AN EXAMINATION OF THE U.S. PACIFIC SHIP REPAIR INDUSTRY'S WORKFORCE AND FACILITIES CAPABILITIES IN THE EVENT OF MISSILE-CENTRIC WARFARE IN THE WESTERN PACIFIC OCEAN

A thesis presented to the Faculty of the U.S. Army
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degree

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Art of War Scholars

by

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ABSTRACT

AN EXAMINATION OF THE U.S. PACIFIC SHIP REPAIR INDUSTRY'S WORKFORCE AND FACILITIES CAPABILITIES IN THE EVENT OF MISSILE-CENTRIC WARFARE IN THE WESTERN PACIFIC OCEAN, by Keegan Alexander Hoey, 183 pages.

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Countless individuals have donated their time and wisdom to helping me accomplish this research endeavor. Without their help, this paper would be a shadow of its current self.

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ACRONYMS

ASBMs	Anti-Ship Ballistic Missiles
ASCM	Anti-Ship Cruise Missile
CD	Current Drydocks
CG	Guided Missile Cruiser
CP	Current Piers
CS	Comparable Ship
CSG	Carrier Strike Group
CVN	Nuclear Powered Aircraft Carrier
CVW	Carrier Air Wing
CW	Current Workforce
DDG	Guided Missile Destroyer
LACM	Land Attack Cruise Missile
MTTR	Mean Time to Repair
NR	Need of Repair
OFRP	Optimized Fleet Response Plan
P_{HIT}	Probability Hit
PLA	People's Liberation Army
PRC	People's Republic of China
RT	Repair Time
WWI	World War I
WWII	World War II

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CHAPTER 1

INTRODUCTION

> Of all the tools the Navy will employ to control the seas in any future war, the most useful of the small types of combatant ships, the destroyer, will be sure to be there. Its appearance may be altered and it may even be called by another name, but no type not even the carrier or the submarine has such an assured place in future navies.
>
> —Fleet Admiral Chester W. Nimitz, "Trial Success," *Bay City Times*

Background

Rear Adm. Eric Ver Hage, the United States Navy's Admiral who is the director of surface ship maintenance and modernization for Naval Sea Systems Command, announced in the summer of 2020 that the United States Navy has insufficient maintenance centers to repair its vessels, even by peacetime standards.[1] Given that a nation's ability to repair damaged vessels in the event of a war is one of the many vital assets to maintain the nation's security, the importance of efficient and capable repair facilities cannot be understated. In World War II (WWII), the United States mobilized large sectors of its industrial base to support the war effort regarding ship maintenance, repair, and construction. Without this effort, the war's outcome would most certainly have been different.[2]

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[1] Richard R. Burgess, "RMC Admiral: Not Enough Ship Repair Capacity for Peacetime, Let Alone Wartime," *Seapower*, August 25, 2020, https://seapower magazine.org/rmc-admiral-not-enough-ship-repair-capacity-for-peacetime-let-alone-wartime/.

[2] Alan L. Gropman, *Mobilizing U.S. Industry in World War II: Myth and Reality* (Washington, DC: Institute for National Strategic Studies, 2012), 2.

In 1981, the United States withdrew direct shipbuilding subsidies, and domestic shipyards have since been unable to compete with global competitors due to heightened regulation, increased labor costs and labor shortages. This has resulted in a decrease in the number of shipyards and an increase in costs and delays across the nation.[3] A shrinking number of civilian shipyards means fewer facilities available for mobilization to support repair efforts in the event of war. It also means a smaller skilled labor pool to tap into should war break out. While the country can deal with delays in repair time (RT) during peacetime, delays during wartime could influence the outcome of the conflict negatively. Should there be another major naval war, many believe even current industrial facilities will be unable to return battle damaged ships to the fight quickly enough.[4]

Concern for the inability to efficiently repair battle damaged ships is not just a hypothetical problem. US Marine Corps Commandant Gen. David Berger raised significant concerns over the United States' ability to replace combat losses in the event of a war in the Western Pacific in a 2020 report entitled "Naval Campaigning: The 2020 Marine Corps Capstone Operating Concept." In his report, Gen. Berger noted that repair ability is an element of deterrence. If the United States' adversaries believe the nation does not possess the ability to engage in a protracted fight, then they may be more

[3] Aaron Klein, "Decline in U.S. Shipbuilding Industry: A Cautionary Tale of Foreign Subsidies Destroying U.S. Jobs," Eno Center for Transportation, September 1, 2015, https://www.enotrans.org/article/decline-u-s-shipbuilding-industry-cautionary-tale-foreign-subsidies-destroying-u-s-jobs/.

[4] Megan Eckstein, "Navy Issues Revision to OFRP Deployment Schedule," *USNI News*, October 28, 2020, https://news.usni.org/2020/10/28/navy-issues-revision-to-ofrp-deployment-scheme.

aggressive with their military strategy and diplomacy. Additionally, these adversaries may consider that a strategic longer-term victory lies in a short-term defeat, based on the inability of the US to reconstitute its power projection forces in a timely manner.[5]

Growing threats in China are concerning for the US Navy and its ship repair industry. A 2020 Department of Defense annual report on China's military and its role in China's foreign policy stated the following:

> The PLA's objective is to become a "world-class" military by the end of 2049—a goal first announced by General Secretary Xi Jinping in 2017. Although the CCP [Chinese Communist Party] has not defined what a "world-class" military means, within the context of the PRC's [People's Republic of China's] national strategy it is likely that Beijing will seek to develop a military by mid-century that is equal to—or in some cases superior to—the U.S. military, or that of any other great power that the PRC views as a threat. As this year's report details, the PRC has marshaled the resources, technology, and political will over the past two decades to strengthen and modernize the PLA in nearly every respect.[6]

Concerns over China's growing military might is worrisome, as many of China's beliefs and claims do not sit well with the international community, and many countries are opposed to their ascension as a result.[7] Although these beliefs and claims do not necessitate a war, China seems increasingly intent on challenging the United States and the international community by pressing its claims to the disputed areas around its borders, to include the South China Seas and Taiwan.

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[5] Paul McLeary, "In War, Chinese Shipyards Could Outpace US in Replacing Losses; Marine Commandant," *Breaking Defense*, June 17, 2020, https://breakingdefense.com/2020/06/in-war-chinese-shipyards-can-outpace-us-in-replacing-losses.

[6] Ibid.

[7] Human Rights Watch, "The Costs of International Advocacy," September 5, 2017, https://www.hrw.org/report/2017/09/05/costs-international-advocacy/chinas-interference-united-nations-human-rights#.

According to a Center for Strategic and Budgetary Assessments article on the Maritime Pressures in the Western Pacific, there are four features of China's rise that trouble the United States. First, China has become more active on the international stage, pushing its diplomacy regionally and globally through economic investments, political agreements and military deployment. Second, is China's geopolitical orientation. In recent times, China has shifted its focus to maritime capabilities such as missiles and anti-satellite weapons. Third is China's attitude toward the international status quo, which has been coined "Wolf Warrior Diplomacy" to describe its aggressive style.[8] And fourth is China's domestic political system which has shown increasing disregard for human rights, causing ideological tension with the United States and other allies.[9]

In a potential war with China, the US Navy will likely be among the first to fight. The success of any follow-on strategy will depend first on the US Navy's ability to dominate the Pacific Ocean, as it ultimately did in WWII against Japan.[10] The strategy[11]

[8] Ben Westcott and Steven Jiang, "China is embracing a new brand of foreign policy. Here's what wolf warrior diplomacy means," *CNN*, May 29, 2020, https://www.cnn.com/2020/05/28/asia/china-wolf-warrior-diplomacy-intl-hnk/index.html.

[9] Thomas Mahnken, Travis Sharp, Billy Fabian, and Peter Kouretsos, "Tightening the Chain: Implementing a Strategy of Maritime Pressure in the Western Pacific" (Report, Center for Strategic and Budgetary Assessments, Washington, DC, 2019), 12-13.

[10] Zack Cooper and Hal Brands, "Getting Serious About Strategy in the South China Sea," *Naval War College Review* 71, no. 1 (2018): article 3, 6.

[11] This strategy was to advance on two fronts. MacArthur's troops hopped from island to island in the southwest Pacific while "a central Pacific campaign began with the invasion of Tarawa in the Gilbert Islands in November 1943." This was coupled with unrestricted submarine warfare. The goal being to dislodge the Japanese from the southwest Pacific and advance forces towards the Japanese mainland. National WWII

the US Navy used to dominate the Pacific Ocean during WWII will change as the character of warfare will change should conflict break out in the Western Pacific. While repair estimates due to "classic" weapons such as mines, torpedoes, and gunfire are plentiful, these more conventional weapons are unlikely to be the impetus for repairs. The 2020 Military and Security Developments Involving the People's Republic of China report highlights that should a war break out with China, the weapon of choice will likely be long range missiles, both ballistic and cruise. "Land-based conventional ballistic and cruise missiles: The PRC has more than 1,250 ground-launched ballistic missiles (GLBMs) and ground-launched cruise missiles with ranges between 500 and 5,500 kilometers."[12]

Since the end of the Cold War, while the United States was distracted by non-naval focused events abroad such as the Global War on Terror, China has made substantial gains in their naval sea power and capability.[13]

Just recently it was announced that the "PRC has the largest navy in the world, with an overall battle force of approximately 350 ships and submarines, including over 130 major surface combatants."[14] China has also been reported to have the most active

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Museum, "The Pacific Strategy, 1941-1944," n.d., accessed May 6, 2021, https://www.nationalww2museum.org/war/articles/pacific-strategy-1941-1944.

[12] McLeary, "In War, Chinese Shipyards Could Outpace US in Replacing Losses."

[13] Office of Secretary of Defense, *Military and Security Developments Involving he People's Republic of China* (Washington, DC: Government Publishing Office, 2020), 143, https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF.

[14] Richard Sisk, "China's Military Has Surpassed US in Ships, Missiles and Air Defense, DoD Report Finds," Military.com, September 1, 2020,

land-based cruise and ballistic missile programs in the world[15] meant to counter sea-borne threats e.g., the United States Navy. Among many of its new long-range missiles, China has also developed what has been called the "world's first carrier killer"[16] ballistic missile, the Dong-Feng 21D.[17] Reports state that this missile has an unclassified range of 1,000 miles from the mainland and a potential warhead size of 1,000 lbs.[18] Recently, the DF 26 missile has also been tested, which has a reported range of 3,000 to 4,000 km, making it capable of strikes against land targets.[19] These weapons could make it difficult

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https://www.military.com/daily-news/2020/09/01/chinas-military-has-surpassed-us-in-ships-missiles-and-air-defense-dod-report-finds.html.

[15] National Air and Space Intelligence Center in collaboration with Defense Intelligence Ballistic Missile Analysis Committee, "Ballistic and Cruise Missile Threat" (Report, National Air and Space Intelligence Center, Wright Patterson AFB, OH, July 2017), https://www.nasic.af.mil/Portals/19/images/Fact%20Sheet%20Images/2017%20Ballistic%20and%20Cruise%20Missile%20Threat_Final_small.pdf?ver=2017-07-21-083234-343.

[16] It is worth noting that the Chinese were not the first to come up with the tactic of the "carrier killer missile," but that they are one of the first to truly realize the idea. The first were the Russians. During the 1960s and 1970s, they were developing such a missile called by multiple names including SS-NX-13, P-27K, and D-5. The missile was a submarine-launched ballistic missile that at the time was the only missile with the targeting ability to hit mobile sea objects. However, the missile was never fully realized due to constraints put in place by the SALT treaty in 1972 and evolving Russian strategic direction at the time.

[17] Otto Kreisher, "China's Carrier Killer: Threat and Theatrics," *Air Force Magazine* (December 2013): 44-47, https://www.airforcemag.com/article/1213china/.

[18] Office of Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2013* (Washington, DC: Government Printing Office, 2013), 9, https://archive.defense.gov/pubs/2013_china_report_final.pdf.

[19] Missile Defense Project, "DF-26 (Dong Feng-26)," Missile Threat, Center for Strategic and International Studies, January 8, 2018, accessed May 6, 2021, https://missilethreat.csis.org/missile/dong-feng-26-df-26/.

for US naval forces to approach the Chinese mainland and maintain dominance in the East and South China Seas, as depicted in Figure 1.

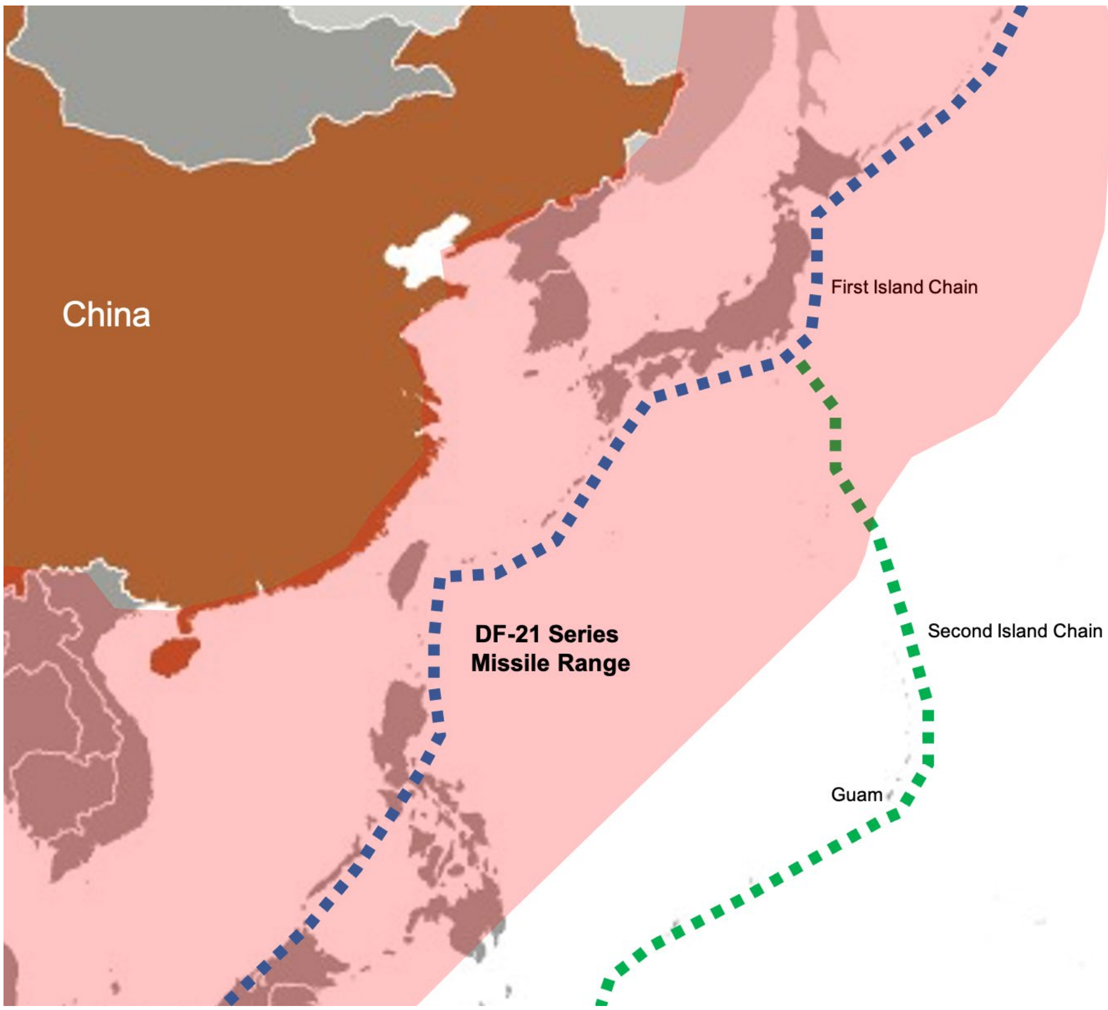

Figure 1. First Island Chain and Second Island Chain in Relation to DF-21 Series Missile Range

Source: Central Intelligence Agency, "The World Factbook: China Details," accessed March 20, 2021, https://www.cia.gov/the-world-factbook/countries/china/locator-map.

The world has yet to see a modern war on the scale of WWII that includes the use of missiles, and thus uncertainty exists regarding the influence of large-scale missile use against a battle force in protracted conflict. The closest historical example of missile warfare was the Falklands War in 1982. Fought between Argentina and Great Britain, this war only lasted 74 days.[20] Due to its brevity, ship-to-ship battles with missiles were few (when compared to the rate of battle in WWII) and the timelines involved prevented ship repair from playing a role in determining the outcome of the conflict.

The Falklands War took place 39 years ago, and the character of missile warfare has only intensified since then. For example, in 1983, just one year after the conclusion of the Falklands War, the USS *Ticonderoga*, the first AEGIS Cruiser (CG) warship, with a fully digital large volume automated search and targeting radar system, along with commensurate anti-air missiles was commissioned.[21] From there the technology, capability, strategy, and tactics surrounding missile warfare has evolved dramatically in complexity and capacity.

Missile technology has advanced significantly from the 1970s French-made first generation Exocet missiles used in the Falklands War. These early anti-ship missiles were limited in range, and used relatively simple targeting systems. Modern missiles enjoy significantly more complex search and targeting, as well as improved warheads and up to 10 times the range for cruise missiles, and 40 times the range for ballistic missiles. Additionally, early missiles were sub-sonic, while many modern variants approach their

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[20] Alejandro L. Corbacho, "74 Days under the Argentine Flag: The Experiences of Occupation during the Falklands/Malvinas War" (CEMA Working Paper, Universidad Del CEMA, Buenos Aires, 2018), 1.

[21] Guy J. Nasuti, "USS Ticonderoga (CG-47)," Naval History and Heritage Command, November 21, 2019, https://www.history.navy.mil/content/history/nhhc/research/histories/ship-histories/danfs/t/ticonderoga-v.html.

targets at Mach speeds, greatly increasing the kinetic energy and penetration of the weapon. All these improvements have greatly increased modern anti-ship missiles' destructive power. These missiles pose a much greater danger compared to the threats of 39 years ago. With these advancements in technology, mixed with their destructive potential and proliferation, it is reasonable to expect that missiles will be the primary weapon in any future naval war. Modern missile warfare carries continually increasing challenges and greater consequences.

The way in which the United States fights naval battles, with an emphasis on carrier (CVN) warfare, is changing due to evolving missile capability. The modern US Navy Carrier and its Air Wing (CVW), as the center of the Navy's main maneuver element the Carrier Strike Group (CSG), are together the main offensive striking powers of the US Navy. While Tomahawk Cruise missiles support offensive strikes, they are limited in capacity compared to the combat staying power of a CVW. A CVW can be continually reloaded and reconstituted at sea, while Tomahawks cannot. Together with its guided missile destroyer (DDG) and guided missile cruiser (CG) escorts, the CVN is now protected by a ring of units providing anti-missile defense.[22] Despite this, the CVN is still vulnerable. If a small missile were to hit (or even skim) a sensitive flight deck, that alone could prove fatal to the CVN's mission of providing a base of operations for the CVW.

[22] Benjamin S. Lambeth, *American Carrier Air Power at the Dawn of a New Century* (Santa Monica, CA: RAND Corporation, 2005), 83.

Operating in its current architecture, without the CVN, the US Navy would face limitations in its ability to wage effective offensive naval warfare in 2021 and beyond.[23]

The United States' adversaries know this and have been creating new and powerful weapons to target and destroy CVNs, making the anti-missile defense units more important to naval warfare. Today, CGs are designated and built for tasking primary air defense units for CSGs. However, given their limited numbers and age, the unit that shoulders this burden the most is the AEGIS Destroyer. The DDG is the frontline ship for the defense of the CSG (CVN).[24] Until the new Constellation frigate program can produce enough ships to alleviate the stress on DDGs, they will remain a major pillar in the defense of CVNs for the foreseeable future.

As discussed above, potential adversaries have spent years perfecting weapons that are designed to penetrate the CSG's defenses. Air defense includes several methods to defeat threat systems. As shown in the Falklands War, ships hit by missiles were either sunk or suffered such damage that they required major repair, taking them out of the fight for the duration.[25] Expanding on this, there is a high probability that missile warfare will play a very large part in any future naval engagements due to technological advantages and destructive power. However, not every ship is going to be sunk by missiles and some

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[23] MC3 George J. Penney III, "Pacific Fleet Commander Visits USS Nimitz," Commander, United States Pacific Fleet, May 21, 2014, https://www.cpf.navy.mil /news.aspx/030398.

[24] Edward J.Walsh, "Navy Steps Out on Modernization," *Military and Aerospace Electronics*, March 1, 2009, https://www.militaryaerospace.com/trusted-computing /article/16709526/navy-steps-out-on-modernization.

[25] Many destroyers and cruisers damaged by Kamikaze suicide planes or by 500 lb to 1,000 lb-class bombs were also taken out of the fight for extended periods of time.

will be worth repairing. Conversely, it would also be unwise for the United States to rely solely on the shipbuilding industry to replace every missile-damaged ship with a new ship, due to time and resource constraints. Therefore, having adequate repair capabilities will be vital to a sustained war effort, and to timely force reconstitution post conflict.

The 2020 *Military and Security Developments Involving the People's Republic of China* report makes clear that China has made its military might an increased focus:

> More striking than the PLA's staggering amounts of new military hardware are the recent sweeping efforts taken by CCP leaders that include completely restructuring the PLA into a force better suited for joint operations, improving the PLA's overall combat readiness, encouraging the PLA to embrace new operational concepts, and expanding the PRC's overseas military footprint.[26]

If war does come, the United States must be ready. The consequences to the established and hard-fought current world order will be dire if not. China has spent decades growing and expanding their military might, whereas the United States has been preoccupied with wars for the last twenty years that were inherently not naval-orientated, which in turn created an environment where naval resourcing was strained in support of other needs.[27] Today, China has new long-range missiles, missile platforms, and tactics specifically designed and focused on the destruction of CVNs and CSGs. While DDGs remain a critical element in the front lines of missile defense, realistically many will likely be hit by missiles in heavy combat and some will be destroyed. However, it is also statistically probable some will survive with damage that can be repaired.

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[26] McLeary, "In War, Chinese Shipyards Could Outpace US in Replacing Losses."

[27] Department of the Navy, *Highlights of the Department of the Navy FY 2018 Budget* (Washington, DC: Government Publishing Office, 2018), 1-4.

Knowing that the shipbuilding industry in the United States is in decline, planning to replace every missile-damaged ship with a new ship is unwise and potentially infeasible due to time and resource constraints. Therefore, the ability to repair and return missile-damaged DDGs to the fight as quickly as possible could be critical to any sustained war effort. In addition, for shorter duration conflicts, the ability to reconstitute the force remains central to the US' ability to remain relevant on the world's stage. So then, the critical need extends to the US ship repair industry.

Statement of the Problem

Inability to repair missile-damaged destroyers in the event of a sustained war in the Western Pacific puts the United States at risk of losing the war, or losing the peace post-conflict without a relevant naval power able to deploy.

Purpose of the Study

It is the purpose of this thesis to determine whether the United States' Pacific ship repair workforce and facilities are robust enough to repair US Navy missile-damaged destroyer class ships in the event of a war in the western Pacific.

Primary Research Question

The primary research question seeks to understand whether the current status of the Pacific ship repair industry is sufficient to sustain the Pacific Fleet should a naval war erupt in the western Pacific. The primary research question is:

Is the United States' Pacific ship repair industry capable of sustaining a war in the Western Pacific?

Secondary Research Questions

The primary question necessarily drives a series of secondary questions, which will be useful to examine in order to better understand the United States' current ship repair capabilities. These secondary questions are:

1. How much effort (expressed in man-days) is required to repair the average missile-damaged destroyer?
2. What is the Pacific Fleet's ship repair industry's workforce capacity for repairing missile-damaged destroyers?
3. What is the Pacific Fleet's ship repair industry's facilities capacity for repairing missile-damaged destroyers?
4. In a hypothetical war in the western Pacific, how often will destroyer class vessels require repair?

Assumptions

1. The hypothetical conflict will take place in the Western Pacific.
2. There will be no exchange of nuclear weapons.
3. Major Damage (as defined) requires a drydock for repairs.
4. Moderate Damage (as defined) requires a pier for repairs.
5. At the start of the hypothetical conflict, the Optimized Readiness Fleet Plan will still be in effect (i.e., one-third of the Pacific Fleet will be undergoing maintenance, one-third of the Pacific Fleet will be in the Basic Phase and one-third of the Pacific Fleet will be available for immediate deployment).
6. One destroyer will join the Pacific Fleet via new construction every six months.

7. One destroyer will exit the Maintenance and Basic Phases and become available for deployment every two months.
8. All ships entering the hypothetical conflict will remain deployed until sunk or damaged.
9. Workforce and Facilities capabilities are assumed to grow at the rates seen during WWII (applicable to Chapter 3, Subsection (C)'s Dynamic Analysis).
10. Growth experienced by the shipyard industry during WWII was experienced proportionately between ship repair facilities and ship construction facilities such that this growth rate can be applied to either.
11. All existing Pacific ship repair facilities and workers are available for battle damage repair tasking for US Navy destroyers.
12. All US Navy destroyers are available for tasking.

Limitations

1. Only piers and drydocks reported by the United States Maritime Administration are considered (facilities in Japan and Guam were not reported and therefore not included).
2. The wargame scenario is limited to unclassified information.

Delimitations

1. The study is limited to destroyer and destroyer-class vessels.
2. This thesis will only research and discuss ship repair facilities on the west coast, and US territories on the west coast.

3. Shipyards solely building ships for the US Army or US Corps of Engineers were not included.
4. This thesis will only examine shipyards that are capable of repairing DDG class vessels.
5. Offensive attacks are limited to missiles (other forms of warfare are not considered).
6. Allied shipyards and forces are not considered.
7. Resource availability is not considered.
8. Common maintenance due to extended time at sea that might otherwise cause a ship to require repairs will not be conducted for those ships entering the fight.
9. Ships returning from repairs will not undergo training and/or workups and will instead proceed immediately to the fight.

Significance of the Study

China's expansionism is creating increasing tension with the United States as it threatens free access to the Global Commons. So too, is China's increasing industrial base and Navy in support of this expansionism. Currently, the two countries have reached an uneasy equilibrium where China pushes and the US attempts to contain. However, any small movement on either side could upset this delicate balance, which could result in war.

If the United States' ship repair industry declines, while China's continues to improve, this could threaten the balance to the equilibrium as the United States may be unable to field an adequate force. The United States operates in the sphere of deterrence.

It trusts that its ships and presence create sufficient negative incentive via risk to prevent a Chinese attack. If the PRC perceives that the United States would be unable to engage in or sustain a conflict with China due to an inability to field and repair its missile-damaged ships during or post conflict, this model of deterrence could crumble.

Thus, determining whether the United States has the requisite capabilities to fight and deter such a war is of utmost importance to the interests of national security, national strategy, and the current world order.

Summary

This chapter provided an overview of the United States ship repair industry and its importance to national security interests. It detailed the background of the US ship repair industry, the changing nature of naval warfare and the changing relationship with China. The primary research question of whether the United States Navy's Pacific ship repair industry is capable of supporting a war in the Western Pacific was presented along with the purpose of this study.

Chapter 2 will provide a review of the relevant literature on this subject and will detail the United States ship repair industry at relevant times in history to determine its rate of decline along with several case studies of missile-damaged (or comparably damaged) ships.

CHAPTER 2

LITERATURE REVIEW

> In practice, the size will be decided by the government. This decision marks the start of military activity-it is indeed a vital part of strategy-and the general who is to command the in the field usually has to accept the size of his force as a given factor. Either he was not consulted in the matter, or circumstances may have prevented the raising of a sufficiently large force
>
> —Clausewitz, *On War*

Introduction

The purpose of this literature review is to familiarize the reader with necessary background information and scholarship regarding whether the United States has the capabilities necessary to support a war in the western Pacific.[28] As discussed in the Introduction, should a war in the western Pacific break out, the main offensive weaponry used is expected to be missile technology. Thus, in order to understand this primary question, the review of existing literature in this chapter is broken down into the following component parts: (1) how has modern Chinese missile technology evolved; (2) what is the importance of the destroyer in defending against missile attacks; (3) what is the history of the United States' ship repair industry; (4) how has the United States ship repair industry handled battle damage in the past; (5) what is the current status of the ship repair industry's facilities?; and (6) what is the current status of the ship repair industry's workers?

[28] After a thorough review of the literature, this author believes no quantitative study of the nature and magnitude encompassed in this paper has been conducted in the unclassified realm. Therefore, this Literature Review provides background information in order to familiarize the reader with the necessary subject matter to better understand the forthcoming methodology.

A good deal of press recently has been devoted to whether the United States Navy is capable of waging war with China, however, a thorough examination of what that war might look like for a specific naval combatant class has not been done. Ultimately, this literature review will help to understand the primary research question of whether the Pacific ship repair industry is capable of supporting a war in the Western Pacific.

Evolution of Chinese Missile Technology

Whether the United States has adequate repair facilities to support a war with China necessarily requires an examination of the threat China presents to the United States to establish the level of risk regarding damage to combatants. Missile technology, as previously discussed, will likely be the dominant offensive technology in modern Naval warfare and thus, an examination of the history of China's missile development is presented.

Since the late 1950s China has been developing its cruise missile program, largely motivated by the need for a coastal defense. Early on, the Chinese sought the expertise of the Soviet Union. However, as the Chinese progressed, they gradually moved away from Soviet support in the 1980s, preferring to use their own technology. Even still, a majority of their systems have a Russian identity.[29]

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[29] Dennis M. Gormley, Andrew S. Erickson, and Jingdong Yuan, "A Potent Vector: Assessing Cinese Cruise Missile Developments," *Joint Force Quarterly* 75 (4th Quarter 2014): 98-105.

In the 1990s, after the fall of Soviet Union, China resumed using the Russian arms market and proceeded to continue importing missile technology and ships. Today, China has a mix of their own indigenous missile technology and Russian imports.[30]

To the Chinese, the 1991 Gulf War began a new era of modern warfare. "Mechanized warfare," which characterized WWI and WWII, was over and the new era of high-tech warfare had begun.[31] For example, Tomahawk cruise missiles were perfected and used starting in the 1990s.[32] In response to the rise of this new technology, the Chinese started their own Land Attack Cruise Missile (LACM) program using their own technology and assistance from Russia. This effort led to the creation of the DH-10[33] and Yj-63 cruise missile systems, created in the 1990s.[34]

China has also made great strides in their ability to target and locate US Naval ships. The timeframe in which China has made these improvements is rapid when compared to the rest of the world's great navies. As an example, in 1996 China would be hard pressed to locate and target fleets beyond the visual range of its coasts. However, fast forward to 2017 and China now has a broad range of over-the-horizon intelligence,

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[30] Gormley, Erickson, and Yuan, "A Potent Vector," 98-105.

[31] Ibid.

[32] Ibid.

[33] Identified in some literature as the "CJ-10."

[34] Ibid.

surveillance, and reconnaissance capabilities that have multiple abilities of holding US Carriers and surface at risk.[35]

China's development of the Anti-Ship Cruise Missile (ASCM) has made vast improvements in the last 50 years. Currently, China's Navy has one of the world's largest arsenals of ASCMs onboard their ships and submarines. These ASCMs present a direct threat to CSGs.[36] The Chinese strategy is troubling. Early projections from the Congressional Research Service predicted that the PLAN would surpass the US Navy in size: "while the PLAN had 137 large surface ships in 2012, this number will only increase to 146–147 by 2015 and will likely remain at that level through 2020."[37] Support for this concern was seen as early as the 2006 Department of Defense's Quadrennial Defense Review. China was singled out, stating that China has "the greatest potential to compete militarily with the United States and field disruptive military

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[35] Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Tao Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *Tallying the U.S.-China Military Scorecard: Relataive Capabilities and the Evolving Blance of Power* (Santa Monica, CA: RAND Corportation, 2015).

[36] Gormley, Erickson, and Yuan, "A Potent Vector," 98-105.

