ENTERPRISE LEVEL VALUE STREAM MAPPING AND ANALYSIS FOR AIRCRAFT CARRIER COMPONENTS

by

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Submitted to the Sloan School of Management and the Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

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ABSTRACT

Northrop Grumman Newport News is committed to implementing lean on the enterprise level. This thesis is focused around work toward creating a global, high-level information and material value stream map for a specified pipe assembly. It identifies the largest areas of waste in the value stream and their root causes. The recommendations assist with the reduction and elimination of the major time delays, inventory buildups, re-work, excessive processes and other waste in the system. The pipe assembly chosen as the basis for the enterprise value stream map is part of a system, newly developed for the current aircraft carrier. The pipe assembly is representative of other pipe assemblies fabricated in the shipyard, so challenges experienced with the manufacturing and flow of the selected assembly are likely to be seen in many other pipe assemblies in the facility.

A large number of assemblies was examined to determine the root causes of delivery problems. The analysis was based on the criticality of the ship need date. The root causes for the late assembly delivery were found to be inadequate material inventory levels in the warehouses, lack of fabrication timeline coordination between fabrication shops, late engineering drawing revisions, underestimated fabrication durations, late supplier delivery, late material purchase order placement, and lost material.

Suggestions are provided to improve operational efficiencies by targeting the elimination of these root causes that result in the delay of assembly fabrication. Some include material ordering process reorganization, shop loading variability elimination, fabrication timeline alignment, metric realignment, and rework system prioritization. Recommendations for future work focus are concentrated on the control of the stock material inventory levels, alignment of the incentives across the enterprise, and reorganization of the planning processes.

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1. Background

1.1 Northrop Grumman Newport News

Northrop Grumman Newport News is the sole designer and supplier of Nimitz class aircraft carriers as well as nuclear-powered submarines, which are constructed in conjunction with the Electric Boat Corporation, for the sole customer, the United States Navy. The shipyard provides overhaul and maintenance services for aircraft carriers, submarines, and other military and commercial ships. The Newport News Shipbuilding and Dry Dock Company was originated in 1886 and remained a private company until Collis Potter Huntington's heirs sold its shares in 1940. In 1969, Tenneco bought the shipyard and, after 27 years, spun off Newport News Shipbuilding into an independent company. In 2001, Newport News Shipbuilding merged with Northrop Grumman Corporation and currently represents one of the company's seven sectors with annual revenue of $2.8 billion.

The shipyard is located on 550 acres stretching 2 miles along the James River waterfront and currently employs approximately 18,000 people, 4,500 of which are designers and engineers. The shipyard has seven dry docks and one floating dry dock, two outfitting berths and four outfitting piers, which provide extensive capabilities for building and maintaining the fleet of aircraft carriers, submarines, and other commercial vessels. Newport News has a wide range of machining capabilities with 300,000 square feet of machine shop facilities containing more than 500 machines. Steel production, fabrication, pipe fabrication, and sheet metal facilities, electrical shop, joiner shop and model shop, foundry, blast and coat facility are located in the shipyard among other facilities. Warehousing area covers 1.2 million square feet where about 500,000 inventory items are stored. Material is moved from receiving to the warehouse via a fleet of 80 trucks and Newport News' railroad system.

People at Northrop Grumman Newport News are highly trained and skilled in various trades, many of whom graduated from the 4 year Apprentice School. Fourth and fifth generations of shipbuilders are found working here. Newport News' motto is 'Great Company, Great Products, Great People, Great Results'.

1.2 Business Environment: US Navy Customer

Northrop Grumman is involved in a variety of defense and commercial programs in the United States and abroad. The defense industry is characterized by intense competition and long operating cycles, where Northrop Grumman is the second largest defense contractor. Northrop Grumman provides products and services through seven business sectors that include electronic systems and technology, combat aircraft, missiles, and nuclear and non-nuclear navy ships. The company conducts majority of its business with the U.S. Government's Department of Defense.

Northrop Grumman Newport News, unlike the other sectors of Northrop Grumman, does not experience direct competition. No other shipyard in the United States has the capacity to build aircraft carriers. Electric Boat Corporation and Northrop Grumman Newport News are the only two companies in the United States who have the ability to manufacture nuclear powered submarines. The two companies are teaming in the building of the Virginia class submarines in conjunction with each other, which eliminates competition. Therefore, Northrop Grumman Newport News has no competition in the production of nuclear powered submarines and aircraft carries in the United States.

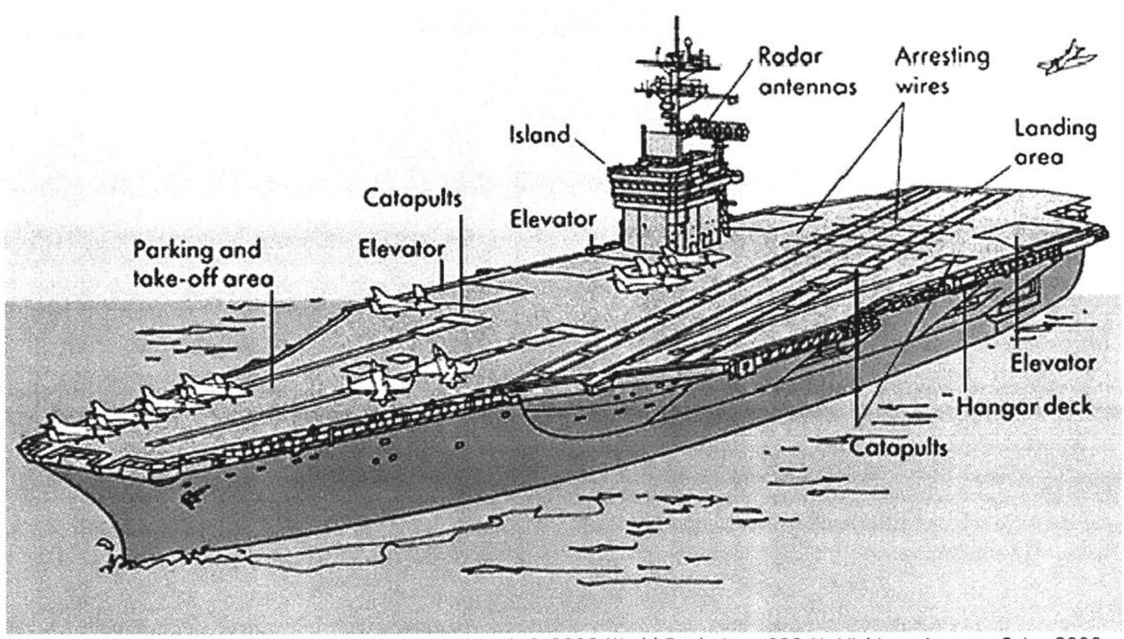
The US Navy enters into a fixed-price contract with Northrop Grumman Newport News for aircraft carrier construction. The nature of the fixed-price contract allows the company to gain cost savings, but also exposes the company to the risk of revenue loss due to excess spending. If the initial calculations used to price the contract are wrong, the company may lose money on the ship. If the aircraft carrier is late with respect to the US Navy's expected delivery date, the company experiences decrease in financial profit. The amount of profit lost is determined based on a financial and schedule overrun according to the share line, which shows the relationship between cost, schedule, and profit loss/gain. US Navy finances the construction of the ship through progress payments, which are provided at various stages of the ship's construction. The payment is based on the weighted average of the engineering and labor hours spent on the design and fabrication, and the cost of the material used for the fabrication. US Navy and the shipyard share the profits, if the ship construction costs less than specified in the contract, and the losses, if the ship cost overruns are experienced. US Navy expects the shipyard to deliver a quality aircraft carrier constructed to the specifications in a timely manner.

1.3 Aircraft Carriers

Aircraft carriers are the largest existing warships in the world. There are 9 operational Nimitz class aircraft carriers currently serving in the fleet of the US Navy with the last Nimitz class aircraft carrier currently under construction with the expected delivery date in 2008. Nimitz class aircraft carriers have two nuclear reactors and four shafts, and an overall length of 1092 feet, width of 252 feet, height of 244 feet, displacement of 97,000 tons, and speed of 30+ knots. Carriers hold approximately 85 aircraft and 5,500 military Navy personnel.

Construction of an aircraft carrier takes about five years and costs approximately $4.5 billion with the expected life of 50 years with one refueling after 25 years. Aircraft carriers are constructed modularly using large units (Superlifts) that are placed in the dry dock and welded together. The ship is made up of 163 superlifts with each superlift weighing up to 900 tons. Approximately 30,000 light fixtures, 1,325 miles of cable and wiring, 1 million feet of pipe, 47,000 tons of structural steel and 1 million pounds of aluminum make up an aircraft carrier. Technological innovations are implemented in aircraft carriers during the construction making no two aircraft carriers identical.

Figure 1-1: Aircraft Carrier



World Book illustration by Robert Keys From World Book

1.4 Newport News Shipyard Lean Effort

Northrop Grumman Newport News' vision for Lean methodology is "to transform the shipyard into a Lean organization so effectively that we will be recognized as the foremost proponent and practitioner of Lean in the shipbuilding industry within three years. Lean will be an accepted 'state of mind' and the entire enterprise will focus on improving customer value by continually improving processes and eliminating waste. Lean will be recognized as a new and permanent way of thinking and part of the shipyard culture".

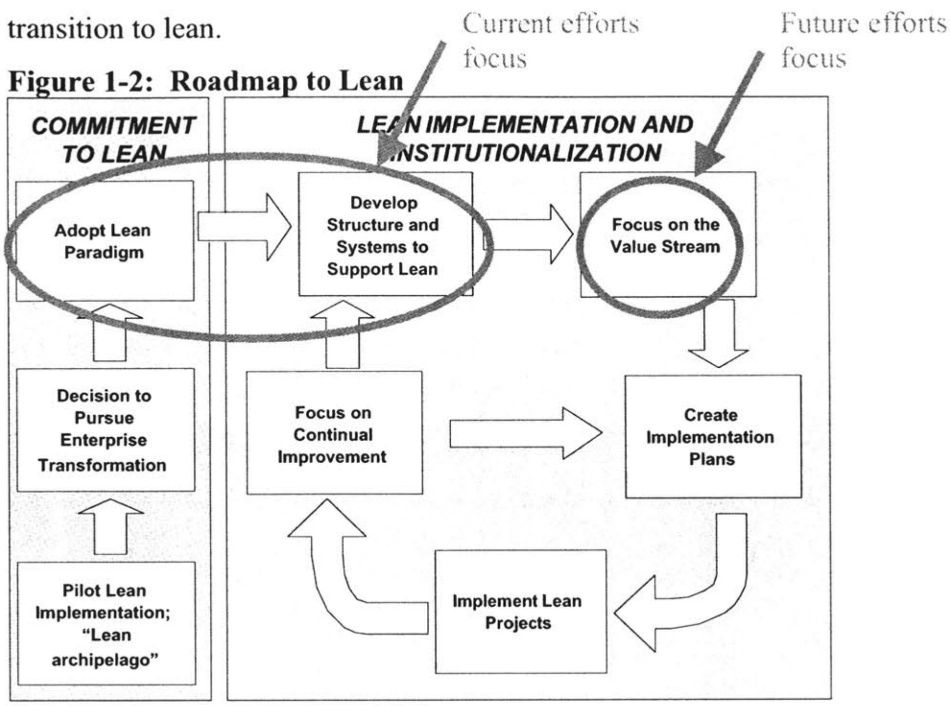
The Road to Lean white paper was created in the beginning of 2003 by the President of the shipyard to capture the strategy for implementation of and to show the sector's commitment to Lean.

A number of shops and various departments started implementing lean principles in the late 1990s. As a result, systems and processes were not standardized and were optimized on the department level, but not on the enterprise level. When Northrop Grumman acquired the shipyard in 2001, its commitment to lean influenced and reinforced the shipyard's lean initiatives. The effort to implement lean on the enterprise level started with the creation of The Road to Lean document. An environment for successful implementation of lean has been created through deployment of cross-functional Lean Implementation Teams with a Lean Implementation Coalition leading the effort. The cross functional teams were chartered with the development of structures and systems to support lean.

A number of lean events, Rapid Improvement Workshops, took place in departments of different areas such as manufacturing, supply chain, logistics, planning, engineering, HR, and finance. These events were geared towards identifying opportunities for improvements and determining steps to fix problems and eliminate waste. Some departments undergo lean qualifications, which are a five-step maturity methodology with step five being fully lean, to ensure full Lean implementation within the department. Some departments have developed criteria for step three and are working hard to move towards Phase III maturity.

Newport News shipbuilding uses a customized version of the Enterprise Level Roadmap (Figure 1), developed by MIT's Lean Aerospace Initiative (LAI), to guide the transition to lean.

Figure 1-2: Roadmap to Lean



A customized approach for deployment of the Lean Enterprise Self Assessment Tool developed at LAI is used to align management on the current state of lean implementation. Current lean efforts are concentrated on the adaptation of the lean paradigm and developing structure and systems to support implementation of lean principles. The focus of the next step is the creation, analysis, improvement, and control of the end-to-end value stream, which motivated the need for the research that is presented in this thesis.

1.5 Thesis Structure

The structure of this thesis is as follows:

Chapter 1: An overview of Northrop Grumman Newport News, descriptions of the business environment with the US Navy as a customer, Nimitz class aircraft carriers, and the shipyard's lean initiative, and an overview of the organization of this thesis.

Chapter 2: Project motivation, scope, goals, objectives, and approach are discussed in this chapter.

Chapter 3: Discussion of lean principles, value stream mapping, definitions of waste, benefits of waste elimination, and application of lean principles in the shipyard.

Chapter 4: Description of the enterprise value stream mapping in the shipyard.

Chapter 5: Discussion of the assembly and detail representation verification in the copper, steel, and assembly pipe shops.

Chapter 6: Data analysis and problem origin identification. Description of the general analysis approach and detailed explanation of each problem origin are provided in this chapter.

Chapter 7: General methodology for conducting value stream maps, which includes understanding the organization, identifying waste, understanding differences between lean in high and low volume manufacturing, identifying data sources, conducting analyses, and performing verification, is discussed in this chapter.

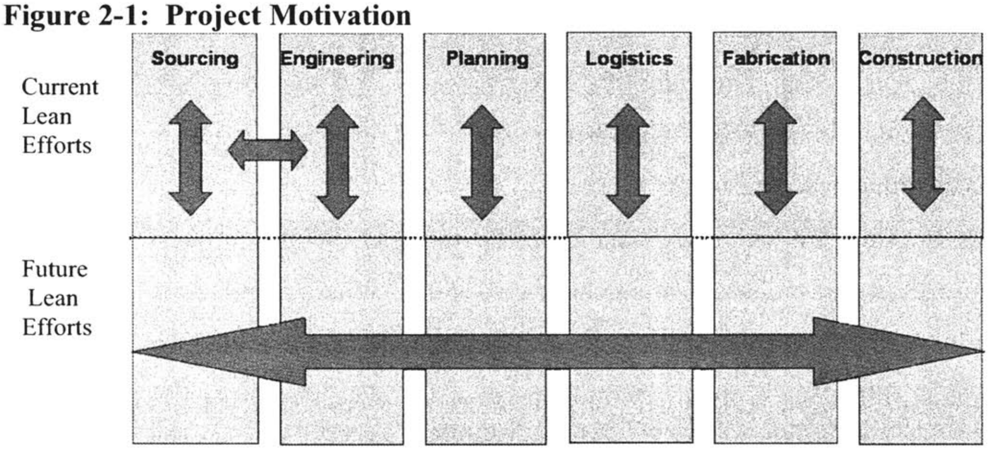
Chapter 8: Discussion of the recommendations, suggestions for the future work and conclusions.

2. Problem Statement and Approach

2.1 Project Motivation and Scope

A current thrust in Northrop Grumman Newport News' transition to lean is the creation of the end-to-end value stream map. The enterprise level value stream map is expected to assist with the current lack of understanding of the systemic complexities that exist among interrelating processes throughout the shipyard. There is some anecdotal evidence that upstream processes cause downstream delays, but very little data to support it. In addition, systems and processes are currently being improved with the help of lean principles on the department level, which results in sub-optimization. In order to ensure full optimization of all the processes in the shipyard, the lean effort needs to be implemented at the enterprise level as shown in Figure 2-1. The effort will increase operational effectiveness by cost and waste reductions and improve process flexibility to ensure shorter reaction time to changes.

Figure 2-1: Project Motivation



The results of the project will be used as a basis for the focus of the future lean projects and initiatives. The project is carried out by an intern who is a student at MIT's Leaders for Manufacturing (LFM) program in six and a half months.

The scope of the project includes the information and material flow for a pipe assembly across all the departments of the shipyard starting with engineering and sourcing and ending with the assembly testing on the aircraft carrier, which is currently under construction. Information and material movements that deviate from the typical flow are not included in the high level value stream map, but major time delays caused by these movements are mentioned and addressed.

An enterprise level value stream map is created by tracing the movement of material and information for a pipe assembly through the shipyard. The assembly chosen as a basis for the value stream map is regarded as representative of most assemblies fabricated in the shipyard. Movement of other randomly chosen parts and assemblies through the shops are tracked to ensure the problems seen with the chosen assembly are also found in other assemblies as well.

2.2 Goals and Objectives

The following are the goals of the enterprise level value stream mapping project:

- Create a global, high level information and material value stream map for the chosen pipe assembly. The value stream map has to be understandable and provide useful visual portrayal of the end-to-end value stream.
- Provide detailed analysis of the major problems uncovered by the data gathering and the value stream map. Identify areas of re-work and inventory buildup and determine their root causes. Gain better understanding of interactions between processes that cause problems.
- Assist the shipyard with understanding its operating challenges, process coordination and synchronization challenges and document insights.
- Provide a set of recommendations to assist with the reduction and elimination of the major time delays, inventory buildups, re-work, excessive processes and other waste in the system.
- Develop methodology for mapping and analyzing enterprise level value streams, assisting the shipyard with advancing its lean capabilities.

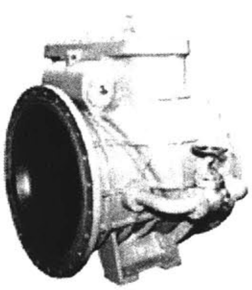
2.3 Project Approach

Enterprise level value stream map is the first initiative to capture part of the processes within the shipyard and their dynamic interactions. Jones and Womack suggest that value stream mapping is intended to segregate operational issues to the level of specific products, which are grouped into a product family. A product family is a set of products that undergo similar processing and use common equipment. In the process of identifying the basis for the value stream mapping effort, project sponsor's team considered families of pipe, valves, and fittings to serve as the basis for the enterprise value stream map of the shipyard. However, the families of one type of component excluded a number of processes occurring in the shipyard on regular basis. For example, valves are normally installed without alterations, thus bypassing most manufacturing processes in the shipyard. A suitable unit to serve as a basis for the value stream map needs to contain a variety of equipment and fittings. Therefore, a pipe assembly is chosen to serve as a basis for the enterprise value stream map.

A pipe assembly consists of valves, fittings, and pipe and flows through a number of fabrication facilities. Examples of gaskets, valve, and a pipe assembly are shown in Figure 2-2. A pipe assembly was chosen to be traced from 'cradle to grave' because this effort captures most processes and their interactions taking place in the shipyard. The pipe assembly can be broken down to and tracked at the detail level, therefore providing a workable model for the value stream map.

