDC since it is clear to see they will directly benefit from the development project. However, it is important to note that acceptance of the AMDC by internal customers is largely dictated by the center's ability to form networks.

The AMDC is chartered to create a competitive advantage for RMS. To be successful, the center must be capable of balancing a number of factors in selecting development projects; short-term vs. long-term, low risk vs. high risk, and small return vs. large return. For the sustainability of the center, it is important to strategically consider both the short-term and long-term goals. In the short term, it is important for the AMDC to secure a stream of funding and win the support of customers thereby identifying opportunities for manufacturing innovation and obtaining a stream of funding. The short-term center needs are to create specific manufacturing technologies to build credibility. The acceptance of the AMDC by other entities is more likely to occur once the new center's capabilities have been proven. By creating early 'wins' the AMDC will effectively signal others of their credibility to develop practical manufacturing technologies.

In the long-term, the decision to invest in and develop new manufacturing technologies should be strategically evaluated to create the largest impact for RMS. Recall, the long-term emphasis of the AMDC is to create a competitive advantage for the company by not only developing innovative and practical manufacturing technologies but also by becoming proficient at manufacturing development. In essence, the long-term goal of the center should be to make the existence and capabilities of the AMDC a competitive advantage, providing RMS with the skills and reputation for identifying manufacturing risks and developing new manufacturing technology during product development. The need to build early wins for short-term benefits might result in a less than optimal manufacturing research portfolio. It is likely that the AMDC will reach the limits of their resources, particularly in terms of available staff, in the near future. With that constraint in mind, the projects that are accepted in the short-term will dictate the center's direction for a significant period of time.

Similarly, the center must be proactive in choosing development projects that balance low risk projects with high risk projects. Risk in manufacturing development include such factors as the probability that the manufacturing need will manifest itself in the final product, the probability that the center will be able to find a practical innovative solution and that there is a feasible investment required. Development projects with a lower risk are more attractive in the short-term since the likelihood of success is high and the return on investment, while relatively low, is clearly visible. In addition, traditional return on investment calculations favor short-term, low risk projects.

It is necessary to build the capabilities that provide adequate service to programs whose projects carry higher risks. Higher risk projects inherently have a high degree of uncertainty although these projects have the potential for generating much larger benefits. These projects would presumably include a higher degree of complexity allowing the AMDC to explore and expand their development capabilities. As mentioned earlier, current internal incentives often lead employees to pursue lower risk projects who are more likely to see an early return, albeit a small one. There are currently few incentives to encourage and reward long-term planning throughout Raytheon. Aside from the traditional financial numbers that are typically involved in investment decisions, the pursuit of development projects should include strategic considerations to diversify risks and benefits in the AMDC project portfolio.

4.3.2. Political Lens

The implementation of a new organization has clear implications that challenge the existing political structure. After extensive internal discussions with multiple stakeholders, it was decided that the AMDC would report directly to the Director of Operations instead of under an existing organization within Operations.

> "Radical and incremental innovations have such different competitive consequences because they require different organizational capabilities. Incremental innovation reinforces the capabilities of established organizations, while radical innovation forces them to ask a new set of

questions, to draw on new technical and commercial skills, and to employ new problem-solving approaches."[127]

The center's focus on developing radical manufacturing processes presents additional challenges for existing organizations. Manufacturing innovation would require a skill set from the employees and the leaders different from their current capabilities.

Of the multiple stakeholders described earlier, two in particular are challenged by the existence of the AMDC: the Manufacturing Engineering Center and the Knowledge Center. The Manufacturing Engineering Center (MEC) develops manufacturing processes and generates step-by-step instructions for line workers. Original support for the AMDC came from the MEC with the belief that combining the knowledge of existing manufacturing capabilities and factory environments with the development of new manufacturing capabilities would allow them to provide more thorough manufacturing solutions for different programs. However, the MEC has traditionally focused on project engineering from a manufacturing viewpoint and on resolving manufacturability issues that arise while in production. Their manufacturing development skills can be characterized as design for manufacturing and assembly and as incremental improvements to existing processes.

The Knowledge Center is an internal repository for knowledge and tools that provide training to product development groups to improve the design. In addition, they have prototyping capabilities, primarily stereolithography equipment, within their labs. The Knowledge Center is in the process of revitalizing their organization and control over the AMDC would help them provide additional services to product development programs.

Both of these organizations had an interest in controlling the direction of the AMDC. The decision to make the AMDC a distinct entity within operations generated some resentment. A negative relationship between the three would generate mistrust and

[127] Rebecca M. Henderson and Kim B. Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative Science Quarterly* 35, no. 1, Special Issue/Technology, Organization, and Innovation (Mar., 1990), pg. 9.

prevent collaboration, which is key in providing complete manufacturing support to product development. A clear understanding among all three parties of the roles and responsibilities of each is needed along with definitions of how the three centers can work together to maximize the overall benefit to RMS. Overlapping interests between the three should be clearly defined to prevent duplicate efforts, competition, and potential undermining of the other's contributions. Significant effort should be made to prevent any existing organization from becoming threatened by the AMDC.

Additionally, it is important to determine who will benefit from the goodwill generated by the AMDC. Assigning credit for development work is critical in establishing internal sustainability for the AMDC. In manufacturing innovation projects, it is primarily the teams that are responsible for developing new manufacturing technology and should be rewarded and recognized accordingly for their efforts. Recognizing team members will lend credibility to employees who pursue careers that include manufacturing innovation. The AMDC should receive some of credit to build its reputation and credibility. More importantly, the customers, programs and their managers should be recognized for their support of the center and their proactive approach to modifying product development efforts. Widespread recognition will help publicize the benefits of process innovation.

In every development project, there is the likelihood that an effort will not be as successful as initially expected. If a viable, low-cost solution is developed, the project should be classified a win and credit dispersed throughout the organization. Conversely, the inability to implement a new manufacturing process should not be a burden on the team or stakeholders if exogenous factors outside of their control are the constraint. To label a development effort as a failure will prevent others from becoming involved as team members in the development work or in funding new projects all together.

4.3.3. Cultural Lens

In order for the AMDC to fulfill its mission and explore its full potential, it is necessary to combine, to some degree, two distinct cultures: engineering and operations. Section

4.4 describes a model to help understand how these two groups of people relate to each other in the context of changing current product development efforts. Engineering and operations often work in isolation from each other, locally optimizing their contribution but not considering the others needs or constraints. This phenomenon is common in many US manufacturing companies; traditional manufacturing development is based on designs that were thrown over the wall from engineering. Ivory walls built to prevent disturbances to engineering's product development efforts have reinforced the disparity between the two. Reinforcement of the current culture has led to the establishment of a hierarchy between the two where employees involved in product development are valued as leading Raytheon's competitive efforts.

Each organization has a distinct status within RMS where engineering is at the core of development and operations is a support function that more often than not constrains the system. Each community has developed specific skills and behaviors that benefit the efforts of their separate communities that further prevent them from being able to collaborate and coordinate with each other. More specifically, the different communities use different metrics with different incentives and are driven to pursue distinct goals. The engineering organization focuses its efforts on product development where engineers are measured on their ability to design the best performing product from a technical standpoint. The operations organization is concerned with making the physical product and meeting the delivery schedule. Employees within operations are measured on quality, yield, and delivery status. In extreme cases, if engineers exceed their development timeline and hand off the design to the operations group at a date later than expected, operations employees are still expected to meet the delivery schedule.

Raytheon's culture is one that has emphasized the importance of engineering development work and has attributed the company's success to this capability. Thus far, RMS has succeeded in the market and continues to do so by following and encouraging that belief. Coordination between the two requires that existing beliefs and perceptions change. "Changing something implies not just learning something new but unlearning something that is already there and possibly in the way."[128] For people to change within RMS, they must unlearn how they perceive the boundaries of product development as well as the current roles and contributions of engineering and operations.

Because it is easier to build on the existing strengths of the culture it is important to build on the belief that innovation and striving to push technology is important. "The shared beliefs, assumptions, and values then function in the organization as the basic glue that holds it together, the major source of the organization's sense of identity, and the major way of defining its distinctive competence.[129] One of Raytheon's core capabilities is to develop state of the art technologies and generate practical applications. Implementing the AMDC does not require that the value and contributions of the engineering community be eliminated, instead it is necessary to add another layer to product development by considering manufacturing issues early in the process.

Within Advanced Programs, the engineering community is driven by their ability to continually find military applications for new technologies. Their incentives and accountability, as well as time and resource constraints, have thus far prevented any substantial acceptance of the need to identify and mitigate manufacturing risks early in development.

4.4. System Dynamic Causal Loop Diagrams

As mentioned in Section 1.3.3, System Dynamics is a management tool used to view and understand complex systems. One application of System Dynamics, aside from those topics previously discussed, is to understand the underlying forces that have led to the current organization and see how those driving forces will react to change. System Dynamics focuses on understanding the feedback processes within a system. "All dynamics arise from the interaction of just two types of feedback loops, positive (or self-

---

[128] Schein, pg 116
[129] Schein, pg 92

reinforcing) and negative (or self-correcting) loops."[130] Reinforcing loops reinforce the behavior or change that is currently driving the system. Correcting or balancing loops counteract change and force the system back to its original state of equilibrium. To make full use of the capabilities of System Dynamics, a complete mathematical model of the company could be developed, quantitatively identifying the relationships between different parameters such as how different people relate to each other, the impact that factors have on the system, etc. However, the results of the model would be ambiguous at best since there is no data available to quantitatively define those relationships.

For this research, system dynamics is used to identify and understand the drivers of behavior through a visual model known in the System Dynamics nomenclature as causal loop diagrams. A causal loop diagram, while simplistic, will show how the different factors relate to each other and leave the user to define the impact of the relationship on the system. Causal loop diagrams are a visual way to display the reinforcing and balancing feedback loops in a system to understand how different factors relate to each other. Each factor identified in a system either positively or negatively affects the subsequent factor, denoted by an arrow with a + or - symbol.

If the goal of this center is to create new manufacturing technologies to enable product designs under development, there is an underlying need to modify the product development process to develop the entire system. Three causal loop diagrams were developed to reflect an organization's change response revolving around product development - Customer Level, Managerial Level and Employee Level. The models are not intended to reflect solely the environment within RMS but to include similar issues faced by other manufacturing companies. The information used to develop these causal loop diagrams was gathered through observing the environment at Raytheon Missile Systems, by interviewing various employees and through frank discussions with other manufacturing companies that face similar product development dilemmas.

---

[130] Sterman, pg 12.

4.4.1. Customer Level

As described at length earlier, the customer impact in the defense industry is significant in shaping the competitive environment and driving change down to different organizations. The first causal loop diagram, shown in Figure 9, is a high-level general description of the forces that drive a company's performance. A causal loop diagram describing the customer's impact is detailed in Figure 9 below.

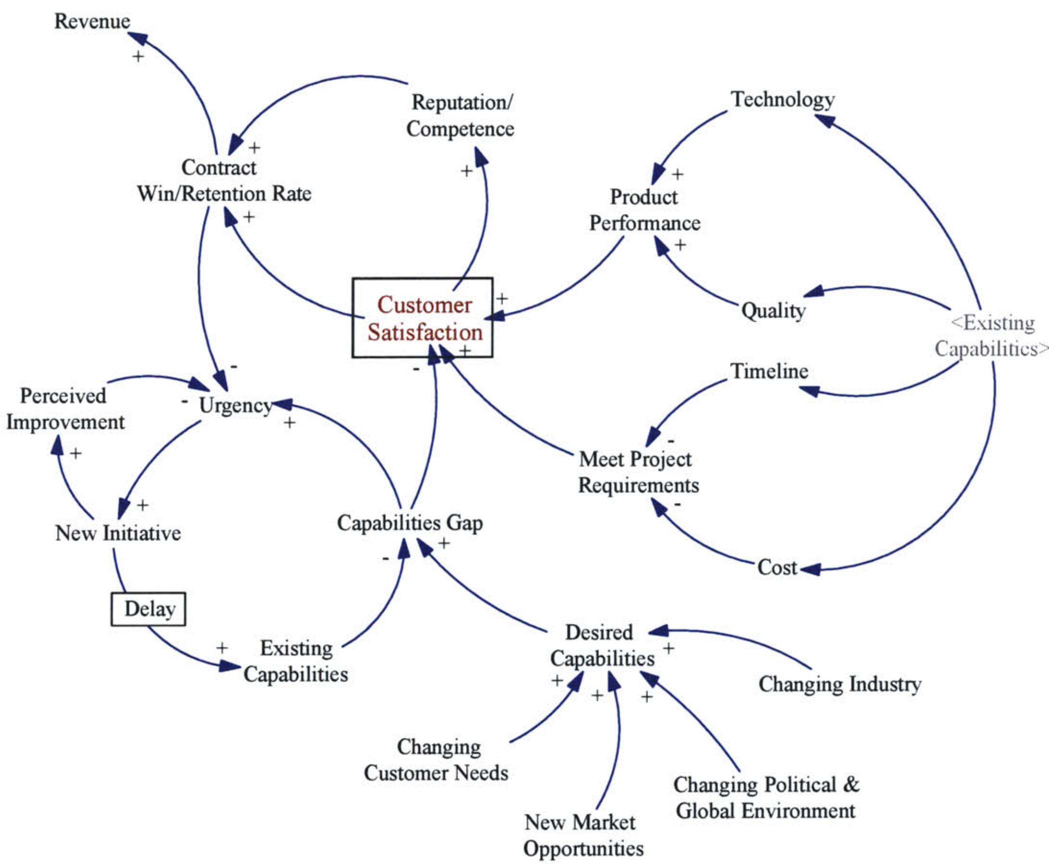

Figure 9 Customer Level Causal Loop Diagram

Causal loop diagrams can be understood by choosing a starting point in the model and following the arrows to determine its impact on subsequent parameters. Conversely, the arrows leading into a starting point can be traced to identify how parameters drive the starting point.

The central driver of this causal loop diagram is level of *Customer Satisfaction* achieved by a company. The higher the level of *Customer Satisfaction*, the more likely a company is to improve their *Reputation/Competence* as well as their *Contract Win/Retention Rate*. A company's ability to retain and win contracts generates additional *Revenue*. *Customer Satisfaction* is achieved by an increase in *Product Performance* while maintaining the ability to *Meet Project Requirements*. A higher level of *Product Performance* is driven by improvements in *Technology* and *Quality*, which are dictated by a company's *Existing Capabilities*. To better *Meet Project Requirements*, a company should strive to decrease their development *Timeline* and *Cost*, the drivers of that parameter. An increase in the company's *Existing Capabilities* can reduce their development *Timeline* and *Cost*. In this portion of the model, the parameter, *Existing Capabilities*, is shown in muted tone to depict the parameter exists in another portion of the model that will be described shortly.

Conversely, this model also relates the negative impact of a customer and company relationship. As *Existing Capabilities* decrease, *Timeline* and *Cost* increase which in turn decrease a company's ability to *Meet Project Requirements*. Not meeting project requirements leads to a decrease in *Customer Satisfaction*. Similarly, a decrease in *Existing Capabilities* leads to a decrease in *Technology* and *Quality*. Consequently, *Product Performance* also decreases leading to further loss of *Customer Satisfaction*. As *Customer Satisfaction* decreases, a company begins to lose its *Reputation/Competence*, decreases their *Contract Win/Retention Rate* and consequently decreases their *Revenue*.

Continuing with other aspects of the model *Changing Customer Needs*, *New Market Opportunities*, *Changing Political and Global Environment*, and a *Changing Industry* determine a company's *Desired Capabilities*. By comparing their *Existing Capabilities* with their *Desired Capabilities*, a company can determine their *Capabilities Gap*. A company that does not address their *Capabilities Gap* is likely to decrease the level of *Customer Satisfaction*, which can eventually lead to a decrease in *Revenue*. A company that is able to decrease their *Capabilities Gap* increases *Customer Satisfaction*. In addition, a company's *Existing Capabilities* increases resulting in an increase in *Product Performance*, and its ability to *Meet Project Requirements.*

Using real world terminology, this causal loop diagram describes the effect that changing customer needs is having on the industry. RMS leadership has intuitively identified a gap between their current capabilities and the capabilities they will need to stay competitive in the new defense environment.

