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## EXPEDITIONARY ADVANCED BASE OPERATIONS (REFUEL) 2045

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December 2023

**By:** Pablo J. Rodriguez  
Elizabeth M. Courtney  
Gabra A. Bailey

**Advisor:** Geraldo Ferrer  
**Co-Advisor:** Susan K. Aros

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**EXPEDITIONARY ADVANCED BASE OPERATIONS (REFUEL) 2045**

Pablo J. Rodriguez, Lieutenant Commander, United States Navy  
Elizabeth M. Courtney, Lieutenant Commander, United States Navy  
Gabra A. Bailey, Major, United States Marine Corps

Submitted in partial fulfillment of the  
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December 2023**

Approved by: Geraldo Ferrer  
Advisor

Susan K. Aros  
Co-Advisor

Aruna U. Apte  
Academic Associate  
Department of Defense Management

Rene G. Rendon  
Academic Associate  
Department of Defense Management

Robert F. Mortlock  
Academic Associate  
Department of Defense Management

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# **EXPEDITIONARY ADVANCED BASE OPERATIONS (REFUEL) 2045**

## **ABSTRACT**

This study evaluates the supportability of Expeditionary Advanced Base Operations (EABO) fuel logistics in the Indo-Pacific area of responsibility during contested environments. EABO, a strategy for establishing nimble bases for power projection, confronts substantial logistical hurdles, particularly in fuel supply. The research utilizes tools like the Replenishment at Sea Planner (RASP) and the Fuel Usage Study Extended Demonstration (FUSED) to scrutinize fuel use and devise optimal supply strategies under routine and high-demand conditions for various EABO configurations. Findings reveal a significant variance in fuel consumption based on unit size, equipment use, and operational pace. The study provides a data-driven analysis of EABO fuel logistics to enhance responsiveness, resilience, and effectiveness. Recommendations from the study suggest specific asset combinations to ensure adequate fuel support, emphasizing the importance of strategic asset prepositioning to accommodate heightened operational demands.

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## LIST OF ACRONYMS AND ABBREVIATIONS

|           |                                                                                                              |
|-----------|--------------------------------------------------------------------------------------------------------------|
| A2/AD     | anti-access/area denial                                                                                      |
| AOR       | area of responsibility                                                                                       |
| ASW       | antisubmarine warfare                                                                                        |
| C5ISRT    | command, control, communications, computing, cyber intelligence, surveillance, reconnaissance, and targeting |
| CLF       | combat logistics force                                                                                       |
| CNO       | Chief of Naval Operations                                                                                    |
| CONSOL    | fuel consolidation                                                                                           |
| COTS      | commercial off-the-shelf                                                                                     |
| CSS       | combat support service                                                                                       |
| DARPA     | Defense Advanced Research Project Agency                                                                     |
| DFM       | diesel marine fuel                                                                                           |
| DMO       | distributed maritime operations                                                                              |
| DOD       | Department of Defense                                                                                        |
| EAB       | expeditionary advance bases                                                                                  |
| EABO      | expeditionary advanced base operations                                                                       |
| FMF       | fleet marine force                                                                                           |
| F-76      | naval distillate fuel                                                                                        |
| FARP      | forward arming and refueling point                                                                           |
| NGLS      | next-generation logistics ships                                                                              |
| FSV       | fast supply vessel                                                                                           |
| FUSED     | fuel usage study extended demonstration                                                                      |
| INDOPACOM | Indo-Pacific Command                                                                                         |
| JP-5      | jet propellant 5                                                                                             |
| JP-8      | jet propellant 8                                                                                             |
| LSM       | medium landing ship                                                                                          |
| MSC       | Military Sealift Command                                                                                     |

|        |                                |
|--------|--------------------------------|
| NAVAIR | Naval Air Systems Command      |
| NLI    | naval logistics integration    |
| PSV    | platform supply vessel         |
| RASP   | replenishment at sea planner   |
| SFC    | single fuel concept            |
| TAKE   | dry cargo ammunition ship      |
| TAO    | large fleet oilers             |
| TAOE   | fast cargo support ship        |
| TAOL   | navy light replenishment oiler |
| TLR    | top-level requirements         |
| UNREP  | underway replenishment         |
| USMC   | United States Marine Corps     |
| VBA    | visual basics for applications |
| WEZ    | weapon engagement zone         |

## EXECUTIVE SUMMARY

This study evaluates the supportability of Expeditionary Advanced Base Operations (EABO) fuel logistics in the Indo-Pacific area of responsibility (AOR) during contested environments. EABO is a new Navy and Marine Corps operational concept that relies on establishing small, mobile bases to project power into contested areas. However, sustaining fuel supply for EABO poses a significant logistical challenge.

