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ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Next Generation Logistics Ships: Supporting the Ammunition and Supply Demands of Distributed Maritime Operations

December 2020

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ABSTRACT

The purpose of the project is to conduct unbiased research to determine the optimal type and quantity of next generation logistics ships (NGLS) based on a notional scenario and demand requirements for ammunition and supplies. In recent decades, the United States Navy has proceeded unfettered by conventional threats or serious rivalry from near-peer competitors. Guidance from both the Chief of Naval Operations (CNO) and Commandant of the Marine Corps (CMC) have driven the Department of Navy (DoN) to pursue Great Power Competition and to recalculate the advantages and disadvantages our military force has over our adversaries. This increase in demand for innovation and capability advantage supplied new concepts such as distributed maritime operations (DMO), littoral operations in contested environments (LOCE), and expeditionary advanced base operations (EABO). These concepts changed how the U.S. Navy would employ and distribute its forces across contested environments. The Strategic Mobility and Combat Logistics Division's (N42) staff asked a complex question: how can the Navy logistically support and sustain these distributed forces without unnecessarily risking the combat logistics force (CLF) ships vital to the long-term sustainment of the fleet? We offer a framework using a transshipment mathematical model to rearm and resupply future logistics requirements in support of LOCE, DMO, and EABO.

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ABOUT THE AUTHORS

Captain Carlson is a Logistics Officer who enlisted in the Marine Corps in March of 2000 as an Infantryman. In October of 2000, Captain Carlson reported to 2nd Fleet Antiterrorism Security Team (FAST) Company for duties as a basic security guard. During this time he served as a fireteam leader, squad leader, and Close Quarters Battle Team leader. Upon completion of his tour with 2nd FAST Company in October 2003, Captain Carlson reported to 2nd Battalion 1st Marines (2/1). While with 2/1, Captain Carlson deployed to Iraq in support of OPERATION VIGILANT RESOLVE in 2004 and again in 2005 in support of OPERATION STEEL CURTAIN. During this time he served as the personal security detachment platoon sergeant, machinegun squad leader, and machinegun section leader.

Upon returning from his deployment, Captain Carlson reported to the School of Infantry (West) for service as a combat instructor in 2006. In 2008 he was selected for Marine Corps Enlisted Commissioning Education Program (MECEP) and attended California State San Marcos, California where he graduated with a Bachelor of Science in Business Administration in 2011. In December of 2011 he was commissioned as a Second Lieutenant and attended The Basic School from March 2012 to September 2012 followed by MOS training as a Logistics Officer. Upon completion of the Logistics Operations School in Camp Lejeune, North Carolina, he was assigned to 3D Light Armored Reconnaissance Battalion where he served as a Maintenance Management Officer, Motor Transportation Platoon Commander, and Assistant Battalion Logistics Officer.

In February 2016 Captain Carlson reported to Combat Logistics Battalion 7 where he served as the Assistant Operations Officer, H&S Company Commander, and Transportation Services Company Commander. In May 2018 he received orders to serve as the Executive Officer of the Logistics Combat Element (LCE), SPMAGTF 19.1. While with the LCE he deployed to Al Jaber airbase in Kuwait. Upon returning from deployment, Captain Carlson was assigned to the Naval Post Graduate School in Monterey CA as a student in the Operations and Logistics Management curriculum.

Upon graduation, Captain Carlson reported to Marine Corps Logistics Command at MCLB Albany in January 2021. Captain Carlson is married to Jessica Carlson with whom he has two children ages 11 and 9.

Major Brown is a native of Fayetteville, Arkansas. Upon graduating from high school – Maj Brown enlisted in the Marine Corps Reserves in 2005. In 2006, Major Brown deployed in support of OPERATION IRAQI FREEDOM. During this time, he served as an Intelligence Analyst for 1st Battalion 24th Marines in Fallujah, Iraq. Upon returning from deployment – Maj Brown attended the University of Arkansas in Fayetteville, AR where he graduated with a Bachelor of Arts in International Relations in 2010.

In December 2010 he was commissioned as a Second Lieutenant in the Marine Corps. He attended The Basic School from April 2011 to October 2011. Upon completion of the Logistics Officers' Course in Camp Lejeune, NC he reported to 1st Maintenance Battalion in May 2012 where he served as the H&S Company Commander, Assistant Operations Officer, and Battalion Logistics Officer over the course of his tour.

In May 2015 he was assigned as Battalion Logistics Officer for 2d Light Armored Reconnaissance Battalion in Camp Lejeune, NC. In June 2016, he served as the Aide to the 2d Marine Division Commanding General.

In July 2017, Maj Brown was assigned as the Maintenance Management Officer (MMO) for 8th Marine Regiment and subsequently deployed in support of OPERATION FREEDOM'S SENTINEL in Afghanistan as part of the Resolute Support Mission in December 2017. Maj Brown served as a Logistics Officer for Task Force Southwest as the Installation Manager at Shorab – formerly known as Camp Leatherneck. Upon return from deployment in November 2018, Maj Brown was assigned as the Assistant Logistics Officer and MMO for 8th Marine Regiment.

In June 2019, Maj Brown reported to the Naval Postgraduate School. In January 2021 he will report to Marine Corps Logistics Command at MCLB Albany. Major Brown is married to Carrie Brown from Searcy, AR. They have three children together – Julia (8), Joshua (6), and Caroline (2).

Maj Matthew Halligan is a Marine Corps Logistician who has a Bachelor of Science in Business Administration from the University of Akron. He commissioned a Second Lieutenant in March of 2009. Upon graduating from the Basic School and Logistics Officer Course, he reported to the 3rd Marine Logistics Group where he served in Landing Support Company and Combat Logistics Battalion 31 (CLB-31). While in Okinawa, Maj Halligan served as a Landing Support Platoon Commander, Motor Transportation Platoon Commander, and Logistics Officer.

Following two years with CLB-31 and the 31st Marine Expeditionary Unit, he reported to the Deputy Commandant, Installations and Logistics in 2012. He served as a Logistics Combat Element Structure Analyst, Aide-de-Camp, and deployed to Afghanistan serving in the ISAF/Resolute Support HQ, CJ4. During the deployment, he served as a Logistics Planner and Military Assistant. Upon returning from Afghanistan in 2015, he attended the Basic Airborne Course at Fort Benning, Georgia, and Resident Expeditionary Warfare School (EWS) at Quantico, Virginia. After graduating from EWS in 2016, he reported to the 1st Marine Division at Camp Pendleton, California. During this tour, he was the Logistics Officer for 1st Light Armored Reconnaissance Battalion and the division's Truck Company Commander at Headquarters Battalion. In July 2019, Maj Halligan checked into the Naval Postgraduate School. He Married his wife Lindsay in July of 2008 and currently has three kids: Olivia (9), Simon (6), and Cora (2). Upon graduation, he will report to Deputy Commandant, Installations and Logistics at the Pentagon. He will serve as a Material Management Officer in the Data Analytics & Visualization / Condition Based Maintenance Branch.

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From Matt:

I am forever grateful for my wife Lindsay, whose patience and support enabled me to get through this adventure. Your passion, positivity, and gentleness truly inspire me. 2020 presented many challenges for our family, it was your strength that held us all together and allowed me to remain focused on my research.

Thanks to professors Aruna Apte and Ken Doerr for taking this project on and trusting three Marines to work a complex naval challenge. You are true professional whose guidance, mentorship, and availability created an environment for us to deliver credible results to the sponsor.

From Andrew:

I would like to thank my bride Carrie and my three beautiful children: Julia, Joshua, and Caroline. They have been the epitome of love and strength in the face of a difficult season of life. I am humbled—as I have learned so much about being a husband and father during this unique time.

