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ACQUISITION RESEARCH PROGRAM
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Next Generation Logistics Ships (NGLS): Refuel

December 2020

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

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ABSTRACT

The purpose of this project is to conduct independent research to determine the optimal types and quantities of next generation logistics ships (NGLS) required to meet future intra-theater survivable logistics demand. This research addresses these requirements through the logistical lens of refueling. Capabilities and limitations have been identified via top-level requirements necessary to meet the future joint naval concepts of distributed military operations, littorals in a contested environment, and expeditionary advanced base operations. Research in support of the NGLS force analysis is centered on capacity, capability, employment, and distribution. This research assumes that commodities will be required both afloat and ashore in contested regions. The project uses elements of literature review and modeling to determine the optimal type and quantity of platforms capable of meeting the forecasted demand. This research recommends an optimal solution focused on minimizing the number of resupply missions within the contested regions. The project expands on potential information and bias gaps that may have been overlooked by the project sponsor at the Office of the Chief of Naval Operations (OPNAV N4).

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ABOUT THE AUTHORS

Captain Barry Loseke a graduate of Colorado State University. He commissioned into the Marine Corps in 2011 via the Officer Candidate Course (OCC). His company grade assignments include tours at Marine Aviation Logistics Squadron (MALS) 13 Yuma, MALS-41 Detachment Miramar, and MALS-41 Fort Worth. He has served as MALS Detachment OIC for multiple deployments and exercises, to include SPMAGTF 15-1 (Bahrain), SPMAGTF 17-1 (Spain), and UNITAS. After graduation from the Naval Postgraduate School, Captain Loseke will report to Fleet Readiness Center East.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	anti-access/area denial
AO	area of operations
bbl	barrel (1 bbl = 42 gallons)
FARP	forward arming and refueling point
CLF	Combat Logistics Force
CNO	Chief of Naval Operations
EAB	expeditionary advanced base
EABO	expeditionary advanced base operations
FARP	forward arming and refueling point
FMF	Fleet Marine Forces
FSV	fast supply vessel
DDG	guided missile destroyer
DMO	distributed military operations
DOD	Department of Defense
DON	Department of the Navy
FFG(X)	frigate guided missile destroyer
JP-5	jet propellant-5
LAW	light amphibious warship
LCAC	landing craft, air cushion
LCS	littoral combat ship
LHA	landing helicopter assault
LHD	landing helicopter dock
LOCE	littoral operations in a contested environment
LOG	logistics
LOTS	logistics over the shore
LPD	landing platform dock
LSD	landing ship dock
LST	landing ship tank
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force

MEU	Marine Expeditionary Unit
MPF	Maritime Prepositioning Force
MPS	maritime prepositioning ship
NGLS	next generation logistics ship
OPNAV N4	Office of the Chief of Naval Operations
PSV	platform supply vessel
RAS	replenishment at sea
SAG	Surface Action Group
STOVL	short takeoff and vertical landing
T-AKE	dry cargo/ammunition ship
T-AO	fleet replenishment oiler
T-AOE	fast combat support ship
T-ESB	expeditionary mobile base (formerly afloat forward staging base [AFSB])
T-ESD	expeditionary transfer dock
TLR	top-level requirement
UNREP	underway replenishment
WEZ	weapons engagement zone

I. INTRODUCTION

The Department of Defense (DOD) is the largest consumer of energy in the United States and is the world's largest international user of petroleum (Crawford, 2019). As such, fuel is imperative to the DOD's mission to enable the "combat-credible military forces needed to deter war and protect the security of our nation" (Mattis, 2018, p. 1). In order to continue this advantage over our advancing near-peer adversaries of China and Russia, the U. S. Navy and Marine Corps team need to reexamine the way that fuel is distributed in a maritime environment. Currently, our maritime logistics force is lacking in its ability to sustain the force in a multi-domain fight of tomorrow based on the Navy and Marine Corps future operating concepts. As it stands, "the Government-owned sealift fleet is rapidly approaching a capacity cliff" (Walton et al., 2019, p. ii), which directly equates to shortfalls in maritime logistic operations. The National Defense Strategy prioritizes "resilient and agile logistics" (Mattis, 2018, p. 7) as one of eight capabilities necessary to maintain our competitive advantage. The technological advancements of our adversaries enable them to track our logistic footprints. If they have the ability to stop our forces from being resupplied due to our old paradigm of large logistic bases, then an "unsupported force may quickly become a defeated one" (Walton et al., 2019, p. i). This capabilities shortfall leads up to the question: How many platform supply vessels (PSVs), fast supply vessels (FSVs), and light amphibious warships (LAWs) will the joint maritime force need to meet the forecasted demand necessary to sustain the Navy and Marine Corps in a contested environment?

This study attempts to provide an optimal solution to this problem. The model is set up to develop a framework for the employment of next generation logistics ships (NGLSs) in support of future naval operations that match the demand and architecture of distributed military operations (DMO). The output provides a recommendation of the optimal quantity and vessel type of NGLS assets. The end state of the project is to provide the Office of the Chief of Naval Operations (OPNAV N4) with an independent, data-driven recommendation on the optimal NGLS composition necessary to support their forecasted DMO and expeditionary advanced base operations (EABO).

A. BACKGROUND

The expanded military presence of Russia and China within the great-power competition has led to significantly increased military capabilities. The Navy and Marine Corps must reexamine their ability to sustain and survive a future conflict where the adversary has a decided advantage in interior lines of communications and near peer-level lethality. China has been strategic in their positioning within the South China Sea, Russia has been bullying the neighbors of their borders, and North Korea has been continuing to act like outlaws (Mattis, 2018). “The last time the United States confronted a competitor with the economic capacity, global maritime infrastructure, and naval power of China was over two hundred years ago” (Haynes, 2020, p. 106). As seen with the current state of a heightened contested environment, the enemy can challenge American freedom of movement and can attack amphibious forces well before they arrive in the area of operations (AO). This forces the U.S. military to rethink its method of resupplying forces within the weapons engagement zone (WEZ). The Navy and Marine Corps need to be innovative and creative in posturing and sustaining amphibious forces. Sustainment capabilities must be responsive to maneuvering forces engaged with the enemy, and they must be protected from adversary actions across all warfighting domains. The evolving character of war indicates that future conflicts may be fought over greater distances, stretching sustainment capabilities. These factors illustrate the importance of emerging technologies in efforts to create more efficient supply chains, which are necessary in sustaining amphibious operations within the WEZ. The Navy and Marine Corps need to counter their sustainment challenge of iron mountains. This can be done by fielding more capabilities within vessels that operate inside a contested environment. These actions will require a shared Navy and Marine Corps vision that integrates Navy and Marine Corps operating concepts and an understanding of how maritime logistics need to evolve in order to avoid a culminating point.

1. Navy and Marine Corps Vision

The National Security Strategy sets a strong tone; while the United States is currently the strongest military force in the world, the advantages that the nation has been accustomed to for so long are now dwindling because competitors are no longer temporary problems but rather sustained long-term threats (Mattis, 2018). As it is now and has forever been the United States' commitment to protect the American people, it is more important than ever to do this through an integrated naval force (Mattis, 2018). Chief of Naval Operations (CNO) Admiral Mike Gilday and Commandant of the Marine Corps General David Berger both have communicated visions, concepts, and shortfalls that can be mitigated through an integrated force's ability to fight, dominate, and win as a team. ADM Gilday expressed with great emphasis the importance of a unified Navy and Marine Corps team in his military strategy:

> A Navy that is ready to win across the full range of military operations. We must have a Fleet that is manned, trained, equipped, integrated, and ready to meet requirements of our senior leaders at any time. Alongside the Marine Corps, the Navy will deliver decisive Integrated American Naval Power. (Gilday, 2019, p. 1)

According to the Navy's 2016 Force Structure Assessment, the Navy will need 355 ships within its fleet to meet the capabilities that the combatant commanders deem necessary to continue leveraging maritime superiority (O'Rourke, 2020). However, that need for decisive American naval power forced a once-in-a-generation change; in the Integrated Force Structure Assessment, 390 ships were requested to address the shortfall within the fleet architecture, which will be necessary to combat the nation's near-peer adversaries (O'Rourke, 2020). This requested adjustment aligns with the vision to win across all military domains.

The Marine Corps is getting back to its roots as a Fleet Marine Force (FMF) and is reinforcing its commitment of seizing or defending advanced naval bases to support the overall naval campaign (Title 10). GEN Berger expressed his vision in his *Commandant's Planning Guidance* that

> the focal point of the future integrated naval force will shift from traditional power projection to meet the new challenges associated with maintaining a persistent naval forward presence to enable sea control and denial operations. The Fleet Marine Force (FMF) will support the Joint Force Maritime Component Command (JFMCC) and fleet commander concept of operations, especially in close and confined seas, where enemy long-range precision fires threaten maneuver by traditional large-signature naval platforms. Future naval force development and employment will include new capabilities that will ensure that the Navy-Marine Corps team cannot

> be excluded from any region in advancing or protecting our national interests or those of our allies. (Headquarters Marine Corps [HQMC], 2019, p. 2)

To meet this end state, it is imperative that commanders are provided a competitive advantage to operate, maneuver, and destroy the enemy within the so-called *gray zone* (HQMC, 2020). This vision starts with the alignment and advancement of military concepts, DMO, littoral operations in a contested environment (LOCE), and EABO. These concepts are a foundational element for creating and sustaining the advantage in a future fight.