Using deterministic modeling tools like the Fuel Usage Study Extended Demonstration (FUSED) system and the Replenishment at Sea Planner (RASP), this study analyzes the fuel consumption patterns and optimal resupply strategies for different EABO configurations. Five EABO setups were examined, each with a central hub called an Expeditionary Advanced Base (EAB) Company+ and four smaller EAB Platoons. Fuel demand was calculated for both routine “sustained” operations and intense “surge” conditions.

Key findings include:

- Fuel consumption varies significantly based on EAB unit size, equipment uses, and operational tempo. The EAB Company+ required 45,172 gallons/day for sustained ops but 69,045 gallons/day for surge, a 50 percent increase. Each EAB Platoon’s demand rose from 1,794 to 2,477 gallons/day (a 38 percent increase).
- Optimal delivery fleet mixes were identified to meet on-time resupply thresholds. For sustained operations, as few as 2 Liberty Lifters and 2 Medium Landing Ships (LSMs) with 1 Platform Supply Vessel (PSV) sufficed from the South and West fuel consolidation (CONSOL) stations. But meeting surge demands required pre-positioning LSMs near EAB Platoons and using between 2 and 6 LSMs, 2 Liberty Lifters, and 1 or 2 PSVs to achieve on-time deliveries before receiving stations fall below their safety threshold. More delivery assets were needed when using the

East CONSOL station as it was farther away. Its greater distance prevented on-time deliveries even with added PSVs.

Recommendations to suit this EAB scenario in the Indo-Pacific Command (INDOPACOM AOR) include:

- Employ 4 LSMs, 2 PSVs, and 2 Liberty Lifters as a robust force mix.
- Pre-position LSMs and use Liberty Lifters dynamically to handle surge demands.
- Additional PSVs are required if the CONSOL station is greater than 2,300 nautical miles from the EABO hub.

This study provides a data-driven analysis of EABO fuel consumption patterns and tailored resupply strategies. The modeling, deterministic optimizations, and recommendations create an analytical framework that could be further used to analyze other scenarios in different locations to enhance EABO logistics support for both sustained and surge operational demands.

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Special thanks are also due to the Family of Expeditionary Fuel Systems at the Headquarters, U.S. Marine Corps, Combat Development and Integration (HQMC, CD&I). Their provision of U.S. Marines equipment demand data significantly enhanced the practical relevance and depth of our study.

We are equally grateful to Anton Rowe from the Naval Postgraduate School Operations Research Department. His assistance in conducting optimization runs with the Replenishment at Sea Planner (RASP) model was instrumental in bringing a critical aspect of our thesis to successful completion.

This journey, marked by learning and growth, has been made possible by the collective support and contributions of all these remarkable individuals and organizations. We are deeply thankful for their generosity, time, and willingness to share their knowledge and resources with us.

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## I. INTRODUCTION

In the increasingly intricate landscape of the Expeditionary Advanced Base Operations (EABO), one issue stands at the precipice of an unresolved logistical challenge in the Indo-Pacific Command (INDOPACOM) Area of Responsibility (AOR). The crux of the problem is this: the U.S. Department of Defense (DOD) has yet to devise an effective, reliable, and sustainable method for fuel supply and resupply in contested environments. This capstone project seeks to rectify this critical gap, offering an opportunity to reassess, re-imagine, and reinvent the logistics supportability of the EABO Concept of Operations (CONOPS).

This capstone project evaluates the logistical supportability of EABO CONOPS in the INDOPACOM AOR during contested environments. This study supports the 2022 National Defense Strategy Force Planning Construct, which states that the Department of Defense (DOD) will prioritize a future force that “securely and effectively provides logistics and sustainment to continue operations in a contested and degraded environment, despite adversary disruption” (Department of Defense, 2022, p. 18). This study aims to answer the following questions:

1. How does the daily fuel consumption vary across different proposed EAB configurations, and what factors influence these variations?
2. What are the optimal numbers and deployment strategies for Navy Light Replenishment Ship (TAOL), Medium Landing Ship (LSM), and Liberty Lifter to support EABO missions in both contested and non-contested environments?