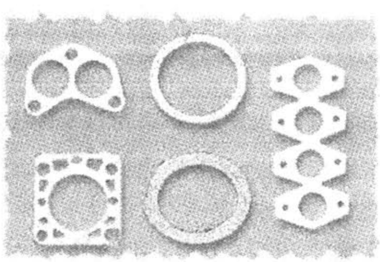
Figure 2-2: Images of Fittings, Valves, and Pipe

Valve

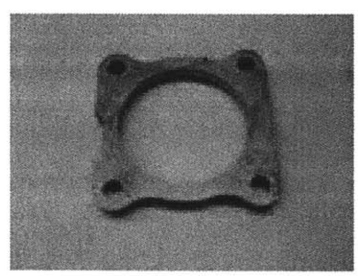


Elbow

Gaskets

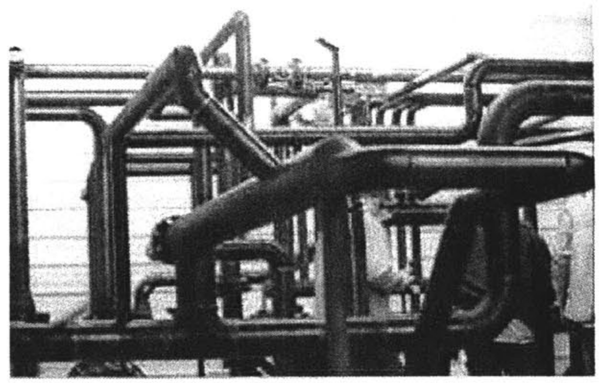


Flange



Pipe Detail

Pipe Assembly



Source: www.google.com/images

A pipe assembly for a newly developed system that has never been employed on an aircraft carrier was chosen as the basis for the enterprise level value stream map. This assembly, referred to as Assembly I, was selected with the help of two Production Engineers each with 40 years of experience working in and managing numerous pipe shops in the shipyard. The engineers believe that Assembly I is representative of most pipe assemblies fabricated in the shipyard. Thus, challenges experienced with manufacturing and flow of the selected assembly apply to most pipe assemblies in the facility. Section 6 of this thesis provides data that establishes commonality of the problems experienced with the chosen assembly with a number of other pipe assemblies fabricated in the shipyard, showing that Assembly I is representative.

The enterprise level value stream map creation requires extensive data gathering from every department that is involved with the design, fabrication, and provision of information to support the manufacturing of the chosen assembly. Interviews were conducted with a representative from each department to understand his/her involvement with the chosen assembly and determine touch and process time values. Most data associated with information and material flow within the pipe and assembly shops was drawn directly from the Management Resource Planning system (SAP) utilized by Northrop Grumman Newport News. In this thesis, all numeric information has been modified to conceal proprietary data without skewing actual patterns to portray trends within various processes.

3. Review of Key Concepts

3.1 Lean Principles

Lean theory was developed and implemented in the Toyota Motor Company in the early 1970s. In an organization that follows lean principles all the employees are focused on finding and removing all the sources of inefficiencies and waste in all the areas of the organization. (Bozdogan, et al., 2000) Womack and Jones identified five principles of lean:

- *Specify value*: identify the right product for the customer, provide the product at a good price and in timely manner
- *Identify Value Stream*: determine actions needed to bring the specified product through three business management activities: problem-solving, information management, and transformation.
- *Flow*: continuous movement of process steps that bring value to the customer
- *Pull*: allowing the customer pull to the product as needed as opposed to pushing unneeded product onto the customer
- *Perfection*: continuously improving business operations by enhancing value, value stream, flow, and pull

Two strategic concepts in addition to Womack and Jones' five principles have been identified by the MIT's Transition-To-Lean (TTL) Team to capture the nature of lean. The two concepts are:

- *Horizontal Organizational Focus*
- *Relationships Based on Mutual Trust and Commitment*

In addition to the lean concepts and principles mentioned above, MIT's Lean Aerospace Initiative (LAI) has developed five principles of Lean *Enterprise* Value (Murman, et al., 2002):

- Create lean value by doing the job right and by doing the right job
- Deliver value only after identifying stakeholder value and constructing robust value propositions
- Fully realize lean value only by adopting an enterprise perspective
- Address the interdependencies across enterprise levels to increase lean value
- People, not just processes, effectuate lean value

3.2 Value Stream Mapping

A value stream map is a tool—often created using a pencil and paper—that assists with the understanding of the flow of material and information. The map tracks a product as it moves from one process step to the next, from its origins at the suppliers to the final end customers. (Rother and Shook, 1999) A product group, which consists of parts that undergo similar processing on a common set of equipment, should be selected for the creation of the value stream map. (Jones and Womack, 2002)

Rother and Shook (1999) summarized the benefits of value stream mapping.

- Assists with visualizing the flow across the entire process
- Assists with identifying sources of waste
- Provides universal language for talking about processes
- Provides common view point for effective decision making
- Unites lean techniques and principles to ensure an efficient approach to problem solving
- Provides a baseline to work from during lean implementation
- Shows interactions between information and material flow, which is unique to this tool
- Describes in quantitative and qualitative detail how the facility operates and how it should operate to ensure flow.

3.3 Definition of Waste and Benefits of Waste Elimination

Identification and elimination of non-value added steps in all the processes of an enterprise is the essence of the lean enterprise. Womack and Jones divided waste, or muda, into seven categories

- Errors that require rework
- Production of unneeded goods
- Excessive processing steps
- Unnecessary people, material, and information movement
- Idle people, machinery, or material

- Manufacturing products and rendering services which do not meet customer's needs
- Excessive inventory

Benefits of waste elimination improve overall efficiency of an enterprise. The following benefits are observed when waste is eliminated (Bozdogan, et al., 2000).

- Improvement in responsiveness to customers, decrease in quality defects reaching customers, decreased cycle time
- Improvement in manufacturing floor organization and overall reduction of floor space
- Labor productivity increase
- Simplification of production and information control systems
- Timely arrival of shipments from the supplier
- Reduction of warehouse space
- No finished goods inventory build up
- Reduction in inventory levels across the value stream

3.4 Application of Lean Principles in the Shipyard

The external customer of the shipyard is the US Navy. The internal customers are the trades that perform the outfitting and fabrication of the ship, therefore all the information and material flow should be scheduled to satisfy the ship need dates. Examination of the value stream map shows that every process' customer is the process found downstream from it, with information supporting all the manufacturing processes.

Lean implementation in the shipyard to this point has occurred in functional areas and not across the enterprise as a whole. This can result in sub-optimization of various processes. No personnel are responsible for tracking the progress of a system or an assembly as it travels through all the process steps. Thus, it is difficult to identify and fix obstacles to fabrication completion that stem from interdependencies across multiple departments. The lean principles and enterprise value principles should be applied to all the processes along the value stream to improve the enterprise efficiency and effectiveness.

> "In addition to creating and delivering value to end-use customers, there are many stakeholders involved in an enterprise, including employees, suppliers, shareholders, labor unions (if any), and society." (Nightingale, et al., 2003)

The needs of the downstream process, as an immediate customer, should be identified at each step of the process keeping in mind the needs of the ship, as the internal customer, and the US Navy as the external customer. Value stream identification across the entire enterprise is necessary to identify all the value added steps. The enterprise level value stream map described in this thesis is an effort to identify the value stream in the shipyard.

Continuous flow and pull are necessary for smooth operations of production in the shipyard. The two concepts are difficult to implement considering the shipyard's job shop environment and push mentality. All the processes across the value stream should always be in a state of continuous improvement to achieve perfection. Horizontal organizational focus should be maintained to ensure optimization of the entire value stream as opposed to the sub-optimization of individual process steps. Relationships based on mutual trust and commitment should be reinforced and the decision making power should be transferred to the personnel on the production floor with engineering and planning providing support to the personnel in the shops, platen, and dry dock.

The shipyard can benefit from the elimination of the wastes described in Section 3.3. The US Navy often changes the specifications for different systems at the time when the system is being worked by engineering and planning. Adoption of lean principles and elimination of waste will allow the shipyard to be more flexible and respond to the US Navy changes faster. Also, when errors, which need to be fixed upstream, are found downstream, the response time will be shorter and less costly due to the robustness of the enterprise as a whole.

The shipyard, unlike a high volume manufacturer, does not benefit from overall process cycle time reductions. The delivery of the ship to the US Navy needs to take place on the day when the US Navy requested the delivery of the ship. If the carrier is delivered early, the US Navy will not accept the product and the ship will remain sitting in one of the dry docks with large overhead dry dock costs. If the carrier is delivered late, the shipyard loses part of its profit due to the untimely delivery and penalties. However, it is important that the cycle times of the individual processes comprising the enterprise are shortened to absorb uncertainty. This will provide the enterprise with flexibility and predictability that enables the shipyard to meet schedule commitments consistently.

The remaining benefits listed in Section 3.3 fully apply to the shipyard. Reduction of inventory, improvement of manufacturing floor organization, reduction of warehouse space, etc. would significantly boost the efficiency and effectiveness of the shipyard.

4. Value Stream Mapping Literature Review

Many manufacturing companies, such as Boeing and American Axle, concentrate efforts and devote resources to implementing lean in their factories. Different approaches are used to create current state value stream maps. The theory, approaches, challenges associated with each approach, and typical outcomes are examined and compared in this section.

4.1 Value Stream Current-State Map Creation Process

Rother and Shook (1999) describe the current-state value stream map creation process in their book, Learning to See: Value Stream Mapping to Add Value and Eliminate Muda. The authors use a simple example to explain the nuances of the current-state map creation process. The following are some of the important aspects to a successful value-stream map creation:

- Always collect current-state information while walking along the actual pathways of material and information flows yourself.
- Begin with a quick walk along the entire door-to-door value stream.
- Begin at the shipping end and work upstream.
- Bring your stopwatch and do not rely on standard times or information that you do not personally obtain.
- Map the whole value stream yourself.
- Always draw by hand in pencil.

These tips are provided to make sure that the creator of the current-state map understands the whole flow, obtains accurate information, and begins with the processes that are closely linked to the customer. Utilization of these tips when creating the current-state value stream map is discussed in Section 4.4.

4.2 Boeing 717 Final Assembly Line

Victoria Gastelum (2002) used heuristic approach when creating a value stream map for Boeing 717 final assembly line. The heuristic approach was used to bypass the utilization of mathematical models due to the lack of all the required resources. Gastelum assembled a team of industrial engineers from the Airframe, Systems, and Interiors areas, which constituted the final assembly line. The engineers had a good understanding of the key steps and requirements that needed to occur in their respective areas to complete the construction of the plane in the efficient and timely manner. However, there was a lack of understanding of the step sequence across the entire final assembly line.

The construction of the current state value stream map for the Boeing 717 final assembly line occurred over the period of one and a half months. The first step of the final assembly value stream map creation occurred with the engineers constructing a value stream map of their area, and then linked the value streams from each area. The step sequence was printed on a large paper scrolls and then posted on the wall. This assisted the engineers with the understanding and visualization of the interrelations between all the steps occurring in all three areas.

All the process steps across the final assembly line were divided into five families based on the constraints, such as physical space or location, associated with each step. The engineers provided the touch and cycle times for each step. The most challenging part of the value stream map creation process was dealing with the changing sequencing nature of the steps and/or constraints, such as design specifications or space constraints, across the value stream.

Value stream mapping effort assisted the management and engineers with the understanding of the main drivers of the flow time, planning of the next rate break, and implementing consequent lean tactics and methods.

4.3 American Axle Tonawanda Forge Facility

Stephen King (2004) performed a value stream mapping exercise at American Axle Tonawanda forge facility for a family of the ring gear and net shape gear product lines. Management looked to understand the product value stream in the forge facility as well as to use the obtained information to optimize the extended value stream. King used a hybrid approach to value stream mapping, which he defined as "a process of directly observing the flows of information and materials as they occur in the entire manufacturing system, summarizing them visually, and the envisioning a future state with improved performance". The product family was chosen based on the commonalities of the manufacturing processes.

The first steps of the King's value stream mapping process consisted of determining the strategy of the organization for the product family and the scope of the mapping exercise. The value stream map included all the processes starting with the raw steel supplier and ending with the customer's assembly plant. King created value stream maps for the gear product family processing facilities that were controlled by American Axle. King utilized a database to extract the needed information for all the process steps performed in the Tonawanda Forge Facility. Then, he interviewed the operators, first line supervisors, and engineers to determine accuracy and applicability of the information found. Through these informal interviews, King also determined the perceived problem areas from the staff's vantage point. Finally, King interviewed senior staff such as plant, material, and business planning managers to find out large scale issues applicable to the entire facility.

The external value stream map creation process started with King sending out questionnaires to determine key process and information flow parameters to the suppliers. Once the questionnaires were completed, King visited every supplier's site to verify, discuss, and find additional needed information. The customer value stream maps were created in the same manner as the suppliers'.

The created Tonawanda value stream maps were connected to each other and to the external companies' value stream maps to form an extended value stream map. The entire current state value stream mapping process took approximately a month.

4.4 Comparison of the Value Stream Mapping Processes

The three value stream map creation processes at Boeing, American Axle, and Northrop Grumman differ from each other and from the theoretical approach discussed in

Section 4.1. The differences and similarities between the theoretical and actual value stream map creation processes are discussed in this section.

The boundaries of the value stream maps created in each company varied significantly. The value stream map created for the assembly line at Boeing had smaller boundaries than the value stream map created for Northrop Grumman's shipyard. The value stream map for the Northrop Grumman shipyard had smaller boundaries than the entire forge facility, its supplier and customer sites at American Axle.

Northrop Grumman's enterprise value stream map was created through the interviews of representatives from various departments along the value stream. Some of the numeric information was extracted from the MRP system. The detailed description of the enterprise value stream map created at Northrop Grumman Newport News is provided in the next chapter.

Rother and Shook suggest collecting current-state information while walking along the actual pathways of material and information flows and map the whole value stream yourself. This is a challenging task in many companies, because information and material flows are very extensive. However, it seems that the benefit from understanding the entire value stream for the chosen product family is invaluable. One person was dedicated in each company to create the entire value stream map. Each individual utilized the knowledge and expertise of other personnel working in different areas along the value stream to create the maps. Therefore, the persons responsible for the value stream maps in each company understood the entire flow for the chosen product family.

Another tip discussed in Section 4.1 is to begin the value stream mapping process by a quick walk along the entire value stream. Although the door-to-door walk provides a great sense of the flow and sequence, it is not always feasible to walk along the entire value stream. At Northrop Grumman, some difficulties were experienced when identifying information part of the value stream. In order to understand the functions of different departments involved with the information creation for the chosen product group, extensive interviews had to be conducted with its' members. Therefore, it would not be possible to determine which departments were part of the appropriate value stream through a quick walk. When creating a value stream map for the American Axle's forge facility and its customer and supplier sites, it would be difficult to conduct a quick walk due to the extensive boundaries of the value stream.

Rother and Shook suggest starting the value stream map creating process at the shipping end and then move upstream. At Boeing, the value stream map process considered all three assembly areas simultaneously. At Northrop Grumman, the process started at the fabrication shops, which are located in the middle of the value stream. At American Axle, the value stream map creation process started at the forge facility and then was extended to the customer and supplier sites. It appears that the value stream map creation process in the companies is easier to start in the areas that are easily accessible, which do not always correspond to the shipping end. For example, at Northrop Grumman the shipping end is considered to be the dry dock where the aircraft carrier is assembled. Starting value stream map creation process there would be very challenging due to the complexity of the product and difficulty of the accessibility of the chosen product family.

Another tip provided by Rother and Shook is bringing a stopwatch and not relying on standard times or information that is not personally obtained. In all three companies the information was obtained either through interviews or through MRP systems, without the use of the stopwatch. The value stream maps were so extensive that it would take a long time to measure all the functions with a stopwatch. In a job shop environment, such as in the Northrop Grumman's shipyard, it is not necessary to determine the times accurately, since most jobs are rarely repeated. It is necessary, however, to determine the typical times to understand where the majority of the waste is located along the value stream. Also, it is difficult to use stopwatch to time some functions, such as engineering drawing design, which takes weeks to complete. Of course, it is important to ensure that the information drawn from sources such as a MRP system are reliable.

At times, those jobs that can be timed are not easy to time correctly. For example, during an initiative at one of the companies, some jobs were timed with a stopwatch. Later, it was found that the workers slowed down their pace to ensure that the time measured would be larger than the typical time it takes to complete a job. This was done to introduce some buffer time into the total job time. This buffer time is used to deal with jobs that are more difficult than typical or if a problem with a typical job is encountered. This way, if the job takes longer than the measured time, the workers do not get reprimanded. Also, if the jobs are completed faster than the measured time, the workers benefit from the early job completion.

In the summary, some of the theoretical ideas regarding the value stream map creation process are difficult to use when creating value stream maps in a company. Different methods are used to create value stream maps in different companies and depending on the boundaries of the process for which the value stream map is being created, the accessibility of information, and the complexity of the process itself.

5. Value Stream Mapping at Newport News Shipbuilding

"The way that ships, and most other manufactured artifacts, are actually produced is by procuring or fabricating parts and joining them to create subassemblies. In turn, these are combined through several manufacturing levels to produce increasingly larger subassemblies. Thus, the ideal way to subdivide ship-construction work is to focus on needed parts and subassemblies, i.e., the actual interim products that preoccupy workers. A scheme to subdivide work in accordance with an interim-product view, is a product-oriented work breakdown structure" (Okayama, 1982)

In this section, the process of enterprise level map creation for Assembly I am described. High level and detailed enterprise value stream maps are shown in Exhibit 2 and Exhibit 3, respectively. List of all the icons used in the value stream maps is shown in Exhibit 1. A walk through the copper, steel and assembly pipe shops was the starting point of the creation process. Julie Wilhelmi (2001) started her value stream mapping effort in the factory as well when creating a value stream map for Boeing 777's outboard stowbin. The next steps involved meeting with and interviewing representatives from upstream departments such as planning, engineering, and sourcing to determine their amount of involvement with the Assembly I's design, development, and planning. Information obtained from these departments is a rough estimate since no systems exist to capture the baseline on the exact amount of time spent on the performing functions associated with Assembly I. Most data captured for the material and information movement and fabrication through the shops is extracted from SAP. All of the values have been changed to prevent the disclosure of proprietary information with all the trends remaining true.

During the process of interviewing and data gathering, it became apparent that perception on how in the process works differs between management and the practitioners of the process. The process of implementing the improvements requires the alignment of the understanding between all the parties involved.

5.1 Customer, Contracts and Pricing, Engineering, Sourcing, and Suppliers

Customer, Contracts and Pricing, Engineering, Sourcing, and Suppliers work closely with one another to set up and price the contract, design the systems, and order the material. Times associated with each department's involvement in various functions are roughly estimated due to the challenge of separating each department's level of participation.

5.1.1 Customer and Contracts and Pricing

The entire process is initiated by the customer, the United States Navy, deciding to purchase an aircraft carrier. The first step in the process is the U.S. Navy's submittal of the Request for Proposal (RFP), which outlines and describes system requirements for the aircraft carrier, to Northrop Grumman Newport News' Contracts and Pricing department. The current carrier is the first aircraft carrier that the Navy submitted a Contract Plan for, which roughly described specifications and requirements for the carrier, a few years prior to the release of the RFP. The provision of the Contracts Plan greatly assisted Northrop Grumman Newport News with timely review of the RFP.

Personnel from Contracts and Pricing involved numerous departments throughout the shipyard such as engineering, manufacturing, sourcing, etc. to evaluate the requirements described in the RFP. The design of numerous systems with some alterations was transferred over from the previous aircraft carrier. Some of the systems, such as System I, which Assembly I is part of, were unique to the current carrier. Once the RFP was evaluated and priced, Contracts and Pricing submitted the Proposal to the Navy. The Navy's personnel evaluated the Proposal, which initiated negotiations between the Navy and Northrop Grumman Newport News' Contracts and Pricing department. When negotiations were completed, the base contract between the U.S. Navy and Northrop Grumman Newport News was signed.

System I was not part of the RFP and was proposed by the shipyard's engineering as an Engineering Change Proposal (ECP). The ECP is a vehicle for evaluating and presenting design changes to the customer in a standard manner. The ECP was evaluated, priced, negotiated, and accepted prior to the signing of the Base Contract. System I ECP became part of the Base Contract and the values, such as costs and time associated with its development and negotiation, could not be extracted from the values associated with the Base Contract. The enterprise level value stream map captures the time interval from the

RFP submission to the Base Contract signing and not just System I ECP, which is equivalent to eighty weeks. Value added time for the System I could not be determined due to the complexity and size of the base contract.

5.1.2 Engineering

The engineering department is comprised of system and production engineers and designers. System engineers are heavily involved with the proposal preparation and once the contract is signed, they initiate the development of the aircraft carrier on the system level. The conceptual design effort results in a two-dimensional system diagram for each pipe system where major pieces of equipment, sizes, and flow directions are identified. System diagrams are checked by other system engineers to ensure all the calculations and design to specifications are correct. System engineers work with vendors to obtain vendor equipment drawings based on the requirements captured in the system diagrams. Next, system diagrams are released to the Navy for the approval and after the approval is received, the engineering supervisor for the system approves and releases the system diagram.