2. Concepts of Operations in a Contested Environment

The advancing threat of our near-peer adversaries creates strategic implications for how the Navy and Marine Corps team plans to evolve and posture the force to enable rapid engagements for maritime superiority. This capability can be summarized in this way: "In the short term, a maritime strategy is about buying time to find advantages, mobilize one's industrial and innovation bases, and extend the enemy's perimeter" (Haynes, 2020, p. 104). Currently, three main concepts provide this type of advantage through a supported/supporting relationship between the Navy and Marine Corps team to be able to execute within the adversary's WEZ: DMO, LOCE, and EABO. These three concepts are tailored and "designed to complicate enemy targeting and enable naval forces to concentrate fires on enemy forces" (Clark & Walton, 2019, p. 21). These concepts allow for the forces to be integrated through a network, which creates the ability to counter adversary forces of sea denial and sea control.

a. Distributed Military Operations

DMO is the overarching, prominent naval concept for theater-level operations that creates a new paradigm of maritime dominance through a distributed architecture (Clark & Walton, 2019). This architecture forms the ability for the U.S. naval force to shape the necessary conditions required to operate and support forces in a contested environment. This architecture is provided to the Navy with three essential components: (a) integrated command relationships, (b) strong mission command, and (c) applied risk acceptance of the overall naval scheme of maneuver (Corbett, 2018).

b. *Littoral Operations in a Contested Environment*

LOCE is the direct unified effort between the Navy and Marine Corps integrated mission. As part of the Marine Corps Operating Concept, this is very important because the adversary's capabilities can extend the depth and AO known as the littorals. The littorals are

> comprised of two segments. The seaward portion is that area from the open ocean to the shore that must be controlled to support operations ashore. The landward portion is the area inland from the shore that can be supported and defended directly from the sea. (U. S. Marine Corps [USMC] Concepts and Programs, 2018, p. 1)

Controlling the littorals creates the unified network necessary to project maritime power.

c. *Expeditionary Advanced Base Operations*

EABO directly complements LOCE to achieve the principal DMO strategy because it enables the naval force "to persist forward within the arc of adversary long-range precision fires to support our treaty partners with combat credible forces on a much more resilient and difficult to target forward basing infrastructure" (O'Rourke, 2020, p. 24). EABO creates an opportunity to establish an inside force through sea control and sea denial that is operationally relevant while maintaining low signatures (Corbett, 2018). This persistent and temporary presence is essential in order to gain and maintain a foothold within the adversary's WEZ.

3. Maritime Logistics

To ensure that the innovative paradigm shift of these new concepts is feasible, maritime logistic technologies, capabilities, and capacities need to inherently match the architecture required to align with the National Defense Strategy. The National Defense Strategy states, "The surest way to prevent war is to be prepared to win one" (Mattis, 2018, p. 5). During World War II, the United States was prepared with thousands of vessels that allowed for many strong fronts to support and resupply the Allies and defeat the enemy (Walton et al., 2019). After the Cold War, the maritime environment was largely uncontested (USMC Concepts and Programs, 2018). This created an unintended consequence over decades because "the Navy and Marine Corps were able to focus on the capabilities that support maritime power projection unfettered by a corresponding need to fully invest in those capabilities required to establish sea control" (USMC Concepts and Programs, 2018, p. 1). Due to the U. S. Navy logistics platforms being one to two generations removed from World War II, they have been focused solely on minimizing costs because they are designed to be utilized in a secure and uncontested environment (Walton et al., 2019).

Presently, the Navy has 29 ships within the Combat Logistics Force (CLF), which supports the mission of replenishment at sea (RAS; Walton et al., 2019). This is strategically important because it allows for an extended range of military operations at sea without having to come back to port. The construct of this hub- and- spoke process has been successful for decades, but as adversaries increase capabilities and range through advancing technology, this process becomes quickly insufficient. Due to these ships being soft targets with relatively limited means to defend themselves, the Navy cannot afford high attrition of these assets within the battlespace (Walton et al., 2019).

Currently, the naval force structure is not postured to support the Navy and Marine Corps vision, nor is it prepared to support and resupply the concepts of DMO, LOCE, and EABO. Our legacy fleet is vulnerable when operated within the parameters of the WEZ. This is imperative to the force because

> many times, in history, military campaigns have been cut short, if for nothing else, a lack of logistical foresight. We want to ensure that this does not occur in the planning factors used to calculate fuel requirements in execution of U.S. Navy operations afloat. (Long, 2011, p. 2)

These calculated risks inherently increase as the force attempts to overcome the tyranny of distance associated with DMO and our adversary's increasing reach.

B. PURPOSE

A 2019 Center for Strategic and Budgetary Assessments (CSBA) report states,

> The current and programmed defense maritime logistics force of the United States is inadequate to support the current U.S. National Defense Strategy and major military operations against China or Russia. The Summary of the 2018 National Defense Strategy specifically highlights "resilient and agile logistics" as one of eight capability areas that need to be strengthened to

> prepare the United States for an era of renewed great power competition. (Walton et al., 2019, p. i)

The purpose of this project is to provide OPNAV N4 with an independent, data-driven recommendation on the optimal NGLS composition necessary to support their forecasted DMO and EABO framework. Results are calculated via a scalable transshipment model utilizing OPNAV N4's forecasted demand. The model focuses specifically on intra-theater fuel requirements of ashore and afloat assets within the WEZ. The project's end state is to provide OPNAV N4 with an unbiased recommendation on the specific number and type of NGLS vessels to assist in the planning, acquisition, and budgeting process of NGLS platforms.

1. Objectives

This report aims to meet the following objectives:

- Provide a capabilities overview of the three vessels being considered for the Navy's intra-theater NGLS family, including the PSV, FSV, and LAW.
- Analyze each vessel's capabilities at both the threshold and objective level as defined by each vessel's top-level requirements (TLRs). *Threshold* equals minimum acceptable value; *objective* equals desired goal. The difference between the threshold and objective values sets the trade space (Office of the Under Secretary of Defense for Acquisition and Sustainment. [OUSD A&S], 2018).
- Identify Jet Propellant-5 (JP-5) fuel requirements of afloat and ashore assets operating within the WEZ as forecasted by OPNAV N4.
- Create a transshipment model to identify the optimal NGLS family mix (via type and quantity of each vessel) required to meet demand and minimize deliveries within the WEZ.
- Provide sufficient details to understand the objectives of and the constraints within the model.
- Provide OPNAV N4 with recommendations on the ideal NGLS composition to aid in the planning and acquisition process.

2. Scope

As Naval Sea Systems Command outlined in its industry day announcement posted on May 15, 2020,

> the NGLS will enable refueling, rearming, and resupply of Naval assets—afloat and ashore—in support of Distributed Maritime Operations, Littoral Operations Contested Environment, and Expeditionary Advanced Base Operations. The NGLS is envisioned to be smaller than existing ships in the Combat Logistics Force, and will operate near contested environments, sustaining afloat (Surface Action Group) and ashore (Expeditionary Advanced Base) requirements. (Naval Sea Systems Command [NAVSEA], 2020)

In order to keep the project aligned with NGLS acquisition goals, this model assumes the following parameters:

1. Demand is limited to fulfilling requirements from surface action groups (SAGs) and expeditionary advanced bases (EABs). SAG equates to afloat demand; EAB equates to ashore demand.
2. Demand for one SAG is comprised of three guided missile destroyers (DDGs) and one littoral combat ship (LCS), or three DDGs and one frigate guided missile destroyer (FFG[X]).
3. EAB demand is broken down by specific EAB type, which includes anti-surface warfare (ASuW) strike units, short take off and vertical landing (STOVL) forward arming and refueling point (FARP) units, and maritime/naval logistics units.
4. All fuel requirements—including ship, aviation, and ground—are consolidated into a single fuel requirement, JP-5, per OPNAV N4 guidance.
5. Ship selection is limited to the NGLS family of PSV, FSV, and LAW. Each vessel is considered equally survivable on their specified arcs within the model.
6. PSVs cannot service EABs due to docking requirements.
7. The CLF remains outside the WEZ and is the sole replenishment node from which NGLS assets draw fuel. (In this report, a *node* indicates a point of supply, a point of demand, or a transshipment point.)
8. Replenishment of CLF assets is outside the scope of the project; therefore, fuel supply at the CLF is considered unconstrained.
9. Vessel capacity is constrained by delivery capacity, which is calculated by the fuel transfer rate capable within a specified time window.

II. LITERATURE REVIEW

The NGLS family consists of three specific platforms: the FSV, the PSV, and the LAW. All three platforms leverage industry innovation and expertise by largely utilizing commercial off the shelf (COTS) parent ship designs to accelerate fielding and acquisition. According to NAVSEA (2020), “The NGLS is planned to be a new class of ships to augment the current CLF ships, through the use of commercial ship designs tailored for military applications to conduct logistics missions.”

The NGLS family can be broken down into two distinct subgroups: the PSV/FSV and the LAW. The PSV and the FSV are strictly logistics platforms that lack armament or survivability modifications. They are civilian crewed and lack any ability to provide direct conveyance to beaches.

The LAW, as its name implies, is the most survivable and militarily capable of the three platforms. It is a multipurpose, light warship that serves in both logistics and warfighting capacities. The LAW is the only beach-able platform capable of providing direct conveyance for onload and off-load of expeditionary forces, equipment, and supplies. It is designated as a risk-worthy asset that prioritizes survivability for its crew and embarked forces against proportional threats (United States Navy [USN], 2020b).

In accordance with the Joint Capabilities and Integration Development System (JCIDS), each vessel has TLRs that must be satisfied to meet the vessels’ operational goals. Each TLR is broken down into two categories: threshold (T) values and objective (O) values. Per the 2018 JCIDS manual,

> Thresholds, Objectives, and Tradespace. Sponsors shall express performance attributes using a threshold/objective format. They are chosen to be technically achievable, quantifiable, measurable, testable, unambiguous, supported by documented trade-off analysis, and defined in a manner that supports efficient and effective training and evaluation.
>
> Thresholds. Performance below the threshold value is not operationally effective or suitable or may not provide any improvement over current capabilities.
>
> Objectives. The objective values are applicable when a higher level of performance represents significant increase in operational utility. If

> applicable, the objective value is the desired operational goal achievable, but at higher risk in life cycle cost, schedule, and technology. Performance above the objective value does not justify additional expense.
>
> Tradespace. The difference between threshold and objective values sets the trade space for balancing multiple performance attributes while remaining above the threshold values. (OUSD A&S, 2018, p. B-G-3)

A. PLATFORM SUPPLY VESSEL

The PSV, an example of which is shown in Figure 1, is a dedicated logistics vessel with the greatest fuel capacity and slowest speed in the NGLS family. It is civilian crewed and nonbeach-able, and it cannot provide direct support to ashore EABs within the WEZ. Its design is very similar to current PSV designs used by the offshore oil and gas industry (USN, 2019b).