[37] Ronald O'Rourke, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress* (Washington, DC: Congressional Research Service, 2021).

technologies that could over time offset traditional US military advantages absent US counter strategies."[38] Ultimately, this prediction was realized.[39]

The cruise missile has large appeal to China. Cruise missiles are a force multiplier that allow precision strikes with minimum risk. They also can be deployed by multiple platforms allowing flexibility combined with a risk to reward ratio not seen in warfare until modern times. Naval platforms offer a constant presence and China has capitalized on this by developing and importing ships and submarines that are capable of launching a variety of ASCMs. Chinas strategy of employing ASCMs over other types of conventional weapons is evident. Conventional submarines appear to have 3:1 ratio between ASCMs to torpedoes and Chinese aircraft have been outfitted with improved ASCM and cruise missiles.[40]

ASCMs are becoming an important pillar in Chinese defense strategy. New ships are being created for the sole focus of firing ASCMs. The Type 022 Houbei is an example of this tactic, created as an expendable craft that only has one purpose: to fire ASCMs. The Office of Naval intelligence stated: "The PLA[N] has more than quadrupled the number of submarines capable of firing . . . ASCM[s], installed missiles with longer

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[38] Department of Defense, *Quadrennial Defense Review Report* (Washington, DC: Government Printing Office, 2006).

[39] Sisk, "China's Military Has Surpassed US in Ships, Missiles and Air Defense, DoD Report Finds."

[40] Gormley, Erickson, and Yuan. "A Potent Vector," 98-105.

ranges and more sophisticated guidance packages on its surface combatants, [and] built over 50 high-speed ASCM[s] carrying patrol craft."[41]

To China, ASCMs and LACMs promise to be the answer to many military problems regarding their defense and power projection aspirations. A report published by the Department of Defense in 2011 states:

> China's A2AD focus appears oriented toward restricting or controlling access to the land, sea, and air spaces along China's periphery, including the Western Pacific. For example, current and projected force structure improvements will provide the PLA with systems that can engage adversary surface ships up to 1,850 km [1,150 mi] from the PRC coast. These include: conventional (SS) and nuclear-powered (SSN) attack submarines: Kilo-, Song, Yuan, and Shang-class attack submarines capable of firing advanced ASCMs surface combatants: Luzhou, Luyang I/II, Sovremenny II[/III]-class guided missile destroyers with advanced long-range antiair and anti-ship missiles. Maritime strike aircraft: FB-7 and FB-7A, B-6G, and the SU-30 MK2 armed with ASCMs to engage surface combatants.[42]

Two of China's many goals are to deter Taiwan from making any more moves towards independence and stopping US influence in the region. As a result, Chinese strategists have placed a significant role on the ASCM and LACM. China has moved to counter the supposed threats by creating, acquiring, and employing ASCMs and LACMs that are able to strike US allies, bases, and platforms throughout the region.[43]

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[41] Timothy Hu, "A Morning Star Shines: China's Military Modernization," *Jane's Defense Weekly*, July 30, 2008.

[42] Eric Arnett, "Military Technology: The Case of China," in *SIPRI Yearbook: Armaments, Disarmament and International Security*, ed. Stockholm International Peace Research Institute (New York: Oxford University Press, 1995), 359-386.

[43] Michael J. Barron, "China's Strategic Modernization: The Russian Connection," *Parameters* 31, no. 4 (2001): 72-86.

The Chinese view the US Aircraft Carriers as a critical requirement to US strategy in the region and a major threat to Chinese aspirations in the region. The People's Liberation Army (PLA) Academy of Military Science stated: "an aircraft carrier is a colossus; it will undoubtedly be the main target in future sea battles."[44] As such the Chinese have tried to find ways to efficiently take the aircraft carriers out of the fight through discovering vulnerabilities. Their answer: the missile.[45]

The Chinese are aware of the defense provided by the AEGIS escorts and have elevated them to essential targets as well. They are hopeful that once the AEGIS escorts are removed the carrier will be much easier to destroy.[46] This logic has led the Chinese to utilize doctrine that involves large multi-axis ASCM attacks against CSGs and AEGIS escorts.[47]

The Arleigh Burke Destroyer's AEGIS based defense system has been the focus of Chinese researchers and strategists since even as early as June 2002. The Dalian Naval Academy studied the ability of an Arleigh Burke Class Destroyer to overcome an ASCM

[44] Liu Tonglin, *A Sharp Lance of Modern Naval Warfare* (Beijing: Military Science Press, 2003), 321.

[45] While the Chinese have developed both ASBMs and ASCMs, in the author's opinion, it is more likely that the Chinese will rely more heavily on ASCMs due to their abundance and advanced targeting capabilities.

[46] Yi Heng and Xin Hua, "Six Trump Cards to Cope with Aircraft Carriers," *World Outlook* 3 (February 2001): 60-61.

[47] Gormley, Erickson, and Yuan. "A Potent Vector," 98-105.

saturation.[48] Other research conducted by the Chinese discovered that if a missile could successfully avoid ship radar and could avoid detection from its electronic signature, then the missile had a high chance of hitting the ship.[49]

The Beijing University of Aeronautics and Astronautics reports to have "conducted extensive modeling and simulations studies regarding ASCM penetration."[50] These tests have claimed a success rate of 83 to 99 percent of hitting the intended target.[51] The Chinese claimed to have developed specialized techniques to deal with AEGIS defense, programming their missiles with complicated maneuvers such as the "snake" (side-to-side) and the "porpoise" (up-and-down) movements to confuse AEGIS, making it difficult for the system to pinpoint the incoming missile. Further studies conducted by the PLA Electronic Engineering Academy in developing techniques to hide missiles from defenses have had success as well, stating "[e]ven if they are discovered, the time left for defense systems to respond is very short, which makes interception

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48 Yan Zhongxi, Wang Gang, and Yang Zu-kuai, "An Analysis of the Antiship Missiles Saturation Attack Capability of an 'Arleigh Burke'-Class Destroyer," *Modern Defense Technology* 30, no. 3 (July 2002): 10-13.

49 Wang Tao and Kuang Zhikao, "The Stealth Technology of Anti-ship Missiles," *Modern Ships* (April 2005): 38.

50 Gormley, Erickson, and Yuan. "A Potent Vector," 98-105.

51 Qiang Yuxian, "Research on Integrated Penetration of the Anti-Ship Missile," *Journal of Beijing University of Aeronautics and Astronautics* 30, no. 12 (December 2004): 1212-1215.

difficult. By pre-set programs, they can go around fixed air defense positions and hit the targets from the side or from behind."[52]

China fully expects that the US will use their carrier fleet to respond to any threat to US interests, especially in cases involving Taiwan. Therefore, cruise missile sites have been placed in range of Taiwan in order to intercept carriers operating in the region and many of these missiles will come from shore-based systems. Cruise missiles may also be augmented with ASBM "carrier killers" on mobile launchers such as the Dong-Feng 21D that could penetrate missile defenses and stop the US fleet capacity to defend Taiwan.[53] The US is not blind to this threat and has placed Patriot batteries in Taiwan to help defend against such attacks. However, Chinese LACMs conceivably have the ability to destroy the Patriot batteries, and the ASCMs that are on a majority of Chinese ships and submarines have the capacity to destroy CSGs.[54]

The capabilities of ASCMs and LACMs help explain why the Chinese began employing these weapons at such a high rate in the last decade. As a result, "U.S. ASCMs are now outnumbered seven to one."[55] When compared to the United States' arsenal, the delta is unsettling. The United States fields only the Harpoon missile and not in large numbers, either.[56] However, new US developments are in the works with the Standard

[52] Tseng Fesheng, "America Considers Communist China's Counter-Intervention Strategy," National Policy Foundation, June 17, 2010, www.npf.org.tw/post/3/7677.

[53] Gormley, Erickson, and Yuan. "A Potent Vector," 98-105.

[54] Ibid.

[55] Ibid.

[56] Ibid.

Missile 6, Naval Strike Missile, and the Maritime Strike Tomahawk, among other initiatives such as the Long-Range Anti-Ship Missile.

In 2021, the Chinese have created a system to counter US approaches of mainland China as well as operations in the region. If a kinetic conflict arises and US forces move closer to the mainland, they will be in range of more and more deadly shore-based Chinese missiles. As the force continues to advance, they will have to contend with ASCMs. As a result, the US Navy will be unable to operate unopposed in this area.[57] If a war does break out, the US Navy will most certainly suffer damage and require sufficient repair capabilities to support both ongoing and post conflict force reconstitution requirements.

Importance of the Destroyer

In order to understand whether the United States has adequate repair facilities to support a war in the western Pacific, it is important to examine current naval warfare tactics, specifically related to the ship class at issue—the destroyer. This section provides a brief overview of the history of naval warfare tactics as it relates to the CSG and why ensuring the expeditious repair of destroyers is so vital to any war effort.

On December 7, 1941 the United States had eight active aircraft carriers and 11 keels laid.[58] The tactics governing these unique ships changed throughout their use in

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[57] Gormley, Erickson, and Yuan. "A Potent Vector," 98-105.

[58] Scot MacDonald, "Evolution of Aircraft Carriers," Naval History and Heritage Command, August 7, 2017, (originally published October 1962), 32, https://www.history.navy.mil/research/histories/naval-aviation-history/evolution-aircraft-carriers.html.

WWII. By the middle and end of the war, aircraft carriers were operating in carrier task forces, which involved multiple carriers working together. US Navy tactics grouped individual CSGs together to create strong offensive and defensive capabilities.[59]

However, aircraft carriers still required smaller ship escorts to defend from attack. During 1942, a single carrier had an escort of two cruisers and three destroyers.[60] Escorts were organized in a "wagon wheel" formation that formed a circle around the aircraft carrier. Movement of the force required all ships to change course at the same time and in the same direction while maintaining this circular structure. The escort ships created a "screen" that provided valuable air, surface, and submarine defenses. All ships were manufactured to maintain speeds of up to about 30 knots.[61]

By 1944, tactics had been refined. The Carrier Task Forces were composed of four heavy carriers with three to five cruisers and twelve to fourteen destroyers acting as escorts. At this point, carrier groups were easier to control while the escorts still provided all the necessary protection.[62] Throughout WWII, aircraft proved their superiority over battleship-centric warfare due to their longer range and improved accuracy in ordnance

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[59] MacDonald, "Evolution of Aircraft Carriers," 47.

[60] John Hamill, "Aircraft Carrier Tactics of world War II," John's Military History, accessed May 2, 2021, http://johnsmilitaryhistory.com/Aircraft CarrierTacticsofWorldWarII.html.

[61] Wayne P. Hughes, *Fleet Tactics* (Annapolis, MD: Naval Institute Press, 1986), 88-90.

[62] Donald MacIntyre, *Wings of Neptune* (New York: W. W. Norton, 1963), 255-256.

delivery against opposing forces. As a result, the aircraft carrier became the US Navy's dominate naval warfighting system.

After the end of WWII, the US Navy experimented with launching heavier aircraft off carriers. On May 5, 1948 fighter squadron 17-A became the first carrier qualified jet squadron.[63] The improvements continued. By 1954, the USS *Hancock* was equipped with the first steam powered catapult C-11, which allowed aircraft laden with more fuel and ordnance to launch. This provided even more range and firepower.[64]

By 1955, it was well understood that the older classes of carriers had reached their limit in terms of capability, innovation, and operational lifespan. Enter the USS *Forrestal* (CVA 59), the US Navy's first "supercarrier." Forrestal class ships measured 1,036 feet and had a displacement of 56,000 tons with an integrated angled deck. They carried up to 90 aircraft with large hangars and flight decks. The Kitty Hawk class were the next evolution of supercarriers after the Forrestal class, with improvements being made to the elevators and overall length when compared to the Forrestal class. Progress continued and in 1961 the USS *Enterprise* (the first nuclear powered aircraft carrier) was commissioned. Nuclear power greatly extended the Enterprise's range of operations and operational capability. The Enterprise was also fitted with a phased array radar. However, only one of this class was built due to rising construction costs.[65]

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[63] MacIntyre, *Wings of Neptune*, 255-256.

[64] Ibid.

[65] Analise Underwood, "Evolution of the Aircraft Carrier," Naval History and Heritage Command, April 12, 2015, https://usnhistory.navylive.dodlive.mil/2015/04/12/evolution-of-the-aircraft-carrier/.

Carrier development continued and in 1975 the first of the Nimitz class supercarriers were commissioned. Improvements included the Catapult Assisted Take-Off But Arrested Recovery system for increased speed during takeoff and recovery. An angled flight deck for simultaneous recoveries and launches, and an improved nuclear reactor, which allow the carrier to carry more fuel and more ordnance. Today there are a total of 10 active service Nimitz class carriers.[66]

In 2017 the US Navy commissioned the USS *Gerald Ford*, ushering in a new era of carrier warfare. Numerous improvements and enhancements allow the new class to operate more efficiently and effectively. Ford class carriers have a displacement of more than 90,000 tons, a length of 1,092 feet, ability to go 30 knots, support a crew of 4,297 personnel, and have an expected 50-year service life.[67]

However, like their predecessors, the Nimitz and Ford Class carriers still require escorts to provide protection. Today, escort configuration is extremely scalable and tailorable to the mission. Typical deployments of carriers will have them operate independently of other carriers; however, they remain more than capable of operating together. The modern CSG is typically escorted by one cruiser and a Destroyer Squadron of three to four Arleigh Burke class destroyers. Operating in sectors around the carrier, the same logic of the "wagon wheel" applies that provides vital Air defense, Surface defense, and Submarine defense. The major change since WWII was the introduction of AEGIS technology in 1983. This forms a protective shield around the carrier to guard

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[66] Underwood, "Evolution of the Aircraft Carrier."

[67] Ibid.

against threat interference with its operations. During flight operations, one of the destroyers will be tasked with "plane guard" duties, which requires the ship to remain at a certain angle and distance from the carrier to act as rescue ship, should one of the pilots crash into the ocean and to provide additional "line up lights" for the landing aircraft.[68]

Maintaining this protective shield is critical to the protection and force projection of the US Navy. However, ships break, rust, and crews require rest and re-training. In order to continue this shield and uphold force protection requirements for the Combatant Commanders, the US Navy mandates that ships participate in a life cycle schedule known as the Optimized Fleet Response Plan (OFRP).[69] The OFRP for an Arleigh Burke class destroyer is a 36-month cycle created to balance the maintenance and training for a seven-month deployment with a sustainment period built in where a ship or strike group could redeploy.[70]

The cycle also contains a 24-week Chief of Naval Operations Availability for maintenance and repair.[71] However, in recent years the Chief of Naval Operations

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[68] Maurice Joyce, "A Safer Way for Ships to Do Plane Guard," *Proceedings* (August 2018), https://www.usni.org/magazines/proceedings/2018/august/safer-way-ships-do-plane-guard.

[69] Office of the Chief of Naval Operations (CNO), OPNAV Instruction, 3000.15A, *Optimized Fleet Response Plan* (Washington, DC: Department of the Navy, November 10, 2014).

[70] Sam LaGrone, "Navy, DoD Conducting Parallel Reviews of OFRP," *USNI News*, January 16, 2020, https://news.usni.org/2020/01/16/navy-dod-conducting-parallel-reviews-of-ofrp.

[71] CNO, OPNAV Instruction, 3000.15A.

Availability has not been meeting its 24-week goal, and many ships have been exiting this stage in the cycle.[72]

These delays create ripple effects across the fleet and have caused the US Navy to update and amend the cycle.[73] Even with these delays the OFRP attempts to maintain the force to deploy quickly and keep ship's maintenance calculable.[74]

As such, the importance of the destroyer cannot be understated when it comes to current warfare tactics. If destroyers take on missile hits and are unable to be repaired in time to return to the fight such that their numbers are severely depleted, this will leave the carriers more vulnerable and put victory at risk.

A modern example of the importance of the destroyer in a conflict is the Falklands War. While the United States was not directly involved in the Falklands War, it is still worth discussing, as it is the only modern Naval war that saw the regular use of missile technology. The conflict itself lasted only ten weeks and was waged between Argentina and the United Kingdom in 1982 over a dispute regarding two British

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[72] US Government Accountability Office, "Navy Ship Maintenance: Evaluating Pilot Program Outcomes Could Inform Decisions to Address Persistent Schedule Challenges" (Report to Congressional Committee, Government Accountability Office Washington, DC, May, 2020).

[73] Eckstein, "Navy Issues Revision to OFRP Deployment Schedule."

[74] Megan Eckstein, "GNO Gilday Defends 36-Month Carrier Cycle, Says Navy Has Never Missed a Deployment," *USNI News*, March 2, 2020, https://news.usni.org /2020/03/02/cno-gilday-defends-36-month-carrier-cycle-says-navy-has-never-missed-a-deployment#more-74034.

territories in the South Atlantic.[75] The specifics of the War are worth reviewing as the rate and type of damage the vessels received is critical to understanding what types of damage vessels might receive in a modern conflict involving missile technology.

A total of eight Type 42 Destroyers participated in the war. Each were relatively similar in displacement and mission when compared to an Arleigh Burke Destroyer. Out of the eight, two were ultimately sunk, three were damaged, and three were unharmed.[76]

The Destroyer, HMS *Coventry*, was sunk by Argentine Skyhawks on May 25. However, before it was sunk, the HMS *Coventry*'s Lynx helicopters fired the first Air-Surface Anti-Ship missiles and was the first to fire Sea Dart surface-air missiles in action. During the conflict, the HMS *Conventry* conducted anti-air defense with the carrier battle group, Task Group 317. On May 25, the HMS *Coventry* was attacked by two waves of Argentine Douglas A-4 Skyhawks carrying bombs. The attack was successful and three bombs struck on the port side. Within 20 minutes, the ship had been abandoned, capsized, and eventually sank. Nineteen crewmembers died and 30 were injured in the attack. The rescue of the rest of the crew was conducted by the HMS *Broadsword*.[77]

The HMS *Sheffield*, a Type 42 guided missile destroyer, did not share the exact same fate as the HMS *Coventry*. During the conflict the HMS *Sheffield* took part in Task Force 317. On May 4, the HMS *Sheffield* was hit by an Exocet missile fired from

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[75] Kenneth G. Weiss, "The War for the Falklands: A Chronology" (Professional Paper, Center for Naval Analyses, Alexandria, VA, August 1982), https://apps.dtic.mil/dtic/tr/fulltext/u2/a153614.pdf.

[76] Ibid.

[77] David Dyke, *Four Weeks in May* (London: Atlantic Books, 2007).

Argentine Super Etendards.[78] Twenty crewmembers died due to the explosion and subsequent fires. Six days later, the HMS *Sheffield* sank due to flooding caused by high seas.[79]

The HMS *Glamorgan* was a County-class destroyer of the Royal Navy. Unlike the HMS *Sheffield*, which sunk, an MM-38 Exocet missile hit the *Glamorgan* but it survived.[80] The impact occurred on June 12, 1982 at 0637.[81] Ahead of the strike, the *Glamorgan* executed a highspeed turn away from the missile, but the missile still succeeded in striking the port side near the stern, resulting in a 10 by 15-foot hole in the hangar deck.[82] The resulting fires were extinguished and the ship was underway again by 1000.[83] Following the end of the War, the *Glamorgan* underwent repairs from July of 1982 through 1983 until it was deployed in November of 1983.[84]

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[78] BBC News, "1982: Argentines destroy HMS Sheffield," *BBC*, May 4, 1982, http://news.bbc.co.uk/onthisday/hi/dates/stories/may/4/newsid_2504000/2504155.stm.

[79] Commander in Chief, "Loss of HMS Sheffield," National Archives, May 28, 1982, https://webarchive.nationalarchives.gov.uk/20121109063631/http://www.mod.uk/NR/rdonlyres/9D8947AC-D8DC-4BE7-8DCC-C9C623539BCF/0/boi_hms_sheffield.pdf.

[80] Ian Inskip, *Ordeal by Exocet: HMS Glamorgan and the Falklands War* (S. Yorkshire: Frontline Books, 2012), 160-185.

[81] Ibid.

[82] Ibid.

[83] Ibid.

[84] Helis, "D19 HMS Glamorgan," accessed October 15, 2020, https://www.helis.com/database/unit/63-HMS-Glamorgan/.

HMS *Glasgow*, another Type 42 destroyer, saw early action on May 2, the Lynx helicopter badly damaged the Argentine naval vessel Alferez Sobral. On May 12, *Glasgow* and the Type 22 frigate Brilliant were working together to defend from aircraft attacks. The ships were attacked by four A-4B Skyhawk jets. The HMS Brilliant's Sea Wolf missiles were able to shoot multiple aircraft during the first wave. When a second wave of Skyhawks attacked, a bomb was dropped and damaged the HMS *Glasgow's* fuel systems and disabled the two Tyne cruise engines. Damage control teams stabilized the damage and the HMS *Glasgow* returned home for repairs and did not return until the conflict was over.[85]

At the beginning of the Falklands war the HMS *Antrim*, a County-class destroyer, was one of the main command and control platforms during Operation Paraquet, which was a British operation to take back the island of South Georgia from Argentine military control.[86] During the war, the HMS *Antrim*'s helicopter was responsible for the rescue of 16 British SAS troopers and played a key role in the detection and disabling of an Argentinian submarine. During the landing at San Carlos Water, multiple bombs were dropped on the location and missed. One bomb did penetrate the hull, but did not

[85] Stephen Luscombe, "The Falklands War: HMS Antrim," The British Empire, accessed February 18, 2021, https://www.britishempire.co.uk/forces/armycampaigns/southamerica/falklands/antrim.htm.

[86] Naval History, "PRELIMINARY BRITISH OPERATIONS (Parts 20-30) Part 22. SOUTH GEORGIA RETAKEN Operation 'Paraquet'," May 31, 2013, https://www.naval-history.net/F32-South_Georgia_retaken-Paraquat.htm.

explode. It took the crew of the HMS *Antrim* ten hours to remove the bomb from the interior of the ship.[87]

During the war, the HMS *Bristol*, a Type 82 destroyer, launched Sea Dart missiles without success in defense of the carrier battle group, Task Group 317. On May 25, HMS *Bristol* took over HMS *Coventry*'s anti-aircraft role after it was lost. During the end of the war the HMS *Bristol* was used as a flagship when the HMS *Hermes* departed until September 17. The HMS *Bristol* did not receive any damage throughout the war. After the war, it was refitted with updated armaments based on lessons learned from the conflict.[88]

The type 42 destroyer, HMS *Exeter*, was never damaged during the Falkland war. However, the HMS *Exeter* saw action on May 30 and shot down two Argentine aircraft and another on June 7 all with their own Sea Dart Missiles.[89]

The Type 42 destroyer HMS *Cardiff*, saw action early in the war as well. On May 22, an Argentine reconnaissance plane was fired on by the HMS *Cardiff*. The HMS *Cardiff* fired two Sea Darts at the aircraft, however, both of the missiles missed. Throughout the conflict the HMS *Cardiff*'s primary role was anti-aircraft defense and shore bombardment. On June 6, in a regrettable action, the HMS *Cardiff* accidently shot

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[87] Stephen Luscombe, "The Falklands War: HMS Glasgow," The British Empire, accessed February 18, 2021, https://www.britishempire.co.uk/forces/armycampaigns /southamerica/falklands/glasgow.htm.

[88] Seaforces, "D-23 HMS Bristol," *Seaforces Online*, accessed February 18, 2021, http://www.seaforces.org/marint/Royal-Navy/Destroyer/D-23-HMS-Bristol.htm.

[89] Seaforces, "D-89 HMS Exeter," Seaforces Online, accessed February 18, 2021, http://www.seaforces.org/marint/Royal-Navy/Destroyer/D-89-HMS-Exeter.htm.

down a friendly Army helicopter. On the morning of June 13, HMS *Cardiff* shot down the last Argentine aircraft to be lost during the war with a Sea Dart missile. Toward the end of the conflict, the HMS *Cardiff* accepted the surrender of an Argentine garrison. By the war's end, HMS *Cardiff* did not receive any damage and fired a total of nine Sea Dart missiles and one Mk 46 torpedo.[90] A summary of the damage each ship received and its ultimate fate is included in Chapter 4, Table 7.

History of US Ship Repair Industry

The United States' ship repair industry is heavily linked with the shipbuilding industry. Relevant to this thesis are shipyards that are capable of repairing missile damage. Potentially, ships hit by missiles will require dry docking or a least pier facility that are capable of major repair. Generally, yards capable of major repair have a dry-dock capability. However, it is worth noting that the damage caused will depend heavily on the type of missile, its trajectory, point of entry, and its flight path. As such, it is important to understand the history of shipbuilding as well as ship repair in the United States.

The ship repair industry traces all the way back to colonial times from the arrival of the colonists to the new world. Starting in 1631 with the launching of "Blessing of the Bay" in Massachusetts, American shipbuilding and ship repair has been a strong industry, producing merchant vessels and even warships for the Royal Navy.[91]

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[90] Seaforces, "D-108 HMS Cardiff," Seaforces Online, accessed February 18, 2021, http://www.seaforces.org/marint/Royal-Navy/Destroyer/D-108-HMS-Cardiff.htm.

[91] Robert M. Brown, "The United States Shipbuilding and Ship Repair Industry: Adequate for Prolonged Global Conflict" (Master's Thesis, US Army Command and General Staff College, Fort Leavenworth, KS, 1989), 27.

During the lead up to the American Revolution, the Continental Congress attempted to construct a Navy, but its efforts were plagued with difficulties.[92] The most obvious difficulties were financing a new fleet,[93] lack of blueprints, shortages in equipment and lack of skilled labor.[94] Despite this, American ship design produced faster and more agile ships than their British counterparts, which would play a role in the Revolution.[95]

Shipyards became targets of attack for the British during the American Revolution. For example, the Gosport Shipyard (now known as the Norfolk Naval Shipyard), founded by Andrew Sprowle, was destroyed during the Revolution. During the war, Sprowle remained loyal to the Crown and fled. The Commonwealth seized the shipyard, which British forces ultimately burned.[96]

Fast forward to the industrial revolution and many American shipyards found the transition from wooden sailing ships to iron, steam powered ships, to be difficult.[97] While the Civil War provided some lift to shipyards across the nation, by the end of the

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[92] Brown, "The United States Shipbuilding and Ship Repair Industry," 30.

[93] Ian W. Tolls, *Six Frigates* (New York: W. W. Norton, 2006), 67.

[94] Brown, "The United States Shipbuilding and Ship Repair Industry," 30.

[95] Ibid., 31.

[96] Robert Nobles, "Norfolk Naval Shipyard," Navel Sea Systems Command, September 18, 2012, https://www.navsea.navy.mil/Home/Shipyards/Norfolk/About-Us/History/.

[97] Brown, "The United States Shipbuilding and Ship Repair Industry," 33.

war, shipyards were in a precarious position, with many of them unable to compete on a global stage.[98]

The quarter century before the outbreak of World War I (WWI) saw the first large US peacetime naval building program which provided support to the American ship building and repair industries.[99] Between 1885 and 1895, the Naval Advisory Board slated thirty modern naval vessels to be constructed.[100] This led to an increased demand in the repair market, which was a welcome relief for a struggling industry.

The beginning of WWI exposed many issues with American shipyards. When the war started, there were only 61 private shipyards, employing 45,000 workers, with 235 building ways capable of constructing oceangoing merchant vessels.[101] In 1916, President Wilson convinced Congress to accept an act establishing a five-member shipping board (the USSB). This placed shipyards under government control as an emergency and temporary situation during the war. However, it was not until 1917, and the formation of the War Industries Board, that the industry became more stabilized.

Under the War Industries Board, the government had built 158 shipyards, blooming the total number of available shipyards to 341, employing 380,000 workers on

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[98] Brown, "The United States Shipbuilding and Ship Repair Industry," 35.

[99] Ibid., 36.

[100] Ibid.

[101] Ibid., 38.

1,284 build ways.[102] By the end of the war, American shipyards had constructed 2,312 ships at 13.6 million tons.[103]

With the war ending, the United States no longer needed to maintain such a massive fleet. The passing of the Merchant Marine Act in 1920, more commonly known as the Jones Act, provided for these many government owned vessels to be sold off. However, the Jones Act also provided for the maintenance of American shipyards through: (1) federal mortgage guarantees for US made vessels; (2) a $25 million construction loan fund; and (3) the reinstatement of the requirement that US built, owned and crewed ships carry all US domestic trade.[104]

Despite these efforts, the depression following the war forced the closure of many shipyards, leaving only the largest still in operation. These were Newport News Shipbuilding, Bethlehem Steel, Electric Boat, and Bath Iron Works.[105] With no need for shipbuilding, these yards were kept afloat through repair jobs. Even still, by 1937, only ten shipyards with a total of 46 build ways existed in the United States, employing 60,000 workers.

The election of President Roosevelt and the establishment of the Maritime Commission in 1936 did a great deal to enliven American shipyards. This was needed,

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[102] Brown, “The United States Shipbuilding and Ship Repair Industry,” 40.

[103] Ibid., 41.

[104] Ibid., 43.

[105] Ibid., 43-44.

because in just two years, the German invasion of Poland would call upon the resources of American shipyards in a way that had never been tested.

By 1937, the number of American shipyards had increased from its low of ten to 19, yet this still was not enough to meet increasing demands.[106] By 1941, the United States government financed the construction of nine shipyards with 65 building ways. By 1945, 80 shipyards were producing ships on 300 building ways.[107]

Along with a rapidly expanding number of shipyards came a rapidly expanding number of job opportunities. In June of 1939, private shipyards employed 80,000 workers. By the attack on Pearl Harbor, the workforce had swelled to 500,000 workers and reached its peak in November of 1943 at 1,459,000.[108] More incredible than the sheer numbers was the rise in productivity. It is estimated that the "1,800 percent increase in workers was accompanied by an almost 5,200 percent rise in productivity."[109]

The assimilation of large amounts of new workers brought with it new problems. Shipyards adjusted training so that tasks were broken into easily taught, repeatable actions that could be replicated. This allowed shipyards to train workers in much less time, roughly one month for a common welder.[110] Long working hours also contributed

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[106] Brown, "The United States Shipbuilding and Ship Repair Industry," 47.

[107] Ibid.

[108] Ibid., 49.

[109] Ibid.

[110] Ibid., 51.

to a high turnover rate amongst workers, averaging about 10 percent per month.[111] Strikes and "pirating" of workers with higher wages led to the formation of the Shipbuilding Stabilization Board.[112] The Shipbuilding Stabilization Board's management created rules around labor strikes and employer lockouts and established wage scales throughout the country.[113]

The United States' shipbuilding industry, and thus American shipyards, saw a steady decline in the years following WWII. At the end of the War, the Navy terminated or cancelled all new ship construction contracts.[114] In 1972, a report demonstrated that ships built in Naval Shipyards cost roughly 30 percent more than ships built by commercial shipyards.[115] As a result, all Naval shipbuilding ceased and five of the nine remaining Navy-operated shipyards closed.[116]

Commercial shipyards did not fare much better during this time. In the 64 years following Eisenhower's election, the number of active shipyards capable of building oceangoing naval ships of at least 400 feet in length decreased drastically, from over 30 to just 9 (3 of which are not active in the market).[117]

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[111] Brown, "The United States Shipbuilding and Ship Repair Industry," 51.

[112] Ibid., 52.

[113] Ibid.

[114] Tim Colton, "Shipbuilding History," Shipbuildinghistory.com, accessed October 17, 2020, https://www.shipbuildinghistory.com/.

[115] Ibid.

[116] Ibid.

[117] Ibid.

Not only has the number of shipyards declined since the end of WWII, but the workforce has as well. Data from the Bureau of Labor Statistics reveals that since the 1980s, the shipyard labor force has shrunk significantly. Revenue from repairs has also remained relatively stagnant when adjusted for inflation since the 1980s.[118] While wages have stayed relatively stable compared to the Adjusted Gross Revenue, there have not been any significant positive trends that would attract workers to the industry.

A complete tabulation of workforce and facilities statistics are included in Appendixes A and B, respectively.

Ship Repair Industry Past Efforts

Missile technology is relatively recent when compared to the history of all naval warfare. As a result, the USS *Stark* and USS *Boston* are the only US Naval vessels that have been hit by missiles. Even still, the United States has had to contend with repairing ships with the sort of damage one would expect from a direct missile hit ("Missile Like Damage"). Below is an overview of ships that suffered missile-like damage and their RTs.

The USS *Savannah* was hit in Turret III by an early archetype of the air-to-surface missile: the radio-controlled Nazi Fritz X glide bomb.[119] The USS *Savannah* took eight

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[118] Colton, "Shipbuilding History."