The remainder of the model describes how companies can address their *Capabilities Gap*. An increase in a *Capabilities Gap* leads to an increased sense of *Urgency* within the company. An increased sense of *Urgency* will help drive the implementation of a *New Initiative*. However, a time *Delay* is present in the system between the start of a *New Initiative* and the time that the *Existing Capabilities* are increased. If the *Existing Capabilities* are increased, the *Capabilities Gap* will decrease and result in improved *Customer Satisfaction*. However, as the *New Initiative* is rolled out, there will be a short-term increase in the level of *Perceived Improvement* that decreases the sense of *Urgency*. If the decreased sense of *Urgency* is believed, the momentum for building up *Existing Capabilities* will be lost and the *Capabilities Gap* will not be addressed.

This portion of the model clearly translates to the need for a long-term commitment and dedication from the enterprise to truly address changing customer and industry needs to build new capabilities. This resonates strongly with the implementation of the AMDC and pursuing its potential to capture the long-term benefits of building a sustainable competitive advantage for the company. Without strong commitment, the AMDC could degenerate to a small entity whose potential was never realized.

4.4.2. Managerial Level

As in any organization, the beliefs and policies of managers also help dictate the relationships and culture within an organization. The second model, shown in Figure 10, describes how this community responds to change, particularly the implementation of a new cost center.

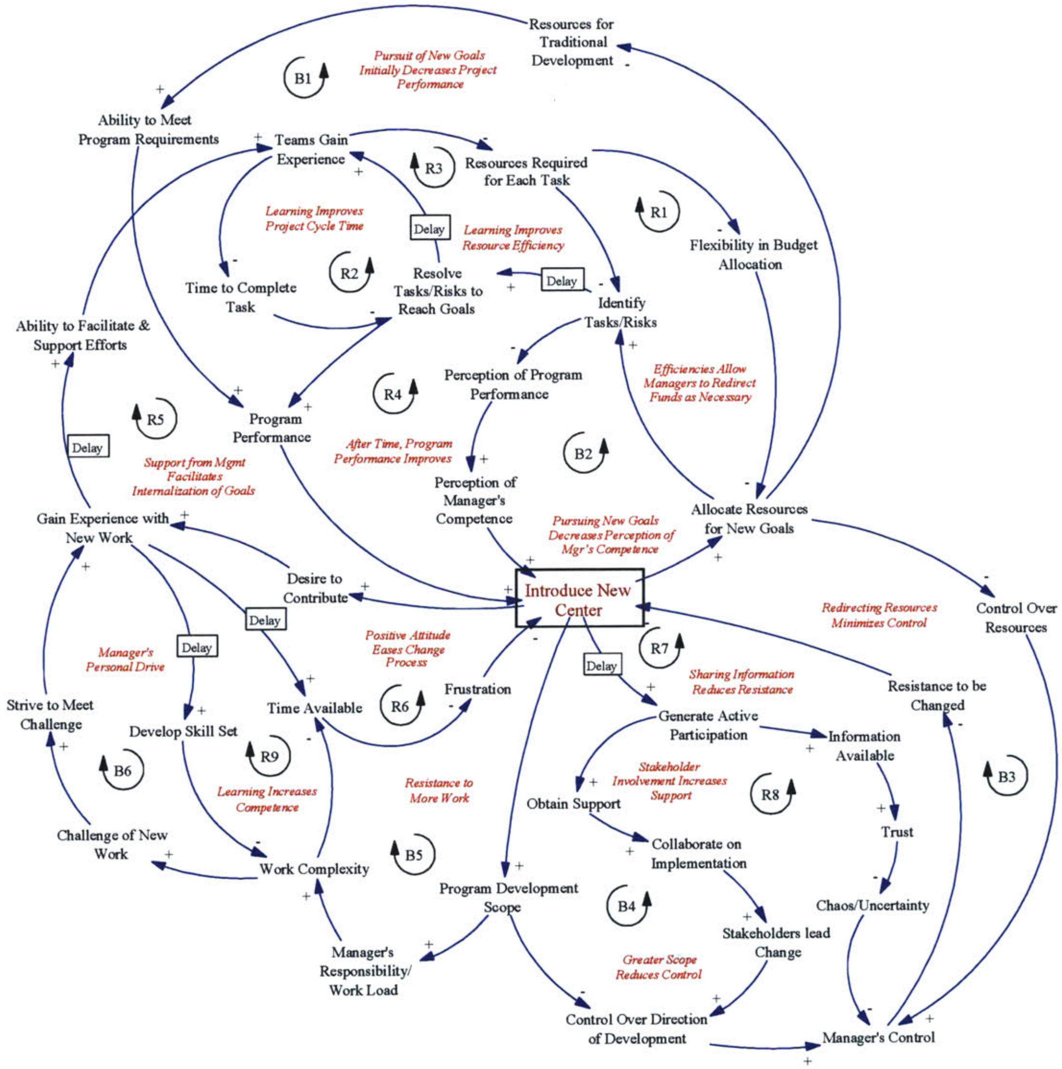

Figure 10 Manager Level Causal Loop Diagram

This model is generalized to encompass the implementation of a new center providing services that require significant cultural adjustments. For this research, the new center is representative of the AMDC whose goals are to modify the product development methodology to include the identification of manufacturing capability gaps, the creation of a standard method to address those gaps and the collaboration from managers and employees within Advanced Programs. Given the scope of this research, the researcher had minimal exposure to program managers at RMS. Thus, mental models depicted in this causal loop diagram are not specific to RMS. The diagram was therefore created using the author's experience outside of RMS and within academia.

As this causal loop diagram is significantly more complex than the customer model, the individual parameters are described in Appendix B. The complexity of this environment creates multiple reinforcing and balancing loops in the diagram. Each loop is given a title describing the dominant behavior. The model behavior can be described using the various loops.

For the AMDC to be effective, there must be coordination with development programs in Advanced Programs. Evaluation of a product design could result in the identification of a gap in existing manufacturing capabilities to produce the new system. Increased coordination requires managers to increase their workload, resulting in resistance that is transferred to their support of the new center (**B5 Resistance to More Work**). Collaboration with the AMDC necessitates that development programs have a greater scope, thereby reducing the manager's level of control (loop **B4 Greater Scope Reduces Control**).

A gap in capabilities initiates a new manufacturing development project within the AMDC and requires investment of resources that would further reduce control on how discretionary funds are invested (**B3 Redirecting Resources Minimizes Control**). Redirecting resources to manufacturing research reduces the amount of funds directed to meet the program's requirements resulting in an initial decrease in program performance (**B1 Pursuit of New Goals Initially Decreases Program Performance**). In addition, poor performance reflects on the manager's capabilities (**B2 Pursuing New Goals Decreases Perception of Manager's Capabilities**) further increasing the resistance to change. All of the loops described above are balancing loops that describe the system's desire to remain at the status quo.

Overcoming the initial resistance to change necessitates reinforcing loops. Two of the major reinforcing loops found in the model show that **(R8) Stakeholder Involvement Increases Support** for the center and that **(R5) Support from Management Facilitates the Internalization of Goals**. For the AMDC to benefit from these reinforcing loops, a concerted effort must be made to involve all stakeholders in the implementation and development of the new center. Ensuring that their opinions and concerns are heard and understood by the AMDC will facilitate obtaining their buy-in and support. In addition, **(R7) Sharing Information Reduces Resistance** of the stakeholders. By being aware of the internal and external drivers that are shaping the new center, they will more likely support its efforts. Similarly, a manager that maintains a **(R6) Positive Attitude Eases the Change Process** due to a desire to contribute. The ability to see the change process as a learning opportunity is a personal characteristic that describes a **(B7) Manager's Personal Drive**[131].

After a considerable amount of delay in the system, adapting to the new work results in significant benefits to the organization. Gaining experience with coordination and collaboration results in **(R9) Learning that Increases Competence, (R2) Learning that Improves Project Cycle Time**, and **(R3) Learning that Improves Resource Efficiency**. As manufacturing development projects and teams become familiar with the new work, their competence increases. Competent teams are more efficient and require less time to complete projects. Competency also results in better use of resources and investments. **(R1) Efficiencies Allow Managers to Redirect Funds as Necessary**, thereby gaining back control over development. **After Time, Program Performance Improves (R4)** with learning and efficiency.

4.4.3. Employee Level

As mentioned many times, the benefits of the AMDC can only be fully exploited through the collaboration between engineering and operations. The final diagram developed for

[131] Although loop B6 is a balancing loop according to the standards of causal loop diagrams, it is still a factor that supports the adoption of a new center. The appendix will expand on this loop.

this research describes the dynamics of change at the employee level. The relationship between the two communities, as well as their incentives and skills, are displayed in Figure 11.

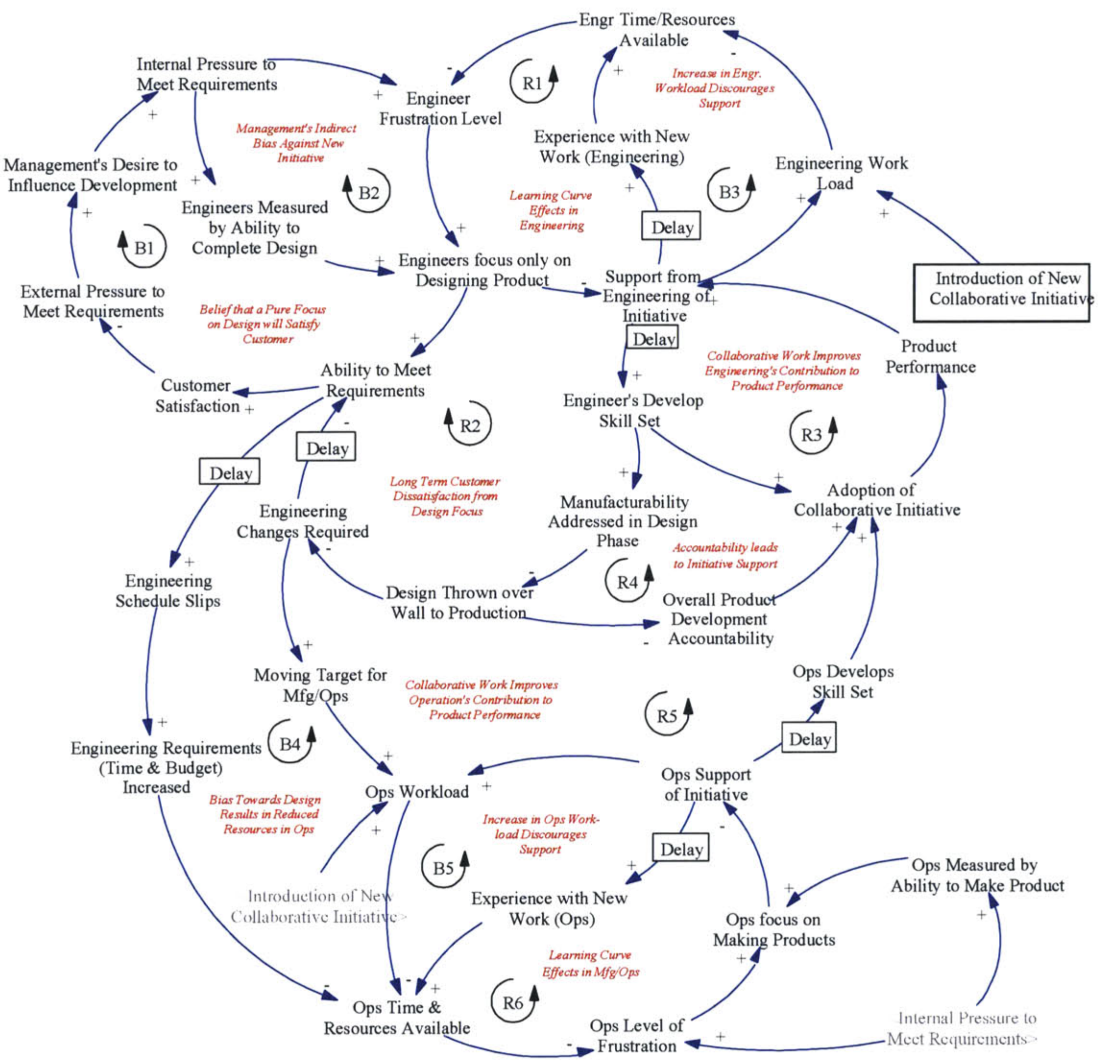

Figure 11 Employee Level Causal Loop Diagram

Similar to the Manager Level Causal Loop Diagram, a model of the employee level relationships and their change response is complex. A more detailed description is included in Appendix C. The initial response at the employee level is to continue to follow their current beliefs and incentives. The **(B1) Belief that Pure Design Focus Will Satisfy Customer** is prevalent throughout many companies. Managers of product development programs typically have an engineering background and are primarily concerned with advancing product technology. Consequently, management favors investments in product technology **(B4 Bias Toward Design Results in Reduced Resources for Operations)** instead of manufacturing research and consequently sends a signal to employees about their priorities. Similarly, management's support of engineering results in an initial resistance to support the AMDC **(B2 Management's Indirect Bias Against New Initiative)**. Other balancing relationships describe the added workload that both Engineering and Operations see due to an increase in complexity from collaborating during development **(B3/B5 Increase in Engineering/ Operations Workload Discourages Support)**.

In addition to factors uncovered in the management level causal loop diagram, there are a number of reinforcing loops at the customer level that can be exploited to support the AMDC. The inherent delays in the system show that eventually, **(R2) Long-Term Customer Dissatisfaction from Pure Design Focus** would become apparent. Demonstrating the industry changes to all levels of the organization would create a sense of urgency and drive their acceptance of collaborative work. Also, adding accountability between the two communities would encourage collaboration between the two communities **(R4 Accountability Leads to Initiative Support)**.

Overcoming the initial delays in the system provides significant benefits to RMS. As in the management loop, there are learning benefits gained from continuous experience **(R1/R6 Learning Curve Effects in Engineering/Operations)** such as efficiency, productivity and the development of new skills to improve everyone's contribution to product development. The model shows that **(R3/R5) Collaborative Work Improves Engineering's/Operations' Contribution to Product Performance**.

4.4.4. System Dynamics Results

System Dynamic models were developed to understand the current organizational culture and the driving forces surrounding the need for manufacturing innovation. The major drivers of change are external and stem from satisfying changes in customer requirements. There are a number of forces that limit the acceptance of change. On a primary level, available financial investments as well as time constraints limit the availability of resources to focus on other areas of development such as manufacturing research. On a cultural level, existing silos and skills prevent employees from expanding their responsibilities beyond their current state or from building collaborative relationships across the enterprise. The lack of accountability throughout product development does not encourage collaboration across the silos. In addition, the inherent system delays and long product development cycle encourage a short-term focus that rewards immediate results where long-term plans "waste" current resources and shift focus away from short-term needs.

There are a number of options that can help overcome an organization's resistance to change. Creating incentives and accountability would encourage employees to move outside of their boundaries to collaborate with each other to influence adoption. Delays inherent in the system require strong leadership to overcome initial barriers and reap the long-term benefits of collaborative product development.

4.5. Chapter Summary

Chapter four describes the Advanced Manufacturing Development Center as the focus of manufacturing innovation for RMS. The majority of the chapter is devoted to discussing the challenges faced in implementing the center. Developing the Three Business Lenses of Organizational Processes uncovered a number of major issues in introducing change into an organization. The strategic lens discussed the importance of determining the organizational fit of the AMDC and how to meet the challenge of manufacturing innovation. The political lens reveals how the AMDC would challenge the existing political structure. The cultural lens stresses the need to combine the two distinct communities of engineering and operations.

System Dynamics was used to visually layout the competitive and cultural environment of RMS. The causal loop diagrams developed in this study identified potential problems in implementing the AMDC as well as different methods to overcome initial organizational resistance.