Figure 1. Example of a Commercial PSV. Source: Snyder (2019).

The PSV's core mission is to provide logistics support to afloat assets within the WEZ. In order to meet afloat demand, the PSV draws supplies from the CLF (outside the WEZ) and delivers to afloat assets inside the WEZ: SAGs, LAWs, and FSVs. The PSV is capable of sustained speeds up to 13 knots with a range up to 4,000 nautical miles. Its cargo fuel tank capacity ranges from approximately 18,000 to 28,000 barrels (bbl) of JP-5 and can deliver up to 5,260 bbl per hour to afloat assets. The vessel must be capable of replenishing cargo, ammunition, and fuel at sea from the CLF (USN, 2019b). Support for

EABs is indirectly supported via the pass-through demand at the transshipment node (USN, 2019b).

B. FAST SUPPLY VESSEL

The FSV is the smallest and most agile vessel in the family. It too is merchant manned, but due to its speed and agility, it is considered risk worthy to replenish ashore-based EABs (USN, 2019a). An example of a potential prototype is shown in Figure 2.

Figure 2. Render of Potential FSV Design. Source: Swiftships (2020).

The FSV's small footprint allows for an exceptionally fast and nimble vessel. Its core mission is performing logistics runs within the WEZ. It has minimal range and crew endurance, so missions consist of receiving supplies from PSVs or LAWs within the WEZ and delivering to ashore EABs also within the WEZ. The FSV is capable of sustained speeds up to 26 knots with a range up to 1,000 nautical miles. Its cargo fuel tank capacity ranges from approximately 950 to 1,400 bbl of JP-5 and is capable of delivering up to 2,000 gallons per minute to ashore units via hose reel. The FSV must be capable of replenishing cargo, ammunition, and fuel from PSVs and LAWs (USN, 2019a).

C. LIGHT AMPHIBIOUS WARSHIP

The LAW is the only military crewed and armored vessel in the family. It is also the only platform that is purpose-built for direct conveyance to the shore for roll on/ roll off capabilities. The LAW is similar in size to the PSV, but as a multipurpose warship, it exchanges a significant portion of cargo fuel capacity for passenger force space (USN, 2020a). An example of a potential LAW design is shown in Figure 3.

Figure 3. LAW Prototype Illustration. Source: Eckstein (2020).

Per the mission statement of the LAW Resources and Requirements Board,

> The LAW will complicate the enemies targeting by providing a highly maneuverable, mobile, independent, intra-theater range ship to complement the mix of traditional amphibious warfare ships. The LAW fills the gap in capability between the Navy's large, multipurpose amphibious warships and smaller landing craft, such as the Landing Craft Utility (LCU) and Landing Craft Air Cushion (LCAC). (USN, 2020a)

The LAW plays an integral role in the joint force transition to future operational concepts of DMO, LOCE, and EABO.

For the scope of this project, the LAW's primary mission is providing logistics support to ashore EABs. The LAW receives supplies from PSVs inside the WEZ and delivers to ashore-based EABs inside the WEZ. It is also capable of replenishing FSVs operating within the WEZ. The LAW's key differentiating characteristic is its beach-able design capable of providing direct conveyance to shore for the onload and off-load of expeditionary forces, equipment, and supplies. It is also the only armored vessel that is militarily crewed with organic self-defense weapons. The LAW is capable of sustained speeds up to 22 knots with a range up to 6,500 nautical miles. Its cargo fuel tank holds approximately 2,100 bbl of JP-5 and is capable of delivering up to 600 gallons per minute to ashore units via multiple hose reels. The LAW must be capable of replenishing cargo, ammunition, and fuel from the CLF and PSVs (USN, 2020a).

D. SUMMARY OF PLATFORMS

Each vessel in the NGLS class has very distinct, differing capabilities. The PSV is the most capable in terms of capacity but does not have the survivability to operate deep within the WEZ. The FSV, while fast and agile, has minimal capacity and is only survivable due to its speed and small footprint. The LAW could technically handle all requirements, but its trade-off in design as a dual-purposed warship makes it highly inefficient for bulk fuel transport, with approximately one-tenth the cargo fuel capacity of a PSV. It is important to note that these key capabilities and limitations serve as the basis of constraints in our transshipment model.

E. TOP-LEVEL OVERVIEW OF NODES

The underlying importance within the operating concepts of DMO, LOCE, and EABO is a connected architecture that is heavily reliant on the ability to redistribute supplies, equipment, and troops. All vessels need to be capable of maneuvering from sea-based to land-based nodes within the AO. As we seek to identify the optimal solution of NGLS to transport fuel, the requirement for fuel within an AO "imposes three major types of costs: resources, capability reductions, and additional vulnerability" (Regnier et al., 2015, p. 1). The NGLS family's superior fuel redistribution capabilities are anticipated to become the enabling factor that will drive the force and create the speed and tempo that is required to maintain a competitive advantage over adversaries. That advantage is a result of the establishment and maneuverability of EABs and the SAGs. As near-peer adversaries create a tyranny of distance to overcome the U.S. joint maritime force, it is imperative that the Navy has the ability to connect sea-based and land-based nodes to turn operational energy into the operational capability required in executing these concepts (Regnier et al., 2015).

1. Expeditionary Advanced Bases

The unique infrastructure of EABs enables rapid and highly mobile deployment of U.S. forces, creating a competitive advantage unable to be matched by adversaries. The EABs' expeditionary footprint and operations make them challenging to identify and target, allowing the United States to grow capabilities within the WEZ (Corbett, 2018). This creates fewer vulnerabilities to the force because the force is less concentrated, (O'Rourke, 2020). The significance of EABs is that they are

> embedded within this scaled response from the Marine Corps and its inherent capability to be self-supporting on foreign shores. With the assistance of its sister service, the U.S. Navy, the Marines have, and continue to develop, methods to facilitate operations from the sea and follow-on operations ashore. (Strand, 2015, p. 1)

In order to meet the maritime joint force demand, three specific types of EABs have been identified as providing essential supporting capabilities that have the capacity to be scaled to any size to challenge adversaries and create various opportunities within the WEZ. Those EABs are ASuWs, FARPs, and Logistics.

a. Anti–Surface Warfare

ASuW EABs create windows of opportunity to disrupt the adversary's ability to achieve anti-access/area denial. "This forward-deployed and survivable capability will enhance the lethality of our naval forces and will help to deny our adversaries the use of key maritime terrain" (Larter, 2020, para. 2). The extension of naval power from sea to land creates the integrated force that GEN David Berger mentions in his planning guidance (HQMC, 2019). The establishment of this land-based EAB creates freedom of movement within the littorals, thus enhancing the redistribution of supplies from node to node. This can be accomplished by characteristics of the PSV and the LAW.

b. *Forward Arming and Refueling Points*

FARPs are force multipliers because they are scalable and mobile, and they extend the lethality within an AO due to the ability to rearm and refuel in austere locations. The mission of a FARP is "to provide fuel and ordnance necessary for highly mobile and versatile helicopter, tiltrotor, and fixed-wing operations" (U.S. Marine Corps [USMC], 2019). This diverse capability creates an extension of combat power from sea to shore. The significance of this EAB is the reduced turnaround time generated to maximize the amount of fuel within an aircraft before it enters the AO (USMC, 2019). FARPs can be staggered, established, and supplied through the versatility of the FSV and the beach-ability of the LAW.

c. *Logistics*

The future of warfighting is directly dependent on the maritime force's ability to generate combat power through organic logistics. "The ability to provide logistic support to forward-deployed naval forces is essential in ensuring that these forces can remain on station indefinitely in any potential conflict" (Morse, 2008, p. 2). The capability to provide the full arrangement of classes of supply creates strategic opportunities for land-based forces to extend the distributed lethality. The austere environment in which these nodes are operational can be served by the fast agility and capability of the FSV to support the FSV's dynamic demand signal.

2. Surface Action Group

The SAG is one of the versatile and flexible packages that the U. S. Navy organizes to support tactical missions in any maritime environment. Two of those missions that are critical in the execution of DMO, LOCE, and EABO are anti–surface warfare and anti–submarine warfare. These two packages provided by the SAG generate the distributed lethality that is necessary to deter adversaries, which "combines more powerful ships with innovative methods for employing them" (Richards, 2015, p. 4). The composition of a SAG for this model is comprised of three DDGs and one LCS, or three DDGs and one FFG(X). These collective capabilities enable the freedom of movement necessary to sustain and drive the joint maritime force in a contested environment.

a. Guided Missile Destroyers

DDGs are destroyers that “provide multi-mission capabilities, operating independently or as part of carrier strike groups, surface action groups, amphibious ready groups and replenishment groups” (Ingalls Shipbuilding, n.d.). In this scenario, a DDG’s capability is equally important to its capacity.