[119] Robert J. Cressman and Mark L. Evans, "Savannah IV (CL-42)," Naval History and Heritage Command, December 6, 2018, https://www.history.navy.mil/research/histories/ship-histories/danfs/s/savannah-iv.html.

months (December 23, 1943 to September 4, 1944) to repair in the Philadelphia Navy Yard before being placed back into active service.[120]

The USS *Colombia* was damaged by multiple Kamikaze attacks, the final Kamikaze attack that took it out of the fight, resulted in a 551lbs bomb exploding on the forward superstructure in addition to the Japanese aircraft impact.[121] The USS *Colombia* took five months to upgrade and repair (January 12, 1945 to May 15, 1945), sharing the time between San Pedro Bay in Leyte Gulf, the Hawaiian Islands, and San Pedro in California.[122] The USS *Colombia* returned to active service and continued to fight in the Pacific theater of war against the Japanese.[123]

The USS *Boston* was a guided missile cruiser that was in service from 1943 through 1970. On June 16, 1968, while conducting naval gunfire against North Vietnamese targets, in company with Australian guided missile destroyer HMAS Hobart, the USS *Boston* was accidentally attacked by a US Air Force jet aircraft from the 366th TFW. Two Australian sailors were killed, and minor damage occurred to both warships.[124]

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[120] Cressman and Evans, "Savannah IV (CL-42)."

[121] Gregory N. Stern, "Columbia VI (CL-56)," Naval History and Heritage Command, March 5, 2020, https://www.history.navy.mil/research/histories/ship-histories/danfs/c/columbia-vi.html.

[122] Ibid.

[123] Ibid.

[124] NavySite.de. "USS Boston (CAG 1)," accessed February 17, 2021, https://www.navysite.de/cg/cag1.htm.

The USS *Arthur W. Radford* was a Spruance-class destroyer in service from 1977 through 2003. On February 4, 1999, the USS *Arthur W. Radford* collided with a container ship as it was preparing to enter the Chesapeake Bay. When the ships collided, the container ship struck the USS *Arthur W. Radford's* starboard side, creating a large circular gash from the main to the waterline. The repairs of the USS *Arthur W. Radford* required $32.7 million and seven months to complete at the Norfolk Naval shipyard.[125]

The USS *Kinkaid* was a Spruance-class destroyer that was in service from 1976 through 2003. In November of 1989, while returning from an Arabian Gulf deployment, the USS *Kinkaid* collided with another ship in the Strait of Malacca. The subsequent fire caused major damage, which cost $15 million and 12 months to repair.[126]

The USS *Belknap* was the lead ship of the Belknap class of guided missile cruisers. It was in service from 1963 through 1995. On November 22, 1974, the Belknap was involved in a collision with the USS *John F. Kennedy* when the two ships collided due to rough seas during air exercises. Due to its topside aluminum construction, the USS *Belknap* suffered serious damage and underwent repairs that started in 1976 and lasted four years. It did not rejoin the fleet until 1980.[127]

The USS *Stark* was an Oliver Hazard Perry class of guided missile frigates. On the evening of May 17, 1987, the USS *Stark* was hit by two Exocet missiles fired from an

[125] NavySite.de, "USS Radford (DD 968)," accessed February 17, 2021, https://www.navysite.de/dd/dd968.htm.

[126] NavySite.de, "USS Kinkaid (DD 965)," accessed February 17, 2021, https://www.navysite.de/dd/dd965.htm.

[127] NavySite.de, "USS Belknap (CG 26)," accessed February 17, 2021, https://www.navysite.de/cg/cg26.htm.

Iraqi F-1 Mirage fighter.[128] The two missiles hit roughly in the exact same location near the port bridge wing.[129] The USS *Stark* took 10 months (November 1, 1987 to August 30, 1988) to complete repairs at Ingalls Shipbuilding, Pascagoula in Mississippi with a budget of $142 million dollars.[130] The USS *Stark* returned to active service and was later scrapped in 2006.[131]

The USS *Cole* was damaged by an alongside improvised bomb on August 8, 2000, when refueling in the Port of Yemen.[132] Two Al-Qaeda terrorists were able to bring an explosives laden small vessel alongside *Cole*'s portside amidships where the resultant blast created a 40-foot-wide hole and penetrated deep into the ship.[133] The USS *Cole* arrived at Northrop Grumman Corporation's Ship Systems on December 13, 2000,

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[128] Chairman, Joint Chiefs of Staff, *Formal Investigation into the Circumstances Surrounding the Attack on the USS (FFG 31) on 17 May 1987 (U)* (Washington, DC: Department of Defense, 1987), 1.

[129] Ibid., 8.

[130] Sam LaGrone, "The Attack on USS Stark at 30," *USNI News*, May 17, 2017, https://news.usni.org/2017/05/17/the-attack-uss-stark-at-30.

[131] Naval Vessel Register, "Stark (FFG 31)," accessed March 2, 2021, https://www.nvr.navy.mil/SHIPDETAILS/SHIPSDETAIL_FFG_31.HTML.

[132] Naval History and Heritage Command, "USS *Cole* (DDG-67)," October 18, 2020, https://www.history.navy.mil/content/history/nhhc/browse-by-topic/ships/modern-ships/uss-cole.html.

[133] Ibid.

and left 14 months later on April 19, 2002.[134] According to the Naval History and Heritage Command the total cost of repair was $243 million dollars.[135]

The USS *Porter* was an Arleigh Burke class guided missile destroyer. It was commissioned in 1999 and remains in service today. On August 12, 2012, the USS *Porter* collided with an oil tanker in the Strait of Hormuz. The *Porter* suffered extensive damage to the forward starboard hull.[136] It took an estimated $50 million and 12 months to repair.[137]

A more modern example was the USS *Fitzgerald*. A collision off the cost of Japan with the commercial container ship, the ACX Crystal, heavily damaged the USS *Fitzgerald* on June 17, 2017.[138] ACX Crystal collided with the DDG creating a hole

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[134] Jim McIngvale, "USS Cole Returns to U.S. Navy Fleet Following Restoration by Northrop Grumman," Huntington Ingalls Industries, April 19, 2002, https://newsroom.huntingtoningalls.com/releases/uss-cole-returns-to-u-s-navy-fleet-following-restoration-by-northrop-grumman.

[135] Raphael Perl, "Terrorist Attack on USS Cole," Naval History and Heritage Command, May 13, 2020, accessed October 20, 2020, https://www.history.navy.mil /research/library/online-reading-room/title-list-alphabetically/t/terrorist-attack-on-uss-cole-background-and-issues-for-congress.html.

[136] NavySite.de, "USS Porter (DDG 78)," accessed February 17, 2021, https://www.navysite.de/dd/ddg78.htm.

[137] US Carriers, "USS Porter," accessed February 17, 2021, http://www.uscarriers.net/d"dg78history.htm.

[138] Office of the Chief of Naval Operations, *Report on the Collision between USS Fitzgerald (DDG 62) and Motor Vessel ACX Crystal and Report on the Collision between USS John S. McCain (DDG 56) and Motor Vessel ALNIC MC* (Washington, DC: Department of the Navy, October 2017), https://www.secnav.navy.mil/foia/reading room/HotTopics/CNO%20USS%20Fitzgerald%20and%20USS%20John%20S%20McCain%20Response/CNO%20USS%20Fitzgerald%20and%20USS%20John%20S%20McCain%20Response.pdf.

forward of amidships on the starboard side of the main superstructure, also causing a penetration below the waterline causing flooding and extensive damage.[139] The USS *Fitzgerald* was taken to Ingalls Shipbuilding in Pascagoula, Mississippi on January 19, 2018, and 30 months later departed for an underway to its new homeport in San Diego June 13, 2020.[140] The USNI reported the total cost of repairs at $327 million dollars.[141]

The final case is the USS *McCain*. On August 21, 2017, the USS *McCain* collided with the tanker Alnic MC.[142] It suffered a puncture in the port side, at the waterline, which resulted in flooding into the crew berthing.[143] USS *McCain* entered into Yokosuka Naval Shipyard dry dock on December 13, 2017, and left 22 months later on October 21, 2019.[144] The total cost of repairs was estimated at $233 million dollars.[145]

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[139] Office of the Chief of Naval Operations, *Report on the Collision between USS Fitzgerald (DDG 62) and Motor Vessel ACX Crystal and Report on the Collision between USS John S. McCain (DDG 56) and Motor Vessel ALNIC MC*.

[140] LaGrone, "Navy, DoD Conducting Parallel Reviews of OFRP."

[141] Sam LaGrone, "USS Fitzgerald Leaves Mississippi Drydock After More Than a Year of Repairs," *USNI News*, April 16, 2019, https://news.usni.org/2019/04/16/uss-fitzgerald-leaves-mississippi-drydock-after-more-than-a-year-of-repairs.

[142] Office of the Chief of Naval Operations, *Report on the Collision between USS Fitzgerald (DDG 62) and Motor Vessel ACX Crystal and Report on the Collision between USS John S. McCain (DDG 56) and Motor Vessel ALNIC MC*.

[143] Ibid.

[144] Gidget Fuentes, "USS John McCain Back to Operations Almost 3 Years After Fatal Collision," *USNI News*, June 16, 2020, https://news.usni.org/2020/06/16/uss-john-mccain-back-to-operations-almost-3-years-after-fatal-collision.

[145] Ibid.

Current Status of the Ship Repair Industry

As discussed, historically the US navy shipbuilding and ship repair industry has played a critical role in the maintenance and upkeep of the US Naval fleet in war and in peace time. However, today it is struggling to uphold its legacy. In 2018, only 24 percent of ships completed their maintenance availability on time.[146] Highlighted in 2019 and in January 2020, Chief of Naval Operations Adm. Michael Gilday stated that repetitive delays in the shipyards was damaging the Navy's OFRP cycle and fixing it was critical. "We are getting 35 to 40 percent of our ships out of maintenance on time: that's unacceptable," Gilday said at the USNI Defense Forum. "I can't sustain the fleet I have with that kind of track record."[147]

The problem stems from overuse and extended use of the Naval assets in contrast to expected budgeted norms and timeframes. Due to increased demand for limited US naval vessels for various missions across the world, ships are out longer than the usual seven months (ranging from nine to ten months). During that time more equipment breaks and more wear on hulls is sustained. This greater time at sea leads to what the industry calls "growth work" where more work and repairs are required or discovered during the maintenance phase that needs to be repaired than what was previously budgeted at the start of the availability.[148] Shipyards and OFRP schedules as they operate

[146] David B. Larter, "Is the US Navy Winning the War on Maintenance Delays?" *Defense News*, September 20, 2020, https://www.defensenews.com/naval/2020/09/19/is-the-us-navy-winning-the-war-on-maintenance/.

[147] Ibid.

[148] Ibid.

now with their current budgets and infrastructure are not equipped to sustain these increased mission timeframes and increased repair costs which puts strain on the OFRP system when ships are delayed due to their growth work. These delays lead Fleet Forces Commander Adm. Chris Grady to summarize in 2020 that "Last year, we averaged 110 days delayed per ship in private avail[ability]."[149]

However, the United States Navy is not going to let these trends continue and as stated by Capt. Dave Wroe, US Fleet Forces Command's deputy fleet readiness officer improvements are being made. "On-time ship maintenance availability completion rates in private shipyards improved to 37% in FY19 . . . [with] current performance trends in FY20 projected to be 65%."[150] Wroe continues on, stating that the recent COVID-19 outbreak has not derailed efforts. "Things are much better this year—even with COVID-19. . . . We go from about one-third avails finishing on-time to two-thirds. That is great. But, again, each delay has real impact on our readiness, and we need to keep working together to do better."

Even though the OFRP is at the center of this issue, however, it is not the problem as stated by Fleet Forces Commander Grady in 2020. "My bottom line here is that, as a process, OFRP works. . . . If we are looking where to improve upon it, each of these studies came to the same conclusion: the biggest inhibitor to fleet readiness is

[149] Larter, "Is the US Navy Winning the War on Maintenance Delays?"

[150] Ibid.

maintenance and modernization performance in the shipyards. We simply must get better, and I know you share my concern."[151]

For ships powered by nuclear systems budget cuts were an even bigger blow causing even more delays.[152] In addition, the US Government Accountability Office report in 2020 highlighted that delays exists in Submarine and Aircraft Carrier yards: "75% of planned maintenance periods were completed late for aircraft carriers and submarines in FY 2015-2019, with an average delay of 113 days for carriers and 225 days for submarines." The report highlighted two major reasons are growth work and workforce performance and capacity.[153] For both non-nuclear and nuclear powered ships, the Government Accountability Office also stated that other factors like starting maintenance periods on time, imprecise estimates of the length of the availability, transparency by the US Navy into the capacity of shipyards, and finally with restrictions in place of a one year availability on appropriations add to delays.[154] Finally, the Government Accountability Office report continues to point out that the "the Navy incurred 3,096 days of maintenance delay through June of fiscal year 2020 on surface

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[151] Larter, "Is the US Navy Winning the War on Maintenance Delays?"

[152] Ibid.

[153] US Government Accountability Office, "Navy Report Did Not Fully Address Causes of Delays or Results-Oriented Elements" (Report to Congressional Committes, Government Accountability Office, October 2020).

[154] Mallory Shelbourne, "GAO: Navy Needs to Consider More Factors to Better Understand Ship Maintenance Delays," *USNI News*, November 4, 2020, https://news.usni.org/2020/11/04/gao-navy-needs-to-consider-more-factors-to-better-understand-ship-maintenance-delays.

ship . . . likewise, the Navy incurred 730 days of maintenance delay through June of fiscal year 2020 on aircraft carriers and submarines at public shipyards."[155]

These delays have not gone unnoticed by Congress. Ranking Republican on the House Armed Services sea power and projection forces subcommittee and Virginia Representative Rob Wittman stated in 2020 that "Navy ships that can't regularly deploy due to maintenance delays aren't worth much . . . and if those ships aren't at sea, they aren't sending the right message to U.S. adversaries. . . . We can have the greatest ships in the world, from our nuclear aircraft carriers to our submarines to our destroyers. . . . But if we can't keep them on a regular cycle of being deployed, then they're not worth much."[156] These delays impact American presence aboard, national goals, and ability to deter enemies according to Wittman "[t]hat creates problems for the United States, especially when it is critically important that we have presence around the world to deter our enemies. . . . If our ships aren't there, that sends a signal to our adversaries about where we are and our seriousness concerning the United States Navy."[157]

Representative Wittman listed changes that need to occur in Navy shipyards to include increases in capacity, updating infrastructure new workspaces and upgraded technology, attracting young people to work in these shipyards, and finally keep senior

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[155] Shelbourne, "GAO: Navy Needs to Consider More Factors to Better Understand Ship Maintenance Delays."

[156] Diana Stancy Correll, "Ship Maintenance Delays Are Jeopardizing National Security, Congressman Says," *Navy Times*, September 30, 2020, https://www.navytimes.com/news/your-navy/2020/09/30/ship-maintenance-delays-are-jeopardizing-national-security-congressman-says.

[157] Ibid.

personnel who are experienced. "If you have a less experienced workforce, you're going to have more hiccups in how the work gets done" states Wittman.[158]

In response to the growing demands to revitalize its industry the Navy in 2018 created the Shipyard Infrastructure Optimization Program which adds $21 billion into modernizing infrastructure over 20 years.[159] The overall aim of the program centers around repairing dry docks, updating shipyard facilities, and replacing and refurbishing old equipment.

The looming Great Power Competition is driving a majority of these changes. According to a 2020 Department of Defense report given to Congress reported that China is the "top ship-producing nation in the world by tonnage and is increasing its shipbuilding capacity and capability for all naval classes."[160] Representative Wittman is concerned by China's growing capability in relation to our own. "[It's] worrisome because if we do have an extended conflict, there is going to be damage and attrition. . . . If our yards don't have the ability to get ships back to sea, or even to produce additional ships if it's an extended conflict, and China does, that gives them an overwhelming superiority in the conflict and it doesn't bode well for us."[161]

Another driver is the realization that the US does not possess the capabilities that the US did in WWII. Many bases and shipyards have closed in recent years. However,

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[158] Correll, "Ship Maintenance Delays Are Jeopardizing National Security, Congressman Says."

[159] Ibid.

[160] Ibid.

[161] Ibid.

the loss of WWII capabilities did not happen overnight, but has been a gradual process. The Federal Property and Administrative Services Act of 1949 created a process known as Base Realignment and Closure where a number of military installations were closed.[162] Base Realignment and Closure was instituted following WWII and accelerated following the end of the Cold War.

Six rounds of closures have been completed resulting in a loss of more than 350 installations since 1988.[163] Naval stations have certainly been affected by Base Realignment and Closure with the following Naval facilities being shut down or realigned: Portsmouth Navy Yard (1965), Brooklyn Navy Yard (1965), Naval Station Galveston (1988), Naval Station Lake Charles (1988), Naval Station New York (1988), Naval Station Puget Sound (1988), Naval Station San Francisco (Realignment, 1988), New Orleans Military Ocean Terminal (1988), Naval Station Long Beach (1991), Naval Station Philadelphia (1991), Naval Station Puget Sound (1991), Naval Air Weapons Station China Lake (Realignment 1991), Philadelphia Naval Yard (1991), Naval Station Charleston (1993), Naval Station Mobile (1993), Naval Station Staten Island (1993), Naval Station Treasure Island (1993), Naval Supply Center, Oakland (1993), Naval Shipyard, Long Beach (1995), Naval Surface Warfare Center Dahlgren Division (1995).[164]

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[162] Secretary of Defense, *Base Closure and Realignment Report* (Washington, DC: Government Printing Office, 2005), https://www.acq.osd.mil/brac/.

[163] Congressional Research Service (CRS), *Base Closure and Realignment (BRAC): Background and Issues for Congress* (Washington, DC: Congressional Research Service, 2019).

[164] CRS, *BRAC.*

The public sector is not alone, the private sector has also experienced closures and realignments. Most recently, the BAE Systems Hawaii Ship Repair site located on the Pearl Harbor Naval Base closed its doors to ship repair in the first quarter 2021.[165] BAE Systems in Hawaii is the largest private sector repair facility in the state.[166] The author finds this troubling for a number of reasons. First, the Pacific Ocean is large and Hawaii is an excellent midpoint for travel. If a war does break out in the Pacific, ships will have to travel farther to be repaired if the Pearl Harbor Naval Base is unable or at capacity to assist. This will no doubt lengthen the time before the ship can return back to the fight. Second, building and resourcing locations like Hawaii is difficult and expensive due to its position in the ocean. When the facility falls out of repair, it will be expensive to revamp it in case it is needed again.

The decision to close the base cited by BAE was due to the US Navy changing its contracting procedures. Originally the US Navy used a Multi-Ship Multi-Option, however, it has recently changed to Multiple Award Contracts—Indefinite Delivery, Indefinite Quantity which would allow the US Navy to control costs with firm fixed pricing.[167] The reasoning behind this change is that the US Navy wants to lower costs and reduce the number of ships waiting to undergo maintenance, a third-party contractor

[165] Nick Blenkey, "BAE Systems Ship Repair to cease Pearl Harbor Operations in 2021," *Marine Log*, December 25, 2019, https://www.marinelog.com/shipyards/shipyard-news/bae-systems-ship-repair-to-cease-pearl-harbor-operations-in-2021.

[166] Ibid.

[167] Ben Werner, "BAE Systems Shuttering Pearl Harbor Maintenance Operation," *USNI News*, December 24, 2019, https://news.usni.org/2019/12/24/bae-systems-shuttering-pearl-harbor-maintenance-operation.

to identify and plan the work, and increase competition opportunities to help save the taxpayer money.[168] With firm fixed pricing, prices remain constant despite contractor performance.[169] The facility officially closed in March of 2021 which expected to be permanent impacting all 290 employees.[170]

The island of Guam, one of the closest US territories to China, removed the drydocks in 2016. The USS *Richland*, an AFDM-3-Class Drydock, was sold in 2016. The drydock, which had been in service since WWII, was sold due to the Gaum pier facilities receiving repairs. According to Navy leadership, this resulted in insufficient room for the drydock.[171]

After shutting down the US Navy base in Subic Bay Philippines in 1992, the Navy moved "Big Blue" (named for the paint scheme), an AFDB-8-Class drydock, to Guam. In 1997 the shipyard bought the drydock and used it for repairs. However, the

[168] US Government Accountability Office, "Office of Congressional Workplace Rights: Weaknesses in Cybersecurity Management and Oversight Need to Be Addressed" (Report to Congressional Committes, Government Accountability Office, Washington, DC, February 2020).

[169] Werner. "BAE Systems Shuttering Pearl Harbor Maintenance Operation."

[170] Blenkey, "BAE Systems Ship Repair to cease Pearl Harbor Operations in 2021."

[171] Stars and Stripes, "WWII-Era Drydock Moving from Guam to Philippines," January 28, 2016, https://www.stripes.com/news/wwii-era-drydock-moving-from-guam-to-philippines-1.391147.

drydock was in need of repairs and in 2016 has, once again, been removed and sent to a Singaporean ship repair facility.[172]

The above closures and realignments have created ripple effects throughout the fleet where maintenance is already a concern. This, combined with the United States' withdrawal of subsidies in 1981, has continued to put strain on the availability of shipbuilding and ship repair resources. According to a report by Naval Sea Systems Command, as of 2014 there were only 54 navy certified drydocks located in the public and private shipyards across the United States.[173]

The withdrawal of subsidies in the 1980s is worth revisiting in more depth. In 1981, the Office of Management and Budget started terminating subsidies for commercial shipbuilding.[174] Undertaken under the Reagan Administration, this was a reflection of the trend away from government market interference. Since the termination of these subsidies, the domestic commercial shipbuilding market has all but collapsed. In the first ten years following the end of the subsidies, the United States saw production workers

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[172] Gaynor Dumat-ol Daleno, "Dry Dock Moved from Guam for Repairs," *Pacific Daily News*, August 30, 2016, https://www.guampdn.com/story/news/2016/08/30/dry-dock-moved-guam-repairs/89574436.

[173] Bradley Martin, Michael E. McMahon, Jessie Riposo, James G. Kallimani, Angelena Bohman, Alyssa Ramos, and Abby Schendt, *A Strategic Assessment of the Future of U.S. Navy Ship Maintenance* (Santa Monica, CA: RAND Corporation, 2017), 43.

[174] Committee on Appropriations, House of Representatives, *An Analysisof President Reagan's Budget Revisions for Fiscal Year 1982* (Washington, DC: Congress of the United States, 1981).

drop from 120,000 to 72,000 and 110 shipbuilders down to 60.[175] This trend has only continued. It is estimated that only nine shipyards are currently active today that have the ability to construct large commercial and naval ships.[176]

These industry failings are compounded by the Navy's ship-building programs in its latest three classes of ships in the last 20 years. The new Ford class nuclear aircraft carrier is now over budget and has yet to be brought to full fighting capability. Originally acquired in 2008, the aircraft carrier is now expected to enter the fleet in 2024 because of multiple system problems regarding its launching and evaluator systems which principally means the aircraft carrier is unable fight.[177] Originally, the carrier was to cost $10.5 billion, but now has increased 28 percent to $13.3 billion.[178] Additionally, the other three ships in the class are expected to take 10 to 13 years to build as well.[179]

It does not end there, the two other ship class commissioned by the Navy are not living up to their potential. The Zumwalt destroyer, due to budget cuts and decreases in the number of ships purchased, now possesses a gun that uses ordinance that is too

175 Maritime Executive, "U.S. Shipbuilding Industry Tops 110,000 Jobs," *The Maritime Executive*, November 3, 2015, https://maritime-executive.com/article/us-shipbuilding-industry-tops-110000-jobs.

176 Tim Colton, "U.S. Builders of Large Ships," Shipbuildinghistory.com, accessed October 17, 2020, https://www.shipbuildinghistory.com/.

177 Sam Lagrone, "Carrier Ford May Not Deploy Until 2024, 3rd Weapons Elevator Certified," *USNI News*, October 22, 2019, https://news.usni.org/2019/10/22/carrier-ford-may-not-deploy-until-2024-3rd-weapons-elevator-certified.

178 Ibid.

179 "Report to Congress on Gerald R. Ford Class Carrier Program," *USNI News*, April 3, 2018, https://news.usni.org/2018/04/04/report-congress-gerald-r-ford-class-carrier-program.

expensive to develop, stock and fire.[180] The Littoral Combat Ship fair no better. Plagued with engines and propulsion system issues, many of the ships are to be de-commissioned early. In 2020 the US has 293 ships, in a recent Defense News Report the Pentagon would like to grow the fleet to 530 ships to include more surface ships, logistical ships, and various artificial intelligence craft to include submarines and ships.[181] If the pentagon gets their way that will be an increase of 35 percent by 2030.[182] Given the length of time it takes to build and commission ships, a strategy relying mainly on ship construction may not be wise. Even if that were to be the strategy, growing the Fleet by such a size will, in this author's opinion, result in increased pressures on the repair industry.

The Current Status of the Shipyard Industry Workers

An overview of the Pacific ship repair industry's challenges regarding the workforce by region is worth reviewing.

San Diego serves almost as many ships as Norfolk. In the San Diego area, the repair industry is in competition with other industries in the area. Potential workers in the area are drawn away by job security. Industries that require the same skills that are prized in the ship repair industry such as electrical knowledge, propulsion knowledge, and construction skills are a big pull because they offer work at a more constant rate without

[180] Steve Cohen, "We Need a Bigger and Smarter Navy," *The Hill*, January 30, 2021, https://thehill.com/opinion/national-security/536389-we-need-a-bigger-and-smarter-navy.

[181] Ibid.

[182] Ibid.

the fear of being laid off when compared to ship repair. Unfortunately for the ship repair industry in San Diego, workers that are laid off due to lack of work have low rates of returning when the work rate increases as they have usually found other opportunities. Ultimately, this creates a challenge when work increases because labor cannot be called up in quick demand. Specific to the San Diego area is the use of immigrants and dual citizens in the ship repair industry. Coming from Mexico, these workers come across the border to work, and therefore are subject to current immigration policies and laws which can be a challenge for maintaining consistent workforce numbers.[183]

In Puget Sound the public shipyard is the dominant figure in the area, with private shipyards being much smaller. However, like San Diego, there are other industries that offer better and more consistent opportunities to the available skilled work force. However, unlike San Diego, the tempo of work at the public shipyard is relatively steady which helps attract and keep workers. In addition, the demand in the public arena is relatively high for ship repair, and upkeep makes the public shipyard attractive for workers. This work flow does not overflow into the private shipyards, however, which still suffer from inconsistent work tempo, impacting their workforce reserves. Of note, as a whole, the private shipyard industry in Puget Sound is the smallest when compared to other major regions in the continental United States.[184]

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[183] RAND interview with industry stakeholders and author, San Diego, CA, September 10, 2019.

[184] RAND interview with industry stakeholders and author, Puget Sound, WA, September 17, 2019.

The US Navy created the Hawaiian shipyard industrial base =. Because of this, there is no organic Hawaiian ability within the state's economy that could be bolstered to meet new demand. However, there does appear to be support to accommodate workers being brought to the island due to increased demand. The Hawaiian Islands seem to have a steady equilibrium of work to workers.[185] A future challenge the state will have to contend with is whether or not the infrastructure for housing and others can handle a large influx of workers should the industry grow in the future.

Overall, the United States shipyard and shipbuilding industry is reliant on a mix of public and private workers from all over the country and the world located in bases all around the world. In a study conducted in 2016 by the US Census Bureau there were approximately 104,800 total workers employed at private shipyards. While the public (US Government owned) shipyards, employed nearly 38,800 people.[186]

However, demand for ship repair jobs is expected to decline. In a study conducted by the US Bureau of Labor Statistics forecasts show that the national demand for ship repair jobs and related trades is anticipated to drop by an overall 2.2 percent in the 2018 to 2028 timeframe. Even more of a drastic downward trend, were Bureau of Labor

[185] More data will have to be collected to see if the BAE closure will have any effect on this worker to work equilibrium in the future. The author hypotheses that the US Navy will take ownership of remaining facilities for the foreseeable future.

[186] US Census Bureau, "County Business Patterns (CBP) Tables 2002-2016," accessed February 17, 2021, https://www.census.gov/programs-surveys/cbp/data/tables.html.

Statistics projections for the 2016 to 2026-decade, showing a minimum of an overall 4.5 percent downtrend for most ship repair occupations.[187]

The downward trend is not just with overall demand but with worker productivity. Worker figures has grown while workforce demands have declined. From 2004 to 2014 the number of workers grew by 17 percent, at the same time, the direct man-days only grew by disproportionate rate of 7 percent.[188] In addition, there is growing concern over the experience of worker in the industry. Workers with less than ten years' experience in the industry are increasing, and workers with ten years of experience or more are decreasing. In 2014 workers with less than ten years' experience increased to almost 50 percent of the total workforce, at the same time, workers with 20 to 29 years of experience decreased to just 12 percent.[189]

Another concern through the Pacific ship repair industry is the lack of welders. When polled, the skill that was reported in the highest demand throughout the Pacific region was welders.[190] This may stem from an overall problem in dogmatic education values in 2021 American society. The pressure to earn a college degree after completing

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[187] Martin et al., *A Strategic Assessment of the Future of U.S. Navy Ship Maintenance*; US Bureau of Labor Statistics, "Employment Projections," accessed March 20, 2021, https://data.bls.gov/projections/occupationProj.

[188] Jessie Riposo, Michael McMahon, James G. Kallimani, and Daniel Tremblay, *Current and Future Challenges to Resourcing U.S. Navy Public Shipyards* (Santa Monica, CA: RAND Corporation, 2017), https://www.rand.org/pubs/research_reports /RR1552.html.

[189] Ibid.

[190] Naval Sea Systems Command, "Navy Industry Leadership Meeting" (Briefing, September 20, 2018), 61, pssra.org/wp-content/uploads/2018/10/FMMS-2018-INDP-Navy-Indsutry-Leadership-Consolidated-Brief_FINAL_20Sep18no-backups2314.pdf.

high school is extremely high. American students are not as interested or encouraged to get a career in shipyard work, and recruiting them for this task has proven extremely difficult. Many industrial recruiters are not welcome or invited to come to high schools which hampers their recruiting efforts even more. This fact is compounded even more, according to William Crow, President of the Virginia Ship Repair Association, when the industry lays off these individuals due to work shortage, and then the former employees do not return when work picks up again. All of this combines to make prospective workers adverse to the industry when they learn of its practices.[191]

Summary

Chapter 2 contained a detailed review of the relevant literature on several topics relevant to the primary and secondary research questions. It reviewed the evolution of Chinese missile technology and the importance of the destroyer-class vessel in naval warfare tactics. It also reviewed several aspects of the US ship repair industry including its history, its ability to meet demands during WWII, and current concerns surrounding both facilities and the workforce.

The above literature review indicates that missiles will play a large part in any future war in the Western Pacific. Missile damage often requires extensive repairs that take many months to years to complete. The number of trained shipyard workers is decreasing and new workers are not entering the industry at a steady rate. All of this indicates an inability of the ship repair industry to meet war-time repair demands for destroyer-class vessels.

[191] Kreisher, "China's Carrier Killer," 44-47.

In Chapter 3, the methodology for determining whether the Pacific Fleet's ship repair industry is capable of sustaining naval warfare in the Pacific, both at current levels and should the industry grow as seen during WWII, will be detailed.

CHAPTER 3

METHODOLOGY

> War is not for waging but for winning. Armies do not get paid to come second, not least due to the severe penalties incurred in losing. Useful military theories relate to winning. We want things that work; not merely things that are elegant or intellectually pleasing.
>
> —Jim Storr, *The Human Face of War*

Introduction

The purpose of this primarily ex-post facto quantitative study is to determine whether the United States' ship repair industry, as applicable to destroyer-class vessels, is prepared to support Naval warfare in the Pacific and if so, for how long.

The body of this chapter is organized into three subsections. Subsection (A) presents the independent and dependent variables and their parameters. Subsection (B) presents the methodology for the "Static Analysis," which examines the Pacific ship repair industry at current capabilities. Subsection (C) presents the methodology for the "Dynamic Analysis," which examines the Pacific ship repair industry capabilities assuming growth similar to that seen during WWII.

A brief summary of the process concludes the chapter. A full discussion of data analysis and actual results is included in Chapter 4, Analysis.

Subsection (A): Variables

Table 1 presents the independent and dependent variables used in this study.

