AN EVALUATION OF SHIPYARD PRACTICES AND THEIR CORRELATION TO SHIP COSTS

by

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**Title**: An Evaluation of Shipyard Practices and Their Correlation to Ship Costs

Arleigh Burke-class destroyers are produced by Bath Iron Works in Bath, Maine, and Huntington Ingalls Industries in Pascagoula, Mississippi. This thesis evaluates the processes executed by the acquisition community and selected the shipbuilders at the Ingalls shipyard to discover opportunities to gain efficiency in the overall ship acquisition process. The methods of research include analysis of empirical earned value management data, evaluation of the procurement contract, and an observational tour of the Ingalls shipyard conducted in August 2017. Exploring the problem space and shareholders with the power and interest to effect change reveals four main focus areas in which appropriate action may result in more efficient shipbuilding. These four areas are the macro-processes that take place off the shipyard, micro-processes that take place on the shipyard, the shipyard’s layout and infrastructure, and the procurement contract. The results of the analyses of each of these areas revealed several opportunities for improvement. This thesis culminates with a list of recommendations for respective stakeholders that, if carried out, will improve cost efficiency, schedule adherence, and ship quality at the Ingalls shipyard.
ABSTRACT

Arleigh Burke-class destroyers are produced by Bath Iron Works in Bath, Maine, and Huntington Ingalls Industries in Pascagoula, Mississippi. This thesis evaluates the processes executed by the acquisition community and selected the shipbuilders at the Ingalls shipyard to discover opportunities to gain efficiency in the overall ship acquisition process. The methods of research include analysis of empirical earned value management data, evaluation of the procurement contract, and an observational tour of the Ingalls shipyard conducted in August 2017. Exploring the problem space and shareholders with the power and interest to effect change reveals four main focus areas in which appropriate action may result in more efficient shipbuilding. These four areas are the macro-processes that take place off the shipyard, micro-processes that take place on the shipyard, the shipyard’s layout and infrastructure, and the procurement contract. The results of the analyses of each of these areas revealed several opportunities for improvement. This thesis culminates with a list of recommendations for respective stakeholders that, if carried out, will improve cost efficiency, schedule adherence, and ship quality at the Ingalls shipyard.
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<tbody>
<tr>
<td>AAW</td>
<td>anti-air warfare</td>
</tr>
<tr>
<td>AC</td>
<td>actual cost</td>
</tr>
<tr>
<td>ALO</td>
<td>aegis light off</td>
</tr>
<tr>
<td>ASW</td>
<td>anti-submarine warfare</td>
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<tr>
<td>AT</td>
<td>acceptance trials</td>
</tr>
<tr>
<td>BCA</td>
<td>business case analysis</td>
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<tr>
<td>BIW</td>
<td>Bath Iron Works</td>
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<tr>
<td>CAPEX</td>
<td>capital expenditure</td>
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<tr>
<td>CG</td>
<td>guided missile cruiser</td>
</tr>
<tr>
<td>CMA</td>
<td>crew move aboard</td>
</tr>
<tr>
<td>CNO</td>
<td>Chief of Naval Operations</td>
</tr>
<tr>
<td>CPI</td>
<td>cost performance index</td>
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<tr>
<td>CSA</td>
<td>covered slab area</td>
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<tr>
<td>DDG</td>
<td>guided missile destroyer</td>
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<tr>
<td>DDG-1000</td>
<td>Zumwalt-class destroyer</td>
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<tr>
<td>DDG-51</td>
<td>Arleigh Burke-class destroyer</td>
</tr>
<tr>
<td>DMAIC</td>
<td>define-measure-analyze-improve-control</td>
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<tr>
<td>DOD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>DODI</td>
<td>Department of Defense instruction</td>
</tr>
<tr>
<td>EV</td>
<td>earned value</td>
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<tr>
<td>EVM</td>
<td>earned value management</td>
</tr>
<tr>
<td>FFP</td>
<td>firm fixed price</td>
</tr>
<tr>
<td>FM</td>
<td>family manufacture</td>
</tr>
<tr>
<td>FY</td>
<td>fiscal year</td>
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<tr>
<td>GD</td>
<td>General Dynamics</td>
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<td>GT</td>
<td>group technology</td>
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<tr>
<td>HBCM</td>
<td>hull block construction method</td>
</tr>
<tr>
<td>HII</td>
<td>Huntington Ingalls Industries</td>
</tr>
<tr>
<td>INSURV</td>
<td>board of inspection and survey</td>
</tr>
<tr>
<td>LHA</td>
<td>amphibious assault ship</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>LPD</td>
<td>amphibious transport dock</td>
</tr>
<tr>
<td>MIG</td>
<td>metal inert gas</td>
</tr>
<tr>
<td>NAVSEA 04</td>
<td>Naval Sea Systems Command for Logistics, Maintenance, and Industrial Operations</td>
</tr>
<tr>
<td>NSC</td>
<td>national security cutter</td>
</tr>
<tr>
<td>NSFS</td>
<td>naval surface fire support</td>
</tr>
<tr>
<td>O&amp;S</td>
<td>operation and sustainment</td>
</tr>
<tr>
<td>PMS 400D</td>
<td>DDG-51 program office</td>
</tr>
<tr>
<td>ROI</td>
<td>return on investment</td>
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<tr>
<td>SSGC</td>
<td>Supervisor of Shipbuilding Gulf Coast</td>
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<tr>
<td>TOC</td>
<td>theory of constraints</td>
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<tr>
<td>U.S.</td>
<td>United States</td>
</tr>
<tr>
<td>VCHT</td>
<td>vacuum collection, holding, and transfer</td>
</tr>
<tr>
<td>VLS</td>
<td>vertical launch system</td>
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<tr>
<td>WIP</td>
<td>work in progress</td>
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<tr>
<td>ZOFM</td>
<td>zone outfitting method</td>
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<td>ZPTM</td>
<td>zone painting method</td>
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EXECUTIVE SUMMARY

The U.S. Navy has acquired guided missile destroyers (DDG) from two major defense contractors since 1985. The two shipyards, each constructing approximately half of the Navy’s DDG inventory, Bath Iron Works (BIW) of Bath, Maine owned by General Dynamics (GD), and Ingalls shipyard of Pascagoula, Mississippi owned by Huntington Ingalls Industries (HII), have produced more than 70 DDGs. At its inception, the Zumwalt-class destroyer (DDG-1000) program was intended to eventually supplant the Arleigh Burke-class destroyer (DDG-51) program. To this end, it was believed that construction of USS William P. Lawrence (DDG 110) at Ingalls shipyard beginning in 2008 would be the last DDG constructed in Pascagoula. That is, until a shift in strategic focus along with cost concerns related to DDG-1000 provoked a change to acquisition plans. An increased need for the capabilities offered by DDGs along with the inflated cost of DDG-1000 led Congress to reconstitute the DDG-51 program and, in 2013, Ingalls shipyard began construction on USS John Finn (DDG 113). Commencement of construction on DDG 113 marked a “restart” of DDG construction at Ingalls shipyard after retiring their DDG-production processes. It is expected that reconstituting the DDG-production process at a shipyard and hiring the needed employees is complex and takes time. As such, it is likely that there are opportunities to gain efficiencies is the DDG-production process. The ideal state is a DDG-production process that is more efficient and produces higher-quality ships. The problem space is that space that exists between current practices and this ideal future state. This thesis defines the problem space, identifies relevant stakeholders, explores the concomitant state of the processes and procedures within the problem space, and makes recommendations that will result in improved shipbuilding efficiency, improved quality, or both.

Researching the shipbuilding processes at Ingalls shipyard involves developing an understanding of the problem space. Within the problem space relevant to this thesis are four dominant areas. The first of these is the macro-processes that take place away from the shipyard. The macro-processes begin with the establishment of a national security strategy and continue until the capability need for DDGs is determined. The macro-
process determines the demand signal for DDGs and is the largest contributor to the required production rate of the shipyard. The second area within the problem space is the micro-processes that are executed at the shipyard. These processes include the aggregated efforts related to construction of the ship and were evaluated by on-site observation. The third relevant area within the problem space is the shipyard itself. The infrastructure and organization of the shipyard were also surveyed by on-site observation. The fourth, and final realm within the problem space is the procurement contract. Using earned value management (EVM) principles it is proven that waterborne construction is less efficient than modular construction that takes place prior to hull erection and subsequent launch. Furthermore, a comparison of practices at Ingalls shipyard to those of the competitor, BIW, revealed a practice of launching ships considerably earlier at Ingalls shipyard than at BIW. An evaluation of the contract, particularly the incentives that are offered, revealed opportunities for improvement that would increase the efficiency of the shipbuilding process as well as the quality of the ships being produced.

Evaluation of the macro-processes and their effects on the ability of the shipyard to efficiently produce ships reveals the need to stabilize the demand signal. In this thesis, the effects of fluctuating demand on a shipyard are described in detail. Changing the required production rate of a shipyard forces managers to make decisions that negatively affect cost, quality, or both. However, synchronization of the acquisition and production tempos offer the opportunity to gain considerable process efficiencies as well as explore potential technical and process innovations that result in appreciable improvement to the shipbuilding process. To help stabilize the demand signal applied to shipbuilders when strategy changes, the need to stabilize current inventory through quality-centric maintenance is recommended. Stabilizing the current inventory would improve the longevity and operational availability of existing hulls while minimizing the magnitude of changes to the demand signal for new hulls resulting from changes to the Navy’s inventory goal.

An observational tour of Ingalls shipyard revealed several bottlenecks in the production process. These bottlenecks, observable as work in progress (WIP), exist in both construction and outfitting. The WIP observed at the integration bays indicate a
constraint in the stacking hall while WIP in the outfitting storage and staging area indicate a constraint in the outfitting process as well as an incongruence with just-in-time protocol. The first recommendation related to the micro-processes of the shipyard is to subordinate every step of the shipbuilding process to the two observed constraints. Although counterintuitive, the attenuating the rest of the process to the constraints minimizes WIP without impacting throughput. Addressing other issues with the micro-processes, this thesis recommends completing as much construction as practicable prior to erecting the hull. Within this thesis, several examples of work items that could have been completed prior to hull erection are described. An exhaustive audit of shipbuilding processes is recommended to determine a comprehensive list of work items that could be further completed prior to launch and thereby reduce the proportion of construction and outfitting required after the ship is launched.

During the on-site observance of the shipyard processes, opportunities to gain process efficiency through infrastructure investment was evident. This infrastructure investment would be conducted through the capital expenditure (CAPEX) initiative, as described herein. Expanding, or increasing the size of the stacking hall would alleviate the constraint currently experienced. Similarly, expanding the integration bays so three hulls may be erected abreast rather than two removes the current constraint experienced there. An expansion of the stacking hall and integration bays would mitigate or reduce the impact of the constraints and allow the shipyard to increase throughput. As it is not always practicable to elevate constraints in the short term, the reduction of their negative impact may be achieved through exercising the CAPEX incentive to cover the outfitting storage area. Covering the outfitting storage area mitigates the adverse effects of weather on the finished components awaiting installation as well as reduces the occurrence of weather delays.

A detailed evaluation of the procurement contract reveals the necessity for altering the current construct to incentivize progress prior to launching the ship. This incentive would provoke the shipbuilder to further complete construction of the ship prior to launch, thereby leaving less construction to be completed waterborne. Utilizing the dynamic period performance incentive to provoke construction progress prior to launch
may encourage the shipbuilder to progress construction further prior to launch. If proven effective, it is recommended to develop a stand-alone incentive in future procurement contracts that compels the shipbuilder to achieve sufficient construction progress prior to launch.
I. INTRODUCTION

A. BACKGROUND

The program to develop and build Arleigh Burke-class guided missile destroyers (DDG-51) began in the late 1970s. The intent of this program was to deliver modern multi-mission surface combatants that could replace the Spruance- and Kidd-class destroyers that were in service at the time. Emphasis for the guided missile destroyer (DDG) was placed on anti-air warfare (AAW), air defense, and mid-ocean operations. As such DDGs, along with guided missile cruisers (CG), would become the host vessels for the Aegis combat system which had been in development since the late 1960s. In the 32 years since the program’s inception, 77 DDGs have been procured and 65 of them delivered to the United States (U.S.) Navy by two defense contractors, Bath Iron Works (BIW) of Bath, Maine, which is owned by General Dynamics (GD) and Ingalls Shipbuilding of Pascagoula, Mississippi, owned by Huntington Ingalls Industries (HII).

The contract to build the first DDG, USS Arleigh Burke (DDG 51), was awarded to BIW in 1985. The second ship of the class, USS Barry (DDG 52), was built by Ingalls Shipbuilding. Since the beginning of the DDG program a total of 35 DDGs have been constructed by BIW and 30 by Ingalls Shipbuilding. The first 28 of these DDGs are known as flight I/II ships. These ships are 505 feet long with a beam width of 66 feet and displace 8,300 tons when fully loaded. They are propelled by two shafts that are each driven by two gas turbine engines and host early variants of the Aegis weapon system with a AN/SPY-1 naval radar system manufactured by Lockheed Martin.

In the mid-1990s, the Navy initiated a design upgrade to the DDG ship class which included the addition of a helicopter hangar, an increase in the number of vertical launch system (VLS) cells, an updated Aegis baseline software package, and other improvements. This new design is known as the flight II/A DDG-51s. Figure 1 illustrates the comparison of flight I/II destroyers to the flight IIA destroyer. To incorporate the added capability, flight IIA destroyers are four feet longer and displace approximately
1,000 additional tons when fully loaded; much of this attributable to the embarked helicopter and its hangar.

Figure 1. Profile of DDG 51 Flight I/II and DDG 51 Flight IIA.