Chapter 5 Industry Analysis

A portion of this research focuses on creating the center's organizational infrastructure that would best suit the management and development of manufacturing innovation. One of the tools used extensively by Raytheon's Six Sigma program is benchmarking to identify best practices throughout different industries. The Raytheon Benchmarking Handbook states "benchmarking enables us to measure our products, services, and processes against those of our toughest competitors and best-in-class companies...To achieve Raytheon's vision and strategy to be the best, we must benchmark ourselves against the best – both inside and outside the company."[132]

Two benchmarking activities were begun as part pf this research in an effort to build off of external practices to benefit the development of the AMDC. This chapter includes a description of the methodology used to gather the benchmarking information as well as a general summary of the results. Through the benchmarking, two industries, semiconductors and pharmaceuticals, were identified that are heavily involved in manufacturing innovation and concurrent process development. These industries are discussed in detail in this chapter, highlighting the correlations they have with the defense industry as well as general information on their manufacturing innovation efforts.

5.1. Benchmarking Analysis

Raytheon's Corporate Knowledge Transfer and Benchmarking Office defines benchmarking as "(1) a process of measuring products, services and practices against best-in-class companies and world-class practices, [and] (2) Learning from others...fast!"[133] Raytheon's active pursuit of benchmarking activities, lends itself to this research due to the high level of internal knowledge and skills regarding the best way to proceed with the AMDC.

[132] Raytheon Company Internal Benchmarking Handbook, ed. September 2002, pg 5.
[133] Raytheon Company Internal Benchmarking Handbook, ed. September 2002, pg 11.

5.1.1. Gathering Data

Benchmarking efforts for this research were two fold, personal interviews and a quantitative study. A number of companies within the Leaders for Manufacturing (LFM) program[134] network were contacted over electronic mail to identify potential candidates willing to share their company's efforts in addressing process innovation. Personal interviews were conducted to establish a rapport with company representatives. This medium lends itself to tailor the questions based on their response to better understand product development within a particular industry. Positive responses resulted in roughly unstructured interviews ranging in duration from fifteen minutes to over an hour. All of the companies involved in the interview process were large corporations with thousands of employees and multiple business units, similar to Raytheon. For the purposes of this thesis, the confidentiality of the contacts and companies involved in the study is maintained.

The primary goal of these interviews is to understand how manufacturing innovation and development is viewed across different industries. A sample of questions asked are listed below

- What leads the product development cycle – product or process innovation?
- How is manufacturing development managed?
- Where does manufacturing development fit into the enterprise?
- What is the current level of in-house process development?

Follow up interviews were also conducted with companies whose practices were significantly more applicable to AMDC. The information gathered was used to determine a few high-level best practices among those interviewed.

The quantitative study was initiated to formalize the benchmarking efforts through Raytheon's Corporate Knowledge Transfer and Benchmarking Office. A questionnaire

---

[134] Leaders for Manufacturing (LFM) is a dual degree Engineering and Management program at the Massachusetts Institute of Technology. LFM is a partnership between academia and industry with a number of companies serving on the operating committee. Graduates of the program form another part of the network, many employed by partner companies.

was generated to obtain a top-level view of how manufacturing innovation was managed throughout the network of companies involved in formal benchmarking partnerships with Raytheon, some not accessible through the LFM network. The questionnaire consisted of nineteen questions and is included in Appendix C, along with the results. The benchmarking office disseminated the questionnaire to the benchmarking offices of companies within their network, along with Raytheon Missile Systems. Five high-tech companies outside of RMS responded and the results of the study were tabulated.

5.1.2. Benchmarking Results

Many of the companies involved in the benchmarking studies were found to have vastly differing strategies to address manufacturing process innovation. The fundamental policy of most companies is that process development should be considered as important as product development to have a strong competitive impact. The center's likelihood of success depends largely on how RMS and AMDC leaders choose to manage innovation.

5.1.2.1. Interview Results

The interviews generated a great deal of information about each company, particularly in understanding how their product development process is geared to match their industry needs and constraints. The details of each company's approach to manufacturing development and innovation varied widely. One of the more difficult aspects of discussing manufacturing innovation was the unclear definition of what type of development constituted innovative manufacturing processes. There was ambiguity in distinguishing between process improvement and process innovation.

Within that ambiguity, the manufacturing process development efforts of different companies fell in all ranges of the spectrum, some focusing more on incremental process improvements others on advanced manufacturing research and innovation. The goals of the companies that participated in manufacturing innovation also differed. Some companies chose to focus exclusively on generating new processes that provided practical applications for their respective companies. Other companies formed research and development groups that pushed manufacturing technology forward into product development without a pre-existing need.

Organizationally, a number of companies formed a centralized organization to address the manufacturing innovation needs of the entire corporation. Others followed a decentralized approach, allowing each business unit to create their own manufacturing innovation organization to address their own specific needs. Within either of these approaches, some of the manufacturing organizations had permanent staffs while the rest borrowed people from other organizations to rotate through. Staffing needs were filled with either research scientists, design engineers or manufacturing engineers and mixes ranged across the spectrum.

There is no evidence to support or oppose any of these decisions. During the interviews, it was difficult to determine what the specific drivers were that led companies to make each decision. Many of the decisions companies made in managing innovation are strategic in nature and are not transferable from one company to another. These are preferences based on current management, business processes, and market position that dictate how risk averse a company is and how they will respond to changes in industry. It is likely that much of a company's history, goals, and previous attempts at manufacturing innovation also shape their current efforts, either strategically or tactically. As such, none of their decisions can be deemed correct or incorrect and are simply a general description of how companies manage manufacturing innovation. Evaluating projects and making investment decisions is difficult and while most companies recognize the challenge, there is no proven way to eliminate the systematic uncertainty and risk.

Within those discussions, the main topic that resonated with the AMDC and RMS leadership was that many companies approached development efforts with strategic considerations in mind. Decisions on whether or not to pursue a new manufacturing innovation project should consider the strategic implications for future competitive advantage. In addition, there were a number of over-arching principles that would be useful for RMS in the development of the AMDC. Many companies interviewed had some form of committees that guided development efforts with strategic considerations in mind. Many companies created and maintained manufacturing technology roadmaps to ensure that current development efforts would also satisfy long-term needs. Of the companies interviewed, many representatives believed development goals and guidelines, for products and processes, should be dynamic and constantly evaluated to ensure that efforts are able to continually respond to changes in industry.

5.1.2.2. Quantitative Results

Raytheon's Corporate Benchmarking Office gathered and compiled the questionnaire answers. All companies in the study did not rate themselves highly on their integration of manufacturing with product development cycle. Most respondents have active, cutting edge manufacturing technology approaches and have been involved in advanced manufacturing technology research for a significant period of time. Similar to the interview study, most companies used manufacturing technology roadmaps to guide manufacturing development or investment. In addition, most had standard processes to develop and fund manufacturing technology and transition products to production.

All respondents stated funding for manufacturing research comes from overhead pools except Raytheon who receives program funding for manufacturing development. However, programs have the option to support manufacturing development or provide funding requests. Funding profiles - the mix of how companies support existing product lines, products in development of manufacturing innovation research - vary widely. Commercial businesses tend to provide more funding to products in development.

Similar to the interview study results, it is difficult to determine which, if any, of these companies have a best practice approach to manufacturing innovation. The questionnaire could be interpreted in a number of different ways depending on the individual that is responding for their company. However, the main goal of creating a quantitative benchmarking study was to open the official benchmarking channels of other companies.

The final question formally asks companies if they are willing to continue benchmarking by providing additional information or hosting RMS for a site visit. The majority of respondents asserted they are willing to continue to explore the topic of manufacturing innovation with RMS. In addition, a quantitative study paints a clear picture of where RMS stands in comparison to other companies and may help create a sense of urgency.

5.2. Industry Analysis

Companies face different challenges depending on their markets and industry. There are many differences across industries that help mold a company. Because of those different factors, companies within a specific industry respond to them differently and establish unique characteristics compared to companies in other industries.

The different industries involved in the interview portion of the benchmarking study were analyzed to determine correlations and applicability within the defense industry. Table 5 summarizes the industry analysis, including the information most pertinent to this study.

Industry	Aerospace	Automotive	Consumer Products	Defense	Biotech/ Pharma	Semi-conductor
Drives development	Product	Product	Dual emphasis	Product	Product	Process
Product maturity	Mature	Mostly mature	Wide range	Mostly mature	Wide range	Young
Prod. Dev. Cycle Time	Decades	Years	Months	Years/ decades	Years	Few Years
Competition	Oligopoly	Intense International Comp.	Very comp-etitive	Oligopoly	Very comp-etitive	Very comp-etitive
Other Notable Info				Strong government regulation	Strong government regulation	

Table 5 Summary of Industry Analysis

The intent of the comparison is to focus further benchmarking efforts and invest additional resources in understanding those industries. RMS would increase their learning by conducting benchmarking site visits that include direct contact between leaders with the pertinent information. The top-level industry analysis highlights two industries that are more likely to aid RMS in the development of the AMDC: Semiconductors and Biotechnology/Pharmaceuticals.

5.2.1. Semiconductor Industry

The semiconductor industry is defined by Hoover's as companies "engaged in diversified manufacturing activities, offering a product line of integrated circuits, microprocessors, logic devices, chipsets and memory chips for a wide variety of users including telecom, computer networking, wireless, and other instrumentation industries."[135] The semiconductor industry is often highlighted as having strong process development capabilities. It is this latter reputation of developing new manufacturing processes for each new product that makes the semiconductor industry of particular interest. It is very likely that they have developed a standard methodology to research, develop, and implement advanced manufacturing processes.

To better understand the industry and the applicability to their advanced manufacturing efforts, it is necessary to understand their competitive environment. The semiconductor industry has formed an international coalition to have a better grasp on the industry-wide technological challenges they face.

> "The International Technology Roadmap for Semiconductors (ITRS) is an assessment of the semiconductor technology requirements...to ensure advancements in the performance of integrated circuits. [ITRS] is a cooperative effort of the global industry manufacturers and suppliers, government organizations, consortia, and universities."

This international roadmap sets the bar for competitive technological development in semiconductor companies. Each year, creation of the roadmap entails debate among the participants to determine the "industry drivers, requirements, and technology

---

[135] Hoover's On-line – Semiconductor Industry (accessed on January 2003); available on www.hoovers.com.

timelines".[136] The roadmap includes product performance and characteristics as well as the process capabilities required to meet those needs.

Gordon Moore, co-founder of Intel, observed that "the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented." He extended this observation to predict that the trend would continue, a technology trend - termed Moore's Law. Although the rate of improvement has slowed, modifying Moore's law to 18 months, it is still a widely held belief of the capabilities of the technology and serves as a development goal for companies in this industry.[137] Design efforts by all semiconductor companies to meet Moore's law focus largely on the reduction of transistor size. In addition, major design efforts work to increase the wafer diameter size. The variables of transistor and wafer size are driven by the development of new manufacturing capabilities. "Product innovation in semiconductors depends on process innovation to a greater extent than is true of many other industries, since semiconductor product innovations frequently require major changes in manufacturing processes."[138] A company's future competitive standing in this industry is directly linked to their ability to manage and develop new manufacturing capabilities.

Semiconductor companies must pursue manufacturing innovation other than to meet Moore's law. The development capabilities of semiconductor companies are quickly reaching their limits. Products in this industry typically have a market life of two to four years at which point they become obsolete. The product development cycle requires an average of three to five years for completion. Recall that proficiency in manufacturing innovation allows a company to reduce their product development cycle time, improving their ability to match if not exceed the obsolescence rate with their product introduction rate. Facing intense competition in the industry, companies that are first to introduce a

[136] International Technology Roadmap for Semiconductors (accessed October 2002); available on http://public.itrs.net/.
[137] Webopedia, on-line encyclopedia (accessed January 2003); available on http://www.webopedia.com/TERM/M/Moores_Law.html.
[138] Nile W. Hatch and David. C. Mowery, "Process Innovation and Learning by Doing in Semiconductor Manufacturing," *Management Science* 44, no. 11 (Nov 1998), pg 1462.

product to the market can achieve significant benefits such as capturing market share, increasing sales, and setting new product standards across the industry.

Using Pisano's framework, products within the semiconductor industry fall into the Process Enabling category. As such, product innovations require a high degree of process innovation as well as product innovation to bring them to market. One company in particular has successfully redefined their organization to improve their product development methodology. A general description of their organization is shown in . Figure 12.

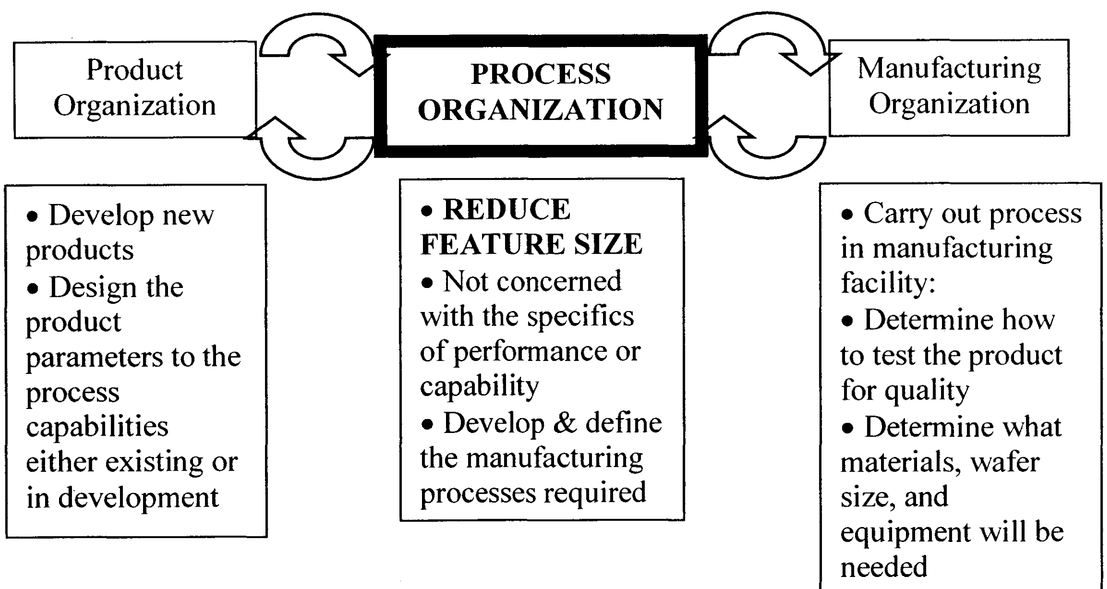

Figure 12 Organization of a Semiconductor Company[139]

The three major organizations within this company are the Product Organization, the Process Organization and the Manufacturing Organization. All three groups are deeply involved in the development of new products, requiring intense levels of coordination and collaboration between the three. The Process Organization leads most development efforts since the main driver, or constraint, of new products is a company's ability to reduce the feature size (transistor size). As previously mentioned, the ability to change feature or wafer size is directly driven by actively managing manufacturing innovation.

[139] Benchmarking Interview

The Process Organization is not concerned with product performance; that is the main goal of the Product Organization. The Product Organization's goal is to create products that match customer's needs while fitting within the process capabilities, either existing or in development. The Manufacturing Organization is responsible for the final production and is the user of all manufacturing processes developed within the Process Organization. The Manufacturing Organization keeps established industry standards and constraints, ensuring that all new products and processes do not infringe them.

The development of new products includes accountability between all three entities. A high degree of accountability ensures the stakeholders will coordinate their efforts instead of throwing designs, specification, and requirements over the wall. In order to create a new product that (1) pushes the limits of technology, (2) delivers the performance and capabilities to the customer, and (3) is manufacturable at a low cost with a high yield, all three groups must be involved in development. To some degree, RMS is striving to achieve all of these results with the AMDC.