Table 1. Description of Variables

Variable	Abbreviation	Class	Description
Mean Time to Repair	MTTR	Dependent Variable	The average amount of effort it takes (expressed in man-days) to repair a missile-damaged destroyer.
Repair Effort	RE	Dependent Variable	The amount of effort it takes (expressed in man-days) to repair a specific missile damaged destroyer.
Repair Time	RT	Dependent Variable	The amount of time it takes to repair a missile damaged destroyer.
Current Workforce	CW	Independent Variable	The number of workers at a given shipyard.
Current Shipyard Piers	CSP	Independent Variable	The number of piers at a given shipyard.
Current Shipyard Drydocks	CSD	Independent Variable	The number of drydocks at a given shipyard.
Need of Repair	NR	Dependent Variable	The number of ships in need of repair at any given time.
Pacific Fleet Workforce	PFW	Dependent Variable	The number of workers at any given shipyard, adjusted for WWII growth.
Pacific Fleet Piers	PFP	Dependent Variable	The number of piers at any given shipyard, adjusted for WWII growth.
Pacific Fleet Drydocks	PFD	Dependent Variable	The number of drydocks at any given shipyard, adjusted for WWII growth.
Probability of Hit	P_{HIT}	Independent Variable	The probability of a missile strike
Force Flow	N/A	Independent Variable	The rate at which destroyers are added to the fight from the Fleet

Source: Created by author.

In order to determine whether or not current (and expected) workforce and facilities capabilities are capable of sustaining war in the Pacific, one must determine whether a gap exists between the Pacific Fleet's current workforce and facilities compared to anticipated repair needs. By comparing the variables Current Workforce (CW), Current Piers (CP) and Current Drydocks (CD) with the Need of Repair (NR) outcome, whether the Pacific Fleet ship repair industry is able to keep up with demand and for how long can be determined.

Should the US enter into a war with a major power in the Pacific, it is unlikely that current workforce and facility capabilities will remain stagnant. As seen during WWII, employment in shipyard workforce and the number of facilities increased. As such, Subsection (C)'s Dynamic Analysis applies a calculated growth rate based on growth seen during WWII to both current workforce and facilities capabilities.

In order to determine the anticipated repair need, a stochastic war simulation sequence is used to provide an estimate. Thus, by comparing the outcome of this sequence to the variables listed above, one is able to determine whether a gap exists and if so, how large it is.

Subsection (B): Static Analysis

In this Subsection (B), the methodology to determine whether the Pacific ship repair industry is capable of sustaining war in the Pacific at current levels is described. To do this, the Pacific's current capabilities (in both workforce and facilities) must be calculated and then compared to what the US Navy anticipates its need for repair will be in the event of a war in the Pacific.

Step One: Calculate Mean Time to Repair (MTTR)

This dependent variable estimates the amount of effort, expressed in man-days per ship, it takes to repair the average missile damaged destroyer-class vessel. Missile damage can and does vary depending upon many factors. As such, the author needed to develop a way to calculate this figure.

In order to calculate the Mean Time to Repair (MTTR), a survey of damaged US Naval vessels was conducted. Those ships meeting the following parameters were selected for inclusion in the class:

1. The vessel was capable of being repaired; and
2. The vessel had a similar displacement and/or mission to the Arleigh Burke class destroyer; and
3. Damage was concentrated in one area; and
4. Damage met one or more of the following descriptions:
    a. Hit by a Missile
    b. Hit by a Missile-like Projectile;
    c. Explosion at or above the water line; or
    d. Significant hull damage at or above the water line.

The most accurate figures would be the actual number of man-days it took to repair each ship that qualified for inclusion in the class. However, this data is not published (and for some companies, was considered a trade secret). Therefore, an alternative methodology was developed to estimate the number of man-days it took to repair each ship, as follows:

Of the ships selected for inclusion, the final cost to repair the ships is easily accessible and available information. It is also estimated that approximately 48 percent of the repair costs for any given repair job come from material costs, with the remaining 52 percent coming from labor. Finally, as of 2015, one man-day was estimated to cost \$500.[192] This figure can be adjusted for inflation using the Bureau of Labor Statistics online inflation calculator.[193]

Therefore, to estimate the number of man-days it took to repair each ship (the Repair Effort, RE), the following equation can be used:

$$Repair\ Effort\ (RE) = \frac{Cost\ of\ Repair}{Cost\ per\ Manday\ (Adjusted)}\ x\ 0.52$$

Finally, the sum of the Repair Effort for each ship is calculated and divided by the total number of ships in the class to produce the MTTR.[194] This can be expressed mathematically as follows:

$$Mean\ Time\ to\ Repair = \frac{Sum\ of\ Repair\ Effort\ for\ each\ ship}{Number\ of\ ships\ in\ the\ class}$$

$$\text{MTTR} = \frac{\sum_{i=1}^{n} REi}{n}$$

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192 Martin et al., *A Strategic Assessment of the Future of U.S. Navy Ship Maintenance.*

193 US Bureau of Labor Statistics, "CPI Inflation Calculator," accessed March 20, 2021, https://www.bls.gov/data/inflation_calculator.htm.

194 The MTTR equation can be used should additional ships be added to the class or should more accurate figures regarding the Repair Effort for each ship be published. This equation's usefulness is not limited to this methodology alone.

The class is divided into ships that suffered heavy damage and ships that suffered moderate damage. An MTTR for each type of damage can be calculated using the above equation. While the above equation is used to estimate the MTTR, this figure can easily be substituted should more accurate estimates be published.

Step Two: Determine Repair Time (RT)

Now that the MTTR has been calculated, the speed in which any particular ship can be repaired can be determined RT. The RT is calculated by dividing the MTTR by the number of workers assigned to work (or capable of working on) the ship at any given time. The RT for both moderate and heavy damage can be calculated using the below equation.

This can be expressed mathematically as follows:

$$Repair\ Time = \frac{MTTR\ (mandays)}{Workforce}$$

$$\mathrm{RT} = \frac{MTTR}{W}$$

Step Three: Calculate Current Workforce (CW)

In the Static Methodology, the CW is simply the number of workers currently employed by each shipyard facility in the Pacific capable of repairing battle damaged destroyers. Therefore, to calculate the CW, the current employment figures for each shipyard capable of repairing missile damaged destroyer-class vessels must be determined. This data was obtained by calling the human resources departments of the various shipyards.

Step Four: Calculate Current Facilities

In any conflict, even if there is an adequate workforce to handle the repairs, there must be adequate facilities to receive the vessels in NR. Thus, the number of current piers and drydocks available in the Pacific at specific shipyards for use by the US Navy was determined.[195] These figures are expressed as the independent variables "Current Shipyard Piers" and "Current Shipyard Drydocks." This data was also obtained by inquiring with the various shipyards.

Step Five: Calculate Need of Repair (NR)

The NR is the final variable that must be calculated. This variable represents the rate at which destroyers will be hit by missiles and therefore require repair. This independent variable is a projected contemporary estimate based on a logical process which analyzed ex-post facto WWII data. The following summarizes the analytic process used to arrive at the value.[196]

Battle Tempo

Step One of the process is to determine the battle tempo. In order to determine the battle tempo, a survey of major naval engagements was conducted for selected US warships types in the Pacific from January 24, 1942, through October 26, 1944. WWII

[195] Ship repair facilities in Guam or in Japan were not counted towards these totals. The logic for this is because both Guam and Japan are within missile striking distance of the South China Sea and therefore could become targets if repairs were conducted there.

[196] This sequence is used in lieu of classified war games or figures that could be used in order to keep this paper in the unclassified realm.

was selected for the following reasons: (1) it is a relatively recent conflict which included modern naval warfare; (2) the combatants that participated were similar to the missions and displacement of current combatants; (3) the location and scale of the conflict is similar to what the author expected to see; (4) the conflict was against a peer competitor; (5) the length and frequency of the engagements are similar to what the author would expect in modern times; and (6) supply chain management used to refuel and repair previous combatants are those the author would expect to use in a current conflict and therefore any influence on the engagements due to logistics is already accounted for.[197]

A table of this data is produced in table 6, Chapter 4, Analysis. This ex-post facto data includes the date of each engagement and the number of US cruisers (light and heavy) that participated.[198] These data points assist us in determining the rate of battle and the number of vessels that participated in each engagement.

Probability Hit (or P_{HIT})

The next step is to determine the Probability Hit (P_{HIT}) of a missile. The "probability of hit" is defined as the probability of hits being made on a target out of a given number of projectiles directed at the target. In this simulation, this represents the probability that a ship will be hit by a missile during any given battle.

[197] The Falklands War was considered but ultimately not selected for use for the rate of engagement due to the limited timeframe in which the war was fought, the limited size of the conflict and the participants in the war.

[198] Cruisers were selected due to their similar size and displacement to modern Arleigh Burke class destroyers.

Because the P_{HIT} value of a future competitor's missile technology is unknown, four P_{HIT}'s were used in this simulation to provide an understanding of how higher or lower rates affect the simulations. The first is an assumed "worst case scenario" P_{HIT} of 0.75, which means that each destroyer has a 3 out of 4 chance of being struck by a missile.

The second P_{HIT} figure was 0.625 and was based on Falklands War data. A survey of the eight destroyers that took part in the Falklands War and their fate was conducted. A table of this data is produced in table 8, Chapter 4, Analysis. The Falklands War was used as a recent example of modern naval warfare that included use of anti-ship missiles.

The third P_{HIT} figure was a median P_{HIT} of 0.5 and the fourth figure was a "best case scenario" of 0.25.

Damage

The third step is to determine what sort of damage a vessel might receive if they are struck by a missile. History has shown that not all ships hit by missiles were sunk. Some survived the hits and required repairs that could be fixed pier side, while others that survived required deeper repairs that required a drydock.

The Falklands War provided sufficient data in terms of the type of damage a ship encountered once it was hit. If the vessel was hit by a missile, then the type of damage it received was categorized based on the outcome of the Falklands War. The outcomes included "Sunk," "Moderate Damage," and "Heavy Damage." By tallying the number of ships that were hit by missiles in the Falklands War and determining their fate, the probability of a ship receiving each type of damage was determined.

Ships that were hit by a missile but not immediately requiring repair were classified as receiving "Moderate Damage," whereas ships that were hit but immediately required repairs were classified as receiving "Heavy Damage."

Force Flow

The next step is to determine the "force flow." The force flow represents the number of destroyers available to deploy in the Pacific at any given time. The reason for the two different force flow models is because if a war in the Pacific does happen, ships from the Atlantic Fleet may be rerouted to support, as was seen in WWII. However, there is no guarantee that Atlantic Fleet ships will be available to be rerouted and therefore, a model where no ships from the Atlantic are rerouted is also valuable to examine. Thus, two different force flow models were used.

The first is labeled a "Weak Force Flow." In this scenario, only one third of the destroyers stationed in the Pacific will be available to be deployed (with the remaining two thirds in maintenance and workups). One destroyer will exit the maintenance and basic phase every two months and be available to deploy. One destroyer will join the Pacific Fleet via new construction every six months. However, in this scenario, no ships will be rerouted from the other fleets to assist with this conflict.

The second scenario is labeled "Realistic Force Flow." In this scenario, the starting number of destroyers will be the same as above, however, it is assumed that ships from other Fleets will be reassigned to support the war in the Pacific.

Not all ships will be available to be deployed to the Pacific. Therefore, it is assumed that 75 percent of the remaining ships stationed elsewhere will be redeployed to the Pacific, or a total of 21 vessels. In this scenario, it is assumed that there will be an initial surge of ships sent to the Pacific followed by a trickle as deeper efforts to ready and sortie needed ships are accomplished. Thus, six additional ships will be available at the first battle with a decreasing linear feeder for each subsequent month (i.e., month two will see five additional ships, month three will see three additional ships and so forth).

For both scenarios, it is assumed that a ship entering the fight will remain in the fight until sunk or damaged. It is also assumed that no ships will require voyage repairs beyond Unit Level capabilities.

Procedure

A simulation designed by the author was conducted based on the above data points for each combination of P_{HIT} and Force Flows for a total of eight simulations. At the start of the simulation, the number of ships in workups, in maintenance and available for the fight are determined. Those ships in maintenance are assigned to available piers and drydocks in the Pacific and requisite number of workers is assigned to each ship for those repairs. For convenience, Appendix V is included to assist with assigning ships to appropriate piers and drydocks.

Using the Battle Tempo data, the required number of vessels is assigned to the first battle. A die is cast for each vessel to determine whether the vessel receives damage (based on the assigned P_{HIT} value) and the result is recorded. If the vessel receives damage, another die is cast to determine whether the vessel is sunk, receives light damage or heavy damage (damage is based on the statistical probability from the Falklands' War data) and the result is recorded. If the ship receives light damage, it is assigned to a pier space. If the ship receives heavy damage, it is assigned to a drydock. For each ship assigned to either a pier or drydock, workers are assigned to that specific ship to complete repairs and the time it takes to repair the ship is recorded.

The above sequence is continued until a saturation point is reached for either workforce or facilities or there are an inadequate number of ships remaining to meet the battle demand. A detailed summary of the steps taken during each simulation is included in Appendix C.

Figure 2 displays the above methodology in an easy-to-follow flow chart. A full analysis and discussion of the results is presented in Chapter 4, Analysis.

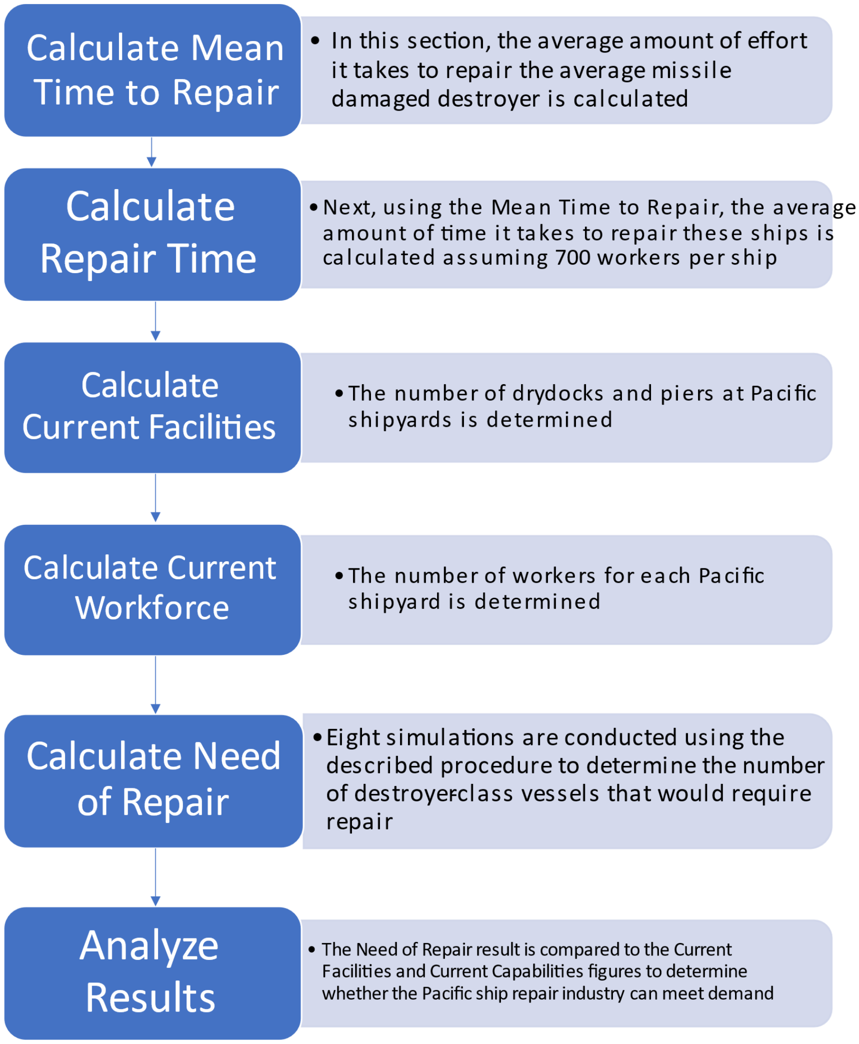

Figure 2. Static Analysis Methodology Flow Chart

Source: Created by author.

Subsection (C): Dynamic Analysis

In Subsection (C) a Dynamic Methodology was applied to each of the eight simulations to determine whether the Pacific shipyard industry is capable of sustaining Naval warfare in the Pacific assuming that both the Workforce and Facilities variables experienced equivalent growth as seen during WWII.

Step One: Calculate Pacific Fleet Workforce

This independent variable represents the total employment in man-hours on construction and repair of naval vessels at some future time in the Pacific theater. It is based on ex-post facto data obtained from contemporary naval and industry sources. The Pacific Fleet Workforce is calculated by applying a growth rate to the CW variable (as detailed in Subsection (B) Step Two). This growth rate represents an analogous historical national mobilization effort where the industrial workforce was rapidly mobilized to support a war effort, which (as discussed above) is something one might expect to see should a war in the Pacific break out.

Data was collected which detailed the increase in workforce numbers by region. This data is presented in tabular form in Chapter 4, Analysis. Next, the relative change for each shipyard was calculated by taking the percentage change between each month. The result was then applied to the CW for each shipyard.

Step Two: Calculate Pacific Fleet Docks and Pacific Fleet Piers

As with the workforce, the country's industrial base saw an increase in the number of piers and drydocks available for repairs. Thus, the Pacific Fleet's current number of piers and drydocks can be adjusted based on anticipated growth the United States might see, based on WWII growth rates.

The independent variable Pacific Fleet Docks represents the physical number of drydocks, available in the Pacific, capable of supporting repairs for heavily damaged destroyer-class vessels. It is calculated by applying a growth rate to the CD variable (as determined in Subsection (B) Step Four). The Facilities Growth Rate was based on historical WWII data from January 1940 through December 1944.[199] This data is presented in tabular form in Chapter 4, Analysis. Next, the relative change for the Growth Rate (Facilities) was calculated by taking the percentage change between each year. The result was then applied to each shipyard's CD.

Pacific Fleet Piers is calculated in the same way. This independent variable represents the physical number of pier spaces, available in the Pacific, capable of supporting repairs of moderately damaged destroyer-class vessels. It is calculated by applying the Growth Rate (Facilities) to the CP variable (as determined in Subsection (B) Step Four).

Step Three: Analyze Results

Any simulation in which Workforce or Facilities saturation was met (i.e., at some point during the conflict an insufficient number of workers or insufficient number of facilities was reached) was identified. For those specific simulations, the increased workforce and/or facilities figures were applied and the results recorded.

Summary

Chapter 3 detailed the methodology employed to answer the secondary research questions. Eight simulations in total were conducted, four for the Static Analysis (Weak

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[199] Both ship repair and ship construction facilities were included due to lack of records that distinguish between the two. As stated in Chapter 1, Introduction, it is assumed that the growth experienced by the shipyard industry as a whole was experienced proportionately between ship repair facilities and ship construction facilities such that this growth rate can be applied to either. This period was selected as it best represents the nation's maximum output in response to a direct attack (i.e. Pearl Harbor). Earlier timeframes were rejected because in this author's opinion a buildup as seen during early WWII times will not happen in a future war in the Western Pacific.

Force Flow) at four P_{HIT} values and four for the Static Analysis (Realistic Force Flow) at four P_{HIT} values. These results will then be re-evaluated assuming growth rates in both the facilities and workers, assuming a growth rate seen during WWII.

Figure 3 displays the above methodology in an easy-to-follow flow chart. Chapter 4 contains the results of each sequence and resulting analysis.

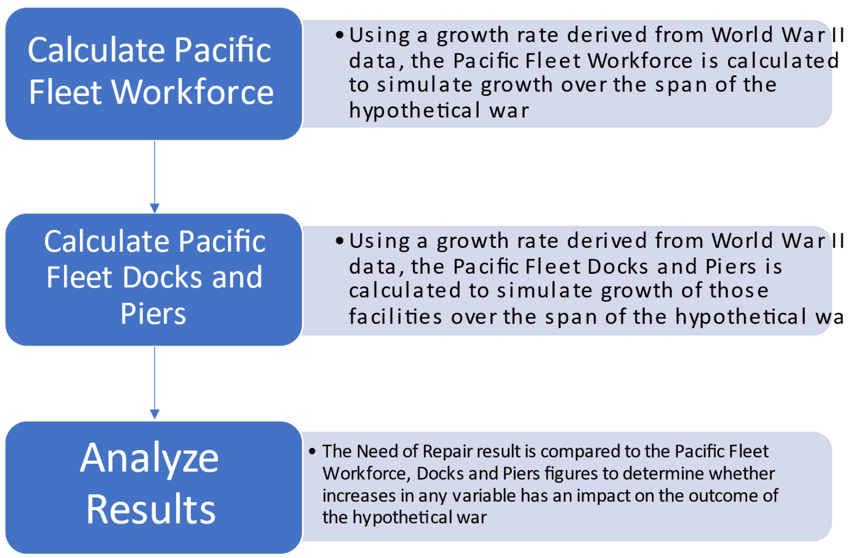

Figure 3. Dynamic Methodology Flow Chart

Source: Created by author.

CHAPTER 4

ANALYSIS

Introduction

As described in chapter 3, this chapter is broken into two parts. Subsection (A) contains the static analysis, which determined whether the Pacific ship repair industry is capable of sustaining a war in the Pacific at current levels. Subsection (B) contains the dynamic analysis, which determined whether the Pacific ship repair industry is capable of sustaining war in the Pacific assuming that sector sees growth similar to that of WWII.

Subsection (A): Static Analysis

Step One: Calculate Mean Time to Repair (MTTR)

Four ships met the criteria detailed in chapter 3 for inclusion in the class. The USS *Stark* and USS *Cole* suffered heavy damage and therefore were put into the "Heavy Damage" subclass. The USS *Porter* and USS *Kinkaid* received moderate damage and therefore were put into the "Moderate Damage" subclass.[200] The relevant data for each ship is detailed in table 2.

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[200] The USS *Boston* was ultimately not selected because it did not require repairs beyond Unit Level capabilities. The USS *Arthur W. Radford* was not selected because the damage was not concentrated in one area and the majority of damage fell beneath the waterline. The USS *Belknap* was not selected as, due to the fire that broke out following the collision, her aluminum superstructure completely collapsed (modern Arleigh Burke class destroyers do not have aluminum superstructures). While the USS *Stark* was selected and did have an aluminum superstructure, the USS *Stark* did not suffer the subsequent fire that led to the superstructure's collapse, as was seen with the USS *Belknap.* The USS *Fitzgerald* was not selected given the damage it suffered below the waterline. The USS *McCain* was also not selected due to the damage it suffered below the waterline.

Table 2. Ship Class Data			
Ship	Year of Repair	Cost per Man-day	Total Repair Cost
USS *Stark*	1987-1988	$248	$142,000,000
USS *Cole*	2000-2002	$375	$243,000,000
USS *Porter*	2013	$493	$50,000,000
USS *Kinkaid*	1990	$273	$15,000,000

Source: NavySite.de, "USS Stark (FFG 31)," accessed February 18, 2021, https://www.navysite.de/ffg/FFG31.HTM; Raphael Perl, "Terrorist Attack on USS Cole," Naval History and Heritage Command, May 13, 2020, accessed October 20, 2020, https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/t/terrorist-attack-on-uss-cole-background-and-issues-for-congress.html; Seaforces, "DDG 78 USS Porter," Seaforces Online, accessed February 18, 2021, https://www.seaforces.org/usnships/ddg/DDG-78-USS-Porter.htm; NavySite.de, "USS Kinkaid (DD 965)," accessed March 17, 2021, https://www.navysite.de/dd/dd965.htm.

In order to calculate the Repair Effort, the total cost of repair was divided by the estimated cost per man-day (as adjusted for inflation).[201] The product was then multiplied by the ratio of labor to materials costs for repair jobs, or 0.52. The results for each ship are detailed in table 3. See Appendix D for detailed calculations.

[201] Using the Bureau of Labor Statistics online calculator, $500 in 2015 was used as the benchmark and was adjusted based on the year the repairs were completed. In the case of the USS *Stark*, that was 1988, for the USS *Cole* the year 2001 was selected, for the USS *Porter* 2013 and for the USS *Kinkaid,* 1990.

Table 3. Repair Effort Summary			
Ship	Year of Repair	Cost per Man-day	Repair Effort (Man-days)
USS *Stark*	1987-1988	$248	297,742
USS *Cole*	2000-2002	$375	336,960
USS *Porter*	2013	$493	52,738
USS *Kinkaid*	1990	$273	28,571

Source: NavySite.de, "USS Stark (FFG 31)," accessed February 18, 2021, https://www.navysite.de/ffg/FFG31.HTM; Raphael Perl, "Terrorist Attack on USS Cole," Naval History and Heritage Command, May 13, 2020, accessed October 20, 2020, https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/t/terrorist-attack-on-uss-cole-background-and-issues-for-congress.html; Seaforces, "DDG 78 USS Porter*," Seaforces Online,* accessed February 18, 2021, https://www.seaforces.org/usnships/ddg/DDG-78-USS-Porter.htm; NavySite.de, "USS Kinkaid (DD 965)," Navy Site, accessed March 17, 2021, https://www.navysite.de /dd/dd965.htm; Repair Effort (Man-days) calculated by author.

Next, the MTTR for both heavy and moderate damage was calculated. Calculations can be found in Appendix 2. The MTTR (Heavy) was determined to be 317,351 man-days. The MTTR (Moderate) was determined to be 40,654.5 man-days. See Appendix E for calculations.

Step Two: Determine Repair Time (RT)

Data collected from the repairs of the USS *Cole* indicated that the total number of workers available to work on a destroyer under repairs at any given time is a maximum of 700.[202] Thus, by assuming that 700 workers worked on the ship for the entirety of its repair period, the shortest RT (and therefore the best case scenario) is determined. The

[202] Huntington Ingalls Industries, "USS Cole Returns to U.S. Navy Fleet Following Restoration by Northrop Grumman," April 19, 2002, https://newsroom.huntingtoningalls.com/releases/uss-cole-returns-to-u-s-navy-fleet-following-restoration-by-northrop-grumman.

maximum available workers are assumed because if there is a war of this magnitude, it would be reasonable to assume all available workers would be assigned to repairing ships damaged in battle (and monetary concerns put aside).

Therefore, the RT was determined by taking the MTTR for both heavy and moderate damage and dividing it by 700, to determine the average amount of time it took to repair each type of damage. This resulted in a RT for Heavy damage of 1.2 years or 14 months (rounded down) and a RT for Moderate damage of 1.9 months (or 2 months rounded up). See Appendix F for calculations.

Step Three: Determine Current Workforce (CW)

The current number of workers employed at each shipyard capable of handling a destroyer-class vessel is detailed in table 4.

Table 4. Workforce by Shipyard (2021)

Shipyard	Workforce
Puget Sound Naval Shipyard and Intermediate Maintenance Facility	12,340
Continental Marine (San Diego)	400
BAE San Diego	1,230
GD Nassco (San Diego)	2,170
Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility	6,500
VIGOR Portland (Oregon)	725
VIGOR Seattle (Washington State)	316
Total:	23,907

Source: Created by author. The number of workers employed at each shipyard was determined by personal phone calls to each respective shipyard and discussions with human resources representatives.

Step Four: Determine Current Facilities

The current number of drydocks and piers at each shipyard capable of handling a destroyer-class vessel are detailed in table 5.

Table 5. Current Facilities (2021)

Shipyard	Piers Capable of Handling DDG	Drydock Capable of Handling a DDG
Pearl Harbor	6	3
VIGOR Seattle	6	3
VIGOR Portland	2	2
Puget Sound	9	6
GD Nassco	4	2
Continental Marine	4	0
BAE	5	1

Source: Created by author. The number of piers and drydocks was originally provided by a United States Maritime Administration representative, which data was later confirmed through a survey of each shipyard using Google Maps and the respective locale's Geospatial Information System (GIS) websites.

Step Five: Calculate Need of Repair (NR)

A survey of all major naval engagements in the Pacific from January 24, 1942, through October 26, 1944, along with the number of US destroyer-class vessels that participated (during WWII, the comparable vessel was the cruiser based on displacement) is detailed in table 6.

Table 6. Naval Engagements from January 24, 1942 through October 26, 1944		
Date	Name of Battle	# of Cruisers Present
1942 January 24	Battle of the Balikpanan	0
1942 February 4	Battle of Makassar Strait	4
1942 February 18	Battle of Badung Strait	3
1942 February 27	Battle of the Java Sea	5
1942 February 28	Battle of the Sunda Strait	2
1942 March 1	Battle of Bawean Island	1
1942 May 4-8	Battle of the Coral Sea	8
1942 June 4-7	Battle of Midway	8
1942 August 9	Battle of Savo Island	8
1942 August 24	Battle of the Eastern Solomons	4
1942 October 11	Battle of Cape Esperance	4
1942 October 26	Battle of Santa Cruz Islands	6
1942 November 12-15	Battle of Guadalcanal	5
1942 November 30	Battle of Tassafaronga	5
1932 January 29	Battle of Rennell Island	6
1943 March 2-5	Battle of Bismark Sea	2
1943 March 26	Battle of the Komandorski Islands	3
1943 July 5-6	Battle of Kula Gulf	3
1943 July 12-13	Battle of Kolombangara	3
1943 August 6-7	Battle of Vella Gulf	0
1943 October 6-7	Battle of Vella LaVella	0
1943 November 1-2	Battle of Empress Augusta Bay	4
1943 November 25	Battle of Cape St. George	0
1944 June 18	Battle of the Phillippine Sea	21
1944 October 23-26	Battle of Leyte Gulf	24

Source: Naval Museum of the US Navy, “Pacific Naval Surface Battles,” Naval History and Heritage Command, accessed April 28, 2021, https://www.history.navy.mil /content/history/museums/nmusn/explore/photography/wwii/wwii-pacific/chronological-list-naval-battles-land-campaigns/pacific-surface-naval-battles.html.

As discussed in chapter 2, a survey of the eight destroyers that took part in the Falklands War and their fate was conducted. Of the eight destroyers that participated in the Falklands War, three received no damage, two were sunk and three were damaged. Of the three that were damaged, two received heavy damage (requiring drydocking facilities to repair) and one received moderate damage (requiring only a pier to repair). A summary of this data is included in table 7.

Table 7. Damage Type

Ship	Fate	Damage Level
HMS *Coventry*	Sunk	NA
HMS *Sheffield*	Sunk	NA
HMS *Glamorgan*	Damaged	Heavy
HMS *Glasgow*	Damaged	Moderate
HMS *Antrim*	Damaged	Heavy
HMS *Bristol*	No damage	NA
HMS *Exeter*	No damage	NA
HMS *Cardiff*	No damage	NA

Source: Created by author using data from Naval History and Heritage Command, "British Ships Lost and Damaged," accessed April 28, 2021, https://www.naval-history.net/F62-Falklands-British_ships_lost.htm.

From this data, the probability of receiving each type of damage/fate was derived and is included in table 8.

Table 8. Damage Probability

Sunk	2 out of 5
Heavy Damage	2 out of 5
Moderate Damage	1 out of 5

Source: Created by author.

Using the rules outlined in Appendix C, a simulation was conducted for each of the four P hit values at both weak and realistic force flows for a total of eight simulations.

Step Five: Analyze and Graph Results

Weak Force Flow

Simulation 1—P_{HIT} 0.75

When the simulation was conducted with a P_{HIT} value of 0.75, the Pacific Fleet was unable to meet battle demand before the 8th battle (averaging just over one battle per month, this simulation lasted until the sixth month). At this P_{HIT} value, the repair industry never became saturated in either workers or facilities. However, the percentage of ships that took on heavy damage was large, and thus, with the resulting long RT, lack of ships to meet battle demand was what ultimately stopped the simulation.

The results for this simulation can be found in Appendix G.

Simulation 2—P_{HIT} 0.625

When the simulation was conducted with a P_{HIT} value of 0.625, the Pacific Fleet was unable to meet battle demand before the 7th battle (averaging just over one battle per month, this simulation lasted until the fifth month). Interestingly enough, this was an earlier stopping point compared to the first simulation (P_{HIT} value of 0.75). However, that can be attributed to the random dice roll aspect of the simulation.

At a P_{HIT} value of 0.625, the repair industry never became saturated in either workers or facilities. The percentage of ships that took on heavy damage was also large, as seen in the first simulation, and that led to an inability to meet battle demand given how long it takes to repair heavy damaged destroyers.

A table of the results for this simulation can be found in Appendix H.

Simulation 3—P_{HIT} 0.5

When the simulation was conducted with a P_{HIT} value of 0.5, the Pacific Fleet was unable to meet battle demand before the 7th battle (averaging just over one battle per month, this simulation lasted until the fifth month) . Again, at this P_{HIT} value with a weak force flow, the repair industry never became saturated, however ships were not being returned to the fleet quickly enough in order to meet battle demand.