> By virtue of being larger, destroyers can more easily carry and generate the power for more powerful high-resolution radar and a larger number of vertical launch cells. They can thus provide theatre wide air and missile defense for forces such as a carrier battle group and typically serve this function. (Husseini, 2019)

Being able to sustain longer missions within an AO creates less vulnerability during a potential resupply, which in turn means longer sustained operational capability.

b. Frigate Guided Missile

Although the FFG has similar capabilities to the LCS, the main difference is that they vary in size, which can become a limiting factor in execution in a contested environment. Due to FFGs being smaller, they are

> used as escort vessels to protect sea lines of communication or as an auxiliary component of a strike group whereas destroyers are generally integrated into carrier battle groups as the air defense component or utilized to provide territorial air and missile defense. (Husseini, 2019)

In the context of DMO, depending on the package and capability that is required, an FFG’s low signature from its smaller size and onboard firepower must be accounted for, creating different opportunities of transport within the model.

c. Littoral Combat Ship

The LCS has a unique capability within the maritime force because, unlike the FFG, it “is a modular, reconfigurable ship, with three types of Mission Packages: Surface Warfare (SUW) Mission Package, Mine Countermeasures (MCM) Mission Package, and Anti-Submarine Warfare (ASW) Mission Package” (U.S. Navy Office of Information, n.d.). The flexible packages provide the maritime force with mission capability near shore where agility and stealth are very important in contested waters to deter adversary forces and obtain key terrain to establish EABs.

3. Summary of Nodes

These nodes create a scalable, flexible, and lethal joint maritime force. “However, fulfilling our national strategy to support allies, deter aggressors, and—when necessary—project power, has a fundamental but strategic requirement that we don’t explore enough: the availability of fuel whenever and wherever we need it” (Knepper & Singer, 2015, paragraph 1). These nodes, combined with the NGLS platforms, create the availability and redistribution of fuel that is required when and where it is needed. This is imperative as near-peer adversaries attempt to create a tyranny of distance to overcome for the joint maritime force, demanding the appropriate amount of PSVs, FSVs, and LAWs to sustain and drive the nodes’ capabilities. Thus, each node distributes specific supporting requirements in order to meet demand signals to achieve maritime superiority. After analyzing the nodes and the distinct capability of each NGLS platform, each capability generates restraints and constraints that can be distinctly defined as inputs for the transshipment model.

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III. DATA AND METHODOLOGY

Our model was designed to provide OPNAV N4 with an unbiased, data-driven recommendation on the optimal NGLS composition to meet the future architecture of DMO and EABO. In collaboration with our advisors, Dr. Apte and Dr. Doerr, we developed a transshipment model with an objective function designed to minimize the number of deliveries necessary to support an aggregate resupply event. The end state goal was reduction of mission risk through the minimalization of deliveries within the WEZ. Figure 4 gives a visual representation of the model.

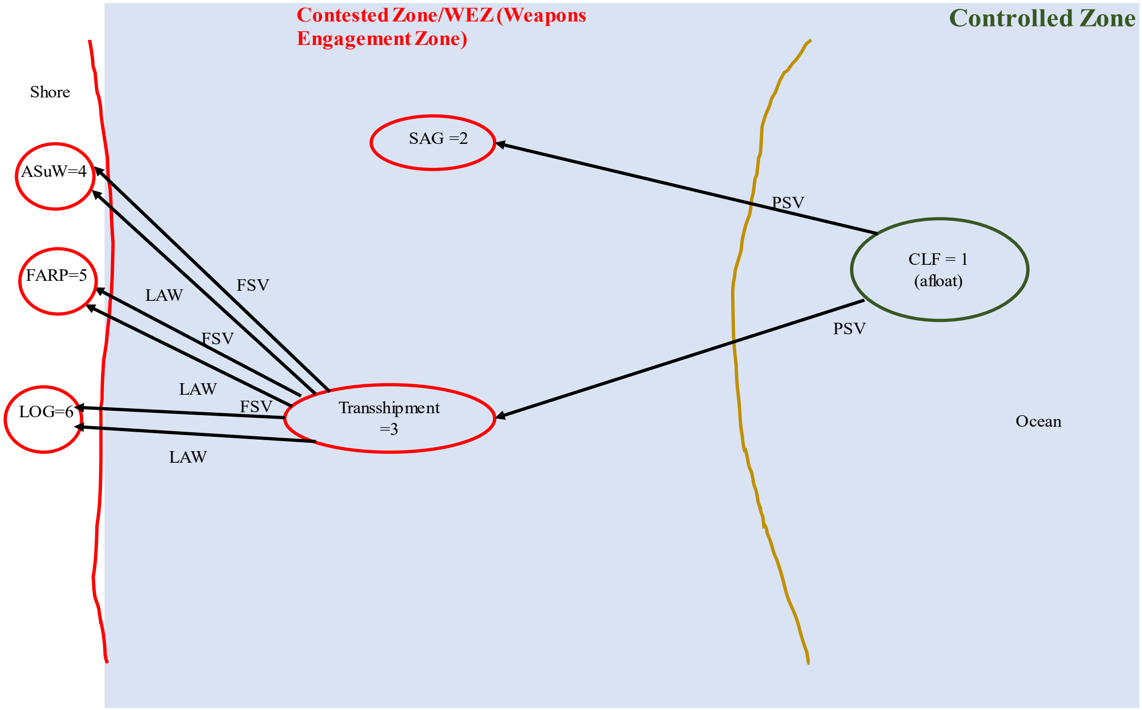

Figure 4. NGLS Model Framework

A. GENERAL FRAMEWORK

Due to the unclassified nature of this report, all parameters are hypothetical with intentionally approximated values. The supply and demand values are only placeholders to show the capability and scalability of the model.

1. Demand will be limited to fulfilling requirements from SAGs and EABs. SAG equates to afloat demand; EAB equates to ashore demand.

2. Demand for one SAG is comprised of three DDGs and one LCS, or three DDGs and one FFG(X).
3. EAB demand is broken down by specific EAB type, which includes ASuW strike units, STOVL FARP units, and maritime/naval logistics units.
4. All fuel requirements—including ship, aviation, and ground—are consolidated into a single fuel requirement, JP-5, per OPNAV N4 guidance.
5. Ship selection is limited to the NGLS family of PSV, FSV, and LAW and is considered equally survivable in the model.
6. PSVs cannot service EABs due to docking requirements.
7. The CLF remains outside the WEZ and is the sole replenishment node from which NGLS assets draw fuel. (In this report, a *node* indicates a point of supply, a point of demand, or a transshipment point.)
8. Replenishment of CLF assets are outside the scope of the project; therefore, fuel supply at the CLF is considered unconstrained.
9. Vessel capacity is constrained by delivery capacity, which is calculated by the fuel transfer rate capable within a specified time window.

These scope considerations play an integral role in the framework and design of the model. Specific transportation nodes and transportation arcs must first be designated in order to define the decision variables,

1. Nodes

A transportation node represents a specific point of supply, a point of demand, or a transshipment point. Each node location is considered an origin, transshipment, or destination location. An origin node is the starting point from which the resources demanded are supplied. A transshipment node is simply a transfer point in which all outflows must be less than or equal to the capacity of the delivering vessel. No resources can be stored at the transshipment point; it solely represents transfer of resources (fuel) from one vessel to another. A destination node is the ending point where resources are required. It is important to note that a destination node will not be used as a transshipment or origin node in the model. It is assumed that all demand at a destination node is consumed solely by that node. The base model designates the following nodes. (The numbers correlate to the symbols in Figure 4.)

1. **CLF:** origin node, provides fuel. This is where all fuel supply is drawn. Fuel supply at the CLF is unconstrained (unlimited).
2. **SAG:** destination node, demands fuel.
3. **Transshipment:** transshipment node, transfer point. Strictly a transfer activity in which all outflows must be less than or equal to the capacity of the delivering vessel.
4. **ASuW:** destination node, demands fuel.
5. **FARP:** destination node, demands fuel.
6. **Logistics (LOG):** destination node, demands fuel.

With the nodes established, the next step was to designate which vessel(s) could service each transportation arc.

2. Arcs

A transportation arc connects two nodes and can either be one-way or two-way (A. Apte, personal communication, January 15, 2020). This model exclusively utilizes one-way arcs with all resources consumed at the destination node(s). The type of vessel that can service an arc is dependent on the arc's location within the AO combined with the capabilities and limitations of the vessel. Below is a breakout of the vessel(s) capable of servicing each arc.

- CLF to SAG = PSV
- CLF to Transshipment = PSV
- Transshipment to ASuW = LAW or FSV
- Transshipment to FARP = LAW or FSV
- Transshipment to LOG = LAW or FSV

It is important to note that while the LAW and the FSV can technically satisfy the requirements necessary to perform duties from the CLF to SAG or from CLF to Transshipment, operational and capacity constraints designate the PSV as the sole servicer of these nodes. On the contrary, the PSV cannot physically satisfy any of the Transshipment to EAB nodes due to its nonbeach-ability, relatively slow speed, and lack of armament and/or self-defense capability.

3. Decision Variables

The decision variables for this model are the number of deliveries by vessel (k) required to satisfy the demand from node (i) to node (j). The variables are as follows:

- Ykij = number of deliveries by vessel (k) from node (i) to node (j)
- k = vessel type (1 for PSV, 2 for FSV, 3 for LAW)
- i = origination node (1 for CLF, 3 for Transshipment)
- j = destination nodes (2 for SAG, 3 for Transshipment, 4 for ASuW, 5 for FARP, 6 for LOG)
- Xkij = flow on vessel k from node i to node j (k, i, j defined as above)

For instance, a PSV going from the CLF to the SAG would be depicted as Y112, while a LAW traveling from the Transshipment node to an ASuW node would be Y334.

B. VESSEL CAPACITY AND DEMAND FIGURES

The supply capacity of each vessel is based strictly off the (T) and (O) levels set forth in each vessel's TLR documentation. The demand signal of each node was provided by OPNAV N4 and does not fluctuate. While there is only one of each node represented, a multiplier can be used to scale to unlimited node variations.