Flight II/A DDG-51s were intended to be the last ships of the class that would be commissioned. For years, the Navy’s plans were to cease procurement of DDG-51s in fiscal year (FY) 2005. At that time the procurement of DDG-51s was to stop as procurement of Zumwalt-class destroyers (DDG-1000) was to begin. Originally, 32 DDG-1000s were to be procured. This decision resulted from the strategic shift from post-cold war naval strategy that anticipated open-ocean engagements with sophisticated opponents capable of power projection toward a strategy that anticipated littoral engagements where naval surface fire support (NSFS) was integral to success. Zumwalt-
class destroyers were to be technologically superior to the preceding DDG-51s with an abundant capacity for electrical power generation that would facilitate future weapons demanding such capability. Furthermore, as stated in Congressional Research Service reports, the DDG-1000s were intended to regain the large-caliber naval gun capability that was lost after the decommissioning of the Iowa-class battleships (O’Rourke 2017a). Increased automation would decrease the crew size and thereby decrease the operation and sustainment (O&S) costs incurred over the life cycle of the ship. Finally, at a displacement 65% larger than the Arleigh Burke-class destroyers, the Zumwalt-class destroyers incurred a cost of nearly $4 billion per ship in FY15 dollars.

The DDG-1000 acquisition strategy submitted by the Navy in 2004 called for the first vessel to be built by HII/Ingalls. The second hull was to be built by GD/BIW; followed by an additional six hulls that would be evenly distributed between HII/Ingalls and GD/BIW. However, in 2005, the Navy proposed a competition between HII/Ingalls and GD/BIW would determine which contractor was awarded a contract to build all DDG-1000s planned for procurement at that time. According to the Congressional Research Service, this proposal was rejected by Congress in a provision to the Emergency Supplemental Appropriations Act for 2005 which required a “two-lead-ship” acquisition method (O’Rourke 2017a). This direction from congress did not specify the proportions by which shipbuilding contracts would be awarded to the two contractors. Negotiations continued between the Department of Defense (DOD), GD/BIW, and HII/Ingalls to determine the contractors that would produce the planned DDG-1000s for the next three years. Finally, in 2009, it was announced that an agreement between the Navy, GD/BIW, and HII/Ingalls had been reached. By agreement, all three procured DDG-1000s would be produced by GD/BIW while HII/Ingalls would produce various parts of each ship, most notably the composite superstructures.

Displacing procurement of DDG-51s with the new DDG-1000s and the award of the contract to build DDG-1000s to GD/BIW meant a possible reduction in the number of ships that would be produced for the U.S. Navy at Ingalls shipyard in Pascagoula, MS. However, countering the negative impact to Mississippi’s industrial base, the drawdown of DDG-51 production in Pascagoula began as HII/Ingalls planned for an increase in
production of other ship classes such as the America-class amphibious assault ship (LHA), San Antonio-class amphibious transport dock (LPD), and the Legend-class national security cutter (NSC). Finally, in August 2005 Hurricane Katrina struck the Gulf Coast causing extensive damage to Ingalls shipyard to include buildings, vehicles, and cranes. An imminent end to procurement of DDG-51s, the restructuring of Ingalls shipbuilding to produce LHAs, LPDs, and NSCs, coupled with the damage sustained from Hurricane Katrina each served to reduce Ingalls’ need and capability to continue to produce DDG-51s.

Only three years later another change is naval strategy would significantly modify shipbuilding plans. The 2008 naval strategy, based upon anticipated future operational requirements, called for increased focus on open-ocean anti-submarine warfare (ASW), countering ballistic missiles, and countering anti-ship cruise missiles. This new focus is seen as a response to rising large-scale navies and adversarial militaries capable of developing and utilizing such capabilities. As such, a reconstitution of the DDG-51 program was seen as more cost efficient than modifying and procuring more DDG-1000s to meet these requirements. In 2009 Congress approved the Navy’s FY2010 budget submission that proposed terminating procurement of DDG-1000s after the third hull and reconstituting the DDG-51 program. Before this approval, the last destroyer that would be produced by HII/Ingalls was USS William P. Lawrence (DDG 110) which was commissioned in June 2011. After the shift in naval strategy and the Congressional approval to reconstitute the DDG 51 program, the next destroyer built by HII/Ingalls was USS John Finn (DDG 113). Construction on USS John Finn began in September 2012. The commencement of construction of USS John Finn is referred to as “restart” amongst shipbuilding professionals. This term refers to the notion that HII/Ingalls was restarting its DDG-51 production line after believing they had produced their last destroyer in 2011 and is a significant term in the sections that follow.

B. PROBLEM DESCRIPTION

As expected, HII/Ingalls terminated production of destroyers and shifted focus toward the other ship types they would continue to produce. It is conceivable that
restoring a production line, instituting construction processes, and hiring or training the required personnel to build destroyers after deconstructing the destroyer-producing infrastructure would be challenging. Preparing for production of a Navy warship is a process that typically requires sizeable capital investment and takes time. To restore the destroyer-production capability at Ingalls shipyard and expect they could simply resume proficiently producing destroyers at the same level of efficiency as before production ceased is not reasonable.

Since the restart, HII/Ingalls has produced, or is currently producing six destroyers. In this same timeframe, GD/BIW has produced, or is currently producing five destroyers. Presumably, the efficiency with which HII/Ingalls is producing destroyers is less than that of GD/BIW, not as victimized by the need to restart the DDG-51 program production. Instead, GD/BIW continued to produce DDG-1000s which utilize much of the same tooling, facilities, processes, and workforce. Additionally, GD/BIW does not produce as many ship classes as does HII/Ingalls, as they only produce DDG-1000s and DDG-51s. These points suggest a steeper decline in HII/Ingalls efficiency during the years when DDG-51 procurement was thought to be complete than the decline that may have been experienced at GD/BIW.

Opportunities to gain efficiencies in the production of destroyers exist at HII/Ingalls. These opportunities exist in the form of identifying potential process improvements, exploitation of the principles of modular ship construction, infrastructure investments, and contract actions or protocol that could positively affect contractor practices. An evaluation of the current production infrastructure, production processes, and contract structure could reveal these opportunities. Furthermore, improved efficiency in the production of destroyers by HII/Ingalls would result in cost savings that could be shared by the contractor and the Government.

C. THESIS OBJECTIVES

This thesis will describe ship production concepts as they apply to the modern shipbuilding industry. Furthermore, contractual concepts and practices will be explored to include contract structure and incentivization protocol. Additionally, the relationship
between the acquisition tempo and production tempo will be evaluated. Finally, a survey
of the destroyer production infrastructure and processes at HII/Ingalls will be detailed to
include any bottlenecks in the process and infrastructure investment possibilities that
might present opportunities for process improvement.

The intended outcome of this thesis is a collection of recommendations for HII/
Ingalls, Supervisor of Shipbuilding Gulf Coast (SSGC), the Program Executive Office
Ships (PEO Ships), and any other relevant organization with purview over the processes
and lines of effort discusses within. The conclusions and recommendations of this thesis
are not intended to indict the effort or capability of any organization nor are they intended
to criticize any decisions that have been made. While the information available to the
author is not perfect, as it rarely is, the information, conclusions, and recommendations
within are made in good faith and according to the concomitant information available.
II. LITERATURE REVIEW

A. MODERN SHIPBUILDING CONCEPTS

As shipbuilding processes improve, so too does the capability of the ship that is produced. Future chapters of the thesis will show that improved processes may save time or money or improve quality but it is also conceivable that improved processes can help to add capability in the same way system research and development might.

Once the contract to build a ship has been awarded, the objective of the shipbuilder is to deliver the ship at minimal cost. This allows the shipbuilder to maximize their profits. The required materials are typically purchased by the shipbuilder in advance or provided by the purchaser. Likewise, the wages of the workers are more heavily determined by the labor market and the industry, not by the shipbuilding companies themselves. So, the greatest opportunity to minimize cost in ship production is to minimize the labor hours required to build the ship. Reduction of the labor hours required relies heavily on efficient processes that accomplish a task in the least amount of time while minimizing the propensity for rework. It is with this in mind that many of the modern concepts of shipbuilding have come to be. The following sections describe many modern shipbuilding concepts that are relevant to the subject at hand including construction processes, production tempo control, shipyard layout, and production flow.

a. Zone Construction Method

Antiquated shipbuilding methods, such as the skeleton-method, require laying the ship’s keel, erecting stem and stern posts, building the ship’s frame, and finally attaching the ship’s skin. Compared to contemporary construction methods, this method is inefficient and time consuming. Instead of building ships from the keel upward, the zone construction method coordinates building several zones of the ship simultaneously. These zones are combined into larger sections of the ship, called blocks. Blocks are then combined into even larger portions of the ship, called grand blocks. Finally, grand blocks are combined to form the ship’s final form. Management of this method of shipbuilding is complicated and requires much coordination of various shops, disparate trades,
logistics, and work flow. The overall concept of zone construction is made up of the following supporting methods:

- hull block construction method (HBCM)
- zone outfitting method (ZOFM)
- zone painting method (ZPTM)
- group Technology (GT)

(1) Hull Block Construction Method

The construction of blocks, or zones, is the dominant focus of this concept. Blocks should be of nearly maximum size achievable given the facilities within which the blocks are constructed. This objective minimizes the number of blocks of which a ship is comprised while increasing efficiency of the overall construction process by reducing the number of pieces that must be fit together to form grand blocks, and eventually the ship. The area and volume of blocks should be sufficient to achieve reasonable accessibility to allow workers to achieve better efficiency (Storch et al. 1995, 68). However, blocks should be nearly equally sized when compared to one another, even at the expense of design convenience, to afford even distribution of work load across the fabrication and assembly shops that construct the blocks (Storch et al. 1995, 68). As previously stated, blocks are aggregated to form progressively larger subsections of the ship until a fully distinguishable ship is eventually erected. Figure 2 illustrates this concept as shops fabricating parts of the ship supply a facility that creates system assemblies of these parts. System assemblies in turn, are combined to form sub-blocks which are then combined to form blocks. Blocks are adjoined to create grand blocks which are finally assembled to form the ship.
Parts fabrication is the first manufacturing level and is the most elemental. That is, parts fabrication conducts manufacturing processes that cannot be broken down to a lower level. This includes such processes as cutting adjoining stiffeners to steel to create stiffened plate or creating beams of various shapes from raw material. The next level of manufacture, system assembly, begins to assemble systems from the manufactured parts. These system assemblies are often assembled on platforms, or skids, and eventually placed into sub-blocks and adjoined with nearby supporting components such as ventilation, piping, or cableways. The next three levels of manufacture join similar sized subsections of the ship into progressively larger subsections. These levels of manufacture are often performed with the sections of the ship upside down. This is intended to make assembly of the ship simpler in that much of the labor of these manufacturing levels takes place in the overhead space of the ship. Conducting this work, such as welding, is considerably easier and more efficient if performed in a down-hand fashion. Typically, once blocks are manufactured and ready to be combined to form grand blocks, the blocks are flipped to their recognizable, right-side-up configuration. In shipbuilding this configuration is referred to as “ship shape.” Once ship shape, blocks are combined into

Figure 2. HBCM Manufacturing Levels. Adapted from Storch et al. (1995).
grand blocks at which point parts installation continues until the grand blocks are constructed to the maximum level of overall completion that is reasonably achievable. This is an important objective of grand block construction as this is the last opportunity to progress in overall ship construction completion before the ship begins to take shape as the grand blocks are erected into final hull form. Once grand blocks are adjoined, the ship begins to take shape and construction efficiency is reduced as accessibility of spaces and movement throughout the ship are restricted.

(2) Zone Outfitting Method

Zone outfitting method refers to the method by which the parts, components, and systems are integrated into predetermined zones. That is, as the HBCM described in the preceding section describes generally how the ship is erected, the ZOFM describes how it is outfitted with the various pumps, piping, ventilation, electronics, and machinery that make up the anatomy of the ship. This method utilizes a zoning protocol as HBCM does, however the zones determined by ZOFM are independent of those used in HBCM. That is, as the ship is being erected according to the zones determined by HBCM, many systems are being installed on board that ship in zones that might span across HBCM zones and may not share common boundaries.

Outfitting the ship with material is completed according to three levels. The first of these levels is on-unit outfitting. This refers to outfitting that is performed independent of hull structure (Storch et al. 1995, 82). On-unit outfitting is performed in a shop or some other facility separate from the area where structural construction is taking place. This outfitting level is relatively safer than outfitting on a block and highly efficient due to ease of accessibility and increased range of motion.

The second outfitting level of ZOFM is on-block outfitting. On-block outfitting is the installation of equipment that takes place on structural blocks as they are being constructed. As previously stated, the zones of ZOFM do not need to match the HBCM zones. As such, outfitting may occur across HBCM zones or multiple ZOFM zones may be contained within a single HBCM zone. Storch et al. (1995) provide an excellent example of this as the equipment to be installed while a block is inverted may be one
zone while the equipment to be installed once the block is ship shape might be another zone. This level of outfitting becomes less safe or efficient than on-unit outfitting as maneuvering within the block construction zone becomes necessary.

The third and final level of ZOFM outfitting is onboard outfitting. This is the continued outfitting of the ship after the ship has been erected. As the structural construction of the ship is nearly completed, this level of outfitting is the most difficult, least safe, and least efficient (Storch et al. 1995, 82). It is often the objective of shipbuilders to limit the amount of onboard outfitting that is necessary due to its cost and inefficiency. As some level of onboard outfitting is always necessary, concessions are sometimes made in the structural completion of the ship to facilitate final outfitting efforts. These concessions include such actions as delaying installation of decking and handrails or allowing openings in the hull or bulkheads to afford accessibility to certain areas.

The ZOFM begins with the procurement or fabrication of the components that are to be installed. These components are used to manufacture the systems of the ship and installed appropriately according to the most efficient outfitting method. Structural construction and component outfitting proceed simultaneously until the ship is erected and all systems are installed. Finally, once a system is installed, it undergoes testing to verify proper operation. Figure 3 shows the three levels of outfitting described earlier within the context of all of the manufacturing levels involved in the installation of ship systems.
Productivity of ZOFM, just as with HBCM, is improved when the level of effort required within each zone is equally apportioned. This minimizes the probability of any one smaller zone awaiting completion of a larger zone before being allowed to continue outfitting. Other objectives of the ZOFM include (Storch et al. 1995, 82)

- taking advantage of inverted spaces so as much outfitting as possible can be conducted in the down-hand position rather than outfitting overhead
- limiting the amount of outfitting taking place in small or narrow spaces by maximizing on-unit outfitting or on-block outfitting prior to erecting the ship
- simultaneously outfitting zones that do not conflict with one another in terms of space, location, or tooling so as to minimize the time needed to complete outfitting
(3) Zone Painting Method

The zone painting method (ZPTM) integrates painting and preservation of shipboard equipment and spaces with the outfitting and construction of that equipment and spaces. This is an extension of the logic of the HBCM and ZOFM construction and outfitting methods (Storch et al. 1995, 89). Before the realization of ZPTM, painting and preservation would traditionally be performed once the ship was erected, when the ship was on the floating dock prior to launch, or even after the ship was launched and waterborne. However, waiting until construction is nearly complete to paint and preserve the ship is highly inefficient and ineffective as many areas of the ship cannot be accessed.

