Driving Cycle Time Reduction Through An Improved Material Flow Process In The Electronics Assembly Manufacturing Cell

by

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B.S. Management and Engineering for Manufacturing, University of Connecticut, 2007

SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT AND THE ENGINEERING SYSTEMS DIVISION IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF MASTER OF BUSINESS ADMINISTRATION

AND

MASTER OF SCIENCE IN ENGINEERING SYSTEMS
IN CONJUNCTION WITH THE LEADERS FOR GLOBAL OPERATIONS PROGRAM AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2012

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division on May 11, 2012 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Engineering Systems

Abstract

Many companies have implemented lean and six sigma programs over the past twenty years. Lean has been a proven system that has eliminated waste and created value at many companies throughout the world. Raytheon IDS's lean program, "Raytheon Six Sigma" became a top priority in the past ten years at the Integrated Air Defense Center (IADC) in Andover, MA. However, as Raytheon's corporate goals state, they want to take this further and bring "Raytheon Six Sigma" to the next level, fully engaging customers and partners.

A focus of this continuous improvement effort was the Electronics Assembly Rack manufacturing cell, which was experiencing high levels of cycle time variability. To help reduce cycle times within the cell, a continuous improvement project was undertaken to improve the material flow process. A current state analysis of the process showed an opportunity to improve process standardization and prioritization while lowering inventory levels. In addition to working with managers from EA to evaluate the material flow process, a kitting cart was developed with a cross functional project team to serve as a tool to help improve the process. Although the improvements were not rolled out to the entire cell during the project, a successful pilot was conducted that helped improve engagement with operators and create a path for future success.

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Acknowledgments

First, I would like to thank my LGO classmates. They have been an incredible support network and have made the entire two year experience a complete joy.

Second, I would like to thank the people I worked with at Raytheon, especially Mike and Justin, who helped frame my thinking and kept my project marching forward throughout the six months.

Finally, I'd like to thank friends and family for always being supportive of my commitment to ongoing education through the Leaders for Global Operations program.

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1 Background

This chapter will establish a background for the focus of a six month internship completed at Raytheon IDS as part of the graduation requirements for the Leaders for Global Operations program at MIT. The internship took place within the Electronics Assembly (EA) Rack cell at the Integrated Air Defense Center (IADC) in Andover, MA and focused on improving the material flow process within the cell. This section begins with a background on the larger defense industry and then a deeper dive into the specific cell where the internship took place. In addition, section 1.4 discusses a previous internship completed in the EA Rack cell by Tauber Michigan MBA students and some of the challenges the area has faced after completion of that project.

1.1 Industry Overview

Raytheon is part of the Aerospace and Defense industry. Per the 2009 Stockholm International Peace Research Institute, Raytheon was the sixth largest arms producer in the world as seen below in Table 1 (The Stockholm International Peace Research Institute, 2009).

Rank	Company	Country	Arms Sales ($ Millions)
1	Lockheed Martin	USA	$ 33,430
2	BAE Systems	UK	$ 33,250
3	Boeing	USA	$ 32,300
4	Northrup Grumman	USA	$ 27,000
5	General Dynamics	USA	$ 25,590
6	Raytheon	USA	$ 23,080
7	EADS	Europe	$ 15,930
8	Finmeccanica	Italy	$ 13,280
9	L-3 Communications	USA	$ 13,010
10	United Technologies	USA	$ 11,110

Table 1: Top ten defense companies globally, by 2009 sales

During the 1990's the US government drove a major consolidation of defense contractors from over 100 small, medium and large companies down to five major contractors. Raytheon, Boeing, BAE, Northrup

Grumman and Lockheed Martin make up the five and have considerable power and control in the market. When small firms grow, they are often bought by the big five, ensuring their long term survival. Given this dynamic supported by the US Government, the defense industry experiences less intense competition than other industries. This helps explain some of the resistance and skepticism to change discussed further in Chapter 5 (Chao, 2005).

The current market environment for defense contractors is one of War. The US has major conflicts in Iraq, Afghanistan and smaller operations in several other countries. Pierre Chao, Director of Defense-Industrial Initiatives at the Center for Strategic and International Studies hypothesized that, "In war, schedule matters, and performance and especially cost matter less" (Chao, 2005). However, performance is valued above all else at Raytheon, as evidenced by their technology focused vision statement: "To be the most admired defense and aerospace company through our world-class people, innovation and technology." Within EA, however, schedule was equally important, as they were behind schedule on the Patriot program. This pressure resonated with the front line more as it is a challenge for the operators to understand how their day to day decisions affect high level costs changes.

1.2 Company Overview

Raytheon is a global technology and innovation company that specializes in defense, homeland security and other government markets throughout the world. Raytheon has over 72,000 employees worldwide and generated revenues of $25 billion in 2010. The global headquarters is in Waltham, MA. There are six divisions that make up Raytheon including Integrated Defense Systems (IDS), Intelligence and Information Systems (IIS), Missile Systems (RMS), Network Centric Systems (NCS), Space and Airborne Systems (SAS), and Technical Services (RTS).

The project took place in IDS, which is headquartered in Tewksbury, MA. In 2010 IDS had sales of over $5.5 billion with 14,800 employees worldwide. Raytheon IDS is responsible for over 1,300 contracts at 19 mission centers across the globe. Its main domestic customers include the US Missile Defense

Agency, the US Armed Forces, and the Department of Homeland Security. In addition, it serves a number of international customers including Saudi Arabia, United Arab Emirates (UAE), Taiwan and Japan. Due to restrictions on the use of the latest technology for international contracts, products need to be reengineered to meet different contract demands. This adds increased complexity to the supply chain for manufacturing cells, which handle production for multiple countries.

1.3 Facility Description

The project took place in Andover, MA at the IADC. The main program involved in the project was the Patriot Missile Defense system for the Army. Due to new demand from the United Arab Emirates and Taiwan, the program has recently expanded and is dealing with the challenge of ramp up after the line had been shut down for several years.

1.4 Electronics Assembly (EA) Description

EA is a high mix, low volume cell broken up into six sub-cells: Rack, Power Supply, Cabinet, Exciter, Transmitter, and Whole Life. The internship focused primarily on the Rack cell. The supply chain process of the area is incredibly complex, as it supplies multiple programs and receives material through multiple feeder areas and distribution centers. A dedicated distribution center within IADC, the Fabrication and Materials Distribution Center (FMDC) serves as the last stop for much of the material that is supplied to EA, however there are many exceptions and many parts and materials are delivered directly to EA from outside areas.

1.5 FMDC Area Description

Although under different management, the FMDC area is closely tied to the success of EA.

FMDC reports through the logistics group which reports through the supply chain function. The basic process begins when someone in EA "cuts" or releases a kit in the system. This is usually done long before a product would theoretically be due because of limited knowledge of actual lead times. FMDC commits to a 5 day lead time, though this is not achieved for all parts, with actual lead time being wildly variable. As soon as FMDC starts kitting the parts for the assembly, the part is "owned" by EA and the lead time by which EA is measured would begin. When the kit is complete, there are certain parts that need to be stenciled. Stenciling is a process where markings are added to metal parts. This is a separate area staffed with two operators, but managed by FMDC. The process then calls for the complete kit to recombine in the FMDC area and be sent to the floor to be placed on a rack marked for incoming parts. However, sometimes the incoming rack is completely full of parts and the material handler will place the part wherever there is space. There is no system to notify EA cell leads when these assemblies arrive in EA, making it difficult for them to gage when parts have arrived and in what order.

FMDC measures itself based on its own manual records of cycle time in an excel spreadsheet (discussed more in the next section). It only counts the time when it starts kitting the part until the specific parts are sent to be stenciled.

1.6 Organizational Structure

The organizational structure at Raytheon IDS is the typical matrix type organization that you find within most large companies. Two key functions relevant for this thesis, operations and supply chain, are very distinct, powerful and separate organizations. As seen below in the simplified organization chart (Figure 1), this division begins at the top of the company and continues down to the lower layers of the organization.

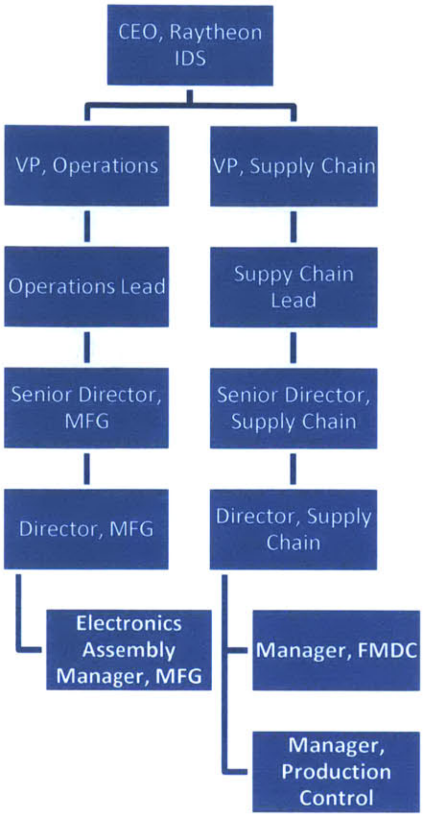


Figure 1: Simplified Organizational Chart

A major challenge within this organization is the fact that the lower level managers and front line leaders from different functions must make day to day decisions. This means operations cell leads, operators and managers are working together with a production control manager and multiple managers responsible for kitting in FMDC.

As is seen in many matrix organizations, each function has its own distinct goals and metrics making it challenging for cross-functional teams to agree on which metric to maximize or minimize. An example of the mismatch of incentives is the fact that EA is measured on the lead time of the assemblies it produces. This includes the time when an assembly begins the kitting process in FMDC. However, FMDC is only measured on the time it takes to complete the kitting process and the number of parts it is able to kit per day. These different metrics would be fine if both areas are aligned on what to produce, in what order, but they are not. This leads both areas to maximize locally, while not sharing the same ultimate goals of doing what is good for the business. This is discussed in more depth in Chapter 4.

1.7 Tauber Project, Summer 2010

This internship and thesis was a follow-up to a project completed by two University of Michigan Tauber Business School interns in the summer of 2010. Their project focused on implementing lean principles in the design and setup of the EA Rack cell to handle a large increase in demand due to the UAE Patriot contract. Prior to this, the cell only had a few operators helping satisfy demand for spare and replacement parts. The team designed the ideal state cell based on future demand. They used historical cycle times and divided the cell into multiple product lines.