After all the necessary approvals are received, the System I diagram, along with vendor equipment drawings, is released by system engineers to the modeler. The modeler inputs and creates a three-dimensional drawing of each piece of equipment, fittings, and pipe into a program used by designers, who create a preliminary three-dimensional arrangement drawing to ensure the system fits into the designated space on the ship. To create a producible design, designers work in conjunction with production engineers to break down the system into assemblies, details and loose parts. Once the system break down at the assembly level is complete, assemblies are further broken down into details and loose parts and then details are broken down into parts. The two production engineers, who helped with the selection of the Assembly I, were heavily involved with the system break down. Production engineers use their shop fabrication and ship experience to ensure the system is optimally designed to allow efficient fabrication on the shop floor. They group parts into assemblies and details and provide a sequence sheet with the description of group boundaries to designers who then create engineering bills of material (EBOM). System engineers check designers' and production engineers' arrangement drawings to make sure no mistakes were made. After, system engineers submit the Planned Independent Requirement (PIR) to sourcing to order material. Additional submitted items include drawings, EBOM, and group list to planning which is described in Section 5.2.

The enterprise level value stream map shows system engineering lead time to be 18 weeks with value-added time of 2 week and designer and production engineering lead time to be 18 weeks with value-added time of 12 weeks.

5.1.3 Sourcing and Suppliers

The sourcing department works with various suppliers to ensure the correct material order is placed with the suppliers and the material is delivered on schedule to ensure timely shop fabrication and ship construction completion. Sourcing department personnel, buyers, are organized into sub-groups based on the type of commodity they are responsible for. All the material necessary, pipe, fittings, and blowers, for the Assembly I was ordered by three buyers. Assembly I roughly consists of 10 valves, 5 pieces of pipe, 10 fittings, and 29 details. Each detail consists of 3-5 pieces of pipe and 5-10 fittings.

The material purchasing process is initiated when buyers receive the Planned Independent Requirement (PIR), which contains the material description, quantity, and specifications from system engineers for all material. Next, the buyers create a Request for Quote (RFQ) using the information provided in the PIR and submit it to the appropriate supplier. The supplier evaluates the RFQ and returns a quote with the dollar value and the estimated delivery date. Prior to submitting a purchase order to the supplier, buyers make certain that the quote contains all the correct information and check the adequacy of the estimated delivery date. Once the purchase order is received, the supplier submits the software report, which consists of all the associated paper work, such as engineering reports and drawings, accompanying the material ordered, to the buyer. All the software associated with new or unique material is submitted to the material engineers to ensure the material satisfies the navy specifications and shipyard's requirements. Software approval can be a lengthy, iterative process between the engineers, suppliers, and buyers. Once the software is approved, the supplier starts material manufacturing. All the material required for Assembly I fabrication is ordered in parallel with the longest ordering process duration of approximately 30 weeks with 2.3 week of value added time.

5.2 Planning and Warehousing

Engineering completion of the design and drawing breakdown triggers the planning departments to initiate their five-tier planning process. The process includes creating assembly groups, detail grouping and attaching material in the MRP system, and developing a detailed schedule for all the shops to ensure timely assembly fabrication completion, and initiating the material flow.

5.2.1 Advanced Planning, Grouping, and Production Planning

The first tier of the five tier planning process is advanced planning. During the assembly's or detail's drawing break down process, production engineers place a request to advanced planners to create a group number in a database for the assembly or detail. The assembly's unique group number shows the aircraft carrier number that the assembly is designated for, the cost class, and the assembly's location on the ship. Advanced planners create the group number in the database and transmit the number to the production engineers. Once production engineers complete their break downs and the designers complete the drawings, they pass the assembly and its detailed drawings, EBOM, and the group number to the advanced planners. The planners perform a quality check to ensure the material included in the EBOM matches the material needed as shown on the drawings. If a problem is found, advanced planning returns the information to engineering to resolve the problem. According to advanced planning, they find problems with approximately 50% of the drawings. The time it takes to resolve the issue varies depending on the complexity of the problem and the engineering work load. Once the information is verified, the advance planners pass down the information to a person who transfers the information from the database to SAP, which is used throughout the shipyard.

Grouping is the second tier of the five tier planning process. Grouping is responsible for assigning material to the assembly and detail groups in SAP. Prior to starting the material assignment, grouping makes sure that the correct quantities and part numbers are listed on the drawing. If a problem is found, grouping returns the information to the advanced planning to resolve the problem. If advanced planning is not able to fix the issue, they transfer the information back to engineering for problem resolution. It is not possible to determine the percentage of the information that has to return to engineering or the problem resolution timeline. According to grouping, they find problems with approximately 10% of the information passed down from advanced planning. Once verification is complete, grouping converts EBOM to planning bill of material (PBOM) by assigning quantities and part numbers in SAP for all the parts needed to build an assembly or detail. Grouping is responsible for the detail and assembly routing to the shops. For example, they decide whether the steel or copper pipe shop needs to fabricate a particular detail and route the detail group in SAP to be fabricated in the appropriate detail shop. Once material is attached and groups are routed in SAP, grouping passes the information to production control.

Production control is the third tier of the planning process. The main function of production control is detail and assembly routing through the shops and production package creation. The first step of production control is to check the quality of the information passed down from grouping to ensure an exact match between the drawing and the PBOM. If a problem is found, production control returns the information to grouping for correction. If grouping is not able to resolve the issue, they pass the information back to advanced planning. If advanced planning is not able to resolve the problem, the information is returned to engineering. According to production control, they find problems with approximately 50% of the information passed down from grouping. Once information is verified, production control determines the shop operation steps and sequence that parts need to undergo to be fabricated into a detail or assembly.

As an example, the following is the planning process that a detail, consisting of a bent pipe and an elbow attached to one end of the pipe, undergoes. Production control routes the pipe through the bending operation, where pipe is bent, then through the fabrication operation, where the elbow is tack welded to the pipe, and finally the welding operation, where the elbow is welded to the pipe, completing the detail. Production control uses a target tool to specify target duration for each operation step referred to as the target time. Next, production control performs a simulation in SAP, which takes into consideration the ship need date (SND) and target time, to determine each shops fabrication start and end dates. Production control's last step is to create a planned package, which is a folder containing detail or assembly drawings and the target time sheet. Once finished, production control pushes all the completed planned packages to the MRP controller, the fourth tier of the planning process. The functions of the last two planning steps are described in section 5.2.2.

The enterprise level value stream map shows advanced planning, grouping, and production planning lead times to be 8.4, 3.5, and 6.4 weeks with value-added times of 6, 20, and 16 hours, respectively, including rework.

5.2.2 Shop Planning and Warehousing

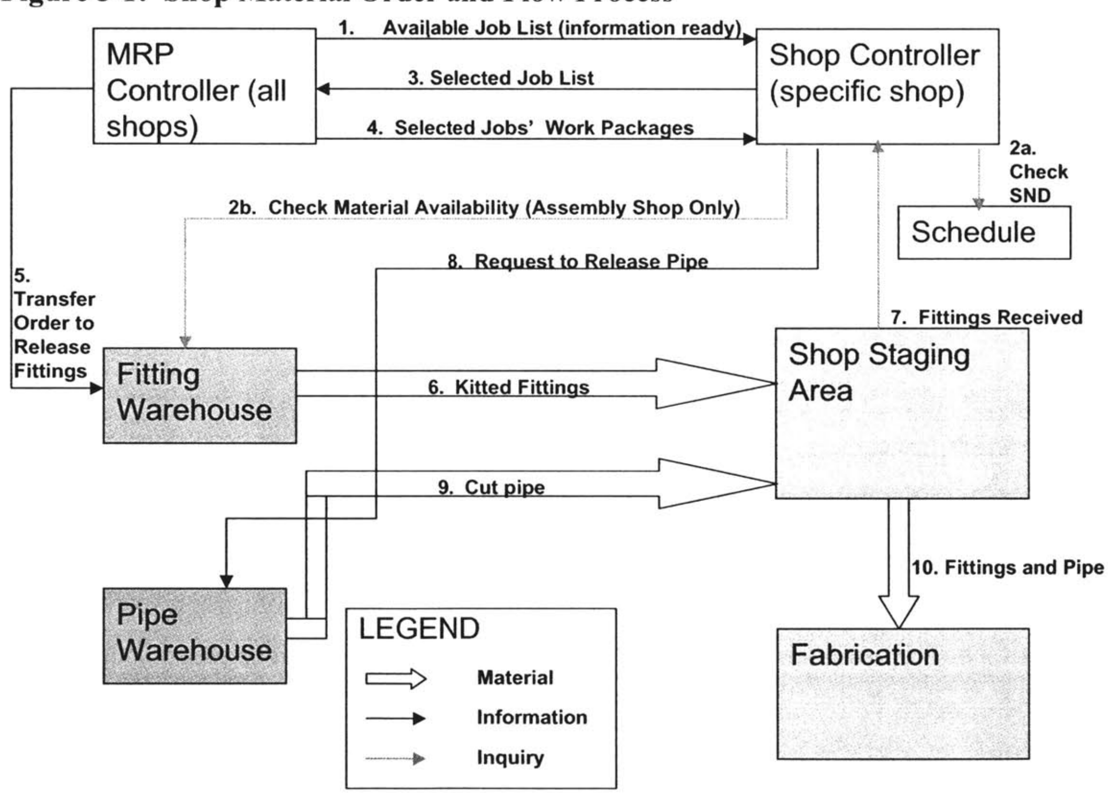
Shop planning and warehousing are highly interconnected processes. Shop planning consists of a MRP controller, who provides information to all the detail and assembly shops, and shop controllers, who are responsible for the material and information flow at each shop. The MRP controller and shop controllers are respectively the fourth and fifth tiers of the five tier planning process.

One part of the Assembly I, a flange, was fabricated in the steel fabrication and machine shops. Part of the process captured in the VSM that involves steel warehouse, steel fabrication shop, and machine shop are not going to be looked at closely in this thesis, since the majority of the Assembly I was fabricated in the pipe fabrication shops.

The MRP controller receives assembly and detail planned packages from the production planners and converts the planned packages into the work packages by adding a break down report. A production order (PO) number is created in SAP for each work package. A detailed breakdown of all the fabrication steps is created for each work package. The breakdown report provides all the detailed information needed for the assembly or detail fabrication. It includes ticket numbers, which are bar codes used by personnel on the shop floor to keep track of the actual time spent on a task. The bar codes are further discussed in Section 5.3. The MRP controller checks to see if the material needed for a detail and assembly fabrication is available in the warehouse. If material is available, the work package is released to the shops and material is committed. Material commitment in SAP signifies the reservation of the material for the specific assembly or detail. SAP prevents another reservation of the committed material to a different assembly. However the inventory level in SAP is not reduced and still shows the committed material availability. If an assembly or a detail that has a higher priority than the assembly with the committed material needs the same material, the material is recommitted. If material is unavailable, the MRP controller contacts the material operations department, 'material chasers', to find the missing material. This process will be further discussed in Section 5.3.

All the information is pushed down the value stream starting with engineering and ending with the MRP control. Shop controllers pull the information provided to them by the MRP controller. General shop material order and flow process is shown in Figure 5-1 and explained in the text that follows the Figure.

Figure 5-1: Shop Material Order and Flow Process



Released assembly and detail work package POs are added to each shop's released job queue list. A separate list of the available jobs is maintained for each pipe shop in a database accessible to both MRP and shop controllers. Pulling the jobs into the shops provides flexibility for the shop controllers to efficiently level load the shops. Shop controllers take into the account need date and material availability as well as the shop floor and work force availability prior to requesting the information and material needed for fabrication of a detail or an assembly. The shop controller provides new planned fabrication start and finish dates, which often differ from the original planned fabrication timeline, based on this information, but the fabrication date still should support the ship need date. Once a shop controller requests the work package, the MRP controller enters new planned fabrication dates into SAP and initiates material flow by sending a transfer order (TO), which specifies material needed and its quantity, to the warehouses. At this point, the material becomes reserved for the assembly or detail. Finally, MRP controller prints out the breakdown report, adds it to the work package, and brings it to the shop. The enterprise level value stream map shows the MRP controller and shop controller lead times to be 4 days and 15.6 weeks, respectively, with value-added time of 4 hours each.

The TOs sent by the MRP controllers enter a warehouse TO queue upon receipt. Assembly I consists of fittings and pipe, therefore TOs were sent to the fitting and pipe warehouses. From experience, shop controllers are aware that the fitting delivery process is not as reliable as the pipe delivery process. Fittings are not always available even if the system shows that they are. Generally, pipe is a lot larger than the fittings, so the shop does not have the space to store the pipe while waiting for fittings due to shop storage area space constraints. Therefore, shop controllers order fittings first, wait for their arrival to the shop, and then order the pipe. Once the pipe arrives, shop controllers release the material and information to start fabrication.

The fitting warehouse operator obtains the material for the TOs on a first come first serve basis with the exception of the priority requests. The operator pulls all the requested fittings from various locations, kits them together in the warehouse, and sends them to the shop. Once the shop receives the fittings designated for a specific assembly, the shop controller places a request via email to the pipe warehouse operator with the request to fill the pipe TO associated with the assembly. The pipe warehouse operator places the request into the queue of other pipe requests that are filled on a first come first serve basis with the exception of the priority requests. The pipe warehouse operator cuts various pipe to the requested lengths, kits the pipe sections in the pipe warehouse, and sends them to the designated shop for fabrication.

Shop material control personnel kits together the pipe, valves, and the fittings, designated for a specific detail or assembly, in the shop staging area and informs the shop controller of the material availability for fabrication. Once the space and personnel becomes available for the fabrication start, the shop controller requests material control to release and deliver the material to the designated space on the shop floor. The enterprise level value stream map shows warehouse operators and material controllers lead times to be 4 weeks and 2 days with value-added time of 2 days and 4 hours, respectively.

5.3 Fabrication Shops

Operations of the steel, copper, and assembly pipe shops are examined in this section. Steel and copper pipe shops fabricate details consisting of fittings and pipe, while assembly pipe shop fabricates assemblies consisting of pipe, fittings, valves and details. In most cases assemblies are considerably larger than details therefore it takes a longer period of time to fabricate assemblies than details.

5.3.1 Steel and Copper Pipe Shops

Steel and copper pipe shops perform similar functions however the two shops are segregated due to the differences in the characteristics of the two metals. The difference in softness of the two metals, with copper being softer than steel, requires the use of special handling techniques for each metal. The copper pipe shop is smaller than the steel pipe shop due to the lesser number of copper details required for the carrier construction.

Detail fabrication in the copper and steel pipe shops usually starts when all the material becomes available. If some material is unavailable, the two shops have a material operations representative whose sole purpose is to find the missing material and ensure its speedy delivery to the shop. Material operators work closely with MRP controller and shop controllers to identify which material is missing. Once identified, material operators work closely with warehouses and sourcing to identify the reason for the material delay and resolve the immediate problem. Once all the material arrives to the shop, detail fabrication starts. The shops perform a number of different operations such as bending, cleaning, fabrication, welding, and joint x-raying. The two shops fabricate details consisting of pipe and fittings or just pipe. Details with associated work packages move from one operation to the next as specified by production control.

Actual time spent on each job is tracked by the bar code system through bar codes, otherwise known as ticket numbers, associated with each operation step that are included in the breakdown report of a work package. For example, a welder scans in the bar code at the beginning of the welding operation step, which starts the count of the actual time spent on welding. When the welder completes the job, the material is moved to the next operation step specified in the work package. Once finished with the first job, the welder moves to the next job and scans in the bar code of the next work package. This stops the time count for the first job and starts the time count for the second job. Total time spent on the welding operation for the first job is now captured by the system. The bar code system is used in the copper and steel pipe shops to determine the touch time for each operation step and total time spent on a job also referred to as an actual fabrication duration. This information is used to determine the correct dollar amount to charge the customer for the work performed.

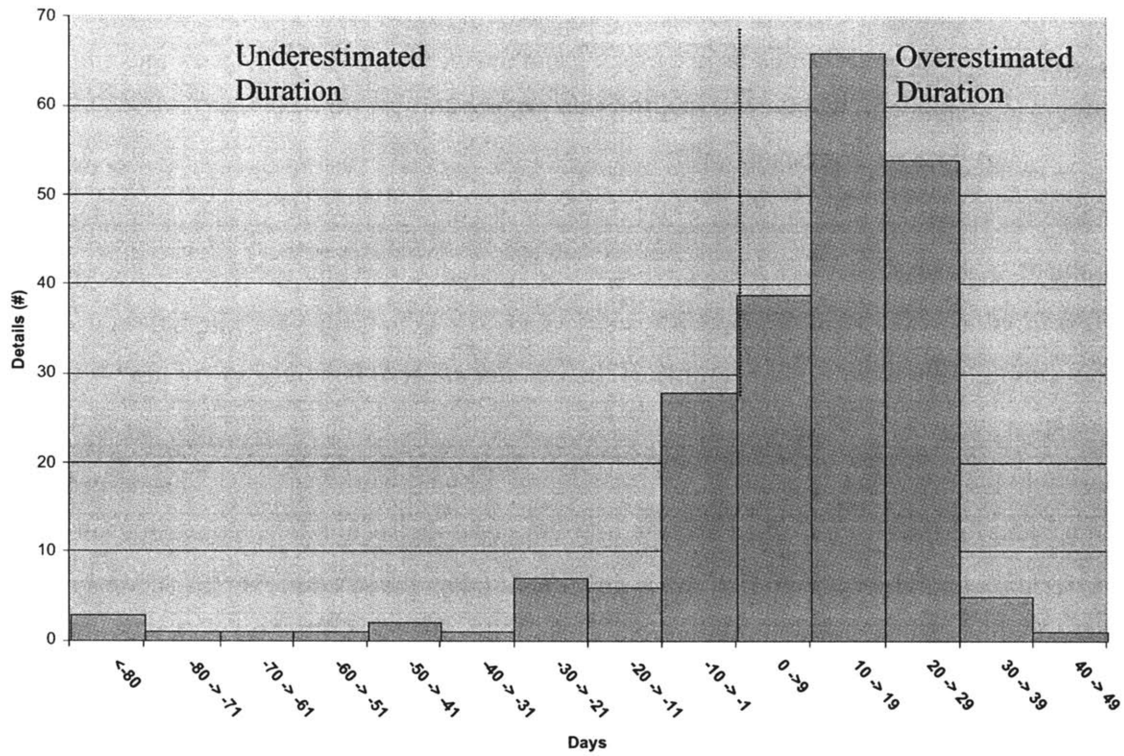
Summary of the details shop planning process is shown in Table 5.2.1.

Table 5.2.1 Copper and Steel Pipe Shops Planning Process

	Step 1	Step 2	Step 3 (Final Schedule)
Department	Production Control	Shop Control	MRP Control
Method/System	SAP Simulation	Email Communication to MRP Control	SAP Production Data
Inputs	-Ship Need Date -Target Tool Estimated Fabrication Duration	-Material and Information Availability -Shop Floor Availability -Personnel Availability	Shop Control Email Communication

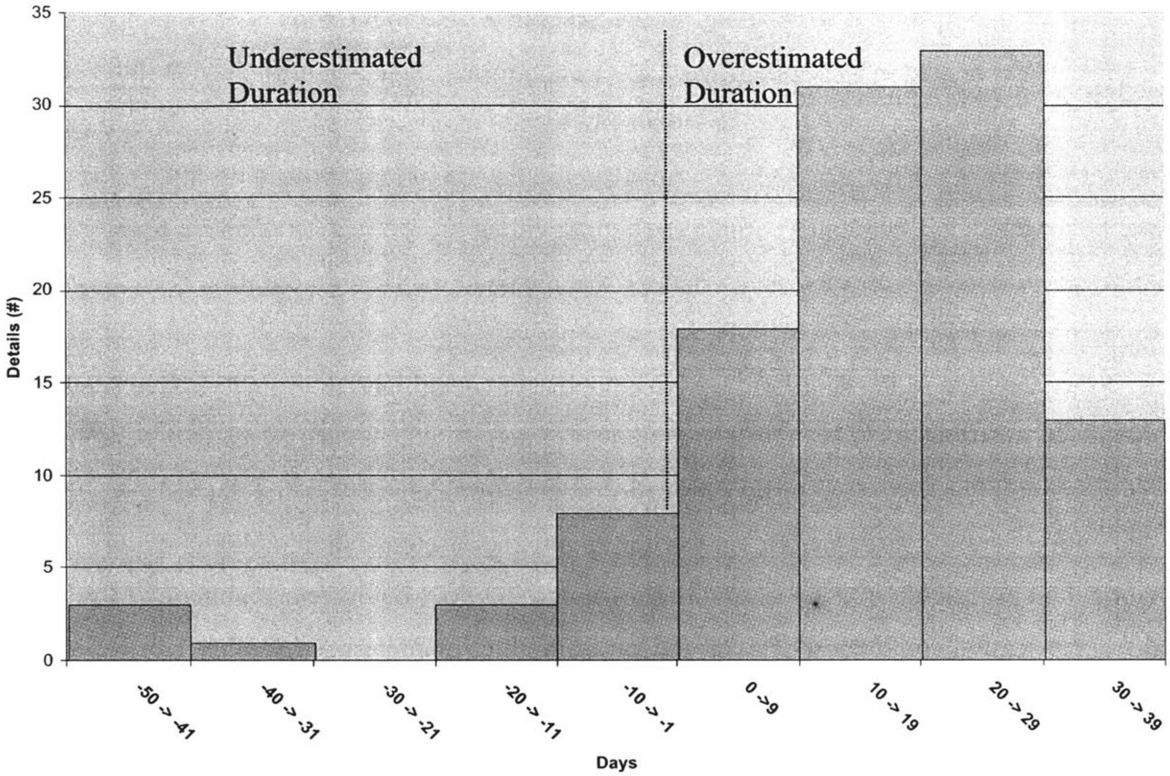
Figures 5-2 and 5-3 show the differences between the planned fabrication duration provided by the shop controller and the actual fabrication duration for copper and steel pipe shops, respectively. Sample size of 112 details, fabricated in each shop, is examined.