Treating painting as part of the manufacturing process affords the opportunity to gain efficiency in the overall construction of the ship but coordination is required between the managers of the painting processes and those of the construction and outfitting processes. Among the attributes that need to be coordinated are the timing of each manufacturing process to prevent any future step from needing to wait for primer or paint application or curing. Furthermore, the accuracy of manufacturing work on equipment and spaces should be carefully considered so as to minimize the need for painting rework due to manufacturing and construction mistakes (Storch et al. 1995, 89).

The modular paint and preservation method, ZPTM, is comprised of several stages that begin with the application of shop primer. This is the primer that is applied to raw material before it is manipulated to form structural components such as strength members or outfitting components. Then, following its first manufacturing level, partially manufactured portions receive an anti-corrosive primer that is applied to achieve as close to complete coverage as achievable. Once fully primed and ready for installation onto a unit, block, grand block, or erected ship, the component receives undercoats of paint followed by its topcoat. The fully preserved and painted outfitting component or structural assembly continues in its respective manufacturing or construction process until an erected ship is formed. At this phase of construction, the erected ship is preserved and painted to the maximum reasonably achievable extent and only painting that could not have been previously completed remains. Figure 4 illustrates the ZPTM manufacturing levels which must be coordinated with the aforementioned HBCM and
ZOFM processes throughout construction and outfitting to achieve overall shipbuilding efficiency.

(4) Group Technology

Group technology, also known as family manufacture (FM) or cellular manufacture, is the grouping of machines and operators according to a product or family of products rather than according to their function. In the second edition of *Ship Production* by Storch et al. (1995), GT is defined as:

A technique for manufacturing small to medium lot size batches of parts of similar process, of somewhat dissimilar materials, geometry and size, which are produced in a committed small cell of machines which have been grouped together physically, specifically tooled, and scheduled as a unit. (Storch et al. 1995, 48)
This concept was born out of the desire to create a more efficient method of manufacturing products that require a variety of processes performed to that product. Prior to implementing GT, conventional processes typically grouped similar machines into shops while the product that was being manipulated was transported from shop to shop until the final product was finally formed. As an example, a batch of unprocessed pipes might be transported to a shop containing lathes. After processing the batch of pipes was finished, this batch of pipes might be transported to the milling shop followed by the cutting shop, drill press shop, and finally the grinder shop. The result of this process would be a batch of finished pipes ready for installation. Transporting batches of material between shops and conducting a process on an entire batch is time consuming. While the batch of material is undergoing a process at one shop, the machines of the other shops are idle and therefore not contributing to production.

GT rearranges the tools and operators of the manufacturing process according to a product family which facilitates a more continuous flow. Instead of operating all lathes in the lathe shop, milling machines in the milling shop, and so forth, each shop contains one of each type of tool required for the entire manufacturing process. This allows the unprocessed pipe to enter the shop and receive every step of the process before departing that singular shop. A comparison of each of these processes is illustrated in Figure 5.
Instituting group flow affords the opportunity to save time. For example, assume a batch size of 50 units and each step in the process takes three minutes. Also assume the production facility has five of each type of tool as depicted in Figure 5. Using conventional flow, five pipes could be machined in any shop simultaneously and those five pipes would be finished in that shop every three minutes. A shop could finish machining all 50 pipes in 30 minutes and send the batch onward to the next shop. Sending the batch of 50 pipes through all five shops in the process would require $30 + 30 + 30 + 30 + 30 = 150$ minutes. However, utilizing the group flow method, the unprocessed pipes would be evenly distributed amongst the five cellular shops shown in Figure 5. The first pipe in each shop would progress through the entire production process in $3 + 3 + 3 + 3 + 3 = 15$ minutes. Another pipe would complete the process every three minutes thereafter. By this method, a batch of 50 pipes would be fully processed in 42 minutes, saving 102 minutes when compared to the conventional processing method.
b. Production Tempo Control

Shipyard production tempo is a function of many factors. These factors include the processes of the shipyard, capability limitations, number of employees, customer requirements, adverse effects of weather, and more. In their book, Ship Production, Storch et al. point out some of the actions that impose required output changes in construction of Navy ships are changes to the contract requiring newer technology, correcting design flaws, or compliance with higher directives such as environmental laws. Furthermore, output changes may be caused by delays in providing customer-furnished material to the builder by a prescribed time that aligns with the builder’s schedule. Output changes may be imposed by the shipbuilder aimed at reducing cost or by a natural disaster, such as hurricanes (Storch et al. 1995, 38). Anything that may change the required, or optimal output of the shipyard must be managed in a way that achieves the maximum efficiency possible.

Figure 6 illustrates the effects of required output changes. In this figure, assume the required output follows curve A. That is, the optimal rate of output to minimize average production cost is at the trough of the curve, point q*. The average cost at this rate of production is shown on the vertical axis at $\frac{c}{q}$. Production at a rate below q* incurs higher average cost due to the workforce and facilities not being utilized to an optimal degree and the wasted potential results in inefficiencies that increase cost. Likewise, increasing production rate above q* increases average production cost as additional personnel must be hired, overtime must be authorized, process capacity is stretched beyond efficient design, or facilities must operate beyond capacity. It is the objective of the shipbuilder to understand the output versus cost curve that applies and seek to operate at a rate of output as close to q* as possible.
An increase to the required output caused by one of the aforementioned actions would cause the output versus cost curve to shift upward and to the left. The magnitude of this shift and the shape of the new curve are dependent upon the change that caused the shift. After the change to required output, the new output versus cost curve might be represented by curve B. Since the trough of curve B does not align with that of curve A, the shipyard now has a new rate of output that is most efficient, represented by \( q^{**} \). The shipyard must then decide which of the following actions to take, all of which increase average production cost.

- Option 1: Maintain the previous rate of output, \( q^* \). Because of the additional requirements, to maintain the same rate of output additional employees must be hired or overtime authorized. This option also requires lengthening the project schedule.

- Option 2: Slow the rate of production to the new efficient rate, \( q^{**} \). This requires lengthening the schedule more drastically than option 1 and
possibly requires executing shipyard processes and operating facilities below design capacity.

- Option 3: Do not adjust manning or overtime and allow the rate of output to decrease according to its natural tendency given the new requirements. The new rate of output is represented by $q^c$. This option would cause an inherent slip in schedule as the rate of output decreased to some level below the original rate.

- Option 4: Maintain program schedule. To accomplish this, the rate of output would need to be increased to meet the new demand on the same timeline. This increased rate of output is shown as $q^r$. Increasing the rate of production requires adding the manning or overtime necessary to complete the project on the same schedule.

In Figure 6 the average cost of production before any change is incorporated is shown on the vertical axis at point $c/q$. The change that brought about curve B also causes an increase in average production cost, no matter which option is selected.

c. Shipyard Layout

As shipbuilding processes have evolved over time, so too has the supporting shipyard layout. The layout of a shipyard can serve the shipbuilder as an asset or a liability depending on whether the layout is conducive to efficiency and supportive of the processes employed. The evolution of shipyard layouts can be considered as four generations. The first generation consists of those shipyards established before World War II. Second-generation shipyards are those developed during World War II and up to the year 1960. Third-generation shipyards are those developed between 1960 and the mid-1990s. Finally, fourth-generation shipyards are the most modern and are being constructed today, either originally constructed or through the modernization of existing shipyards. The characteristics of each generation of shipyard and the attributes that set them apart will be discussed in the following paragraphs.

(1) Third-Generation Shipyard

The first two generations of shipyard evolved from the beginning of modern shipbuilding history until the middle of the 20th century. The first-generation shipyard is characterized by its long and narrow configuration. The ship was constructed on a hull
erecting platform and the outfitting was performed waterborne. The second-generation shipyard, developed from the need to support shipbuilding requirements during World War II, began pre-fabricating ships. That is, considerable portions of the ship were fabricated and constructed in shops and assembly bays, away from the area where the hulls were eventually erected (Storch et al. 1995, 163). Improvement in welding processes as well as pre-fabrication practices allowed shipbuilders to construct the large, sturdy warships of World War II. However, the process-oriented shipyard was inflexible and unable to efficiently adapt to reduced demand once the war was over.

The Egyptian blockade following the Six Day War in 1967 closed the Suez Canal for the next eight years. Storch et al. credit this geopolitical condition with ushering in the era of the supertanker. As the demand for very large ships grew, the need for facilities and processes that could support construction of these larger ships also increased. Supertankers, large military ships, and eventually most ships, would be constructed at third-generation shipyards.

Third-generation shipyards, built since the early 1960s, saw an amplification of many of the attributes that are assigned to second-generation shipyards. That is, steel cutting, steel-based manufacturing, welding, and assembly line manufacturing processes were developed further. In-line, or mass-production processes were incorporated into the shipbuilding industry to give the ability to increase throughput even further. Facilities and work areas around the shipyards were clearly defined and further supported construction of the ship away from the launch area. Outfitting began to be distributed amongst various stages of construction although most outfitting continued to be performed later in the construction process, either in the hull erecting area or after the ship was launched.

The series production of ships in third-generation shipyards continued the evolution of process-oriented shipbuilding. Like earlier shipyards, the process-oriented third-generation shipyards are relatively inflexible and rely on high demand to ensure sustainable efficiency. These shipyards are highly mechanized to support a high volume throughput but are not well suited to remain efficient if demand is reduced. Figure 7 shows a simplified functional block diagram illustrating the functions about which the process-oriented third-generation shipyard is designed.
As shown in Figure 7, materials are accepted at the respective staging areas for outfitting materials, structural materials, and machines. The structural material is processed in the steel fabrication facilities, painted, and then transported to the block assembly facility. Similarly, the outfitting materials are used to manufacture outfitting components and systems prior to being painted. Painted outfitting components and systems are transported to the relevant assembly area for installation on board the ship. As previously stated, most outfitting takes place in the hull erecting area or waterborne. Like the outfitting material, machine material is received, processed, and eventually moved to an assembly area for installation on board the ship.

(2) Fourth-Generation Shipyard

The fourth and most current generation of shipyard shifts the focus of shipbuilding efficiency from process-orientation to product-orientation. These shipyards utilize the concepts of GT and remain flexible in process such that changes in workload due to changes in demand are handled efficiently. Production within the various facilities associated with the aggregated shipbuilding process are synchronized to minimize on-hand inventory, otherwise referred to as buffer storage or work in progress, which will be described in detail in later sections of this thesis (Storch et al. 1995, 168). Utilizing GT concepts, intermediate manufacturing and assembly processes are highly efficient and
flexible. The balanced workload of each shop, facilitated by optimized block size, promote parallel processes of construction rather than the in-line process-oriented layout of the third-generation shipyard (Storch et al. 1995, 168). Figure 8 illustrates the functional blocks around which the product-oriented shipyard is organized.

Figure 8. Fourth-Generation Shipyard Block Diagram

The parallel arrangement of shops, shown in Figure 8 exemplifies the fourth-generation shipyard. Like its predecessor, materials are received at their respective staging areas for the structural, outfitting, and machine lines of effort. However, rather than entering an assembly line process of fabrication, this material is converted from raw material to nearly finished product within a single shop as the GT concept suggests is most efficient. The product, whether structural assembly, outfitting system, or machine is
transported to the relevant assembly bay where blocks are assembled to a higher degree than those of previous generations of shipyards. Once block assembly is completed to an optimal level, that block is transported to the appropriate hull erecting area where the ship is eventually nearly fully assembled prior to launch. As with previous generations, the fourth-generation shipyard continues machine installation and outfitting during hull erection and after launch however, these actions are predominantly conducted during block assembly leaving little outfitting remaining once the ship is waterborne.

B. PROCESS IMPROVEMENT

Continuous process improvement is an organizational focus across many industries and internationally. As presented in the sections outlining the history of shipbuilding, process improvement can contribute to the evolution of an industry just as technological research and development does. As such, investment into educating personnel on process improvement methodologies has been a priority of many industries for the past few decades. One of these methodologies follows a cyclical process defined by its steps. These steps consists of define, measure, analyze, improve, and control (DMAIC). This cycle is illustrated in Figure 9.
Figure 9. DMAIC Cycle

The DMAIC cycle begins with defining the problem, process, or opportunity for improvement as well as defining internal and external customers. As the DMAIC cycle is integral to the lean six sigma initiatives for reduction in waste and variation, defining the process is often performed in terms of value added for the customer. However, the DMAIC process can serve as a stand-alone method to improve a process for which value added to the customer is not the primary objective. Once defined, measuring the current process status in terms of overall process health, effectiveness, efficiency or another attribute is completed. An analysis of the subject process to determine root cause of inefficiencies or other unwanted process behaviors follows. Once effective analysis has determined the root cause of the defects within the process, deliberate steps are planned and executed. These steps are aimed at the root causes of the processes shortcomings thereby improving the process. Finally, the last step of the DMAIC cycle is to control the newly improved process. That is, the new process is actively controlled to prevent reversion to the old process as is often the natural tendency when changes are not managed.
Along with execution of the DMAIC process and in effort to achieve continuous process improvement, there are other relevant concepts such as lean production and the theory of constraints (TOC). These concepts will be discussed in detail in the following sections.