Thanks to my Thesis Advisor Professor Aruna Apte and Second Reader Professor Ken Doerr. Their guidance and faith in us has been unshakeable during our brief time here at NPS. Naval logistics is unfamiliar terrain for most Marines; therefore we, as an organization, owe much to their patience and willingness to get their hands dirty on such an important topic.

From Chad:

To my wife Jessica, you inspire me. I sincerely believe I couldn't have done this without you. Your support of my career, research, and care for our family enables my focus and I am immensely grateful for you as a person and a partner in life.

Professors Aruna Apte and Ken Doerr , I am truly grateful for the support and academic mentorship you both provided over the past year. Your assistance with this project truly served as the impetus behind delivering meaningful results to our sponsor.

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious Ready Group
ASuW	anti-surface warfare
A2	anti-access
AD	area denial
BSAH	Batiments de Soutien et d'Assistance Hauturiers or Offshore Support and Assistance Multipurpose Vessel
CLF	combat logistics force
CMC	Commandant of the Marine Corps
CNO	Chief of Naval Operations
CSG	carrier strike group
C2	command and control
DDG	guided missile destroyer
DMO	distributed maritime operations
EABO	expeditionary advance base operations
EAB	expeditionary advance base
FARP	forward arming and refueling point
FFG	guided-missile frigates
FSV	fast supply vessel
HADR	humanitarian aid disaster relief
HIMARS	high mobility artillery rocket system
HMNZS	Her Majesty's New Zealand Ship
LAW	light amphibious warship
LCS	littoral combat ship
LOCE	littoral operations in contested environments
LOG	logistics node
LP	linear program
MEU	Marine Expeditionary Unit
MPF	Maritime Prepositioning Force
MRE	meal ready to eat
MSC	Military Sealift Command
N42	U.S. Navy Strategic Mobility and Combat Logistics Division

NAVSEA	U.S. Naval Sea Systems Command
NGLS	next generation logistics ships
NZDF	New Zealand Defense Force
OPNAV	Naval Operations
OSV	offshore support vessel
PSV	platform supply vessel
RAS	replenishment at sea
SAG	Surface Action Group
T-AKE	military sealift auxiliary cargo (K) and ammunition (E) ship
T-AO	military sealift auxiliary oiler
T-AOE	military sealift fast combat support ships
TLR	top level requirement
UNREP	underway replenishment
USMC	United States Marine Corps
USNS	United States naval ship
WEZ	weapon engagement zone

I. INTRODUCTION

For the last 30 years, the United States has been uncontested across all domains and has largely been able to employ its military forces where and when they were needed. The United States 2018 National Defense Strategy, however, assumes every domain will now be contested—air, land, sea, space, and cyberspace. The Chief of Naval Operations (CNO) Design for Maritime Superiority points out that it has been "decades since we last competed for sea control, sea lines of communication, access to world markets, and diplomatic partnerships" (Chief of Naval Operations [CNO], 2018, p. 3). The current security environment will force the Navy to conduct distributed operations over a larger geographic area of responsibility. With units operating at extended distances in contested environments, their lifeline of sustainment becomes one of the top priorities. Specifically looking at the Indo-Pacific region of the world, the United States' potential adversaries' long-range precision fires and anti-access/area denial (A2/AD) capacities present significant concern to the U.S. lines of communication. This project will help strengthen naval power at and from the sea by informing the seventh line of effort identified in the CNO's *Design for Maritime Superiority*: "posture logistics capability ashore and at sea in ways that allow the fleet to operate globally, at a pace that can be sustained over time," and "assess and develop options for improved ability and resilience to refuel, rearm, resupply, and repair" (CNO, 2018, p. 8).

In March 2020, the Commandant of the Marine Corps (CMC), General Berger, released the United States Marine Corps' (USMC) *Force Design 2030*. This document made a few points that specifically help frame the problem addressed in this project. A key point in the document is that the Marine Corps is actively pursuing ways to effectively operate in an adversary's weapon engagement zone (WEZ) to create a competitive advantage. Thus, "Logistics (sustainability) is both a critical requirement and a critical vulnerability. Forces that cannot sustain themselves inside the WEZ are liabilities; however, those that can sustain themselves while executing reconnaissance and counter-reconnaissance missions create a competitive advantage" (Berger, 2020, pp. 5–6). The CMC did not believe that the Phase I and II planning efforts gave sufficient attention to the logistics needed to execute distributed maritime operations (DMO), littoral operations in contested environments (LOCE), and expeditionary advanced base operations (EABO) "in contested littoral environments against our pacing threat" (Berger, 2020). If sustainment of naval forces in the current security environment is not given appropriate attention, the force's effectiveness will significantly diminish.

A. HISTORY OF U.S. NAVAL OPERATIONS IN CONTESTED ENVIRONMENTS

As new concepts such as DMO, LOCE, and EABO are introduced, we can still learn considerably from the history of naval operations in contested environments. While technologies have changed significantly, the fundamentals and characteristics that led to success are still relevant today. Modern day logisticians can learn greatly from the sustainment success and failures that occurred during the Battle of Guadalcanal in World War II. This was an environment where the U.S. Navy and Marine Corps were conducting amphibious operations in a contested environment. In the early days at Guadalcanal, reactionary logistics provided the U.S. Marine Corps a chance to reinforce its reputation for doing more with less. Speed and mobility are critical when operating in an environment where sea and air control are contested. Logistics assets that are fast enough to dash in and dash out, large enough to carry a useful load, and small and agile enough to disperse supplies are critical in the early stages of a contested landing, particularly if they are sufficiently self-contained to execute their own landing and stevedoring (Schuck, 2019). Schuck (2019) attributed the Navy's ultimate success in Guadalcanal to their ability to respond faster than the Japanese and the United States' superior capabilities. While the U.S. forces got away with their lack of sustainment planning in Guadalcanal, sustainment of this reactionary posture in the current security environment and in the presence of long-range precision weapons will meet with catastrophic consequences.

Looking at the future operating concepts, the CNO has established a Next Generation Logistics Ship (NGLS) Task Force (Eckstein, 2020). The task force will analyze the medium platform ships for logistic missions to complement the current Combat Logistic Force (CLF). These medium platforms will predominately support surface action groups (SAGs) and expeditionary advance bases. NGLS will support refuel, rearm, and resupply of naval assets in support of DMO, LOCE, and EABO concepts both inside and out of the WEZ. The Department of the Navy is currently seeking commercial ship designs that can be customized for military requirements. The department is considering platform supply vessels, fast supply vessels, light amphibious warships, and other offshore support vessels (OSVs).

B. NAVAL SUSTAINMENT

For the U.S. Navy to be effective over extended periods at sea, replenishment at sea (RAS) is critical. Since World War II, the modern-day Military Sealift Command (MSC) has fulfilled this role. The Navy's CLF operates various ships to provide logistic support to deployed U.S. Naval combatants and coalition forces ships. The CLF is foundational to extending the U.S. Navy's culmination point afloat by resupplying bulk fuel, ordnance, food, repair parts, and other various classes of supply. Without the CLF, maritime sustainment would rely on friendly ports, thus limiting their power projection (Wakim, 2019). The CLF is currently made up of 29 auxiliary ships that are operated by U.S. Government Civil Service Merchants. The CLF is comprised of three different types of ships: fleet replenishment oilers (T-AO; Figure 1), dry cargo and ammunition Ships (T-AKE; Figure 2), and fast combat support ships (T-AOE; Figure 3).