While a number of different interviews were conducted with representatives of this company it was difficult to obtain pertinent information. For example, RMS would benefit from obtaining a more detailed description of how the three organizations collaborate and the accountability involved for a deeper understanding of the relationship and culture at this semiconductor company. Ideally, a historical account of the product development methodology before process development led all development efforts would help RMS obtain a better grasp of the changes in their company. Similarly, it would help to identify the factors that drove them to change and the lessons learned while changing the organization. This type of information would provide a better context to evaluate the effectiveness of their change efforts and the benefits they obtained. In addition, the AMDC would directly benefit from a description of the facilities, the process development environment and incentives offered to employees. The above information would be more readily obtained through formal relationships and benchmarking site visits at this company.

5.2.2. Biotechnology & Pharmaceutical Industry

The industry that correlates most with defense is the biotechnology and pharmaceutical industry. The pharmaceutical industry includes manufacturers and distributors offering "a broad and diverse line of drug and health care products; these industry leaders that have made a significant commitment to the research and development of a long pipeline of drugs."[140] "The Biotech industry includes companies engaged in drug discovery and production, research, and biologically engineered food."[141] The pharmaceutical and biotechnology industry have the same basic phases of product development shown in Figure 13.

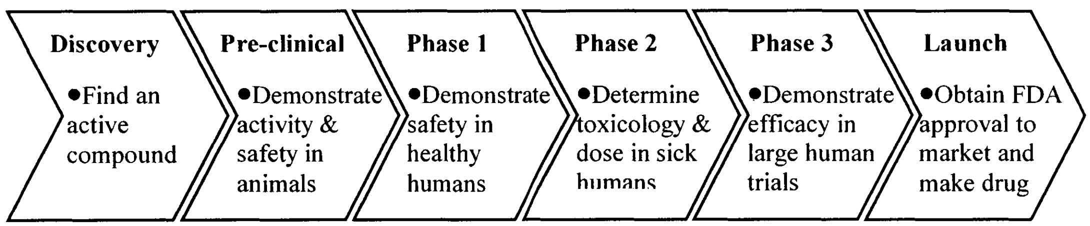

Figure 13 Phases in Drug Development[142]

The primary difference between the two types of industries is the methodology by which new drugs are discovered and manufactured. Traditional pharmaceutical companies use chemically synthesized organic molecules to create new compounds. Historically, pharmaceutical companies would randomly screen their compound library to search for compounds that were effective in treating an illness. Often, in the search for a treatment of illness X, a compound would be accidentally discovered to treat illness Y. In recent years, the pharmaceutical industry has turned to rational drug design, working backwards

[140] Hoover's On-line - Pharmaceutical industry (accessed on January 2003); available on www.hoovers.com.
[141] Hoover's On-line – Biotechnology Industry (accessed on January 2003); available on www.hoovers.com.
[142] Benchmarking interview

from a detailed knowledge of a disease's biochemistry to determine what chemical compounds can inhibit the chemical reaction involved.[143]

The biotechnology industry uses synthesized protein molecules to create new treatments. Discovery of new treatments is much more systematic than the random screening process of traditional pharmaceutical. Biotech companies use molecular biology to study diseases at the cell level and identify potential treatment. Genetic engineering allows scientists to manipulate the genetic structure of cells to produce certain proteins, thereby manufacturing the critical treatment.[144]

Once a compound appears to have promising results in a laboratory environment, pre-clinical development begins. This phase requires a slightly larger quantity of the compound to perform experiments on animals and determine the appropriate activity occurs within living species. If the results are positive, the compound moves on to the first phase of clinical trials. Phase I ensures that the compound does not cause adverse reactions and are tested on a small number of healthy humans. A slightly larger amount of testing material is needed in each subsequent phase. Successful Phase I trials moves testing to Phase II.

In Phase II, the compound is tested on a subset of individuals who are afflicted with the disease. Phase II is focused on determining the possible side effects as well as the appropriate dosage levels. Phase III tests the efficacy of a drug in larger human trials, requiring a significant scale up in manufacturing capacity. Once thorough clinical trials have occurred, a company will file a request to the FDA to release the drug to the market. If the FDA request is approved, the company will then launch the product and begin manufacturing and marketing the drug. The funnel effect is used to describe the dramatic reduction of the number of drugs in development due in large part to the rigorous tests and limited financial resources to pursue all potential compounds.

---

[143] Pisano (1997), pgs 55, 64
[144] Pisano (1997), pg 68-69

As mentioned earlier, each phase of development requires rigorous tests and it is necessary to begin producing small quantities of the drug very early in development. Figure 14 illustrates the different requirements for manufacturing processes at each phase of development.

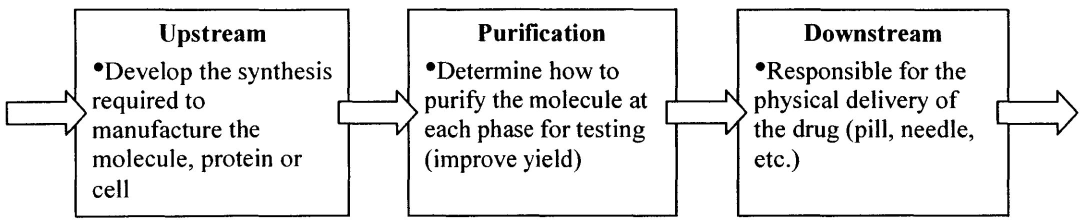

Figure 14 Process Requirements in Each Phase of Drug Development[145]

As the scale of production increases, additional research must be conducted to reduce process complexity, improve manufacturing yields to deliver the appropriate amount of material for testing and eventual production.

Process research typically begins during the pre-clinical development phase and involves lab-scale production of the drug. Production quantities range from one gram to one kilogram. Pilot development begins near Phase I of the clinical trials. The manufacturing process is evaluated in a pilot plant and the design of the equipment and facility occurs. Production levels of the pilot plant range from one kilogram to 100 kilograms. Near Phase III, the process is transferred to a commercial plant and the manufacturing environment is validated. The FDA requires full development of manufacturing processes before submitting a request for approval. Artificially simulating the manufacturing environment is not sufficient; it is necessary to physically create the manufacturing facilities that will produce the drug to demonstrate the effectiveness of the manufacturing process. Production levels range from 100 kilograms to metric tons of the material once the product is launched.[146]

---

145 Benchmarking interview
146 Pisano (1997), pg 119

The biotechnology and pharmaceutical companies undertake high risks in their product development. Only one in eight to ten thousand compounds from the discovery phase reach the market. "A new product must have peak sales of over $200 million a year to recoup research and development costs."[147] Investments in new manufacturing facilities range from $100 to $400 million dollars and are ready to begin production and release the drug to the market on the day approval is granted. However, FDA approval is not guaranteed and companies have been left with a useless facility that requires additional investment to retrofit for the next potential drug.[148]

Of all of the companies involved in the benchmarking study, the biotechnology and pharmaceutical industry is a better match for RMS. In comparing the two industries, a number of similarities surfaced between them and the goals of the AMDC. Within biotech/pharmaceutical, the product and process development efforts are tightly linked requiring new manufacturing processes for each new compound. As in defense, the product's requirements drive development efforts, i.e. the discovery of a new compound in biotechnology or pharmaceuticals. Both industries face long product development cycles and a stringent qualification of product requirements. In addition, there is a significant amount of government regulation in each industry. Both industries cope with high financial risks during development and have a similar gating process to evaluate projects at different stages development.

There are a number of differences that distinguish defense from biotechnology and pharmaceuticals. Although both industries face stringent government regulations, the defense industry is protected by the structure of their business. The government provides funding for a large portion of research and development costs, minimizing the development risks for defense companies. In addition, defense systems are low volume production compared with blockbuster drugs and have less opportunity to obtain economies of scale. Unlike biotechnology and pharmaceutical companies, defense

---

[147] A. Webster and V. Swain, "The Pharmaceutical Industry: Towards a New Innovative Environment," *Technology Analysis & Strategic Management* 3, no 2 (1991), pg 131-132.
[148] Pisano (1997), pg 73

companies can validate the performance of a product while allowing a considerable amount of leverage to modify the manufacturing processes.

Currently, the biotech/pharmaceutical industry is undergoing a transformation requiring them to introduce drugs with significant therapeutic improvements. Intense industry competition stresses the importance of being first to market and thereby requires companies to reduce their development time. Decreased price flexibility in the industry and shorter market lives of new drugs results in lower margins. The speed at which other companies enter the same market also reduces the time for the original company to generate a blockbuster profit to recuperate the large development investments. These results highlight a company's need to lower their development costs to remain competitive.[149] Similar to the defense industry, the biotech/pharmaceutical industry is undergoing a "Better, Faster, Cheaper" revolution. Faced with similar pressures, Raytheon and the biotechnology and pharmaceutical companies would benefit from learning how the other addresses a changing industry.

5.2.3. Industry Results

In further studying this industry, benchmarking efforts should focus on building collaborative relationships with pharmaceutical companies. Although, biotechnology companies face similar development issues as pharmaceutical companies, they are smaller and younger. Many pharmaceutical companies have been in the drug development business for decades and have accumulated a wealth of experience. In a larger organization, such as traditional pharmaceutical companies, managing technology development while coordinating limited resources is more challenging. Large organizations usually separate and compartmentalize responsibilities and tasks into distinct organizations requiring coordination during development.

A pharmaceutical company's experience should result in a stronger drive toward identifying best practices and standardizing proven methods to proceed at each phase. In

[149] Pisano (1997), pg 79

addition, they are likely to have established an evaluation method to prioritize development efforts and strategically allocate resources. The challenges that both defense and pharmaceutical companies face in the changing environment are numerous and both are likely to benefit from creating a collaborative learning relationship.

Additional research in either of these companies would provide RMS with more useful information. Site visits, in particular, would be ideal; however pursuing these efforts during the course of this research exhausted the resources of the researcher. Sufficient interest could not be generated from companies in either industry to invest additional time or resources to host RMS. The disinterest could stem from a distrust of RMS attempting to gather sensitive, competitive information. However, there is no overlap in the types of products developed in each industry. More importantly, benchmarking is typically a quid pro quo and there may be limited interest by other companies to learn from RMS because there is a limited transparent correlation.

5.3. Chapter Summary

A number of general practices obtained through benchmarking are readily applicable to the AMDC such as establishing a committee and creating a roadmap to guide manufacturing innovation. The LFM network is well suited to meet the needs of the interview portion of the benchmarking activities as participation by company contacts required minimal time and investment. However, attempts made to organize site visits were lost. LFM representatives may not have the right contacts or influence to commit their company to a site visit. Involving Raytheon's Benchmarking Office in a quantitative study engages other benchmarking offices that are familiar with the benchmarking process and benefits for their company.

The information gathered in phone interviews was top level in nature and summarized the manufacturing development efforts at these companies. The main result of the quantitative study was a formal acceptance by a number of companies to continue to address the topic of manufacturing innovation through additional benchmarking.

Additional analysis identified specific industries that have a higher correlation with the defense industries and are facing issues similar to Raytheon's. Further benchmarking and analysis of these would yield more useful information.

This page intentionally left blank.

Chapter 6 AMDC Operational Model

For this research, an operational model was developed to provide a general framework to facilitate the management and development of manufacturing technologies. A model can be created for the AMDC by using information gathered from other companies and academics on the topics of manufacturing innovation and technology management. The information used to develop the AMDC operational model was derived from a wide variety of sources, particularly from the benchmarking activities and industry analysis, common practices in implementing sustainable change and academic research on creating effective teams. This chapter is intended to serve as a stand-alone guide for the AMDC and RMS to use to effectively manage manufacturing process research and innovation. The model is intended to be dynamic with continual evaluation by the AMDC to ensure the changing needs of RMS are being met.

The AMDC operational model includes five distinct stages that should occur continually and concurrently once the center reached a steady stage. The five stages of manufacturing innovation include Identify Manufacturing Technology Needs, Plan Manufacturing Technology Development, Manage the AMDC, Develop & Validate New Manufacturing Technology, and Create Rapid Manufacturing Development Capabilities. Figure 15 displays a visual representation of the operational model including each of the five stages and major tasks within each.

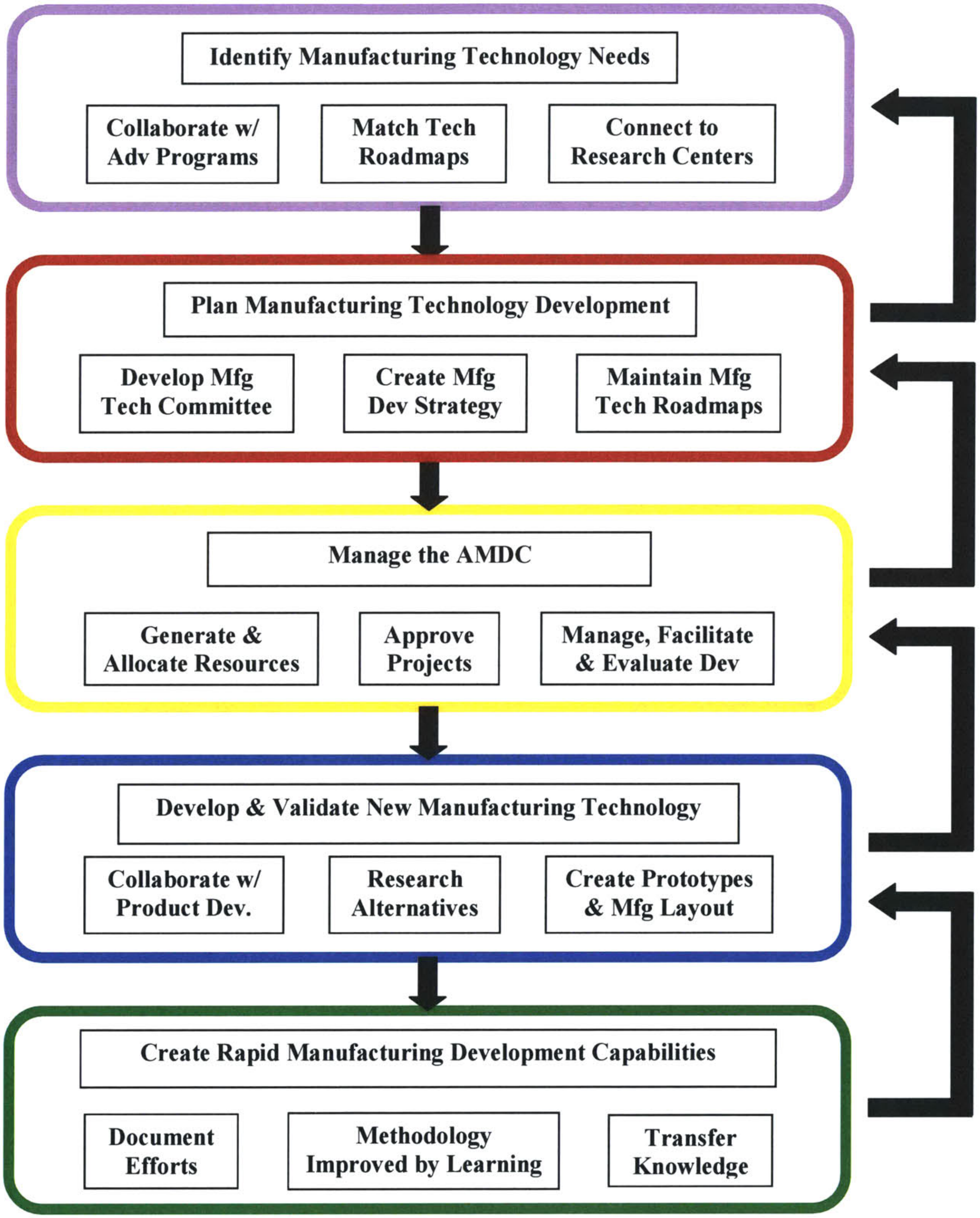

Figure 15 AMDC Operational Model

6.1. Identify Manufacturing Technology Needs

The AMDC intends to pursue development projects that address internal manufacturing technology needs by providing practical solutions. Technology and development within the AMDC must be pulled from customer needs. The AMDC can access distinct avenues within Advanced Programs to identify specific manufacturing technology needs. The majority of Advanced Program work is the development of new defense systems based on new product technologies. System development within each program is at varying degrees of completion.