The project was a success in the initial roll out, but struggled to achieve the predicted improvement of 30% overall decrease in cycle time (not including FMDC's component of the cycle time) when production ramped up in the fall and winter of 2010. A number of issues limited the potential improvement that the project was able to achieve:

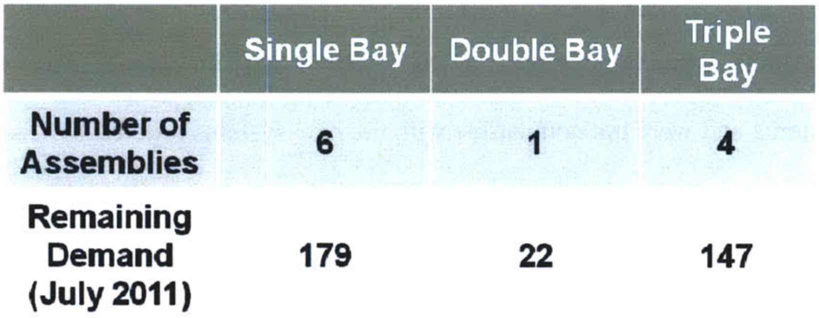
1. **Upgraded product:** A number of the parts that were in production were replacement parts for old Patriot systems and were not compatible with the new systems ordered by UAE. Thus, a lot of engineering work had to be done up front to change the design. As demand shifted from engineering to manufacturing, EA faced further challenges as it progressed on its learning curve, as new processes and technology were introduced into the design.
2. **Supplier quality**: Given that may of the products were first time build, this also meant that suppliers had to invest in their own engineering resources to upgrade their past products or to develop new ones. Supplier quality issues were a major issue in the initial production ramp up and a lot of time had to be spent working with them to receive parts that met specifications.
3. **Front line challenges:** With increased complexity of the product and supplier challenges, cell leads and other front line support staff spent a lot of time working on those issues. They did not

have the extra capacity to focus on improving the cell design or process. Pressure was on front line supervisors to meet strict delivery dates and most people within the business unit worked overtime or extra hours to work towards that goal.

1.8 EA Rack Assembly Cell Description

This internship took place under the direction of the manager of the EA Rack manufacturing cell. At the time of the internship, the cell staffed 40 front line operators on two shifts (1st and 2nd) who build, test and inspect the various assemblies. The cell runs 12 shifts a week, 2 every weekday and 1 each on Saturday and Sunday.

EA Rack is a low volume-high mix environment within EA with over 700 possible assemblies that feed multiple programs, with the majority of the volume feeding Patriot programs. However, this internship focused on 11 unique assemblies, which make up the majority of the current volume in the cell. Table 2 shows the three types of assemblies as well as the remaining demand (in units) for each of the products:



	Single Bay	Double Bay	Triple Bay
Number of Assemblies	**6**	**1**	**4**
Remaining Demand (July 2011)	**179**	**22**	**147**

Table 2: Breakdown of major assemblies built in EA Rack

An example of a double bay rack is seen in Figure 2:

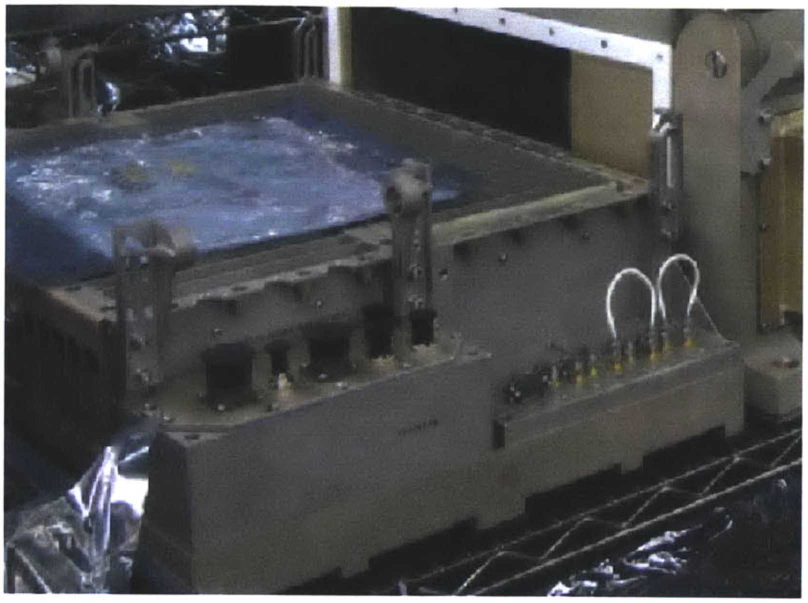


Figure 2: Double bay rack assembly made in the EA rack area

There is a general process for the single, double and triple bay racks that can be seen as outline in Figure 3 below. Each assembly starts out as a "naked" rack and then becomes a "loaded" rack near the end of production. The main difference between the two designations is the addition of a circuit card assembly, installation of covers and final touch up and inspection. Green signifies the start of the process, blue boxes show production, orange shows inspections and purple shows tests:

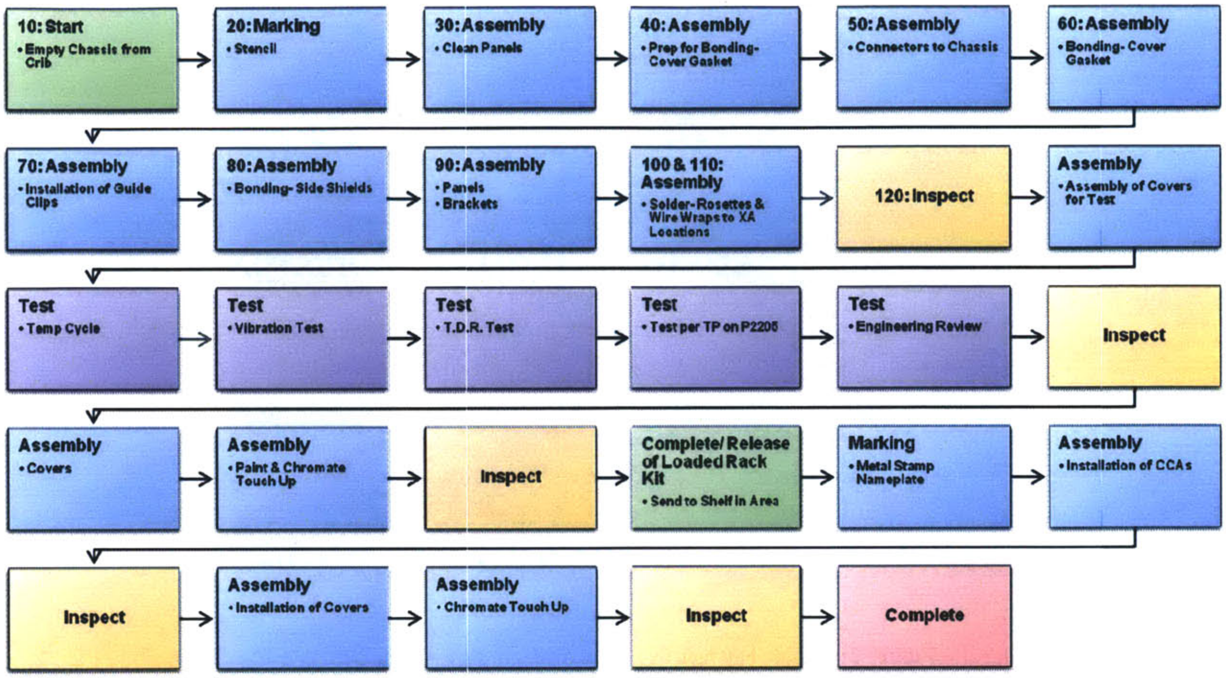


Figure 3: General Build Process for Single, Double and Triple bay racks

The nature of the work is very similar to a job shop, where individual operators typically work on one assembly throughout the entire build process. At the beginning of the day, operators go to a bench where they typically work every day. There is a system in place so that operators can work at any bench, but this does not happen. After that a cell lead assigns each operator assemblies to work on based on part availability or what they had been building previously. The operator will work on that assembly until the end of the shift, until it is completed or until there is a part shortage or rework required. At the end of the shift, the operator will move the assembly to the appropriate storage rack: work in process, waiting for parts, or ready for inspection. Although there is clear marking for different areas such as incoming, waiting for parts and work in process, operators are unable to follow this process due to a lack of space and will either keep the assembly on a moveable cart or on their bench.

Given the low volume, high mix nature of the cell, production is performed using a batch process, treating each assembly as unique, which in turn drives inefficiency and opportunities for improvement.

1.9 Chapter Summary

This chapter has outlined background information on the defense industry and how Raytheon fits within that industry. In addition, a deeper dive into the processes and current status of EA, FMDC and EA Rack cell were presented.

The rest of this thesis will cover the improvements in EA Rack that attempted to build on the successes and opportunities of the University of Michigan Tauber project from 2010, as covered in section 0.

1.10 Thesis Overview

This thesis will outline the internship project focused on improving the material flow process of the EA Rack cell. The following chapters will help create background, context and analysis of the attempted improvements.

- **Chapter 2**: Discussion of lean manufacturing best practices and how these can apply to Raytheon's lean transformation efforts within EA.
- **Chapter 3**: A discussion of the overall motivation for lean improvements and a definition of the problem central to this thesis.
- **Chapter 4**: A current state analysis of comparable manufacturing cells at Raytheon IDS and a deeper dive into the issued within EA Rack.
- **Chapter 5**: Discussion of the current and ideal state of the material flow process as well as an intervention that was introduced to aid this change effort.
- **Chapter 6**: A discussion of the best practices and opportunities for Raytheon management to support change throughout IADC and especially, EA Rack.
- **Chapter 7**: Three recommendations for Raytheon to build on the successes of this internship and support their lean transformation journey.

2 Best Practices in Lean

Lean manufacturing is a proven set of tools and approaches that help companies eliminate waste and deliver increased value at lower cost to the customer. With its roots in post World War II in Japan, lean thinking has evolved over the years and taken on a rigorous set of principles practiced by most leading operations companies today.

2.1 History of lean practices

The basic concepts of lean production were born out of Toyota post World War II. Faced with financial difficulties and a struggling business, Toyota had to change the way it did business. Then President Toyoda Kichiro made a goal for the company, "Catch up with America in three years" (Ohno, 1988). This challenge evolved over time to become the Toyota Production System (TPS), the most profiled and admired operating system of all time.