Figure 5-2: Copper Pipe Shop Fabrication Duration Variance (Final Schedule)



The histogram shows that the planned fabrication duration is overestimated on average 16 days with standard deviation of 7 days for 70 % of the details, correctly estimated for 16% of the details, and underestimated on average of 27 days with a standard deviation of 25 days for the remaining 14% of the details.

Figure 5-3: Steel Pipe Shop Fabrication Duration Variance (Final Schedule)



The histogram shows that the planned fabrication duration is overestimated on average 20 days with standard deviation of 9 days for 82% of the details, correctly estimated for 9% of the details within 3 days, and underestimated on average of 24 days with standard deviation of 17 days for the remaining 9% of the details.

It is not possible to determine how many details are fabricated in a timely manner to allow the assembly shop to start assembly fabrication on time with respect to the ship need date. No schedule exists, with the exception of the original simulated one, to specify assembly shop need date for the copper and steel pipe shops. Since the original schedule is overridden once the MRP controller changes the dates based on the shop controller's estimation of the new fabrication durations, it is not possible to determine if the detail is fabricated in timely manner.

Although a large number of details is fabricated early in comparison to the planned fabrication completion date, these details still do not meet the assembly shop's need dates.

Detail shop controllers work to completing the detail fabrication within the allowed month once the information becomes available. Detail shop controllers are allowed this flexibility to ensure efficient shop work loading. If the material arrives to the shop as expected, most details are fabricated in a couple of weeks. The controllers have no confidence that the material requested is actually available and will be delivered to the shop within the typical delivery timeline. Thus, detail shop controllers use the maximum allowed duration of five weeks for the detail fabrication timeline when providing the fabrication duration to the MRP controllers. Figures 5-2 and 5-3 show that the detail fabrication duration is overestimated for a lot of the details.

Since the goal of the detail shops is to complete the detail fabrication within five weeks and not to meet the assembly need date, number of details, which varies greatly depending on the assembly, delay assembly's fabrication completion. Overestimated detail fabrication duration introduces great variability into the assembly shop's planning and fabrication process. Since the assembly shop controller does not have an estimate of the detail fabrication completion date, he/she has difficulties planning an assembly fabrication. Recommendations to improve the process are suggested in Section 8.1.

5.3.2 Assembly Pipe Shop

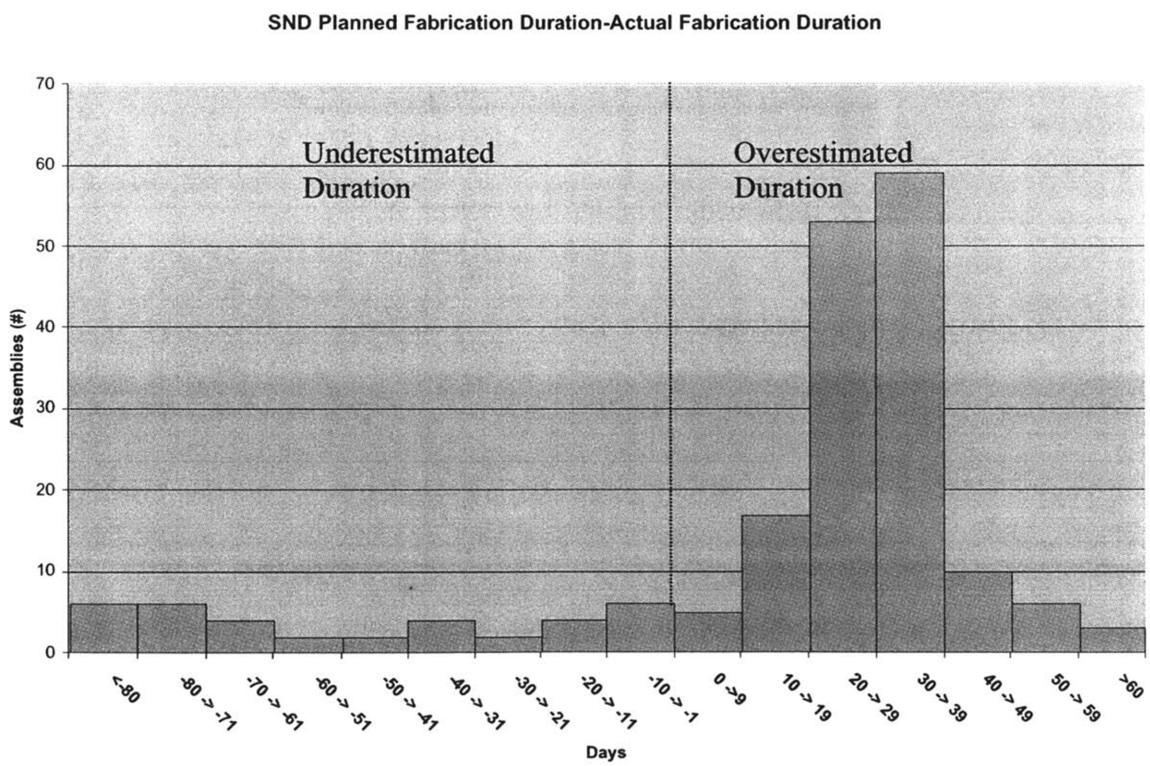
Assembly pipe shop operates differently from the copper and steel pipe shops. Generally, assembly shop starts fabrication when approximately 70% of material becomes available. The reason behind the premature fabrication start is that the shop cannot delay the start of the assembly fabrication until all the material is available to ensure timely job completion according to the schedule. The shop controller anticipates that the unavailable material becomes available during the process of the assembly fabrication before the planned finish date will be missed. The material operation representative dedicated to the assembly shop performs the same functions in this shop as the one in the steel and copper pipe shops. As the delinquent material becomes available it gets incorporated into the assembly.

An assembly is assigned to a specific assembly shop floor space and its fabrication occurs at that designated space from start to finish. The assembly shop uses photogrammetry, which is a digitizing process that estimates the relationship between points to develop a plan for fixture positioning on the shop floor. Photogrammetry allows the assembly shop to fabricate the assembly off the ship in the assigned assembly space with a precise mockup of the ship's space.

Typically, one or two pipe fitters work on one assembly with a welder assisting them as needed. Actual time spent on each operation is tracked using the bar code system in the same manner as in the copper and steel pipe shops.

Original estimate of the assembly fabrication duration changes throughout the planning process. The original fabrication duration is estimated during the creation of the ship construction schedule. This duration is estimated based on the assembly design specifications and the available assembly drawings. Figure 5-4 shows the differences between the original planned fabrication duration estimated during the initial schedule development with respect to the ship need date and the actual assembly fabrication duration.

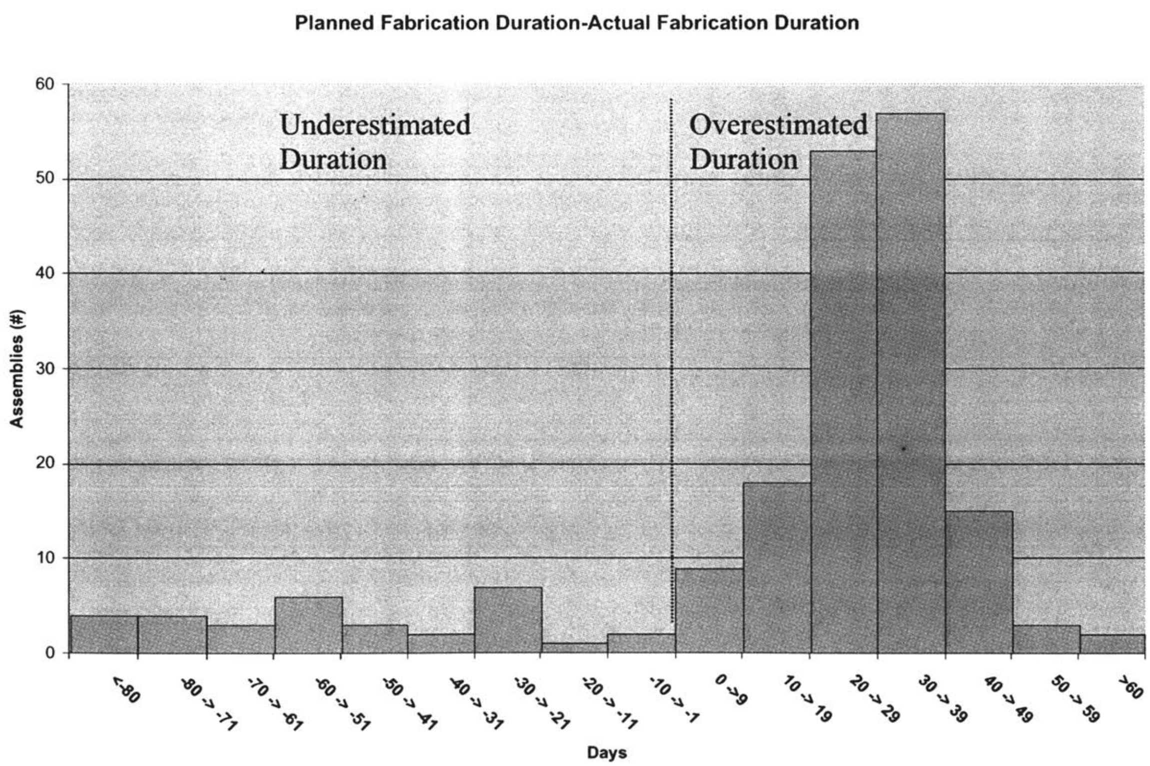
Figure 5-4: Assembly Fabrication Duration Variance (Original Schedule)



The histogram shows that the planned fabrication duration is overestimated on average 30 days with standard deviation of 10 days for 80 % of the assemblies and underestimated on average of 53 days with standard deviation of 40 days for the remaining 20% of the assemblies.

The initial creation of the schedule for the shop fabrication duration is generated through simulation by production controllers in SAP. Target tool, which assigns target time for each operation, and the ship need date are used in the simulation to create the planned fabrication duration. When the shop controller requests a work package, new dates for the fabrication are created, which override the dates created through simulation. The new planned fabrication duration takes into consideration material, shop space, and personnel availability, photogrammetry report, and the ship need date. The final assembly fabrication duration is developed in the same manner as the detail fabrication durations summarized in Table 5.2.1. Figure 5-5 shows the differences between the planned assembly fabrication duration provided by the shop controller and the actual assembly fabrication duration.

Figure 5-5: Assembly Fabrication Duration Variance (Final Schedule)



The histogram shows that the planned fabrication duration is overestimated on average 29 days with standard deviation of 11 days for 83 % of the assemblies and underestimated on average of 50 days with standard deviation of 34 days for the remaining 17% of the assemblies. Figures 5-4 and 5-5 show that assembly planned durations are overestimated similarly to the detail shops as captured in Figures 5-2 and 5-3. Assembly shop controllers overestimate fabrication durations due to the unreliability of timely material arrival to the assembly shop. Majority of the problems come from late details and other material. The problems that result in the assembly fabrication delay are discussed in Section 7.

5.4 Construction

Ship construction occurs on the platen, where Base A and superlifts are built and staged, and in the dry dock, where superlifts are joined together to complete the structure of the aircraft carrier.

On the platen, the Base As are outfitted with electrical and piping system parts and are blasted and painted. Once the platen outfitting is complete, the Base As are joined together to form a superlift. A lot of piping is put in place in the Base A and safeguarded for lifting, but not permanently installed to ensure efficient joining to the systems in the Base A or superlift adjacent to it. A number of pipe systems are hydro and pressure tested on the platen. When all the planned outfitting is completed Base As are fitted and welded together to form a superlift. The superlift is lifted and placed into the dry dock for further outfitting and is joined to its adjacent superlifts. In order to optimize the use of the 900 ton crane and to ensure efficient construction, superlifts that weigh close to the crane capacity are lifted into the dry dock. System testing continues in the dry dock to ensure proper functionality. Once the ship is completed and prior to its acceptance, the US Navy takes it out for the sea trials for testing to ensure the functionality of all the systems.

Majority of the information presented in this chapter is associated with the Assembly I. In Chapter 6, other pipe assemblies' information and material flows are examined to prove that the Assembly I is representative of other assemblies fabricated in the shipyard. In Chapter 7, a large set of the assemblies is analyzed to determine the root causes of the problems preventing the timely assembly fabrication completion.

6. Assembly and Detail Representation Verification

At the beginning of the project, an assumption was made that the pipe assembly chosen to be used as the basis for the value stream map is representative of other pipe assemblies. Therefore, challenges experienced with manufacturing and flow of the Assembly I are assumed apply to most pipe assemblies fabricated in the shipyard. Copper, steel, and assembly pipe shops are chosen as the setting for the analysis because the shops represent the node where information and material flows unite. In this section, assembly and detail representation assumptions are verified.

6.1 Assembly Pipe Shop

Fabrication in the assembly shop usually starts when approximately 70% of the material becomes available as mentioned in Section 5.3. As the delinquent material becomes available it gets incorporated into the assembly.

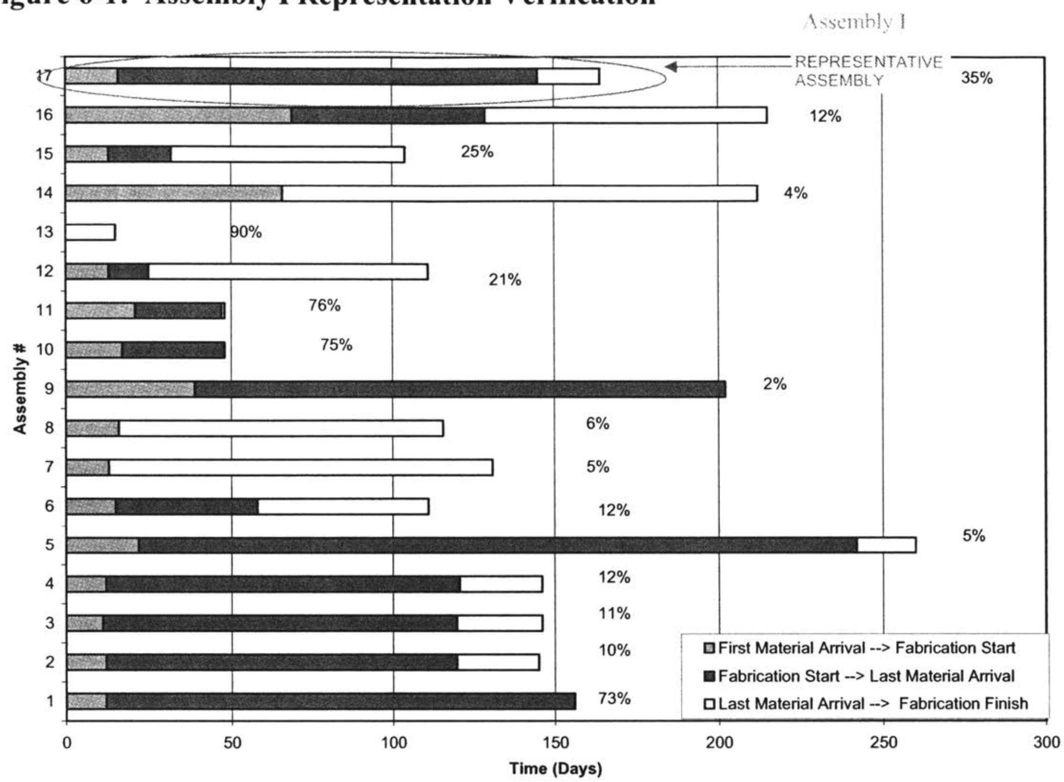
Sixteen assemblies were randomly selected from the list of approximately 50 assemblies that were completed during the same month. All the assemblies are composed of a different number and type of pipe and fittings. Some of the assemblies were completed on time while others were late with respect to ship need date. Information associated with assemblies is always available prior to the start of assembly fabrication. Durations for material flow prior to and during fabrication up to fabrication completion are analyzed to portray chosen assembly's representation in Figure 6-1.

Material flow and fabrication duration is broken down into three intervals:

1. First material arrival date to fabrication start date.
2. Fabrication start date to last material arrival date.
3. Last material arrival date to fabrication finish date.

Assembly I's timeline is shown as assembly #17 at the top of the graph in Figure 6-1.

Figure 6-1: Assembly I Representation Verification



The largest time gap of approximately 150 days represents the time from the fabrication start to the last material arrival date for assembly # 17 (Assembly I). Actual fabrication of the Assembly I was occurring 50 out of the 150 days (35%), while during the remaining 100 days the assembly was sitting idle on the assembly shop floor waiting for delinquent material. The material designated for assembly #17 fabrication was sitting idle on the assembly shop's floor longer than value added assembly fabrication time. Examining the problematic material flow trend for the remaining 16 assemblies, 12 assemblies exhibit the same trend as the representative Assembly I. This shows that Assembly I is, in fact, representative of most pipe assemblies fabricated in the shipyard.

6.2 Copper Pipe Shop

Fabrication in the copper pipe shop usually starts when all the material becomes available. Material flow in the copper pipe shop occurs differently than in the assembly pipe shop as described in Section 5.3.1. The copper shop controller always orders fittings first, and once fittings arrive, the controller orders the pipe. Fabrication starts upon pipe arrival to the shop.

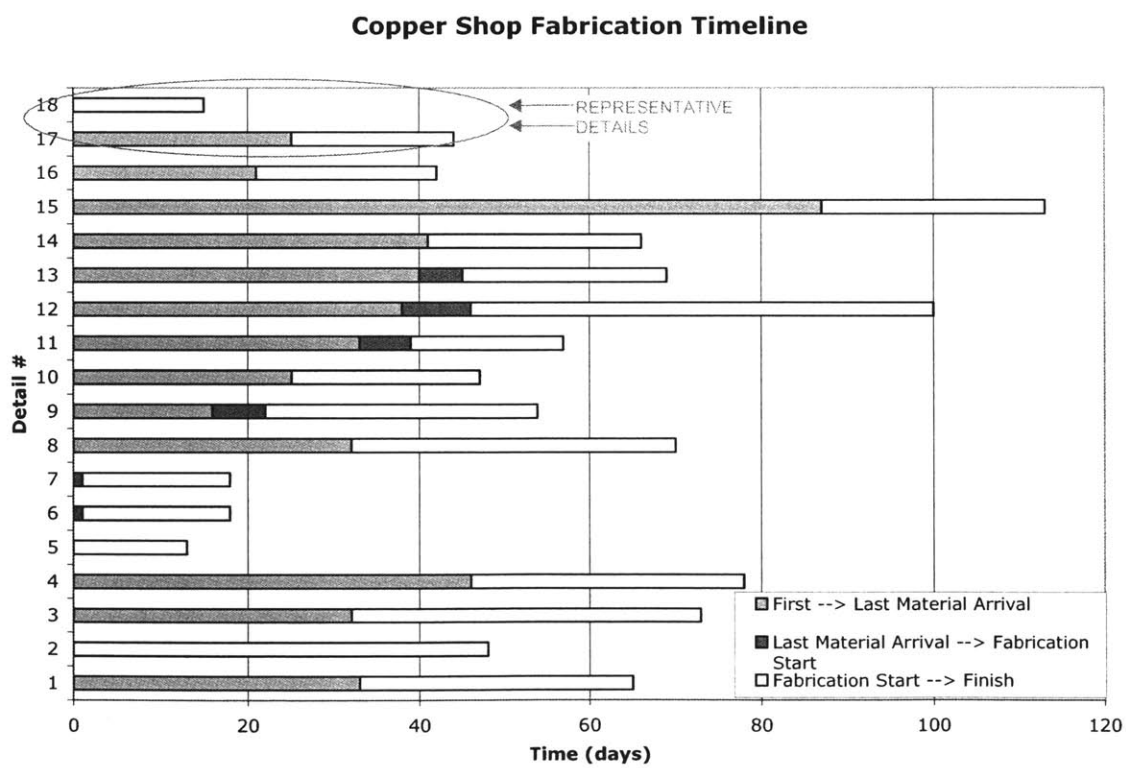
Sixteen details were randomly selected from the list of approximately 40 details that were completed during the same week. All the details are composed of a different number and type of pipe and fittings. Some of the details were completed on time, while others were late. Information associated with details is always available prior to the time of the first material arrival in the shop. Durations for material flow prior to fabrication and up to fabrication completion are analyzed to portray a chosen details' representation in Figure 6-2.