1. **Lean Production**

Lean production, also known as lean manufacturing or simply lean, is the effort to improve a process by systematically eliminating waste within the process. In his book, *Essentials of Lean Six Sigma*, Salman Taghizadegan lists and describes the seven most important types of waste. Any attempt to apply lean principles to a process in effort to reduce waste must begin with the endeavor to discover the waste that exists. The types of waste that Taghizadegan suggests are most important and prevalent are:

- overproduction
- delay and wait time
- transportation
- processing and complexity
- excess inventory
- waste motions / underutilized talent
- errors and defects

The first of these types of waste, overproduction, refers to the production of material for which there is no demand. This production is wasteful as it may often lead to a disposal of the produced material before it is put to its intended use. One example of overproduction waste is the restaurant that disposes of food that was never ordered by a customer. Delay and wait time are wasteful as the process must be temporarily halted to adjudicate the cause for delay. Taghizadegan provides some typical examples of this type of waste as machine down time, awaiting approval for something, or delay in receipt of materials. The third waste type is transportation. Taghizadegan defines transportations as “delivering to and from outside the factory warehouse facility.” Of course in the shipbuilding context, where Taghizadegan uses the word factory, the words shop,
assembly area, shipway, or dock could be substituted. He goes on to proclaim that the delivery of finished goods to another location is typically resultant of poor plant or process layout. Waste attributed to processing and complexity can be classified by the identification of work in progress (WIP) (Taghizadegan 2006, 64). The necessity to store WIP and eventually transport it to the next step in the process adds processing steps and is inherently wasteful. Similarly, the next type of waste, excess inventory, is the storage of finished goods for which there is no demand such as the car lot containing unsold cars from an earlier model year (Taghizadegan 2006, 64). This type of waste, like overproduction, results in tying up resources to facilitate material storage or could lead to the disposal of finished goods that were never put to their purpose. The penultimate waste that Taghizadegan describes is waste motions and the underutilization of talent. He notes waste in motion resulting in lost time as well as increasing the propensity for error. The underutilization of talent allows inefficiency in the process by not exploiting employee skills, ideas, or recommendations. Finally, errors and defects are wasteful in that they typically incur rework (Taghizadegan 2006, 65).

2. Theory of Constraints

The theory of constraints was created by Dr. Eliyahu M. Goldratt in the early 1980s and states that the performance of a process is limited by its constraints. A constraint is any aspect of the process that prevents the process from achieving higher performance. In his 2010 article published for the peer-reviewed online encyclopedia, Scholarpedia, Dr. John Blackstone of the University of Georgia describes the concomitant seven steps for managing constraints. These steps are:

1. Determine the process goal.
2. Determine process performance measures.
3. Identify the constraint.
4. Exploit the constraint.
5. Subordinate the rest of the process to the constraint.
6. Elevate the constraint.
7. Repeat the process to identify and alleviate the new constraint.
Similar to the DMAIC cycle for process improvement, the theory of constraints begins with the definition of the process, its goals, and the metrics that will be utilized to measure the process. Once these steps are complete, the constraint must be identified. Most often the constraint is identified by locating an excess of WIP at some stage in the process (Blackstone 2010). Excessive WIP indicates a bottleneck in the process about which the overall performance of the process is restricted. Once identified, the constraint must be exploited. That is, the process step that creates the bottleneck must be evaluated and modified to ensure it is operating at its maximum capacity. Dr. Blackstone points out that once the constraint is identified, the natural tendency is to get more people, tools, or material to relieve the bottleneck. He states, the addition of resources to the constraint is premature if the constraining step is not operating at its capacity. Only after being exploited, should the constraint be elevated by adding resources or revising policy to increase the throughput of the constraint. As the constraint is that which limits the overall process performance, an elevation of the constraint serves to improve performance of the entire process. Finally, once the constraint is elevated and the process improved, there is a new constraint. Dr. Blackstone states there will always be a constraint. The constraint may be a process constraint which is amendable by the process master or might be a market constraint, such as a limited demand, which is typically beyond the ability of process improver to solve.

In deference to the theory of constraints, in their book, Ship Production, Storch et al. point out the negative impact of bottlenecks on the shipbuilding industry. Specifically, bottlenecks in the production process often force shipbuilders to delay subsequent process steps. This chain of events is one of the most common causes for shifting the output versus cost curve introduced in the section of this chapter on production tempo control and shown in Figure 6 (Storch et al. 1995, 40). As such, Storch et al. advocate for detailed planning as it helps assure near-level work load thereby reducing the propensity for waste in the form of WIP.
C. **EARNED VALUE MANAGEMENT**

Earned value management (EVM) is a project management methodology that facilitates cost and schedule control as well as projections into final cost and schedule at project completion. EVM considers project cost, schedule, and performance parameters to give managers a means to assess project performance at any moment during project execution. In an effort to improve defense acquisition practices, Department of Defense Instruction (DODI) 5000.02 mandates EVM methods are applied to all cost and incentive contracts valuing $20 million or more. EVM provides a robust set of diagnostic metrics that may be used to assist in project management. Of these, the concept that applies most directly to this thesis is cost performance index (CPI).

CPI is a ratio that represents the cost performance of the work that has been completed to date. It is quantified as a ratio of earned value (EV), or the value of the work that is complete, and the actual cost (AC), the cost incurred to complete the work that has been performed. A CPI greater than 1.0 indicates favorable cost performance while a CPI less than 1.0 represents unfavorable costs performance. In project management terms, favorable cost performance is referred to as “below cost” while unfavorable performance is termed “above cost.” The formula for CPI is as follows:

\[ CPI = \frac{EV}{AC} \]

D. **SUMMARY**

By examining the history of shipbuilding one can surmise the importance of shipbuilding processes over time. The advancement of ships is attributable not only to the research and development of the components and systems aboard the ships but also to advancements in the shipbuilding processes themselves. It is the evolution of building ships from the keel upward to frame building, then eventually building with metal and rivets and finally welding and modular shipbuilding processes that allow ships to have the size and strength that they do today. For this reason, studying and developing shipbuilding processes is important and may provide the path to the next major advancement in ship capability.
Modern shipbuilding is highly modular and requires meticulous planning and organization to be done efficiently. Ships are constructed in zones. These zones are determined in two different ways. Structural construction of the ship is performed by zones called blocks while outfitting with the components and systems aboard the ship is completed according to logical zones that may be independent of the blocks. The processes for hull construction and ship outfitting must work together in a cooperative manner so as to maintain positive progress in constructing the ship in the most efficient way possible.

Effective shipyard layout can facilitate increased efficiency of the shipbuilding process. As shipbuilding processes have evolved, so too have the yards within which these processes are practiced. The latest generation of shipyards are organized around a product, not a process. That is, the application of GT and lean practices in the manufacture of ships and their systems improve the flexibility of the shipyard to efficiently support either low or high demand. Furthermore, the flexibility gained by a product-oriented shipyard make it easier for that yard to adjust to changes in ship designs and sizes.

It is a priority of shipbuilders to maintain the tempo of production as constant as possible. Although often out of the control of the shipbuilder, a constant production tempo affords the opportunity to execute the details of the shipbuilding plans as originally designed. Changes in tempo are detrimental to the shipbuilder as they force decisions pertaining to the adjustment of workers hours, hiring or firing employees, incurring increased cost to produce the product, or schedule slippage. Each of these instances incur consequences that the shipbuilder must be aware of when making decisions on how to contend with either forced or unforced production tempo changes. However, since many of the causes for tempo changes are uncontrollable by the shipbuilder, such as weather, geopolitical influence, or material availability, the shipbuilder must be aware of the propensity for tempo changes and ready to act.

Lean manufacturing and the theory of constraints apply to shipbuilding just as with many other industries. To maximize efficiency of the shipbuilding processes, reduction of waste and bottlenecks is crucial. As the shipbuilding process is one that
involves many steps and a large geographic area, the opportunity for bottlenecks to exist undiscovered is present. As such, a detailed evaluation of shipbuilding processes with intent focus on identifying waste and constraints may be beneficial.

Finally, EVM is applied to Navy shipbuilding as it is to any Department of Defense (DOD) program exceeding $20 million contract value. Within the EVM methodology, cost performance can be communicated in terms of CPI. Furthermore, an evaluation of CPI at various stages in the shipbuilding process may reveal the portions of the process that exhibit the worst cost efficiency and therefore warrant the most deliberate focus of those with the goal of improving efficiency.
III. RESEARCH APPROACH AND DATA COLLECTION

A. INTRODUCTION

This chapter of the thesis discusses research techniques and relevant data will be applied to address the problem statement introduced in Chapter I. The methods will include a detailed discussion of the problem space and an evaluation of the areas within the problem space that may be manipulated in effort to progress toward a solution. Along with the analysis of the problem space, a stakeholder analysis will be conducted as it will be applicable to the final recommendations provided to the cognizant organizations. A detailed analysis of the current processes, shipyard layout, and acquisition contract model will be discussed as they will each contribute to realizing the solution to the problem set.

B. SYSTEMS ENGINEERING APPROACH

A good systems engineering approach to any problem set is tailored to the problem and the desired outcome. As such, some systems engineering tools and techniques may be applied to solving problems for which component or system designs are not the predominant issues. Instead of recommending design changes to some existing system or attempting to fill a capability gap, the simple classification of a problem, relevant stakeholders, and identification of viable solutions can benefit from a systems engineering approach just the same. The following sections exercise some common systems engineering techniques to assist in the accurate classification of the problem set as well as identification of the stakeholders that may either positively or negatively affect change.

1. Problem Definition

The problem space is that area that exists between the current condition and the desired condition. In this instance, the problem area is the void between current shipbuilding infrastructure and processes at Ingalls shipyard and those improved infrastructure and processes that would result in the production of DDGs in a more cost
efficient manner. For illustrative purposes, Figure 10 shows the current condition, desired condition, and the existence of the problem space.

Figure 10. DDG Production Problem Space

Figure 10 shows the current condition of the DDG production process retaining its current levels of efficiency and quality. The goal of the recommendations that will result from this research is to continue to produce DDGs at Ingalls Shipyard with the same level of quality or better, but in a more cost efficient manner. Furthermore, improved processes in shipbuilding will inherently create more efficiency, whether this is cost or schedule efficiency, as will the realization of predictable acquisition and production tempos. Evolving from the current condition to the desired condition requires a transition through the problem space in a systematic manner.

Existing within the problem space is a variety of realms that bear some proportion of the weight contributing to the solution. These include the layout and infrastructure of the shipyard, the macro- and micro-processes, and the contract under which DDGs are constructed. These relevant areas of the problem space are shown in Figure 11.
2. **Stakeholder Analysis**

The stakeholders of the subject process are those individuals and organizations that have some affiliation with the process or its outcome. The stakeholders come from inside and outside the process. As stakeholder analysis is typically subjective and up to the interpretation of the systems engineer performing the analysis as to the scope of the process and system boundaries, the following list of stakeholders is not intended to be all inclusive nor firm. The paragraphs that follow list and describe the stakeholders in general terms and are not intended to indict any individual or organization. The following list of stakeholders will prove useful when recommendations are constructed as it is often helpful to know which individuals or organizations have purview over certain process aspects and which may affect positive change as well as those that may resist, rebut, or rebuff it.
a. American Taxpayer

As with any DOD program, funding originates with the American taxpayer. The taxpayer wants to feel safe and secure. Part of this assured feeling comes from the knowledge that the U.S. Navy is the most capable and advanced navy in the world. Of course, achieving this dominance costs money and the taxpayer wants the national security strategy executed as cost efficiently as possible.

b. U.S. Navy

In December 2016 the U.S. Navy released a new force inventory goal of 355 ships. This is a revision to the preceding 308-ship goal. To reach this goal, the Navy has requested the funds to procure 21 DDGs through FY23, an increase from 14 DDGs under the previous force goal (O’Rourke 2017b). This plan requests funds to acquire nine new ships in FY18, including two DDG-51s, with the potential to acquire a third DDG during FY18 if the accelerated shipbuilding plan is adopted (O’Rourke 2017b). The Navy, in effort to meet expectations laid forth in the national military strategy, has identified a capability gap that can be filled by acquiring more DDGs. The accelerating trend of ship procurement along with the finite nature of the Navy’s budget suggest acquiring ships in the most cost effective manner is crucial. Discovering and exploiting efficiencies in the shipbuilding process will increase the Navy’s buying power.

c. PEO Ships

PEO Ships is the organizational entity that manages the design, construction, and delivery of most navy surface combatants, including DDGs. As one of the stated objectives within their program summary, PEO Ships is responsible for “driving affordability into shipbuilding programs” (PEO Ships 2017). The effort to seek efficiencies in the construction of DDGs is within PEO Ships’ purview and interest.

d. DDG-51 Program Office (PMS 400D)

PMS 400D is the program office responsible for executing the objectives of the DDG-51 program. Reporting to PEO Ships, PMS 400D is the organizational entity that has direct cognizance over the design, construction, and delivery of DDGs. This
organization is directly responsible for the cost efficient delivery of DDGs and is therefore, among the most powerful in terms of those able to affect change.

e. **SSGC**

Contract and construction oversight is conducted by the Navy staff at SSGC. This organization reports to Naval Sea Systems Command for Logistics, Maintenance, and Industrial Operations (NAVSEA 04). SSGC staff makes up most of the Navy’s personnel on-site at the shipyard observing the day to day shipbuilding processes and progress. In effort to assist in achieving cost efficient shipbuilding according to the aforementioned goal of PEO Ships, SSGC is best suited since they are wholly immersed in the shipbuilding effort.

f. **Ship’s Crew**

Cost efficient shipbuilding is critical to the Navy’s intent to grow the force to 355 ships. However, cost efficiencies that come at a cost to quality are counterproductive as they simply incur cost growth later in the life cycle of the ship during O&S. Cost efficient shipbuilding must be pursued while sustaining or improving overall ship quality. The ship’s crew, current and future, must operate and maintain the ship to its potential or it may be removed from operation for maintenance and modernization, thereby reducing its operational availability and causing other ships of the fleet to fill the void caused by the absence.

g. **HII/Ingalls**

The company producing DDGs at Ingalls shipyard, HII, must remain competitive in shipbuilding to sustain viability as future contracts are awarded. The pursuit of improved processes and cost savings that may be passed to the customer serve the company well in maintaining itself as a top-tier competitor. Not only are cost savings passed to the customer, they typically improve the company’s profit which, in turn, awards shareholders. This increases public investment into the company allowing it to flourish.
h. *Ingalls Shipyard Employees*

Improved processes and cost efficiency improve the company’s standing, thereby making it more competitive in bidding for future contracts. Increased quantity and value of contracts awarded increase workload which offers stability to the employees. As the company grows, so too do the number of opportunities for the employees contributing to the company’s success. Furthermore, each Ingalls shipyard employee is a taxpaying American who has all of the interests and motivations outlined in the earlier section describing the American taxpayer as a stakeholder.