Taichi Ohno is the one most widely credited with taking these initial ideas and developing the TPS. For him, these concepts all boiled down to a specific focus on waste. "All we are doing is looking at the time line, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value added wastes" (Ohno, 1988)

Today, most large companies have some derivation of Ohno's original TPS with varying degrees of success. According to the 2007 Industry Week/MPI Census of Manufacturers, "nearly 70% of all plants in the US are currently employing Lean Manufacturing as an improvement methodology" (Pay, 2008).

Ohno's ideas were first formalized in 1990 in *The Machine that Changed the World.* The word "lean" is credited to John Krafcik, who helped in the research for the book while at MIT and also was the first American Engineer hired by the NUMMI joint venture by GM and Toyota(Womack, Jones, & Roos, The Machine that Changed the World, 1990). The ideas were taken further by James Womack, in *Lean Thinking*, which was published in 1996. In the book he outlined a structure for large enterprises to begin adopting these methods on a large scale. Specifically, he outlined the five key principles to lean operations(Womack & Jones, Lean Thinking, 1996):

1. **Value**: Value can only be defined by the customer and it is only meaningful when expressed in terms of a specific product which meets the customer's needs at a specific price at a specific time
2. **Value stream:** The set of actions required to bring a product through the three critical management tasks of problem solving, information management and physical transformation
3. **Flow:** The continuous movement of a product through value added processes
4. **Pull:** The customer drives the production and "pulls" the line rather than building to stock or pushing the line
5. **Perfection:** Focus on continuous improvement to drive value in the value stream and to move towards states of flow and pull.

In recent years, lean practitioners have placed increased focus on the behavioral aspects of lean, especially among operations leaders. Steve Spear, in his book *The High-Velocity Edge,* outlined the four capabilities that high performing organizations are likely to have (Spear, 2009):

1. **Capability 1:** System Design and Operation
2. **Capability 2:** Problem Solving and Improvement
3. **Capability 3:** Knowledge Sharing
4. **Capability 4:** Developing High-Velocity Skills in Others

Compared to the five principles outlined by Jones and Womack in 1996, these capabilities are much more holistic. They build upon the technical foundation of lean principles and apply it to a large enterprise.

2.2 Lean in the Defense Industry

The Defense Industry began to adopt lean practices as they began to spread through automotive and aerospace industries. However, the industry was not quick to accept these practices throughout the 1990's. However, acceptance gained steam at the beginning of the 2000's.

In 2001, in a report from RAND titled *Military Airframe Acquisition Costs: The Effects of Lean Manufacturing*_authors Cynthia Cook and John Graser conclude that "it would be premature for the DoD to adjust its cost-estimating tools to reflect projected savings from lean manufacturing" (Cook & Graser, 2001). Part of the problem they found is that "none of the manufacturers surveyed had yet implemented lean manufacturing practices on a broader scale, either from the beginning to the end of the value stream or within the factory as a whole" (Cook & Graser, 2001). Consulting firm Booz Allen Hamilton backed up these claims in the early 2000's, finding that "by conservative estimates, most aerospace & defense platform designers and producers are operating at less than 50% capacity utilization" and that "machining capacity was found to be operating at less than 10% utilization industry wide (Booz Allen Hamilton, 2000). However, low utilization could likely be driven by a number of factors including the fact that the 1990's were a decade of mostly peace and that low utilizations are typical of machining environments. Still, the fact remains that with such low utilizations, there is enormous potential for improvement.

2.3 Lean manufacturing best practices

Toyota has been one of the most recognized companies in terms of lean best practices. However, many companies have tried to copy their system, The Toyota Production System, and have failed to achieve the same consistent gains as Toyota. This led many to investigate the company further. One of the works that came out of this was Jeffrey Liker's *Toyota* Way, which describes the 14 principles which have driven their success throughout the years. These principles have been grouped into four high level themes (Liker, 2004):

1. Long-term philosophy
2. The right process will produce the right results

3. Add value to the organization by developing your people and partners
4. Continuously solving root problems drives organizational learning.

While Liker was working with Toyota, he spoke with Toyotoa Motor Company President Fujio Cho, who noted that, "The key to the Toyota Way and what makes Toyota stand out is not any of the individual elements...But what is important is having all the elements together as a system. It must be practiced every day in a very consistent manner, not in spurts" (Liker, 2004).

The operations practice at McKinsey & Company has taken these principles a step further and identified the behaviors that align with success in lean and six sigma programs. The four behaviors they identified were(Tilley, 2009):

1. **Role modeling**: The leadership must teach and coach their charges, constantly challenging them and reinforcing "our way of doing it" by demonstrating the desired behavior.
2. **Fostering alignment, understanding and conviction from bottom to top**. Engaging with every employee and ensuring that each understands what is expected of them. Ensuring that everyone takes ownership for the things they can do.
3. **Formal management infrastructure**: Rigorously monitoring performance in real time, and then managing it, meaning that countermeasures' are put into place quickly, so that the system supports continuous improvement and sustainability and concepts like PDCA (plan-do-check-act) really work, every day.
4. **Capability building**. Ensuring that every employee is constantly developing the new skills they need to do their job more effectively

Similar to Spear's four capabilities (Spear, 2009), both models provide us an opportunity to analyze the current state of the lean programs at Raytheon IDS.

2.4 Chapter Summary

Lean research has come a long way in the past two decades. Initial research focused on the operating principles that drove high performing "lean" companies such as Toyota in manufacturing in the early 1990's. More recently, however, the focus has shifted towards a more holistic focus on capability building, knowledge sharing and lean leadership. This is exemplified by two behavioral leadership models offered by Jeffrey Liker and McKinsey & Company.

3 Motivation and Problem Statement

This chapter outlines the high level impetus for change at Raytheon as well as how the internship fit within the broader goals of the organization. It also explores the specific problems that the internship aimed to solve within the EA Rack manufacturing cell.

3.1 Motivation

As stated in Raytheon's corporate goals, the business focus for operations is to "Bring Raytheon Six Sigma to the next level" (Raytheon's Vision, Strategy, Goals and Values, 2011). Raytheon began its lean transformation journey in 2001 after the Integrated Air Defense Center (IADC) was on the brink of being closed. This was necessary to avoid layoffs and build towards a sustainable future. Within operations, employees have embraced the Lean and Six Sigma concepts as a part of that initial lean transformation, but are at the stage where the company wants to move to the next level.

There has been a renewed pressure within Raytheon to focus on affordability of its equipment. This has been driven by the US Department of Defense (DoD) which has increased the percentage of fixed costs contracts instead of cost-plus contracts. Given the fact that the company is heavily influenced by DoD pressures, most of their foreign contracts have also shifted to fixed costs, creating further incentive for operations improvement. These foreign contracts have seen increased competition in recent years, especially from Chinese and Russian defense companies.

Raytheon IDS has committed to a lean transformation at the enterprise level. However, since the Electronics Assembly (EA) cell has been dormant for several years, it did not benefit from the lean improvements that occurred throughout IDS. After winning contracts for at least 18 new Patriot Missile Defense systems from Taiwan and the UAE, EA had to expand rapidly to meet the expected downstream demand while also adopting some of the lean practices that other areas had already been working on for several years.

3.2 Problem Statement

Starting in 2010 with the Tauber project, there have been multiple continuous improvement projects that have attempted to improve the performance of the cell. However, EA Rack has struggled to sustain the impact of these interventions. As a result, the cell is still plagued by a number of core symptoms:

1. **Excess inventory:** Inventory levels are much higher than the number of assemblies that could be worked on. A main driver of inventory is high levels of idle time, which is more than 90% for single, double and triple bay racks.
2. **A lack of prioritization:** There are a number of assemblies being built, but there are no clear priorities.
3. **Excessive fire fighting:** There is a focus on removing short term barriers, not true root cause problems. Assemblies are removed from the line when there are issues, which are shown by a high ratio of idle time to build time.

During the internship, the top concern within EA was a lack of a standardized material flow process. This thesis explores the project that was undertaken at Raytheon to understand the current process and to present a potential future state. By focusing on improving the process and identifying problems in the current state, the goal is to identify areas of unpredictability which can be removed to help decrease variation in process and ultimately reduce cycle time.

3.3 Chapter Summary

This chapter discusses the motivation for change in the EA rack cell. Excess inventory, a lack or prioritization and excessive fire fighting are driven by a lack of a standardized material flow process. This thesis will discuss the interventions taken to attempt to improve on that process.

4 Current State Analysis of Raytheon IADC and EA

This chapter discusses the current state of comparable manufacturing areas within IADC and will show that high variability and inability to meet quoted cycle times is not specific to EA. However, the causes of these results were not explored further in areas outside of EA. This chapter will also discuss the performance of the FMDC kitting area and its effect on performance results in EA. Finally, there will be an in depth analysis of inventory, prioritization and continuous flow within the EA rack manufacturing cell.

4.1 Analysis of other IADC manufacturing cells

While conducting a current state analysis of EA, I was urged to talk to value stream managers in other areas of IADC to see if there were systematic challenges throughout the entire plant. While it was found that other areas were facing similar challenges meeting quoted cycle times, the reasons were not exactly the same as EA, but did help confirm that EA is facing larger challenges compared to the rest of IADC.

Using an 80/20 analysis approach, the top 80% of parts in terms of volume were analyzed for cycle time performance from January 2010 to March 2011. In addition to EA, the following areas were analyzed:

1. Circuit Cart Assembly (CCA)
2. Metal Fabrication
3. Cables (IADC)
4. Cables (SCC): Though not physically at IADC, the IADC oversees the management of this cables area in Portsmouth, RI.
5. Electronic Component Operations (ECO)

The data points for comparison are the actual and quoted cycle times, both of which include the time it takes to build the part until it is completed and delivered to the appropriate downstream cell.

4.2 Definition of Cycle Time

Cycle time is defined as the time from the beginning of the production process and completion of the part or assembly. This includes production and idle time as well as rework and testing.