A table of the results for this simulation can be found in Appendix I.

Simulation 4—P_{HIT} 0.25

When the simulation was conducted with a P_{HIT} value of 0.25, the Pacific Fleet was unable to meet battle demand before the 14th battle (averaging just over one battle per month, this simulation lasted until the eleventh month). This was a marked improvement in terms of the Fleet's ability to last compared to the other simulations with higher P_{HITs}.

As seen with the other simulations, repair facilities never became an issue. The RTs themselves were simply too long and therefore by November of the first battle year, the Fleet no longer had enough ships to meet battle demand.

A table of the results for this simulation can be found in Appendix J.

Realistic Force Flow

In this simulation group, the force flow was adjusted to represent a more realistic scenario. Should a war in the Pacific break out, it is unlikely that ships stationed in the Atlantic would remain there. At least some of these ships would be ordered to the Pacific. As such, a cascading approach was used in the following four simulations where six ships were added from the Atlantic fleet in the first battle month, with additional ships added each month in decreasing numbers until to one ship was added in June, with the remainder staying in the Atlantic.

Simulation 1—P_{HIT} 0.75

When the simulation was conducted with a P_{HIT} value of 0.75, the Pacific Fleet was unable to meet battle demand before the 14th battle (averaging just over one battle per month, this simulation lasted for eleven months). This was a marked improvement in terms of the Fleet's ability to last compared to weak force flow at the same P_{HIT} value.

One of the assumptions for the simulations was that workers did not travel between shipyards. Given the great distance between shipyards and the fact that shipyard workers are not members of the armed services (and therefore they cannot be ordered to report to another shipyard), this assumption was logical. However, this assumption's ramifications was seen in this simulation.

Repair facilities and workers did become an issue during this simulation. After Battle 10, there were an insufficient number of workers to meet repair demands at the only facilities left with drydocks. While there were enough workers at other shipyards, those shipyards did not have any available drydocks. Thus, while the workforce on the whole could have accommodated the repair work, due to the assumption that workers did not travel between shipyards, there were insufficient number of workers.

The simulation was continued, however, the number of drydocks also became saturated after Battle 13. There were always available pier spaces.

A table of the results for this simulation can be found in Appendix K.

Simulation 2—P_{HIT} 0.625

When the simulation was conducted with a P_{HIT} value of 0.625, the Pacific Fleet was unable to meet battle demand before the 24th battle (averaging 1.2 battles per month, this simulation lasted 29 months. This was a marked improvement in terms of the Fleet's ability to last compared to the 0.75 P hit value at the realistic force flow value.

Repair facilities and workers did become an issue during this simulation. At Battle 11, worker saturation was met at two separate facilities. By Battle 14, drydocks had become saturated, with nowhere to put heavy damaged destroyers except for piers.

The simulation was continued and piers never became an issue. A table of the results for this simulation can be found in Appendix L.

Simulation 3—P_{HIT} 0.5

When the simulation was conducted with a P_{HIT} value of 0.5, the Pacific Fleet was able to meet battle demand for the entire war (averaging 0.7 battles per month, this simulation lasted the full 34 months). This was the first of all the simulations where there were sufficient ships to meet the demand for the last battle.

Both repair facilities and workers did reach saturation during the course of the conflict. At Battle 9, workers had reached saturation compared to the available drydocks. By Battle 15, drydocks had reached saturation and thus, heavily damaged ships had to be placed in piers. Throughout the course of the war, there were always available piers.

A table of the results for this simulation can be found in Appendix M.

Simulation 4—P_{HIT} 0.25

When the simulation was conducted with a P_{HIT} value of 0.25, the Pacific Fleet was able to meet battle demand for the entire war (averaging 0.7 battles per month, this simulation lasted the full 34 months). In addition, there was a surplus of 18 ships available to fight the last battle, compared to the battle demand.

Furthermore, workers and facilities (both drydocks and piers) never became saturated. Most ships that were damaged during the course of the war were able to be returned to the fight such that at the end of the war, only three ships remained in piers and four ships in drydocks.

A table of the results for this simulation can be found in Appendix N.

Subsection (B): Dynamic Analysis

In Subsection (C) a Dynamic Methodology determined whether the contemporary Pacific shipyard industry was capable of sustaining Naval warfare in the Pacific assuming that both the Workforce and Facilities variables experienced equivalent growth as seen during WWII.

Step One: Calculate Pacific Fleet Workforce

In order to calculate the Pacific Fleet Workforce, data was collected which detailed the increase in workforce numbers by region. This data is contained in Appendix O.

The relative change for employment for each month was calculated and then applied to the CW variable for each shipyard. Detailed calculations can be found in Appendix P.

Step Three: Calculate Pacific Fleet Docks and Pacific Fleet Piers

The number of piers and drydocks also saw increases during WWII. In order to calculate the growth the shipyard industry saw during WWII and apply it to CP and CD, a survey of all shipyards in existence in the Pacific region for each year was conducted. Whether the shipyard delivered ships to the US Navy before WWII or began delivering only after the war started was recorded. Then, the growth in shipyards coming online for each year was able to be determined. The results are detailed in Appendix Q.

The percentage change between each year was then calculated and applied to CP and CD for each individual shipyard. Detailed calculations can be found in Appendix R.

Step Three: Analyze Results

Weak Force Flow

Simulations 1 through 4

Simulations 1 through 4 did not see worker or facilities saturation. Therefore, an increase in either of these variables did not make a difference.

Realistic Force Flow

Simulation 1

Simulation 1 was a P_{HIT} value of 0.75 with a Realistic Force Flow. In the original simulation, the Fleet was unable to meet battle demand by Battle 14 and reached worker saturation at two shipyards. Facilities saturation was met by the eleventh month.

With the increases to the workforce and the facilities, worker and facility saturation was not reached. Both variables were able to meet repair demands. However, the fleet was still unable to meet battle demand by Battle 14 simply because there were insufficient ships available in the fight. Even if all ships necessitating repairs would have had the requisite number of workers, the Fleet would still have been unable to meet battle demand after Battle 14 (at a deficit of three ships). Thus, the increase in workforce and facilities did not affect the outcome of this simulation. Detailed results of this simulation are included in Appendix S.

Simulation 2

Simulation 2 was a P_{HIT} value of 0.625 with a Realistic Force Flow. In the original simulation, the Fleet was unable to meet battle demand for the last battle, Battle 25. Workforce saturation was seen starting at Battle 11 and facilities (drydocks) saturation was seen starting at Battle 14.

With the increases to the workforce and the facilities, worker saturation was still seen at specific shipyards , but later, starting at Battle 12. Drydock saturation was also seen for a period of time until new drydocks came online. With the increased workers and facilities available, the ship repair industry was able to return five ships that it otherwise would not have been able to return. This did allow the Fleet to meet battle demand for the last battle. Therefore, worker and facilities growth did affect the outcome of this simulation.

Detailed results of the simulation are included in Appendix T.

Simulation 3

Simulation 3 was a P_{HIT} value of 0.5 with a Realistic Force Flow. In the original simulation, the Fleet was able to meet battle demand for the last battle, or Battle 25 and reached worker and facilities saturation starting at Battle 9 and 15, respectively.

With the increase to the workforce and the facilities, worker saturation was seen for only a brief period of time at one shipyard before resolved and facility saturation was not reached. Both variables were able to meet repair demands. This ultimately resulted in an additional four ships being available for the last battle, giving the Fleet a surplus of four ships. Thus, while facilities and workforce increases did not impact the overall outcome of the simulation, it did provide additional resources at the last battle.

Detailed results of the simulation are included in Appendix U.

Simulation 4

This simulation did not see worker or facilities saturation and the fleet was able to meet battle demand throughout the conflict period. Therefore, an increase in either of these variables did not make a difference.

Summary

Chapter 4 detailed the results of eight total simulations. It also evaluated whether or not dynamic workforce or facilities figures would have impacted the overall outcome of the simulated conflicts. In the worst case scenario simulation (with a P_{HIT} of 0.75 and a weak force flow), repair industries were not tested because the Fleet was unable to meet battle demand early into the fight. In the best case scenario (with a P_{HIT} value of 0.25 and a realistic force flow), repair industries did not meet saturation and the Fleet was able to meet battle demand for the course of the war.

Chapter 5 concludes with conclusions and recommendations for further research.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

> The nation which abandons itself to an existence of ease and looks upon war with horror, rots away without advancing. It is destined to decline and become a slave of other nations which have not lost the virile qualities.
>
> —President Theodore Roosevelt, *The Moral of Troops*

Introduction

In any future war involving the United States, the ability of the nation, its armed forces, and supporting industries to respond quickly will be critical. It is unlikely that the United States will have the time to prepare for that war, as it did in WWII. Therefore, it is necessary for the United States to maintain a heightened state of readiness. In 2021, the Pacific ship repair infrastructure is at significant risk of not being capable of repairing ships at a rate needed in a wartime scenario.

Ship repair is critical to sustaining a naval fleet during wartimes. Ships will be damaged and will need to be repaired and sent back out. The tempo at which a nation does this can play a large part in determining that war's outcome. Thus, understanding the current status of the Pacific ship repair industry is crucial. This thesis examined the current state of the Pacific ship repair industry via eight simulations. Four examined various P_{HIT} values if the Pacific Fleet received no additional ships to fight the war. Four examined P_{HIT} values if the Pacific Fleet did receive additional ships to fight the war. After conducting the simulations, the following conclusions can be drawn.

Weak Force Flow Simulations

The "Weak Force Flow" simulations did not survive long enough to meet battle demand for the length of the war. The longest scenario in the Weak Force Flow category was seen with a P_{HIT} value of 0.25 and even then, the simulation only lasted until November of the first year. In the Weak Force Flow simulations, ship repair did not affect the outcome because the Fleet simply ran out of ships to fight the war.

Recommendations for these simulations would be to relocate ships from the Atlantic Fleet to the Pacific Fleet. In this situation (as well as in the Realistic Force Flow simulations), the Panama Canal will become crucial for the United States' success and therefore may become a target in need of defense.

Another recommendation would be to build additional ships. Of course, this recommendation has additional implications such as food, maintenance, housing, parking, and others, and whether the West coasts' facilities are capable of handling such an influx is not examined in this paper.

Realistic Force Flow Simulations

The four simulations involving Realistic Force Flows fared better, however, not as well as expected. Of the four P_{HIT} values, the only two simulations in which battle demand was met through the length of the war was a 0.5 and 0.25 P_{HIT} value.

When the P_{HIT} value was 0.75, worker and facilities still were not at issue as the Fleet was unable to meet battle demand before either of those figures became saturated. For values 0.625 and 0.5, worker and facilities saturation was seen. For the 0.625 Model, this worker and facilities saturation prevented the Fleet from fielding enough ships to fight in the last two battles. Whereas, for the 0.5 Model, the Fleet was able to field enough of a force for the last battle, but there were no ships to spare. For the P_{HIT} value of 0.25, the repair facilities were able to keep up with the demand and the Fleet was able to make it to the end of the war, therefore repair facilities did not affect the outcome of the conflict.

Dynamic Analysis

In the dynamic analysis, the author examined whether or not growth in the workforce and facilities variables would change the outcome of the simulation. Using WWII data, both the workforce and facilities figures were adjusted upward by comparable percentages. The only simulations where the workforce and facilities were capable of making an impact in the outcome was for the Realistic Force Flow 0.75, 0.625 and 0.5 P_{HIT} values.

For the 0.75 Realistic Force Flow Static Analysis Model, the increase in workforce and facilities did not impact the Fleet's ability to meet battle demand and therefore, despite resolving workforce and facilities saturation, it ultimately did not affect the outcome of the model.

For only the 0.625 Model, did the increase in workforce and facilities make an impact in the Fleet's ability to fight. In the Realistic Force Flow Static Analysis, the 0.625 Model was unable to meet battle demand at the second to last battle. However, with an increase in workforce and facilities, the Fleet was able to field enough vessels to be able to fight the second to last battle. Thus, in this simulation, the increase in workforce and facilities did affect the outcome.

For the 0.5 Model, the increase in workers and facilities did not ultimately impact the outcome of the scenario because the Fleet had been able to make it to the last battle. It did, however, resolve some worker and facilities saturation seen and provided additional ships over the battle demand for the last battle.

While not impactful for all of the scenarios, growth seen in the Dynamic Analysis would help to alleviate demand from new construction, planned maintenance, and non-battle damage repairs (which for purposes of this paper, were not taken into account).

Workforce

The Workforce at individual shipyards became important. While the workforce figures itself did not change the Fleet's ability to meet battle demand in the scenarios with their specific situations, the simulations assumed that all workers at the shipyards would be immediately available to work on damaged destroyers. This, of course, may not be the case. While the destroyer is expected to be the obvious target for most missiles, there will certainly be other ships requiring repair and maintenance in any naval warfare, and therefore in an ideal situation the workforce may not have been crucial, in a more realistic scenario, they may make the difference.

Throughout the course of the simulations, the imbalance between workforce figures at the large, public shipyards, and the small, private facilities could be seen. For example, Vigor Seattle's facilities are roughly equivalent to those at Pearl Harbor, however, they have a significantly smaller workforce. Thus, during the simulations, private shipyards with smaller workforces were assumed to not be able to handle large repairs (or did not have the requisite 700 workers to be able to repair the ship in the maximum amount of time).

Recommendations to address this imbalance could be to hire and train more workers based on the facility's capabilities, ensure that private shipyards will have sufficient workers to utilize their capabilities, and create infrastructure to move workers to different shipyards based on repair needs.

Facilities

As seen with the workforce, in certain scenarios, drydocks became saturated. Interestingly enough, piers never became saturated in any of the scenarios. While the paper ultimately concludes that an increase in the number of facilities would not make a tremendous impact to the outcome of the naval engagement on the whole, this again assumes idealist conditions. It is very likely that drydock facilities may be taken by other ships in the course of a naval engagement and therefore, an increase may become crucial.

Recommendations for the facilities is to build more drydocks along the Pacific Coast, Hawaii, and the Alaskan Coast. Also, existing drydocks that are not able to accommodate repairs should be upgraded or put into compliance. As seen during WWII, another option would be to field floating drydocks so that repairs can be made without towing ships all the way back to the coasts or to allow heavily damaged units to repair enough to self-motivate home. This will ultimately help expedite repairs and shorten travel time.

Repair Time (RT)

The RT was a critical factor in the outcome of all the simulations. Piers never became saturated and while there are certainly more piers, it was also due to the fact that moderate RTs were significantly shorter than heavy damage RTs.

Recommendations to address the RT issue include building a new class of ships specifically made for battle that are simpler than the very complex Arleigh Burke destroyers that also are easier to repair. Another recommendation would be to create new classes os hips that are mission specific. Rather than the "do it all" Arleigh Burke destroyer, other classes that are only Anti-Submarine, Anti-Surface or Anti-Air could be created. These new ships would be mission specific and could be mass produced such that they would have sufficient equipment for that mission but no more. This would help decrease both the time in which they are constructed and repaired.

One of the other variables that will affect RT is the experience of the workforce. Veteran shipyard workers will be more experienced and likely faster at repairing vessels, and therefore efforts should be made to retain skilled workers. If this is not feasible, ways to shorten RTs for heavily damaged destroyers should be explored as this will immediately impact the outcome of any naval engagement.

P_{HIT} Values

It is no surprise that the Fleet fared the best when the P_{HIT} values were lowest. Of course, it is easy to recommend that AEGIS be improved in order to keep the P_{HIT} value as low as possible, but this may not be feasible as this may be beyond AEGIS and would require a full multi-domain effort to deny or degrade the enemy's kill chain targeting. Other options include improving and developing new countermeasures on ships, but also improving training for existing weapons onboard. This would require an examination of ship schedules and an adjustment to inspections. Things such as including more Anti-Air missiles on ships (such as the SM-6 or follow on variants), improving and adding additional Close in Weapons Systems' and bringing smokescreen back to ships may also be effective in helping keep P_{HIT} values low.

Further Conclusions Involving Governmental Agencies and Localities

As seen in the Literature Review, Congress previously established a series of government subsidies for shipyards that originally helped US shipbuilders compete on a global scale. With those subsidies gone, the domestic ship repair and shipbuilding industry have been unable to compete as effectively. Congress should reconsider reinstituting these subsidies for shipyards such that the domestic industry can compete abroad. This will help the industry become less reliant on the US Navy, which only has periodic needs during peacetimes.

The Department of Transportation's MARAD division oversees domestic maritime transportation infrastructure, to include shipyards. One recommendation following the research results would be to increase the relationship between MARAD and these shipyards such that if shipyards are beginning to fail, MARAD has the ability to step in with grants or other funding sources before the shipyard is forced to shut down.

As discussed in the workforce section herein, there is a real need for highly trained and experienced workers in the shipyard industry. Congress should consider developing the relationship between the Department of Education, shipyards and the US Navy to incentivize the training of skilled shipyard workers. The Department of Education can get further involved by sponsoring career fairs, internships and apprenticeships at high schools across the nation to encourage students to enter these important trades.

Finally, tax relief may be an avenue to provide shipyards more flexibility during times when demand is slower. Lowering or eliminating property and machinist taxes by local governments may help to reduce overhead costs for these facilities (which by design operate in areas of high value by being on the coasts, often require large facilities, driving real property taxes up, and have expensive equipment, driving machinist taxes up).

The issue of maintaining this nation's shipyard industry is not just a US Navy problem. It will require support from other agencies across the government, as well as buy-in from the American people.

Further Research Recommendations

Over the course of conducting the research, several questions became relevant that did not fall within the scope of this thesis. These include the following:

The simulations assumed that ships were able to be towed out of the battlefield to receive repairs when damaged. However, whether this will always be feasible and how it will be accomplished was not explored.

The simulations assumed that workers were fixed at each specific shipyard. This played a critical part in whether or not worker saturation was reached for specific shipyards. Whether or not worker mobility programs could be created to help meet demand and best utilize the workforce is worth exploring.

This relates to another topic, which is worker retention. As discussed briefly, recruiting high school students to go to trade school has proven difficult and led to good talent going elsewhere. Likewise, the demand plays a factor in retaining good talent. Thus, understanding what incentives might be instituted to increase worker numbers and retention is worth exploring.

During WWII, not all repairs were done by the ship repair industry's civilian workforce. Many of the repairs were completed by the crew itself. Thus, exploring whether it is feasible to train the crew to complete some repairs (say for example, moderate damage) and whether supply chains could support providing materials and equipment for such repairs in order to aid with RT is worth exploring.

With the switch to firm fixed pricing, many private shipyards are being forced to close. Exploring this switch and its costs and benefits is worth exploring.

Also, the simulations conducted used RTs developed from peacetimes, where obtaining materials was not an issue. However, if a war in the Pacific does break out, supply chains will certainly be interrupted or face over-demand. An analysis on the amount of materials that might be impacted by such a halt in trade and the repercussions on RTs and abilities is worth exploring.

This study assumed that workers and facilities would be available to repair battle damaged destroyers without regards for other ships. Expanding this model to account for other ship repair demands would be worth exploring.

Research on the ability of an adversary to attack or negatively influence US ship repair workers, facilities and supply chains and the implications for meeting battle demand is worth exploring.

It is possible for a single missile strike to kill or injure a sizeable amount of a ship's crew. This may decrease a ship's capability to man watch stations and battle positions. Research on the ability of a ship's crew to continue to effectively fight after being struck is worth exploring.

Finally, naval tactics have always focused on the aircraft carrier, as discussed herein. However, these tactics may be outdated when confronted with missile technology. Whether there are alternative tactics that should be employed in the face of missile technology is something worth exploring.

Final Thoughts

"What is going to start the war with China?" is an important question with several possible answers. Today, these answers have not yet manifested into true impetus for war and hopefully never do. Yet, even if the United States does not want to fight a war on the scale of World War III, it must still be ready for it.

As described by Ret. Gen. Dubik: "This is the war, however, that the combined forces must be prepared to fight and win—otherwise deterrent credibility decreases. The paradox of deterrence, however, is at play in this contingency: the less prepared the allies are for the scenario no one wants, the more likely that scenario case becomes."[203] Even if war is not currently on the horizon, the country must still be ready for it. Many did not believe that WWII would occur, and yet it did. Having the necessary industrial capabilities to support such a war was critical in its success.

Demonstrating these capabilities on a national scale leads to deterrence. Deterrence is the "persuasion of one's opponent that the costs and/or risks of a given course of action he might take outweigh its benefits."[204] Put another way, deterrence is a form of coercion, and "coercion seeks to change the behavior of states (or occasionally

[203] James J. Dubik and Nic Vincent, *America's Global Competitions: The Gray Zone in Context* (Washington, DC: Institute for the Study of War, 2018), 24, http://www.understandingwar.org/sites/default/files/The%20Gray%20Zone_Dubik_2018.pdf.

[204] Lawrence Freedman, "General Deterrence and the Balance of Power," *Review of International Studies* 15, no. 2 (April 1989): 199-210, https://www.jstor.org/stable/20097179?seq=1.

significant non-state actors)."[205] Coercion in the military arena involves the threat of force or use of force to back up that threat. Persuasion in this situation is the message that the United States is ready for any and all conflict. Today, it is deterrence that keeps the world powers in balance and World War III from happening.

Deterrence is a delicate dance. In the challenge and response dynamic that exists between China and the United States, the world powers find themselves in a state of competition. A competition that if not solved and handled correctly could lead to war. The looming threat of devastation of that war hangs over the heads of world leaders. If the threshold of war is crossed it could mean incredible destruction. Therefore, the nations of today are taking advantage of everything they can to stay below the threshold of war. These efforts have been categorized as "Grey Zone" activities, as they are not necessary peaceful, but also not acts of war."[206]

This is the current world order as it stands today. Competition between global powers, doing everything they can to jockey for their various political positions and goals, all while staying below the threshold of war because of the promise of deterrence. This requires that the art of deterrence strategy be correct as it is critical to peace and the global order. One key component to deterrence is the idea that an opponent can field and sustain a fighting force. For purposes of this thesis, the Pacific ship repair industry was

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[205] Robert A. Pape, *Bombing to Win* (Ithaca, NY: Cornell University Press, 2014), 12.

[206] Donald Stoker and Craig Whiteside, "Blurred Lines: Gray-Zone Conflflict and Hybrid War—Two Failures of American Strategic Thinking," *Naval War College Review* 73, no. 1 (Winter 2020), https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=8092&context=nwc-review.

examined. The answer to whether it is capable of sustaining such a war in the Western Pacific is a solid “maybe.”

Under certain simulations, the repair industry was not tested because the Fleet itself was not large enough to meet battle demand. In other scenarios, the ship repair industry did become saturated at both the worker and facilities level. However, an increase in either would have only changed the outcome of the war in one out of eight simulations. At the crux, the issue that prevented the Fleet from operating effectively was the length of time it took to repair these ships.

The United States ship repair industry must find a way to repair ships faster. It is difficult to control or reduce the P_{HIT} value. Thus, the crucial variable becomes how fast ships can be repaired and sent back out to the fight in order to meet battle demand.

As the simulations were meant to take place in the near future, it was assumed that shipbuilding would remain at current levels. If additional ships could be added to the Fleet quickly, that could affect the outcome, but only for a short time. Again, the model of replacing all ships that are damaged with new ones is likely not sustainable under wartime conditions.

As was seen in the realistic force flow scenarios, even growing the workforce and facilities by WWII rates, it did not influence the outcome of meeting battle demand. Furthermore, as discussed in the introduction, some Chinese sources report that their systems have a P_{HIT} value between 0.83 and 0.99. If this is true, with a value this high, ship repair will become even more crucial. Thus, the ability to repair ships in a shorter time is what will be critical to sustaining the Fleet during any conflict in the Western Pacific.

It was obvious that any chances at maintaining battle tempo and meeting battle demand required support from the Atlantic Fleet and thus, the United States Navy should be aware of this as it continues to evaluate its maintenance facilities on the Pacific coast. Of course, the question then becomes, if the majority of the Atlantic Fleet is sortied to assist with a war in the Pacific, how will Eastern adversaries, such as Russia or Iran, react? This may possibly leave the United States vulnerable on the East Coast.

As stated by the Chief of Naval Operations in Advantage at Sea:

> Since the beginning of the 21st century, our three Sea Services have watched with alarm the growing naval power of the People's Republic of China and the increasingly aggressive behavior of the Russian Federation. Our globally deployed naval forces interact with Chinese and Russian warships and aircraft daily. We witness firsthand their increasing sophistication and growing aggressiveness. Optimism that China and Russia might become responsible leaders contributing to global security has given way to recognition that they are determined rivals. The People's Republic of China represents the most pressing, long-term strategic threat.[207]

Many believe that the United States can simply "turn on" their shipbuilding and ship repair needs, believing that this was what occurred during WWII. However, the United States had a head start before entering the war. Liberty and Victory class ships were being built and delivered to allies before entering and therefore, the industries were already turned on. However, this will likely not be the same situation should a war in the Western Pacific break out in the coming years.

As it stands now, the ship repair industry is struggling to keep up with repair demand. However, this assumption is unlikely to remain true in any prolonged conflict.

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[207] Naval Service, *Advantage at Sea: Prevailing with Integrated All-Domain Naval Power*, December 2020, https://media.defense.gov/2020/Dec/16/2002553074/-1/-1/0/TRISERVICESTRATEGY.PDF.

Furthermore, the trend with both shipyard facilities and workers is downward. If this trend continues, even in ideal scenarios of low P_{HIT} values, the industry may not be able to keep up with demand. Ways to shorten RTs and increase facilities should be developed so that the United States is ready.

Continuing reports of declining capabilities and an inability to maintain the Fleet as-is is counterproductive in the sphere of deterrence. If the United States continues to use deterrence as its main tool, then the repair industry, even in times of peace, needs to be capable of meeting demands. "America and its allies must focus on the first leg of deterrence—actual capability—to keep competition below the threshold of conventional war."[208]

The United States ship repair industry is critical to the United States' diplomatic endeavors. The Pacific ship repair industry is even more so, considering how close it is to potential western adversaries. While sufficient in ideal scenarios, if it continues to decline, the repercussions could affect the current global order.

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[208] Dubik and Vincent, *America's Global Competitions*, 15.

APPENDIX A

WWII WORKFORCE RATES BY MONTH

WWII Workforce Rates		
Year	Month	Workers (in thousands)
1941	November	505.8
	December	556.1
1942	January	558.7
	February	660.1
	March	726.4
	April	803.3
	May	882.9
	June	949.6
	July	1038.6
	August	1143.8
	September	1224.3
	October	1277.1
	November	1346.9
	December	1406.4
1943	January	1478.9
	February	1529.7
	March	1589.9
	April	1628.2
	May	1640.5
	June	1686.6
	July	1720.5
	August	1714.9
	September	1717.1
	October	1715.3
	November	1721.7
	December	1722.5
1944	January	1683.2
	February	1673.4
	March	1649.4
	April	1628
	May	1612.2
	June	1588.3
	July	1562.3
	August	1527.9
	September	1499.3
	October	1474.9
	November	1468.9
	December	1454.4

Source: Created by author using data from US Department of Labor, *Wartime Employment, Production, and Conditions of Work* (Washington, DC: Department of Labor, 1945), Table 1.

APPENDIX B

WWII FACILITIES RATES BY YEAR

WWII Facilities	
Year	Total Pacific Shipyards
Pre-1940	10
1940	12
1941	24
1942	54
1943	77
1944	83
1945	85

Source: Tim Colton, “Shipbuilding History,” Shipbuildinghistory.com, accessed October 17, 2020, https://www.shipbuildinghistory.com/. This table was derived using the resources from https://www.shipbuildinghistory.com and examining each shipyard’s specific detail page and documenting their location, their first delivery, and their first delivery to the US Navy.

APPENDIX C

DETAILED PROCEDURE OF SIMULATION

The following rules bind the simulation:

1. The starting number of ships will be the total number of destroyers stationed in the Pacific.

2. At the start of the first engagement, only one third of these destroyers will be available to be deployed (the remaining two thirds will be in the maintenance and basic phase).

3. One destroyer will exit the maintenance and basic phase every two months and be available to be deployed.

4. One destroyer will join the Fleet via new construction every 6 months.

5. All ships entering the fight will remain in the fight until sunk or damaged.

6. Damaged ships will be sent to the closest available repair facility.

7. Travel times for Pearl is one month for each leg. Travel times for all other repair facilities is two months for each leg.

8. Depending on the P-Hit value, the first die will be as follows:[209]

[209] While a physical die can be used, for purposes of the simulation, the author used an online dice rolling website to generate the dice rolls. Roll a Dice, accessed April 20, 2021, https://rolladie.net.

- 0.75 four-sided die
    - Numbers 1-3 is a hit
    - Number 4 is a miss
- 0.625 eight-sided die
    - Numbers 1-5 is a hit
    - Numbers 6-8 is a miss
- 0.5 two-sided die
    - Number 1 is a hit
    - Number 2 is a miss
- 0.25 four-sided die
    - Number 1 is a hit
    - Numbers 3-4 is a miss

9. The second die will always be a five-sided die, with the following outcomes:
    - Numbers 1-2 is sunk
    - Numbers 3-5 is damage

10. The third die will always be a three-sided die, with the following outcomes:

  - Numbers 1-2 is heavy damage
  - Number 3 is moderate damage

The following is detailed procedure for conducting the simulation:

1. Randomly assign one-third of the ships to maintenance with 2/3 in piers and 1/3 in drydocks.
2. Randomly assign one-third of the ships to workups.
3. Randomly assign one-third of ships as available to fight.
4. At the start of each month, adjust OFRP ships as necessary using the above rules.
5. Roll dies 1, 2 and 3 (as applicable) for the first ship in the battle and record the result.
    a. If a ship is heavily damaged, assign the ship to the closest available public shipyard drydock and adjust the facilities and workforce figures. If there are no more available spaces at public shipyards, then assign ship to private shipyards.
    b. If a ship is moderately damaged, assign the ship to the closest available public shipyard pier and adjust the facilities and workforce figures. If there

are no more available spaces at public shipyards, then assign ship to private shipyards.

c. If saturation is reached in either workforce or facilities, assign the ship to a facility and record the insufficiency.

d. For all ships requiring repairs with adequate workforce and/or facilities, note when repairs will be finished and when the ship can return to the Fleet.

6. Repeat the dice rolls for all ships participating in the battle.

7. Repeat steps 4 through 6 above for all battles. Stop the simulation when there are an insufficient number of destroyers to meet battle demand.