Figure 1. USNS *Patuxent* (T-AO 201). Source: U.S. Navy photo # 100329-N-1082Z-140 Djibouti by MC2 Jason R. Zalasky (2010).

Figure 2. USNS *Cesar Chavez* (T-AKE-14). Source: U.S. Navy photo # 190714-N-DX868-1223 Gulf of Tadjoura by HM1 Kenji Shiroma (2019).

Figure 3. USNS *Supply* (T-AOE 6). Source: U.S. Navy Photo # 100310N1082Z-050 by MC2 Jason R. Zalasky (2010).

> According to Navy and MSC officials, a greater reliance on distributed operations and the lethality provided by a widely distributed fleet will require resupplying ships that are farther apart and generally increase the demand on the combat logistics force. This stands in contrast to the Navy's traditional concept of operations, in which Navy combatant ships operate in task group formations—such as carrier strike groups or amphibious ready groups—and to support these formations, combat logistics force ships transit with them and replenish them with supplies as needed. (Pendleton, 2017)

The Navy refers to this concept of operations as shuttle ship/station ship (Cribbs, 2016). Figure 4 represents how the U.S. Navy is currently supported afloat.

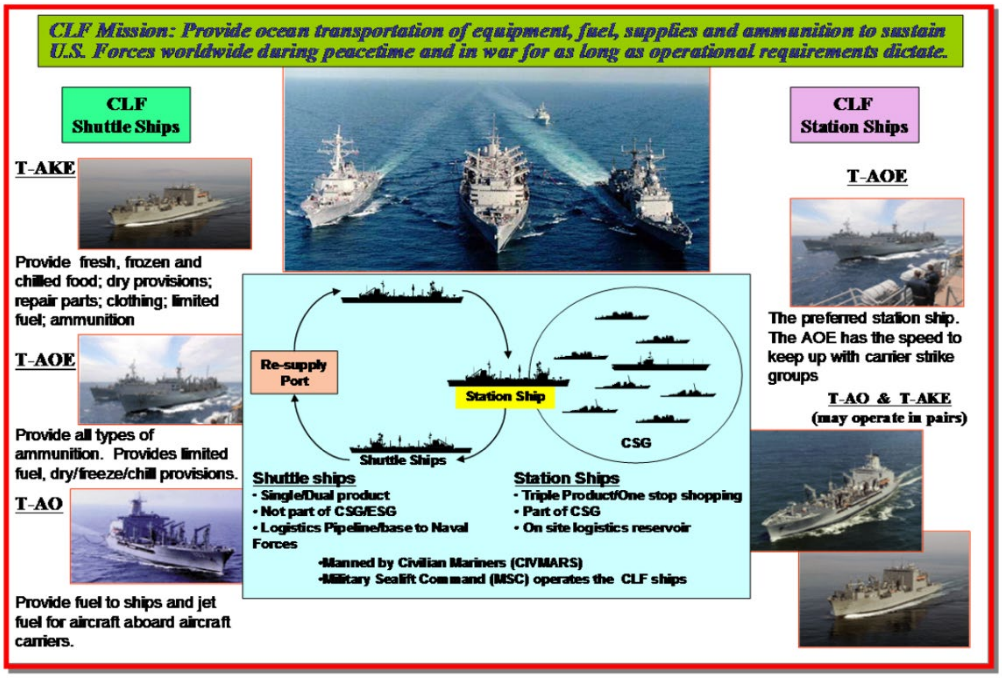

Figure 4. Shuttle vs. Station Ship Concept. Source: Cribbs (2016).

The changing security environment has created the need to adjust to a more distributed concept of operations across the Department of the Navy. The stress this creates on the CLF has taken front stage in Department of the Navy and is in large part why the NGLS task force has been analyzing different concepts of sustainment to complement the CLF. Additionally, as the Marine Corps finalizes its EAB concept of operations in support of naval forces inside the WEZ, more sustainment demand will be put on the CLF. As it stands, the task force and planners across the Marine Corps believe the platform supply vessels, fast supply vessels, and a light amphibious warship are the answer to this problem.

C. OBJECTIVE

As priorities shift to great power competition and external state actors become more militarily aggressive, it is paramount that the Navy and Marine Corps logistics communities ready themselves to support worldwide deployment. The goal of our project is determining the optimal type and quantity of NGLS to fulfill the ammunition and supply demands laid out by the Department of the Navy's N42 staff. We conduct unbiased research in parallel with the NGLS task force to analyze the ship requirements to fulfill the future resupply and rearm demands. The task force has provided a family of platforms as the solution set for these requirements. Our research assumes that commodities will be required ashore and afloat in contested regions. Additionally, CLFs will operate outside the WEZ while the NGLS will shuttle supplies into the WEZ to support the SAG and EABO.

We use a notional Indo-Pacific scenario analysis to build an optimization model that will inform the optimal type and quantity of platforms to purchase and produce.

II. BACKGROUND

A. OPERATIONAL LOGISTICS IN THE U.S. NAVY

The U.S. Navy has one of the most unique logistics networks in the world. From underway replenishment (UNREP) of a carrier strike group (CSG) to the detailed coordination of prepositioned materiel in support of naval operations stitching across the globe, the challenges of supporting such a vast logistical system are formidable. Yet, seamlessly, the CLF keeps the operating arm of the Navy from overextending. Whether that be in support of a Marine Expeditionary Unit (MEU) embarked upon an Amphibious Ready Group (ARG) scattered across the map or a humanitarian aid and disaster relief (HADR) mission coming to the aid of displaced personnel from a different nation, the CLF has demonstrated its flexibility and endurance by meeting the needs of those missions. The 32nd chief of naval operations, Admiral James Richardson, placed extreme emphasis on the logistics capabilities of the U.S. Navy in his 2019 Design for Maintaining Maritime Superiority:

> Overextension in the short and long-term pursuit of ends that are beyond the ways and means of the force is self-defeating. Over the long timelines that characterize the current competition, the navy will be ready to fire effectively first, but also be able to defend and return fire. We will aim to act as early as possible to de-escalate any crisis on our terms and be ready for the next move. This will require that we sustain the fight with the logistics capabilities needed to refuel, rearm, resupply, and repair our operational forces. (CNO, 2018, p. 6)

The problem of overextension is a logistics problem, and part of solving that problem is ensuring that U.S. Navy and Marine Corps teams grasp and consider the uncertainty of facing a peer threat. RAND testimony in 2017 before the Committee on Armed Services Subcommittee on Seapower and Projection Forces concluded that "No force is immune to every threat; no force can operate with impunity in a heavily contested environment" (Martin, 2017, p. 9). This uncertainty is tied to the A2/AD threat of the enemy through surface warfare, sub-surface warfare, long-range weapon systems, and mines. Since the Korean War, the U.S. Navy has not employed its amphibious arm into harm's way (Martin, 2017). The nature of amphibious warfare is incredibly involved and requires knowingly placing units into uncertain environments. The establishment and sustainment of these amphibious naval forces rests on the logistics elements of the U.S. Navy (Martin, 2017). Additionally, their readiness is dependent upon a logistics network that is reliable and postured appropriately for DMO and Expeditionary Advanced Base Operation (EABO) concepts (USN, CNO, 2018, p. 8).

The U.S. Navy has committed itself to "seek a medium amphibious ship that can support the kind of dispersed, agile, constantly relocating force described in the LOCE and EABO concepts the USMC has written, as well as the overarching DMO from the navy" (Eckstein, 2020, p. 2). The NGLS and light amphibious warship (LAW) will play the role as interlocutor between the CLF and the operating forces whether ashore or afloat, maneuvering supplies into contested zones.