The described stakeholders have varied degrees of interest and power in terms of the shipbuilding process and the ability to affect change. As such, a power versus interest grid is helpful in determining which stakeholders should be the target of specific recommendations and which might be resistant to recommended changes. The power versus interest grid for the described stakeholders is shown in Figure 12.

![Figure 12. Stakeholder Power versus Interest Grid](image-url)
C. SHIPYARD EVALUATION

Ingalls shipyard is comprised of 800 acres on the west bank of the Pascagoula River in Pascagoula, Mississippi. As the largest employer in the state of Mississippi, Ingalls shipyard currently employs more than 11,000 employees and houses a fire department, medical center, and training complex (HII 2017). The current shipyard was established in 1968 and has since delivered commercial, U.S. Navy, and U.S. Coast Guard ships and submarines as well as manufacturing major portions of ships being constructed at other shipyards around the country. The construction of these ships is according to the modular construction and outfitting methods described in Chapter II of this thesis.

The fabrication and assembly of the ship’s structure is executed in an L-shaped configuration beginning at the northeast corner of the shipyard. Eventually taking a 90 degree turn, the process continues southward down the lateral center of the shipyard until grand blocks are placed in the integrating bays to be erected into hull form. There are five integration bays each with the capacity for two grand blocks situated abreast of one another facilitating erecting two hulls at any given time. As the hull is being erected, access to and from the ship is through a support tower that is permanently affixed in the integration area. This support tower contains offices, meeting rooms, tool issue locations, and restroom facilities.

Ingalls shipyard is roughly square in shape and jettisons out into the Mississippi sound. The nature of the shipyard’s shape and location currently offer approximately 3,000 linear feet of pier space. This pier space is loosely divided into seven berths which may moor a ship while construction and testing continues to completion. An aerial view of Ingalls shipyard is shown in Figure 13.
While structural progress advances, the manufacturing of the various components that will go into the ship takes place in shops situated in the shipyard separated from the aforementioned facilities. Components are installed onto units, blocks, or the ship according to an outfitting plan or they are stored in a designated area of the shipyard awaiting installation.

D. PROCEDURE EVALUATION

The processes associated with acquiring a DDG from the shipbuilder take place both on and off the shipyard. As discussed in Chapter II, the overall process efficiency is dependent upon the processes exercised in the shipyard during the construction of the ship but also the processes that take place away from the shipyard which pertain to the creation of the national security strategy, the identification of the need for a DDG, along with creation and award of the contract. It is the events that occur away from the shipyard that typically have the greatest affect on demand signal and required output rate and therefore effect the tempo with which ships are expected to be produced. It is with this in mind that the ship procurement process can be broken into two categories. That is, the processes that take place away from the shipyard, the macro-level process, and the
shipbuilding processes taking place on the shipyard, the micro-level process. The sections
that follow evaluate each of these processes as they exist today.

1. Macro-Level Process

The acquisition of DDGs, as with most military equipment, begins with the
national security strategy. This strategy is devised by the National Security Council
which is chaired by the President of the United States and charged with creating the
strategy about which the U.S. will achieve and maintain national security. This national
security strategy, relevant to many departments within government, is interpreted at the
DOD level for relevance to the department and parsed into the national military strategy.
The national military strategy tasks combatant commanders with executing their
cognizant portions of the strategy and, from this expectation, the commanders assess the
capability needs.

As the climate, geo-political landscape, and technological reality evolve, so too do
the strategies that are devised to ensure national security. It is under this premise that the
number of ships requested for the Navy’s inventory changes over time. The concomitant
inventory request is for 355 ships. This request is based on an assessment of the changing
go-political atmosphere that raises the propensity for open water naval engagement.
Among the most significant capability needs are ASW, ballistic missile defense, and
countering anti-ship cruise missiles. The ability of DDGs to provide these capabilities,
coupled with the increased desire for these capabilities, has led to an increased demand
for DDGs.

Once a need for an existing system is determined, the system is acquired through
a procurement contract. The contract is modeled according to prevailing contract theory
and the situation for which it is best suited. Once drafted, the contract is presented to the
industrial base, giving companies the opportunity to submit proposals. These proposals
are collected, evaluated, and compared during a selection process intended to determine
the company and proposal best suited to deliver the requested equipment. Upon selection
of a proposal, the contact is awarded to the respective company and administered
throughout the execution of the contract’s period of performance.
2. **Micro-Level Process**

Building a DDG at Ingalls shipyard begins with raw material and outsourced components being transported to the yard for processing and assembly. Approximately three years later the material and components are delivered, as an operational warship, to the U.S. Navy. The paragraphs that follow outline the shipbuilding processes as they specifically apply to Ingalls shipyard. This process is illustrated in Figure 14.

![Figure 14. Ingalls Shipyard Process Map](image)

Steel, either plate, shaped, or forged, arrives in the steel yard situated in the northeast corner of the shipyard. This steel arrives by truck, train, or barge and is subsequently unloaded and made ready to be transported to the fabrication shop using gantry cranes. This is step one in the process map illustrated in Figure 14. As shipyard organization often follows a coded identification system which aids in planning and process control, this area is referred to as the 200 area.

Once in the fabrication shop, step two on the process map, the surface of the steel is prepared and primer is applied. The steel is then cut to size and bent to shape. This
steel will make up the strength members of the structure of the ship. Exiting the fabrication shop, the shaped steel proceeds to the panel shop or shell shop, marked as step three on the map, to be metal inert gas (MIG) welded to steel plates to form panels and bulkheads. The output of the panel shop is finished panels and bulkheads that are ready to be assembled into units or tailored spaces of the ship.

The finished panels and bulkheads proceed to either of two covered slab areas (CSA) for continued assembly. The CSAs are marked as steps 4a and 4b on the process map. Units moved to the southern CSA, marked 4a, are utilized in the assembly of units. Many of these units are assembled in an inverted configuration to make further assembly and outfitting more efficient by maximizing down-hand work. The units transported to the northeastern CSA, marked 4b on the map, are intended for the outfitting of assemblies or machinery skids that will eventually be installed on board the ship at some stage of construction. As outfitting components become ready for installation they are installed in their respective units according to the on-unit outfitting concept presented in Chapter II.

The ship’s structural units leave the CSA and the 200 area to enter the 400 area. The first step of the process in this area takes place in the building labeled CSA II, also known as the stacking hall and labeled step five on the process map. It is at this point in the shipbuilding process that units and blocks are combined to form grand blocks. Outfitting continues here according to the on-block outfitting method. Upon assembly, grand blocks depart the 400 area for the 600 area.

Once in the integration bays of the 600 area, marked on the process map as point six, the hull is erected by adjoining grand blocks into the final hull form. While in the 600 area, the hull continues to take shape and prepare for launch. Onboard outfitting continues according to the outfitting plan. When ready to launch, the ship is traversed to a launch platform, point seven on the process map, to be placed in the water for the first time.

With a ready ship on board, the launch platform submerges to introduce the ship to the water, allowing the ship to float off the platform and be towed to the 900 area, point eight on the process map. This moment in the shipbuilding process is termed
launch. The berths of the 900 area are the final destination of the ship until construction, outfitting, painting, testing, and inspection are complete and the ship is ready for delivery.

One area of the shipyard not yet mentioned in this process flow is the 300 area. This area consists of the combined shops, industrial products department, and a large storage and staging area where ready components await outfitting onto units, blocks, or the ship. Production proceeds in the shops within the 300 area concurrently with the rest of the process steps described in the earlier paragraphs of this section. The combined shop fabricates piping, ventilation, and electrical components while the industrial products department manufactures structural support items like bits, hand rails, ladders, pad eyes, and other items. As these components are fabricated, they are transported to the unit, block, or hull if they are ready to receive the manufactured item. Otherwise, the manufactured item is placed in the storage and staging area where the item awaits the moment when it is installed.

Each coded area discussed in this section is clearly marked in Figure 15.

![Figure 15. Area Boundaries of Ingalls Shipyards](image-url)
E. CONTRACT EVALUATION

The contracts awarded to GD/BIW and HII/Ingalls are firm fixed price (FFP) contracts with incentive fees available. That is, the contract awards the respective contractor with the opportunity to construct a DDG at a target cost with an assumed target profit. The sum of these values makes up the total target price. If, once construction is complete, the price of the vessel is below the target price, the government and the contractor share the savings according to a 50/50 ratio. Similarly, if the fully constructed vessel’s price exceeds the target price, the government and contractor share in this burden according to the same 50/50 ratio. This is only up to a certain point. If the price of the vessel breaches a predetermined ceiling price, the burden for increased cost falls solely on the contractor as the Navy does not share in the burden of increased cost above the ceiling price.

Incentive fees are a separate source of funds that are made available to the contractor and are intended to encourage contractor performance. Incentives are earned by the contractor by performing to certain standards, adherence to schedule milestones, or executing the contract in a stable and predictive manner. As with any contract involving incentives, the construct of those incentives must be carefully considered by the government since they are a valuable tool in communicating to the contractor the aspects of contract performance that the government determines are among the most important at the time of contract award. The section that follows outlines the incentives applied to contemporary DDG construction contracts.

1. Incentives

As a means to influence contractor performance, incentives can be very effective. The predominant theme common to many of the incentives offered in the construction of DDGs is that of schedule stability. The first of several incentives that will be evaluated is the Aegis Light Off (ALO) schedule stability incentive. ALO is a contractual milestone that requires the readiness of all of the support systems required to operate the Aegis weapon system. The air, water, and power necessary to operate the weapon system must be ready for operation such that the weapon system is made available for commencement
of operational testing. The objective of this incentive is to encourage the contractor to complete ALO no later than the date laid forth in the contract. The contractor, when ready, must request a date to conduct ALO and, as closely as achievable, execute ALO on that requested date. The criteria for the award of this incentive is outlined in Table 1.

Table 1. ALO Schedule Stability Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALO date is established at least 120 days before ALO and not changed within 120 days</td>
<td>100%</td>
</tr>
<tr>
<td>ALO date is established at least 120 days before ALO and changed 90 to 119 days prior to ALO</td>
<td>75%</td>
</tr>
<tr>
<td>ALO date is established at least 120 days before ALO and changed 60 to 89 days prior to ALO</td>
<td>50%</td>
</tr>
<tr>
<td>ALO date is established at least 120 days before ALO and changed less than 60 days prior to ALO</td>
<td>0%</td>
</tr>
</tbody>
</table>

The second incentive related to ALO is the ALO readiness incentive. This incentive is intended to assure readiness for ALO as its scheduled date approaches. As such, to earn the incentive the contractor must have installed all cables that are required to conduct ALO as well as complete work in all spaces relevant to ALO such that they are accepted by the Navy’s oversight personnel of SSGC. Furthermore, these actions must be completed by a certain time in order to qualify for the incentive according to the criteria outlined in Table 2.

Table 2. ALO Readiness Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>All readiness conditions met at least 7 days prior to scheduled ALO date</td>
<td>100%</td>
</tr>
<tr>
<td>All readiness conditions met less than 7 days prior to scheduled ALO date, but prior to scheduled ALO date</td>
<td>50%</td>
</tr>
<tr>
<td>All readiness conditions not met prior to scheduled ALO date</td>
<td>0%</td>
</tr>
</tbody>
</table>
Similar to the ALO schedule stability incentive, the timely request of acceptance trials (AT) is also incentivized. AT is the contract milestone preceding delivery of the ship. This is a rigorous inspection conducted by the Navy’s board of inspection and survey (INSURV), the culmination of which is a recommendation to the Chief of Naval Operations (CNO) on whether to accept the ship into the Navy’s inventory. The contractor’s ability to schedule this event in advance of its occurrence and prevent a change to the schedule is awarded according to Table 3.

Table 3. AT Schedule Stability Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT date is established at least 180 days before AT and not changed within 180 days</td>
<td>100%</td>
</tr>
<tr>
<td>AT date is established at least 180 days before AT and changed 120 to 179 days prior to AT</td>
<td>75%</td>
</tr>
<tr>
<td>AT date is established at least 180 days before AT and changed 91 to 119 days prior to AT</td>
<td>50%</td>
</tr>
<tr>
<td>AT date is established less than 180 days before AT or changed less than 91 days prior to AT</td>
<td>0%</td>
</tr>
</tbody>
</table>

Following suit with ALO, the readiness for AT is also incentivized. No less than 18 weeks prior to the start of AT, the contractor must submit to SSGC a list of spaces within which work is not complete and a deferment of that work is requested until after AT. SSGC must review the list of requested deferred work and respond with a list of approved deferred work to the contractor no less than 16 weeks prior to AT. With the approved list of deferred work in their possession, the contractor must complete all other work prior to the commencement of AT. The time at which all of this work is complete and the criteria outlined in Table 4 determine the proportion of incentive fee earned.
Table 4. AT Compartment Completion Inspection Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>All spaces accepted with no unapproved deferred work at least 14 days prior to scheduled AT</td>
<td>100%</td>
</tr>
<tr>
<td>All spaces accepted with no unapproved deferred work at least 7 days but less than 14 days prior to scheduled AT</td>
<td>50%</td>
</tr>
<tr>
<td>All spaces accepted with no unapproved deferred work less than 7 prior to scheduled AT or there is unapproved deferred work</td>
<td>0%</td>
</tr>
</tbody>
</table>

Similar to space inspections and the work within those spaces that will, or will not, be deferred, the contractor must submit a list of tests that will not be completed prior to AT. This list compiles the equipment tests that cannot be completed prior to AT because they must be completed at sea and is required at least 18 weeks before scheduled AT. Again, SSGC is responsible for reviewing the list and responding with a list of tests for which deferral is approved within 16 weeks prior to AT. The timely completion of these tests is then incentivized according to the criteria of Table 5.