1. Threshold and Objective Supply Capacities

The threshold and objective capacity of JP-5 fuel for each vessel is depicted in Table 1. Total capacity represents the maximum storage capacity of the vessel, and delivery capacity represents the maximum amount of fuel that can be transferred within the operational delivery time window.

Table 1. Threshold and Objective Supply Capacity. Adapted from USN (2019a, 2019b).

Vessel	Threshold (T) Total Capacity	Objective (O) Total Capacity	Threshold (T) Delivery Capacity	Objective (O) Delivery Capacity
PSV	18,000	28,000	5,260	10,520
FSV	950	1,400	950	1,400
LAW	2,100	2,100	1,700	1,700
Units: bbl (1 bbl = 42 U.S. gallons)				

2. Demand Requirements

The demand requirements of each node were calculated per a single resupply event. A SAG has two variations: SAG 1 is comprised of three DDGs and one LCS, while SAG 2 represents three DDGs and one FFG(X). Only SAG 1 demand is represented in the model, since it is the greater of the two and the variance did not result in a material difference. The ashore nodes of ASuW, FARP, and LOG remain constant. Demand at each node is represented in Table 2.

Table 2. Node Demand. Adapted from Office of the Chief of Naval Operations (OPNAV, 2020).

Node	Fuel Demand per Resupply Event
SAG 1	18,250
SAG 2	18,165
ASuW	100
FARP	6,300
LOG	100
Units: bbl (1 bbl = 42 U.S. gallons)	

The key takeaways regarding supply capacities and demand data are twofold. First, the supply capacities for each vessel are constrained by an OPNAV N4–directed operational time window. A vessel can only transfer the stated delivery capacity of fuel per delivery, regardless of the vessel's total carrying capacity. For instance, the PSV's (T) delivery capacity is 5,260 bbl, even though its carrying capacity is 18,000 bbl. Therefore, the maximum amount of fuel a PSV can supply per delivery is 5,260 bbl. The second key takeaway relates to the demand data. The figures listed in Table 2 are for a single resupply event, and in order to forecast maximum operational tempo, the model is built to service all demand simultaneously.

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IV. ANALYSIS

The goal of our model was to provide OPNAV N4 with an unbiased, data-driven recommendation on the optimal NGLS composition necessary to satisfy future DMO requirements. Results are presented in four main categories:

- deliveries with (T) capabilities, constrained
- deliveries with (O) capabilities, constrained
- deliveries with (T) capabilities, unconstrained
- deliveries with (O) capabilities, unconstrained

As stated previously, (T) specifications establish the lower bounds of acceptable performance, whereas (O) specifications set the upper bounds. Acquisition programs operate within this trade space to identify solutions capable of optimizing cost, schedule, and performance goals. Delivery constrained outputs limit the supply capacity of each vessel to the amount of fuel capable of being transferred within the operational time window.

A. INTERPRETING DELIVERY NUMBER RESULTS

The number of deliveries can be interpreted in two primary methods. First, if a mission dictates that demand be filled in surge fashion, in which all demand nodes are satisfied simultaneously, one trip would equate to one vessel. The quickest way to do that would be to have a separate vessel for each trip. For example, if four PSV deliveries were required along Arc X and two along Arc Y, the Navy would need a total of six PSVs. This would allow both nodes to be resupplied in parallel at the maximum speed possible. Speed and effectiveness greatly outweigh efficiency in this method.

The second method for interpreting deliveries would be based off meeting demand in series, in which each vessel could make multiple deliveries. The only constraint on the number of deliveries per vessel would be the vessel's total capacity divided by the demand of each event. For instance, a PSV at (T) capability can carry 18,000 bbl and would be capable of satisfying three 5,260 bbl SAG resupply events (18,000 / 5,260 = 3.2) in an unconstrained scenario. However, this does not mean one PSV has to satisfy all three demands. A second PSV could perform two deliveries while the original PSV only performs one. This method should be pursued if cost and efficiency are the top priority.

1. Deliveries with (T) Capabilities, Constrained

Results modeled at (T) capabilities with an operationally constrained time window are shown in Table 3. The parameters resulted in 12 total deliveries, the largest amount of all scenarios.

Table 3. Deliveries Required at (T) Capabilities, Constrained

Arc Description	**Arc**	**Fuel Capacity (bbl)**	**Capacity per Delivery (bbl)**	**Required Deliveries**
PSV from CLF 1 to SAG 2	Y112	18,000	5,260	4
PSV from CLF 1 to Trans 3	Y113	18,000	5,260	2
FSV from Trans 3 to ASuW 4	Y234	950	950	0
FSV from Trans 3 to FARP 5	Y235	950	950	0
FSV from Trans 3 to LOG 6	Y236	950	950	1
LAW from Trans 3 to ASuW 4	Y334	2,100	1,700	1
LAW from Trans 3 to FARP 5	Y335	2,100	1,700	4
LAW from Trans 3 to LOG 6	Y336	2,100	1,700	0
Total Deliveries per Vessel				
PSV				6
FSV				1
LAW				5
Total Combined Deliveries				12

The increased delivery count was driven primarily by the low fuel transfer rate of the PSV. As depicted in Table 3, the PSV's (T) delivery capacity of 5,260 bbl is approximately one third of the vessel's total fuel capacity of 18,000 bbl. This means that the PSV can only expend approximately 30% of its stores on each delivery. The second contributing factor was the reduced transfer rate of the LAW, which constrained its carrying capacity of 2,100 bbl down to 1,700 bbl. Total deliveries required per vessel were PSV = 6, FSV = 1, and LAW = 5.

2. Deliveries with (O) Capabilities, Constrained

Results modeled at (O) capabilities with an operationally constrained time window are shown in Table 4. The parameters resulted in nine total deliveries, a reduction of three from the previous scenario.

Table 4. Deliveries Required at (O) Capabilities, Constrained

Arc Description	**Arc**	**Fuel Capacity (bbl)**	**Capacity per Delivery (bbl)**	**Required Deliveries**
PSV from CLF 1 to SAG 2	Y112	28,000	10,520	2
PSV from CLF 1 to Trans 3	Y113	28,000	10,520	1
FSV from Trans 3 to ASuW 4	Y234	1,400	1,400	0
FSV from Trans 3 to FARP 5	Y235	1,400	1,400	0
FSV from Trans 3 to LOG 6	Y236	1,400	1,400	1
LAW from Trans 3 to ASuW 4	Y334	2,100	1,700	1
LAW from Trans 3 to FARP 5	Y335	2,100	1,700	4
LAW from Trans 3 to LOG 6	Y336	2,100	1,700	0
Total Deliveries per Vessel				
PSV				3
FSV				1
LAW				5
Total Combined Deliveries				9

PSV deliveries required along Arc Y112 and Y113 were reduced by 50% as compared to deliveries necessary at (T) capabilities. Arc Y112 was reduced from four deliveries to two, and Arc Y113 was reduced from two to one. This was directly correlated to the 100 % increase in the fuel transfer rate from 5,260 bbl (T) capability to 10,520 bbl (O) capability. It is important to note that while the transfer rate did increase 100%, delivery capacity still accounted for less than 40% of the PSV's total fuel carrying capacity. The only other material change in the data was the FSV's increased delivery capacity from 950 bbl to 1,400 bbl. However, this did not change the composition of deliveries, as the FSV's 1,400 bbl delivery capacity remained inferior to the 1,700 bbl delivery capacity of the LAW.

3. Deliveries with (T) Capabilities, Unconstrained

Results modeled at (T) capabilities with an unconstrained delivery time window are shown in Table 5. These parameters resulted in eight total deliveries, a reduction of one delivery from the (O) constrained scenario and a reduction of four deliveries from the (T) constrained scenario.

Table 5. Deliveries Required at (T) Capabilities, Unconstrained

Arc Description	Arc	Fuel Capacity (bbl)	Capacity per Delivery (bbl)	Required Deliveries
PSV from CLF 1 to SAG 2	Y112	18,000	18,000	2
PSV from CLF 1 to Trans 3	Y113	18,000	18,000	1
FSV from Trans 3 to ASuW 4	Y234	950	950	0
FSV from Trans 3 to FARP 5	Y235	950	950	0
FSV from Trans 3 to LOG 6	Y236	950	950	1
LAW from Trans 3 to ASuW 4	Y334	2,100	2,100	1
LAW from Trans 3 to FARP 5	Y335	2,100	2,100	3
LAW from Trans 3 to LOG 6	Y336	2,100	2,100	0
Total Deliveries per Vessel				
PSV				3
FSV				1
LAW				4
Total Combined Deliveries				8

The key difference when transitioning from a constrained to an unconstrained model is that each vessel's delivery capacity is no longer bound by its fuel transfer rate. As shown in Table 5, fuel capacity is now set equal to capacity per delivery. This has the most significant impact on the PSV, as it is only capable of transferring approximately one third of its fuel within the (O) and (T) constrained environments.

Even with the significant increase in PSV delivery capacity, the number of deliveries for PSVs remained equal to the results of the (O) constrained environment. The reduction in total delivery count is solely the result of the LAW's increased delivery capacity of 2,100 bbl (up from 1,700 bbl). This reduces the number of deliveries required along Arc Y335 from four down to three. Overall, the total number of combined deliveries is approximately 33% less in an unconstrained environment as compared to vessels built to the same TLRs operating in a constrained environment.

4. Deliveries with (O) Capabilities, Unconstrained

Results modeled at (O) capabilities with an unconstrained delivery time window are shown in Table 6. These parameters required seven total deliveries, which was the minimum of all scenarios. This is a reduction of one delivery from the (T) unconstrained scenario and a reduction of two deliveries from the (O) constrained scenario.