While the technology and the design of the systems are likely to be in a state of flux, it is possible to extrapolate the major manufacturing technology needs by analyzing general system requirements. For example, a missile system that uses lasers for guidance will require the precision assembly of optical lenses. Manufacturing innovation efforts can focus on developing a practical solution that will deliver the design requirements without needing to know the specific design details since "the goal of process research is to define the basic architecture of the process."[150]

If the development of a new system has progressed in its level of detail, it is possible to evaluate the design and identify the manufacturing capabilities needed for producing that system. In doing so, a preliminary bill of processes is created that can compare the required manufacturing capabilities with existing capabilities. Gaps would highlight the manufacturing technologies that must be developed. Evaluating the manufacturing needs of a design before it is transferred to production facilitates subsequent tasks and improves the transition process. For example, the bill of processes could serve as an outline to create detailed work instructions for line operators in the factory.

If a development program has advanced significantly, the potential impact of manufacturing research is reduced. At this stage, designs are more complete and it

---

[150] Gary P. Pisano, "Knowledge, Integration, and the Locus of Learning: An Empirical Analysis of Process Development," *Strategic Management Journal* 15, Special issue: Competitive Organizational Behavior (1994), pg 80.

becomes more difficult and costly to modify - limiting the ability to reach an optimal system solution that balances product and process requirements. In addition, delaying manufacturing innovation to later stages of development could delay the delivery of a system if inadequate time is allotted to develop new manufacturing capabilities. The identification of manufacturing technology needs is dynamic and must become an integral part of product development.

Other avenues that the AMDC can access to identify manufacturing technology needs are corporate research centers and RMS technologists. Throughout Raytheon, there are multiple corporate centers that research and develop new technologies. Typically, research is focused on advancing product technologies that may be developed into new defense systems ten to fifteen years in the future. Internal RMS technologists collaborate with research centers throughout the enterprise to manage research and development at the business unit level. Technologists are concerned with finding practical applications of the new technology within new defense systems. Internal research tends to focus on further development of technologies that may be used eight to ten years in the future.

Senior technical leads within Advanced Programs are responsible for creating product technology roadmaps that forecast what technologies, within different systems, are likely to be applicable in five to ten years. Note that the early stages of proposal work look for correlations between product technology in the research pipeline and the ability to apply the technology to meet the customer's needs. Roadmaps outline the product technologies that are in development, the subsystems that can use the technology, and the system architectures or product platforms that will use the subsystems. RMS technologists are 'keepers' of the internal technology roadmaps as an extension of their link between corporate research centers and internal development programs.

The last two avenues plan product technology on a long-term basis. It is precisely their forward thinking that lends them to coordinate with the AMDC to identify future manufacturing technology needs. One final avenue that the AMDC can access for additional work is Raytheon's supply chain. Once the center becomes proficient at developing new manufacturing capabilities, their skills can be used to aid suppliers; positively impacting long-term supplier relationships as well as improved subsystem designs and production. Overall, the identification of manufacturing technology needs should be dynamic and become an integral part of product development to be able to initiate internal manufacturing research that will benefit the entire enterprise.

6.2. Plan Manufacturing Technology Development

A significant factor in the success of the AMDC is the organization's ability to strategically guide development. A focus on strategic rather than tactical development would result in greater impact and efficacy of the AMDC. A strategic plan would generate balance between short and long-term goals as well as present a number of solutions that address the strategic and political concerns that surfaced in the three lenses.

6.2.1. Manufacturing Technology Committee

The purpose of a Manufacturing Technology Committee is to provide an enterprise level view of development efforts to allow for global optimization of investments in manufacturing innovation. Representatives of the committee should understand the larger business context and be able to gauge the potential impact of projects to help guide development efforts and maintain the Manufacturing Technology Roadmap. Details of the roadmap are included in a subsequent section. In addition, incorporating members whose interests are representative of the enterprise would provide a forum for stakeholders to express their viewpoints. The committee would serve as a formal network for representatives to exchange information with other organizations. Including stakeholders in the committee membership would ensure that their concerns and needs are taken into consideration in the decisions of the AMDC and would consequently align their interests and agendas with the new center.

The committee should be composed of senior leaders throughout RMS that can influence their organizations and have a perspective of overall enterprise and new business opportunities. The primary stakeholders that should be involved in the committee, particularly representatives from engineering and operations. "To have the capability to develop and simulate processes outside the factory, an R&D laboratory needs deep scientific knowledge about the technology as well as detailed knowledge about how the factory actually operates."[151] Engineering leaders would bring a familiarity of the program development efforts; a general awareness of their manufacturing technology needs and of the criticality of developing new capabilities to match those needs. Leaders from operations would bring knowledge of the existing manufacturing capabilities as well as knowledge of the factory environment and skills of the end users. In particular, representatives from operations would have the skills to evaluate programs in development and further assess their manufacturing technology needs. The AMDC manager would serve as the head of the Manufacturing Technology Committee.

6.2.2. Manufacturing Technology Roadmap

Once a list of manufacturing technology needs has been created, it is necessary to create a strategic, long-term plan to address those needs. Similar to product technology roadmaps, a Manufacturing Technology Roadmap can be used to encompass development efforts and include critical information. For example, the roadmap can include the priority and urgency for developing each new capability as well as the amount of resources required for development such as equipment that a project would require. In addition, the feasibility of a manufacturing technology development project should be evaluated to determine if in-house development makes strategic and business sense and is achievable within the available development time, budget and staff.

Creating a roadmap requires identifying each project's timeline in terms of how long development should take and assessing the appropriate time for manufacturing development to begin. The Manufacturing Technology Roadmap can be used to ensure that all development efforts are directly tied to a customer need. In addition, a clear and

[151] Gary P. Pisano, "Learning-Before-Doing in the Development of New Process Technology," *Research Policy* 25 (1996), pg 1099

concise document would facilitate identifying synergies between programs so that similar needs are addressed simultaneously; eliminating duplicate efforts, maximizing return on investment, and allowing for technology re-use.

The creation of a Manufacturing Technology Roadmap should begin by building from the existing Product Technology Roadmaps. As mentioned earlier, specific manufacturing technology needs can be extrapolated from product technologies included on product roadmaps. Ensuring that research and development, in both the performance and manufacturing aspects of a technology, proceeds simultaneously improves the overall quality of product development. More specifically, the roadmaps allow a succinct method to match research investments proportionately between the two, promoting concurrent development efforts across the enterprise.

Due to the proprietary nature of the Manufacturing Technology Roadmap, the content and author's efforts are not included in this thesis. However, the Manufacturing Technology Roadmap highlights development projects that can generate early successes along with projects that focus on critical, long-term technology needs

6.2.3. Manufacturing Development Strategy

A Manufacturing Development Strategy is a systematic method to evaluate projects strategically. This strategy should evaluate the manufacturing technology needs to facilitate project prioritization and resource allocation when making development investment decisions. A manufacturing development strategy could balance development efforts between short-term, low risk projects and long-term projects with inherently a higher risk. Traditional financial analysis, particularly return on investment calculations, favors incremental projects that produce short-term benefits. A manufacturing development strategy would help counter the risk-averse tendencies.

One possible tool is to determine the strategic implications of pursuing each project by answering questions such as those listed below:

- What are the strategic contributions of pursuing this project?
- What are the competitive implications of pursuing this project?
- Are competitors developing or mastering similar manufacturing capabilities?

Questions of this nature would allow development decisions to incorporate both financial and strategic concerns. A Manufacturing Development Strategy could also incorporate general guidelines to evaluate projects. "A central problem in managing and investing in innovations is determining whether and how to continue a development effort in the absence of concrete performance information."[152] Initially, it will be difficult to gauge the appropriate length of time and resources each development project should require. Evaluation of projects will have to be based on the innovativeness and simplicity of the solution, the practicality and robustness of use, the low cost of implementation and production, and the resulting manufacturing yield.

To echo the sentiments of the benchmarking interviews, it is important for development to remain dynamic. A strategy should be continually evaluated and updated to ensure that it does not become antiquated. In addition, as more projects are completed, the center will develop knowledge and standards for developing new technologies that will likely impact the development and evaluation strategy.

6.3. Manage the AMDC

Primarily, AMDC management is responsible for the day-to-day operation as well as ensuring the long-term sustainability of the center. As the leader of the Manufacturing Technology Committee, the AMDC manager helps create the Manufacturing Technology Roadmap and uses it to initiate manufacturing development projects. In addition, AMDC management is responsible for generating new business for the center to ensure that the needs across the enterprise are continually being addressed.

---

[152] Andrew H. Van de Ven and Douglas Polley, "Learning While Innovating," *Organization Science* 3, no. 1 (Feb 1992), pg 92.

The AMDC manager has a number of major responsibilities surrounding the management of innovation. AMDC management controls the pool of resources to develop manufacturing technology. While identifying manufacturing technology needs, resources to invest in development projects should be identified concurrently. The AMDC manager is responsible for generating internal and external funding. In addition, they are responsible for allocating resources to fund development projects.

One of the management's responsibilities is to facilitate the development of new manufacturing technologies. The basic needs of development projects are to have adequate lab facilities and equipment to allow for innovation and experimentation. In addition, it is necessary to create an appropriate environment to encourage innovation, learning, and collaboration. In essence, the AMDC is an opportunity to create a learning organization to encourage innovation. Schein believes that people "cannot learn something fundamentally new if [they] don't have the time, the resources, coaching, and valid feedback on how [they] are doing. Practice fields are particularly important so that [they] can make mistakes and learn from them without disrupting the organization."[153] As described in earlier sections, building the appropriate environment allows development project teams to experiment and make mistakes without repercussions. Instead, mistakes should be seen as opportunities to learn.

Once approval has been granted and funding is secured, the AMDC manager can assemble a team for each development project. A key part of creating and maintaining a learning atmosphere within the AMDC is to identify employees that can thrive and will reinforce this environment while developing new manufacturing technologies. To facilitate selection of employees, specific criteria should be established that highlight an individual's ability to be effective within the AMDC.

Because projects are developed by teams, employees should be able to function effectively with a team. A team member should be able to communicate and collaborate across disciplinary boundaries.

---

[153] Schein, pg 125

Communication is a critical step in combining the inputs from the customer and user to ensure that any new manufacturing technology effectively meets their needs. Similarly, effective communication would allow team members to understand the needs and priorities of the external customer further downstream. Collaboration would allow concurrent development efforts between manufacturing technology development and product technology development, resulting in an optimal defense system. In addition, a team member should be able to understand the science behind the product and process technology to identify and work around inherent constraints.

In order to attract the right employees to the AMDC, appropriate incentives must be set. The most common form of incentives within development projects is to challenge employees to work on something new and interesting. In addition, to "reward people for creative ideas...provide open communication channels, and encourage different and unusual points of view would both attract and develop more creative people."[154] For incentives to be effective, performance measurement metrics must be carefully set. Both individual and team performance must be evaluated based not only on their ability to develop a new manufacturing capability but also on the methodology by which they reached a solution. Metrics that evaluate communication, collaboration, creativity and innovativeness, however are subjective in nature. Team members must be comfortable with subjective evaluations and trust that they are appropriately recognized and rewarded for their efforts. Involving team members in developing metrics and evaluating each other's performance can facilitate acceptance of the metrics.

AMDC management is responsible for ensuring that employees involved in manufacturing research and development projects are pursuing a challenging and respectable career alternative. In the current culture, product technology development and employees in that area receive higher levels of credibility. Because manufacturing development projects require collaboration with product development, the AMDC must

---

[154] Kenneth E. Knight, "A Descriptive Model of the Intra-Firm Innovation Process," *The Journal of Business* 40, no. 4 (Oct 1967), pg 481.

work to establish a reputation and gain credibility within RMS for their efforts. Acceptance of the center would encourage employees across the enterprise to become involved in manufacturing development projects as needed as well as encourage Advanced Programs and other business units to seek the AMDC to help address their manufacturing capability needs.

Finally, AMDC management should facilitate the transfer of knowledge from within the AMDC to the rest of Raytheon, to customers, to government agencies that support manufacturing innovation, to suppliers and to the industry. Sharing information on the efforts of the AMDC would benefit the center in a number of ways. Internally, RMS would directly benefit from the development of new capabilities. Capturing lessons learned and transferring them to subsequent teams will facilitate their progress. To build internal acceptance of the center, team members should also be encouraged to disseminate information throughout their home organizations. Within RMS, the most common form to generate new business for internal centers is through word of mouth. Disseminating information regarding the success stories of the AMDC would raise the level of awareness and ensure the continued support of the internal customers.

Development successes should also be shared with customers and government agencies to build or ensure their continued support, particularly financial, of the center. Informing major suppliers of the AMDC's current efforts to innovate manufacturing technologies sends a signal of RMS' commitment to improving their internal capabilities and begins to lay the groundwork to extend the effort into the supply chain. Obtaining support from suppliers would facilitate future relationship with the AMDC as well as encourage suppliers to build their own internal manufacturing development capabilities. Informing the industry of RMS efforts in manufacturing innovation would bring credibility to the organization and would build upon their existing reputation. All of these efforts would ensure that the AMDC becomes a competitive advantage for Raytheon.

6.4. Develop & Validate New Manufacturing Technology

The responsibility of developing new manufacturing technology falls on employees of RMS. Manufacturing innovation requires employees that possess a number of basic attributes. Primarily, employees should be creative and open-minded. Employees should be able to think outside of the current capabilities and not be constrained by the status quo during development. Creative solutions require employees to explore and experiment with different technology alternatives. Because development will generally occur within teams, the AMDC should be staffed with employees who are comfortable being part of a group effort and can be productive, contributing members.

In addition, employees should be able to communicate across boundaries on several levels. "Teams engage in vertical communication aimed at molding the views of top management, horizontal communication aimed at coordinating work and obtaining feedback, and horizontal communication aimed at general scanning of the technical and market environment."[155] Effective communication skills facilitate and accelerate development since teams can ask for and receive feedback quickly. Employee flexibility within the AMDC is also necessary for a number of reasons. Flexibility is required for employees joining a new organization that while it is learning and defining itself it undergoes significant changes. As mentioned earlier, product development is constantly evolving, making the development of manufacturing technology aim at a moving target. With continual changes in customer needs, employees should be responsive to project level uncertainty.

Due to the high level of uncertainty and lack of pre-existing standards in manufacturing development, teams should be able provide input for their evaluation. Establishing the AMDC creates a new opportunity for development, however, it is difficult to assess the success of a project mid-stream and the viability of continuing development. In addition, it is necessary to evaluate team progress and individual contributions to the creation of new manufacturing technologies. Encouraging team members to develop their own

---

[155] Deborah G. Ancona and David F. Caldwell, "Bridging the Boundary: External Activity and Performance in Organizational Teams" *Administrative Science Quarterly*, 37, no. 4 (Dec., 1992), pg 634.

metrics gives teams an additional stake in ensuring the success of the project since they know they are not measured by arbitrary standards. However, "it is essential to have reward and discipline systems and organizational structures consistent with the new way of thinking and working."[156] For example, evaluating employees based on their ability to quickly complete a project will result in employees settling for incremental improvements to current inadequate capabilities rather than discovering radical new technologies that match the customer's needs.

During development, teams are responsible for researching potential solutions to meet the manufacturing needs of a new system. Research would allow teams to identify existing manufacturing technology alternatives both internal and external to Raytheon. These research efforts prevent teams from duplicating technology that is readily available. Essentially, teams should conduct a technology benchmarking search to identify pre-existing capabilities. Outside of these suggestions, teams should be free to discover their own methodology for developing new manufacturing technologies. Limiting the way a team should operate reduces their ability to exploit their own expertise whether it is to explore the science behind new technologies or by experimentation. Each development project is essentially a learning opportunity for teams and the center. "Everyone learns slightly differently, so it is essential to involve learners in designing their own optimal learning process."[157] However, too much flexibility may lead to inefficient teams with minimal direction.