Table 5. Contractor Responsible Test Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>All test that are not deferred are completed at least 14 days prior to AT</td>
<td>100%</td>
</tr>
<tr>
<td>All test that are not deferred are completed at least 7 days but less than 14 days prior to AT</td>
<td>50%</td>
</tr>
<tr>
<td>All test that are not deferred are completed less than 7 days prior to AT or are not completed prior to AT</td>
<td>0%</td>
</tr>
</tbody>
</table>

Achieving various required certifications prior to the commencement of AT is also incentivized. Achieving these certifications prior to AT removes some of the burden from INSURV inspectors during AT since significant portions of the ship would have already been inspected and accepted. These certifications and the proportion of the available AT certification completion incentive earned is outlined in Table 6.
Table 6. AT Certification Completion Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonar dome pressurization certification</td>
<td>25%</td>
</tr>
<tr>
<td>Aviation certification</td>
<td>25%</td>
</tr>
<tr>
<td>Oil pollution abatement certification</td>
<td>25%</td>
</tr>
<tr>
<td>VCHT¹ certification</td>
<td>25%</td>
</tr>
</tbody>
</table>

¹Vacuum collection, holding, and transfer (VCHT) is the system responsible for the collection, storage, and disposal of the ship’s sewage.

Upon completion of AT, the contractor receives contractor-responsible trial cards describing discrepancies that must be addressed prior to delivery. Delivery of the ship, and its receipt into the U.S. Navy’s inventory, is dependent upon the timely adjudication of these discrepancies. This is another facet of the construction process that is incentivized. Upon correction of a cited discrepancy, the contractor submits the trial card to SSGC for verification of its completion. If accepted, the open trial card is closed. If the contractor submits a completed trial card and SSGC determines the discrepancy is not corrected, the trial card is rejected and the discrepancy must be satisfactorily corrected. To qualify for the delivery readiness incentive, the contractor must correct discrepancies to close at least 90% of the contractor-responsible trial cards issued during AT. Furthermore, the rejection rate of submitted trial cards by SSGC must be less than 10% and the government’s estimate of the value of work on open trial cards must not exceed $10 million. Meeting these conditions within the time periods outlined in Table 7 qualifies the contractor for the requisite proportion of the delivery readiness incentive.

Table 7. Delivery Readiness Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>All conditions met before delivery date</td>
<td>100%</td>
</tr>
<tr>
<td>All conditions met after delivery date, but not more than 7 days after</td>
<td>50%</td>
</tr>
<tr>
<td>All conditions not met, or met more than 7 days after delivery date</td>
<td>0%</td>
</tr>
</tbody>
</table>
The ship’s crew may move aboard the ship whenever the ship is ready to receive them. That is, once berthing spaces, heads, galley and dining spaces, and all of the services required to operate these spaces are operable, the officers and sailors of the crew may move aboard the ship just as in any other ship in the fleet. Meeting these conditions, the contractor may take credit for meeting the contractual milestone termed crew move aboard (CMA). However, in some instances it is neither efficient nor logical to move the crew aboard the ship. One example of this instance is when a maintenance availability is scheduled to immediately follow delivery of the ship and this maintenance availability would require the crew to vacate the ship to facilitate certain work. This is a common scenario in ship construction and maintenance. Given this event, the government may elect to exercise its option to enact a CMA readiness incentive to encourage CMA readiness at some point in time after delivery of the ship. Since this incentive is enacted on a case-by-case basis, the value of this incentive is variable. The source of the money comes from a deduction in the aforementioned delivery readiness incentive. The amount by which the delivery readiness incentive is reduced is the value of the CMA readiness incentive. To qualify for this incentive the contractor must close at least 95% of the contractor-responsible trial cards issued at AT. Like the delivery readiness incentive, the rejection rate of submitted trial cards by SSGC must be less than 10%. Finally, the government must estimate at least 90% of the work to be performed during the maintenance availability is complete. Meeting these conditions according to the schedule outlined in Table 8 qualifies the contractor for the associated proportion of the CMA readiness incentive.

Table 8. CMA Readiness Incentive. Adapted from Naval Sea Systems Command (2011).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>All conditions met no later than the CMA date</td>
<td>100%</td>
</tr>
<tr>
<td>All condition met after CMA date, but not more than 7 days after</td>
<td>50%</td>
</tr>
<tr>
<td>All conditions met more than 7 days after CMA date or all conditions not met</td>
<td>0%</td>
</tr>
</tbody>
</table>
The ninth and final incentive available to the contractor is the dynamic period performance incentive. This incentive is fluid and its value may be divided and awarded at the sole discretion of the government. That is, the cognizant program office and contractual oversight teams may issue contract modifications throughout the period of performance outlining the purpose, intent, and measurement protocol for this incentive. Examples of ways this incentive has been applied include assigning some of its value to incentivize the contractor to reduce indirect, or overhead costs. Another example is the incentivization of good housekeeping and safety practices by conducting housekeeping and safety inspections and objectively scoring the contractor’s performance then associating that score to a percentage of the available fees. As this incentive is distributed and awarded according to the discretion of the cognizant Navy teams, there is not a prescribed criteria table to outline its proportionality as with the other incentives. However, at a typical value of approximately 20% of the total incentive fees for the contract, the dynamic period performance incentive is sizeable and can be a highly effective tool in communicating expectations to the contractor.

2. Capital Expenditures

The contracts awarded to construct DDGs contain within them dozens of clauses. The incentives described in the preceding section are among these clauses. Also among them is a clause offering special incentives for construction. The intended purpose of this clause is to encourage the contractor to commit investment to the shipyard infrastructure, shipbuilding processes, personnel training, and other aspects to improve overall efficiency in shipbuilding and thus program affordability. The primary vehicle for this encouragement is the capital expenditure (CAPEX) incentive.

Awarding the CAPEX incentive is at the discretion of the DDG-51 Program Manager under advisement from the program’s Contracting Officer. The process to be considered for this incentive payment follows a basic process that begins with the presentation of a business case analysis (BCA) by the contractor. The BCA is to outline many things. According to the special incentives for construction clause inserted in many DOD contracts, these include:
• objectives of the investment
• description and rationale for the investment
• anticipated benefit to the contractor and to the Navy
• evaluation metrics that will be used to verify the benefit is realized
• description of investment risks and risk mitigation strategy
• project implementation timeframe
• overall cost estimates and cost sharing protocol
• return on investment (ROI) calculation
• net present value of future savings
• share-line ratio describing proportion of savings allocable to the government

After the BCA has been submitted and reviewed, if approved, the Program Manager will determine the amount and periodicity of incentive payments that will be paid to the contractor. These payments are intended to assist the contractor in funding the investment that is perceived to incur benefit for both the contractor and the government. Presuming the availability of funds, the CAPEX incentive payments for a proposed investment may total as much as $20 million.

Upon completion of the approved project for which CAPEX payments were received, an evaluation as to the actual benefit will be made and compared to the estimated benefit at the time of BCA submittal. If, in the justifiable opinion of the program’s Contracting Officer, the investment does not incur savings reasonably close to those estimated, the prior approval of the CAPEX incentive payments may be unilaterally revoked. The sum of the payments may be recuperated by the government. These moneys may be recovered through garnishing future payments owed to the contractor by the government.

F. SUMMARY

The research method presented began with defining the problem space. Within this space, it is identified that there are three significant areas within which there is a
propensity for improvement opportunities. These three areas are the shipyard, acquisition and shipbuilding processes, and the contract. The data presented within each area is primarily process driven and the following chapter will explore ways for improving these processes. Stakeholder analysis followed the definition of the problem space. Analysis of the stakeholders will likely serve beneficial as recommendations will be presented, and it is important to understand who are the stakeholders that have either the interest or power, or both, to effect change.

The layout of the shipyard and the micro-processes that take place on that shipyard are inextricably linked. Without complimentary shipyard layout and shipbuilding processes, the layout of the shipyard may serve as a hindrance. Contrarily, harmonized layout and processes can serve to improve overall efficiency as the next chapter will explore. Antecedent to the shipbuilding processes however, are the macro-processes of the acquisition process. These processes bear the most credit and responsibility for fluctuations in the acquisition tempo, thereby influencing the required production rate and likely attenuating shipbuilding efficiency.

The FFP contract utilized in acquiring DDGs contains many incentives. These fees are designed and implemented with the intended purpose of encouraging certain shipbuilder behaviors. Most of the concomitant incentives are related to schedule stability; however, there is a fluid dynamic performance period incentive that does not have predetermined qualification criteria and may be an effective tool in communicating expectations to the contractor.

Finally, the contract has within it opportunities for the contractor to qualify for construction incentives through capital expenditure. It is logical that the military-industrial team would work together to maximize production efficiency at contractor’s facilities as the benefits of such efforts are realized by both parties. CAPEX incentives may present a significant opportunity for recommendations as to methods to positively affect the shipbuilding process and the shipyard to gain efficiency.
IV. DATA ANALYSIS AND RESULTS

A. INTRODUCTION

Understanding the focus areas within the problem space facilitates an analysis of these areas in pursuit of discovering inefficiencies or barriers that inhibit the processes. As these areas have been identified, the sections that follow show analysis of the shipyard layout, macro-processes, and micro-processes that make up a large portion of the problem space. The analyses include findings discovered during an on-site visit to Ingalls shipyard as well as data analysis and revelations from a shipbuilding industry seminar that was held at Naval Postgraduate School in August 2017.

B. SHIPYARD ANALYSIS

As Storch et al. suggest, the preferred method to analyze the layout of a shipyard is to “analyze the yard as a total system” (Storch et al. 1995, 168). It is under this premise, and considering the generational shipyard layouts described in Chapter II, that the shipyard analysis takes place. One of the most important benefits gained by fourth-generation shipyards is the flexibility that is added to the yard in dealing with changes in demand signal, varied ship designs, design changes, and new missions such as overhaul or repair. The predominant driver to realizing this benefit is the fact that fourth-generation shipyards are designed around outfitting, compared to preceding generations of shipyards that focus on structural assembly and treat outfitting as an exception. As the only major shipyard built in the United States since the end of World War II, Ingalls shipyard was constructed around fourth generation concepts so is well suited to integrate hull block construction, outfitting, and painting processes. Treating each of these processes as germane to the overall shipbuilding effort, Ingalls shipyard qualifies as fourth generation.

Ingalls shipyard utilizes the HBCM methodology for structural construction. That is, after the raw material progresses through the early process steps creating decking, bulkheads, and panels, these manufactured sections are assembled into grand blocks in the stacking hall before finally assembling into hull form in the integration bays of the
600 area of the shipyard. Meanwhile, on-unit, on-block, and eventually onboard outfitting takes places in their respective locations. Painting and preservation are incorporated into the manufacturing processes throughout the construction process. These practices comport with the HBCM, ZOFM, and ZPTM concepts outlined in Chapter II. Finally, adherence to GT is evident in the shops that produce the components and equipment that are to be installed on board the ship.

Following modern shipbuilding concepts and executing the process in a fourth-generation shipyard serve HII/Ingalls well. However, there are opportunities for improvement. The following sections describe some of these opportunities.

1. **Bottlenecks**

During an observational tour of Ingalls shipyard, a few process bottlenecks were apparent. As stated by Dr Goldratt in his novel *The Goal*, bottlenecks are easily discovered by looking for WIP (Goldratt 2004, 144). A collection of WIP indicates inefficiency in the process. Some WIP is part of the design of the process; however, this does not mean the process is efficient. This simply means inefficiencies have been designed into the process. The first observable WIP was adjacent to integration bay number two. A grand block, shown in Figure 16, was awaiting installation onto DDG 121. This grand block, which was the ship’s forward superstructure, was still under construction but was not in the stacking hall with the other grand blocks under construction. Instead, the grand block was outside, not under a cover, adjacent to the hull, and subject to degradation from weather as well as weather delays in work progress. In its location, this is an indication of a bottleneck as the grand block has not been installed on board the ship and possibly also an indication of an apparent need for weather protection in the areas near the integration bays where grand block construction may take place.
The second observed bottleneck in the construction process is designed into the shipbuilding process. This is the storage and staging area within the 300 area of the shipyard. This area is utilized to store and stage components awaiting outfitting onto units, blocks, or aboard the ship. Shown in Figure 17, the area contains a significant amount of finished product awaiting installation. These components are outdoors and again subject to negative weather effects. A storage area this large and full of WIP indicates a lack of compliance with just-in-time protocol as well as a bottleneck in the outfitting process.
Elimination of bottlenecks from the shipbuilding processes at Ingalls shipyard would increase efficiency, reduce cost of ship production, and improve quality of the ships being produced by the shipyard as weather would have less adverse effect on the ship during its construction. Discovering bottlenecks is the first part of creating process efficiency. The next step is to take positive action to resolve the issues. This possibly means process changes, personnel adjustments, tooling or layout considerations, or infrastructure investments. The next section addresses some areas where infrastructure investments would benefit the shipbuilding processes at Ingalls shipyard.

2. CAPEX Opportunities

Priority should be placed on eliminating bottlenecks by conducting the actions outlines in Chapter II of this thesis. However, in the instance where elimination of the bottleneck is not practical, reducing the negative impact of that bottleneck is a reasonable alternative. Reducing the effects of bottlenecks represent CAPEX opportunities that might improve efficiency of the shipbuilding process and would likely improve the quality of the ships being built. One example of a CAPEX investment at Ingalls shipyard is the DDG support tower that was introduced in Chapter III and is shown in Figure 18.
Maximizing the proportion of the shipbuilding process that is executed beneath a roof reduces the propensity for weather delays, reduces the effects of degradation due to weather, and improves the quality of the ships produced. Increasing the size of the stacking halls where grand blocks are produced allows the shipyard to construct larger grand blocks. This results in fewer grand blocks, as each block is larger and follows the conceptual goal introduced in Chapter II of dividing blocks into near equal proportions of the ship while making these blocks as large as practicable. Figure 19 shows the current stacking hall and five of its 12 bays.
If increasing the size of the stacking hall is not feasible, expanding the number of bays might be a viable alternative. Providing covered areas for work and storage will help alleviate the loss of progress due to weather in an area that, according to the National Oceanic and Atmospheric Administration, receives an average annual rainfall 29% higher than the national average and 4% higher than that received by HII/Ingalls’ closest competitor, BIW (National Oceanic and Atmospheric Administration 2017). One example of this is a covered working area that, as of the moment this thesis is being written, is under construction. Figure 20 shows the covered work area being constructed immediately south of the stacking hall. This addition to the shipyard adds a covered area to construct grand blocks as well as offices and restrooms for shipyard personnel.
Storing manufactured components under a roof while they await installation would benefit the shipbuilding process as this material would not be subject to weather effects while stored. A project similar to the covered area being constructed and shown in Figure 20 would benefit the shipyard and the shipbuilding process.