Material flow and fabrication duration is broken down into three intervals:

1. First material arrival date (fittings) to last material arrival date (pipe).
2. Last material arrival date to fabrication start date.
3. Fabrication start date to fabrication finish date.

Assembly I two details' timeline is shown as details #17 and #18 at the top of the graph in Figure 6-2.

Figure 6-2: Assembly I Copper Details Representation Verification



The largest time gap of approximately 23 days represents the time from the first material arrival date to the last material arrival date for detail #17. The material designated for detail #17 fabrication was idle in the copper shop's storage area longer than the detail's fabrication duration. Twelve out of the sixteen chosen details show similar problematic material flow trend.

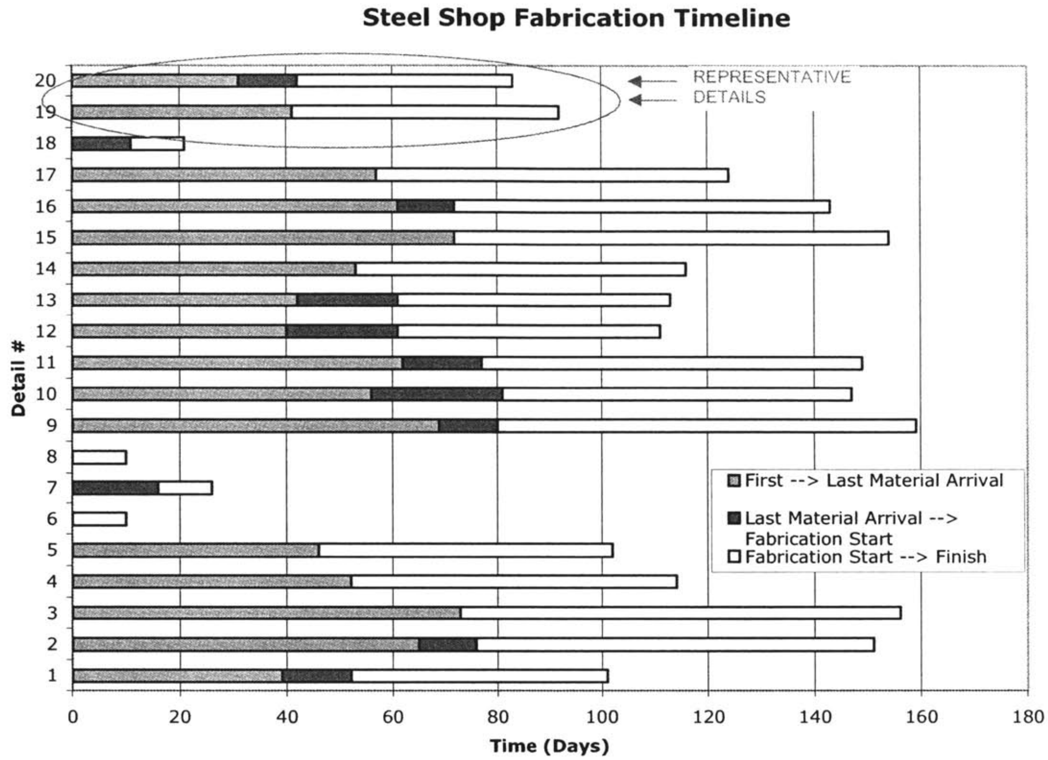
The time gap of approximately 17 days represents the time from fabrication start to fabrication finish for detail #18. All the material designated for detail 17 fabrication arrived at the same time. The remaining 4 details out of the chosen 16 follow similar unproblematic material flow trend. Therefore, majority of the time was spent on the detail fabrication on the copper shop floor. This shows that Assembly I details are, in fact, representative of most copper pipe details fabricated in the shipyard.

6.3 Steel Pipe Shop

Information flow, material flow, and fabrication in the steel pipe shop occur the same way as in the copper pipe shop. Fittings and pipe are requested in the same manner due to the same shop material storage constraints.

Eighteen details were randomly selected from the list of approximately 50 details that were completed during the same day. All the details are composed of a different number and type of pipe and fittings. Some of the details were completed on time, while others were late. Information associated with the details is always available prior to the time of the first material arrival in the shop. Durations for material flow prior to fabrication and up to fabrication completion are analyzed to portray a chosen details' representation in Figure 6-3. Material flow and fabrication duration is broken down into the same three intervals as in copper pipe shop. Assembly I two details' timeline is shown as details #19 and #20 at the top of the graph in Figure 6-3.

Figure 6-3: Assembly I Steel Details Representation Verification



The largest time gap of approximately 33 days represents the time from the first material arrival date to the last material arrival date for detail #20. Additional time gap of roughly 10 days that represents the time from the last material arrival to fabrication start is present for detail #20. Material flow and fabrication timeline for detail #19 are similar to those of detail #20. The material designated for details #20 and #19 fabrication was idle in the steel shop's staging area for an equivalent or longer period than the detail's fabrication duration. Sixteen out of the chosen 18 details have similar problematic material flow trend as the details #19 and #20, which were fabricated for Assembly I. This shows that Assembly I details are, in fact, representative of most steel pipe details fabricated in the shipyard.

Events and actions causing time gaps in the detail and assembly fabrication timeline for all the shops will be discussed and analyzed further in Section 7.

7. Data Analysis and Problem Origin Identification

In this section a general analysis approach, its results, and the detailed analysis of each problem origin are discussed. All the dates and durations have been altered for liability reasons, however the general trends hold.

7.1 General Analysis Approach and Results

The basis of the analysis is the assumption that the ship need date is critical for the timely and successful completion of the aircraft carrier construction. Deckover is a structural completion of a Base A, superlift, or compartment, which completes structural boundaries to the internal space and/or limits the ability to load and outfit the unit. Deckover drives the outfitting schedule and determines the ship need date, which establishes and drives the shops' fabrication completion schedules. A number of negative outcomes emerge if an assembly's fabrication completion does not meet the ship need date. One outcome is that late assembly delays the deckover of a Base A or a superlift unit and thus delays the construction completion of the ship.

Another outcome is that the deckover actually occurs prior to the assembly's availability. In this case, additional costly work happens, consisting of cutting out part of the deck for assembly installation and replacing the 'cutout' of the deck. The work that is normally done on the platen occurs in the dry dock in an inflexible environment where it becomes very difficult to install the assembly. This is a very costly procedure due to the overhead, dry dock renting costs, and interference with other trades. Assemblies need to be delivered to the platen in a timely manner in order to construct the ship according to the schedule. Therefore, it is assumed that ship need date is critical for timely construction completion of the aircraft carrier.

In order to obtain a representative sample of the pipe assemblies for the analysis, binomial sampling is used. The sampling distribution of the pipe assemblies is well described by the binomial distribution in this case, because the total number of assemblies fabricated for the entire aircraft carrier is significantly larger than the sample size. The binomial sampling formula uses the confidence bound of the sampling error to determine how big a sample is required.

L=z*sqrt(p*(1-p)/n)

where

n: sample size

z: confidence level indicator, which means there is a 90% confidence that the mean for a similar data population will not vary by more than the z value (1.65) for the difference between the fabrication completion date and the ship need date. Z value is extracted from the Statistical Table of Standard Normal Distribution and is equivalent to the 90% confidence interval.

p: probability of late assembly delivery in respect to the ship need date

L: sampling error, refers to the difference between the results found based on the analysis of the chosen assemblies and all the assemblies fabricated in the shipyard. All the processing steps across the value stream have permissible durations for completion of the function. For example, planning has 7 weeks to complete the work packages, warehouses have 3 weeks to deliver the material to the shops, and the detail shops have 5 weeks to complete the fabrication. Taking the smallest allowed duration of 3 weeks and including the chosen 6% sampling error changes the precision by 7 hours. This is insignificant in respect to the actual duration since the error introduced is less than 1 workday.

Solving for n in terms of other variables gives $n=z^2*p*(1-p)/L^2$

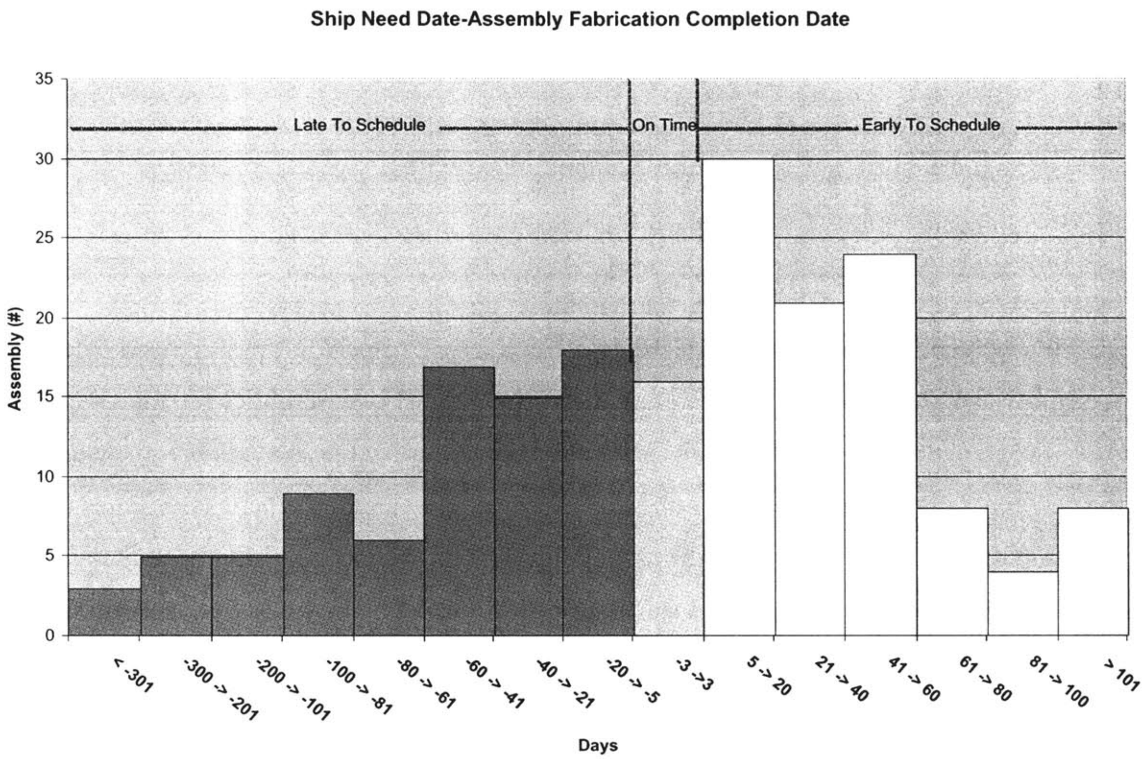
The chosen sampling error of 6% and the confidence interval of 90% were the smallest possible to determine a workable and reasonable sample size to allow the completion of the analysis within the duration of the internship. For example, if the confidence interval of 95% was chosen, the sample size increases to approximately 265 assemblies. The analysis of 265 assemblies would not be feasible to complete the project and produce results that are indicative of other samples within the population.

Probability of late assembly delivery in respect to the ship need date is determined by examining a sample of assemblies that are fabricated in the duration of one month. Approximately 26 out of 50 assemblies fabricated during the chosen month were delivered late to the ship. Therefore, the probability of late assembly delivery is 51%. So:

$n=1.65^2*0.51*(1-0.51)/(0.06)^2=189$

The data for the delivery time line with respect to the ship need date for 189 assemblies is shown in Figure 7-1.

Figure 7-1: Performance to Schedule



A sample of 189 assembles is analyzed to determine the fabrication completion date in respect to the ship need date. All of the assemblies have been divided into three categories: early, on time, and late assembly fabrication completion.

Early assembly fabrication completion:	assemblies completed at least 4 days prior to ship need date.
On time assembly fabrication completion:	assemblies completed between 4 days before and after ship need date.
Late assembly fabrication completion:	assemblies completed at least four days after ship need date.

Table 7.1.1 summarizes the results of the analysis.

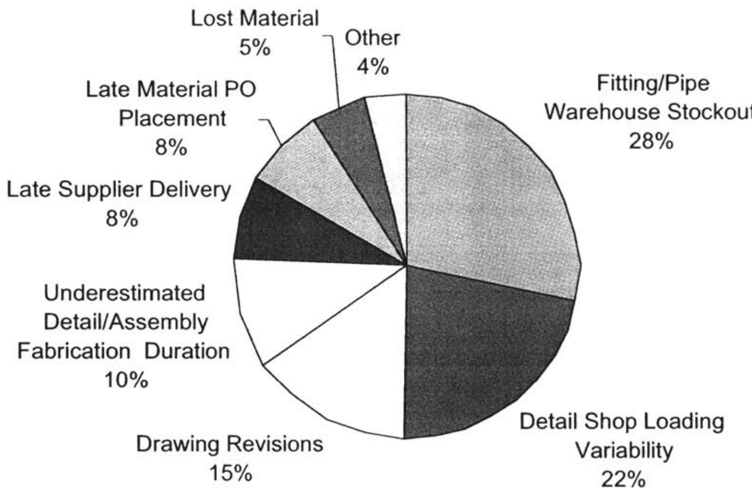
Table 7.1.1 Fabrication Completion Timeline in respect to Ship Need Date Summary

	Early Assembly Fabrication Completion	On Time Assembly Fabrication Completion	Late Assembly Fabrication Completion
Number of Assemblies	95	16	78
Percent of Assemblies	50	9	41
Average (days)	44	2	76
Standard Deviation (days)	35	1	98

Fifty percent of the assemblies were delivered early in respect to the ship need date. Assembly shop has a target of fabricating a specific number of assemblies on annual basis. Also, the shop needs to make certain that enough fabrication work is available to ensure all the personnel in the shop are fully utilized. This creates a situation where assemblies are substituted. Forty one percent of the assemblies with an approaching ship need date had issues that did not allow the shop to start fabrication. These assemblies were substituted with unproblematic assemblies with the ship need dates that were scheduled further out in the future. Thus, the substitute assemblies' fabrications were completed early. A large amount of assemblies is fabricated early due to the combination of the annual assembly fabrication quantity target and maximization of the personnel utilization goals.

The next step of the analysis focuses on determining the reasons for the assembly fabrication completion delays. A total of 78 late assemblies' information and material flow is closely examined. In this thesis, only the first problems that delayed the assemblies were looked at due to the time constraint of the internship. Additional issues compounded the delay of the assembly fabrication duration. The root causes for the delay are divided into 8 categories and shown in Figure 7-2.

Figure 7-2: Reasons for Late Assembly Fabrication Completion



The process and logic used to identify causes for assembly delays is described in detail in Sections 7.2-7.6.

7.2 Warehouse Stock Levels

Pipe and fitting warehouses keep a variety of material in stock designated for new aircraft carrier construction and overhaul, and submarine construction and overhaul. Twenty two assemblies, which represent 28% of all late assemblies in Figure 7-1, were late due to the warehouse stock levels dropping to zero. Fifty percent of 22 assemblies were late due to the fitting warehouse stockout with the remaining fifty percent late due to the pipe warehouse stockout.

Eleven out of 22 assemblies were late because the fitting warehouse ran out of the needed fitting. The analysis for the fitting warehouse stockout is shown in Table 7.2.1 using the data associated with one of the eleven late assemblies.

Table 7.2.1 Fitting Warehouse Stock Depletion

	Shipyard Fitting Receipt Date	Work Package Release/ Material Requested	Shop Fitting Receipt Date	Assembly Fabrication Start Date	Assembly Fabrication Completion Date	Delivery Date
Planned	--	4/28/XX	5/19/XX	5/19/XX	6/30/XX	7/7/XX*
Actual	7/18/XX	7/23/XX	7/25/XX	8/4/XX	8/14/XX	8/16/XX

* Planned delivery date is the ship need date

In the example above, a gasket is the fitting that is usually stocked in the warehouse, but was not available at the time it was needed. Inventory stock level is not used in identifying stock amounts or the date of warehouse's material receipt, because the record does not always reflect historic information. This issue will be covered in Section 7.7.

Normally, the assembly shop controller pulls material when enough material is available to start fabrication. The controller checks if the available material is sufficient to start fabrication. For example, an assembly consists of three fittings. The design specifies that fitting one has to be joined to fitting two and fitting two needs to be joined to fitting three. If fittings one and three are available and fitting two is not, the assembly shop controller does not have sufficient material to start fabrication. If fittings one and two are available but fitting three is not, the shop controller can pull the two available fittings and have the shop work on joining fittings one and two while waiting for the arrival of fitting three.

Material flow for a particular assembly can be examined by tracking Transfer Orders in SAP. Examination of the fittings and details availability for the particular assembly showed that all the material needed to start fabrication was available with the exception of the gasket. SAP also shows that the material availability was checked numerous times, but the work package was not requested or released due to the lack of some material. Although some fittings and details were available, assembly fabrication was not initiated, which implies that a critical piece was missing. As soon as the gasket appeared in the warehouse, the shop controller requested the work package and release of all the remaining material. Therefore, the lack of the gasket in the warehouse caused the assembly fabrication completion date to slip. The same occurrence is observed with the remaining 10 assemblies and/or details, which were late due to the unavailability of the stocked parts.

Eleven out of 22 assemblies were late because the pipe warehouse ran out of the needed pipe. The analysis for the pipe warehouse stockout is shown in Table 7.2.2 using the data associated with one of the eleven late assemblies.

Table 7.2.2 Pipe Warehouse Stock Depletion

	Detail Shop Pipe Request Date	Detail Shop Pipe Receipt Date	Detail Fabrication End Date	Assembly Fabrication Start Date	Assembly Fabrication End Date	Delivery Date
Planned	3/21/XX	3/28/XX	4/25/XX	4/28/XX	6/2/XX	6/9/XX*
Actual	3/21/XX	6/12/XX	6/12/XX	7/21/XX	8/7/XX	8/9/XX

* Planned delivery date is the ship need date

Pipe warehouse stock levels depletion appear mostly when an assembly is late due to a late detail. In the example above, the detail appeared to be the root cause of the assembly fabrication start holdup since the remaining material needed was available. Investigation of the reasons for the detail's delay showed that pipe, designated for the detail, was the last material to arrive. The pipe order was placed on 3/21/XX and the pipe was received on 6/12/XX, almost three months later. Since the detail shop received the pipe after the ship need date, the assembly shop was not able to meet the ship need date. The pipe warehouse operator has a record of the request from the detail shop controller and the reason the operator was not able to fill the order is due to the lack of the material. Therefore, the detail was late due to the pipe warehouse stock out and the assembly was late in respect to the ship need date due to the detail delay. The same occurrence is observed with the remaining 10 assemblies' details, which were late due to the unavailability of the stocked pipe.

7.3 Engineering Drawing Revisions

Changes to the engineering drawings occur through two different routes: revisions and Inspection Reports (IR). Twelve assemblies, which represent 15% of all late assemblies in Figure 7-1, were late due to the engineering drawing revisions. An example of a case, where the engineering drawing is revised after the drawing's release, is shown in Table 7.3.1 and described in this section.