Table 6. Deliveries Required at (O) Capabilities, Unconstrained

Arc Description	**Arc**	**Fuel Capacity (bbl)**	**Capacity per Delivery (bbl)**	**Required Deliveries**
PSV from CLF 1 to SAG 2	Y112	28,000	28,000	1
PSV from CLF 1 to Trans 3	Y113	28,000	28,000	1
FSV from Trans 3 to ASuW 4	Y234	1,400	1,400	0
FSV from Trans 3 to FARP 5	Y235	1,400	1,400	0
FSV from Trans 3 to LOG 6	Y236	1,400	1,400	1
LAW from Trans 3 to ASuW 4	Y334	2,100	2,100	1
LAW from Trans 3 to FARP 5	Y335	2,100	2,100	3
LAW from Trans 3 to LOG 6	Y336	2,100	2,100	0
Total Deliveries per Vessel				
PSV				2
FSV				1
LAW				4
Total Combined Deliveries				7

Gains in the PSV’s fuel capacity from the lower bounds of 5,260 bbl modeled in the first scenario to 28,000 bbl modeled in this scenario produced noteworthy results. Deliveries along Arc Y112 were reduced from four to one, a reduction of 75 %, and from two deliveries to one along Arc Y113, a reduction of 50%. This translates to one PSV being able to satisfy all demand at a SAG and one PSV being able to satisfy all demand at the Transshipment node. Neither the FSV nor the LAW experienced additional gains when increasing from (T) to (O) capabilities in the unconstrained environment.

B. SUMMARY OF FINDINGS

Our findings show that the number of deliveries varies significantly based on the TLR level and the constraints of the environment. As shown in Figure 5, the maximum number of deliveries, 12, occurred when the vessels were modeled at their (T) capabilities and bound by a time constraint. The minimum number of deliveries, seven, occurred when the vessels were modeled at their (O) capabilities and not bound by an operational time constraint. The difference between the maximum and the minimum results equates to an approximate 42% decrease in the number of required deliveries.

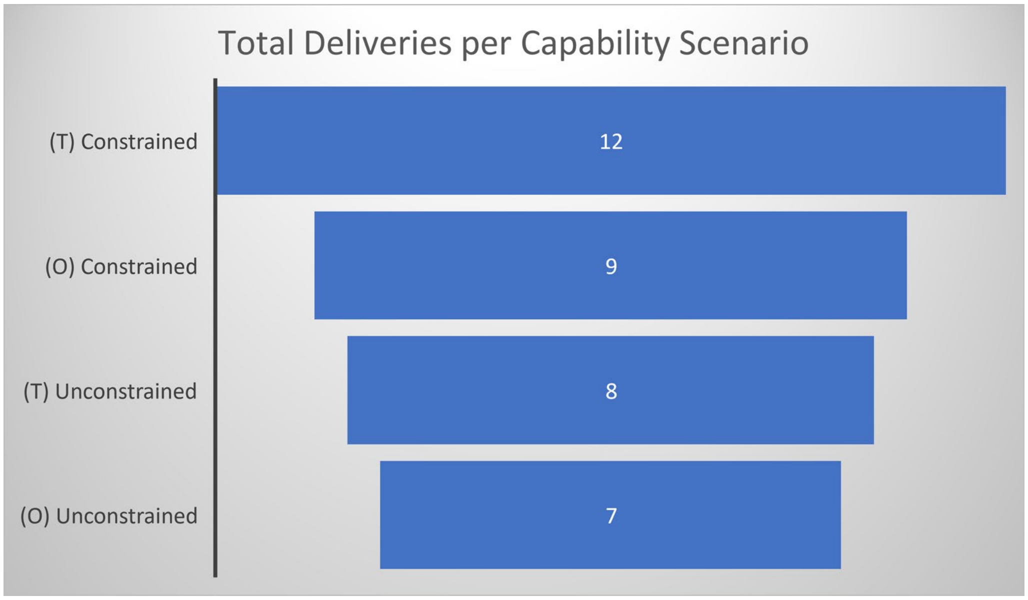
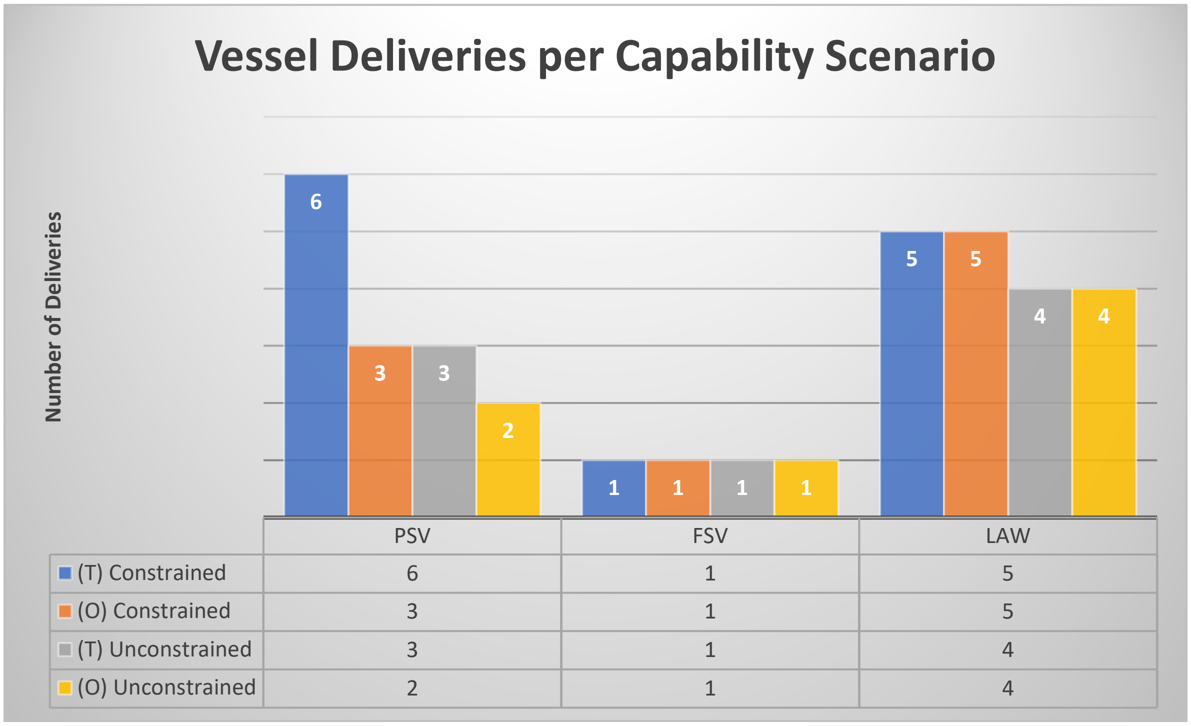


Figure 5. Total Aggregate Deliveries per Capability Scenario

1. Comparing Vessel Deliveries per Capability and Constraint Scenario

The vessel that experienced the greatest variance was the PSV. Progressive increases in the PSV's delivery capacity from scenario (T) constrained to (O) unconstrained accounted for four of the five aggregate delivery reductions. Delivery capacity increases were directly attributed to changes in the vessel's fuel transfer rate and total fuel capacity. The PSV's fuel transfer rate doubled from 5,260 bbl at (T) capability to 10,520 bbl at (O) capability, whereas its fuel capacity increased from 18,000 bbl to 28,000 bbl.

The LAW was the only other vessel that experienced a reduction in deliveries throughout the four scenarios. Its total delivery count went from five to four, reducing the aggregate total by one. This decrease is only possible in unconstrained scenarios, as it was solely a factor of the increased fuel capacity from 1,700 bbl at (T) to 2,100 bbl at (O) capability. It is important to note that while its fuel capacity increased, the fuel transfer rate remained constant at both TLR levels, so there was no benefit from the larger fuel capacity when operating in a constrained environment.



	PSV	FSV	LAW
🟦 (T) Constrained	6	1	5
🟧 (O) Constrained	3	1	5
⬜ (T) Unconstrained	3	1	4
🟨 (O) Unconstrained	2	1	4

Figure 6. Vessel Deliveries per Capability Scenario

The FSV did not experience any change in delivery count even with an approximate 47% increase in delivery capacity from (T) to (O) capabilities. This is primarily driven by the fact that its increased (O) capacity of 1,400 bbl is still lesser than the 1,700 bbl capacity of LAW with which it directly competes.

2. Effects of TLR Level and Constraint on Delivery Capacity

As stated previously, delivery requirements vary substantially based on the combination of TLR capabilities and the operating environment. These changes measured as the difference in delivery capacity between scenarios are depicted in Table 7. For example, the PSV’s delivery capacity increased 432% from 5,260 bbl at (T) constrained to 28,000 bbl at (O) unconstrained ([28,000 - 5,260] / 5,260 = 4.32). Conversely, the FSV and the LAW experienced a lesser 47% and 24% delivery capacity improvement from the lower to upper bound.

Table 7. Changes in Delivery Capacity between Scenarios

Arc Description	(T) C to (O) C	(T) C to (T) U	(O) C to (T) U	(O) C to (O) U	(T) C to (O) U
PSV from CLF 1 to SAG 2	100%	242%	71%	166%	432%
PSV from CLF 1 to Trans 3	100%	242%	71%	166%	432%
FSV from Trans 3 to ASuW 4	47%	0%	-32%	0%	47%
FSV from Trans 3 to FARP 5	47%	0%	-32%	0%	47%
FSV from Trans 3 to LOG 6	47%	0%	-32%	0%	47%
LAW from Trans 3 to ASuW 4	0%	24%	24%	24%	24%
LAW from Trans 3 to FARP 5	0%	24%	24%	24%	24%
LAW from Trans 3 to LOG 6	0%	24%	24%	24%	24%

TLR: (T) = Threshold, (O) = Objective

Environment: C = Constrained, U = Unconstrained

3. Alternate Optimal Solution for FSV and LAW

It is important to note that the FSV and the LAW provide a one-to-one alternate optimal solution for deliveries from the Transshipment node to both ASuW and LOG nodes in all four scenarios. This is because the demand requirement at each node of 100 bbl is less than both platforms' absolute minimum delivery capacity of 950 bbl for FSV and 1,700 bbl for LAW. However, due to anticipated roll on/ roll off operational requirements at ASuW nodes, the FSV would not be capable of servicing ASuW nodes. On the contrary, the LAW is more than capable of servicing LOG nodes, meaning one LAW could replace the one FSV identified to service LOG 6 in each scenario. This would result in all ashore nodes being serviced by the LAW, fully eliminating the need for the FSV. We highly recommend OPNAV N4 conduct further research into the cost effectiveness and efficiencies that could be gained by reducing the NGLS family from three platforms to two.