B. COMMERCIAL OFFSHORE SUPPORT VESSELS

The broader commercial market for OSVs drives the development of the platform supply vessel (PSV) and fast supply vessel (FSV). The first OSVs began to appear after World War II and available vessels consisted of repurposed fishing or military vessels that were used to transport personnel, equipment, and supplies to offshore oil wells (Rose, 2011). The first purpose-built vessel for the offshore industry was named the "Ebb Tide" and became the industry standard with its forward bridge and long flat aft (Rose, 2011). This vessel and all of its successors until the 1980s were, however, designed for use only in water up to 1,000 feet in depth (Rose, 2011). Technological improvements during this time coupled with the increasing demand for oil throughout the world contributed to OSV development for use in "Deep Water," classified as anything greater than 1,000 feet in depth (Rose, 2011). The drilling capability and technology aboard traditional vessels was engineered for shallow waters and became a limitation as increased demand for oil drove OSVs into deeper waters (Rose, 2011). In order to safely operate and support the increased demand for greater exploration, this newer generation of OSVs was required to be more powerful and to have increased cargo capacity. The result was a design that included a larger cargo area and optimized under deck spaces with an increased number of bulk liquid tanks. Additionally, these specialized requirements identified the need for purpose-built ships to serve a variety of needs (Rose, 2011).

The PSV is a generic name for a vessel designed primarily to provide logistic support to offshore oil or gas platforms. The backbone of the offshore supply chain and like the original OSV design, PSVs normally have a large open deck aft for containers and large support equipment and internal bulk liquid tanks for fuel, potable water, and dry bulk. These vessels generally range in size between 50 meters (165 feet) to 100 meters (330 feet) in length and are designed to stay out at sea for up to 7 days (Rose, 2011). Figure 5 depicts a typical PSV.

Figure 5. Platform Supply Vessel. Source: Erikstad and Levander (2012).

The FSV, more broadly known as a crew boat and classified as a Fast Supply Vessel, is like the PSV in capability; however, it differs greatly in capacity and speed. Similar to the PSV, the FSV can transport personnel, above deck cargo, and below deck bulk liquid and dry cargo. These vessels range in size from 9 to 60 meters (30 to 200 feet) and can reach speeds of up to 31 knots while operating near shore (Rose, 2011). Cargo area varies depending on the size of the ship, but some manufacturer's options include up to 1,000 barrels of bulk liquid and up 3,000ft^3 of dry bulk materials. Passenger capacity ranges from 50 to 100 and is limited in duration where overnight accommodations are not usually offered (Rose, 2011). Due to their speed and versatility, the FSV has become an essential part of the logistics chain for offshore operations. Figure 6 depicts a typical FSV.

Figure 6. Fast Supply Vessel. Source: Breaux Global Technologies (2020).

C. PRECEDENCE FOR MILITARY USE OF OSVS

1. BSAH Rhone

The BSAH *Rhone* (Figure 7) is the second vessel in a set of four constructed by Kership for the French Navy. All these vessel names are derived from the French rivers of Loire, Rhone, Seine, and Garonne. They are utilized for rescue missions, environmental protection operations, and provide general support for navy units (Naval Today, 2018). At 230 feet in length, this vessel displaces nearly 2,600 tons, can reach speeds of 14 knots, and has the capacity to operate underway for about 30 days before needing to refuel (Naval Today, 2018). They are fitted with a 26-foot working boat and an 80-foot, 12-ton crane, which enables the transfer of shipping containers. A crew of 17 is required to operate the vessel, and it can accommodate up to 24 passengers. The 2,700-square foot cargo deck provides storage for weapons, ammunition, and shipping containers (Naval Today, 2018).

Figure 7. French Navy Offshore Support Vessel *Rhone*.
Source: Naval Today (2018).

2. HMNZS *Manawanui*

The New Zealand government purchased a new OSV in 2018 to support dive and hydrographic missions, which, at that time, was considered a capability gap for the New Zealand Defense Force (NZDF; Royal New Zealand Navy, 2020). The HMNZS *Manawanui* (Figure 8) is a 280-foot vessel built by a Norwegian firm for civilian use, which was converted after purchase to fit the needs of the missions it would fulfill for the NZDF. One conversion made to this specific vessel is that it was equipped with dive and hydrographic systems. The addition of this new OSV served as a replacement of two previously decommissioned hydrographic survey and diving support vessels. This new OSV will inherit many missions from its predecessors, such as clearing unexploded ordnance from World War II, search and recovery, and studying threats in sea lanes. The purchase of this new vessel equipped with modern design and systems will provide increased capacity, safety, and capabilities over its predecessors. A few of the new enhancements include an upgraded crane with a 100-ton capacity, a Remotely Operated Vehicle, and a Dynamic Positioning system, which increases effectiveness and safety in a wider range of sea conditions (Royal New Zealand Navy, 2020).

Figure 8. HMNZS *Manawanui*. Source: Royal New Zealand Navy (2020).

3. OSV 401 Al Basra

Al Basra (Figure 9) is one of two multipurpose OSVs built for the Iraqi Navy in collaboration with U.S. Naval Sea Systems Command (NAVSEA; Oldham, 2012). This steel hull vessel has length of 197 feet and was built by two ship building firms, Gulf Island Marine Fabricators in Louisiana and Northrop Grumman Sperry Marine (Oldham, 2012). Purposely built to provide a broad range of capabilities, this multipurpose ship will serve as a command and control (C2) vessel for smaller patrol boats which provide protection to oil platforms. The *Al Basra* is a vertical replenishment capable platform and is equipped with deck-mounted weaponry, which includes Seahawk DS-30, a 30mm remote- operated gun mount, and .50-caliber M2 heavy machine guns and six M240 7.62 mm medium machine guns (Oldham, 2012). Additionally, this vessel can carry two fast attack boats and can fulfill a variety of missions ranging from repair and refueling of patrol boats to transportation of troops and firefighting. The *Al Basra* is part of a larger $86 million OSV program that has been serviced by the contracting firm RiverHawk since 2010 (Oldham, 2012).

Figure 9. OSV 401 *Al Basra*. Source: Oldham (2012).

D. THE LIGHT AMPHIBIOUS WARSHIP

To support the EABO concept, the commandant of the Marine Corps (CMC) has submitted a request to Congress for a new warship whose main role will be to service the expeditionary advance base (EAB) in contested environments. Named the Light Amphibious Warship (LAW) this ship will possess the ability to conduct beach landings and will be designed to support the establishment and sustainment of EABs. While the structure of the forces who will occupy the EAB is still under development, it is generally accepted that it will be comprised of multiple reinforced platoons and will be capable of conducting and supporting numerous different types of missions such as anti-ship fires, aircraft arming and refueling, and reconnaissance to name a few (Snow, 2020) The LAW is an integral part of EABO as it will facilitate embarkation, transportation, and landing these units. While modest armor and deck- mounted weaponry will be part of most designs, the LAW's survivability is enhanced by its small size and ability to be easily concealed in coastal areas and among other ships. Additionally, the LAW will receive support from its supported, land-based Marines via missile fires and U.S. Navy forces (Congressional Research Service, 2020).

While the design of the LAW is still under development , many of the key elements have been identified. The new LAW program has been originally presented as a 28- to 30-ship addition to the current amphibious fleet. The key design elements identified by the U.S. Navy and Marine Corps will result in a vessel measuring from 200 to 400 feet and crewed by 40 personnel (Congressional Research Service, 2020). The ship will be able to transport 75 Marines at a minimum and have the cargo capacity to transport up 8,000 square feet of weapons, supplies, and equipment. The defensive weaponry organic to the LAW will come from a 25mm or 30mm gun system and multiple .50 caliber machine guns (Congressional Research Service, 2020). The minimum speed and range requested were 14 knots and 3,500 nautical miles, respectively. Lastly, the LAW differs from many of its close relatives in the beach- able family of ships in that it will be designed either to operate as an addition to a fleet group or to deploy independently. Figure 10 depicts an artist's rendering; however, the actual design could differ from this (Congressional Research Service, 2020).