APPENDIX D

CACULATIONS: REPAIR EFFORT

USS *Stark*:

$$Repair\ Effort = \frac{Cost\ of\ Repair}{Cost\ per\ manday}\ x\ 0.52$$

$$Repair\ Effort = \frac{142{,}000{,}000}{248}\ x\ 0.52$$

$$Repair\ Effort = 297{,}742\ mandays$$

USS *Cole*:

$$Repair\ Effort = \frac{Cost\ of\ Repair}{Cost\ per\ manday}\ x\ 0.52$$

$$Repair\ Effort = \frac{243{,}000{,}000}{375}\ x\ 0.52$$

$$Repair\ Effort = 336{,}960\ mandays$$

USS *Porter*:

$$Repair\ Effort = \frac{Cost\ of\ Repair}{Cost\ per\ manday}\ x\ 0.52$$

$$Repair\ Effort = \frac{50{,}000{,}000}{493}\ x\ 0.52$$

$$Repair\ Effort = 52{,}738\ mandays$$

USS *Kinkaid*:

$$Repair\ Effort = \frac{Cost\ of\ Repair}{Cost\ per\ manday}\ x\ 0.52$$

$$Repair\ Effort = \frac{15{,}000{,}000}{273}\ x\ 0.52$$

$$Repair\ Effort = 28571\ mandays$$

APPENDIX E

CACULATIONS: MEAN TIME TO REPAIR

$$Mean\ Time\ to\ Repair = \frac{Sum\ of\ Repair\ Effort\ for\ each\ ship}{Number\ of ships\ in\ the\ class}$$

$$\text{MTTR} = \frac{\sum_{i=1}^{n} REi}{n}$$

Heavy:

$$= \frac{(297{,}742+336{,}960)}{2}$$

=317,351 man-days

Moderate:

$$= \frac{(52{,}738+28{,}571)}{2}$$

=40,654.5 man-days

APPENDIX F

CACULATIONS: REPAIR TIME

$$Repair\ Time = \frac{Repair\ Effort}{Workers}$$

Heavy:

$$= \frac{317351\ mandays}{700\ men}$$

=453 days (14 months)

Moderate:

$$= \frac{40{,}654.5\ mandays}{700\ men}$$

=58 days (2 months)

APPENDIX G

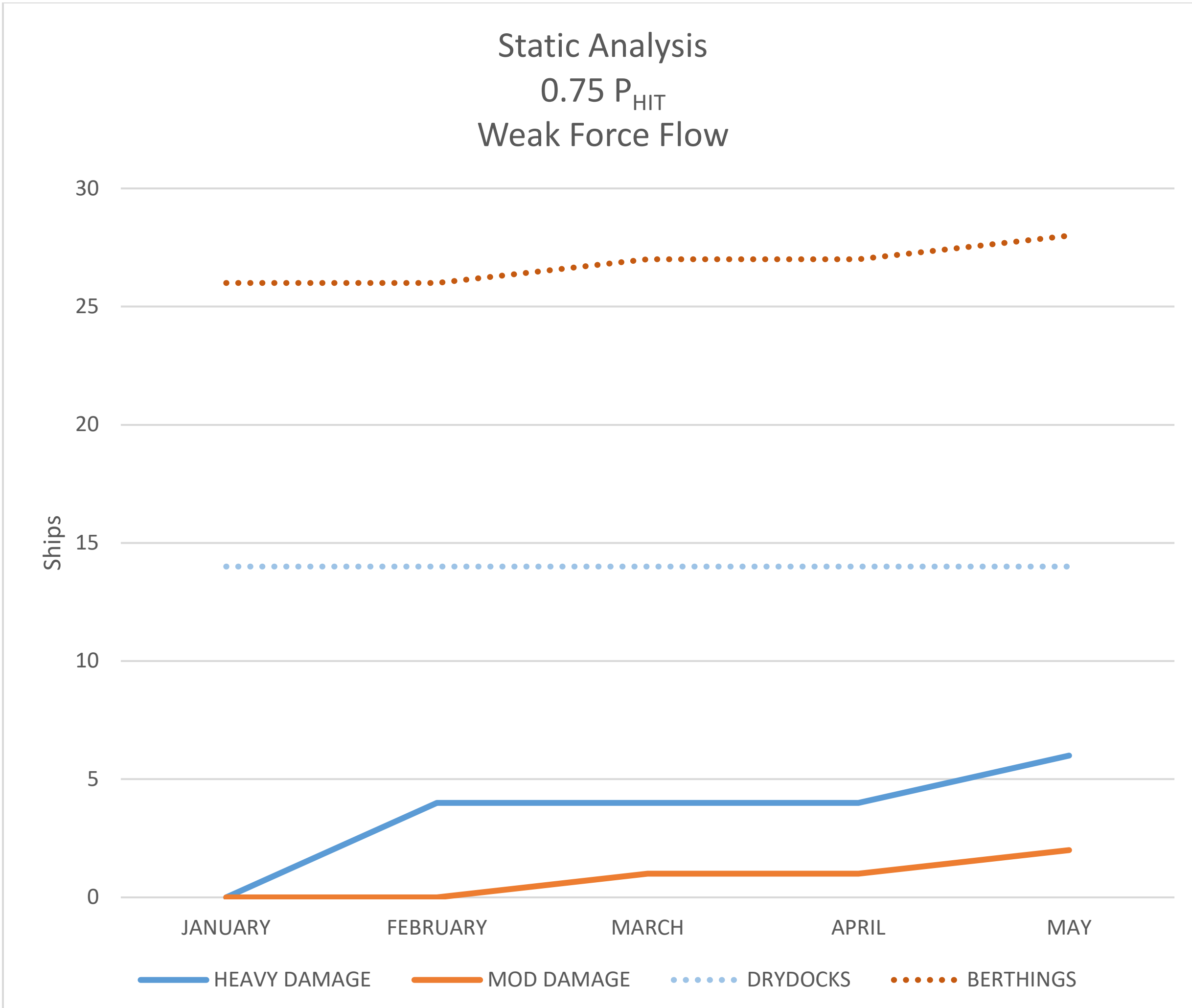
SIMULATION RESULTS: WEAK FORCE FLOW, P_{HIT} VALUE 0.75

Simulations Results: Weak Force Flow, P_{HIT} Value 0.75												
BATTLE INFO			SHIP INFO						BATTLE RESULTS			
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK
JANUARY	1	23-Jan	13	1			14	0	0	0	0	0
	2	4-Feb	14				14	4	2	0	2	0
	3	18-Feb	12				12	3	0	0	1	2
	4	27-Feb	9				9	5	3	0	1	1
FEBRUARY	5	28-Feb	7				7	2	2	0	0	0
MARCH	6	1-Mar	7	1			8	1	0	1	0	0
APRIL			7				7	0	0	0	0	0
MAY	7	4-May	7	1			8	8	2	1	2	3
JUNE	8	4-Jun	2		1		3	8				

Source: Created by author.

Shipyard Statistics: Weak Force Flow, P_{HIT} Value 0.75									
		Start	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6	Battle 7
PEARL	WORKFORCE	6500	6500	5100	4400			3700	3000
	BERTHINGS	6						5	4
	DRYDOCKS	3		1	0				
SEATTLE	WORKFORCE	325	225						
	BERTHINGS	6	5						
	DRYDOCKS	3							
PORTLAND	WORKFORCE	725	625					725	
	BERTHINGS	2	1					2	
	DRYDOCKS	2							
PUGET	WORKFORCE	12340	11840		11140				9740
	BERTHINGS	9	6						
	DRYDOCKS	6	4		3				1
GD NASS	WORKFORCE	2170	1970						
	BERTHINGS	4	3						
	DRYDOCKS	2	1						
CONTINENTAL	WORKFORCE	400	200						
	BERTHINGS	4	2						
	DRYDOCKS	0							
BAE	WORKFORCE	1230	1030						1130
	BERTHINGS	5	3						4
	DRYDOCKS	1							

Source: Created by author.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydocks and Berthings, respectively. As can be seen in this graph, neither the Heavy Damage nor the Moderate Damage intersect with their counterpart and therefore, facility saturation was not reached. Note that the Berthings function increases due to ships leaving OFRP dedicated piers.

APPENDIX H

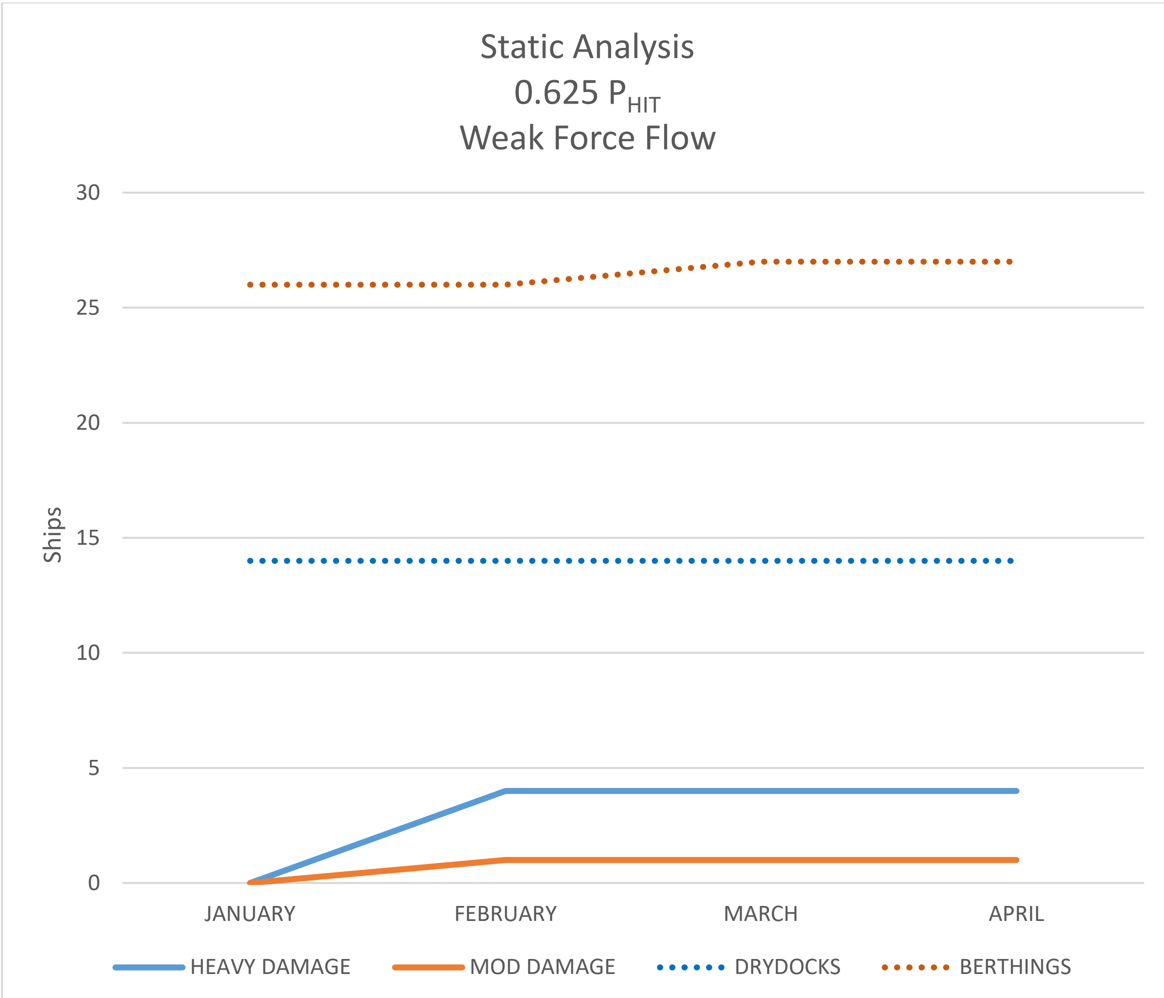
SIMULATION RESULTS: WEAK FORCE FLOW, P_{HIT} VALUE 0.625

Simulation Results: Weak Force Flow, P_{HIT} Value 0.625												
BATTLE INFO			SHIP INFO						BATTLE RESULTS			
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK
JANUARY	1	23-Jan	13	1			14	0	0	0	0	0
	2	4-Feb	14				14	4	0	0	3	1
	3	18-Feb	10				10	3	1	0	0	2
	4	27-Feb	8				8	5	3	1	1	0
FEBRUARY	5	28-Feb	6				6	2	1	1	0	0
MARCH	6	1-Mar	5	1			6	1	0	0	0	1
APRIL			5				5	0	0	0	0	0
MAY	7	4-May	5	1			6	8				

Source: Created by author.

Shipyard Statistics: Weak Force Flow, P_{HIT} Value 0.625								
		Start	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6
PEARL	WORKFORCE	6500		4400		3700	3000	
	BERTHINGS	6				5	4	
	DRYDOCKS	3		0				
SEATTLE	WORKFORCE	325	225					
	BERTHINGS	6	5					
	DRYDOCKS	3						
PORTLAND	WORKFORCE	725	625				725	
	BERTHINGS	2	1				2	
	DRYDOCKS	2						
PUGET	WORKFORCE	12340	11840			11140		
	BERTHINGS	9	6					
	DRYDOCKS	6	4			3		
GD NASS	WORKFORCE	2170	1970					
	BERTHINGS	4	3					
	DRYDOCKS	2	1					
CONTINENTAL	WORKFORCE	400	200					
	BERTHINGS	4	2					
	DRYDOCKS	0						
BAE	WORKFORCE	1230	1030					1130
	BERTHINGS	5	3					4
	DRYDOCKS	1						

Source: Created by author.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydocks and Berthings, respectively. As can be seen in this graph, neither the Heavy Damage nor the Moderate Damage intersect with their counterpart and therefore, facility saturation was not reached. Note that the Berthings function increases due to ships leaving OFRP dedicated piers.

APPENDIX I

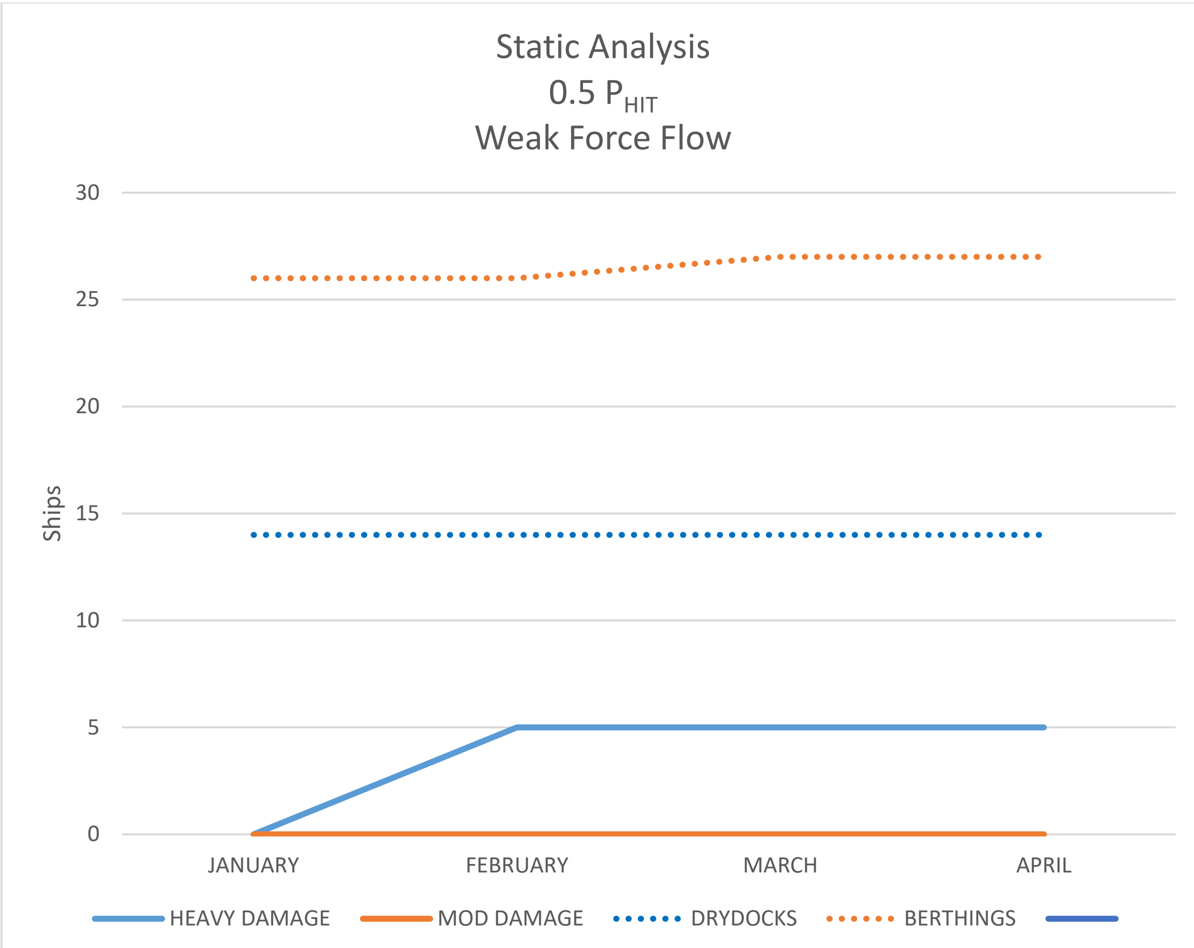
SIMULATION RESULTS: WEAK FORCE FLOW, P_{HIT} VALUE 0.5

Simulation Results: Weak Force Flow, P_{HIT} Value 0.5												
BATTLE INFO			SHIP INFO						BATTLE RESULTS			
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK
JANUARY	1	23-Jan	13	1			14	0	0	0	0	0
	2	4-Feb	14				14	4	1	0	1	2
	3	18-Feb	11				11	3	1	0	1	1
	4	27-Feb	9				9	5	3	0	2	0
FEBRUARY	5	28-Feb	7				7	2	1	0	1	0
MARCH	6	1-Mar	6	1			7	1	0	0	0	1
APRIL			6				6	0	0	0	0	0
MAY	7	4-May	6	1			7	8				

Source: Created by author.

Shipyard Statistics: Weak Force Flow, P_{HIT} Value 0.5								
		Start	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6
PEARL	WORKFORCE	6500		5800	5100	4400		
	BERTHINGS	6						
	DRYDOCKS	3		2	1	0		
SEATTLE	WORKFORCE	325	225					
	BERTHINGS	6	5					
	DRYDOCKS	3						
PORTLAND	WORKFORCE	725	625				725	
	BERTHINGS	2	1				2	
	DRYDOCKS	2						
PUGET	WORKFORCE	12340	11840			11140	10440	
	BERTHINGS	9	6					
	DRYDOCKS	6	4			3	2	
GD NASS	WORKFORCE	2170	1970					
	BERTHINGS	4	3					
	DRYDOCKS	2	1					
CONTINENTAL	WORKFORCE	400	200					
	BERTHINGS	4	2					
	DRYDOCKS	0						
BAE	WORKFORCE	1230	1030					1130
	BERTHINGS	5	3					4
	DRYDOCKS	1						

Source: Created by author.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydocks and Berthings, respectively. As can be seen in this graph, neither the Heavy Damage nor the Moderate Damage intersect with their counterpart and therefore, facility saturation was not reached. Note that the Berthings function increases due to ships leaving OFRP dedicated piers.

APPENDIX J

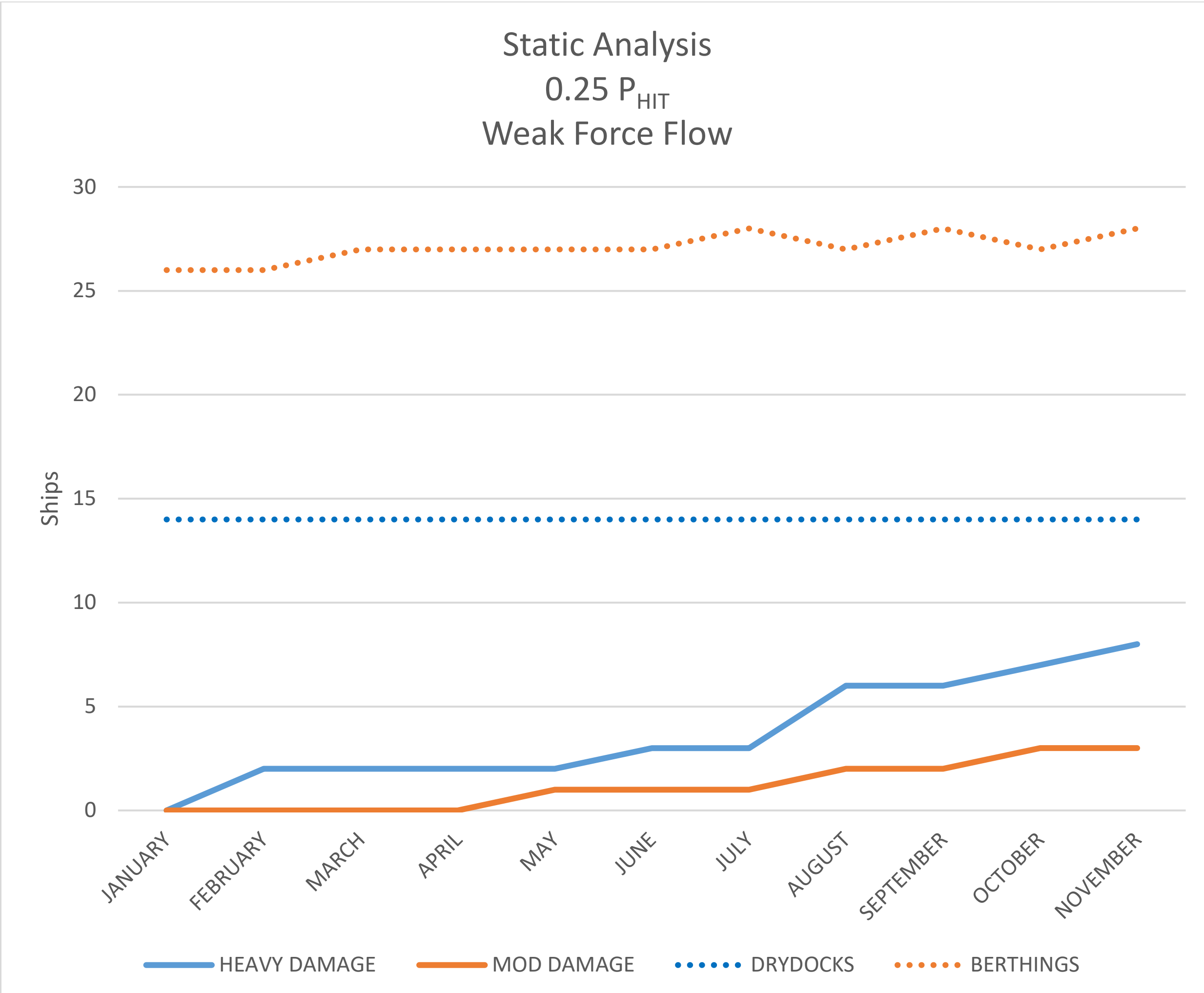
SIMULATION RESULTS: WEAK FORCE FLOW, P_{HIT} VALUE 0.25

Simulation Results: Weak Force Flow, P_{HIT} Value 0.25													
BATTLE INFO			SHIP INFO						BATTLE RESULTS				RETURN FROM REPAIR
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK	
JANUARY	1	23-Jan	13	1			14	0	0	0	0	0	
	2	4-Feb	14				14	4	3	0	1	0	
	3	18-Feb	13				13	3	2	0	0	1	
	4	27-Feb	12				12	5	5	0	0	0	
FEBRUARY	5	28-Feb	12				12	2	1	0	1	0	
MARCH	6	1-Mar	11	1			12	1	1	0	0	0	
APRIL			12				12	0	0	0	0	0	
MAY	7	4-May	12	1			13	8	7	1	0	0	
JUNE	8	4-Jun	12		1		13	8	7	0	1	0	
JULY			12	1			13	0	0	0	0	0	
	9	9-Aug	13				13	8	5	1	0	2	
AUGUST	10	24-Aug	10				10	4	0	0	3	1	
SEPTEMBER			6	1			7	0	0	0	0	0	1
	11	11-Oct	8				8	4	3	1	0	0	
OCTOBER	12	26-Oct	7				7	6	5	0	1	1	
	13	12-Nov	5	1			6	5	3	0	1	1	
NOVEMBER	14	30-Nov	4				4	5					

Source: Created by author.

Shipyard Statistics: Weak Force Flow, P_{HIT} Value 0.25															
		MAX	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6	Battle 7	Battle 8	Battle 9	Battle 10	Battle 11	Battle 12	Battle 13
PEARL	WORKFORCE	6500		5800			5100		4400	3700	3000	3700	3000		
	BERTHINGS	6							5		4	5	4		
	DRYDOCKS	3		2			1			0					
SEATTLE	WORKFORCE	325	225												
	BERTHINGS	6	5												
	DRYDOCKS	3													
PORTLAND	WORKFORCE	725	625					725							25
	BERTHINGS	2	1					2							
	DRYDOCKS	2													1
PUGET	WORKFORCE	12340	11840									9740		9040	
	BERTHINGS	9	6												
	DRYDOCKS	6	4									1		0	
GD NASS	WORKFORCE	2170	1970												
	BERTHINGS	4	3												
	DRYDOCKS	2	1												
CONTINENTAL	WORKFORCE	400	200											300	400
	BERTHINGS	4	2											3	4
	DRYDOCKS	0													
BAE	WORKFORCE	1230	1030						1130		1230				
	BERTHINGS	5	3						4		5				
	DRYDOCKS	1													

Source: Created by author.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydocks and Berthings, respectively. As can be seen in this graph, neither the Heavy Damage nor the Moderate Damage intersect with their counterpart and therefore, facility saturation was not reached. Note that the Berthings function increases due to ships leaving OFRP dedicated piers.

APPENDIX K

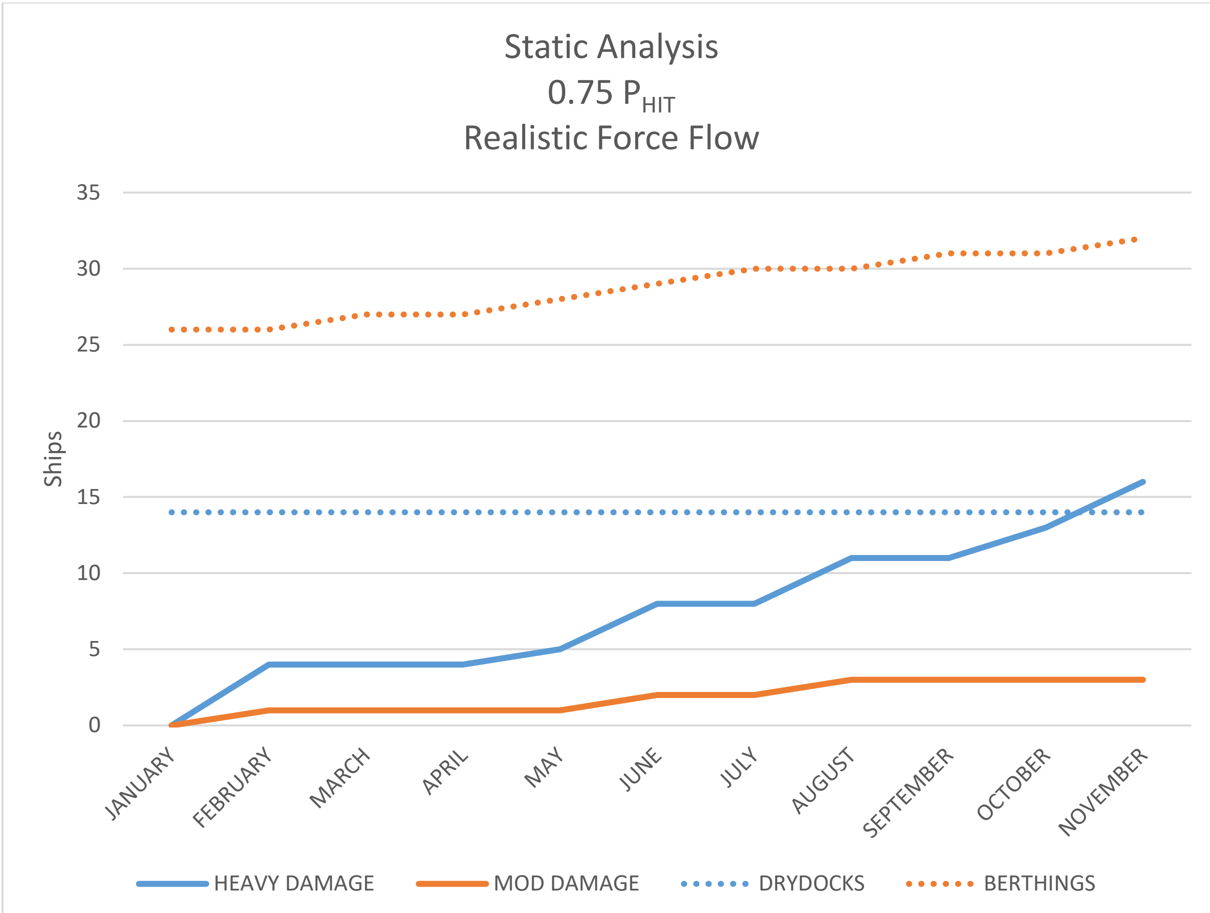
SIMULATION RESULTS: REALISTIC FORCE FLOW, P_{HIT} VALUE 0.75

Simulation Results: Realistic Force Flow, P_{HIT} Value 0.75													
BATTLE INFO			SHIP INFO						BATTLE RESULTS				RETURN FROM REPAIR
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK	
JANUARY	1	23-Jan	13	1		6	20	0	0	0	0	0	
	2	4-Feb	20			5	25	4	2	0	0	2	
	3	18-Feb	23				23	3	1	0	1	1	
	4	27-Feb	21				21	5	1	0	2	2	
FEBRUARY	5	28-Feb	17				17	2	0	1	1	0	
MARCH	6	1-Mar	15	1		4	20	1	0	0	0	1	
APRIL			19			3	22	0					
MAY	7	4-May	22	1		2	25	8	3	0	1	4	
JUNE	8	4-Jun	20		1	1	22	8	2	1	3	2	1
JULY			17	1			18	0					
	9	9-Aug	18				18	8	2	1	2	3	
AUGUST	10	24-Aug	12				12	4	1	0	1	2	
SEPTEMBER			9	1			10	0					1
	11	11-Oct	11				11	4	2	0	2	0	
OCTOBER	12	26-Oct	9				9	6	3	0	0	4	
	13	12-Nov	5	1			6	5	1	0	3	1	
NOVEMBER	14	30-Nov	2				2	5	0	0	0	0	

Source: Created by author.

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.75															
		Start	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6	Battle 7	Battle 8	Battle 9	Battle 10	Battle 11	Battle 12	Battle 13
PEARL	WORKFORCE	6500			5800	4400	3700		4400	3700	3000	3700			
	BERTHINGS	6					5		6	5	4	5			
	DRYDOCKS	3			2	0									
SEATTLE	WORKFORCE	325										-375	-1075		-1775
	BERTHINGS	6													
	DRYDOCKS	3										2	1		0
PORTLAND	WORKFORCE	725	625				725			25			-675		
	BERTHINGS	2	1				2								
	DRYDOCKS	2								1			0		
PUGET	WORKFORCE	12340	11840				11140		10440	9040					
	BERTHINGS	9	6												
	DRYDOCKS	6	4				3		2	0					
GD NASS	WORKFORCE	2170	1970								1270				
	BERTHINGS	4	3												
	DRYDOCKS	2	1								0				
CONTINENTAL	WORKFORCE	400	200									300		400	-1000
	BERTHINGS	4	2									3		4	2
	DRYDOCKS	0													
BAE	WORKFORCE	1230	1030					1130		1230	530				
	BERTHINGS	5	3					4		5					
	DRYDOCKS	1									0				

Source: Created by author.
NOTE: Red cells indicate a deficit in workers. Blue cells indicate ships assigned to berthings that otherwise should have been assigned to drydocks.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydocks and Berthings, respectively. As can be seen in this graph, the dotted blue and solid blue lines intersect, indicating saturation was reached for Drydock facilities. Note the dotted orange line increases due to ships leaving the OFRP cycle, as well as leaving repairs due to moderate damage. No saturation point was reached for Berthings.

APPENDIX L

SIMULATION RESULTS: REALISTIC FORCE FLOW, P_{HIT} VALUE 0.625

Simulation Results: Realistic Force Flow, P_{HIT} Value 0.625

BATTLE INFO			SHIP INFO						BATTLE RESULTS				RETURN FROM REPAIR
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK	
JANUARY	1	23-Jan	13	1		6	20	0	0	0	0	0	
	2	4-Feb	20			5	25	4	1	0	0	3	
	3	18-Feb	22				22	3	2	0	1	0	
	4	27-Feb	21				21	5	2	0	1	2	
FEBRUARY	5	28-Feb	18				18	2	1	1	0	0	
MARCH	6	1-Mar	17	1		4	22	1	0	0	0	1	
APRIL			21			3	24	0					
MAY	7	4-May	24	1		2	27	8	4	1	1	2	1
JUNE	8	4-Jun	24		1	1	26	8	3	0	2	3	
JULY			21	1			22	0					
	9	9-Aug	22				22	8	3	0	4	1	
AUGUST	10	24-Aug	17				17	4	1	0	1	2	1
SEPTEMBER			15	1			16	0					
	11	11-Oct	16				16	4	2	0	2	0	
OCTOBER	12	26-Oct	14				14	6	4	0	1	1	
	13	12-Nov	12	1			13	5	2	1	1	1	
NOVEMBER	14	30-Nov	10				10	5	2	1	1	1	
DECEMBER			7	1	1		9	0					
JANUARY	15	29-Jan	9				9	6	2	0	2	2	
FEBRUARY			5	1			6						2
MARCH	16	2-Mar	8				8	2	0	1	0	1	
	17	26-Mar	6				6	3	0	0	1	2	
APRIL			3	1			4	0					
MAY			4				4	0					2
JUNE			6	1	1		8	0					1
JULY	18	5-Jul	9				9	3	1	1	1	0	
	19	12-Jul	5				7	3	1	0	2	0	
AUGUST	20	6-Aug	3	1			4	0	0	0	0	0	1
SEPTEMBER			5				5	0					
OCTOBER	21	6-Oct	5	1			6	0	0	0	0	0	3
NOVEMBER	22	1-Nov	8				9	4	1	1	1	1	
	23	25-Nov	5				6	0	0	0	0	0	5
DECEMBER			5	1	1		13						
JANUARY			7				13						
FEBRUARY			7	1			14						1
MARCH			9				15						
APRIL			9	1			16						
MAY			10				16						
JUNE	24	18-Jun	10	1	1		18	21					

Source: Created by author.