4. Analysis Summary

The summary findings in Figure 6 and Table 7 provide OPNAV N4 with valuable planning and forecasting information. Figure 6 is instrumental in identifying the upper and lower bounds of deliveries across all scenarios, whereas Table 7 highlights the variances in TLR tradespace based on the operating environment. Summary analysis for each vessel is as follows.

- The PSV shows the greatest spread in delivery count based on its TLR targets and operating constraints. Barring cost and sustainment information, the PSV should be targeted for procurement at its (O) TLR capabilities. In addition, OPNAV N4 should also seek courses of action that reduce or eliminate the delivery time constraints.
- The LAW's ability to affect delivery count is solely a factor of its operating environment. We infer that there is no gain in targeting solutions above the LAW's (T) TLR targets. OPNAV N4 must identify courses of action that reduce or eliminate time constraints in order to achieve the depicted reduction in deliveries.
- The FSV delivery count is not affected by the FSV's TLR level or the operating environment. We infer that there is no positive impact in procurement above the FSV's (T) TLR targets. Additionally, since the FSV's upper bounds of delivery capacity of 1,400 bbl is inferior to the lower bounds of the LAW's 1,700 bbl delivery capacity, the LAW will always be the preferred vessel for demands greater than 1,400 bbl.
- **Alternate optimum solution:** The LAW is capable of replacing the FSV in all scenarios. Further research should be conducted on the potential benefits/drawbacks of eliminating the FSV from the NGLS family.

Table 7 should be closely reviewed by each platform's program manager to identify the trade-offs associated with differing TLR levels and each vessel's anticipated operating environment. For instance, removing the operational time constraint of a PSV at (T) capabilities results in 71% greater delivery capacity as compared to a PSV at (O) capability in a constrained environment (labeled as column "(O) C to (T) U" in Table 7). This means the Navy could save significant money on acquisition and life-cycle costs if able to mitigate time constraints and still meet demand with lower TLR capabilities. Additionally, Table 7 gives planners a general recommendation on potential asset allocation and prioritization by highlighting the platforms and scenarios that produce the greatest capacity improvements.

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V. CONCLUSIONS AND FUTURE WORK

Future amphibious operations will be intense and fought over vast distances. U.S. armed forces will be susceptible to enemy actions well before arriving into the AO. Having the ability to sustain forces from within the WEZ allows for rapid response to multiple locations simultaneously and extends the range and capability of sustainment forces. In order to operate in contested environments, the U.S. Navy and Marine Corps need to continue to build upon capacity while reducing constraints within our platforms in order to sustain operations and survive within the adversary's WEZ. The ability of the Navy and Marine Corps to conduct future amphibious operations is directly proportional to their ability to leverage capacity.

Due to the advancements in technology and the adversary's ability to fight in multi-domain environments, future warfare will escalate quickly and will result in consuming resources—specifically fuel—at quicker rates. This requires sustainment capabilities that are agile, responsive, and able to survive enemy interdiction. In order to properly posture forces against the pacing threat of the great power competition of China and Russia, the Navy and Marine Corps should seek to close distances and allow for enhanced sustainment of the amphibious forces so they do not place forces at risk from culmination.

A. CONCLUSION

Our model was designed to provide OPNAV N4 with an unbiased, data-driven recommendation on the optimal NGLS composition necessary to meet fuel requirements of distributed operations in a contested environment. We developed a transshipment model with an objective function designed to minimize the number of deliveries required to support an aggregate resupply event. The end state goal was the reduction of mission risk through the minimization of deliveries within the WEZ. The NGLS platforms assessed in our model were the fast supply vessel (FSV), the platform supply vessel (PSV), and the light amphibious warship (LAW).

Our findings show that the number of deliveries varies significantly based on the TLR level of the vessel and the constraints of the environment. The maximum number of deliveries, 12, occurred when the vessels were modeled at their (T) capabilities and bound by a time constraint. The minimum number of deliveries, seven, occurred when the vessels were modeled at their (O) capabilities and not bound by an operational time constraint. The difference between the maximum and minimum results equates to an approximate 42% decrease in the number of required deliveries. The most significant improvement in capability—and thus delivery reduction—was captured by the PSV; its delivery capacity increased 432% from 5,260 bbl at (T) constrained to 28,000 bbl at (O) unconstrained. The FSV and the LAW experienced a lesser 47% and 24% delivery capacity improvement from the lower to upper bound. In addition, the model identified that the FSV and the LAW provide an alternate optimum solution for ashore demand (based strictly on capacity requirements).

These findings provide OPNAV N4 with an unbiased assessment of the opportunity costs associated with each platform's trade space and correlating effects of the operational environment. The number of deliveries can be reduced through acquisitioning to higher TLRs or removing the operational time constraints, or the number of deliveries can be maximized by a combination of both. However, the PSV showed the greatest variance between upper and lower bound capacity and should thus get prioritization of effort and resources. These efforts will require both fiscal and doctrinal efforts, as no amount of money can simply remove the operational constraint.

B. FUTURE WORK

This research was designed to find the optimal number of NGLS vessels within a contested environment. As the sponsor receives more information about the costs for each ship, this model could be expanded to include the acquisition costs associated with each vessel. This would create an objective function of minimizing costs to assist the Department of the Navy and the Marine Corps to purchase the ships that not only provide utility through deliveries but also those that are the most economically feasible.

The operational time constraint is a significant variable that should be continuously reviewed. It effectively limits each vessel's delivery capacity to the fuel transfer rate capable of being achieved within the designated time window. Therefore, in the case of the PSV at (T) operating in a constrained environment, its delivery capacity of 5,260 bbl is less than one third of its total fuel capacity of 18,000 bbl. Therefore, OPNAV N4 needs to continuously review this service-imposed constraint and assess whether options exist to mitigate it with current resources. For instance, can a SAG comprised of three DDGs and one LCS not provide enough protection to support an unimpeded fuel resupply event?

In addition, our model did not include the load and unload times to the ASuW, FARP, and Logistic nodes. This could alter the number of vessels required to meet demand and potentially increase risk of exposure due to the number of vessels that would be required. As these nodes increase and move within the contested AO, it is imperative to look at how the load and unload times could affect the placement of these nodes within the scenario.

C. SUMMARY

This study assesses the optimal type and quantity of NGLS deliveries necessary to supply the force with the fuel demanded as outlined by the OPNAV N4 staff. It focuses on the vessels and their ability to sustain nodes within the WEZ. We created a transshipment network that could be modeled mathematically. The model provided a large framework for determining the deliveries required within the designed network architecture of DMO and EABO. Based on the assumptions and constraints used in the model, the results reveal flexibility for the sponsor to determine how they want to minimize the risk and exposure that are often present in logistic operations.

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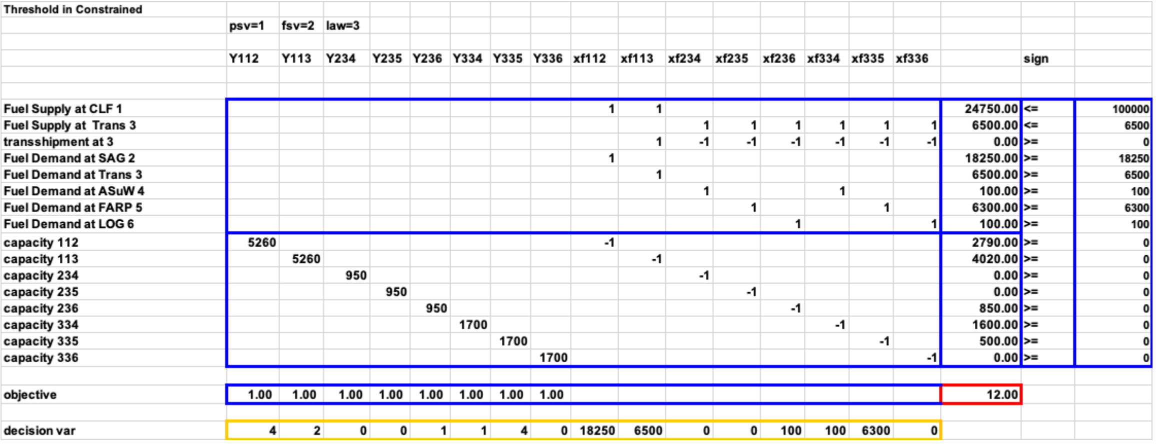
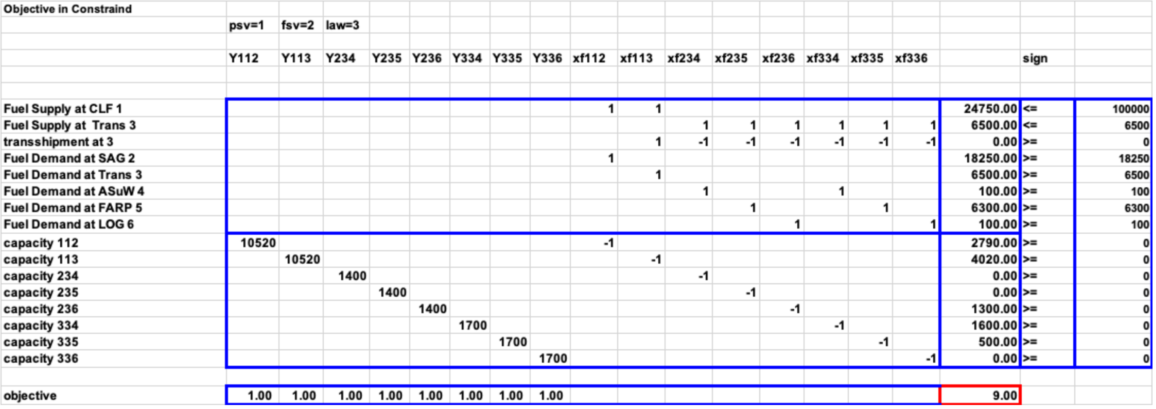
APPENDIX. MODEL OUTPUTS