Table 7.3.1 Engineering Drawing Revision Effect

	Drawing Rev. A Supervisor Complete Date	Drawing Rev. B Supervisor Complete Date	Assembly Fabrication Start Date	Assembly Fabrication Completion Date	Delivery Date
Planned	8/23/XX	--	3/7/XX+1	5/16/XX+1	5/23/XX+1*
Actual	8/23/XX	1/10/XX+1	5/20/XX+1	5/29/XX+1	6/2/XX+1

* Planned delivery date is the ship need date

Allowed normal durations for various process steps between drawing release and assembly fabrication start:

All Planning excluding Shop Control	7 weeks
Material Delivery (Warehouse to Copper/Steel Shop)	3 weeks
Detail Shop Fabrication Duration	5 weeks
Material Delivery (Copper/Steel Shop to Assembly Shop)	3 weeks
Total:	18 weeks

Considering the drawing release date of 1/10/XX+1 plus 18 weeks (126 days) allowed for planning, material delivery, and detail fabrication, the assembly shop is theoretically able to start assembly fabrication on 5/16/XX+1. The assembly shop theoretically needs 70 days to complete fabrication, which means the theoretical assembly fabrication is completed on 7/25/XX+1, which is approximately a month after the ship need date. The actual assembly fabrication start and end dates are listed in Table 7.3.1. Assembly was delivered to the ship one week late. Therefore, late release of the engineering drawing caused the delay in assembly fabrication completion and delivery to the ship. Twelve assemblies were affected by engineering drawing revisions, which caused these assemblies to be late with respect to ship need dates.

An IR is filed when a problem is discovered with a drawing, material, procedure, etc. all along the value stream. Filing an IR ensures a speedy resolution of the problem, because the nature of an IR is to bring importance to an issue.

A majority of the IRs filed in regards to the engineering drawings required part number changes from one number to another. The resultant is that the drawing has to be changed, however it is not going to change until the next planned revision and the planning process will proceed with the change marked on the original revision of the drawing. Material part number changes resulted in rework of the information starting with planning and continuing down the value stream. In most cases, a problem is found in engineering and fabrication shops and affects the stocked parts. Twenty eight IRs were filed against the seventy eight assemblies that were completed late. Fifteen and thirteen IRs were initiated by engineering and the shops, respectively. Although none of the IRs effectuated the initial delay, all the IRs caused the additional setback for the assembly fabrication completion.

7.4 Detail Shop Loading Variability

Shop controllers guide the flow of material and information through the steel and copper pipe shops. Seventeen assemblies, which represent 22% of all late assemblies in Figure 7-1, were completed late due to the approach the detail shop controllers use for shop loading. Thirty five percent of the seventeen assemblies were late due to the time gap between the fitting and pipe order placement. Here, the shop controller received the fittings, but waited for a while before ordering the pipe. Another thirty five percent of the seventeen assemblies were late due to the late material pull. In this case, the material for the detail fabrication was available in the warehouse, but the shop controller waited prior to placing an order to transfer the material to the detail shop. The last thirty percent of the seventeen assemblies were late due to the bending operation batching effect. Here, the shop controllers batch the orders for different assemblies with the similar size pipe that needs to be bent.

Six assemblies were late due to the time gap between the fitting and pipe order placement. The analysis is shown below using the data associated with one of the six late assemblies summarized in Table 7.4.1.

Table 7.4.1 Time Gap between Fitting and Pipe Order Placement

	Detail Shop Fitting Receipt Date	Detail Shop Pipe Order Date	Detail Shop Pipe Receipt	Detail Shop Fabrication Start Date	Assembly Fabrication Start Date	Delivery Date
Planned	6/10/XX	6/10/ XX	6/20/ XX	6/20/ XX	6/23/ XX	8/11/ XX *
Actual	6/10/ XX	7/3/ XX	7/18/ XX	7/25/ XX	8/22/ XX	9/15/ XX

* Planned delivery date is the ship need date

This example examines the issue of the time gap between the fitting receipt date and pipe order date. The detail described above consists of a fitting and a pipe. If the pipe order was placed the same day as the fitting was received then the pipe would have arrived at the shop on 6/20/ XX, considering pipe delivery duration to be approximately 10 days. Assembly shop detail need date was 6/23/ XX, taking into account the ship need date and the planned assembly fabrication duration. The detail would have been completed on time for the assembly shop need date, considering the 2 day detail planned fabrication duration. However, the shop controller waited for 23 days prior to ordering the pipe and starting detail fabrication. Pipe warehouse was not experiencing a stock out at that time. Therefore, the time gap between the fitting receipt and the pipe order placement caused the detail to be late, which resulted in the assembly fabrication completion delay. Five other assemblies were fabricated past the ship need date due to the issue of the fitting and pipe ordering process.

Six assemblies were late due to the late material pull. The analysis is shown below using the data associated with one of the six late assemblies summarized in Table 7.4.2.

Table 7.4.2 Late Material Pull

	Material Availa-bility Date	Material Pull Date	Detail Fabrication Start Date	Detail Fabrication End Date	Assembly Fabrication Start Date	Delivery Date
Planned	2/6/ XX	5/1/ XX	5/15/ XX	6/16/ XX	6/20/ XX	8/18/ XX *
Actual	2/6/ XX	6/19/ XX	7/7/ XX	7/9/ XX	9/5/ XX	9/30/ XX

* Planned delivery date is the ship need date

The example above shows that the detail fabrication completion was late due to the late material pull date. All the material was available 133 days prior to the time it was pulled by the shop controller. The actual pull date occurs one day prior to the scheduled assembly shop fabrication start date. Detail fabrication starts on 7/7/ XX, which is 17 days later than the assembly need date. This did not leave a sufficient amount of time for the assembly shop to complete the assembly fabrication in a timely manner. Five other assemblies were completed late due to the issue of late detail material pull.

Five assemblies were late due to bending operation batching effect. The analysis is shown below using the data associated with one of the five late assemblies summarized in Table 7.4.3.

Table 7.4.3 Bending Operation Batching Effect

	Pipe Order Placement Date	Pipe Receipt Date	Detail Fabrication Start Date	Detail Fabrication Finish Date	Assembly Fabrication Start Date	Delivery Date
Planned	5/1/ XX	5/11/ XX	5/12/ XX	5/26/ XX	5/30/ XX	8/11/ XX *
Actual	8/11/ XX	8/13/ XX	8/15/ XX	9/10/ XX	9/11/ XX	9/29/ XX

* Planned delivery date is the ship need date

The detail shown above consists of one piece of pipe that needed only to be bent. Pipe warehouse did not experience pipe stock out. The material was pulled late due to the shop's bending machine batching practices. Shop controller waited to pull the material until number of details, which contained similarly sized pipe that could be bent in batches, became available. Planned fabrication duration for this detail was estimated at 10 days however the actual fabrication duration was 29 days. Detail shops batch the pipe designated for bending due to the long machine change over times. Therefore, although the pipe was available for bending, it was not bent until enough pipe with the same diameter was pulled into the shop to justify machine change over. Therefore, bending operation batching caused a delay in detail fabrication completion, which resulted in the large assembly fabrication delays. Bending operation batching caused 5 assemblies to be fabricated late in respect to the ship need date.

7.5 Fabrication Duration

Eight out of seventy eight analyzed assemblies, which represent 10% of all late assemblies in Figure 7-1, were late due to the underestimated fabrication duration. Five assemblies and three details, which caused assembly fabrication completion delay, were late due to the underestimated fabrication duration.

Table 7.5.1 Fabrication Duration

	Assembly Fabrication Start Date	Assembly Fabrication Finish Date	Delivery Date
Planned	3/13/ XX	4/17/ XX	4/24/ XX *
Actual	3/14/ XX	7/18/ XX	7/21/ XX

* Planned delivery date is the ship need date

No material problems are experienced and the fabrication started earlier than planned, however fabrication finish occurred later than planned. Fabrication duration is underestimated by 81 days. The same logic was used to evaluate detail fabrication underestimation for those details that caused the assembly fabrication completion to be late.

7.6 Late Purchase Order Placement, Late Supplier Delivery, Lost Material, Other

Eighteen assemblies' fabrication was completed late due to late purchase order placement, late supplier delivery, lost material, and other. The examples below show the details of the analysis.

Six assemblies, which represent 8% of all late assemblies in Figure 7-1, were completed late due to the untimely purchase order placement and material delivery.

Table 7.6.1 Purchase Order Placement and Material Delivery

	PO Placement Date	Lead Time (day)	Material Receipt Date	Assembly Fabrication Start Date	Assembly Fabrication Finish Date	Delivery Date
Planned	6/5/ XX	300	4/1/XX+1	4/4/ XX+1	7/18/ XX+1	8/18/ XX+1 *
Actual	1/13/ XX+1	155	6/18/ XX+1	7/29/ XX+1	9/29/ XX+1	10/1/ XX+1

* Planned delivery date is the ship need date

In the example above, the valve caused the assembly fabrication delay. A valve PO was placed on 1/13/XX+1 with the supplier provided lead time of 300 days. The valve PO should have been placed on 6/5/XX in order to receive the material to meet the assembly fabrication start date. The remaining material needed to start assembly fabrication was available prior to the valve's arrival date. Therefore, the valve was the bottleneck for the assembly fabrication start. Late PO placement is not the root cause, however no systems exist to determine whether the problem originated in sourcing or engineering. Six assemblies were completed late due to the late purchase order placement.

Six assemblies, which represent 8% of all late assemblies in Figure 7-1, were completed late due to the untimely material delivery by the supplier.

Table 7.6.2 Supplier Delivery Timeline

	PO Placement Date	Lead Time (days)	Material Receipt Date	Planned Assembly Fabrication Start Date	Planned Assembly Fabrication Finish Date	Delivery Date
Planned	6/11/XX	270	3/8/XX+1	10/12/XX+1	11/18/XX+1	11/25/XX+1*
Actual	6/11/XX	525	11/18/ XX+1	3/19/XX+2	7/10/XX+2	7/14/XX+2

* Planned delivery date is the ship need date

Material should have been received on 3/8/XX+1 with the PO placement date of 6/11/XX and the lead time of 270 days. Material arrived at the shipyard's inspection station on 11/18/XX+1, 255 days later than the scheduled delivery date. Therefore, the supplier was not able to deliver the material in a timely manner, which resulted in the assembly fabrication delay. A total of six assemblies were delayed due to the late supplier delivery.

Four assemblies, which represent 5% of all late assemblies in Figure 7-1, were completed late due to lost material.

Table 7.6.3 Lost Material

	Missing Material Assembly Shop Receipt Date	Assembly Fabrication Start Date	Assembly Fabrication Finish Date	Delivery Date
Planned	3/10/XX	3/13/XX	4/17/XX	4/24/XX*
Actual	7/17/XX	2/14/XX	7/17/XX	7/22/XX

* Planned delivery date is the ship need date

In the example shown above, all the material was available by 1/24/XX with the exception of the valve that became available on 7/17/XX. The shipyard valve receipt date is not available in SAP, however, the valve was received by the shop and the assembly was completed and released to the ship. Although the system does not specify what happened to the valve, the MRP controller and shop controller, who investigated the issue, indicate in their notes that the valve was lost. The assembly was completed as soon as the valve arrived, which indicates that the valve was the bottleneck against the timely assembly fabrication completion. Similar scenario is seen in a total of four assemblies or its details.

The remaining 3 assemblies out of 78 analyzed, which represent 4% of all late assemblies in Figure 7-1, were late due to various reasons. Two out of the three assemblies experienced a delay of six months to a year when being passed down between the production and MRP controllers. The delay can be attributed to human error, since neither controller was able to explain the phenomenon. The occurrence of such a delay is very infrequent therefore it is not concentrated on at this time. The last assembly analyzed was late to an unknown reason. Examination of all the information and material flow associated with this assembly did not point to the root cause of the late assembly fabrication completion.

7.7 SAP System Problems

The majority of the data covered and analyzed in this thesis is extracted from SAP. In the process of information gathering, numerous problems and discrepancies with the information stored in SAP have been discovered. This section summarizes these issues.

A number of assemblies and details had information discrepancies between the production order and the transfer order displays. The production order display shows all the fabrication operations an assembly or detail has to undergo as well as the material list needed for fabrication. The transfer order display shows the material flow from the warehouses to the designated shop for an assembly or detail. All the material sent from the warehouses to the shops is expected to match the material list in the production order display for a particular assembly or detail. The information for numbers of details and assemblies was found to be mismatched between the two displays. Thus it is not possible to determine if the needed material did not arrive to the shop or the material was not needed and was not removed from SAP.

The production order display also shows the start and end dates for operations for an assembly or detail. Finish dates for some operations in SAP exceed the actual finish dates. For example, a transfer order display shows that a detail left the detail shop on 9/2/XX however one of the operation steps in the detail shop associated with the detail was completed on 11/5/XX. Since the assembly, which incorporates the detail, has been completed on 10/25/XX, it is not possible for the detail's operation step to be completed after the assembly completion date. The transfer order display has a similar issue as the production order display. For example, a flow of ten pieces of material, some loose and some details, are captured in SAP. The system shows that the last fitting arrived on 7/8/XX, however the assembly completion date is 5/8/2003. It is not possible for the fitting to arrive to the shop after the assembly fabrication, which incorporates the fitting, is completed. Thus, at times SAP reflects inaccurate dates.. Since the dates are entered into the system by shop personnel, operators need to ensure timely and accurate data entry. Bar codes can assist with maintaining accurate data input, however the shops currently don't have the barcode capabilities. The shipyard adapted SAP system recently and has not been able to transfer bar coding system to SAP from the legacy system at this time.

Another problem was found when looking at the document structure display. One of the features of this part of SAP shows all the drawing numbers and inspection report numbers associated with a particular assembly. Numerous assemblies have incomplete lists of drawings and the inspection reports shown on the document structure display. Thus, at times SAP reflects inaccurate information. Engineers and planners who link this information in SAP need to ensure that all the information is entered into the system.

Order history for purchase order display does not reflect all the material coming into the shipyard. For example, one assembly was missing a valve for six months. Examination of the purchase order system showed that the valve PO was placed on 10/23/XX with the expected delivery date of 4/25/XX+1. Order history for the purchase order display showed no record of the valve receipt by the shipyard. However, the assembly, which incorporated the valve, was delivered to the assembly shop on 7/8/XX+1 and the assembly fabrication was completed on 10/25/XX+1. Thus, it is not possible to determine when the valve was received or determine its origin. Therefore, the sourcing department and material inspectors should ensure the entry of all the data for all the purchase orders.

Inventory levels are not used in identifying warehouse stock outs due to the lack of historic data as mentioned in Section 7.2. For example, one of the assemblies was determined to be late due to the fitting warehouse depletion of rings. The PO for the rings was placed on 4/28/XX and material was received on 5/20/XX. The transfer order display shows that 6 rings were ordered on 5/30/XX and production order display shows that 6 rings were needed for assembly fabrication. Table 7.7.1 displays the actual stock levels and order history for the ring as shown in SAP.

Table 7.7.1 SAP Stock List

Date	Description	Requested/Required Quantity (Each)	Available Quantity (Each)
11/20/XX	Stock		80
11/20/XX	Safety Stock	-15	65
6/9/XX	Order Reservation	-4	61

Information shown in Table 7.7.1 has been downloaded on 11/20/XX. The actual stock and safety stock levels are shown on the date the download of the information occurs. SAP stock list shows that only 4 rings, as opposed to the actual 6, were ordered around the date when the ring release request for the assembly was placed at the warehouse. SAP does not show the order reservation date of 5/30/XX, but shows 6/9/XX, which is close to the original order reservation date. Also, SAP stock list does not reflect the actual receipt date of 5/20/XX for 80 rings as order history purchase order display indicates. Without the knowledge of the stock replenishment date, it is difficult to determine when the stockout occurs. The same scenario occurred when analyzing other assemblies. Thus, SAP stock display does not reflect all the information in respect to the order history and could not be used for the root cause analysis.

Resolution of the majority of the issues with SAP lies in tighter control of the system and ensuring careful, timely, and accurate data entry.

Value stream analysis traced root causes into engineering, fabrication shops, planning, warehouses, and sourcing. Warehouse stockouts, detail shop loading variability, drawing revisions, and underestimated assembly and detail fabrication durations caused 75% of the delays. Recommendations to eliminate the problems causing the assembly fabrication delays are provided in Section 9. General methodology for conducting a value stream map is described in Section 8.

8. Methodology for Conducting Value Stream Maps

A general approach to enterprise level value stream mapping is described in this section. Approaches to understanding the organization, identifying waste and data sources, performing analyses, and methods to information verification are discussed in this section. Also, the differences between lean in mass and low volume manufacturing are addressed. Some information used in this section is based on the experience obtained in the shipyard during the enterprise level value stream mapping process described in this thesis. Other information is obtained from various sources of literature and research on value stream mapping.

8.1 Understanding the Organization

The first and key step to enterprise value stream mapping is understanding the organization. The organization is shaped by the type of products it manufactures, the type of services it provides, its customers, and the customers' needs. The concentration of this thesis has revolved around one of the shipyard's products: new aircraft carriers. The goal is to deliver a quality product in a timely manner. In order for the ship to be built on time, all the material and information supporting the manufacturing and construction needs to occur without delay. Considering the number of steps the material and information have to go through prior to reaching the platen and the dry dock, the further upstream the problem occurs, the greater the delay in the final construction phase due to the bullwhip effect.

At the beginning of the internship, the intern received a two day shipyard-wide tour to get a general understanding of the shops and various operations occurring in the shipyard. This assisted with comprehension of the enterprise-wide view of the processes and organization prior to starting the project and concentrating on one part of the operations concerned with pipe assemblies.

The start of the value stream mapping effort should occur at the end of the process where the product is completed and traced back upstream. (Rother and Shook, 1999) At the time when the project described in this thesis started, Assembly I's details were being fabricated in the copper and steel pipe shops. The intern spent approximately a week learning the operations of the detail shops. Observation of the various detail fabrication, speaking with welders, fabricators, and line supervisors provided a number of different perspectives on the processes, systems, and problems occurring in the shops. After the detail shop orientation was complete, the intern started piecing the map by traveling up the value stream. At each process step, it was determined who are the immediate customers and suppliers and contact names of the personnel working in those departments who were associated with the Assembly I. Once the process was traced to the suppliers, the intern traced the assembly downstream as it was being fabricated. Unfortunately, the assembly did not get installed on the platen by the time the internship was completed, therefore there are no values associated with the platen and dry dock construction on the value stream map.

The creation process of the enterprise value stream map needs to be concentrated on the overall processes without getting lost in the operational details of each process step. Interviews conducted with the personnel from each department provide an understanding of the general functions. Providing the background of the project and ensuring the understanding of the level of details necessary to complete the project to the interviewees assists with ensuring the right amount of the information is provided. It is easy go get sidetracked on various operational details for each process step, however this falls outside of the project's scope. Once the enterprise value stream map is completed, major gaps become apparent. Problem identification requires exploration of the operational details of the process steps where the major gaps are found. The value stream map shown in Exhibit 3 is created based on the information obtained by drilling one level deeper than shown in the VSM. The high level value stream map shown in Exhibit 2 was created based on the detailed value stream map shown in Exhibit 3. It is critical to maintain the focus on the enterprise as a whole when creating an enterprise level value stream map.

The key to understanding an organization is understanding the people who work in the organization. Richard Welnick (2001) created a value stream map for the Ford Motor Company's Wayne Assembly and Stamping Plant. One of the cultural issues addressed by Richard is a strong presence of two unions that operate as two distinct entities in the same facility. Richard found that understanding the factors that influence the company's current environment, such as the culture, are crucial to the successful implementation of lean.

The intern's initial introductions to the people who work in the shops were made by people who are well-known and respected in the shipyard. When making contacts outside the shops, the intern used the names of the people in the shops as referrals. One of the lean enterprise principles mentioned in Section 3.1 is the existence of the relationships based on mutual trust and commitment. (Murman, et al., 2002) The organization has not advanced in its lean environment far enough to overcome the stigma of cross-functional silos. Therefore, it was extremely helpful to have familiar representatives to set up the meetings. Enterprise level value stream mapping effort cannot be successful without the willingness to help, support of and the belief into the project of the people who work in the various departments along the value stream.

8.2 Identifying waste

Knowledge of the organization, its customers and their needs is necessary in identifying waste. Lean theory summarizes waste in seven categories as mentioned in Section 3.3. The first step to identifying waste is performing a literature search to determine the typical sources of waste found in various industries and applicable to specific theories, such as lean.