4.3 Analysis of Cycle Time Data

The first observation when looking at the data was that the data was skewed to the right. This is common in cycle time data everywhere, as there is a lower bound, but no upper bound. For example, the data for CCA is seen below:

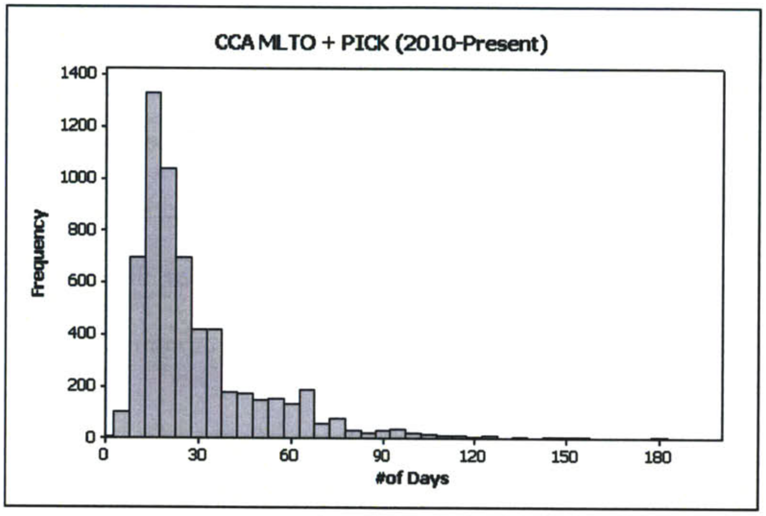


Figure 4: Circuit Card Assembly (CCA) cycle time distribution (Jan 2010 – March 2011)

The skewness to the right can clearly be seen. To account for this in statistical analysis of the data, the median is used instead of the average. As seen in Figure 5, the average of this data is 29.04 days and the median is 21 days.

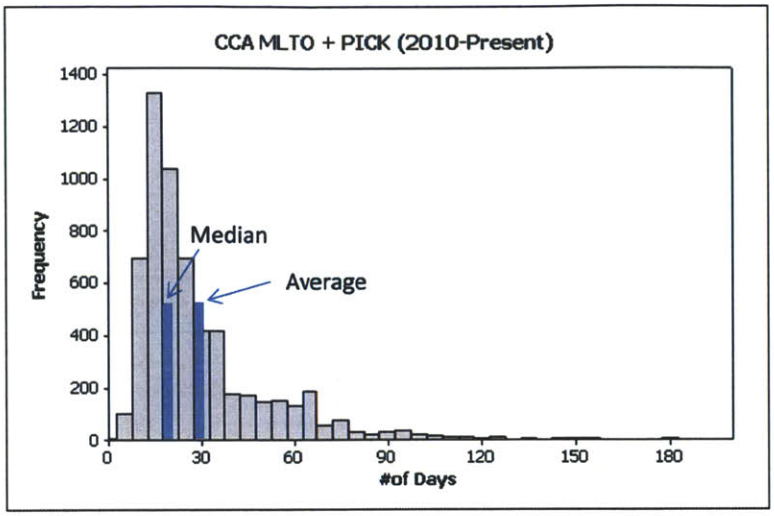


Figure 5: Comparison of median and average in cycle time distribution

4.4 Cycle Time Predictability

Using the median and standard deviation of the sample data and comparing to the quoted lead time, the likelihood that a part will be completed on time can be computed. Although the data is not perfectly normal, by using the median the results will give us information that is directionally correct. The following equation was used in Microsoft Excel:

$$Ability\ to\ meet\ cycle\ time = Normsdist\frac{(Quoted\ Cycle\ Time - Median\ Cycle\ Time)}{Standard\ Deviation}$$

Resulting in the following results for each of the areas:

Area	# of items	Quoted Cycle Time (days)	Median Cycle Time (days)	Standard Deviation (days)	Ability to Meet Cycle Time
CCA	6012	31.10	21.00	22.14	68%
Metal Fab	748	32.20	14.00	26.42	75%
Cables	1689	20.00	10.00	11.11	82%
ECO	2162	43.83	27.00	17.73	83%
SCC Portsmouth	1835	35.26	18.00	14.28	89%
EA	6044	20.79	11.00	19.80	69%

Table 3: Cell Performance Jan 2010 – March 2011

As seen in Table 3, all of the areas struggle to meet their quoted cycle times and no area can reliably meet their quoted cycle time more than 89% of the time, with EA and CCA the two worst performing cells.

4.5 Model Validation

To validate the modeling assumptions, the predicted "ability to meet cycle time" was compared to the actual results from the data. This was done by counting the percentage of items that has cycle times lower than the quoted cycle time. This comparison can be seen in Table 4

	Actual	Model	Difference
CCA	69%	68%	1%
EA	72%	69%	3%
Cables	79%	82%	-3%
Metal Fab	82%	75%	7%
ECO	85%	83%	2%
SCC Portsmouth	87%	89%	-2%

Table 4: Comparison of model versus actual results for cycle time performance

As seen in Table 4, the model accurately predicts the results of each area within +/- 7%.

4.6 EA and EA Rack performance

EA is a large area, but the project focused on only one cell within the entire division, the Rack cell. The Rack Cell makes a variety of products including single, double and triple bay racks, power supplies and several other low volume products. The cycle time for EA and EA Rack both include the time from the beginning of the kitting process in FMDC. The cycle time performance data for the EA Rack cell was similar, but worse than EA as a whole. From the data for January 2010-March 2011:

Area	# of items	Quoted Cycle Time (days)	Median Cycle Time (days)	Standard Deviation (days)	Ability to Meet Cycle Time
EA	6044	20.79	11.00	19.80	69%
EA Rack	1220	26.53	23.00	22.57	56%

Table 5: EA and EA rack cycle time performance predictions

Although the data is from over 15 months, the data showed that the performance did not change much over the period. EA Rack products are typically more complex than the average EA part, which may help explain the worse performance, but is only one of many factors. FMDC Performance

Data for FMDC was taken from a different period, but still had similar results, with high variability and low likelihood to meet the quoted lead times. A smaller sample was taken, on 35 days from May to June 2011:

Area	# of items	Quoted Cycle Time (days)	Median Cycle Time (days)	Standard Deviation (days)	Ability to Meet Cycle Time
FMDC	557	5.00	7.00	4.90	34%

Table 6: FMDC Performance (May-June 2011)

Since EA cycle time begins with the kitting process in FMDC, many of the parts are already behind schedule when they reach EA. This likely drives variation in EA, but the standard deviation in FMDC (4.9 days) is only approximately 25% of the variation in EA (19.8 days). However other issues such as incomplete kits delivered from FMDC could be a contributor to some of the statistical variation seen in EA.

4.7 EA Performance

Given the fact that FMDC does not reliably get the components for the single, double and triple bay racks to the floor in time, EA cell leads and managers compensate by ordering parts ahead of when they are actually due. However, this creates a lot of artificial demand for parts that may or may not be due. Although not the only driver, this behavior contributes to symptoms EA is experiencing including excess inventory, unclear prioritization and lack of continuous process flow.

4.7.1 Excess Inventory

In a census taken in July 2011 of single, double and triple bay racks, there were 49 naked racks in production on the EA rack floor. However, there are only up to 10 benches that are capable of building these racks on each shift. If every operator possible was working on these racks, a maximum of 20 could even be in process on each day. In reality, assemblies spend a lot of time waiting for parts, waiting on a storage racks, waiting for inspection or waiting for missing parts. A summary of the inventory and amount of aging for single, double and triple bay racks taken in July 2011 is seen in Table 7:

	# In Inventory	Average Days on Floor
Single Bay Racks	27	42.4
Double Bay Racks	2	49.0
Triple Bay Racks	19	41.6
TOTAL	**49**	

Table 7: Inventory of single, double and triple bay racks in July 2011

Looking at historical data for the racks, the value added time can be analyzed by looking at the build time versus the average age at completion. A day is defined as two 6 hour shifts. The build time is the time spent building the assembly and the average age at completion is the entire time it spends on the floor:

	Single Bay	Double Bay	Triple Bay
Average Build Time	1.3 Days	3.7 Days	3.7 Days
Average Age at Completion	47.5 Days	68 Days	68 Days
Value Added (%)	**2.7%**	**5.4%**	**5.4%**

Table 8: Build time versus age at completion for EA Racks

As seen in Table 8, the value added time is very small, 2.7% for single bay racks and 5.4% for the double and triple bay racks.

4.7.2 Prioritization

A deeper issue driving the increased inventory and high idle times is a general lack of prioritization on the floor. As part of a deeper analysis of the 49 naked racks in inventory on the floor, the racks required for the Patriot program were analyzed. Using internal systems to retrieve downstream demand, in process racks were placed in order based on the percentage completed. In reality, racks are not assigned to higher level assemblies until they are completed, so ranking by percent completion is the closest approximation. The higher level assemblies require 1, 2, 3 or 4 of each rack per radar. In addition, each radar has specific due dates. For UAE, which has a contract for 10 radars, they are due in sequence with radar 1 being due before radar 2 and so on.

In Table 9 below, the impact of the lack of prioritization becomes obvious. Since assemblies are not assigned to a specific radar until completion, it does not make sense to say there is a correct within one part number. However, assemblies are being worked on for radars that are not due for several months, while other assemblies on the floor are already late or are due sooner. Assemblies for radars 6, 7 and 8 are being built while requirements for radars 3 and 4 have still not been satisfied. Four of assemblies

#13646434 are required for the high level radar #4, but they have not even arrived on the floor yet. This could be due to many reasons including part shortages and poor planning.

SFC	Radar Number	RTR_TYPE	Operation	Days at Operation	Total Aging	%COMPLETE
11474901-989008	3	PRODUCTION	110	0	42	91%
13646451-988012	3	Rework	10	11	58	0%
11456578-988009	4	PRODUCTION	140	4	24	49%
11461581-989001	4	PRODUCTION	120	0	66	59%
11474901-989009	4	PRODUCTION	40	13	35	40%
13646434-988003	4	PRODUCTION	150	3	91	96%
13646451-989001	4	Kit Cut	10	5		0%
13646451-989002	4	Kit Cut	10	5		0%
13646451-989003	4	Kit Cut	10	5		0%
13646451-989004	4	Kit Cut	10	5		0%
11456578-988006	5	Rework	10	19	70	0%
11456578-989002	5	PRODUCTION	130	3	70	45%
11456580-988012	5	PRODUCTION	30	44	45	5%
11456581-988006	5	Rework	10	61	65	0%
11456582-989002	5	PRODUCTION	110	11	59	55%
11461581-988006	5	Kit Cut	10	6		0%
11468651-988014	5	PRODUCTION	90	31	47	19%
11468651-988016	5	PRODUCTION	140	2	35	49%
11468651-989004	5	PRODUCTION	90	24	35	19%
11474901-989010	5	Kit Cut	10	3		0%
13646434-988004	5	PRODUCTION	20	7	7	12%
11456578-988008	6	Rework	10	4	18	0%
11456580-989005	6	Rework	30	1	11	0%
11461581-988005	6	PRODUCTION	70	55	62	30%
11463407-988007	6	PRODUCTION	90	31	54	28%
11463407-988009	6	PRODUCTION	90	31	40	28%
11468651-988011	6	Rework	10	12	53	0%
11468651-988013	6	PRODUCTION	60	21	46	9%
11468651-989003	6	PRODUCTION	80	0	67	12%
11456580-989006	7	Kit Cut	10	6		0%
11463407-988008	7	PRODUCTION	40	31	54	5%
11468651-989005	7	Rework	10	20	32	0%
11463407-989003	8	Rework	10	6	38	0%

Table 9: Summary of inventory aging by high level radar assembly

When asking cell leaders what is a priority, they will often give different reasons for what is being built on different days. Due to a lack of long term capacity and production planning at the cell level and part shortages, cell leads often try to keep operators busy with what is ready to be built, regardless of true due dates or other problems that have not yet been solved.