A. MODEL (T) CAPABILITIES—CONSTRATINED



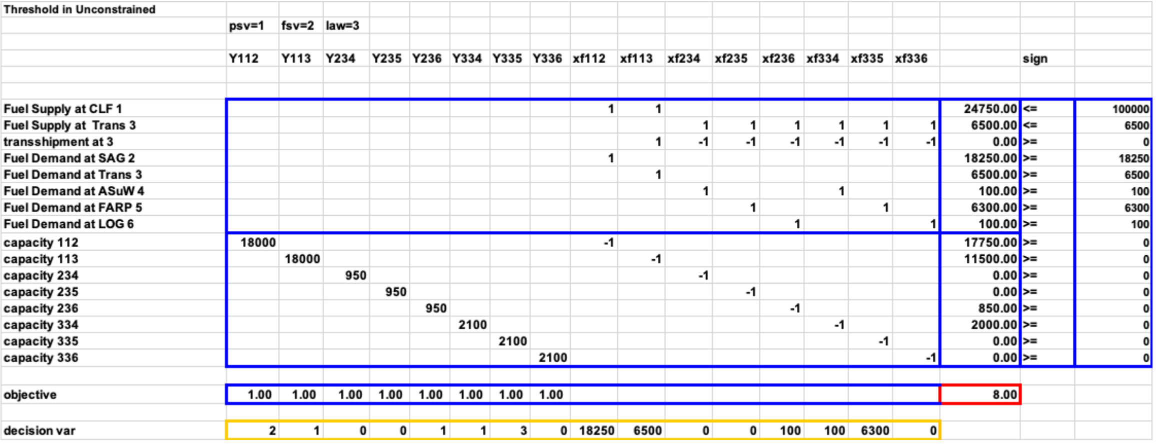
Threshold in Constrained																			
	psv=1	fsv=2	law=3																
	Y112	Y113	Y234	Y235	Y236	Y334	Y335	Y336	xf112	xf113	xf234	xf235	xf236	xf334	xf335	xf336		sign	
Fuel Supply at CLF 1									1	1							24750.00	<=	100000
Fuel Supply at Trans 3											1	1	1	1	1	1	6500.00	<=	6500
transshipment at 3										1	-1	-1	-1	-1	-1	-1	0.00	>=	0
Fuel Demand at SAG 2									1								18250.00	>=	18250
Fuel Demand at Trans 3										1							6500.00	>=	6500
Fuel Demand at ASuW 4											1			1			100.00	>=	100
Fuel Demand at FARP 5												1			1		6300.00	>=	6300
Fuel Demand at LOG 6													1			1	100.00	>=	100
capacity 112	5260								-1								2790.00	>=	0
capacity 113		5260								-1							4020.00	>=	0
capacity 234			950								-1						0.00	>=	0
capacity 235				950								-1					0.00	>=	0
capacity 236					950								-1				850.00	>=	0
capacity 334						1700								-1			1600.00	>=	0
capacity 335							1700								-1		500.00	>=	0
capacity 336								1700								-1	0.00	>=	0
objective	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00									12.00		
decision var	4	2	0	0	1	1	4	0	18250	6500	0	0	100	100	6300	0			

B. MODEL (O) CAPABILITIES—CONSTRAINED



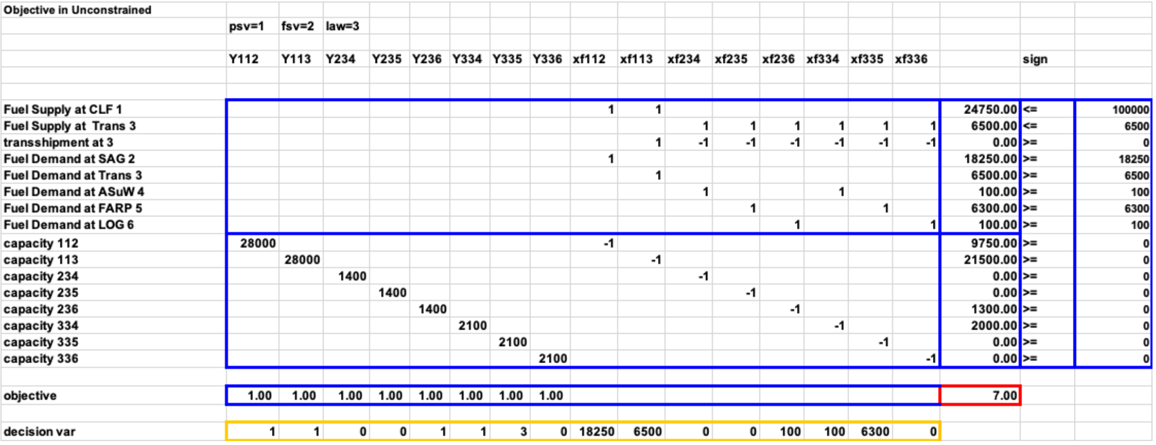
Objective in Constraind																			
	psv=1	fsv=2	law=3																
	Y112	Y113	Y234	Y235	Y236	Y334	Y335	Y336	xf112	xf113	xf234	xf235	xf236	xf334	xf335	xf336		sign	
Fuel Supply at CLF 1									1	1							24750.00	<=	100000
Fuel Supply at Trans 3											1	1	1	1	1	1	6500.00	<=	6500
transshipment at 3										1	-1	-1	-1	-1	-1	-1	0.00	>=	0
Fuel Demand at SAG 2									1								18250.00	>=	18250
Fuel Demand at Trans 3										1							6500.00	>=	6500
Fuel Demand at ASuW 4											1			1			100.00	>=	100
Fuel Demand at FARP 5												1			1		6300.00	>=	6300
Fuel Demand at LOG 6													1			1	100.00	>=	100
capacity 112	10520								-1								2790.00	>=	0
capacity 113		10520								-1							4020.00	>=	0
capacity 234			1400								-1						0.00	>=	0
capacity 235				1400								-1					0.00	>=	0
capacity 236					1400								-1				1300.00	>=	0
capacity 334						1700								-1			1600.00	>=	0
capacity 335							1700								-1		500.00	>=	0
capacity 336								1700								-1	0.00	>=	0
objective	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00									9.00		

C. MODEL (T) CAPABILITIES—UNCONSTRAINED



Threshold in Unconstrained																			
	psv=1	fsv=2	law=3																
	Y112	Y113	Y234	Y235	Y236	Y334	Y335	Y336	xf112	xf113	xf234	xf235	xf236	xf334	xf335	xf336		sign	
Fuel Supply at CLF 1									1	1							24750.00	<=	100000
Fuel Supply at Trans 3											1	1	1	1	1	1	6500.00	<=	6500
transshipment at 3										1	-1	-1	-1	-1	-1	-1	0.00	>=	0
Fuel Demand at SAG 2									1								18250.00	>=	18250
Fuel Demand at Trans 3										1							6500.00	>=	6500
Fuel Demand at ASuW 4											1			1			100.00	>=	100
Fuel Demand at FARP 5												1			1		6300.00	>=	6300
Fuel Demand at LOG 6													1			1	100.00	>=	100
capacity 112	18000								-1								17750.00	>=	0
capacity 113		18000								-1							11500.00	>=	0
capacity 234			950								-1						0.00	>=	0
capacity 235				950								-1					0.00	>=	0
capacity 236					950								-1				850.00	>=	0
capacity 334						2100								-1			2000.00	>=	0
capacity 335							2100								-1		0.00	>=	0
capacity 336								2100								-1	0.00	>=	0
objective	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00									8.00		
decision var	2	1	0	0	1	1	3	0	18250	6500	0	0	100	100	6300	0			

D. MODEL (O) CAPABILITIES—UNCONSTRAINED



Objective in Unconstrained																			
	psv=1	fsv=2	law=3																
	Y112	Y113	Y234	Y235	Y236	Y334	Y335	Y336	xf112	xf113	xf234	xf235	xf236	xf334	xf335	xf336		sign	
Fuel Supply at CLF 1									1	1							24750.00	<=	100000
Fuel Supply at Trans 3											1	1	1	1	1	1	6500.00	<=	6500
transshipment at 3										1	-1	-1	-1	-1	-1	-1	0.00	>=	0
Fuel Demand at SAG 2									1								18250.00	>=	18250
Fuel Demand at Trans 3										1							6500.00	>=	6500
Fuel Demand at ASuW 4											1			1			100.00	>=	100
Fuel Demand at FARP 5												1			1		6300.00	>=	6300
Fuel Demand at LOG 6													1			1	100.00	>=	100
capacity 112	28000								-1								9750.00	>=	0
capacity 113		28000								-1							21500.00	>=	0
capacity 234			1400								-1						0.00	>=	0
capacity 235				1400								-1					0.00	>=	0
capacity 236					1400								-1				1300.00	>=	0
capacity 334						2100								-1			2000.00	>=	0
capacity 335							2100								-1		0.00	>=	0
capacity 336								2100								-1	0.00	>=	0
objective	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00									7.00		
decision var	1	1	0	0	1	1	3	0	18250	6500	0	0	100	100	6300	0			

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