Finally, increasing the width of the integration bays of the 600 area allowing the shipyard to assemble three hulls simultaneously instead of two would alleviate the bottleneck observed at the integration bays and improve shipbuilding efficiency. As stated in the previous section, grand blocks may be placed adjacent to the integration bays awaiting installation on board its respective hull. One reason this may occur is to remove a grand block from the stacking hall, thus vacating one of the stacking hall’s bays allowing commencement of the next grand block to be constructed in that bay. If the capacity of the integration bays were increased, the pace of grand block assembly in the stacking halls would not need to be subordinated to the pace of hull assembly in the integration bays, at least not by the degree to which it is currently subordinated. The current capacity of the integration bays is two hulls abreast of one another. Increasing the
capacity to accommodate three hulls abreast would alleviate the tendency for the shipbuilder to launch a ship earlier than it may be ready to launch simply to vacate integration bays and begin assembly of the next hull for which grand block construction is nearing completion in the stacking hall.

C. MACRO-PROCESS ANALYSIS

The U.S. Navy’s current inventory goal is 355 ships. The increase from the preceding 308-ship goal provoked an increase in the desired number of large surface combatants, including CGs and DDGs, from 88 to 104. The Navy’s inventory goal remained 308 ships for only 21 months from March 2015 until December 2016 (O’Rourke 2017b). The 308-ship goal was a slight increase from the previous year’s goal of 306 ships. At the time that the U.S. Navy established a 308-ship inventory goal, the inventory was between 272 and 280 ships. As the number of ships fluctuates according to a relationship of retiring vessels, newly constructed vessels, those ships removed for long-term maintenance and modernization projects, and ships rendered temporarily inoperable due to accidents or attack, the world continues to take shape. The ever-changing geo-political atmosphere as well as the evolving capability of potential adversaries serve as the impetus for changes to the Navy’s inventory goal.

Changing the long-term shipbuilding plan changes the expected acquisition tempo as more or fewer ships are planned for procurement during future fiscal years. These tempo changes, in turn, cause changes to the expected production rate of the shipyards that deliver the subject ships. As shown in Chapter II, changes to the required rate of output force the shipbuilder to make decisions related to schedule- and cost-adherence that result in schedule slippage, cost overrun, or both. During a shipbuilding industry seminar conducted at Naval Postgraduate School in August 2017, HII President and Chief Executive Officer, Mike Petters, reflected on the need to synchronize the acquisition tempo with the production tempo by stating two distinct benefits. First, the synchronization of the demand and supply tempos affords the opportunity for the shipbuilder to create the most efficient production line achievable thereby allowing workers to complete a task for one hull then move to the next hull and repeat the process.
This contrasts the scenario created when the demand signal is fluctuating and workers must surge and relax the pace of their processes accordingly as is currently the case for the shipbuilding industry. The second stated opportunity to gain efficiency when acquisition and production tempos are synchronized comes from the opportunity to engage in a competition of ideas that realize true and long-lasting efficiencies. That is, when the pace of acquisition and production are relatively constant, Petters believes the industry can take advantage of the opportunity to observe normalized processes and pursue new ideas in shipbuilding. This opportunity may facilitate discovery of the next offset that could bring about the fifth-generation shipyard, evolve the shipbuilding process such that the next family of capabilities may be realized, or discover and implement the next industry-altering gains in cost or schedule efficiency.

D. MICRO-PROCESS ANALYSIS

Most of the ability of HII to affect the efficiency of the shipbuilding processes resides in their shipyards for it is in the shipyard that HII has the primacy to directly affect positive change. Analysis of the micro-processes taking place at Ingalls shipyard reveals improvement opportunities that could improve overall shipbuilding if observed. The following sections detail these opportunities, both in terms of efficiency and quality.

1. EVM Analysis

One of the basic premises of the modular construction concepts detailed in Chapter II is the improved efficiency and, to a degree, quality of the construction processes as the ship is built in equally apportioned blocks, affording worker accessibility and logical product flow. To this end, it is an objective of modular construction practitioners to construct a ship as much as possible before placing the ship into the water. Once waterborne, construction becomes significantly more difficult and less efficient. Furthermore, quality of the work yet to be performed may be negatively impacted as the difficulty of the work is increased, the work area is decreased, and transported tools, materials, and personnel throughout the ship raises the propensity for damage to shipboard components. As such, conventional shipbuilding wisdom suggests maximizing construction progress prior to launch is preferred.
One way of comparing worker efficiency before and after launch is to compare the CPI of the project at the moment the ship is launched to the CPI at delivery. Table 9 shows the construction progress and CPI, in terms of man-hours, of several DDGs constructed by HII/Ingalls. This table also displays the affects to efficiency of waterborne construction as the CPI upon delivery of the ship. Since CPI is cumulative throughout the project’s period of performance, the change in CPI between launch and delivery dates is attributable to the change in efficiency once the ship is waterborne.

<table>
<thead>
<tr>
<th>HII Ships</th>
<th>Launch Date</th>
<th>Progress at Launch</th>
<th>CPI (hours) at Launch</th>
<th>Delivery Date</th>
<th>CPI (hours) at Delivery</th>
<th>CPI Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDG 113</td>
<td>3/28/2015</td>
<td>56.20%</td>
<td>0.72</td>
<td>12/7/2016</td>
<td>0.75</td>
<td>0.03</td>
</tr>
<tr>
<td>DDG 110</td>
<td>12/15/2009</td>
<td>69.70%</td>
<td>0.78</td>
<td>2/23/2011</td>
<td>0.69</td>
<td>-0.09</td>
</tr>
<tr>
<td>DDG 107</td>
<td>3/30/2009</td>
<td>65.39%</td>
<td>0.84</td>
<td>7/26/2010</td>
<td>0.74</td>
<td>-0.10</td>
</tr>
<tr>
<td>DDG 105</td>
<td>1/18/2008</td>
<td>60.73%</td>
<td>0.96</td>
<td>8/17/2009</td>
<td>0.81</td>
<td>-0.15</td>
</tr>
<tr>
<td>DDG 103</td>
<td>4/17/2007</td>
<td>59.27%</td>
<td>0.78</td>
<td>10/24/2008</td>
<td>0.89</td>
<td>0.11</td>
</tr>
<tr>
<td>DDG 100</td>
<td>12/15/2004</td>
<td>64.32%</td>
<td>1.06</td>
<td>12/18/2006</td>
<td>0.86</td>
<td>-0.20</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>62.60%</strong></td>
<td></td>
<td><strong>Average</strong></td>
<td></td>
<td><strong>0.79</strong></td>
<td><strong>-0.07</strong></td>
</tr>
</tbody>
</table>

From Table 9, it is apparent that the reduced efficiency of waterborne construction causes an overall reduction in CPI of 7% on average, an expected trend. The average CPI at delivery is 0.79. That is, on average, the evaluated ships were delivered after overrunning budgeted man-hours by 21%. Of this, 7%, or approximately one third of the degree to which the project is completed over budgeted man-hours is attributable to the construction that is performed after launch. Table 10 reveals identical attributes for DDGs constructed by GD/BIW during a similar timeframe. This table shows the average completion progress of GD/BIW-produced DDGs is 83.80%. Compared to 62.60% completion of HII/Ingalls-produced ships, GD/BIW achieves 21.20% more construction progress prior to launch than does HII/Ingalls. Continuing the comparison, GD/BIW averages a CPI at delivery of 0.90. Of the average a 10% man-hours overrun is experienced at BIW’s shipyard; 3% of it is attributable to waterborne construction. This
is less than half the reduction in cost efficiency experienced at Ingalls shipyard during a similar time period.

Table 10. Progress and CPI at GD/BIW

<table>
<thead>
<tr>
<th>BIW Ships</th>
<th>Launch Date</th>
<th>Progress at Launch</th>
<th>CPI (hours) at Launch</th>
<th>Delivery Date</th>
<th>CPI (hours) at Delivery</th>
<th>CPI Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDG 115</td>
<td>11/1/2015</td>
<td>81.10%</td>
<td>0.72</td>
<td>2/3/2017</td>
<td>0.69</td>
<td>-0.03</td>
</tr>
<tr>
<td>DDG 112</td>
<td>5/8/2011</td>
<td>85.32%</td>
<td>0.93</td>
<td>5/4/2012</td>
<td>0.87</td>
<td>-0.06</td>
</tr>
<tr>
<td>DDG 111</td>
<td>6/6/2010</td>
<td>85.41%</td>
<td>0.94</td>
<td>4/15/2011</td>
<td>0.89</td>
<td>-0.05</td>
</tr>
<tr>
<td>DDG 109</td>
<td>8/2/2009</td>
<td>83.04%</td>
<td>0.97</td>
<td>6/4/2010</td>
<td>0.95</td>
<td>-0.02</td>
</tr>
<tr>
<td>DDG 108</td>
<td>10/19/2008</td>
<td>84.58%</td>
<td>0.98</td>
<td>7/10/2009</td>
<td>0.97</td>
<td>-0.01</td>
</tr>
<tr>
<td>DDG 106</td>
<td>2/24/2008</td>
<td>83.32%</td>
<td>1.04</td>
<td>9/30/2008</td>
<td>1.05</td>
<td>0.01</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>83.80%</td>
<td></td>
<td>Average</td>
<td>0.90</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

2. Work Completion

As the previous section shows, work that takes place prior to launch is inherently more efficient than work that is executed after launch. As a basic tenant of modular ship construction, work that takes place on blocks and grand blocks is also more efficient than work that is left until after blocks are assembled into hull form. Leveraging this, identifying work that could be performed prior to block assembly points out opportunities to gain further construction progress before the ship goes into the water, thus improving overall construction efficiency. During an observational tour of the DDG production process at Ingalls shipyard, many such items were discovered. This section, although not exhaustive, describes several work items that were not performed aboard an assembled ship that could have been performed prior to their discovery.

The first incomplete work item that could have been completed prior to assembly of the hull is the manual valve hydraulic control piping shown in Figure 21. This piping directs hydraulic power to various flood control valves in the nearby area and is a relatively complex system of piping. The open-ended pipes shown in Figure 21 should be connected to piping leading to a control station above the pictured piping on board USS
Delbert D. Black. In its current condition, the piping that will inevitably be connected to the pictured piping must be transported through the ship by a worker who will likely install the piping in place. Performing this outfitting task on-unit or on-block would have been more efficient as the transportation of the piping to its destination would be simpler and the worker would have more room in which to perform installation.

Figure 21. Open-Ended Manual Hydraulic Valve Control Piping

Another example of work that was not performed and could have been, is the lube oil piping missing from main engine room number one. This piping directs lubricating oil throughout the engine room to various loads. The area where this piping should have been installed is shown in Figure 22. Like the aforementioned manual hydraulic valve control piping, the installation of the missing lube oil piping will require a worker, or in this case likely a team of workers, to transport the piping through the ship and commence installation in a movement-restricting area full of already installed piping and equipment.
Although not explicitly described within this thesis, there are many more observations of similar nature that were noted aboard USS *Delbert D. Black* and USS *Frank E. Petersen Jr* including lubricating oil systems, hydraulic oil systems, and fuel systems.

Another probable contributor to reduced waterborne construction efficiency is the difficulty in maneuvering cranes throughout the 900 area and the limited crane accessibility compared to the level of demand placed upon them. The hulls being erected in the integration bays have two cranes immediately adjacent to them and wholly devoted to the assembly of those hulls. The ships in the berths of the 900 area must share crane assets. There are four cranes readily maneuverable within the 900 area for the berthed ships. These cranes are supportive of construction efforts as well as mooring and casting off ships as they enter and depart the berths of the shipyard during underway testing.
E. SUMMARY

Improvement opportunities in the shipbuilding processes exercised at Ingalls shipyard are apparent as WIP indicates the existence of bottlenecks in the process. Bottlenecks should be alleviated by altering the process in such a way that subordinates the rest of the process to the constraint, elevates the existing constraint, and eventually repeats the discovery process to determine the new constraint. Short of completely abolishing the bottleneck, removing some of the detriment of such a bottleneck could benefit the shipbuilding process by mitigating the adverse cost and quality impact of the bottleneck. This opportunity presents itself as CAPEX investment opportunities. Going further, other CAPEX opportunities are apparent when considering methods for increasing process throughput, especially in terms of modular ship construction and following the guidance provided by Storch et al. (1995) pertaining to workload distribution.

The macro-process for identifying the need for DDGs is the greatest determinant of changes to the expected rate of production which, in turn, causes subsequent cost and schedule decisions of which the outcome is almost always detrimental. Stabilization of the U.S. Navy’s inventory goals would allow the shipbuilding processes at shipyards to stabilize, thereby offering the opportunity to flourish ideas that may result in dramatic process improvements, increases in efficiency, or improved cost or schedule performance.

An analysis of the micro-processes taking place at Ingalls shipyard revealed the attenuation to worker efficiency that is exhibited once the ship is launched. Progressing the construction process further prior to launch would reduce the amount of construction necessary once the ship is waterborne and likely improve overall cost performance of the construction process. Also determined by the micro-processes analysis are several opportunities to complete certain construction tasks prior to assembly of blocks and grand blocks into hull form. Completion of these tasks would progress overall construction during earlier phases of the modular construction process thereby affording more work completion prior to launch.
V. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

This thesis addresses the problem statement which generally states the need to evaluate shipbuilding processes to gain efficiencies in the production of DDGs at Ingalls shipyard. The purpose of the thesis is to identify and explore the problem space, identify the stakeholders that may affect change, evaluate the contemporary state of each realm within the problem space, and develop recommendations that could realize more efficient processes.