4.7.3 Lack of continuous process flow

Excess inventory and a lack of prioritization are symptoms of a lack of continuous process flow. To analyze this further, a single bay rack was tracked on a shift by shift basis through completion. As seen in Table 10 below, the green shows the time the product is being built, the yellow shows the time spent in test or rework and red signifies when there is idle time. Typically, when the item is "red" it is sitting in inventory on a shelf in the area or waiting to be built or reworked. For this specific assembly, it remained in production throughout the first five shifts. However, this is the most number of consecutive shifts the product was worked on for the remainder of the process.

		1st Shift	Hours	2nd Shift	Hours			1st Shift	Hours	2nd Shift	Hours
Monday	20-Jun	Assy	4.11	Assy	5.97	Thursday	21-Jul	Idle		Idle	
Tuesday	21-Jun	Assy	4.48	Build/Rework	2.20	Friday	22-Jul	Idle		Idle	
Wednesday	22-Jun	Assy	4.97	Idle		Saturday	23-Jul	Idle		Off	
Thursday	23-Jun	Assy	3.31	Idle		Sunday	24-Jul	Idle		Off	
Friday	24-Jun	Assy	4.27	Idle		Monday	25-Jul	Idle		Rework	0.62
Saturday	25-Jun	Idle		Off		Tuesday	26-Jul	Test	0.19	Idle	
Sunday	26-Jun	Assy	1.43	Off		Wednesd	27-Jul	Idle		Idle	
Monday	27-Jun	Idle		Assy	2.98	Thursday	28-Jul	Idle		Test	1.55
Tuesday	28-Jun	Idle		Assy	1.47	Friday	29-Jul	Idle		Idle	
Wednesday	29-Jun	Idle		Idle		Saturday	30-Jul	Idle		Off	
Thursday	30-Jun	Assy	0.43	Idle		Sunday	31-Jul	Idle		Off	
Friday	1-Jul	Idle		Idle		Monday	1-Aug	Test	4.99	Idle	
Saturday	2-Jul	Idle		Idle		Tuesday	2-Aug	Idle		Idle	
Sunday	3-Jul	Idle		Off		Wednesd	3-Aug	Idle		Idle	
Monday	4-Jul	Idle		Off		Thursday	4-Aug	Idle		Idle	
Tuesday	5-Jul	Idle		Test	0.00	Friday	5-Aug	Test	3.52	Idle	
Wednesday	6-Jul	Test	7.36	Test/Rework	2.58	Saturday	6-Aug	Test	3.09	Off	
Thursday	7-Jul	Idle		Test/Rework	1.87	Sunday	7-Aug	Rework	0.95	Off	
Friday	8-Jul	Idle		Idle		Monday	8-Aug	Idle		Idle	
Saturday	9-Jul	Idle		Off		Tuesday	9-Aug	Idle		Test/Rework	3.13
Sunday	10-Jul	Idle		Off		Wednesd	10-Aug	Test	3.33	Idle	
Monday	11-Jul	Idle		Idle		Thursday	11-Aug	Idle		Idle	
Tuesday	12-Jul	Test/Rework	0.92	Idle		Friday	12-Aug	Test/Rework	1.81	Test	1.10
Wednesday	13-Jul	Idle		Idle		Saturday	13-Aug	Idle		Off	
Thursday	14-Jul	Idle		Idle		Sunday	14-Aug	Idle		Off	
Friday	15-Jul	Idle		Idle		Monday	15-Aug	Paint	4.37	Paint	0.03
Saturday	16-Jul	Idle		Off		Tuesday	16-Aug	Inspect	0.83	Idle	
Sunday	17-Jul	Idle		Off		Wednesd	17-Aug	Rework	0.01	Idle	
Monday	18-Jul	Idle		Idle		Thursday	18-Aug	Idle		Idle	
Tuesday	19-Jul	Idle		Idle		Friday	19-Aug	Rework/Complete	4.42		
Wednesday	20-Jul	Idle		Idle							

Table 10: Summary of build process

From the Table 10, it can be seen that the product went off the production floor and into inventory several times. Including leaving the floor for rework, test and being put on an inventory rack between shifts, the part was moved at least 20 times. When a part encounters a stoppage in production, there is no process to deal with the problem. Given the fact that there are no clear priorities (section 4.7.2), cell leads will give operators any part that is ready to be built rather than solving the immediate problem. Without continuous process flow, problems do not come to the surface (Liker, 2004). Since there is excess inventory, it is easier to put another product into production (even if it is less urgent) than to work on these problems.

A summary of the idle versus build time for this part can be seen in Figure **6** below. The value added time was only 13% of the total time the part spent on the floor, which is better than the historical average from section 4.7.1, but the total build time was greater than average.

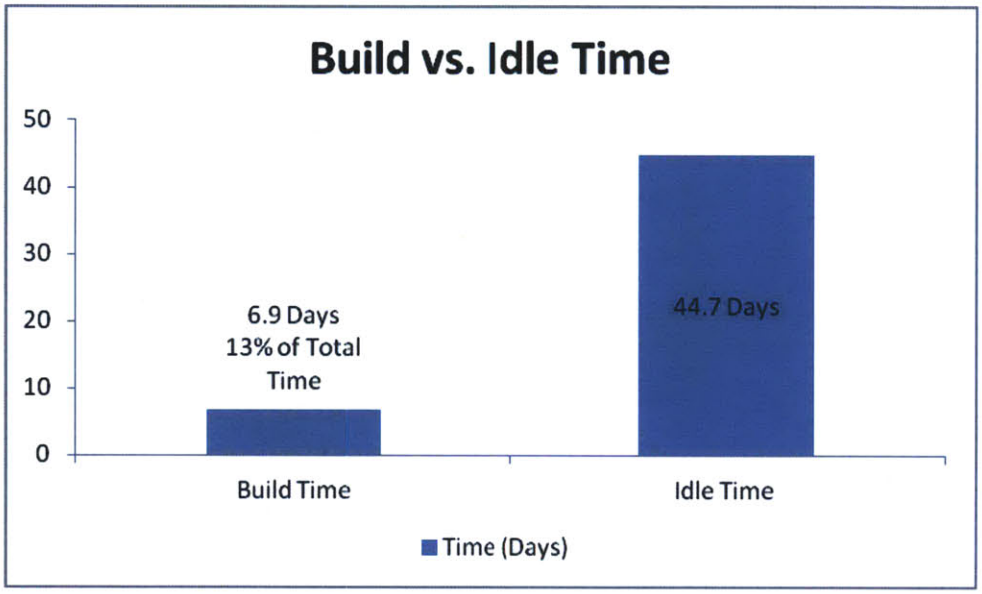


Figure 6: Pilot results, build time versus idle time

4.8 Discussion of Incomplete Kits

Although data was not available for further analysis on the number of incomplete kits within EA, a number of the root causes are known within the cell. First, kits are sometimes delivered to EA without all of the components. This is either deliberate (to begin building a part) or an error (FMDC mistakenly misses a part). Although it has been shown that some parts are not a pressing priority, some are on the critical path and EA will begin building assemblies without all the required parts. There is no standard way to assure that the missing parts are delivered to that assembly when they are available. Second, sometimes parts are taken from other assemblies that are idle so that another assembly can be completed.

4.9 Chapter Summary

This chapter showed that high variability is consistent across multiple manufacturing cells and is one of many reasons driving an inability to consistently meet quoted cycle times, especially EA and EA Rack. FMDC, which delivers kits to EA, is only able to meet its quoted cycle time 34% of the time, which forces EA to be consistently behind schedule. This drives some of the symptoms within the EA Rack area discussed such as excess inventory, unclear prioritization and lack of continuous flow.

5 Improving the material flow process in EA Rack

A project to look at improving the material flow process in EA Rack was underway when the internship began. The main driver of the project was to drive down the cycle time variation the cell was experiencing. Although only one of many causes of the variation, the material flow process was something that was identified that was visual that could clearly be seen and improved quickly. The material flow process was defined as how parts are delivered to the floor, how they are stocked in inventory and how they flow on the floor. This chapter defines the process and discusses the major issues that existed at the time of the internship. In addition, it offers results from the introduction of a material kitting cart that attempted to improve the material flow process.

5.1 Project Goals

The reason the project was undertaken was that there was an opportunity to improve the process of how material flows through FMDC and EA. The project was also a priority, as it would help the cell support recent initiatives towards improved safety (through less heavy inventory all throughout the floor) and it would gain support with front line operators, who consistently listed problems related to material flow as their top complaint.