The research and development of new manufacturing technologies is accomplished through teams made up of cross-functional and multi-disciplinary employees. Integration across functional boundaries is critical for successful process development across system and component interfaces, between different scientific and knowledge bases, across sequences of projects, between R&D and manufacturing.[158] It is a challenging endeavor to get people from two distinct cultures to work together. The skills necessary to develop

---

[156] Schein, pg 125
[157] Schein, pg 125
[158] Pisano (1994), 87-88

new manufacturing technology come from employees within both the engineering and the manufacturing community. Engineers are aware of program needs and have strong technology development skills. Manufacturing brings knowledge of existing capabilities and needs of the end user. Both communities have distinct cultures and assumptions about their role in the company. Changing the product development methodology, embodied in the new center, requires their collaboration.

AMDC teams must collaborate with product development to modify the system design as needed. "The relationship between upstream [product design] and downstream groups [process design] must support and reinforce early and frequent exchange of constraints, ideas, and objectives. Moreover, because problem solving across traditional functional boundaries occurs in real time, the capacity for quick and effective action is critical."[159] Much of this thesis focuses on the need to ensure collaboration across traditional boundaries and encourage new system development to encompass the engineering and manufacturing communities. The causal loop diagrams developed in Section 4.4 show that accountability between the two communities will encourage collaboration. "Mutual trust and joint responsibility are essential to integrated problem solving."[160] Establishing accountability between Advanced Programs and the AMDC would ensure that the two reach an optimal system design where the manufacturing risks have been effectively eliminated.

An ideal staffing arrangement for the AMDC is to have employees that rotate into and out of the center. While periodically rotating employees would be difficult to coordinate, RMS would benefit from exposing many different employees to the center. Participation in manufacturing technology innovation would widen the knowledge base and skills of each employee. In addition, it would provide employees with an awareness of how other internal organizations operate, allowing them to better understand each other's interests and allow for better collaboration throughout the enterprise.

---

[159] Wheelwright and Clark, pg 35
[160] Wheelwright and Clark, pg 38

Unless a project is cancelled, development of a manufacturing technology continues until a viable, low-cost solution is found. In addition, teams must validate the new capability and be able to reliably replicate the manufacturing process within the lab. Development is extended to create appropriate work instructions and design an optimal factory layout as needed. Once a manufacturing technology has been developed, the next step is to implement the solution on the factory floor. "One of the chief challenges of innovation lies not only in designing the process, but also implementing and replicating it within the firm's operating environment."[161]

Ideally, the team responsible for developing a new technology would also be responsible for its implementation in the factory. However, it may not be logistically viable for the team to do so in terms of availability of time between development and implementation as well as whether or not the development team possesses the implementation skills. To ensure accountability between development and the end user, the development team should be involved as much as possible during technology implementation and ramp-up to its full capacity.

Finally, team members are ultimately responsible for transferring knowledge and information from their efforts. Aside from aiding in the transfer of technology to the factory floor, they are responsible for document their development efforts for subsequent development teams to use. Documentation should include the lessons learned during technology development that will improve the efficiency and productivity of future projects. In addition, teams should disseminate the efforts of the AMDC to other internal organizations to encourage other employees to participate in manufacturing innovation, to bring credibility to the AMDC, to encourage other organizations to identify and mitigate their manufacturing risks and to bring overall improvements to RMS.

---

[161] Pisano (1994), pg 86

6.5. Create Rapid Manufacturing Development Capabilities

Finally, it is necessary to consider how the operation of the AMDC can fulfill its long-term goal. The motivation for creating the AMDC was to create a competitive advantage for Raytheon. Each manufacturing technology developed within the AMDC creates a new capability for the company, providing numerous benefits such as built in manufacturability, reduced production costs and facilitation of the transfer from design to production.

However, the greater impact of the center is not in the specific capabilities developed but rather the methodology used to identify and mitigate manufacturing risks. Strategic operation of the center requires being able to view the impact of individual efforts across the enterprise. It also incorporates academic theories and industry practices into the operation. Considering the long-term benefits of current decisions facilitates initial buy-in. For example, continuously analyzing the methods by which manufacturing technology is developed can improve subsequent development projects by taking advantage of learning curve benefits across teams. Ensuring teams learn from the previous efforts will reduce the development cycle time, improve the efficiency of team performance and require fewer investment resources for each project.

As previously mentioned, the AMDC manager's efforts to share successes are directly related to the long-term performance and impact of the center. Establishing competence within the center would allow RMS to extend their development capabilities to create new manufacturing technologies for the supplier base; the benefits of which would directly impact RMS products. Disseminating the AMDC efforts and successes throughout RMS will improve internal visibility and support. Similarly, sharing RMS efforts to other business units within Raytheon will encourage their recognition of the need for manufacturing innovation and facilitate their support to begin similar centers throughout the enterprise. Involving external customers in the development of new manufacturing technologies will not only give customers an insider perspective on the AMDC's capabilities but would also recognize RMS' competitive advantage in development. Finally, publicizing AMDC efforts outside of Raytheon would generate additional recognition for all of the stakeholders for their efforts in manufacturing innovation.

6.6. Chapter Summary

This chapter details an operational model for the AMDC that largely encompasses this research. The model suggested sources to identify manufacturing technology needs. The model includes alternatives to ensure a systematic, strategic outlook for development. In addition, suggestions were made on the roles and responsibilities for the management of technology as well as its development. The key factors in development involve collaboration between engineering and development, accountability between the two communities and incentives that encourage effective technology development.

For RMS, these benefits will translate directly to a more responsive company that is equipped to develop and deliver better products within a faster development time and at significantly cheaper costs. While the AMDC Operational Model developed for this research is static to meet today's needs, it should be continually evaluated to ensure that the AMDC is flexible and can respond to customer needs.

This page intentionally left blank.

Chapter 7 Conclusions and Recommendations

The purpose of this thesis project was to provide RMS with an academic perspective on the implementation and development of a new organization. Research began by identifying if there was a need for a company such as Raytheon to address manufacturing technology innovation. The defense industry is changing where the main customer demands that companies provide defense systems that are Better, Faster and Cheaper. Therefore, it is only natural that Raytheon, or any other defense company that wishes to remain competitive, change to meet the new customer needs.

Implementing a new organization faces a number of challenges. RMS is doing well financially and it is more difficult for a company to change without a burning platform. Also, manufacturing innovation requires collaboration and coordination with the engineering organization. Many American manufacturing companies are struggling to break down the barriers that prohibit the manufacturing and engineering communities from working together. A number of different business tools were used to characterize the cultures and identify options to encourage collaboration. Establishing accountability and appropriate incentives would greatly facilitate changing the two cultures and their current practices.

One of Raytheon's main motivations for including a research project within their development efforts was to be able to study information from academia and other companies. Through benchmarking, RMS has learned general principles that other companies use to manage and develop new manufacturing technologies. Finally, an operational model was developed that in essence summarizes the results of this research, to focus on how to manage and develop new manufacturing technologies and capabilities.

7.1. Research Assessment

As a scientific study, a research project ideally poses a hypothesis and consequently creates experiments to prove, or disprove, its accuracy. Since this thesis is focused on practical applications within a company, there are logistical constraints in performing a complete scientific study. Given the slow clockspeed of the industry, change is internalized at a slow rate. The acceptance of the AMDC within Raytheon as well as changes to product development will likely take years. While the initial stages of implementation coincided with the beginning of this research project, the on-site research ended before any significant theories could be applied. Similar to what academics have found, the effectiveness of this research cannot be proven. It is not feasible to track the correlation between suggestions offered through this research, those implemented, and the success of the center. There are a myriad of other factors that affect the success of the center that cannot be separated from the suggestions offered in this research. The following sections describe the progress of different activities.

7.1.1. AMDC Implementation

Implementation of the AMDC though slow has progressed significantly since its inception in June of 2002. Thus far, the center has generated strong support by the leadership team at RMS on an enterprise level. In addition, significant steps have been taken to build relationships with other stakeholders. The overlap in some of the stakeholders within Operations was addressed, where boundaries, roles, and responsibilities of each were defined. Eventually, the expectation is that some of the different groups will consolidate as each evolves to better match the company needs.

In early January 2003, the AMDC moved to its new location, sharing laboratory facilities with the Knowledge Center and collocated with Advanced Programs. The AMDC management has pitched the center's purpose and goals to leaders throughout Advanced Programs to generate awareness and acceptance of the need for manufacturing technology research.

The System Dynamics models developed were useful in relating the author's mental models and impressions of the organization to the leader's perceptions. Feedback received from these leaders clarified the model and simplified assumptions that the author had made. In general, management accepted that the current driver of all efforts within

RMS was product development and technology. It was agreed that the core competitive advantage of Raytheon lies in their ability to continually innovate and develop new defense systems. In addition, the Director of Operations and the Director of Engineering are working to develop new metrics, incentives and accountability to encourage collaboration between the two communities on an enterprise level. The causal loop diagram has generated interest within RMS to use as a tool to help characterize mental models and causal relationships.

During implementation, a number of key issues surfaced that were unexpected. Primarily, within RMS it is important for a cost center to network in order to sell its service. Networking, particularly within hierarchical organizations, builds on pre-existing internal relationships that rely heavily on established trust and credibility. The center manager for the AMDC and the author were brought in from organizations outside of RMS. Outsiders enter an organization with no internal credibility and attempting to build a network and address internal issues is more difficult. Aside from establishing the AMDC, there are multiple efforts currently in place to improve the performance of RMS on different levels. Raytheon Six Sigma projects are receiving constant attention to encourage all employees to become involved. Also, the supply chain has undergone a significant reorganization to establish better management and control and reduce costs throughout the value stream. Finally, there are a number of 'Design for X' programs, such as manufacturing, six sigma, assembly and so forth, in use to improve current product development designs.

In the beginning of the research project, the author proposed an implementation roadmap that outlined a timeline of different steps needed to implement the center. The roadmap was based primarily on the three lenses analysis detailed in Section 4.3. The timeline was created to meet the internship timeline rather than to reflect the slow clockspeed of the defense industry. Networking, selling the idea and obtaining buy-in for the AMDC took much longer than anticipated. Generating research funds and identifying projects also took significantly longer than expected, preventing any theories from the operational model from being implemented and examined for effectiveness. In addition, facilities were not ready until the end of the internship, and the AMDC operated as a virtual organization mostly involved in planning during the course of the research.

7.1.2. Benchmarking Efforts

One of the main goals of this research was to benchmark companies in a number of different industries to capture best practices for manufacturing technology development and innovation. The benchmarking interviews were conducted to identify the major factors that companies believe affect the need for manufacturing innovation. It allowed the researcher the ability to understand the value that different companies placed on manufacturing research and its place within product development. Through those interviews, information was gathered to characterize the industries. The characterization resulted in identifying two industries that could be considered best in class, semiconductors and pharmaceuticals. The author submitted this information to RMS as potential and rather promising sites to gather best practices.

As was briefly mentioned, the author's attempts to arrange site visits at companies within these industries proved difficult. Unfortunately, no companies were visited during the course of this research. However, it is still in the best interest of the AMDC to continue to research other companies, form relationships, and arrange site visits at other companies.

7.1.3. AMDC Operational Model

The Operational Model developed for the AMDC encompassed a significant portion of this research. To a large degree, the model depends on the center's ability to reach a steady state after the implementation and acceptance have occurred. At the end of the research project, a number of distinct portions of the model were under development. A Manufacturing Technology Committee was being established. Key individuals throughout the enterprise were being identified that fit the description outlined in Section 6.2.1. In addition, the author was charged with creating a Manufacturing Technology

Roadmap. General details of the roadmap are included in Section 6.2.2. RMS and AMDC leaders accepted the need to think strategically about development projects and investments and were focusing on long-term plans for the center.

7.2. Follow-up

The focus of this thesis was to address the management of technology as well as implementing organizational change as they pertained to manufacturing innovation. The research matched the specific needs of this particular project within RMS. Additional research is recommended to prove the theories presented in this thesis and extend the application of these theories outside of the defense industry. This section also presents additional suggestions for RMS to follow

7.2.1. Research Follow-up

While the author's time at the company was limited, future efforts should be made, either by subsequent LFM students interning at RMS or by existing RMS management, to evaluate the effectiveness of the implementation efforts and the operational model. As time progresses, additional academic research will be available that studies the development of manufacturing technology, as it is a relatively young field. It is unlikely that a magic methodology will be developed that solves the problems of manufacturing innovation. Instead, research on manufacturing technology development work will likely result in similar generalities for effective product development.

One of the major challenges on manufacturing innovation is the strategic implication that must be considered. Research on strategy, such as how to evaluate potential projects for development, how to evaluate projects in progress, how to set incentives and accountability to ensure collaboration and effective development, is needed. However, developing generic strategies for development will not lead to competitive advantages. Strategy research should focus on developing and understanding the different tools available as well as understanding the underlying implications of each. Within academia, strategy and organizational change are challenging fields to research, as it is difficult to differentiate between the outcome of a strategic decision and good or bad luck.

7.2.2. Company Follow-up

In particular, RMS and the AMDC should continue the benchmarking efforts that began with this research to create opportunities to find best practices for manufacturing innovation. In building relationships with other companies, RMS should identify their internal practices that could be shared as quid pro quo. Identifying best practices as well as the organizational structure and policies that facilitate and encourage their use is difficult to do without an established relationship at other companies. The most effective way to absorb critical information, particularly as it pertains to organizations and culture, is through first-hand experience; hence the need for benchmarking site visits.

Within RMS, subsequent efforts should focus on evaluating the success of the company. Developing a model that describes the current operation of the center would allow management to compare it to the operational model developed in this research. Any discrepancies between the two should be evaluated to determine if the operational model should be updated or if the center's policies should be modified to ensure the effective development of new manufacturing technologies. Particular attention should be paid to the current decisions that are made as temporary solutions to ensure that they do not result in a status quo that prevents optimal manufacturing innovation. It is the inherent beliefs that have led to the current gap between product and process development and only with diligent management efforts to change those beliefs will the entire product development process be improved.

In addition, the AMDC can be used as a training and experiment facility for ways to improve the product development methodology throughout the enterprise. In particular, the AMDC's emphasis on collaborative development can be used to test changes to the organizational structure and culture to encourage and facilitate product development. Lessons learned from technology development within in the center should be disseminated across the entire company. If the culture can be changed among a subset of employees, they can encourage change within their respective organizations thereby improving the entire product development process at RMS.

7.3. Chapter Summary

It is the author's belief that the theories and research presented in this thesis will facilitate the implementation and development of the AMDC to allow Raytheon to meet the changing customer needs. Along with the author, it is the belief of RMS leaders that effective development of manufacturing innovation will improve the overall product development methodology within the company resulting in the development of improved systems within shorter time frames and at lower developments costs. These results are all crucial for Raytheon to remain competitive in the new defense era of Better, Faster, Cheaper.

As industry and customer needs are constantly changing, companies such as Raytheon should be aware of changes in industry and the competitive environment to ensure that they are prepared to evolve as is needed to remain competitive. In addition, the AMDC, its operational model, as well as its strategies and policies should be continually evaluated and improved upon so that a dynamic best practice of process development exists and can be shared throughout Raytheon's business units.

This page intentionally left blank.

References

Ancona, Deborah G. and David F. Caldwell. "Bridging the Boundary: External Activity and Performance in Organizational Teams." *Administrative Science Quarterly*, 37, no. 4 (Dec, 1992) 634-665.

Boeing F15 Fact Sheet. Accessed February 2003. Available on http://usfighter.tripod.com/f15.htm.

Boeing F15K Fact Sheet. Accessed February 2003. Available on http://www.boeing.com/defense-space/military/f15/f-15k/f15kfacts.htm.

Boeing F22 Fact Sheet. Accessed February 2002. Available on http://www.boeing.com/defense-space/military/f22/f22_back.html.

Boston History Collaborative 2002 History Makers Award. Accessed November 2002. Available on http://www.raytheon.com/feature/hma/index.html.