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.625

			YEAR 1					
			JANUARY	FEBRUARY				MARCH
		MAX	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6
PEARL	WORKFORCE	6500			5800	5100	4400	
	BERTHINGS	6					5	
	DRYDOCKS	3			2	1		
SEATTLE	WORKFORCE	325	225					
	BERTHINGS	6	5					
	DRYDOCKS	3						
PORTLAND	WORKFORCE	725	625				725	
	BERTHINGS	2	1				2	
	DRYDOCKS	2						
PUGET	WORKFORCE	12340	11840					
	BERTHINGS	9	6					
	DRYDOCKS	6	4					
GD NASS	WORKFORCE	2170	1970					
	BERTHINGS	4	3					
	DRYDOCKS	2	1					
CONTINENTAL	WORKFORCE	400	200					
	BERTHINGS	4	2					
	DRYDOCKS	0						
BAE	WORKFORCE	1230	1030					
	BERTHINGS	5	3					
	DRYDOCKS	1						

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.625 (cont.)

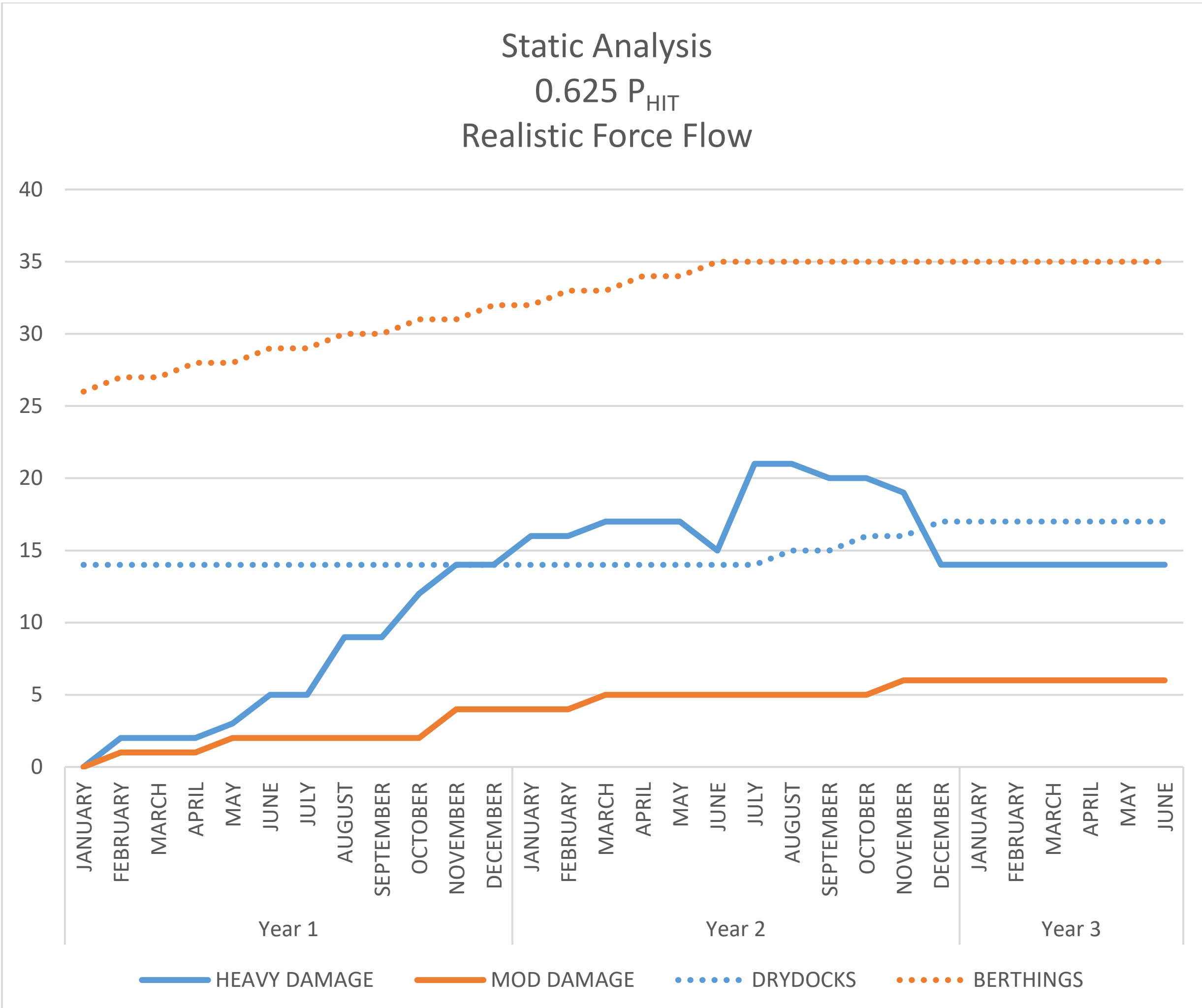
APRIL	MAY	JUNE	JULY	AUGUST		SEPTEMBER	OCTOBER	
	Battle 7	Battle 8		Battle 9	Battle 10		Battle 11	Battle 12
	3700					4400		
	5					6		
	0							
							-475	-1175
							2	1
				25			-675	
				1			0	
		10440		9040				
		2		0				
				1270				
				0				
						300		400
						3		4
1130			1230		530			
4			5					
					0			

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.625 (cont.)								
			YEAR 2					
NOVEMBER		DECEMBER	JANUARY	FEBRUARY	MARCH		APRIL	MAY
Battle 13	Battle 14		Battle 15		BATTLE 16	BATTLE 17		
3700	3000				2300			
5	4				5			
-1875			-2575			-3275		
			4			3		
0								
	-1375		-2075					
	1		0					
				9140			9240	
				7			8	
		1370						
		4						

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.625 (cont.)							
JUNE	JULY		AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	
	BATTLE 18	BATTLE 19			BATTLE 21	BATTLE 22	BATTLE 23
4400	3000	2300		3000	3700	3700	
6	5					4	
2	1	0		1	2	1	
		-3975					
		2					
9340					10040		
9							
					1		
			2070				
			1				

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.625 (cont.)						
	YEAR 3					
DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
						BATTLE 24
		3700				
		5				
10140						
2						

Source: Created by author.
NOTE: Red cells indicate a deficit in workers. Blue cells indicate ships assigned to berthings that otherwise should have been assigned to drydocks.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydock and Pier availability, respectively. As can be seen in this graph, the Heavy Damage line and its counterpart, the Drydocks availability line, intersect and for a period of time the damage function is greater than the drydock function. This shows graphically that facility saturation was reached during this simulation for Heavily Damaged vessels, but later in the simulation, saturation was resolved when ships came out of their repairs. However, this graph also shows that the Moderate Damage line and its counterpart did not intersect. Thus, facilities saturation was not met for Moderately Damaged vessels.

APPENDIX M

SIMULATION RESULTS: REALISTIC FORCE FLOW, P_{HIT} VALUE 0.5

Simulation Results: Realistic Force Flow, P_{HIT} Value 0.5													
BATTLE INFO			SHIP INFO						BATTLE RESULTS				RETURN FROM REPAIR
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK	
JANUARY	1	23-Jan	13	1		6	20	0	0	0	0	0	
	2	4-Feb	20			5	25	4	3	1	0	0	
	3	18-Feb	24				24	3	1	0	1	1	
	4	27-Feb	22				22	5	2	0	2	1	
FEBRUARY	5	28-Feb	19				19	2	0	1	0	1	
MARCH	6	1-Mar	17	1		4	22	1	0	0	0	1	
APRIL			21			3	24	0					
MAY	7	4-May	24	1		2	27	8	3	1	3	1	2
JUNE	8	4-Jun	24		1	1	26	8	2	2	3	1	
JULY			20	1			21	0					
	9	9-Aug	21				21	8	5	0	2	1	
AUGUST	10	24-Aug	18				18	4	2	0	1	1	1
SEPTEMBER			17	1			18	0					2
	11	11-Oct	20				20	4	0	2	0	2	
OCTOBER	12	26-Oct	16				16	6	3	0	1	2	
	13	12-Nov	13	1			14	5	2	1	1	1	
NOVEMBER	14	30-Nov	11				11	5	0	0	0	0	
DECEMBER			11	1	1		13	0					
JANUARY	15	29-Jan	13				13	6	2	2	2	0	2
FEBRUARY			11	1			12						1
MARCH	16	2-Mar	13				13	2	2	0	0	0	
	17	26-Mar	13				13	3	1	0	0	2	
APRIL			11	1			12						2
MAY			14				14						2
JUNE			17	1	1		18						
JULY	18	5-Jul	19				18	3	0	0	0	1	
	19	12-Jul	9				17	3	2	0	0	1	
AUGUST	20	6-Aug	8	1			17	0	0	0	0	0	
SEPTEMBER			9				17						3
OCTOBER	21	6-Oct	12	1			21	0	0	0	0	0	3
NOVEMBER	22	1-Nov	16				24	4	2	1	0	1	
	23	25-Nov	14				22	0	0	0	0	0	
DECEMBER			14	1	1		24						1
JANUARY			17				25						
FEBRUARY			17	1			26						1
MARCH			19				27						
APRIL			19	1			28						
MAY			20				28						
JUNE	24	18-Jun	20	1	1		30	21	13	0	6	2	
JULY			22				22						
AUGUST			22	1			23						
SEPTEMBER			23				23						
OCTOBER	25	23-Oct	23	1			24	24	14	1	4	5	

Source: Created by author.

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.5

			JANUARY	FEBRUARY				MARCH	APRIL	MAY	JUNE
		MAX	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6		Battle 7	Battle 8
PEARL	WORKFORCE	6500		5800	5100	3700	3000			3700	2300
	BERTHINGS	6	6	5	5	5	4			5	3
	DRYDOCKS	3	3	3	2	0	0			0	0
SEATTLE	WORKFORCE	325									
	BERTHINGS	6	6	6	6	6	6	6	6	6	6
	DRYDOCKS	3	3	3	3	3	3	3	3	3	3
PORTLAND	WORKFORCE	725	625				725				
	BERTHINGS	2	1				2				
	DRYDOCKS	2									
PUGET	WORKFORCE	12340	11840							9740	9040
	BERTHINGS	9	6								
	DRYDOCKS	6	4							1	0
GD NASS	WORKFORCE	2170	1970								1270
	BERTHINGS	4	3								
	DRYDOCKS	2	1								0
CONTINENTAL	WORKFORCE	400	200								
	BERTHINGS	4	2								
	DRYDOCKS	0									
BAE	WORKFORCE	1230	1030						1130		430
	BERTHINGS	5	3						4		
	DRYDOCKS	1									0
		docks	22	6	5	3	3	3	3	4	3
		piers	27	11	11	11	12	6	10	11	9

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.5 (cont.)

JULY	AUGUST		SEPTEMBER	OCTOBER		NOVEMBER		DECEMBER	JANUARY	FEBRUARY	MARCH	
	Battle 9	Battle 10		Battle 11	Battle 12	Battle 13	Battle 14		Battle 15		BATTLE 16	BATTLE 17
			3000	3000		2300			900	2300	3000	
			4	4	4	3	3	3	1	3	4	4
			0	0	0	0	0	0	0	0	0	0
	-375				-1075	-1775						
6	6	6	6	6	6	6	6	6	6	6	6	6
3	2	2	2	2	1	0	0	0	0	0	0	0
	25	-675							-2075			
									0			
	1	0										
										9140		
										7		
								1370				
								4				
			300		400							
			3		4							
530												
5												
3	3	2	2	2	1	0	0	0	0	0	0	0
11	6	6	13	10	14	9	9	13	7	16	10	10

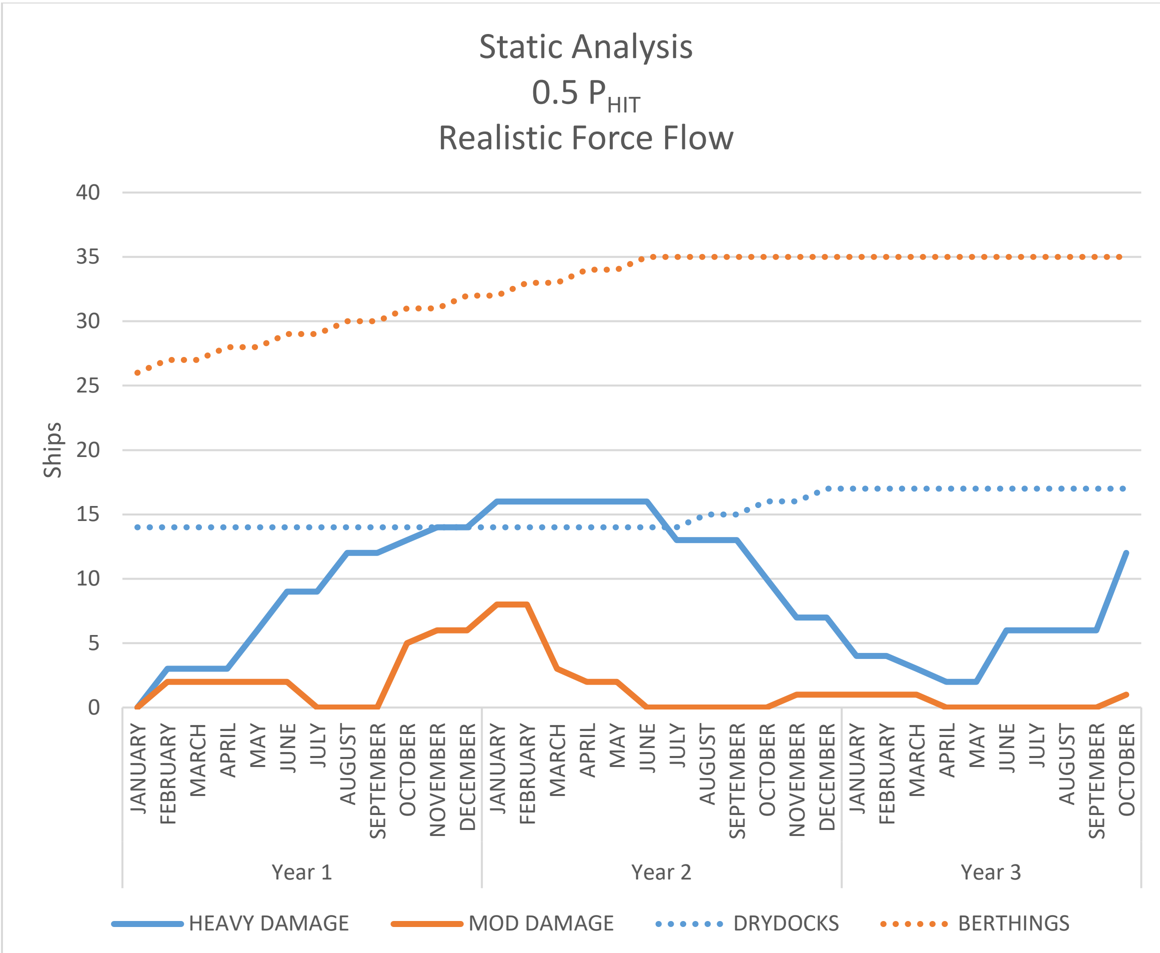
Shipyard Statistics: Realistic Force Flow, PHIT Value 0.5 (cont.)

APRIL	MAY	JUNE	JULY		AUGUST	SEPTEMBER	OCTOBER	NOVEMBER		DECEMBER	JANUARY
			BATTLE 18	BATTLE 19				BATTLE 22	BATTLE 23		
4400		6500						7200			
6	6	6	6	6	6	6	6	5	5	5	5
0	0	3	3	3	3	3	3	3	3	3	3
6	6	6	6	6	6	6	6	6	6	6	6
0	0	0	0	0	0	0	0	0	0	0	0
											-1375
											1
9240		9340					11540	12240		12340	
8		9									
							4	5		6	
				1470				2170			
				1				2			
								1230			
								1			
0	0	3	3	4	3	3	7	11	3	9	4
20	12	21	12	12	12	12	12	11	11	11	11

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.5 (cont.)

FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
								BATTLE 24
7900				5800				5100
6	6	6	6	6	6	6	6	5
3	3	3	3	0	0	0	0	
6	6	6	6	6	6	6	6	
0	0	0	0	0	0	0	0	
				10240				8940
				3				0
								530
								0
3	3	3	3	3	0	0	0	
12	12	12	12	12	12	12	12	

Source: Created by author.



Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydock and Pier availability, respectively. As can be seen in this graph, the Heavy Damage line and its counterpart, the Drydocks availability line, intersect and for a period of time the damage function is greater than the drydock function. This shows graphically that facility saturation was reached during this simulation for Heavily Damaged vessels, but later in the simulation, saturation was resolved when ships came out of their repairs. However, this graph also shows that the Moderate Damage line and its counterpart did not intersect. Thus, facilities saturation was not met for Moderately Damaged vessels.

APPENDIX N

SIMULATION RESULTS: REALISTIC FORCE FLOW, P_{HIT} VALUE 0.25

Simulation Results: Realistic Force Flow, P_{HIT} Value 0.25

BATTLE INFO			SHIP INFO						BATTLE RESULTS				RETURN FROM REPAIR
MONTH	BATTLE #	BATTLE DATE	DDG START	DDG OFRP?	DDG NC?	DDG ATLANTIC?	DDGS AVAILABLE	DDGS NEEDED	# MISS	# MD	# HD	# SUNK	
JANUARY	1	23-Jan	13	1		6	20	0	0	0	0	0	
	2	4-Feb	20			5	25	4	4	0	0	0	
	3	18-Feb	25				25	3	2	0	1	0	
	4	27-Feb	24				24	5	2	0	1	1	
FEBRUARY	5	28-Feb	22				22	2	1	0	0	1	
MARCH	6	1-Mar	21	1		4	26	1	1	0	0	0	
APRIL			26			3	29	0					
MAY	7	4-May	29	1		2	32	8	7	1	0	0	
JUNE	8	4-Jun	31		1	1	33	8	5	0	1	2	
JULY			30	1			31	0					
	9	9-Aug	31				31	8	7	1	0	0	
AUGUST	10	24-Aug	30				30	4	3	0	0	1	1
SEPTEMBER			30	1			31	0					
	11	11-Oct	31				31	4	3	0	1	0	
OCTOBER	12	26-Oct	30				30	6	4	0	2	0	
	13	12-Nov	28	1			29	5	4	1	0	0	
NOVEMBER	14	30-Nov	28				28	5	0	0	0	0	1
DECEMBER			29	1	1		31	0					
JANUARY	15	29-Jan	31				31	6	5	0	0	1	
FEBRUARY			30	1			31						1
MARCH	16	2-Mar	32				32	2	1	1	0	0	
	17	26-Mar	31				31	3	3	0	0	0	
APRIL			31	1			32						
MAY			32				32						2
JUNE			34	1	1		36						1
JULY	18	5-Jul	37				37	3	0	0	4	0	
	19	12-Jul	33				33	3	1	1	1	0	
AUGUST	20	6-Aug	31	1			32	0	0	0	0	0	1
SEPTEMBER			33				33						1
OCTOBER	21	6-Oct	34	1			35	0	0	0	0	0	
NOVEMBER	22	1-Nov	35				35	4	3	1	0	0	
	23	25-Nov	34				34	0	0	0	0	0	
DECEMBER			34	1	1		36						
JANUARY			36				36						
FEBRUARY			36	1			37						4
MARCH			41				41						
APRIL			41	1			42						
MAY			42				42						
JUNE	24	18-Jun	42	1	1		44	21	17	1	1	2	
JULY			40				40						
AUGUST			40	1			41						
SEPTEMBER			41				41						
OCTOBER	25	23-Oct	41	1			42	24	13	2	2	7	

Source: Created by author.

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.25

			JANUARY	FEBRUARY				MARCH	APRIL	MAY	JUNE
		MAX	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6		Battle 7	Battle 8
PEARL	WORKFORCE	6500			5800	5100				4400	3700
	BERTHINGS	6								5	
	DRYDOCKS	3			2	1					0
SEATTLE	WORKFORCE	325									
	BERTHINGS	6									
	DRYDOCKS	3									
PORTLAND	WORKFORCE	725	625			725					
	BERTHINGS	2	1			2					
	DRYDOCKS	2									
PUGET	WORKFORCE	12340	11840								
	BERTHINGS	9	6								
	DRYDOCKS	6	4								
GD NASS	WORKFORCE	2170	1970								
	BERTHINGS	4	3								
	DRYDOCKS	2	1								
CONTINENTAL	WORKFORCE	400	200								
	BERTHINGS	4	2								
	DRYDOCKS	0									
BAE	WORKFORCE	1230	1030						1130		
	BERTHINGS	5	3						4		
	DRYDOCKS	1									

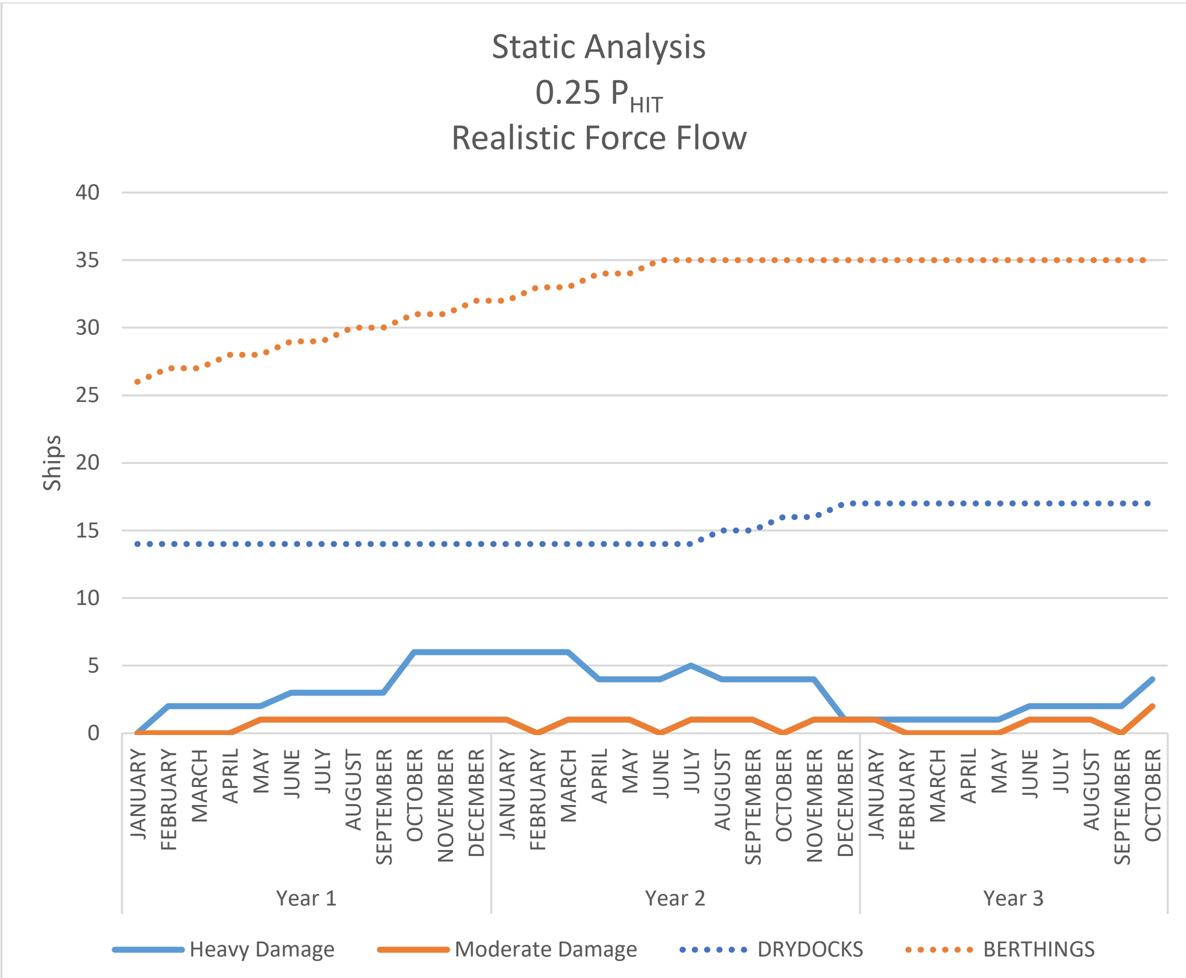
Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.25 (cont.)

JULY	AUGUST		SEPTEMBER	OCTOBER		NOVEMBER		DECEMBER	JANUARY	FEBRUARY	MARCH	
	Battle 9	Battle 10		Battle 11	Battle 12	Battle 13	Battle 14		Battle 15		BATTLE 16	BATTLE 17
	3000		3700			3000		3700		4400	3700	
	4		5			4		5		6	5	
				11140	9740					9840		
										7		
				3	1							
								2070				
								4				
			300		400							
			3		4							
1130												
5												

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.25 (cont.)											
APRIL	MAY	JUNE	JULY		AUGUST	SEPTEMBER	OCTOBER	NOVEMBER		DECEMBER	JANUARY
			BATTLE 18	BATTLE 19				BATTLE 22	BATTLE 23		
		5800		4400		5100	5800	5100			
		6		5			6	5			
		2		1		2					
9940		10040					10140			11140	
8		9									
							2			3	
					2170						
					2						

Shipyard Statistics: Realistic Force Flow, P_{HIT} Value 0.25 (cont.)								
FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
				BATTLE 24				BATTLE 25
	5800			4400				2300
	6			5				3
				1				0
	13240							12540
	6							5

Source: Created by author.



Source: Created by author.

NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydock and Pier availability, respectively. As can be seen in this graph, the Heavy Damage line and its counterpart, the Drydocks availability line, do not intersect. This shows graphically that facility saturation was not reached during this simulation for Heavily Damaged vessels. This graph also shows that the Moderate Damage line and its counterpart did not intersect. Thus, facilities saturation was not met for Moderately Damaged vessels.

APPENDIX O

PACIFIC WORKFORCE GROWTH RATES DURING WWII

Pacific WWII Workforce Rates		
Year	Month	Workers (in thousands)
1941	December	155.9
1942	June	319.0
	December	497.7
1943	January	525.2
	February	536.3
	March	558.0
	April	565.4
	May	558.9
	June	579.4
	July	592.9
	August	587.8
	September	582.7
	October	577.5
	November	579.8
	December	580.7
1944	January	567.7
	February	562.0
	March	553.9
	April	543.0
	May	532.1
	June	525.2
	July	522.2
	August	513.4
	September	513.3
	October	509.9
	November	513.5
	December	507.5

Source: US Department of Labor, *Wartime Employment, Production, and Conditions of Work* (Washington, DC: Department of Labor, 1945), Table 1, https://fraser.stlouisfed.org/files/docs/publications/bls/bls_0824_1945.pdf.

APPENDIX P

PERCENTAGE CHANGE IN WORKFORCE BY SHIPYARD

The monthly workforce figures for each shipyard was calculated using the following equation:

$$Shipyard\ workforce\ (month\ x+1) = \frac{WWII\ workforce\ (month\ x+1)}{WWII\ workforce\ (month\ x)}\ x\ Shipyard\ workforce\ (month\ x)$$

where:

$$WWII\ workforce\ is\ the\ WWII\ workforce\ figure$$

and

$$(month\ x)\ is\ any\ month\ between\ November\ 1941\ and\ December\ 1944.$$

and where

$$Shipyard\ workforce\ is\ the\ workforce\ figure\ of\ the\ specific\ shipyard$$

The table on the next page contains all outputs.

Pacific Fleet Workforce Growth by Shipyard Assuming WWII Rates									
Year	Month	WWII	Pearl	Seattle	Portland	Puget	GD Nass	Continental	BAE
1941	December	155900	6500	325	725	12340	2170	400	1230
1942	June	319000	13300	665	1483	25250	4440	818	2517
	December	497700	20751	1038	2315	39395	6928	1277	3927
1943	January	525200	21897	1095	2442	41571	7310	1348	4144
	February	536300	22360	1118	2494	42450	7465	1376	4231
	March	558000	23265	1163	2595	44168	7767	1432	4402
	April	565400	23573	1179	2629	44753	7870	1451	4461
	May	558900	23302	1165	2599	44239	7779	1434	4410
	June	579400	24157	1208	2694	45861	8065	1487	4571
	July	592900	24720	1236	2757	46930	8253	1521	4678
	August	587800	24507	1225	2734	46526	8182	1508	4638
	September	582700	24295	1215	2710	46123	8111	1495	4597
	October	577500	24078	1204	2686	45711	8038	1482	4556
	November	579800	24174	1209	2696	45893	8070	1488	4574
	December	580700	24211	1211	2700	45964	8083	1490	4582
1944	January	567700	23669	1183	2640	44935	7902	1457	4479
	February	562000	23432	1172	2614	44484	7823	1442	4434
	March	553900	23094	1155	2576	43843	7710	1421	4370
	April	543000	22640	1132	2525	42980	7558	1393	4284
	May	532100	22185	1109	2474	42117	7406	1365	4198
	June	525200	21897	1095	2442	41571	7310	1348	4144
	July	522200	21772	1089	2428	41334	7269	1340	4120
	August	513400	21405	1070	2388	40637	7146	1317	4051
	September	513300	21401	1070	2387	40629	7145	1317	4050
	October	509900	21259	1063	2371	40360	7097	1308	4023
	November	513500	21410	1070	2388	40645	7147	1318	4051
	December	507500	21159	1058	2360	40170	7064	1302	4004

Source: Created by author.