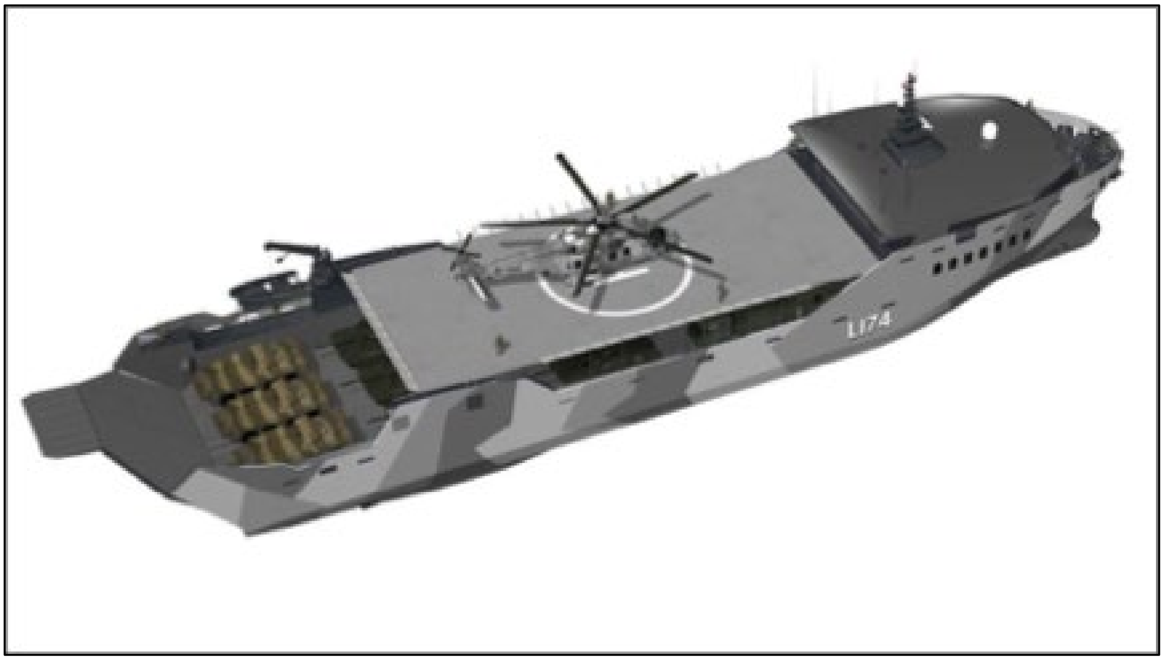

Figure 10. Light Amphibious Warship. Source: Trevithick (2020).

III. SCOPE, DATA SOURCES, AND MODEL

A. SCOPE

The scope of our research is through the lens of the logistic parameters of rearm and resupply. Our project does not include refuel demand requirements, as another Naval Postgraduate School student group is conducting parallel research for that vector (Loseke & Yarnell, 2020). Research for our project focuses on three types of vessels: platform supply vessel (PSV), fast supply vessel (FSV), and LAW. A major assumption is that the CLF will be able to sustain all the demands within the scenario. Lastly, the scope focuses on type and quantity of ships regardless of cost.

Our project is sponsored by the deputy chief of naval operations, installations and logistics OPNAV N4. After discussions with the Strategic Mobility and Combat Logistics Division's (N42) staff, they are specifically concerned that our research and analysis yield the type and quantity of ships they should purchase to fulfill future demand requirements based on new operating concepts. The data analysis for this research will include the capabilities and limitations set by the N42's top level requirements (TLR) for the PSV, FSV, and LAW. This data was then applied to a fictional, realistic wartime scenario that was approved by the sponsor to ascertain the quantities and types of ships needed to sustain the force in the scenario environment. Lastly, our project includes a classified report that analyzes a classified scenario provided by the N42 to provide type and quantity of ships required to fulfill potential demand requirements.

B. DATA SOURCES

1. Vessel TLR Analysis

We analyzed the objective and threshold requirements of PSV, FSV, and LAW. The NGLS task force provided us the TLRs for each vessel. Our methodology utilizes various TLRs to derive capacity and throughput constraints. Tables 1 through 6 depict the TLRs of each vessel that impacts our method.

Table 1. Interim TLR for the Intra-Theater Small Auxiliary Logistics Platform: PSV, Vessel Characteristics Source: OPNAV N4 (2019).

Number	Characteristic	Threshold	Objective
TLR-009	Capable of independent operations	Meet statement	Objective (O) =Threshold (T)
TLR-012	Receive dry cargo, ammunition, and fuel	Must be capable of replenishing cargo, ammunition, and fuel at sea from U.S. Navy CLF	O=T
TLR-013	Deck area/cargo capacity (payload area) for point to point movement and not reload	500 short tons 8,000 square feet	1,200 short tons 12,000 square feet

Table 2. Interim TLR for the Intra-Theater Small Auxiliary Logistics Platform: PSV, Replenishment of Afloat Units, Source: OPNAV N4 (2019).

Number	Characteristic	Threshold	Objective
TLR-102	Capable of transferring pallets of supplies/ammo to afloat units while underway at sea	15 loads/hour in series with refueling	25 loads/hour
TLR-104	Capable of transferring missiles	Skin to skin	Underway

Table 3. Interim TLR for the Intra-Theater Small Auxiliary Logistics Platform: FSV, Vessel Characteristics Source: OPNAV N4 (2019)

Number	Characteristic	Threshold	Objective
TLR-008	Capable of independent operations	Meet statement	O=T
TLR-011	Receive dry cargo, ammunition, and fuel	Must be capable of replenishing cargo, ammunition, and fuel in the littorals from PSV and SLV	At sea from U.S. Navy CLF
TLR-012	Deck area/cargo capacity (payload area) for point to point movement and not reload	2,000 square feet	3,000 square feet
TLR-014	Potable water transfer ashore	11,000 gallons with 2,000 ft hose reel	O=T
TLR-015	Physical interoperability	PSV and SLV	Roll- On Roll-Off Discharge Facility, CLF, and Maritime Prepositioning Force

Table 4. Interim TLR for the Intra-Theater Small Auxiliary Logistics Platform: FSV, Replenishment of EAB, Source: OPNAV N4 (2019).

Number	Characteristic	Threshold	Objective
TLR-101	Capable of delivering fuel to ashore units/facility	500 gpm with 2,000 ft hose reel	1,000 gpm with 2,000 ft hose reel
TLR-104	Capable of transferring cargo to a pier or ashore	Organic lift capability to transfer ISU 90	O=T

Table 5. Draft LAW TLR Justification Matrix (v 2.0), Intermodal Cargo Transfer and Transport (030 Series), Source: N9 DCNO for Warfare Systems (2020).

Number	Characteristic	Threshold	Objective
TLR-140	Cargo area	8,000 sqft	12,000 sqft
TLR-141	Deck loading	450 lb/sqft	500 lb/sqft

Table 6. Draft LAW TLR Justification Matrix (v 2.0), Beach-Ability (010 Series). Source: N9 DCNO for Warfare Systems (2020).