Throughout the history of shipbuilding, process changes and evolved capability in shipbuilding have contributed to gains in ships and seafaring just as the research and development of new and incumbent systems have. Modern shipbuilding concepts revolve around modular construction, outfitting, preservation and painting. These processes are executed in a synchronized manner in a shipyard that is organized around lean concepts in the performance of these tasks. That is, the reduction of waste attributable to any of the described causes of waste is a priority in the modern shipbuilding industry. To comport with this goal, GT is employed and is key to characterizing fourth-generation shipyards. Organizing a shipyard around modular construction and outfitting as well as GT allows the shipyard to complement the shipbuilding processes and elevates the efficiency that may be attained by the shipbuilder.

Acquisition tempo, predominantly driven by the demand signal created by national security strategies, is highly influential in determining the maximum efficiency a shipbuilder may achieve. Changes in acquisition tempo change the production rate which, in turn, harms efficiency in terms of cost, schedule, or both. The decisions incurred by altering the acquisition tempo force changes to the production tempo which require workers to divert focus from repetitive processes and provoke improvisation, unpredictability, and tailored schedules, each of which deter from efficient shipbuilding.
Bottlenecks in the micro-processes of the shipyard are apparent. The identification of WIP reveals the existence of inefficiencies in the shipbuilding process that restrict throughput of the entire process. Upon discovery, bottlenecks should be resolved by elevating the constraint. However, when this is not practicable, minimizing the impact of the constraint is a viable alternative. In this sense, identifying bottlenecks reveals both the opportunity for process improvements as well as the opportunity for infrastructure investment.

Another method for determining the inefficient portions of a process is through the use of EVM. Utilizing EVM concepts and specifically evaluating CPI, it is evident that waterborne construction is less efficient than the modular construction that takes place prior to launching the ship. This is the impetus for modular construction, outfitting, preservation, and painting. Leveraging this result, the shipbuilder may increase overall efficiency by maximizing the construction that is completed prior to launching the ship.

Finally, the contract under which military equipment is procured can be an influential tool in motivating performance. The contact used to procure DDGs is a fixed price contract with incentives that reward schedule stability. The criteria against which the contractor is measured determines how much incentive fee the contractor has earned and communicates to the contractor what the Navy values during the execution of the contract. There is a dynamic period performance incentive that does not have specific criteria associated with it and is awarded according to criteria that is up to the discretion of the program manager.

B. CONCLUSION

Four areas exist within the problem space. Within each of these areas, there are detractors from shipbuilding efficiency that must be resolved. The first of these detractors is the changing demand signal transmitted to the shipbuilder. Of course, it can be difficult to predict the Navy’s inventory needs in the long term; however, if this is done to the best of the Navy’s ability, the benefit will be more efficient shipbuilding processes that incur cost and schedule savings and possible quality improvements.
The second area within the problem space negatively impacting shipbuilding efficiency at Ingalls shipyard relate to the processes that take place at the shipyard. The flow through the production process is not constant nor is it subordinated to the constraints. That is, WIP at the outfitting storage and staging area along with the WIP observed at the integration bays indicate process flow is not properly calibrated. Also contributing to inefficiency is the possible premature launch of ships during construction. As previously stated, modular construction and outfitting prior to hull assembly and ship launch are more efficient than construction efforts attempted in the later stages of the shipbuilding process. Exacerbating the issue of inefficient waterborne construction is the fact that HII/Ingalls routinely launches ships relatively early, compared to their competitor GD/BIW. Early launch leaves more construction yet to be performed while the ship is waterborne. This issue manifests a reduced cost efficiency of HII/Ingalls that is more than double GD/BIW’s reduction after launch. The last item contributing to inefficiency within the micro-process is the work that is not completed while the blocks and grand blocks are being constructed and are instead completed once the hull is erected. Several of these instances were described in Chapter IV.

The third area within the problem space that could be exploited to gain efficiency is the infrastructure of the shipyard. Specifically identified infrastructure investment opportunities include covering areas to mitigate wear due to weather as well as minimize lost production opportunity from weather delays. Additionally, expansion of certain areas of the shipyard where bottlenecks are observable would elevate the identified constraints.

The fourth and final area within the problem space that could contribute to added efficiency is the contract. The contract under which DDGs are constructed includes incentives. The shipbuilder’s performance is incentivized in terms of schedule stability. There is a malleable incentive, the dynamic period performance incentive, which is earned according to criteria determined by PMS 400D. This incentive is currently utilized to reward safety and housekeeping practices but could be adjusted to incentivize any number of behaviors or attributes including provoking the shipbuilder to achieve a higher degree of construction completion prior to launch.
C. RECOMMENDATIONS

Recommendations with the intent of discovering efficiencies in the DDG production process follow the general outline put forth so far throughout this thesis. That is, the recommendations address the conclusion drawn in the preceding section as they pertain to each of the areas that reside in the problem space. As such, the first recommendations relate to the macro-processes. Stabilizing the inventory goal for the U.S. Navy can be challenging as it is difficult to predict future naval strategy as the world takes shape. However, adjustments to the inventory goal can be less disruptive to the acquisition and production processes if the existing inventory is as stable as possible. That is to say, maintaining existing hulls is equally important, some might argue more important, than the efficient construction of new hulls. If the maintenance of the current inventory is conducted reliably with the predominant focus on quality, not cost or schedule, the operational availability of existing ships would improve in the long term. Improved quality of existing ships would allow them to operate longer and more reliably, thereby reducing the urgency with which new hulls are expected to be delivered. Quality-centric maintenance practices, improving the availability and longevity of existing ships, would reduce the magnitude of the fluctuations to acquisition tempo as reasonably small inventory goal changes are made. The cognizant stakeholder for this recommendation is the U.S. Navy at large as the Navy is the entity that has both the power and interest necessary to influence such a profound cultural change.

Micro-processes are those that take place at the shipyard and make up the line of effort directly attributable to the construction of a single hull. Worker efficiency is highly influential over the efficiency of these processes. As such, the determination that waterborne construction is less efficient than on-unit and on-block construction begets two significant recommendations. The first of these recommendations is to seek all opportunity to gain construction and outfitting progress prior to launch. As described in Chapter IV, there are many opportunities to gain progress prior to hull assembly and subsequent launch. Furthermore, a comprehensive audit of recently launched ships, discovering work items that could have already been accomplished would identify even
more opportunities that exist to gain construction progress prior to launch. This audit would inform the shipbuilder in necessary scheduling and process changes that could move many work items to the on-unit and on-block phases of construction versus the waterborne phase of construction thereby increasing overall cost efficiency and likely improving quality. There are several stakeholders relevant to this recommendation. The most interested and powerful stakeholders able to affect this change are HII/Ingalls and PMS 400D as each would have the most to gain by discovering opportunities to progress construction further prior to launch.

The second recommendation related to the shipbuilder’s micro-processes relates to the existence of process bottlenecks. The shipbuilder’s micro-processes contain at least two observable bottlenecks described in detail in Chapters IV and V of this thesis. The first recommendation within the micro-process focus area is to subordinate the rest of the shipbuilding process to the observed bottlenecks. These are the capacities of the stacking hall and the integration bays. The observation of WIP preceding these two parts of the process indicate the limiting nature of these two facilities. As each of these areas are throttling the overall throughput of the shipbuilder, the output of every station within the process should be attenuated so as not to exceed the capacities of the bottlenecks. This recommendation may seem counterintuitive as it requires reducing the output of other stations within the shipyard. However, the existence of WIP would be eliminated, thereby limiting the negative impact that on-hand inventory has on cost efficiency as well as limiting the adverse impact of weather on the WIP. Once the overall process is subordinated to the bottlenecks, elevate the constraints by increasing the capacity and throughput of the stacking hall and integration bays. This leads to the recommendations that follow relating to the infrastructure of the shipyard. Like the previous recommendation, this recommendation is of interest to multiple stakeholders. However, PMS 400D, PEO Ships, and HII/Ingalls are the stakeholders with the requisite interest and power to lead the change.

Identifying the constraints of the shipbuilding process at Ingalls shipyard inform the recommendations for the next focus area, the shipyard itself. The shipyard may be improved through the CAPEX investment incentive as long as it can be demonstrated
that the investment bears sufficient benefit to the Navy. CAPEX protocol limits the investment total to $20 million. However, if it is deemed logical, CAPEX opportunities exceeding $20 million but benefiting multiple shipbuilding programs, as would be the case at Ingalls shipyard, may receive CAPEX funds from the Navy. In return, the benefits of such an investment would be applicable to each shipbuilding program at the shipyard. That is, many investments would not only benefit the DDG program but also the LPD and LHA programs as well as the Coast Guard’s NSC program. Specific CAPEX recommendations include increasing the size, and thus the capacity, of the stacking hall. This would allow the shipbuilder to construct larger grand blocks in greater quantity thereby elevating one of the two identified process constraints. Another CAPEX recommendation is the expansion of the integration bays. Allowing three hulls to be assembled abreast versus two hulls, as is currently the case, elevates the second of two identified constraints. The third and final recommendation for shipyard infrastructure is to cover the area where outfitting components are stored while awaiting installation. Covering this area mitigates the adverse effects of weather upon these components while they await installation; thus improving the overall quality of the ships as they are constructed. HII/Ingalls, PEO Ships, PMS 400D, and the U.S. Navy have the most to gain from these recommendations. Furthermore, the ship’s crew, receiving a higher quality ship would benefit from this recommendation. Thus, there are many cognizant stakeholders for these recommendations.

The last focus area within the problem space is the contract. As shown in Chapter III, the incentives existing in the contract are designed to encourage contractor performance. If the shipbuilder is indeed encouraged to achieve greater construction progress prior to ship launch, this should be incentivized. The dynamic period performance incentive could be utilized to encourage this in the short term. If proven effective, progress performance prior to launch should become its own, permanently affixed, incentive within future DDG acquisition contracts. The incentive criteria would be constructed in such a way that rewards the shipbuilder for achieving a minimal construction progress prior to launch and would likely be tiered so as to allow the contractor to determine what level of completion is cost beneficial for them to pursue.
prior to launch. Table 11 shows an example of perspective incentive criteria. Incentivizing construction progress benefits PEO Ships and PMS 400D as well as the U.S. Navy and the American taxpayer. With the dominating power and interest to affect this change, the most relevant stakeholders are PEO Ships and PMS 400D.

Table 11. Completion Prior to Launch Incentive

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>PERCENTAGE EARNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction progress greater than or equal to 85%</td>
<td>100%</td>
</tr>
<tr>
<td>Construction progress greater than or equal to 80% but less than 85%</td>
<td>90%</td>
</tr>
<tr>
<td>Construction progress greater than or equal to 75% but less than 80%</td>
<td>80%</td>
</tr>
<tr>
<td>Construction progress greater than or equal to 70% but less than 75%</td>
<td>70%</td>
</tr>
</tbody>
</table>

D. AREAS FOR FURTHER RESEARCH

The research effort conducted to support this thesis revealed issues to the author that are outside the scope of this thesis but related in topic. Some of these issues relate to ship maintenance, ship construction, process improvement, and knowledge sharing. The following paragraphs describe some areas that future researchers might evolve understanding or create recommendations that lead to further improvements.

(1) Gain Construction Progress Prior to Launch

One recommendation contained within this thesis suggests conducting an audit of recently launched ships to determine additional work items that may be completed prior to launch. The purpose of this recommendation is to support achieving more construction progress prior to ship launch than is currently achieved thereby improving shipbuilding efficiency and quality. Future researchers would prove the necessity of this effort if they were to conduct this audit and a subsequent academic analysis that could lead to process and scheduling changes at the shipyard.

(2) Maintain Current Ship Inventory in a Quality-Centric Manner

Shifting priorities in ship maintenance from cost and schedule effectiveness to a quality-centric focus would increase the operational availability of each ship and the
overall quality of the fleet. This is a difficult task however, as decisions pertaining to extended maintenance and modernization necessity would be required. As the Navy currently plans for friction in terms of cost by setting aside funds for the express purpose of paying for growth and new work, the contingency for schedule slippage is not apparent. Schedule slippage of maintenance availabilities is commonly hailed as a leading contributor to the lengthening of ship deployments and increased underway time that has been experienced throughout the U.S. Navy over the past several years. In the long term, quality-centric maintenance practices help solve these problems. In the short term however, the shift to quality-centric maintenance may exacerbate the issues of extended underway periods. It is the transition period from today’s maintenance paradigm to the quality-centric focus that future researchers must explore.

(3) Conduct Similar Efficiency Analysis of Shipbuilding Practices at BIW and Create an Index of Best Practices and Recommendations

While the predominant focus of this thesis is on the shipbuilding processes as they specifically relate to HII/Ingalls, there is likely opportunity for improvement by GD/BIW. A detailed evaluation of the shipbuilding processes at BIW’s shipyard in Bath, Maine would likely reveal opportunities for micro-process improvement as well as CAPEX opportunity. Furthermore, a comparison of practices at Ingalls and BIW may reveal best practices that would afford each shipbuilder to benefit from lessons learned from the competitor. While this information would likely be closely guarded by each respective shipbuilder, the U.S. Navy may conduct an analysis from the Supervisor of Shipbuilding perspective in such a way that benefits all stakeholders. Finally, revelations from such research as well as the actions taken subsequent to the research may inform the U.S. Navy on during future contract award decisions.

(4) Conduct Detailed Shipyards Research Postulating the Fifth-Generation Shipyard

Given the evolution in technology related to automation, data processing, scheduling, and process improvements, there is a propensity for the development of the fifth-generation shipyard concept. If any modern or future technology serves as the
impetus for the next-generation shipyard, it would be beneficial for the shipbuilder and U.S. Navy to be aware, and the concept proven, before any future shipyards are constructed or existing shipyards are modernized. Future researchers would take on the task of discovering the offset that brings about the fifth-generation shipyard as well as demonstrating its benefit. A business case analysis may accompany the research to determine the cost viability of modernizing existing shipyards to the fifth generation concept.
LIST OF REFERENCES


INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center  
   Ft. Belvoir, Virginia

2. Dudley Knox Library  
   Naval Postgraduate School  
   Monterey, California