All the waste categories described in Section 3.3 apply to the shipyard. The value stream map captures the rework, which happens on numerous occasions in areas such as planning and shops. Some of the rework is not apparent on the value stream map, but can be easily discovered once an effort is made to determine the root cause of the long non-value added times for various process steps. Also, the value stream map does not show if the assemblies that are being fabricated are actually fabricated in the right time frame. Fifty percent of the assemblies are fabricated early in respect to the ship need date and therefore, create waste. Comparison of the assembly fabrication completion date and the ship need date points out if the assembly is fabricated in timely manner.

One of the examples is the process that occurred in the assembly shop during Assembly I's fabrication. Flanges were the last material to arrive to the assembly shop. The flanges were late because the material was ordered late due to the engineering error. The engineers did not notice that the flange needed for the assembly was atypical and the wrong flange was ordered. The mistake was identified late in the process and the purchase order for the flange material was placed late. The flanges were needed in the assembly shop when fabrication of the first half of the assembly was completed. The material for the second half of the assembly was available, but was not able to be fabricated due to the lack of flanges. The assembly shop made up dummy flanges to be used to complete the assembly fabrication and later replaced by the real flanges. Fabrication, use, and disposal of the dummy flanges were the labor and material wastes of rework due to an error. As the result, Assembly I's fabrication was completed late in respect to the ship need date.

Production of unneeded goods is a large area of waste in the shipyard. Fifty percent of all the assemblies fabricated in the shipyard are fabricated early to the ship need date schedule. Misuse of the resources such as labor and material to fabricate assemblies that are not needed creates waste since the assemblies that are needed are not being fabricated. These assemblies significantly increase the in-process inventory, which creates large carrying and overhead costs. Additionally, these assemblies might get damaged or start rusting while sitting in the warehouses, which requires rework. Inventory excess can be seen across the value stream of unneeded parts stored in the warehouse and in-process material that is fabricated earlier than required.

Excessive processing steps and unnecessary people, material, and information movement can be found at various steps along the value stream. One of the examples is the five tiers of the planning process. Advanced planners are located approximately two and a half miles away from grouping and grouping is located the same distance from production planning. This spread of planners complicates problem resolution and creates unnecessary movement of people and information.

Manufacturing products and rendering services, which do not meet customer's needs, is another source of waste in the shipyard. One of the examples of such waste are pipe templates. In order to determine the space constraints that a pipe has to fit into, templates are created. The template could be a steel rod that is bent in the same manner as the pipe needs to be bent. The template is bent on the ship and then transferred to the shop to be used for a model during pipe bending. Once the pipe is bent, the template is discarded. The template is not a product that the US Navy has requested, but it is used to build the product for the customer, which is non-value added required.

8.3 Differences between lean in high and low volume manufacturing

Application of the lean principles in high and low volume manufacturing environments differs. In a high volume environment, cells are set up to create a one piece flow for the similar families of products. In a low volume, high-mix manufacturing environment cells are difficult to set up due to the high mix or variation of the product. In the shipyard, one piece flow normally exists due to the nature of the pipe assemblies. Each assembly differs by complexity, number of parts, and fabrication operations it undergoes. Therefore, it is difficult to set up cells and create pipe families.

Process standardization is the basis of lean. Challenges associated with process standardization in the shipyard considering the variety and complexity of products are encountered on a daily basis. The copper and steel pipe shops attempt to standardize the processes by dividing the details into families consisting of a small, medium, and large size pipe. In the assembly shop, an assembly does not move during the fabrication with the welders and fabricators rotation between different assemblies. A target tool has been developed to standardize the fabrication processes, however the information captured in the tool is not precise enough to use in the shops. The process steps where the information such as drawings and work packages are created experience challenges with standardization due to the amount of rework associated with each process step. Therefore, it is challenging to standardize processes in the low volume manufacturing as opposed to the high volume manufacturing due to the high variety of products.

In a low volume manufacturing environment, the overall top level cycle time reduction is not necessarily the goal, however the cycle time reduction of individual processes is the goal as described in Section 3.4. In high volume manufacturing, the majority of the time the overall cycle time reduction is the goal.

Lean implementation in high and low volume manufacturing environments differs greatly due to the differences in the products and the challenges associated with each environment. However, number of lean principles can be implemented in the shipyard. Specification of value and identification of value streams should occur. Flow and pull should be established to ensure that all the departments are working to the same schedule based on the ship need date. This will ensure fabrication of the right assemblies to allow timely ship construction completion. The process should always undergo improvements to ensure perfection is achieved.

8.4 Data sources

Data sources for the creation of the value stream map vary across the value stream. All the process steps that deal with the information, such as engineering and planning, provide imprecise data regarding the touch times and the total times that are captured in the value stream map. There are no systems in place to capture the exact durations for various processes that work with information. The data were estimates gathered by interviewing individuals from engineering, planning, and sourcing departments. Those individuals who worked with the Assembly I were targeted. The majority of the individuals were able to provide average durations, which were not necessarily associated with the Assembly I, for various process steps. This created significant difficulties in determining the problems encountered during those process steps, identifying root causes of the problems, their effect on the assembly processing timeline, and providing suggestions to eliminate the problems.

Majority of the information associated with the production shops and material flow captured in the value stream map was extracted from SAP. The accuracy of the data enables determination of the problems, their root causes, and problem elimination. However, lack of some data in SAP, which is described in Section 7.7, increases the difficulty of the analysis.

8.5 Analyses

The value stream map provides lead times and touch times for all the processes, associated with the pipe assembly, across the enterprise. Value added ratio (VAR), which is calculated by dividing the touch time by total cycle time for the particular process step, shows which processes have the most non-value added time. VARs should be looked at in the context of the process. For example, VAR for the material engineering department is 2.4%, which means that the information remains idle in this department a large portion of the time. Examination of material engineers' functions shows that the engineers have to communicate with the US Navy to receive an approval on the material changes and the suppliers to ensure the material specifications are met. The majority of the non-value added time is created by the actions that originate in the external sources such as lengthy response time from the US Navy or the suppliers. Therefore, the overall supply chain needs to be leaned out to enable the material engineering department to decrease the amount of non-value added time in their process. Other processes such as the copper and steel pipe shops with the VAR of approximately 1% should be examined closely, because all the non-value added actions occur within upstream processes of the shipyard. Understanding of the process and the functions performed by various departments is critical in the analysis of the value stream. Operations of the processes with the lowest VARs should be examined closely to determine the causes of the non-value added time. Once the causes are identified, lean events should take place to eliminate the problems and increase the VAR.

Processes where rework occurs are identified on the value stream map with the rework sign such as design, production engineering, advance planning, grouping and production planning. According to lean, rework is one of the wastes and should be eliminated whenever possible.

Another part of the analysis consists of comparing different processes of the enterprise that perform similar functions. One of the examples of such processes are copper and steel pipe shops with VARs of 1% and 54%, respectively. In both shops the material undergoes similar operation steps to be fabricated into details. The difference in VARs shows that there is an issue in the copper pipe shop that does not exist to the same extent in the steel pipe shop. The operations of the two shops need to be examined and the differences, which cause VAR to be significantly lower in the copper pipe shop, should be found and addressed.

The value stream map is a useful tool for identifying wastes in the system, pinpointing the processes where the non-value added time is high and the areas where the lean efforts should concentrate on.

8.6 Verification

After the completion of the enterprise value stream map, the information and processes captured need to be verified to check for accuracy.

The process flow captured in the VSM was identified from the interviews conducted with the personnel from all the departments across the enterprise. VSM has been reviewed by two experienced production engineers, who are very familiar with the processes in the shipyard, in order to verify the process flow. Also, the VSM has been shown to the majority of the personnel who were interviewed during the VSM creation process. The feedback from all the individuals who reviewed the VSM has been addressed and incorporated into the VSM. The information has been presented to the majority of upper and middle management and those concerns that have been raised have been addressed. Therefore, the process flow captured in the VSM has been visually verified through a variety of sources.

The touch and cycle times for each process step has been verified through the personnel interviewed or data captured in SAP. The touch and cycle times for the process steps that deal with the information flow, starting with engineering and ending with production control, are typical times therefore no other data could be captured to verify the accuracy of the times provided. The data shown in the VSM for the material flow, starting with the MRP controller and ending with the construction, is drawn out of the SAP. The data for the material flow is verified by examining the durations of the material flow process for the 78 assemblies, which were inspected closely to determine the problems that caused the assemblies to be late. The data for the detail fabrication timeline and information flow was verified by examining the planning and fabrication timeline for all the details associated with the Assembly I, which is equivalent to approximately 30 details. The data associated with the longest fabrication timeline and lead time was captured in the VSM. The assembly fabrication duration and information flow timeline was verified by examining an additional 78 assemblies. Also, the representation of the Assembly I was examined in Section 6. Therefore, all the touch and cycle time information captured in the VSM has been verified and determined to be accurate.

9. Recommendations and Conclusions

Recommendations for the elimination of some of the operational problems, suggestions for future work, and general conclusions are provided in this section. The basis for the recommendation implementation is the alignment of all the parties involved in the enterprise value stream at all levels of the organization. The VSM is a useful tool to ensure the common ground is reached between operators and managers.

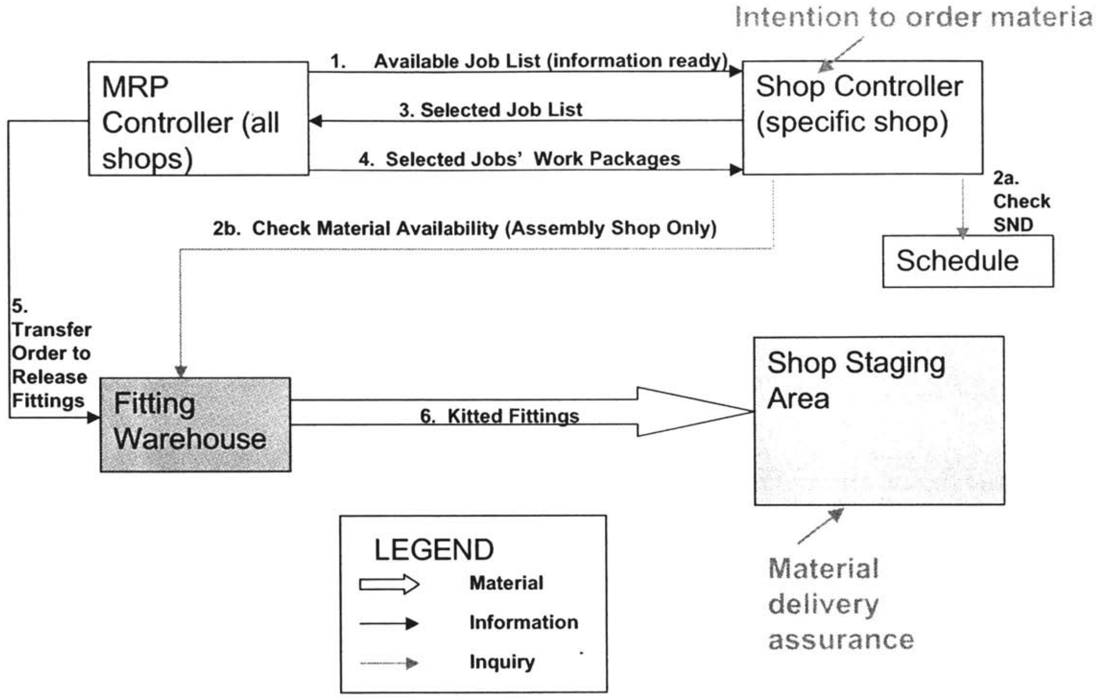
9.1 Recommendations

Recommendations provided in this section are aimed at improving operational effectiveness. Material ordering process reorganization, detail shop loading variability elimination, engineering drawing revisions and planning process minimization are described here.

9.1.1 Material Ordering Process Reorganization

Examination of the high level value stream map shows that one of the largest time gaps occurs during the last two tiers of the planning process, the MRP and shop controllers. Value added ratio (VAR) of 1.1 % (0.4/11) shows that a small amount of time is value added. Fabrication of 28% of the assemblies was completed late due to the fitting/pipe warehouse stock depletion. Examining the material order process that was described in Section 5.2.2 shows that the process can be improved and the assembly fabrication delay could be minimized and/or eliminated. Figure 9-1 captures the part of the stocked material ordering process where one of the issues lies. The situation portrayed here is applicable for the stocked material only. Material assigned to a particular project is unique and does not experience the issues discussed here.

Figure 9-1: Material Ordering Process

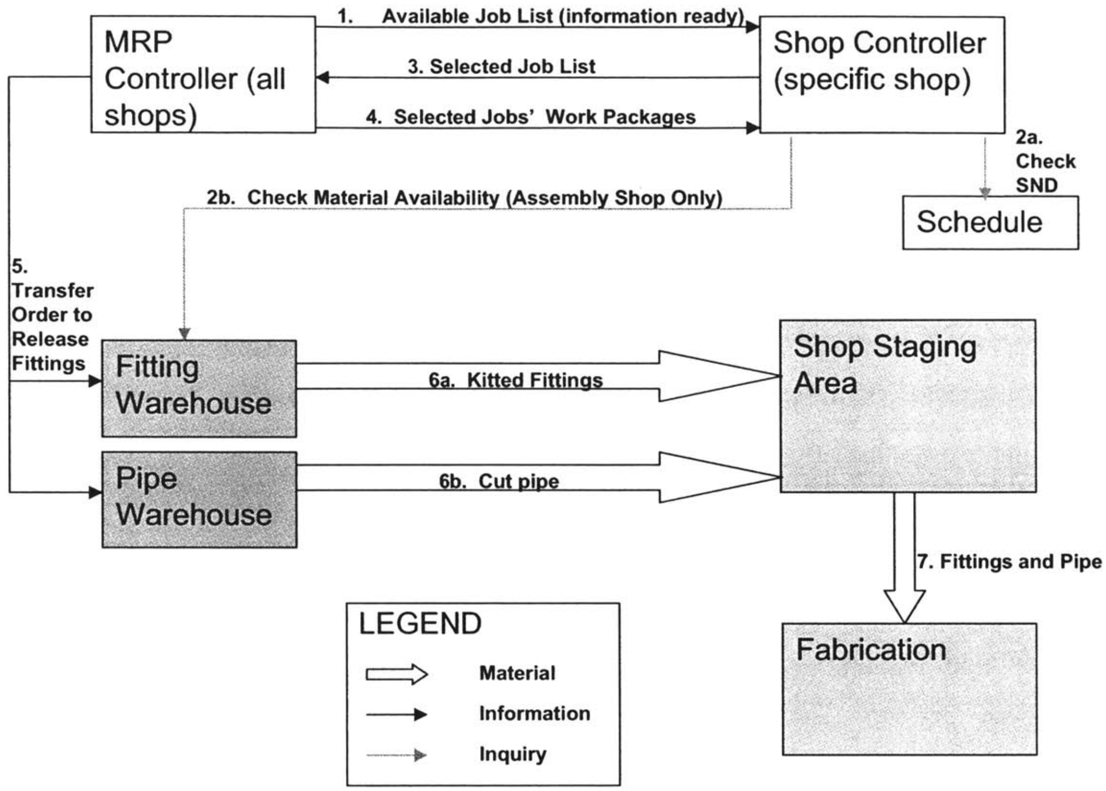


MRP controller releases the available job list (Step 1) to the shop controllers only when all the material is available for copper and steel pipe shops and when partial material is available for the assembly shop. The intention to order material emerges when the shop controller decides to start fabrication of an assembly or a detail by placing a request to the MRP controller to release the work package and initiate the material flow by reserving material. Once a work package and material release request is placed, the shop controller plans the work force requirements and floor allocation for the fabrication of the particular assembly or detail. The shop controller is expecting a timely material arrival to the shop. The transfer order (TO), which initiates the fitting flow, enters into the fitting warehouse TO queue. Two to five days might pass prior to the fitting warehouse operator pulling the material for the particular TO. Therefore the MRP controller at Step 1 checks material availability and material is reserved for the assembly or detail at Step 5. On average, a time gap of up to three weeks occurs between the intention to order the material and the material's arrival at the shop, because the warehouse is allowed three weeks for material delivery if no problems are encountered. During this time, the reserved material could be reassigned to another assembly or detail or withdrawn from the warehouse for another project. At the time when the fitting warehouse operator pulls the stocked material for the designated assembly or detail, no material is available. Historically, this happens more frequently with the fittings than with the pipe. The shop controller knows that the fitting is available for the assembly fabrication only when the fitting arrives at the shop. Reservation of the fitting does not provide assurance of fitting's availability due to the possibility of the fitting's reassignment to another assembly.

Time gap elimination between the intention to order material in Step 1 and the material order placement in Step 5 ensures the material needed for the particular assembly or detail stays available and is not assigned to another assembly, detail, or project. The shop controller and not the MRP controller should reserve the needed material in SAP at Step 2 to eliminate the time gap and ensure the material is reserved for the particular assembly or detail prior to floor, labor, and machine time allocation. The reserved material should not be reassigned to a different assembly, detail or project. The process of the material reservation in SAP takes approximately 1 minute and is currently being performed by the warehouse operators. Therefore, the SAP system does not need to be altered and only the reservation function transfers from the MRP controller to the shop controller. The needed material might become unavailable between the time the MRP controller releases the information associated with an assembly or detail in the available job list (Step 1) and the shop controller decides to start the fabrication. If this occurs, the shop controller will know not to allocate the work force and floor space to the particular assembly or detail due to the material unavailability.

Material order process reorganization allows the shop controller to order the pipe and fittings at the same time, since the fittings are reserved and delivered to the shop in a timely manner. This reduces the material ordering process by a week and decreases the process from ten to seven steps. Figure 9-2 shows the material ordering process after the reorganization.

Figure 9-2: Material Ordering Process after Reorganization



The following are the benefits of the material ordering process reorganization.

- Reduction in number of detail and assembly fabrication delays due to stock material unavailability
- Elimination of the time gap between fitting and pipe order placement
- Assistance with factually determining stock inventory issues
- Aligned with the goal 'having 100% of material for 98% work packages' created by the Vice President of Operations.

9.1.2 Detail Shop Loading Variability Elimination

Fabrication of 22% of the assemblies was late due to the late arrival of the details because of the detail shop loading variability. Three main reasons caused the detail fabrication to be completed late: time gap between the fitting and pipe order placement (35%), late material pull (35%), and bending operation batching effect (30%).

Copper and steel pipe shop controllers receive fittings and theoretically should order pipe on the day when the fittings are received. In the case of the late details for 35% of the assemblies, the shop controllers waited for at least a week prior to ordering pipe. The type of pipe needed for the detail fabrication was available in the pipe warehouse. The delay in pipe ordering caused the detail fabrication to be started and completed late, delaying the assembly fabrication completion in respect to the ship need date.

In the case of the late material pull, copper and steel pipe shop controllers did not request the material for the detail fabrication in a timely manner. All the material needed for the fabrication was available in the warehouses. The detail shops did not complete detail fabrication on time for the assembly shop to be able to complete the assembly fabrication in respect to the ship need date.

The third reason, bending operation batching effect, occurs in the detail shops when the pipe needs to undergo the bending process. Changeover times for the bending machine are extensive and the operators try to minimize the number of changeovers. The shop controller pulls in the details for fabrication that include a similar diameter pipe to ensure that all the pipe will get bent without changing the setting on the bending machine. This creates a problem where some details are fabricated early while other details are fabricated late. The late details delay the assembly fabrication completion in respect to the ship need date.

The underlying problem that results in the detail shop loading variability is the lack of the target date for the detail shops to work towards. The assembly shop works toward the ship need date and the detail shops should work towards the assembly shop need date. Production planners determine the assembly shop need date through the simulation performed in SAP. However, this date is overridden in the system once the detail shops provide new fabrication dates as described in Section 5.3.1. Currently, the detail shops are measured on completing the detail fabrication within the planned fabrication duration. A matrix should be put in place where the detail shops' success is measured based on the number of details completed that meet the assembly shop need date. Detail shop controllers overestimate planned fabrication durations because they cannot rely on the timely material delivery. Overestimated planned fabrication durations introduce a lot of slack into the value stream. Provision of the assembly shop need date to the detail shops, development of a matrix, and reorganization of the material ordering process as suggested in Section 9.1.1, will eliminate the detail shop loading variability and reduce the slack in the value stream.