Number	Characteristic	Threshold	Objective
TLR-210	On/Off Load Time *Not evaluated during LAW RET	90 Min	45 Min

2. Senario Descriptions

The following scenario provided the framework for our research analysis. The situation is generally based on U.S. Naval Forces conducting DMO in the vicinity of Celebes Sea along the First Island Chain. Tensions are high with China over the recent Chinese occupation of the islands of Palawan, Philippines, and Natuna Besar, Indonesia. U.S. naval forces have recently been involved in a small engagement with Chinese naval combatants and have inserted a Marine EAB to support naval operations.

The force laydown of our model was based on the architecture depicted in Figure 11. The battlespace is broken up into two zones named the contested zone or WEZ and controlled zone. The WEZ is the portion of the battlespace where enemy templated weapons have a high probability of engaging friendly forces. The major nodes consisted of the CLF, SAG, EAB, and transshipment point. The primary source of supply services seven demand points via shuttle ships. This source of supply was represented by a CLF, which included standard Maritime Prepositioning Force (MPF) Ships. For the purposes of the scenario, we have assumed that the CLF is capable of providing adequate supplies to support all regional demands. The demand points in this scenario were derived from two primary force locations, one afloat and one ashore. The ashore unit represents an EAB, which is a small contingency of land forces positioned at three different geographical locations. The EABs are identified in our scenario as anti-surface warfare (ASuW), forward arming and refueling point (FARP), and logistics. These represent three unique types of EABs that have different rearm and resupply requirements. The afloat unit representative of SAG consists of three guided missile destroyers (DDGs) and one guided-missile frigates (FFG), all which are tactically dispersed throughout the area of operations. The shuttle ships transport supplies from the CLF to either the SAG or a transshipment transfer node for follow-on transport to the demand points ashore.

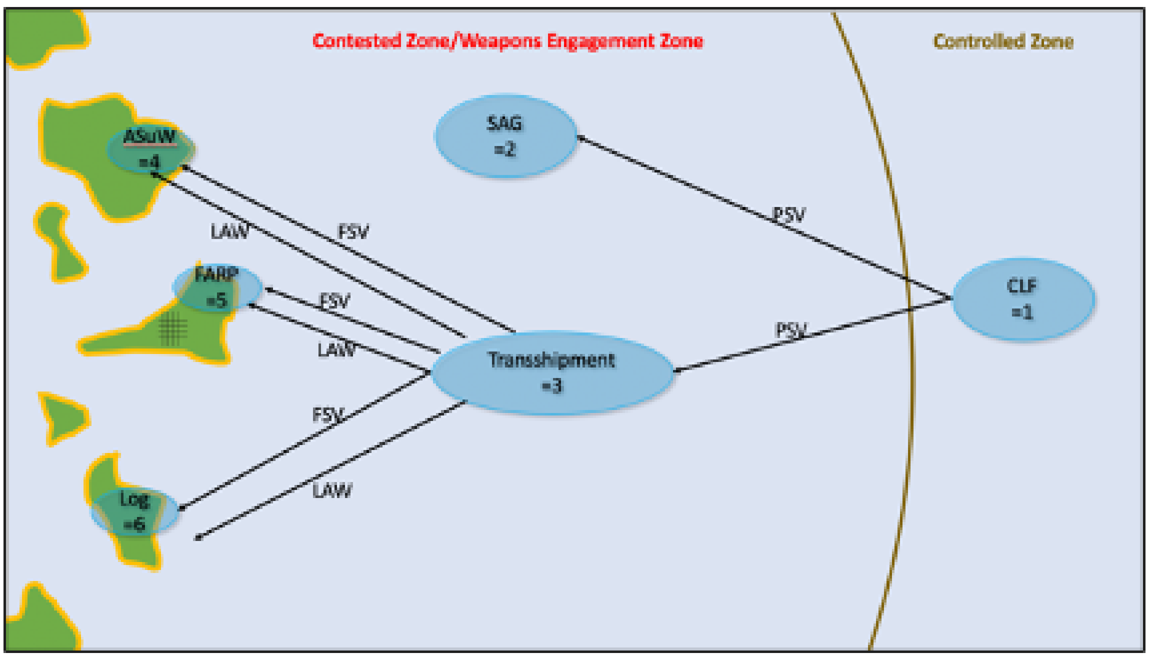

Figure 11. Battlespace/Force Laydown

C. MODEL

1. Methodology

In our desire to seek out the minimal number of vessels required to meet the demands of the Navy's distributed maritime operational architecture, we utilized linear programming (LP) to achieve the lion's share of our analysis. We used an optimization model to find solutions for various scenarios. Microsoft Office Excel was our primary tool for executing the models and enabled us to manipulate spreadsheets through a series of mathematical formulas in such a way that it produced visual data that aided our analysis. With this tool, we were also able to visually understand the impacts on our model if certain constraints were relaxed or conversely, when they were further tightened.

Our project cultivates optimization models that will estimate the quantity and type of naval logistics platforms that would be utilized to support the distributed maritime operations of the U.S. Navy—specifically in support of EABs and SAGs. Variability is introduced into the model by adjusting varying demands and throughput capacities.

In the following paragraphs, we extrapolate on all of the major features of our model that aided our analysis, findings, and results. Our model began as a standard optimization model where we attempted to minimize the number of vessels required to complete a resupply under a given condition. Over time, we bifurcated the model to represent two different sides of the scenario—this dividing line was where a PSV (loaded with supplies from the CLF) conducted an UNREP with a LAW (preparing to resupply an EAB node). However, we identified this UNREP location as a transshipment node, and inserted it as such into the model, effectively changing the nature of our model to solve a transshipment problem.

2. Model Component

a. Decision Variables

i. The vessels were designated by letter and number where *k* signified a vessel and number 1= PSV, 2 = FSV, and 3 = LAW.

ii. The different demand and supply nodes were identified by *i* and the number 1= CLF, 2 = SAG, and 3 = Transshipment.

iii. The specific demand location was labeled *j* and the numbers 2–1 = DDG1, 2–2 = DDG2, 2–3 = DDG3, 2–4 = LCS, 3 = Transshipment, 4 = ASuW, 5 = FARP, and 6 = LOG.

Example #1: *Ykij* = number of deliveries by vessels of type *k* (=1 for PSV, 2 for FSV, and 3 for LAW) from node *i* (=1 for CLF) to *j* (=2-1...4, DDG-1,2,3 and LCS2- 4, Trans =3) and from *i* (=3 for Trans) to *j* (-4,5,6 for ASuw, FARP, and LOG)

Example #2: *Xkij* = flow on vessel *k* from node *i* to *j* (*k*, *i*, *j* defined as above)

b. Objective Function

Our optimization model took the above variables and sought to minimize the number of vessels required to support the scenario. To do this, we assigned vessels with particular routes within the scenario resulting in an optimal quantity of deliveries. The demand fulfilled by these deliveries will feed into the optimal number and type of vessels necessary to meet all requirements.