Clark, Kim B. and Takahiro Fujimoto. *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*. Boston: Harvard Business School Press, 1991.

Department of Defense - Defense Advanced Research Program Agency, DARPA. Accessed July 2002. Available on www.darpa.mil.

Department of Defense, "Operation of the Defense Acquisition System," *Defense Acquisition University*, October 30, 2002. Accessed on November 2002. Available in http://dod5000.dau.mil.

Department of Defense Manufacturing Technology Program, ManTech. Accessed November 2002. Available on www.dodmantech.com.

Ebadi, Yar M. and James M. Utterback. "Effects of Communication on Technological Innovation." *Management Science* 30, no. 5 (May, 1984): 572-585.

Ettlie, John E. and Ernesto M. Reza, "Organizational Integration and Process Innovation," *The Academy of Management Journal* 35, no. 4 (Oct 1992): 795-827.

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

Gertler, Meric S. "'Being There': Proximity Organization, and Culture in the Development and Adoption of Advanced Manufacturing Technologies." *Economic Geography* 71, no. 1, Collaboration and Competition in Geographical Context (Jan, 1995).

Hatch, Nile W. and David. C. Mowery. "Process Innovation and Learning by Doing in Semiconductor Manufacturing." *Management Science* 44, no. 11 (Nov 1998): 1461-1477.

Hayes, Robert H. and Steven C. Wheelwright. *Restoring Our Competitive Edge: Competing Through Manufacturing*. New York: John Wiley & Sons, 1984.

Henderson, Rebecca M., Jesus Del Alamo, Todd Becker, James Lawton, Peter Moran and Saul Shapiro. "Perils of Excellence: Barriers to Effective Process Improvement in Product-Driven Firms." *Production and Operations Management* 7, no. 1 (Spring 1998), 2-18.

Henderson, Rebecca M. and Kim B. Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative Science Quarterly* 35, no. 1, (March, 1990), 9-30.

Hoover's On-line – Aerospace & Defense Sector. Accessed December 2002. Available on www.hoovers.com.

Hoover's On-line – Biotechnology Industry. Accessed on January 2003. Available on www.hoovers.com.

Hoover's On-line - Pharmaceutical industry. Accessed on January 2003. Available on www.hoovers.com.

Hoover's on-line – Raytheon Company profile. Accessed December 2002. Available on www.hoovers.com.

Hoover's On-line – Semiconductor Industry. Accessed on January 2003. Available on www.hoovers.com.

Hughes Aircraft History. Accessed on February 2003. Available on http://www.shanaberger.com/hughes.htm.

International Technology Roadmap for Semiconductors. Accessed October 2002. Available on http://public.itrs.net/.

Knight, Kenneth E. "A Descriptive Model of the Intra-Firm Innovation Process," *The Journal of Business* 40, no. 4 (Oct 1967), 478-496.

Kotabe, Masaaki and Janet Y. Murray. "Linking Product and Process Innovations and Modes of International Sourcing in Global Competition: A Case of Foreign Multinational Firms" *Journal of International Business Studies* 21, no. 3 (1990): 383-408.

Lockheed Martin Patriot Product Fact Sheet. Accessed November 2002. Available on http://www.lockheedmartin.com/factsheets/product187.html.

MIT Lean Aerospace Initiative. Accessed October 2002. Available on http://lean.mit.edu/.

Murman, Earll M., Mules Walton and Eric Rebentisch, "Challenges in the Better, Faster, Cheaper Era of Aeronautical Design, Engineering and Manufacturing," *Lean Aerospace Initiative*, September 2000. Accessed on August 2002. Available on http://lean.mit.edu/.

National Institute of Standards and Technology, NIST. Accessed January 2003. Available on www.nist.gov.

Nicol, Robert A. 'Design and Analysis of an Enterprise Metrics System.' MSM & MSCE, Massachusetts Institute of Technology, 2001.

Ancona, Deborah, Thomas A. Kochan, Maureen Scully, JohnVan Maanen, and D. Eleanor Westney. *Managing for the Future: Organizational Behavior & Processes.* Cincinnati: South-Western College Publishing, 1999.

Pisano, Gary P. *The Development Factory: Unlocking the Potential of Process Innovation.* Boston: Harvard Business School Press, 1997.

Pisano, Gary P. "Knowledge, Integration, and the Locus of Learning: An Empirical Analysis of Process Development," *Strategic Management Journal* 15, Special issue: Competitive Organizational Behavior (1994): 85-100.

Pisano, Gary P. "Learning-Before-Doing in the Development of New Process Technology," *Research Policy* 25 (1996): 1097-1119.

Pisano, Gary P. and Steven C. Wheelwright. "The New Logic of High Tech R&D." *Harvard Business Review* 73. no. 5 (1995): 93-105.

Raytheon Company. Accessed November 2002. Available on http://www.raytheon.com/businesses/.

Raytheon Company 2002 Annual Report. Accessed March 2003. Available on http://www.raytheon.com/finance/annrpt.html.

Raytheon Company 2002 Annual Review. Accessed March 2003. Available on http://www.raytheon.com/finance/annrpt.html.

Raytheon Company Internal Benchmarking Handbook, ed. September 2002.

Raytheon Company Intranet – Integrated Product Development System. Accessed October 2002. Not publicly available.

Raytheon Company Intranet - Six Sigma. Accessed October 2002. Not publicly available.

Rumsfield, Donald. Secretary of Defense, "Annual Report to the President and the Congress," 2002

Schein, Edgar H. *The Corporate Culture Survival Guide: Sense and Nonsense about Culture Change*. San Francisco: Josey-Bass, 1999.

Schroeder, Dean M. "A Dynamic Perspective on the Impact of Process Innovation Upon Competitive Strategies." *Strategic Management Journal* 11, no. 1 (Jan 1990): 25-41.

Senge, Peter M. *The Fifth Discipline: The Art & Practice of The Learning Organization.* New York: Currency Doubleday, 1990.

Sterman, John. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* Chicago: Irwin/McGraw Hill, 2000.

US Airforce Fact Sheet, F15E Strike Eagle. Accessed February 2003. Available on http://www.lakenheath.af.mil/Mission-history/F-15E.htm.

US Centennial of Flight Commission – The Hughes Companies. Accessed February 2003. Available on http://www.1903to2003.gov/essay/Aerospace/Hughes/Aero44.htm.

Utterback, James M. *Mastering the Dynamics of Innovation.* Boston: Harvard Business School Press, 1996.

Van de Ven, Andrew H. "Central Problems in the Management of Innovation," *Management Science* 32, no. 5 (1986): 590-607.

Van de Ven, Andrew H. and Douglas Polley, "Learning While Innovating," *Organization Science* 3, no. 1 (Feb 1992): 92-116.

Wall Street Journal profile of Raytheon Company. Accessed November 2002. Available on www.wsj.com.

Webopedia, on-line encyclopedia. Accessed January 2003. Available on http://www.webopedia.com/TERM/M/Moores_Law.html.

Webster, A. and V. Swain. "The Pharmaceutical Industry: Towards a New Innovative Environment," *Technology Analysis & Strategic Management* 3, no 2 (1991), 127-142.

Wheelwright, Steven C. and Kim B. Clark. "Competing Through Development Capability in a Manufacturing-Based Organization" *Business Horizons* (July August 1992): 29-43.

Whitney, Daniel H. and Charles Fine. "Is the Make-Buy Decision Process a Core Competence?" MIT Center for Technology, Policy, and Industrial Development (1996).

Porter, Michael. *Competitive Advantage: Creating and Maintaining Superior Performance.* New York: Free Press, 1985.

Ettlie, John E. and Ernesto M. Reza, "Organizational Integration and Process Innovation," *The Academy of Management Journal* 35, no. 4 (Oct 1992): 795-827.

This page intentionally left blank.

Appendices

A. System Dynamics

"System dynamics is a method to enhance learning in complex systems. Just as an airline uses flight simulators to help pilots learn, system dynamics is, partly, a method for developing flight simulators, often computer simulation models, to help us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies."[162] People have a tendency to increase the complexity of systems to a level that no one person can absorb, demystify, or manage let alone accelerate change. "All around us are examples of 'systematic breakdowns'... organizations breakdown, despite individual brilliance and innovative products, because they are unable to pull their diverse functions and talents into a productive whole."[163] Complicating the matter further, individuals often understand only a portion of the system and create mental models of that world to simplify it into a manageable size.

Causal Loop diagrams are, in effect, the first phase of System Dynamics models. A causal loop diagram is a way to visually document mental models of how a system operates. For example, the diagram below is a causal loop diagram denoting a simplified system of chicken population.

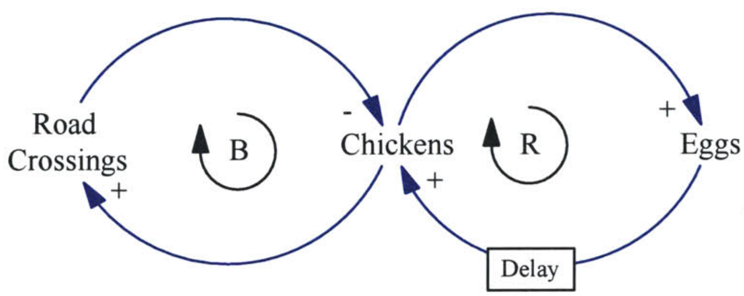

Figure 16 Causal Loop Diagram – Chicken Population[164]

---

[162] Sterman, pg 26.
[163] Senge, pg. 69
[164] Sterman, the Chicken system example is taken from the book and lectures for its simple approach to illustrating the basics of causal loop diagrams.

The primary variable in the system is the number of *Chickens*. The two variables that affect the number of *Chickens* in the system are the number of *Eggs* in the system as well as the number of times chickens attempt *Road Crossings*. The arrows denote that a variable influences a subsequent variable in either a positive or negative way. The left loop can be verbalized in the following manner. The more *Chickens* there are in the system, the higher the overall number of *Road Crossings* that will be attempted. Of those *Chickens* that attempt to cross the road, a percentage of them will meet untimely deaths at which point the overall population of *Chickens* will decrease. Conversely, if there are fewer *Chickens* in the system, the number that will attempt to Road Crossings will decrease and the *Chicken* population will not be affected by accidental deaths. In this system, the left loop is a balancing loop, denoted in the center of the loop with a B. In other words, there is a natural balance to the system, a steady state that prohibits the radical growth or complete demise of the number of *Chickens*.

The right loop in this causal loop diagram shows that an increase in the number of *Chickens* will result in an increase in the number of *Eggs* in the system; more chickens lay more *Eggs*. As *Eggs* hatch, they will increase the size of the *Chicken* population. Conversely, if there are fewer chickens in the system, due to an unforeseen event such as an automobile plowing into the henhouse, there will be a reduction in the number of *Eggs* laid and consequently, a further decrease in the number of *Chickens*. Another factor in the system is *Delay*, a time lapse between a change in one variable and its influence on the next variable. In this case, there is inherently a natural gestation period that limits the rate at which *Eggs* are converted into *Chickens*. The right loop is a reinforcing loop, denoted in the center of the loop with an R, since whatever condition exists will be reinforced until either the *Chicken* population explodes or is eliminated.

Given that this is a relatively simple system, it is intuitive that the right loop dominates the system behavior (assuming that there are significantly fewer *Chicken* deaths due to *Road Crossings* than *Eggs* hatched). In this particular case, the steady state of the system relates to the stable population growth rate. If the only reduction in the number of *Chickens* occurs by their futile attempts to cross the road, then the population will increase as *Eggs* are continuously laid and grow up to be *Chickens* that lay more *Eggs*. In order to grow the *Chicken* population more efficiently, attempts should be made to increase the strength of the dominant loop; increase either the rate at which the *Egg* population grows or increase the speed with which they hatch and become *Chickens*, all within natural system limits.

B. Manager Level Causal Loop Diagram Description

The causal loop diagram describing the response to the implementation of the new center at the managerial level is shown in **Figure 10**. Section **4.4.2** described how the various balancing and reinforcing loops interacted within the entire system. The primary focus of the manager level causal loop diagram is the implementation of the new center. For this research, the new center specifically denotes the AMDC and involves the pursuit of manufacturing innovation early in development that requires additional resources and attention by management. The term 'new goals' is used to generalize the model to include other initiatives that a company may undertake. For the AMDC, the identification and mitigation of manufacturing risks are the new goals. Similarly, new tasks and risks are new projects that are started to pursue the new goals. It is important to distinguish manufacturing innovation *projects* with product development *programs* for this model. This appendix will expand upon each loop, highlighting the principal behaviors of each parameter.

B1 Pursuit of New Goals Initially Decreases Program Performance

With the introduction of a new center, more resources must be allocated to pursue the new goals and are therefore diverted from traditional development. As fewer resources are allocated from traditional development, it becomes more difficult to meet program requirements and program performance suffers, consequently there is less support of the new center.

B2 Pursuing New Goals Decreases Perception of Manager's Capabilities

As the center is introduced and resources are allocated, it is more likely that tasks and risks will be identified. As more risks are highlighted, the perception of program performance and that of the manager's competence decreases leading to decreased support for the new center.

B3 Redirecting Resources Minimizes Control

As resources are allocated to pursue new goals, there is decreased management control over resources leading to decreased level of management's control. As control decreases, there is more resistance to change that leads to decreased support of the center.

B4 Greater Scope Reduces Control

Similar to loop **B3**, the implementation of a new center and pursuit of new goals increases the scope of the program and decreases a manager's control over the direction of development, leading to a further decrease in management's overall control.

B5 Resistance to More Work

As the program scope increases, the manager's level of responsibility and workload also increases leading to added complexity. More work complexity reduces the manager's available time to fulfill all of the new responsibilities leading to added frustration and decreased support of the center.

B6 Manager's Personal Drive*

As work complexity increases, the type of work manager's face becomes increasingly challenging. The additional degree of challenge triggers a manager's drive to meet the challenge leading them to get exposed to the new work and gain experience. As manager's gain experience over time, they develop a new skill set that decreases the complexity and consequently the challenge of the work. This loop, although it encourages the establishment of the new center and the pursuit of the new goals, is a balancing loop because there is a steady state in the level of the work complexity a manager is comfortable with. In effect, manager's will seek to balance work complexity with challenge as there is only a certain amount of work complexity that will trigger the drive to overcome the challenge before the managers become complacent and, in this case, become opposed to the new workload and center.

R1 Efficiencies Allow Managers to Redirect Funds as Necessary

Once tasks and risks are identified for the new center, they will eventually be resolved to reach the program goals. Over time as more tasks are resolved, teams gain more experience that, through learning, reduces the resources required and adds flexibility to the allocation of the program budget. Flexibility leads to a reduction in the amount resources are directed to pursue new goals and triggers the reversal of initial balancing loops described earlier.

R2 Learning that Improves Project Cycle Time

As more risks are resolved and teams gain experience, learning results in a reduction of the time required to complete tasks and consequently more risks can be addressed.

R3 Learning that Improves Resource Efficiency

Similar to **R2**, experience and learning eventually leads to a reduction of resources required for each task thereby allowing more tasks to be identified. Efficiency leads to more risks being resolved within a shorter timeframe.

R4 After Time, Program Performance Improves

As risks are addressed, program performance improves leading to support of the new center. This loop represents the validation and credibility that must be built to demonstrate the benefits of manufacturing innovation and gain support for the AMDC.

R5 Support from Management Facilitates the Internalization of Goals

Support from management builds on their desire to contribute and adds to their level of experience with the new type of work. Eventually, experience leads to an increased ability of managers to facilitate and support the efforts of manufacturing innovation teams. As teams receive more support, they gain more experience leading to increased program performance.

R6 Positive Attitude Eases the Change Process

A manager's desire to contribute, leads to additional experience and an eventual reduction in frustration resulting in support of the center. A positive attitude facilitates a manager's response to the implementation of the new center.

R7 Sharing Information Reduces Resistance

Active participation during implementation leads to a freer flow of information and trust between the AMDC and different stakeholders. As trust is increased, the level of chaos and uncertainty caused by change is decreased resulting in an increase to the manager's level of control over their environment.