9.1.3 Engineering Drawing Revisions and Planning Process Minimization

Fabrication of 15% of the assemblies was late in respect to the ship need date due to the engineering drawing revision late release. The detailed analysis of the engineering drawing revision effect is described in Section 7.3. Placement of an experienced operator, who is responsible for checking the accuracy of the drawing prior to its release, in the engineering department would decrease the amount of drawings needing revision. Concurrent engineering should be practiced to ensure the quality of the drawing is high prior to its release to the downstream processes.

The value stream map captures the information flow through five planning functions. A large amount of rework occurs between the first three tiers of the planning process, where VAR is 5.6%, as described in Section 5.2. Currently, advanced and production planning departments are located approximately two miles from grouping department as shown in Exhibit 4. The distance increases the delay for the rework completion. All three departments should be co-located to ensure fast problem resolution. Further research needs to be done to determine if production planning and grouping could be combined into one process step.

Information rework is not given the priority status in the planning process, therefore there is no time constraint imposed for fixing the information problems. A definite timeline should be established for rework to ensure the problems are resolved in timely manner and do not affect the fabrication timeline in the pipe shops.

The recommendations provided in this section are targeted at making sure the information and material arrives to the assembly shop in timely manner to make certain the assembly shop completes the assembly to meet the ship need date.

9.2 Future Work

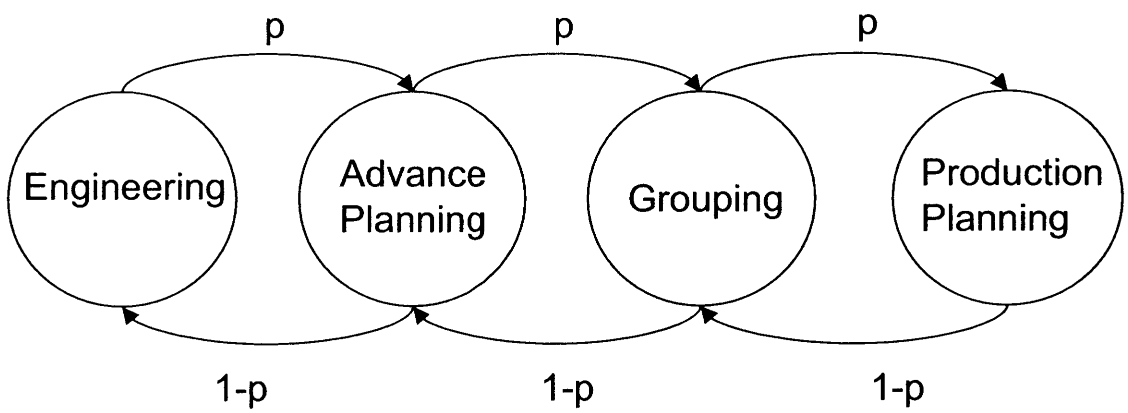
During the process of conducting research for this thesis some suggestions for the future work have been generated and are presented in this section.

Some of the operational issues identified in the shipyard are based on the material availability. The shipyard is in a unique position where the variability due to the external customer demand does not exist. The US Navy requires one aircraft carrier to be built in a five-year time frame. Eight percent of the variability, as shown in Figure 7-1, is caused externally by the late supplier material delivery. Majority of the material demand and variability is internal to the shipyard. Considering the fact that the shipyard has already constructed a number of aircraft carriers in the previous years, it should be possible to look at the historical data to identify the material demand at various stages of the aircraft carrier construction. It will be difficult to estimate the exact inventory levels since no two aircraft carriers are the same however an estimate should greatly improve the inventory management at the shipyard.

Another suggestion for the future work is to study metrics and the behavior driven by these matrices across the enterprise. For example, the assembly shop is tasked with completing the fabrication of a specific quantity of assemblies in a year. In order to reach this goal, the assembly shop fabricates assemblies ahead of schedule, which is a waste according to the lean theory. These assemblies increase the in-process inventory, carrying costs, and overhead if rework is necessary due to damage or loss of the assemblies. Matrices that measure success in each department across the enterprise should be aligned and aimed at the goal of constructing a quality ship in a timely manner.

A study of the effect of the rework in the planning process can uncover opportunities for improvement, cycle time decrease, and rework minimization. Probabilities of the work packages and drawings being returned for rework to engineering, advance planning, grouping, and production planning should be examined as shown in Figure 9-3.

Figure 9-3: Rework Effects



Improvement opportunities to reduce cycle times by eliminating rework of information can be significant and should be studied extensively. As Figure 9-3 shows, probabilities (p) of the information moving forward along the value stream from engineering to production planning and probabilities (1-p) of the information being reworked should be determined by tracking selected work packages. This will provide a full understanding of the rework impact on the value stream.

An effort should be undertaken to ensure the proper and efficient use of the SAP system. Incentives should be put in place to make certain all the information is accurately entered into the system. One critical issue is an accurate maintenance of the inventory stock levels in various warehouses. This will enable the shipyard to perform historical studies to identify the correct inventory levels.

Department locations shown in Exhibit 4 should be carefully studied to ensure that the personnel from various departments who work closely with each other are co-located. This will ensure that non-value added time associated with information or material movement across long distances and personnel communication barriers are minimized.

Suggestions provided in this section need further investigation. There is a large opportunity in improvement with the careful study and analysis of the inventory levels, matrices, incentives, and rework.

9.3 Conclusions

Three main conclusions can be drawn from this project: 1. Enterprise value stream mapping is an effective tool in identifying waste; 2. Environment for lean needs to be created on the enterprise level; 3. Implementation of lean in low volume, high-mix manufacturing environment generates more challenges than a high volume, low mix manufacturing environment. Each is described below.

1. Enterprise value stream mapping is an effective tool in identifying waste.
The enterprise value stream map shows the touch and cycle time for each process step associated with the pipe assembly chosen as a basis for the map. The steps that have the smallest value added ratios represent the process steps with the least amount of the value added and the most amount of the non-value added time. Examination of the internal operational processes of the areas uncovers the sources of the waste and provides opportunities for improvement. The value stream map also shows the amount of rework that occurs at the various steps of the enterprise. Rework creates significant delays and affects the processes downstream, therefore the company should strive towards the elimination of rework. The enterprise value stream map is useful in uncovering the 'hidden factory' for elimination of non-value added activities. The enterprise level value stream mapping is an effective tool in identifying and prioritizing the areas in the enterprise where lean should be applied.

2. Environment for lean needs to be created on the enterprise level.
The enterprise value stream map showed extensive interaction and interrelation of all the processes in the enterprise. Implementing lean on the department level can lead to sub-optimization and affects the processes downstream.

> "Cross-functional teamwork is critical to lean transformations and requires the removal of barriers between complimentary functions. Strong leadership in this area is critical to the establishment of cross-functional linkages. Focus on the products vice the functions is the desired effect which requires the removal of the Not-Invented-Here (NIH) mentality so that a cross-functional organizational structure can support the organization's common goal." (Shields, et al., 1997)

Departmental and functional silos need to be broken down, thus allowing the optimization of the processes on the enterprise level. The enterprise value stream map ensures the alignment of all the parties involved in the enterprise value stream at all levels of the organization. Once the common ground is established, the lean implementation should occur while taking into consideration all the departments and processes and work towards the same goal of constructing a quality ship in a timely manner.

3. Implementation of lean in low volume, high-mix manufacturing environment generates more challenges than high volume, low mix manufacturing environment. Lean principles, which were developed in a high volume manufacturing environment, need to be selectively and carefully applied in a low volume, high-mix manufacturing environment. The goals set for reaching lean in the two environments differ somewhat. While in high volume environment one of the goals is to reduce the overall top level cycle time, in the shipyard one of the goals is to reduce the cycle times of individual process steps without reducing the overall cycle time of the product. Both high and low volume environments have some goals in common and implement lean to reduce costs and improve efficiencies and flexibilities of the processes. Therefore, implementation of lean in a low volume, high mix manufacturing environment, such as the shipyard, should be approached with care and the principles should be applied selectively.

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Exhibit 1: Value Stream Mapping Icon List

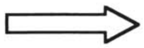
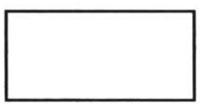
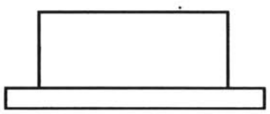
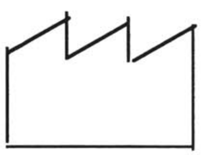
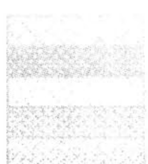
	Manual Information Flow
	Electronic Information Flow
	Detail/Assembly Flow
	Pipe Flow
	Fitting Flow
	PUSH Affow
	Manufacturing/Material Handling Process
	Information Processing
	Outside Sources
	Sourcing Engineering Planning Warehousing Manufacturing
	Value-adding time
	Lead time through the process
	Rework

Exhibit 2: High Level Enterprise Value Stream Map

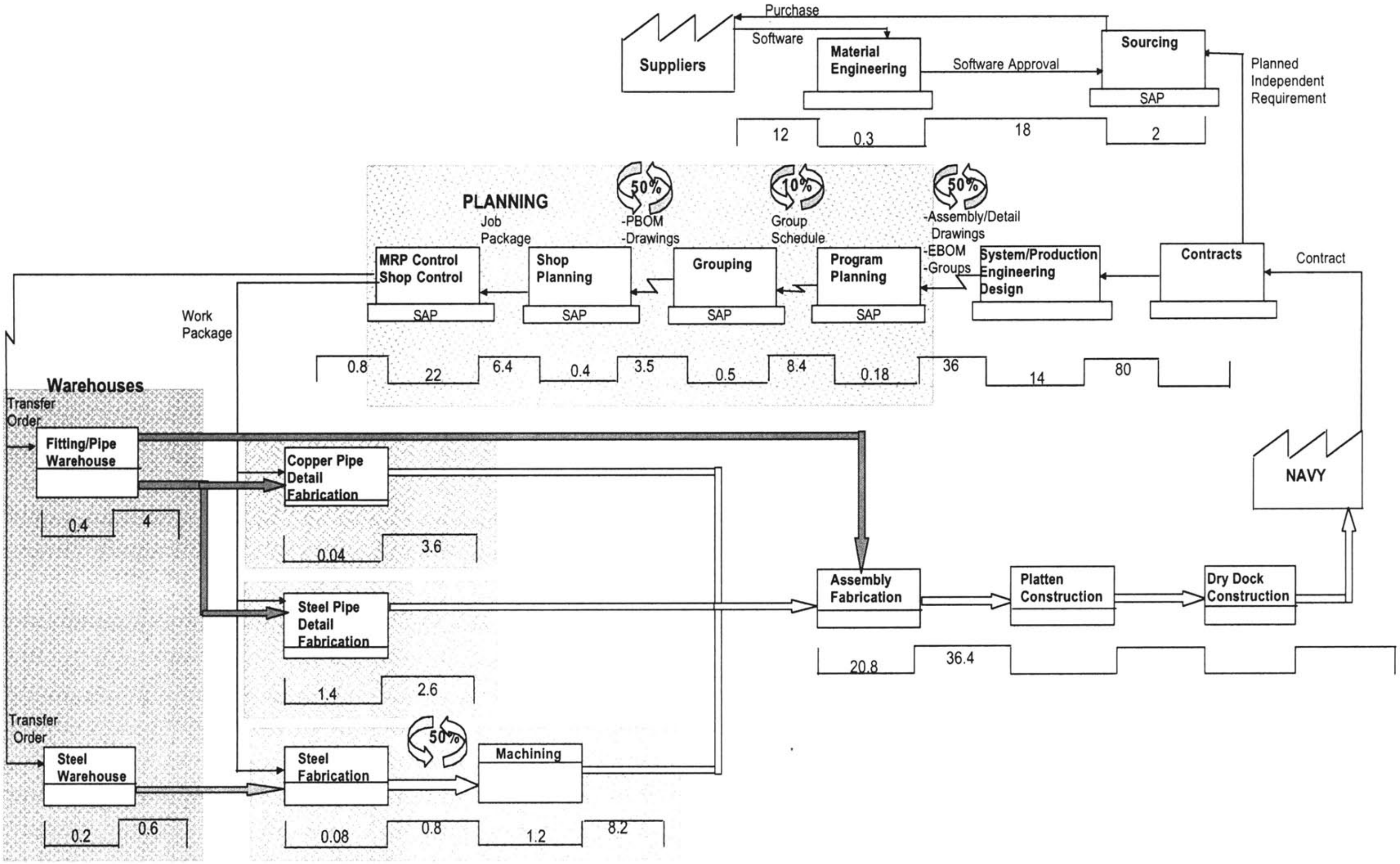


Exhibit 3: Enterprise Value Stream Map

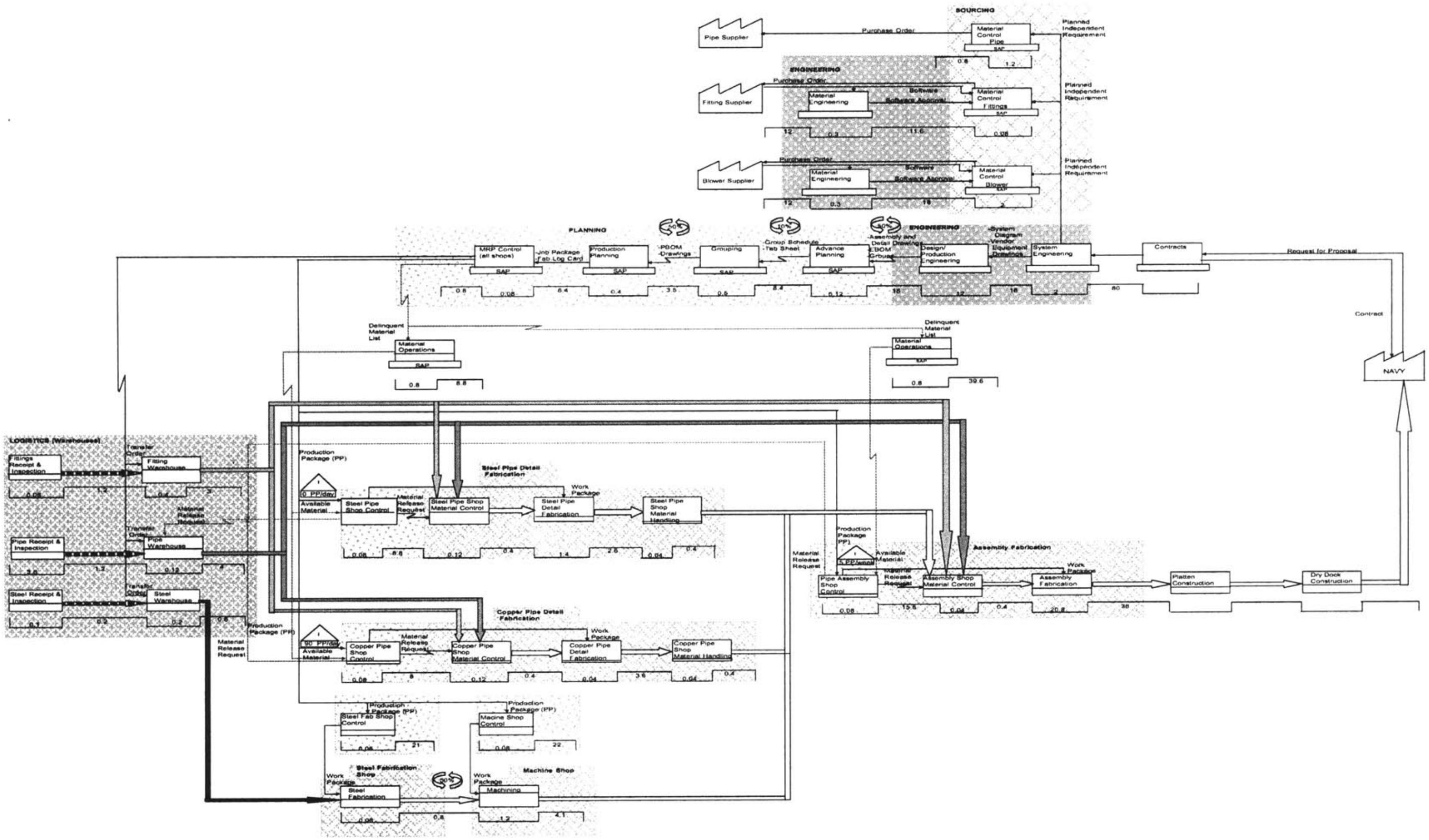
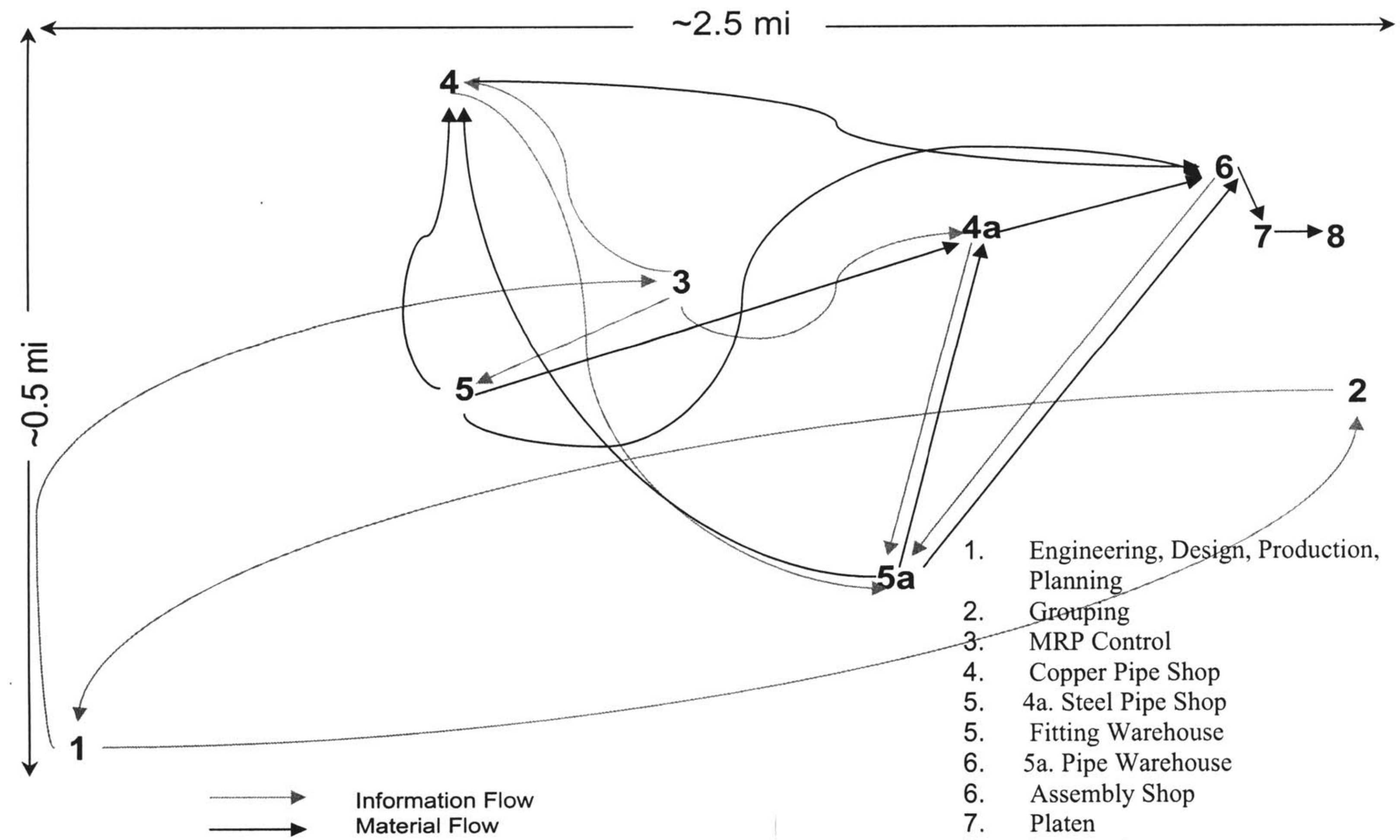


Exhibit 4: Information and Material Flow Across the Shipyard



1. Engineering, Design, Production, Planning
2. Grouping
3. MRP Control
4. Copper Pipe Shop
5. 4a. Steel Pipe Shop
5. Fitting Warehouse
6. 5a. Pipe Warehouse
6. Assembly Shop
7. Platen
8. Dry Dock