The demand signals that drive our model are derived from a classified United States Marine Corps and United States Navy scenario and the model incorporates those demands based on different conditions. These figures were then modified from the classified scenario for inclusion in this report. The mathematical representation of the objective function is as follows:

Min=Y112-1+Y112-2+Y112-3+Y112-4+Y113+Y234+Y235+Y236+Y334+Y335+Y336

c. Constraints

With the variables and optimization function clearly identified, we then applied constraints derived from demand requirements, supplies of the nodes, capabilities, and capacities of the vessels. These inputs are from different scenarios, which induce variability. The architecture of the model was designed as such to conform to different scenarios by changing the various capabilities, capacities, and constraints of the model dictated by the vessels themselves. We incorporate capacity constraints as well as time constraints for naval shipping assets and naval logistics operations. We then consider the capabilities of each vessel, deck space available, bulk fluid carriage space, transfer time, and beach or port accessibility. Our constraints are as follows:

i. Supply:

CLF (1): X112-1+X112-2+X112-3+X112-4+X113 ≤ SF1

At Transshipment (3): X234+X235+X236+X334+X335+X336 ≤ ST3

ii. Demands:

DDG (2-1): Xf112-1 ≥ DF2-1

DDG (2-2): Xf112-2 ≥ DF2-2

DDG (2-3): Xf112-3 ≥ DF2-3

LCS (2-4): Xf112-4 ≥ DF2-4

To Transshipment (3): Xf113 ≥ DF3

ASuW (4): Xf234+Xf334 ≥ DF4

FARP (5): Xf235+Xf335 ≥ DF5

LOG (6): Xf236+Xf336 ≥ DF6

From Transshipment (3): X113-(X234+X235+X236+X334+X335+X336) ≥ 0

iii. Capacities:

cf112-1: Y112-1-Xf112-1 ≥ 0

cf112-2: Y112-2-Xf112-2 ≥ 0

cf112-3: Y112-3-Xf112-3 ≥ 0

cf112-4: Y112-4-Xf112-4 ≥ 0

cf113: Y113-Xf113 ≥ 0

cf234: Y234-Xf234 ≥ 0

cf235: Y235-Xf235 ≥ 0

cf236: Y236-Xf236 ≥0

cf334: Y334-Xf334 ≥ 0

cf335: Y335-Xf335 ≥ 0

cf336: Y336-Xf336 ≥ 0

X's ≥ 0, Y's integer

d. OPTIMIZATION

Our goal throughout our entire course of study and analysis has been to achieve the optimal solution for the U.S. Navy given a certain set of constraints. Utilizing a series of constraints, we have been able to produce a workable and flexible model that will provide an understanding of what the resupply of an EAB and a SAG will look like given certain inputs. "What is the optimal mix of NGLSs required for a given scenario" is the principal question.

e. OUTPUTS

The alternatives in our model are as follows:

- Quantity of deliveries by PSV, given a specific route
- Quantity of deliveries by FSV, given a specific route
- Quantity of deliveries by LAW, given a specific route
- Number of pallets of ammunition and supplies shipped via PSV
- Number of pallets of ammunition and supplies shipped via FSV
- Number of pallets of ammunition and supplies shipped via LAW

This thesis analyzes the appropriate mix of these vessels given the limitations and capabilities of each vessel and the battlespace constraints.

f. UNITS OF MEASURE

The ship capabilities are a portion of our model that govern the objective function. In order to best communicate the results and justification for our analysis we utilized a standard warehouse pallet (pallet) as our unit of measure, 48 × 40 inches (MCRP 4–11.3G, p. 4–1). Based on the square footage available on the deck of a given vessel, we were able to discern its capacity in terms of pallets. Our justification for converting our units to a pallet were driven by how demand is articulated by the EAB and the SAG ("we require delivery of 1 pallet of MREs every day" versus "we require delivery of 13.33 square feet of MREs every day"). This conversion to a simple embarkation language also enables the universal use of this model for various other applications with other platforms whether that be aerial, overland trucking, or rail.

We recognized that some ammunition would not be able to be strapped to a pallet, but rather pre-loaded on a vehicle, such as a M142 High Mobility Artillery Rocket System (HIMARS). For those specific requirements we translated the square footage of a required vehicle to pallets as well, thus continuing the use of a standard unit of measure and embarkation language.

Some capabilities that we did not take into account in our analysis include

- On-board defensive capabilities
- Ship speed given sea states and operational environment
- Crew endurance (Merchant Marines)

While they were not covered over the course of our review, we highly recommend those topics for future study.

g. BATTLESPACE CONSTRAINTS

Some battlespace constraints inherent to our model were induced either by our sponsors or scenario-induced in order to isolate the optimization model. Some of those battlespace constraints are as follows:

a. Time to transfer

b. Payload constraints

c. Transshipment constraints

- The LAW remains within the WEZ and is solely resupplied by the PSV (sponsor induced)
- The EAB is broken out into three geographically separate nodes (scenario induced)
- The SAG will not consolidate into one location for resupply but will maintain its tactical posture (sponsor induced).

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IV. RESULTS AND ANALYSIS

The culmination of our research was to find the optimal number of PSVs, FSVs, and LAWs given a hypothetical scenario. Ultimately, that led us to achieving a secondary objective of minimizing the number of deliveries by NGLS.

The tables listed in this portion of the report indicate the supply and demand attributed to the nodes of the network. Those nodes can be changed, added to, or subtracted from in order to adapt to specific scenario driven requirements, indicated in Figure 11. This illustrates the flexible structure of this model.

A. SUPPLY, DEMAND, AND CAPACITIES COMPARISONS

The capacities in our research are reflective of either the top-level requirements and/or recommendations from subject matter experts (SME), both of which were provided by the sponsor. Table 7 lists all locations within the scenario and altered amounts of palletized supplies and ammunition at each location. The capacity for the CLF is set to 100,000 units which represents a hypothetical quantity which is unlikely to be depleted by the supported force. This allows us to isolate sponsor's problem by eliminating the need to evaluate supply availability prior to this (CLF) point. Additionally, this approach was recommended by SMEs early on in the research in order to limit this project's scope. The supply and demand at the transshipment node are equal to one another as a result of this location only being a supply transfer point. A point where vessels originating from the CLF transfer cargo to the vessels identified to supply the end user of the supplies. Demands for the SAG, ASuW, FARP, and LOG are from specific scenario-driven data; however, these can be changed if the scenario is altered to meet future plans. Additionally, task organization of the EAB is still under refinement and therefore, the demand requirements will likely change once manning requirements are clearly defined in doctrine. Finally, the quantities in the capacity column were derived from the total area of storage space on each vessel with the exception of the vessel capacities from the CLF to the SAG. These capacities represent the transfer capacity of each vessel (30 pallets per hour) and places the sponsor-induced constraint of no more than 2 hours per SAG vessel resupply event.

Table 7. Supply, Demand, and Capacities: Ammunition and Supplies. Source: Apte et al. (2020).

Ammunition and Supplied in Pallets	**Supply/Demand**
A-S Supply at CLF 1	100000
A-S Supply at Trans 3	750
A-S Demand at SAG 2	100
A-S Demand at Trans 3	750
A-S Demand at ASuW 4	50
A-S Demand at FARP 5	350
A-S Demand at LOG 6	350
Ammunition and Supplied in Pallets	**Capacity**
PSV from CLF 1 to SAG 2	60
PSV from CLF 1 to Trans 3	800
PSV from Trans 3 to ASuW 4	800
PSV from Trans 3 to FARP 5	800
PSV from Trans 3 to LOG 6	800
FSV from CLF 1 to SAG 2	60
FSV from CLF 1 to Trans 3	250
FSV from Trans 3 to ASuW 4	250
FSV from Trans 3 to FARP 5	250
FSV from Trans 3 to LOG 6	250
LAW from CLF 1 to SAG 2	60
LAW from CLF 1 to Trans 3	1000
LAW from Trans 3 to ASuW 4	1000
LAW from Trans 3 to FARP 5	1000
LAW from Trans 3 to LOG 6	1000

B. MINIMUM NUMBER OF DELIVERIES FOR TRANSPORTATION

By applying the information, we collected capacity and demand characteristics for each location, node, and vessel. The model then provides us with the optimal solution by providing the number of deliveries per vessel class. These deliveries can be interpreted in a few different ways to suit the planners needs. In one way, the number of deliveries simply equates to the number of vessels needed to accomplish the mission. The result of this interpretation requires more vessels to fulfill demands and inherently adds flexibility within the logistics network. Another interpretation would use the same ship to service multiple locations, which results in fewer total ships, less flexibility in the logistics support system, and longer lead times. Additionally, while not the focus of this research, this second interpretation presents more mission risk due to the impact the loss of one ship would have on the support system. Table 8 depicts the model results when the SAG is comprised of three DDGs and one LCS, and Table 9 shows the model results when the SAG contains three DDGs and one FFG. After making this change, we observed the same total number of vessels; however, the required vessel types have changed between Table 8 and Table 9. This small demonstration is used to show how this model can accommodate a change in the SAG composition and perhaps a change in the mission overall.