APPENDIX Q

SURVEY OF ALL US SHIPYARDS BY REGION

All Pacific Shipyards		
Shipbuilder	*City*	*State*
Anderson and Cristofani	San Francisco	CA
BAE Systems San Diego	San Diego	CA
BAE Systems San Francisco	San Francisco	CA
Barrett and Hilp	South San Francisco	CA
Basalt Rock Co.	Napa	CA
Bendixsen Shipbuilding	Fairhaven	CA
Benicia Shipbuilding	Benicia	CA
Bethlehem San Francisco	San Francisco	CA
Bethlehem San Pedro	San Pedro	CA
California Shipbuilding	Los Angeles	CA
Campbell Industries	San Diego	CA
Chandler, Ralph J.	Wilmington	CA
Colberg Boat Works	Stockton	CA
Concrete Ship Constructors, Inc.	National City	CA
Consolidated Steel	Wilmington	CA
Craig Shipbuilding	Long Beach	CA
Cryer and Sons	Oakland	CA
Dickie Bros.	San Francisco	CA
Dickie, John W., and Son	Alameda	CA
Eureka Boat Building and Repair	Fields Landing	CA
Eureka Shipbuilding	Fields Landing	CA
Fellows and Stewart	Wilmington	CA
Fulton Shipyard	Antioch	CA
General Dynamics NASSCO	San Diego	CA
General Engineering	Alameda	CA
Guntert and Zimmerman	Stockton	CA
Hammond Lumber	Humboldt Bay	CA
Hanlon Dry Dock and Shipbuilding	Oakland	CA
Harbor Boatbuilding	Terminal Island	CA
Hickinbotham Bros.	Stockton	CA
Hodgson-Greene-Haldeman	Long Beach	CA
Kaiser Richmond	Richmond	CA
Kneass, G. W.	San Francisco	CA
Knight and Carver	National City	CA
Kyle and Co.	Stockton	CA
Larson Boat Shop, Al	San Pedro	CA

Long Beach NSY	Long Beach	CA
Long Beach Shipbuilding	Long Beach	CA
Los Angeles Shipbuilding	San Pedro	CA
Lynch Shipbuilding	San Diego	CA
Mare Island NSY	Vallejo	CA
Marine Group Boat Works	National City	CA
Marinship	Sausalito	CA
Moore and Scott Iron Works	Oakland	CA
Moore Shipbuilding	Oakland	CA
Moore Dry Dock	Oakland	CA
NASSCO	San Diego	CA
Pacific Bridge Company	San Francisco	CA
Pacific Coast Engineering (PACECO)	Alameda	CA
Pacific Coast Shipbuilding	Bay Point	CA
Permanente Metals #1 Yard	Richmond	CA
Permanente Metals #2 Yard	Richmond	CA
Permanente Metals #3 Yard	Richmond	CA
Peyton Co.	Newport Beach	CA
Pollock-Stockton Shipbuilding	Stockton	CA
Risdon Iron Works	San Francisco	CA
Rolph Shipbuilding	Rolph	CA
San Diego Marine	San Diego	CA
San Francisco NSY	San Francisco	CA
South Coast Shipyard	Newport Beach	CA
Southwestern Shipbuilding	San Pedro	CA
Standard Shipbuilding	San Pedro	CA
Stephens Marine	Stockton	CA
Stone and Sons, William F.	Oakland	CA
Todd San Pedro	San Pedro	CA
Union Construction	Oakland	CA
Union Iron Works	San Francisco	CA
United Concrete Pipe	Los Angeles	CA
Van Peer Boat Works	Fort Bragg	CA
Victory Shipbuilding	Newport Beach	CA
Western Pipe and Steel	South San Francisco	CA
Western Pipe and Steel	San Pedro	CA
Wilmington Boat Works	Wilmington	CA
Wood, Clyde W.	Stockton	CA
Honolulu Shipyard	Honolulu	HI
Pearl Harbor NSY	Honolulu	HI
Albina Engine and Machine Works	Portland	OR
Astoria Marine	Astoria	OR

Coast Shipbuilding	Portland	OR
Columbia River Packers Assn.	Astoria	OR
Columbia River Shipbuilding	Portland	OR
Commercial Iron Works	Portland	OR
Cooper Marine	Saint Petersburg	OR
Coos Bay Shipbuilding	Marshfield	OR
Diversified Marine	Portland	OR
Foss Shipyard	Rainier	OR
Foundation Contractors	Portland	OR
Giddings Boat Works	Charleston	OR
Grant Smith-Porter	Portland	OR
Gunderson Marine	Portland	OR
Hillstrom Shipbuilding	Coos Bay	OR
Hillstrom Shipbuilding	North Bend	OR
Kaiser Swan Island	Portland	OR
Kruse and Banks Shipbuilding	North Bend	OR
McEachern Ship	Astoria	OR
Mid-Coast Marine	Coos Bay	OR
Nichols Boatworks	Hood River	OR
Northwest Steel Company	Portland	OR
Oregon Shipbuilding	Portland	OR
Peninsula Shipbuilding	Portland	OR
Rodgers Shipbuilding	Astoria	OR
Schooner Creek Boat Works	Portland	OR
Siletz Boatworks	Kernville	OR
Sommarstrom Bros.	Columbia City	OR
St. Helens Shipbuilding	St. Helens	OR
Standifer Construction, G. M.	Portland	OR
Steinbach Ironworks	Tillamook	OR
Sundial Marine Construction	Troutdale	OR
Supple Ballin	Portland	OR
US Barge	Portland	OR
Vigor Industrial	Portland	OR
Wahl Marine Construction, Fred	Reedsport	OR
Willamette Iron and Steel	Portland	OR
Wilson Shipbuilding	Astoria	OR
Zidell Marine	Portland	OR
Aleutian Yachts	Tacoma	WA
All American Marine	Bellingham	WA
Allen Shipbuilding	Seattle	WA
Ames Shipbuilding	Seattle	WA
Anacortes Slipways Co	Anacortes	WA

Armstrong Marine	Port Angeles	WA
Associated Shipbuilders Harbor Island	Seattle	WA
Associated Shipbuilders Lake Union	Seattle	WA
Babare Bros.	Tacoma	WA
Ballard Marine Railway	Seattle	WA
Barbee Marine Yards	Renton	WA
Bellingham Iron Works	Bellingham	WA
Bellingham Marine	Bellingham	WA
Bellingham Marine Railway	Bellingham	WA
Berg Shipyard	Blaine	WA
Birchfield Shipbuilding and Boiler	Tacoma	WA
Boeing Marine Systems	Renton	WA
Chilman Shipyards	Hoquiam	WA
Christensen Yachts	Vancouver	WA
Crawford and Reid	Tacoma	WA
Dakota Creek Industries	Anacortes	WA
Delta Marine Industries	Seattle	WA
Duthie Shipbuilding, J. F.	Seattle	WA
Edwing Boat	Chinook	WA
Everest Marine	Burlington	WA
Everett Pacific Shipbuilding	Everett	WA
Fairhaven Shipyard	South Bellingham	WA
Foundation Contractors	Tacoma	WA
Gig Harbor Shipbuilding	Gig Harbor	WA
Grant Smith-Porter	Aberdeen	WA
Grays Harbor Motor Ship	Aberdeen	WA
Grays Harbor Shipbuilding	Aberdeen	WA
Hansen Boat Company	Marysville	WA
Hitchings and Joyce	Hoquiam	WA
Hoquiam Shipyard	Hoquiam	WA
JT Marine	Vancouver	WA
Kaiser Vancouver	Vancouver	WA
Kvichak Marine	Seattle	WA
Lake Union Dry Dock	Seattle	WA
Lake Washington Shipyards	Houghton	WA
Lindstrom Shipbuilding	Aberdeen	WA
Little Hoquiam Shipyard	Hoquiam	WA
Lockheed Shipbuilding	Seattle	WA
Marco Shipyard	Seattle	WA
Marine Industries Northwest	Tacoma	WA
Marine Power and Equipment	Tacoma	WA
Maritime Shipyards	Seattle	WA

Martinac Shipbuilding	Tacoma	WA
Martinolich Shipbuilding	Tacoma	WA
Matthews Shipbuilding	Hoquiam	WA
Mavrik Marine	La Conner	WA
Meacham and Babcock	Seattle	WA
Moe Enterprises, Howard	Hoquiam	WA
Mojean and Ericson	Tacoma	WA
Moran Bros.	Seattle	WA
Motor Boat Marina	Seattle	WA
Nichols Bros. Boatbuilders	Freeland	WA
Nilson and Kelez Shipbuilding	Seattle	WA
Nordlund Boats	Tacoma	WA
North Star Yachts	Kalama	WA
Northern Marine	Anacortes	WA
Northwestern Shipbuilding	South Bellingham	WA
Olson and Winge	Seattle	WA
Pacific American Fisheries	Bellingham	WA
Pacific Boatbuilding	Tacoma	WA
Pacific Car and Foundry	Renton/Seattle/Tacoma	WA
Pacific Fishermen	Seattle	WA
Pacific Mariner	LaConner	WA
Pacific Shipways	Anacortes	WA
Penn Cove Shellfish	Coupeville	WA
Petersen, Andrew	Aberdeen	WA
Peterson Shipbuilding	Tacoma	WA
Prothero Boat Company	Seattle	WA
Puget Sound Bridge and Dredging	Seattle	WA
Puget Sound Boatbuilding	Tacoma	WA
Puget Sound NSY	Bremerton	WA
Puget Sound Shipbuilding	Olympia	WA
Reliable Welding Works	Olympia	WA
Rozema Boat Works	Mount Vernon	WA
Sagstad Shipyards	Seattle	WA
Sanderson and Porter	Willapa Harbor	WA
Sea-Tac Shipbuilding	Seattle	WA
Sea-Tac Shipbuilding	Tacoma	WA
Seabell Shipbuilding	Seattle	WA
Seaborn Shipyards	Tacoma	WA
Seattle Dry Dock	Seattle	WA
Seattle North Pacific Shipbuilding	Seattle	WA
Seattle Shipbuilding	Seattle	WA
Skinner and Eddy	Seattle	WA

Sloan Shipyards	Anacortes	WA
Standifer Construction, G. M.	Vancouver	WA
Tacoma Boatbuilding	Tacoma	WA
Tacoma Shipbuilding	Tacoma	WA
Todd Seattle	Seattle	WA
Todd Tacoma	Tacoma	WA
Treutle Marine Ways	Seattle	WA
Tripple and Everett Marine Ways	Seattle	WA
Vigor Industrial	Ballard	WA
Vigor Industrial	Seattle	WA
Vigor Industrial	Tacoma	WA
Vigor Industrial	Vancouver	WA
Western Boatbuilding	Tacoma	WA
Western Towboat	Seattle	WA
Westport Yachts	Westport	WA
Westport Yachts	Port Angeles	WA
Westport Yachts	Hoquiam	WA
Winslow Marine Railway	Winslow	WA
Wright Shipyards	Tacoma	WA

Source: Tim Colton, "Shipbuilding History," Shipbuildinghistory.com, accessed October 17, 2020, https://www.shipbuildinghistory.com/.

Active WWII Pacific Shipyards Ship Delivery					
Shipbuilder/repair, that built/repair ships for the USN/USMC/USSB in WWII	**City**	**State**	**Were present before Dec 7, 1941**	**1st ship ever delivered**	**Date of 1st navy ship delivered to the USN/USMC/USSB**
Puget Sound NSY	Bremerton	WA	yes	1900	1901
Associated Shipbuilders Harbor Island/lake union/Puget Sound Bridge and Dredging Company	Seattle	WA	yes	1903	1940
Martinac Shipbuilding	Tacoma	WA	yes	1926	1940
Harbor Boatbuilding	Terminal Island	CA	yes	1925	1941
Kaiser Richmond No. 3	Richmond	CA	no	1942	1942
Northwestern Shipbuilding	South Bellingham	WA	no	1942	1942
Olson and Winge	Seattle	WA	yes	Nov-41	1942
Pacific Boatbuilding	Tacoma	WA	yes	1937	1942
Pacific Car and Foundry	Renton/Seattle/Tacoma	WA	no	1942	1942
Pacific Shipways	Anacortes	WA	no	1942	1942
Ackerman Boat	Newport Beach	CA	no	1943	Apr-05
Chilman Shipyards	Hoquiam	WA	yes	1910	1943
Hillstrom Shipbuilding	North Bend	OR	no	Jul-43	1943
Pollock-Stockton Shipbuilding	Stockton	CA	no	1943	1943
Gunderson Marine	Portland	OR	yes	1944	1945
Sagstad Shipyards	Seattle	WA	yes	1912	1945
Mare Island NSY	Vallejo	CA	yes	1860	Jun-14
Moore Dry Dock	Oakland	CA	yes	1888	Aug-17
Albina Engine and Machine Works	Portland	OR	yes	Mar-18	Mar-18
Todd San Pedro	San Pedro	CA	yes	Jun-18	Jun-18
Seattle-Tacoma Shipbuilding, Tacoma	Tacoma	WA	yes	1917	Jul-18
Western Pipe and Steel	South San Francisco	CA	yes	Sep-18	Sep-18
Western Pipe and Steel	San Pedro	CA	yes	1919	Jan-19
Basalt Rock Co.	Napa	CA	yes	1938	Jan-41
Bellingham Iron Works/Bellingham Marine Railway/Shipyards	Bellingham	WA	yes	1917	Feb-41
Commercial Iron Works	Portland	OR	yes	1933	Jun-41
Lake Washington Shipyards	Houghton	WA	yes	1901	Jun-41
Consolidated Steel	Wilmington	CA	yes	Sep-41	Sep-41
General Engineering/Hanlon Dry Dock	Alameda	CA	yes	Jun-26	Sep-41

Lynch Shipbuilding	San Diego	CA	yes	Oct-41	Oct-41
Peterson Shipbuilding	Tacoma	WA	yes	1938	Nov-41
Anderson and Cristofani	San Francisco	CA	yes	1904	Dec-41
Fulton Shipyard	Antioch	CA	yes	1926	Dec-41
Stephens Marine	Stockton	CA	yes	1908	Dec-41
Oregon Shipbuilding	Portland	OR	no	Jan-42	Jan-42
California Shipbuilding	Los Angeles	CA	no	Feb-42	Feb-42
Permanente Metals #2 Yard	Richmond	CA	no	Feb-42	Feb-42
Colberg Boat Works	Stockton	CA	yes	1919	Mar-42
Birchfield Shipbuilding and Boiler	Tacoma	WA	no	Apr-42	Apr-42
South Coast Shipyard	Newport Beach	CA	yes	1930	May-42
Astoria Shipbuilding Company	Astoria	OR	yes	1924	Jun-42
Ballard Marine Railway	Seattle	WA	yes	1890	Jul-42
Kaiser Vancouver	Vancouver	WA	no	Jul-42	Jul-42
Kruse and Banks Shipbuilding	North Bend	OR	yes	1903	Jul-42
Seattle Shipbuilding	Seattle	WA	yes	1936	Jul-42
Tacoma Boatbuilding	Tacoma	WA	yes	1937	Jul-42
Western Boatbuilding	Tacoma	WA	yes	1917	Jul-42
Permanente Metals #1 Yard	Richmond	CA	no	Aug-42	Aug-42
San Diego Marine	San Diego	CA	yes	1917	Aug-42
San Diego Marine Construction	San Diego	CA	yes	1917	Aug-42
Lake Union Dry Dock	Seattle	WA	yes	1925	Sep-42
Marinship	Sausalito	CA	no	Oct-42	Oct-42
Olympic Shipbuilders Inc	Port Angeles	WA	no	Nov-42	Nov-42
Fellows and Stewart	Wilmington	CA	yes	1903	Dec-42
Kaiser Swan Island	Portland	OR	no	Dec-42	Dec-42
Larson Boat Shop, Al	San Pedro	CA	yes	1919	Dec-42
Pacific Bridge Company	San Francisco	CA	no	Dec-42	Dec-42
Seattle-Tacoma Shipbuilding, Seattle	Seattle	WA	no	Dec-42	Dec-42
Cryer and Sons	Oakland	CA	yes	1890	Feb-43
Victory Shipbuilding	Newport Beach	CA	no	Feb-43	Feb-43
Everett Pacific Shipbuilding	Everett	WA	no	Mar-43	Mar-43
Kneass, G. W.	San Francisco	CA	yes	1898	Mar-43
Pacific Coast Engineering (PACECO)	Alameda	CA	yes	Mar-43	Mar-43
Wilmington Boat Works	Wilmington	CA	yes	1920	Mar-43
Concrete Ship Constructors, Inc.	National City	CA	no	Apr-43	Apr-43
Kaiser Richmond No. 4	Richmond	CA	no	Apr-43	Apr-43

Mojean and Ericson	Tacoma	WA	yes	1926	Apr-43
Peyton Co.	Newport Beach	CA	no	Apr-43	Apr-43
W. F. Stone and Sons, William F.	Oakland	CA	yes	1896	Apr-43
Winslow Marine Ways	Winslow	WA	yes	1879	Apr-43
Bethlehem San Pedro	San Pedro	CA	yes	Jan-21	May-43
Associated Shipbuilders Harbor Island/lake union/Puget Sound Bridge and Dredging Company yard 1	Seattle	WA	no	Jul-43	Jul-43
Hodgson-Greene-Haldeman	Long Beach	CA	yes	predates war	Jul-43
Barrett and Hilp	South San Francisco	CA	no	Aug-43	Aug-43
Permanente Metals #3 Yard	Richmond	CA	no	Aug-43	Aug-43
Campbell Industries	San Diego	CA	yes	Jun-26	Oct-43
Anacortes Slipways Co	Anacortes	WA	no	1942	Nov-43
Bethlehem-Alameda Shipyard Inc.	Alameda	CA	yes	1906	Nov-43
Columbia River Packers Assn.	Astoria	OR	no	Jan-44	Jan-44
Eureka Shipbuilding	Fields Landing	CA	no	Jan-44	Jan-44
Barbee Marine Yards	Renton	WA	no	Feb-44	Feb-44
Siletz Boatworks	Kernville	OR	yes	1928	Feb-44
Associated Shipbuilders Harbor Island/lake union/Puget Sound Bridge and Dredging Company yard 2	Seattle	WA	no	Mar-44	Mar-44
Willamette Iron and Steel	Portland	OR	yes	1889	Jun-44
Bethlehem San Francisco	San Francisco	CA	yes	1885	Dec 1889

Source: Tim Colton, "Shipbuilding History," Shipbuildinghistory.com, accessed October 17, 2020, https://www.shipbuildinghistory.com/. This table was derived using the resources from https://www.shipbuildinghistory.com and examining each shipyard's specific detail page and documenting their location, their first delivery, and their first delivery to the US Navy.

APPENDIX R

PERCENTAGE CHANGE IN FACILITIES BY SHIPYARD

The yearly facilities figures for each shipyard was calculated using the following equation:

$$Shipyard\ facilities\ (year\ x + 1) = \frac{WWII\ facilities\ (year\ x + 1)}{WWII\ facilities\ (year\ x)}\ x\ Shipyard\ facilities\ (month\ x)$$

where:

$WWII\ facilities\ is\ the\ number\ of\ shipyards\ in\ the\ U.S.\ at\ any\ given\ year\ from\ pre - 1940\ through\ 1943$

and

$$(year\ x)\ is\ any\ year\ before\ 1940\ and\ through\ 1943$$

and where

$$Shipyard\ facilities\ is\ the\ number\ of\ piers\ or\ drydocks\ at\ a\ given\ shipyard\ at\ some\ future\ time$$

The tables on the following pages contain all outputs.

Piers Growth Rates by Shipyard									
Year	**Current +**	**Total Pacific Shipyards**	Pearl	Seattle	Portland	Puget	GD Nass	Continental	BAE
Pre-1940	**Year 0**	10	6	6	2	9	4	4	5
1940	**Year 1**	12	7	7	2	11	5	5	6
1941	**Year 2**	24	14	14	5	22	10	10	12
1942	**Year 3**	54	32	32	11	49	22	22	27
1943	**Year 4**	77	46	46	15	69	31	31	39
1944	**Year 5**	83	50	50	17	75	33	33	42
1945	**Year 6**	85	51	51	17	77	34	34	43

Source: Created by author.

Drydocks Growth Rates by Shipyard									
Year	**Current +**	**Total Pacific Shipyards**	Pearl	Seattle	Portland	Puget	GD Nass	Continental	BAE
Pre-1940	**Year 0**	10	3	3	2	6	2	0	1
1940	**Year 1**	12	4	4	2	7	2	0	1
1941	**Year 2**	24	7	7	5	14	5	0	2
1942	**Year 3**	54	16	16	11	32	11	0	5
1943	**Year 4**	77	23	23	15	46	15	0	8
1944	**Year 5**	83	25	25	17	50	17	0	8
1945	**Year 6**	85	26	26	17	51	17	0	9

Source: Created by author.

APPENDIX S

SIMULATION RESULTS: DYNAMIC ANALYSIS, REALISTIC FORCE FLOW P HIT VALUE 0.75

			Jan	Feb				Mar	May	June	August		October		November
		MAX	Battle 1	Battle 2	Battle 3	Battle 4	Battle 5	Battle 6	Battle 7	Battle 8	Battle 9	Battle 10	Battle 11	Battle 12	Battle 13
PEARL	WORKFORCE	6500			5800	4400	3700		4400	3700	3000	3700			
	BERTHINGS	6					5		6	5	4	5			
	DRYDOCKS	3			2	0									
SEATTLE	WORKFORCE	325										257	-327		-981
	BERTHINGS	6													
	DRYDOCKS	3										2	1		0
PORTLAND	WORKFORCE	725	625				725			25			994		
	BERTHINGS	2	1				2								
	DRYDOCKS	2								1			0		
PUGET	WORKFORCE	12340	11840				11140		10440	9040					
	BERTHINGS	9	6												
	DRYDOCKS	6	4				3		2	0					
GD NASS	WORKFORCE	2170	1970								1270				
	BERTHINGS	4	3												
	DRYDOCKS	2	1								0				
CONTINENTAL	WORKFORCE	400	200									300		400	-23
	BERTHINGS	4	2									3		4	2
	DRYDOCKS	0													
BAE	WORKFORCE	1230	1030					1130		1230	530				
	BERTHINGS	5	3					4		5					
	DRYDOCKS	1									0				

Source: Created by author.

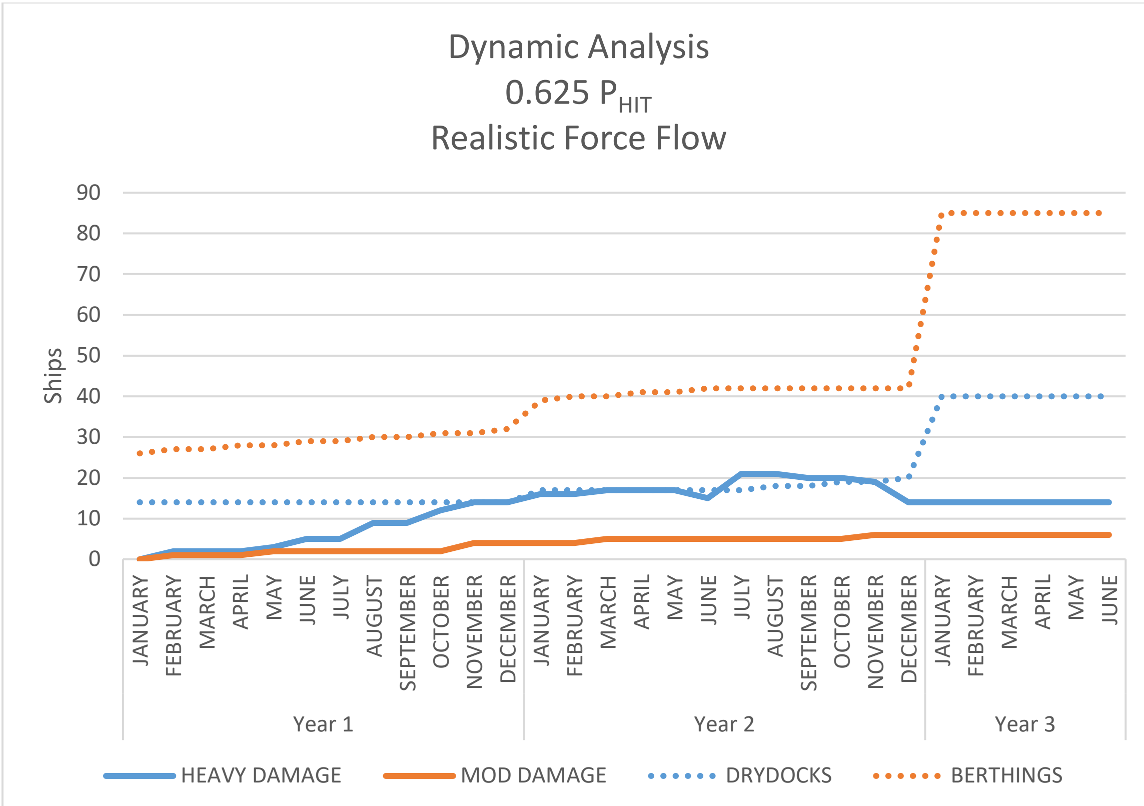
APPENDIX T

SIMULATION RESULTS: DYNAMIC ANALYSIS,

REALISTIC FORCE FLOW P_{HIT} VALUE 0.625

		OCTOBER		NOVEMBER		DECEMBER	JANUARY
		Battle 11	Battle 12	Battle 13	Battle 14		Battle 15
PEARL	WORKFORCE			3700	3000		20937
	BERTHINGS			5	4		
	DRYDOCKS						0
SEATTLE	WORKFORCE	373	-327	-981			
	BERTHINGS						
	DRYDOCKS	2	1	0			
PORTLAND	WORKFORCE	994			-1375		549
	BERTHINGS				1		
	DRYDOCKS	0					0
PUGET	WORKFORCE						
	BERTHINGS						
	DRYDOCKS						
GD NASS	WORKFORCE					1370	
	BERTHINGS					4	
	DRYDOCKS						
CONTINENTAL	WORKFORCE		400				
	BERTHINGS		4				
	DRYDOCKS						
BAE	WORKFORCE						
	BERTHINGS						
	DRYDOCKS						

Source: Created by author.



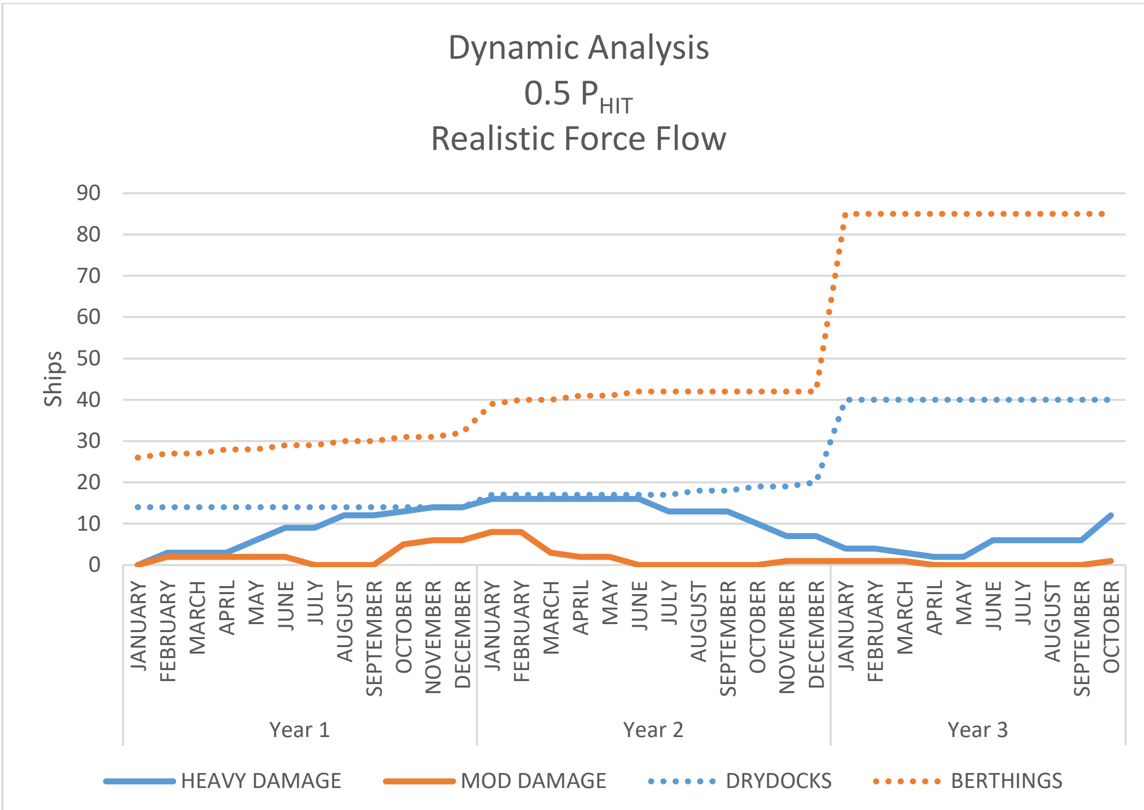
Source: Created by author.

NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydock and Pier availability, respectively. As can be seen in this graph, the Heavy Damage line and its counterpart, the Drydocks availability line, intersect. This shows graphically that facility saturation was reached during this simulation for Heavily Damaged vessels. It also shows that when new Drydocks came online, there was no longer facilities saturation for Heavily Damaged vessels. Facilities saturation was never reached for Moderately Damaged Vessels.

APPENDIX U

SIMULATION RESULTS: DYNAMIC ANALYSIS,

REALISTIC FORCE FLOW P_{HIT} VALUE 0.5



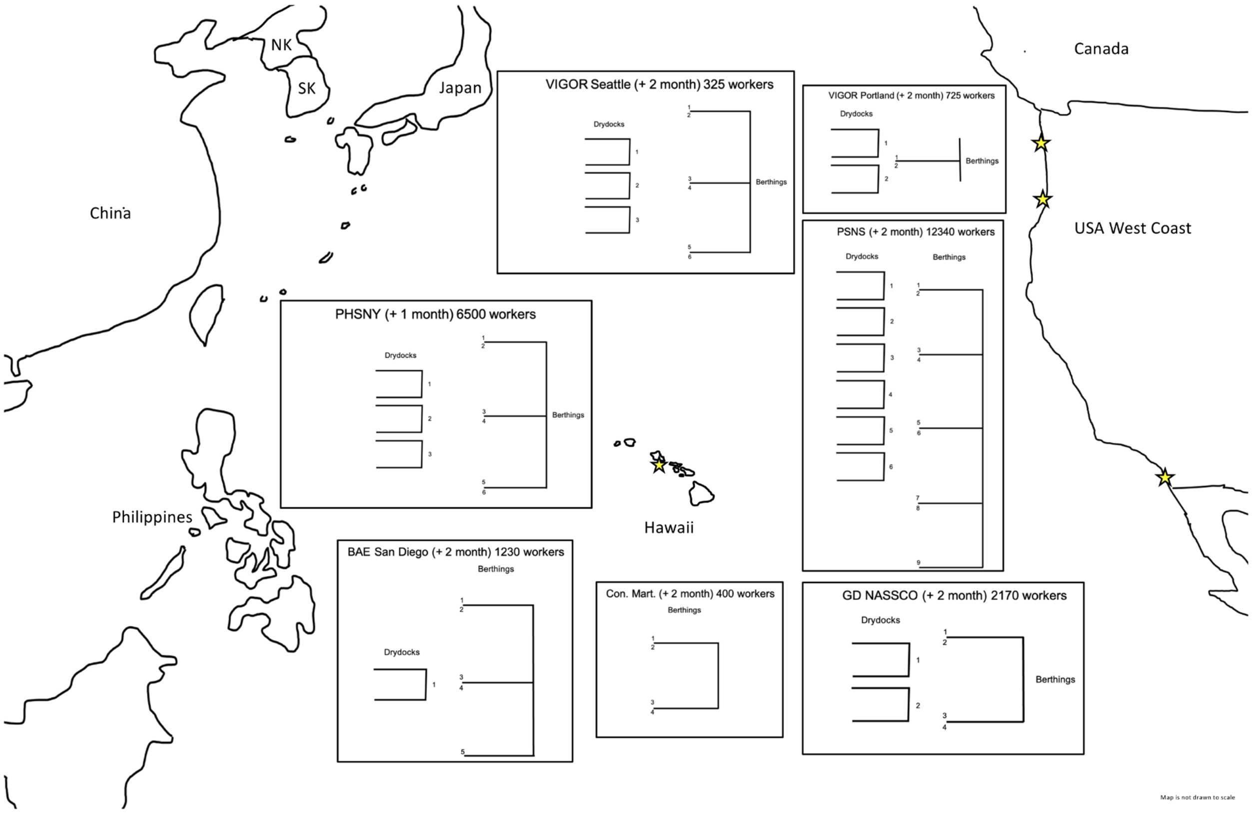
Source: Created by author.
NOTE: The above graphs the results of the simulation by month. The solid blue and orange lines represent Heavy Damage and Moderate Damage, respectively. The dotted blue and orange lines represent Drydock and Pier availability, respectively. As can be seen in this graph, the Heavy Damage line and its counterpart, the Drydocks availability line, briefly touch. This shows graphically that for a brief period of time, facility need exactly matched facility capability (meaning that there were no additional drydocks available, but that none were also needed at that time). It also shows that when new Drydocks came online, it was an insufficient number to keep up with demand. Facilities saturation was never reached for Moderately Damaged Vessels.

		AUGUST		SEPTEMBER	OCTOBER		NOVEMBER		DECEMBER	JANUARY
		Battle 9	Battle 10		Battle 11	Battle 12	Battle 13	Battle 14		Battle 15
PEARL	WORKFORCE			3000	3000		2300			17437
	BERTHINGS			4	4	4	3	3	3	1
	DRYDOCKS			0	0	0	0	0	0	1
SEATTLE	WORKFORCE	257				-327	-981			
	BERTHINGS	6	6	6	6	6	6	6	6	6
	DRYDOCKS	2	2	2	2	1	0	0	0	0
PORTLAND	WORKFORCE	25	734							549
	BERTHINGS									
	DRYDOCKS	1	0							0
PUGET	WORKFORCE									
	BERTHINGS									
	DRYDOCKS									
GD NASS	WORKFORCE								1370	
	BERTHINGS								4	
	DRYDOCKS									
CONTINENTAL	WORKFORCE			300		400				
	BERTHINGS			3		4				
	DRYDOCKS									
BAE	WORKFORCE									
	BERTHINGS									
	DRYDOCKS									
		3	2	2	2	1	0	0	0	1
		6	6	13	10	14	9	9	13	7

Source: Created by author.

APPENDIX V

GAMEBOARD FOR SIMULATION



Source: Created by author.

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