Our investigation finds its anchor in the 2022 National Defense Strategy Force Planning Construct, which underscores the urgency of a future force able to withstand operations in contested environments, even in the face of adversary disruption. This issue is further magnified by the reality of modern warfare, wherein adversaries are increasingly leveraging extended-range weapons supplemented with precision munitions. The hurdles are high, but the U.S. resolve must be higher. The importance of the DOD’s ability to

organically support its forces abroad continues to increase, as the freedom of commerce around the world continues to be challenged by adversaries. During a conflict, adversaries will likely prevent the U.S. from effectively using foreign ports and contracted sources the U.S. has been using for the past 20 years to support operations abroad. This capstone study examines the fuel consumption of EABO, studying different configurations and the ability of EABO refueling support by the Combat Logistics Force (CLF) utilizing Next Generation Logistics Ships in a contested environment.

The study conducts deterministic optimizations of various EABO configurations using the Replenishment at Sea Planner (RASP). RASP is an advanced software that has been specifically designed to optimize refueling schedules. To achieve this, RASP relies on a transportation linear programming solution to generate data. This data serves as the foundation for RASP, allowing it to perform a comprehensive analysis of naval logistics. By integrating the output of the linear programming model with RASP's analytical capabilities, the research process is enhanced, providing a holistic view of the logistics landscape.

Additionally, the study uses the Fuel Usage Study Extended Demonstration (FUSED) system, which was created by NPS faculty Mr. Brandon Naylor in 2015. FUSED allows users to calculate the fuel amounts consumed by units pre-populated in the program, then it identifies the required assets to replenish these units depending on asset availability, sea state, and other configurable variables. FUSED can be tailored to create realistic scenarios with customized configurations to determine burn rates and supporting requirements.

In this study, we employ decision modeling to optimize different scenarios in an EABO-contested environment, particularly focusing on fuel consumption and resupply logistics. Decision modeling is a quantitative technique used to help make informed decisions based on complex variables and factors. The method is particularly useful in situations involving a prominent level of uncertainty, enabling decision-makers to evaluate possible scenarios and their respective consequences. Through the alteration of parameters such as sea state, asset availability, and fuel type, the decision model can project various

operational scenarios and their potential outcomes. It will help assess and evaluate the viability of various supply chain configurations.

Daily operations are simulated on five EABO configurations, each incorporating at least one Forward Arming and Refueling Point (FARP). A standard fuel demand table for various EABO mission sets is integrated into FUSED. The optimization models generate an output of each asset configuration support during two demand scenarios, sustained and surge, and with the CLF using a single fuel (JP-5), to measure the impact of these variables on the CLF refueling capabilities availability. As in real-world conflict, these scenarios seek to reduce mission risks during contested environments. Therefore, the CLF force will be restricted to staying outside the WEZ, and only Medium Landing Ships (LSM), and Fast Supply Vessels (FSV) will be allowed to deliver fuel inside the WEZ.

This chapter introduced the study and outlined the questions we intend to answer. Chapter II provides a more detailed background of the problem, an overview of the single fuel concept, EABO, and USN Battle Force 2045, and the future of U.S. Navy assets. Chapter III reviews the relevant literature. Chapter IV describes the base scenario and the models and methodology used in optimizing our scenarios. Chapter IV also lists limitations and a detailed overview of the optimization results. Chapter V outlines and summarizes the model outputs and discusses the conclusions that can be drawn from these results providing recommendations based on these conclusions.

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## II. BACKGROUND

As the U.S. Navy navigates an increasingly complex and demanding operational landscape. Strategically addressing logistics at the point of consumption has never been more crucial. To accomplish this, the DOD must integrate logistics information, control the flow of materiel, and coordinate command structures effectively. This is not merely about the efficient management of resources; it is about the resilience and agility of our forces. Our target is twofold: to enhance operational effectiveness and survivability and to minimize vulnerabilities that could compromise the mission.

In this context, the current capacity of the Navy's amphibious fleet, while significant, does not measure up to the growing demands of the changing environment. The operational landscape is evolving, and our naval capabilities must evolve with it. Through the integration of logistics, a diverse amphibious fleet, and an emphasis on operational effectiveness, the DOD can ensure our readiness for future challenges. To be prepared for the challenges of 2045, the DOD must expand and diversify our amphibious capabilities. Currently, the Amphibious Assault Ships (LHA/LHD), with their robust deck space and advanced command and control systems, serve as the core of the amphibious fleet, acting as the 'mothership' and the 'quarterback' of operations. They are the strategic centers from which the Navy can direct and coordinate its distributed forces.