R8 Stakeholder Involvement Increases Support

If the center's introduction involves generating active participation by the stakeholders it leads to obtaining their support. Stakeholder support leads to collaboration on the center implementation where the stakeholders lead change and thereby acquire control over the direction of development.

R9 Learning that Increases Competence

With the introduction of a new center, there is an inherent desire for managers to contribute to the new initiative. This desire allows individuals to gain experience with the new type of work. With experience and time, new skill sets can be developed that reduce the work complexity, expand upon the available time, reducing the initial levels of frustration and leading to support of the new center.

C. Employee Level Causal Loop Diagram Description

As described in Section **4.4.3**, a causal loop diagram was developed to understand the response of change at the employee level. The diagram is shown in **Figure 11**. The primary driver of the model is the introduction of a new initiative that attempts to combine to some degree the engineering and operations communities. For this research, the new initiatives are manufacturing innovation projects with the AMDC. Similar to Appendix C, the behaviors of the balancing and reinforcing loops of the employee level diagram will be expanded in this appendix.

B1 Belief that Pure Design Focus Will Satisfy Customer

The mental model of the engineering community is that meeting program requirements leads to an increase in customer satisfaction and a reduction of external pressures to meet the requirements. If engineers focus exclusively on designing the product without other considerations such as manufacturing, the status quo belief is that program requirements of technology and performance will be met. If there are no added external pressures from the customer, management's desire to influence development to alter the status quo decreases and there are consequently no internal pressures to meet additional requirements. Without additional internal pressures on the engineers above their existing commitments, frustration levels are relatively low. The balancing factor in this loop occurs when a steady state is reached, i.e. engineers find a balance between the extent to which they focus on the design aspects of the program and their level of frustration.

B2 Management's Indirect Bias Against New Initiative

A manager's bias to continue pursuing technological development leads to the establishment of incentives that encourage a focus on design. With no external pressures to alter product development, engineers are measured on their ability to complete the design further encouraging the status quo.

B3/B5 Increase in Engineering/ Operations Workload Discourages Support

Similar to what managers experience with new work, a new initiative increases the workload of all employees. A higher workload results in a reduction to the time and resources available to address all tasks. Fewer time and resources leads to an increase in frustration that encourages employees to reduce their workload and return to address the type of tasks in program development before the new initiative was introduced. Consequently, there is a decreased support of the initiative by the employees.

B4 Bias Toward Design Results in Reduced Resources for Operations

Although loop **B1** shows a balancing loop that encourages the status quo, eventually the engineering schedule slips since other factors in program development are ignored. As the schedule slips, additional resources are required by the engineering community that are consequently increased to meet program requirements. Resources are diverted from engineering to operations resulting in an increase to the level of frustration by employees within operations. As mentioned earlier, as frustration increases, employees tend to focus on their previous workload, resulting in decreased support of the new initiative.

R1/R6 Learning Curve Effects in Engineering/Operations

With time and experience, employees can garner the benefits of learning, thereby reducing the time and resources required to complete tasks and decreasing the level of frustration. As frustration is reduced, there is a shift in the steady state of balancing loops **B1** and **B2** and the exclusive focus in design is reduced.

R2 Long-Term Customer Dissatisfaction from Pure Design Focus

As designs are thrown over the wall to production to meet program requirements, there is the increased possibility of subsequent engineering changes flowing to operations to further enhance program performance and technology. More engineering changes late in the development stage eventually results in a decreased ability by operations to meet other program requirements such as cost and delivery timeline. Not meeting requirements results in decreased customer satisfaction leading to external pressure for the company to meet those requirements. External pressure from the customer leads managers to alter the course of development and generate internal pressure for employees to meet the requirements. Increased pressure leads to an increase in frustration and alters the steady state of the balancing loops **B1** and **B2**, leading eventually to increased support of collaborative initiatives.

R3/R5 Collaborative Work Improves Engineering's/Operations' Contribution to Product Performance

As employees support the new initiative, they are eventually able to build their skill set so that other issues are addressed during development - leading to more collaborative work and the elimination of designs being thrown over the wall. As collaboration increases, fewer changes are needed in later stages of development and customer requirements are consistently met, thereby improving the overall product performance.

R4 Accountability Leads to Initiative Support

As employees develop new skill sets, their ability to contribute to collaborative work also increases. Introducing accountability into the current system is an external factor that prevents designs from being thrown over the wall and generates incentives leading employees to support the new initiative.

D. Quantitative Benchmarking Questionnaire

Raytheon

Title: **Manufacturing Development Benchmarking Study (Blinded)**

To: **Study Participants**

Date: **01/06/03**

Knowledge Transfer & Benchmarking Office

Bill Baker
Raytheon KT&B Champion

Barbara Newell
Raytheon Benchmarking Coordinator

972-344-0400

When we benchmark, we search for best methods, practices, and processes. Our goal is to adopt or adapt the best features of a process or practice and to implement those best features in our own process to produce the "best of the best."

Manufacturing Development Benchmarking Study

Table of Contents

Manufacturing Development

Benchmarking Study

Scope:

To understand how leading companies approach advanced manufacturing technology and development.

Contact/sponsor of the study: Raytheon Operations

Study Schedule:

The schedule was established and required an approximate three-week turnaround. The schedule is shown below.

Manufacturing Development Benchmarking Study Schedule – 2002

	Nov				Dec			
	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4
Kickoff			▲					
Submitted survey tool			▲					
Obtained survey tool approval			▲					
Collect data			▲	—	—	▲		
Analyze data							▲	
Project completion							▲	

Responses:

We received responses from the following companies:

Raytheon, plus five high technology companies.

Findings:

Question 1: All five respondents did not rate themselves highly (all rated 5 of 10 points) on integration of manufacturing with product development cycle – including Raytheon.

Question 2: Manufacturing capabilities were rated high by:

Company	Rating
Company B	9
Company A	9
Company D	8
Company F	8

Question 3: Four of five respondents have active, cutting edge manufacturing technology approaches:

Company B	Company D
Company C	Company F

Question 4: Company B is the only "new comer" to advanced manufacturing technologies – 3 years.

Question 5: All respondents rated themselves above average on their company's ability to develop and implement new processes (ratings of 6 to 8 on the 10 point scale).

Question 6: Some companies require "manufacturing capability verification" on all new products:
- Company B
- Company E

Question 7: All companies but Company E utilize a Technology Roadmap:
- Company B
- Company C
- Company D
- Company F
- Company A

Question 8: Raytheon is the lowest ranked on the actual use of Technology Roadmaps!

Company	Rating
Company B	8
Company F	6
Company C	5

Company A	2

Question 9: Most companies have standard processes to develop and fund "manufacturing technology and transition products to production."

Question 10: Organizationally, manufacturing development is:

Centralized in Operations	Decentralized
Company B	Company E
Company C	Company F
Company D	
Company A	

Question 11: Companies use design engineers and scientists in addition to manufacturing/industrial engineers.

Question 12: Depending on the organization – companies indicate hundreds of people involved in manufacturing technology development.

Question 13: Most companies "permanently assign" employees to manufacturing development. Only Company E and Raytheon "loan" employees.

Question 14: "Allure of challenging new technology" is the incentive for all respondents including Raytheon.

Question 15: All respondents funding comes from overhead pools except Raytheon (program funding).

Question 16: Funding from programs, product lines or platforms have options to support or provide funding requests.

Question 17: Funding profiles vary widely, but more commercial businesses (Company F, Company D, Company B) tend to provide more funding to products in development.

Question 18: Suggested Benchmarks:

Aerojet	By Company D
DuPont	By Company F
3M	By Company F
Kodak	By Company F

Question 19: All respondents except Company B are open to a more detailed discussion (teleconference or site visit).

Benchmarking Study Matrix:

Questions	Company A Raytheon	Company B	Company C	Company D	Company E	Company F
	Companies					
Are you answering for your:						
Company		X		X		X
Division						
Department	X		X			
Other					X Indiv	
1. On a scale of 1 to 10, how do you rate your company on integrating manufacturing within the product development cycle? (10=integral in all aspects, 1=completely separate)	5	5	5	5	5	5
2. How would you rate your company's ability to provide the manufacturing capabilities needed? (10=excellent, 1=poor)	9	9	7	8	5	8
3. Do ou actively develop new, advanced, or cutting edge manufacturing processes and technologies? Y/N	Y	Y	Y	Y	N	Y
4. How long has your company been actively/aggressively involved in developing advanced manufacturing technology capabilities? (in years)	20+	3	30+	50+		100
5. How do you rate your company's ability to develop new manufacturing processes and turn those into capabilities? (10=world class, 1=lagging industry)	8	8	8	7	6	8
6. To what degree are new products evaluated to identify critical manufacturing capabilities before they are transitioned into production?						
Evaluation required of all products		X			X	X
Evaluation of products recommended	X		X	X		
Evaluation would be useful but not currently done						
Evaluation isn't necessary						
7. Do you use a form of manufacturing technology roadmaps? Y/N	Y	Y	Y	Y	N	Y
8. If so, please rate to what extent you use the roadmaps to guide manufacturing development or investment. (10=used as an explicit plan, 1=used as a thinking exercise)	2	8	5	5		6
9. Does your company have a standard process for the following activities? (Please check all that apply)						
To transition products or components from design into production?	X	X	X	X	X	X
To develop new, advanced or cutting edge manufacturing technologies?		X	X	X		

Questions	Companies					
	Company A Raytheon	Company B	Company C	Company D	Company E	Company F
9. (cont.) Does your company have a standard process for the following activities? (Please check all that apply)						
To choose which technologies to invest in and develop?	X	X	X	X		
To evaluate the progress of development projects?	X	X	X	X	X	
10. What is the organizational structure surrounding manufacturing development and innovation?						
Group within the design community						
Group within operations or manufacturing	X	X	X	X		
Separate entity						
Decentralized, spread throughout the enterprise					X	X
11. What is the mix of skills of employees involved in advanced manufacturing technology development?						
Mostly design engineers					X	X
Mostly manufacturing or industrial engineers	X					
Mostly scientists		X				
Even balance		X	X	X		
12. How many employees are involved in advanced manufacturing technology development?	12	200	600	100	1	~500
13. When staffing advanced manufacturing technology development needs, which of the following best describes the process?						
Employees are loaned to a manufacturing development project as needed	X				X	
Employees are periodically rotated throughout different areas, including manufacturing development						
Employees are permanently assigned to manufacturing development efforts		X	X	X		X
Other, explain						
14. Which of the following best describes the most common form of incentives for employees to work on developing advanced manufacturing technology capabilities?						
Additional bonus/salary upgrade						
Allure of challenging new technology	X	X	X	X	X	X
Critical part of career path						X
Other, explain						
15. Where does the majority of funding for advanced manufacturing technology development come from?						
Internal, overhead investment		X	X	X	X	X
Programs, product lines or platforms	X					
External, customer investment				X		

Questions	Companies					
	Company A Raytheon	Company B	Company C	Company D	Company E	Company F
16. To what extent do programs, product lines or platforms invest in manufacturing development?						
All are required to invest a fixed amount		X				
As managers within those areas deem necessary	X		X	X		X
As suggested by other managers, leaders						
Not at all					X	
17. What percentage of manufacturing development funds are dedicated to each of the following:						
To support existing product lines?	80%	30%	70%	20%		60%
To support products in development?	10%	40%	20%	60%		30%
To develop new, advanced or cutting edge manufacturing technologies?	10%	30%	10%	20%		10%
18. Is there any one company that you consider as being a recognized leader in manufacturing technology development? Y/N	N	N	N	Y	N	Y
If so, which one?				Aerojet		DuPont, 3M, Kodak
19. Would you be willing to discuss your response in more detail in a teleconference or site visit? Y/N	Y	N	Y	Y	Y	Y

Survey Details:

Manufacturing Development
Benchmarking Study

Purpose/Scope of this Raytheon Benchmarking Study: To understand how leading companies approach advanced manufacturing technology & development.

Company/Organization Name:		
Street Address:		
City:		
State:		Zip:
Phone:		Fax:
Contact Name:		
Contact Email Address:		
Industry:		
Major Product or Service:		

Are you reporting for your: ☐ Company? ☐ Division? ☐ Department? ☐ Other?

1. On a scale of 1 to 10, how do you rate your company on integrating manufacturing within the product development cycle? (10 = integral in all aspects, 1 = completely separate efforts) _____.

2. How would you rate your company's ability to provide the manufacturing capabilities needed? (10 = excellent, 1 = poor) _____.

3. Do you actively develop new, advanced, or cutting edge manufacturing processes and technologies? ☐ Y ☐ N

4. How long has your company been actively/aggressively involved in developing advanced manufacturing technology capabilities? _____.

5. How do you rate your company's ability to develop new manufacturing processes and turn those into capabilities? (10 = world class, 1 = lagging industry) _____.

6. To what degree are new products evaluated to identify critical manufacturing capabilities before they are transitioned into production?
   - ☐ Evaluation is required of all products
   - ☐ Evaluation of products is recommended
   - ☐ Evaluation would be useful but currently isn't done
   - ☐ Evaluation isn't necessary

7. Do you use a form of manufacturing technology roadmaps? ☐ Y ☐ N

8. If so, please rate to what extent you use the roadmap to guide manufacturing development or investment. (10 = used as an explicit plan, 1 = used as a thinking exercise) _____.

9. Does your company have a standard process for the following activities? (Please check all that apply)
   - ☐ To transition products or components from design to production?
   - ☐ To develop new, advanced or cutting edge manufacturing technologies?
   - ☐ To choose which technologies to invest in and develop?
   - ☐ To evaluate the progress of development projects?

10. What is the organizational structure surrounding manufacturing development and innovation?
    - ☐ Group within the design community
    - ☐ Group within operations or manufacturing
    - ☐ Separate entity
    - ☐ Decentralized, spread throughout the enterprise

11. What is the mix of skills of employees involved in advanced manufacturing technology development?
    - ☐ Mostly design engineers
    - ☐ Mostly manufacturing or industrial engineers
    - ☐ Mostly scientists
    - ☐ Even balance

12. How many employees are involved in advanced manufacturing technology development? _____.

13. When staffing advanced manufacturing technology development needs, which of the following best describes the process?
    - ☐ Employees are loaned to a manufacturing development project as needed
    - ☐ Employees are periodically rotated throughout different areas, including manufacturing development
    - ☐ Employees are permanently assigned to manufacturing development efforts
    - ☐ Other, please explain _____.

14. Which of the following best describes the most common form of incentives for employees to work on developing advanced manufacturing technology capabilities?
    - ☐ Additional bonus/salary upgrade
    - ☐ Allure of challenging new technology
    - ☐ Critical part of career path
    - ☐ Other, please explain _____.

15. Where does the majority of funding for advanced manufacturing technology development come from?
    - ☐ Internal, overhead investment
    - ☐ Programs, product lines or platforms
    - ☐ External, customer investment
    - ☐ Other, please explain _____.

16. To what extent do programs, product lines or platforms invest in manufacturing development?
    - ☐ All are required to invest a fixed amount
    - ☐ As managers within those areas deem necessary
    - ☐ As suggested by other managers, leaders
    - ☐ Not at all

17. What percentage of manufacturing development funds are dedicated to each of the following:
    - _____% To support existing product lines?
    - _____% To support products in development?
    - _____% To develop new, advanced or cutting edge manufacturing technologies, tools & processes?

18. Is there any one company that you consider as being a recognized leader in manufacturing development technology? ☐ Y ☐N If so, which one? _____.

19. Would you be willing to discuss your response in more detail in a teleconference or site visit? ☐ Y ☐ N

We adhere to the IBC Benchmarking Code of Conduct and will share our information with you and include you in our blinded Final Report.

Raytheon Manufacturing Development Benchmarking - Bill Baker, Coach

Please return completed surveys by 13 December 2002, to:

Benchmarking Coordinator
Barbara Newell
e-mail: **b-newell1@raytheon.com**
Fax: 972-344-0405