5.2 Define the material flow process

Given a lack of standardization the material follows a different and unique process every time an assembly is built. However, there is a general process that every assembly follows that describes the general flow of parts from beginning of kitting through completion of production. This can be seen below in Figure 7:

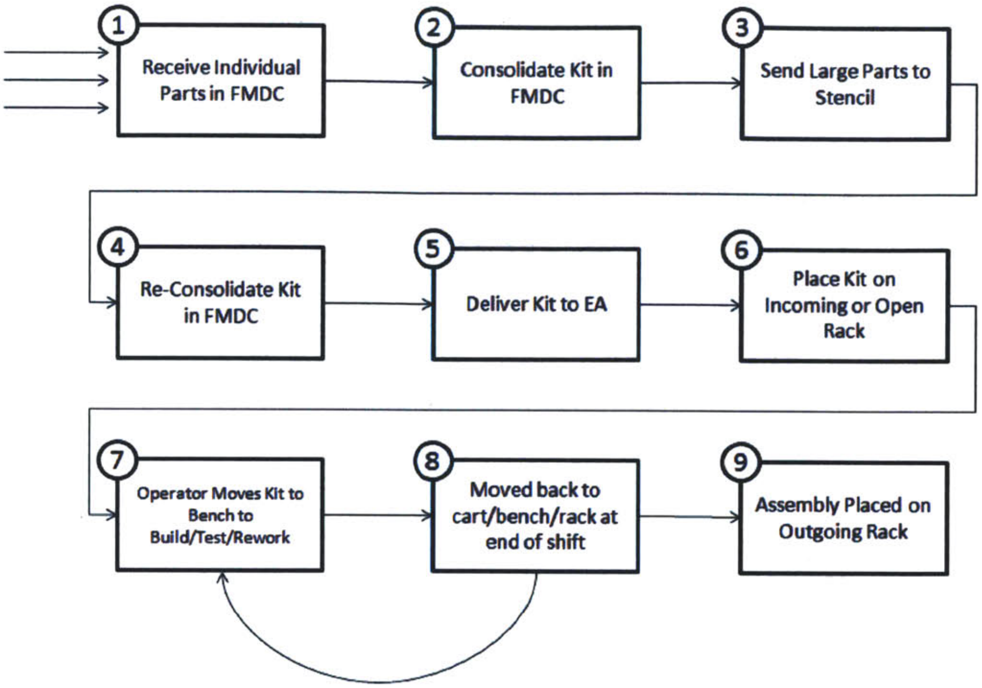


Figure 7: General process for material flow for single, double and triple bay racks

The major point to highlight from this figure is the loop from step 8 to step 7. As discussed in previous sections, assemblies tend to leave and come back to the bench several times throughout the entire build process. Although macro level data is not available for the cell, most of the time is spent after step 6. In Table 10 in the previous section, a sample part was shown to have spent over 50 days from step 6 until step 9. The time from steps 2 to step 5 was summarized in section 0, with the median kitting time averaging 7 days. The following sections will dive into some of these issues further.

5.3 Understand the symptoms

There were a number of symptoms that show the lack of standardization within this process. Three examples are discussed below:

Carts as Inventory Storage: Due to excess inventory there is not sufficient storage space on the production floor. Carts are used as backup inventory racks. In Figure 8 below you can see the kit for a triple bay rack that is being stored on a cart, which is not big enough to do so. The cart is being used because the incoming inventory racks are already filled.

Figure 8: Cart carrying a triple bay kit

Separation of components: Figure 9 shows a storage rack that was created for single, double and triple bay rack covers. Since completion of an assembly takes over a month, covers are stored on this rack instead of traveling with the part. At the end of the process when covers are attached it is a challenge to find the correct cover. Covers on this rack could be for assemblies in process, ones waiting for parts or even covers for parts not on the floor yet.

Figure 9: Covers rack is unclear

Excess Packaging: Operators spend time searching for, organizing and de-trashing (taking the packaging off) parts. In Figure 10 below, you can see the packaging of a single bay kit (top left), the packaging for those parts (bottom left) and small components in individual bags (right). Big parts are fairly easy for operators to identify, but with at least 30 smaller parts in each assembly, the operator has to spend considerable time finding each component and verifying the part numbers on each bag.

Figure 10: Packaging of a single bay kit

All three issues, although not exhaustive, show that there is a considerable opportunity for improvement and to standardize the material process throughout the entire production process.

5.4 Analyze

To further understand these issues, information was collected through analyzing data, working with the frontline operators and observing the process.

5.4.1 Kit complexity

Among the single, double and triple bay racks, the number of parts and size of the major assemblies varies. Among the six single bay racks, there were on average 47 components in each kit. Among the five double and triple bay racks, there were on average 84 components in each kit. Each kit has small and large parts. Single bay racks have 7 large parts, double bay racks have 13 and triple bay racks have 19. The remainder of all parts in each kit is small component parts and is typically delivered to EA within a covered tote box.

5.4.2 Assembly sizes

The large parts mostly consist of the base, chassis, and covers. These large parts take up a lot of space and are the main driver in the current lack of storage space. The bases of the racks have different sizes and the large parts have similar sizes as the base. Among the 11 single, double and triple bay rack bases, there were five major sizes as seen in Table 11.

General Dimensions		
Length	Width	Height
34"	8.5"	8.5"
24.5"	8.5"	8.5"
24.5"	16.5"	8.5"
24.5"	24.5"	8.5"
19"	24.5"	8.5"

Table 11: Five sizes of racks

5.4.3 Operator Input

Operators had a major input into the diagnosis of the issues dealing with the materials flow process. Two of their major concerns that they brought to the teams attention were:

1. **Incomplete Kits:** There is no way for an operator to know if a kit has all its parts unless they go through and verify all the parts at the beginning of every shift. Often there are missing parts because the kit was sent to the floor incomplete or a part was taken to finish another assembly. Many assemblies are "built to short" meaning that they do not have all the parts to complete production, but will be built until the part they need is not available. This drives increased inventory and confusion among the operators.
2. **Lack of space:** There is not a sufficient system for storage of the racks between shifts or visual management of the parts and their status on the line because of the excess inventory. Thus, carts are used to store the assemblies and are constantly moved around on the production floor.

These concerns are only a few of major issues facing the operators. Overall, the morale of the operators was strong, but most were frustrated due to the lack of standard process.

5.4.4 Observation

Considerable amount of time was spent with operators to understand the build process, understand their frustrations and to get them involved in the improvement project. As part of this process, we sat with one operator throughout a simulated build process of a triple bay rack to record the time he spent searching for parts and removing packaging. It was calculated that for he spends approximately 1.3 hours on looking for parts, reorganizing parts and removing the packaging of 84 total parts. A summary of the results is seen in Figure 11:

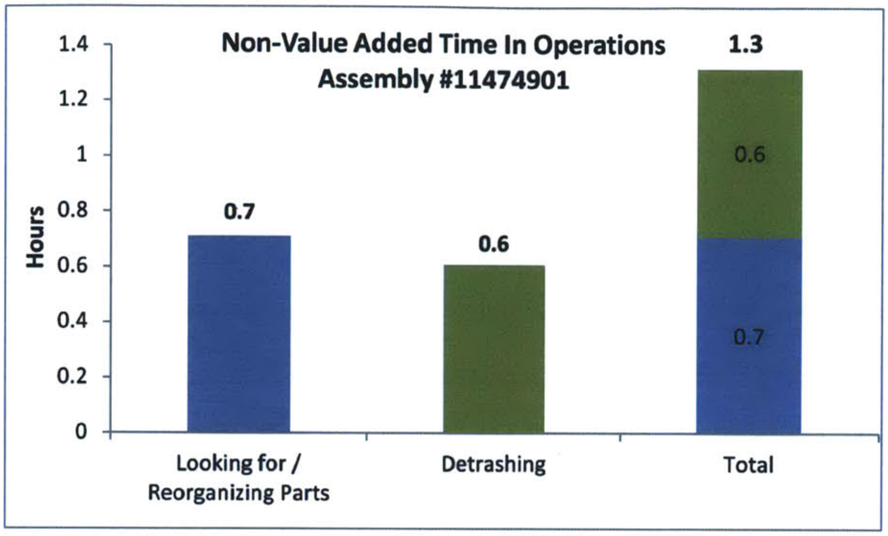


Figure 11: Non value-added time in assembly due to searching and de-trassing

Given the average build time of 3.7 days (44.4 hours) of a single back rack, the removal of all of this non-value added time would only save 2.9% of the time on the build process. Given that the average age at completion is 68 days, this did not seem like a significant direct savings. Regardless, the project team manager felt that the direct savings as a percentage of value added time and the indirect savings that would be achieved through a better process made the project a worthwhile effort.

5.5 Pilot Experiment

Despite the data showing that direct savings from operators will only amount to a maximum of 1.3 hours, there were still many opportunities to improve the process that would help the manufacturing cell reduce inventory and improve its ability to prioritize and introduce flow into the line.

To achieve these goals, several concepts were developed to help improve the material flow process. One concept that was settled on was a movable kitting cart that would enable mobile storage and kitting of the assembly as it went through the production process.

5.5.1 Concept

Working with external vendors, the project team developed an experimental kitting cart design that could be tested using a current assembly. Due to the complexity and size of the double and triple bay racks, the test cart was only designed for use with single bay racks. The goal was to prove the concept and then scale the solution to the double and triple bay rack. The concept was designed on trying to achieve three functions:

1. Kitting: When the carts arrive on the floor they are kitted in a manner that is easy for the operator to quickly assess part availability and begin building.
2. Building: The ability to build the assembly in a safe manner that eliminates lifting or rotating.
3. Transportation: Eliminate the need for lifting heavy assemblies off a bench and on to a storage rack or cart.

An external vendor, Fastube, helped the project team design a cart that that fit these needs. Below in Figure 12 is a cart that is mobile, can fit the major components on the top tray, can fit smaller components on the bottom two pullout trays and finally, can easily be slid under a production bench at the end of a shift:

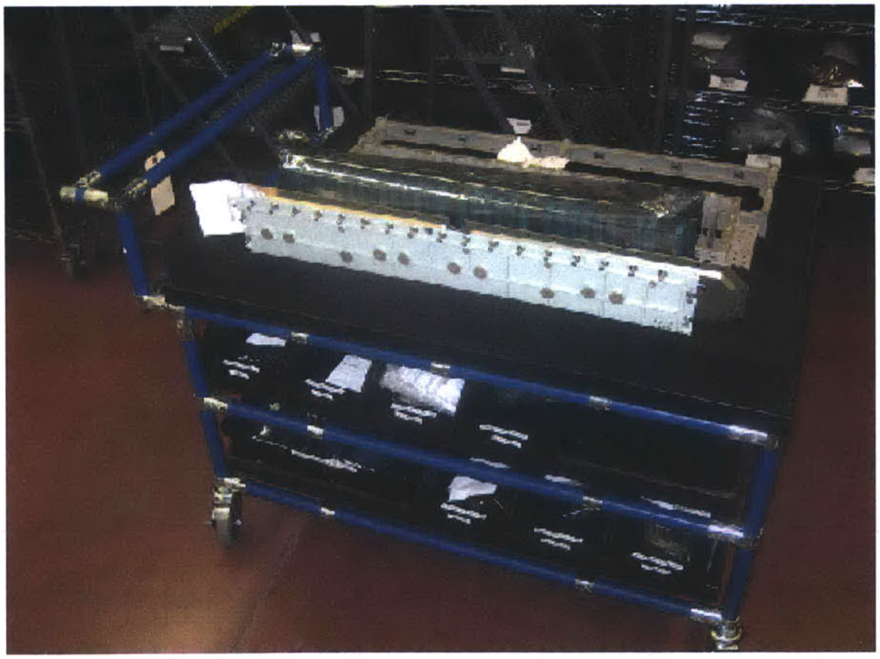
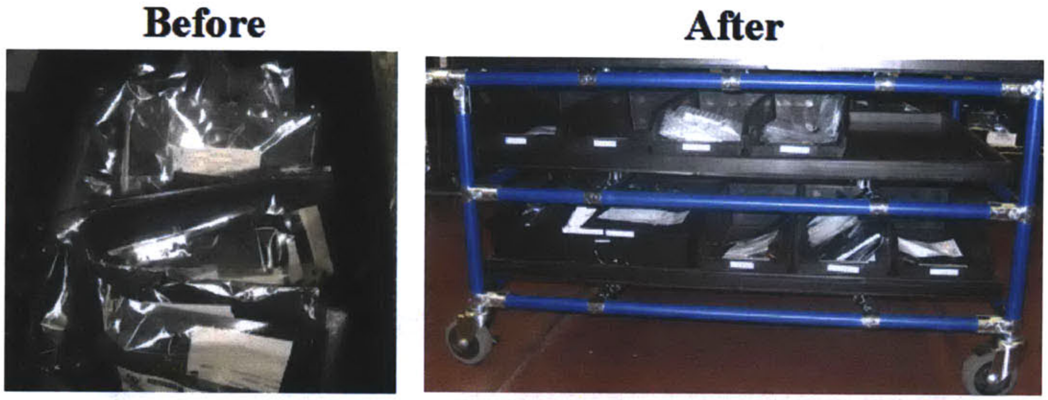