Table 8. Number of Deliveries with LCS. Source: Apte et al. (2020).

Ammunition and Supplies	**Deliveries**
PSV from CLF 1 to DDG 2–1	1
PSV from CLF 1 to DDG 2–2	1
PSV from CLF 1 to DDG 2–3	1
PSV from CLF 1 to LCS 2–4	1
PSV from CLF 1 to Trans 3	1
FSV from Trans 3 to ASuW 4	1
FSV from Trans 3 to FARP 5	0
FSV from Trans 3 to LOG 6	0
LAW from Trans 3 to ASuW 4	0
LAW from Trans 3 to FARP 5	1
LAW from Trans 3 to LOG 6	1
Total	**8**

Table 9. Number of Deliveries with FFG. Source: Apte et al. (2020).

Ammunition and Supplies	Deliveries
PSV from CLF 1 to DDG 2–1	1
PSV from CLF 1 to DDG 2–2	1
PSV from CLF 1 to DDG 2–3	1
PSV from CLF 1 to FFG 2–4	1
PSV from CLF 1 to Trans 3	1
FSV from Trans 3 to ASuW 4	0
FSV from Trans 3 to FARP 5	0
FSV from Trans 3 to LOG 6	0
LAW from Trans 3 to ASuW 4	1
LAW from Trans 3 to FARP 5	1
LAW from Trans 3 to LOG 6	1
Total	**8**

C. DISCUSSION OF THE DIFFERENCES BETWEEN COMBINED AND SPLIT SCENARIOS

An additional feature that was added to our analysis was the bifurcation of the network in order to better understand the amount of deliveries required for two specific portions of our scenario. Articulated in Table 10, we titled the divided transportation networks "Split 1" and "Split 2." Split 1 represented the portion of the model from the CLF ship to the transshipment node, this split included deliveries to the SAG. Split 2 represented the transportation network of the model from the transshipment node to ASuW, FARP, and Logistics.

The advantage of dividing the network as such was to observe the amount of deliveries that would be required for each transportation network. Ultimately, it resulted in three deliveries for each transportation network—which seems inconsequential as the combined transshipment model produced six deliveries. However, the outcomes of each split transportation model produced varying amounts of deliveries utilizing different vessels. This provided significant information regarding the utility of each vessel and aided our conclusions.

The practical advantage of dissecting the network into two distinct parts is seen by the logistics planner. Split 1 mainly consists of a USN demand architecture where the customers are those ships than make up the SAG. Split 2 mainly consists of a USMC demand architecture where the customers are those EAB nodes, however they may be composed.

Table 10. Scenarios: Split Network. Source: Apte et al. (2020).

Scenarios	**Combined**	**Split 1**	**Split 2**
Ammunition and Supplies in Pallets	**Deliveries**	**Deliveries**	**Deliveries**
PSV from CLF 1 to SAG 2	2	2	
PSV from CLF 1 to Trans 3	1	1	
FSV from Trans 3 to ASuW 4	1		0
FSV from Trans 3 to FARP 5	0		0
FSV from Trans 3 to LOG 6	0		0
LAW from Trans 3 to ASuW 4	0		1
LAW from Trans 3 to FARP 5	1		1
LAW from Trans 3 to LOG 6	1		1
Total	6	3	3

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V. CONCLUSION/RECOMMENDATIONS

A. CONCLUSION

This project has given us an appreciation for the wicked problems presented by providing naval logistics inside an adversary's Weapon Engagement Zone (WEZ). Our task was to determine the optimal type and quantity of NGLS to fulfill the ammunition and supply demands laid out by the Department of the Navy's N42 staff. Since the cost was outside of the scope of this project, we did not model an objective to minimizing cost. Additionally, the sponsor did not provide any deadlines to resupply demand afloat and ashore due to the unpredictable nature of this problem. Thus, we found measuring the number of deliveries was an appropriate way to determine the mix of NGLS vessels without addressing the cost and time constraints. We also thought it might be worth finding how long the transportation time would take for these deliveries (only the transportation time, not the unload/load times). Therefore, we took some notional distances and speeds (based on top-level requirements) and showed the minimum time required if only a PSV (and FSV and LAW) makes all the deliveries on the specific route. This was done to support N42 future planning and as a demonstration of how to translate number of deliveries to address questions of the timeliness of those deliveries. Our main objective was to minimize the number of deliveries.

With the expertise and support of our advisors, we used a notional scenario to develop the transshipment network that we could mathematically model. A *delivery* is defined as carrying the commodities from a supply node to a demand node, on the given route by the vessel designed to travel on that route. We assumed that replenishment in the transshipment network is done sequentially. So, we created two separate transportation networks within the transshipment network. This created two advantages: first, the split transportation networks can operate in parallel, thus reducing the total time; second, by creating the splits, planners or decision-makers can better delineate the afloat and ashore demand requirements. Our model provides the planner or decision-maker the flexibility to determine whether 10 deliveries are made by 10 vessels or five vessels making two trips.

B. RECOMMENDATIONS

Our research led us to a couple of recommendations. We recommend that the time constraint for the PSV engaging the SAG inside the WEZ should be investigated. This was the binding constraint in our model, which informed our ship capacity. For example, a PSV has the capacity to carry 800 pallets, but since time to engage the SAG in the WEZ was constraining, we set the ship capacity to what the transfer rate of the ship was, given the amount of time permitted. The sponsor should analyze the possibility of increasing the transfer rate within the top-level requirements or increasing the time that vessels can engage the SAG inside the WEZ.

Based on Table 11 and our analysis, the acquisition of the LAW is favored over the FSV. In all the scenarios, the most FSVs needed to transport ammunition and supplies is one compared to three LAWs. This provides the sponsor with the opportunity to reduce cost of maintaining an addition platform within the NGLS portfolio. Although the FSV is not favored in our model, it does not mean that this vessel does not have a place in the future fight.

Table 11. Scenarios: Split Network. Source: Apte et al. (2020).

		Fuel		Ammunition and Supplies	
Number	Scenario	Number of Deliveries by FSV	Number of Deliveries by LAW	Number of Deliveries by FSV	Number of Deliveries by LAW
1	Scenario Based on Subject Matter Expert Feedback (Figure 6-1 and 6-2)				
1.1	Combined	1	3	1	2
1.2	Split 1 and Split 2	2	4	0	3
2	Scenario Based on Separated SAG: 3 DDGs and LCS with Sustainment (Figure 7-1)	2	3	1	2
3	Scenario Based on Separated SAG: 3 DDGs and FFG with Sustainment (Figure 7-2)	2	3	0	3
4	Scenario Based on Increased Demand Nodes				
4.1	Three SAGS	0	5	0	3
4.2	Two ASuWs	1	4	0	3
4.3	Three SAGs and Two ASuWs	0	5	0	3

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