Figure 12: Kitting cart loaded with a single bay rack

With input from the project team and especially front line operators, the cart was fitted with systems that improved on the current material flow of small and large components:

5.5.2 Small component parts

Before, small component parts were stored in black totes with lids and delivered to the floor. There was no way for operators to know if parts were missing or organize them in build sequence without going through them at the beginning of each shift. The improved system using the cart used step kitting, an FMDC process that kits the components by operation. Using tags showing how many parts were required in each operation, operators could now visually see if anything was missing and notify their cell lead at the beginning of the build process if anything was missing. These improvements are shown in Figure 13:



Before

- **Disorganized**
- **Possible Missing Parts**
- **Have to verify complete at the beginning of each shift**

After

- **Organized in order, by operation**
- **# of parts per operation is listed on each tray, easy to verify**
- **Visual and not hidden in tote box**

Figure 13: Improvements to small part kitting

5.5.3 Large component parts

In the past, large component parts took up a lot of space and would be put anywhere in the cell where there was space. Since room on inventory racks was limited, carts were being used for storage of complete kits. In addition, covers were often separated from the assembly as mention in the beginning of this chapter. The improved system using the cart enabled large parts to stay with the entire kit throughout the process, which could easily be slid under the work bench between shifts to open up space on the production floor. A summary of these improvements can be seen below in Figure 14:

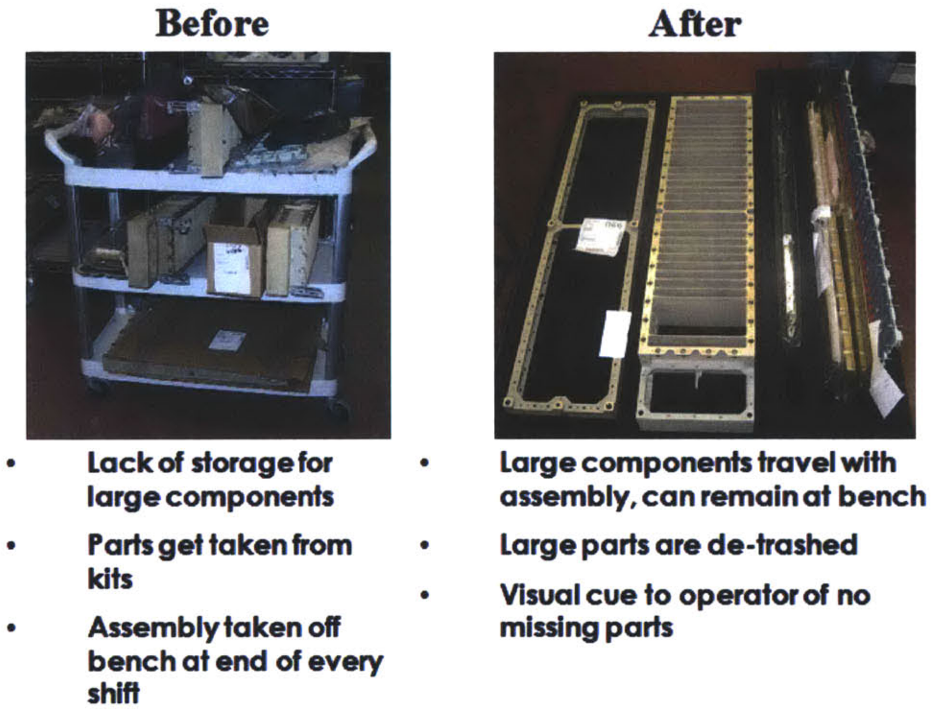


Figure 14: Improvements to large part kitting

5.6 Ideal State Process

Using the kitting cart enables EA to make many improvements to begin to address its challenges. First since the cart also serves as permanent storage for the assembly, it can remain at one bench and be worked on by multiple operators. This eliminates a number of times that the operator would otherwise have to move the assembly from a bench to a cart to a storage rack at the end of the shift and the opposite process at the beginning of the shift. This ideal state process (again, this is generalized) can be seen in the following Figure 15:

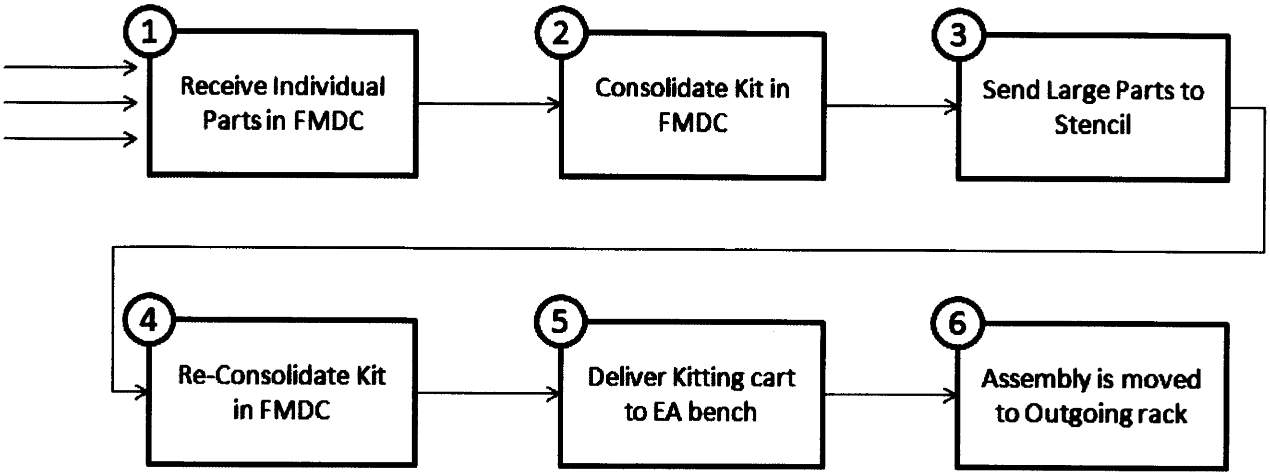


Figure 15: Ideal state process

This ideal state process eliminates the need for parts to be moved to racks at the end of every shift and enables two operators to build one assembly over consecutive shifts. Since the kitting cart stays at a specific bench and gets built by both shifts, cell leaders are forced to solve problems as they arise and make sure that production can resume as quickly as possible. Using this process throughout the cell would force EA to dramatically lower inventory levels, focus on root cause problem solving and enable them to establish an improved prioritization system.

5.7 Results

Although the kitting cart concept and improved process were received well, especially by operators and cell leaders, an initial test using the cart failed to have a quantitative impact. The cart only remained on the line for five consecutive shifts and once the assembly needed to go to rework, the entire assembly was removed from the cart and placed on a rework rack. Although the cart was a major improvement in material presentation, the underlying process was still not mature enough to be consistently followed throughout the cell.

However, as discussed in the motivation for this project, a major incentive for this project was to positively affect worker safety and to improve operator morale, both of which are hard to quantify in the short term. It was observed that the project help excite the operators, cell leads and other front line staff that worked on the project. Through continuous improvement and extension of this type of approach to improving material flow, there is hope on the floor that the next version of this concept can have an even greater impact.

5.8 Chapter Summary

This chapter detailed the process of a project team to address the problem of a poor material flow process. A kitting cart concept was introduced into the manufacturing cell to improve the process. The pilot experiment with the cart was successful in generating excitement on the front line and helped gain buy in from key front line managers and operators to continue on the improvement process.

6 Management implications

Raytheon, like any organization, has its own distinct organizational environment. That environment is driven by a number of influences, but especially by its role as a major US defense contractor. The industry is controlled and regulated heavily by the United States, and a number of behaviors within the organization can be tied directly to that strong relationship. This chapter explores those behaviors and how they relate to helping Raytheon take the next step in its lean journey.

6.1 Three Lenses Analysis

This section will analyze the management perspective of Raytheon IDS and specifically, the Electronics Assembly area (EA) using the Three Lenses framework developed at MIT. The three "lenses" are Strategic Design, Political and Cultural.

6.1.1 Strategic Design

The high level priorities of Raytheon are very clear. Raytheon's vision is "To be the most admired defense and aerospace systems company through our world class people and technology." As part of the plan to achieve this, Raytheon outlines the following goal related to manufacturing:

- **Productivity:** Improve ROIC (return on invested capital) for Raytheon Company. Take Raytheon Six Sigma to the next level, further engaging customers and partners. Deliver greater value and predictability through the Integrated Product Development System (IPDS), Earned Value Management System (EVMS) and Capability Maturity Model Integration (CMMI) ("Raytheon's Vision…" 1).

Like any high level goals, these are hard to directly apply to the day to day activities on the front line. Instead, cell leads and front line managers take cues from their managers on what they should be focusing on. Within the past year, safety has become priority #1 and the CEO has put pressure on the business to change. Thus, managers have rewarded cell leads and other front line staff for implementing changes that directly improve safety. Due to this, EA (as well as many areas across IADC) made significant improvement during the internship period and showed an ability to rapidly change and improve.

6.1.2 Political

Decisions at Raytheon are driven largely by politics and power. Given its close relationship with the military, Raytheon models the military style hierarchy and makes many decisions in a top-down manner. This is helpful for the company when it needs to focus on one accomplishing one goal and has been shown useful at the very beginning of transformation efforts (Womack & Jones, Lean Thinking, 1996). As shown in the previous section, this style was very effective in driving rapid improvements in Safety at IADC.

Within EA, projects are strongly directed in a top down leadership style. This drives the majority of decision making on continuous improvement projects. In studying Toyota, Jeffrey Liker shows that they found success by using a very structured decision making process before implementing solutions quickly. The five steps he defined were (Liker, 2004):

1. Finding out what is really going on
2. Understanding underlying causes that explain surface appearances
3. Broadly considering alternative solutions and developing a detailed rationale for a preferred solution
4. Building consensus within the team, including employees and outside partners
5. Using very efficient communication vehicles to do one through four, preferably on one sheet of paper

These steps outline a very structured approach that can be applied to any project. Within EA, there is an opportunity to add more structure to the decision process to help aid in the success of continuous improvement projects.

6.1.3 Cultural

Raytheon has a very strong culture. As a defense contractor there is a large amount of pride that the products we build, help our military defend themselves. Raytheon has a lot of ex-military people and people with relatives in the military working at its organization. This is an enormous benefit for them compared to other companies with a less motivated workforce. Company leaders are consistently able to leverage this strong pride to enhance commitment to company initiatives.

New CEO Tom Kennedy has leveraged this culture in many communications with employees. In addition, Kennedy showed a strong understanding of the challenges faced within operations. In an internal memo, Kennedy clearly recognized a need for more rigorous front line problem solving:

> "I need your help with a problem that I've seen multiple times since I joined IDS last summer. We all understand the importance of continuous improvement and striving to be our best. These are key behaviors for achieving excellence. However, at times we are falling short of these behaviors by addressing problems with a quick fix that does not correct the root cause. The problem then re-occurs, and we end up spending a lot of time and energy addressing it again in the same or a very similar form.
>
> We need to get better at seeking out and eliminating the root cause of a problem. A classic example in our business happens when one of our suppliers is having difficulty meeting a delivery schedule. Our quick fix is to apply pressure to the supplier in the form of contract letters, phone calls, and meetings to get the attention of their management. In some cases we visit the supplier's facility to expedite their delivery. When we step back and analyze the problem, we find out in 80 percent of the cases, the root cause of the supplier's problem is us. For example, we may have been late in contracting with them, so they did not have adequate lead time to make the required delivery date. In other cases the specifications or technical data package we gave them was incorrect" (Kennedy, 1).

Within EA, it was reassuring to many of the people involved in the project that leaders, especially the CEO, understood some of the day to day frustrations they dealt with. By talking about these issues, Kennedy will likely enable front line leaders to focus on their problem solving skills with support of their managers as they face problems in the future.

6.2 Chapter Summary

Although there are many divisions of power and cultural motivations within Raytheon, this is common in most matrix organization. Unlike many other companies, Raytheon has the cultural advantage of an incredibly committed workforce. Employees have a great amount of pride in the work they do protecting the military. This is a great source of motivation leaders regularly use to refocus and energize the workforce and was successfully used within EA throughout the project. Politically, Raytheon is driven by a top-down style of leadership that is conducive to accomplishing very specific tasks at a fast pace, as evidenced by its ability to radically improve Safety performance in the past year. Within EA, however, as EA continues to build upon its early continuous improvement accomplishments, it will need to introduce more structure into its decision making process to enhance bottoms up support of projects. Finally, EA and other manufacturing areas have the strong support of a CEO that understands the day to day challenges in operations. This support will be vital for the continued success of improvement projects within EA.

7 Recommendations for future continuous improvement efforts

The following chapter includes four recommendations for EA that built on the findings from this thesis and the internship at Raytheon IDS and are natural extensions of the material flow project. These recommendations would also align with ideal future internships that could be executed through Raytheon's partnerships with MIT LGO, Michigan's Tauber Program or even its extensive relationship with the Northeastern Co-op program. .

7.1 Improve coordination between EA and FMDC

Central to the material flow process in EA is the coordination between EA and FMDC. However, both are managed by different functions and measure their success based on different metrics. In addition, there is no planning process between the two aimed at increasing capacity and improving predictability.

FMDC and EA are managed by separate functions, but EA is measured on the performance of the kitting process within FMDC. If FMDC fails, so does EA and when EA is behind schedule, they place blame on FMDC and often force them to expedite parts. Currently, the two areas can be defined by the following three characteristics:

- **No Standard Communication**: There are many interactions and handoffs between the areas. There is no standard way to interact and communicate.
- **Misaligned Goals**: Each area has different reporting systems, different goals and different metrics. EA desires delivery of completed kit with a predictable and reliable lead time. FMDC is focused on meeting a daily target of # of parts kitted.
- **Silo Mentality**: Given the matrix organizational structure, limited resources and the complexity of operations in both functions, it is a challenge for the areas to collaborate on problems facing both areas.

These issues create a huge opportunity for an improvement. Raytheon could approach these issues by using the lean principles of stakeholder alignment and shared metrics. There are discussed in the following two subsections:

7.1.1 Shared Metrics

A key principle of lean manufacturing is aligning metrics within value streams. At Raytheon, FMDC and EA are aligned along the same value stream, but have different metrics to achieve the same goal. In *Toyota Way,* Jeffrey Liker shares 13 tips for companies committing to a lean transformation. First, he notes that companies should "organize around value streams" (Liker, 2004). To an extent, Raytheon has started to shift towards this model. However, they are only aligned around value streams within functions. For example, within operations, employees are organized around a specific program or product. Within the supply chain organization a similar alignment happens. However, as I have shown throughout this thesis, there is not cross functional alignment. In another one of his tips, Liker suggests "realign metrics with a value stream perspective" (Liker, 2004). He notes that at Toyota, metrics are, "an overall tool for tracking progress and they are a key tool for continuous improvement" compared to most companies where metrics are a tool for "short term cost control" (Liker, 2004). Raytheon's continuous improvement and overall company goals would benefit by understanding how front line metrics incentivize behaviors at the front line.

7.1.2 Stakeholder Alignment

In addition to shared metrics, stakeholder alignment is vital to establishing a successful lean manufacturing environment. Without alignment of the people, it will not matter which metrics are established. There are many tools to assess stakeholder alignment and to ensure that managers are driving towards the same goals.

A tool introduced in a prior project at Raytheon IADC by 2006 Leaders for Global Operations graduate Benjamin Lathrop was successfully tested to achieve stakeholder alignment (Lathrop, 2006). In the project, Lathrop developed 11 key values and had stakeholders rank them in terms of importance to themselves and then ranking them in terms of how well the company is delivering this value. The 11 characteristics were(Lathrop, 2006):

1. Schedule/Delivery
2. Product Quality
3. Product Cost
4. Organizational Effectiveness
5. Communication
6. People
7. Job Satisfaction
8. Business Performance
9. Processes
10. Change Management
11. Technical

This tool would be an effective starting point for the leaders of EA and FMDC to begin to understand the friction between the two areas. Also, since the tool was already used at the facility and was embraced by leaders, it has a better chance of success since the culture of IADC has remained very similar.

7.2 100% Commitment to first-in first-out production

The material flow project met immediate challenges because the assembly needed rework early on in the production process. As shown earlier in this thesis, there were no clear priorities in the cell and there is more work than could be in production at one time. This contributed to the pilot assembly becoming lost in a large group of other unfinished assemblies without any clear order or priority. . In order to lower inventory levels, establish clear priorities and focus on solving problems, a commitment will need to be made to first-in first out production.

Currently, assemblies can be taken off the line for any reason. In a single piece flow system, the product stays on the line until the problem is solved. In the short term, this could be a challenge as there are many open issues on the line, but over the long term it would allow front line managers and operators to solve problems quicker and lower inventory levels and confusion.

Jeff Liker, in profiling the Toyota Production System outlined seven benefits Toyota reaps from a focus on these types of systems (Liker, 2004):

1. *Built in Quality* – Operators double as inspectors and stop the line as they spot a defect.
2. *Creates Real Flexibility* – If lead time is shorter, there is more flexibility to react to changes downstream.
3. *Creates Higher Productivity* - Without single piece flow, productivity is artificially inflated due to the building of unnecessary parts, keeping workers busy and looking for missing and replacement parts.
4. *Frees up floor space* – Since assemblies stay on the line, there is less need for buffers or WIP inventory racks.
5. *Improves safety* – With less inventory and increased operator awareness of what is supposed to be on the line and what is not, it creates a safer environment for all.
6. *Improves Morale* – Workers are happier when they do more value added work and are involved in actually solving root cause problems.
7. *Reduces Inventory Costs* – When inventory is not sitting on the floor, working capital is freed up to invest in improvement projects.

Of course, Liker acknowledges the many barriers to quickly implementing single piece flow from a push or mass production environment, but the evidence strongly shows that movement towards this type of system can add a lot of value to a business. A major barrier to this is that EA is currently run like a job shop, and moving from this environment to a true flow model would take an incredible investment of time and resources.

7.3 Embrace the next generation production system

During the project, Raytheon IDS was engaged in pre-rollout of a new production system backbone, PRISM, which is Enterprise Resource Planning (ERP) software by SAP. The new software addresses many shortcomings of the legacy system, which include inability to manage capacity and prioritization, two major issues highlighted throughout this thesis. Managers and front line leaders within EA are excited for the new system and the ability to manage operations with more transparency and control.

The systems have been successfully rolled out already at Raytheon SAS and Raytheon NCS. Raytheon SAS President noted that the system will help them lower variability and said, "When we take the variability out of the business, we take repetition and redundancy out of daily tasks. This frees us to be more creative and innovative." (Raytheon Space Solution News, 2009). Managers within EA are hoping for similar results in IDS.

7.4 Align the leadership message with stronger front line problem solving

A gap exists between the leadership messages and the actions on the front line from a day to day basis. Leaders understand that operations need to do a better job to dig deeper into root causes and solve problems quickly that deliver a larger impact than in the past. As seen in section 6.1.3, CEO Tom Kennedy recognizes that the business needs to do a better job of front line problem solving. However, his sentiment has not yet fully been embraced by the front line in the form of true rigorous root cause problem solving. Supervisors on the floor focus on quick fixes, making it through the day and fixing symptoms of the deeper problems.

To move towards the next step in Raytheon's continuous improvement journey, time will need to be spent with the front line cell leaders and supervisors, who are dealing with problems every day on the manufacturing floor. These are the most influential people within operations and are vital in any attempt to shift mindsets and behaviors. These managers must be at the center of bringing IDS to the next level in its continuous improvement journey.

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