However, it is not just about these heavy hitters. The Navy must also look towards lighter, more agile vessels to supplement its capabilities. A fleet of light amphibious warships that the Navy's inventory currently lacks can add a new dimension to naval operations, providing the Navy with greater flexibility and allowing it to operate effectively in a broader range of environments (Abbott, 2020, para. 8). These vessels can infiltrate shallower waters, move troops and equipment quickly, and operate as part of the Navy's distributed force, which adds to naval strategic advantages. Simply put, the Navy needs to expand, adapt, and innovate to meet the demands of the ever-changing operational environment. The time for action is now. Let us embrace the future with the knowledge that the Navy is prepared to face whatever it brings.

## A. SINGLE FUEL CONCEPT

According to Le Pera's 2005 Trade Journal article, the SFC initiative started in the late 1980s intending to standardize fuels used by all North Atlantic Treaty Organization's (NATO's) allies. In related research, Garrett (1993) uncovered that additives different countries use for freezing prevention were creating filterability problems and causing issues for the engines of the M1 Abrams engines (p. 5). Le Pera (2005) went on to conclude that in an attempt to solve this problem, the U.S. Army adopted the use of JP-8 in 1986, and the DOD mandated JP-8 fuel standardization for air and ground forces in 1989.

JP-8 cannot be used aboard ships due to its low flash point of 100 F, as temperatures onboard ships can easily reach 100°F or higher. Main propulsion systems onboard surface combatant ships use Diesel Marine Fuel (DFM) or F-76, and aircraft and emergency diesel generators use JP-5, as these two have a flash point of 140°F (Sermarini, 2000). JP-5 is the sole fuel compatible with all military branches' onshore and marine bulk fuel needs, but its low market availability may preclude its use for ship propulsion. (Giannini et al., 2002).

Over the years there have been talks about making the sea service a single-fuel operation to reap the benefits of simplicity. Sermarini (2000) pointed out that the reasons why the Navy did not shift from JP-5 and F-76 to a single fuel operation with JP-5 only, was because of a five cents difference in price, and most importantly, JP-5 refinery availability in the U.S. and overseas. He further argued that during a major operation mission, there could be a shortage of JP-5 due to surface combatants' JP-5 usage.

Throughout the years, the Navy has conducted studies to evaluate the feasibility of switching shipboard units to a single fuel type and to also measure the impact on engine fuel consumption, performance, and maintenance. A study conducted by the Fuels and Lubricants Division at Naval Air Systems Command (NAVAIR) found that "there appears to be a sufficient potential JP-5 fuel supply base available to convert to JP-5 as a single fuel at-sea for U.S. Naval aviation, ship propulsion systems, and USMC [United States Marine Corps] ground forces equipment" (Giannini et al., 2002, p. 7). The study also measured the cost of switching, as in 2002 JP-5 would cost between two to eleven cents per gallon more than F-76. This price difference has steadily increased by one cent a gallon

since 2018. According to Giannini et al., the following are potential benefits of switching to JP-5 as a single fuel:

- Reduction in shipboard maintenance due to using cleaner fuel
  - Savings in infrastructure due to less piping, valves, and pumps required to manage a single fuel
  - Ultimately reducing the cost of JP-5 due to the large demand quantity
  - Greater flexibility to support other units
  - Reduced transportation risk
  - Improved readiness
  - Enhance naval capability to sustain major contingency operations.
- (2002, p. 8)

Garrett, and Le Pera both argued that there could be shipboard engine problems if switching from F-76 to JP-5, but a 2022 study from the Machinery Research and Silencing Division of the NAVSEA Naval Surface Warfare Center, Philadelphia found that “the adoption of JP-5 as the single naval fuel at-sea could be accomplished with no major impacts on Naval diesel engines.” Guimand’s study found some minor issues with a small number of pumps used by Special Operations Warfare Command but agreed that the F-76 to JP-5 transition “should be transparent” (2007, p. 30). Guimond also recommended that more shipboard evaluation tests be conducted on major engines to measure fuel consumption and impacts on the required maintenance.

## **B. DISTRIBUTED MARITIME OPERATIONS (DMO)**

The former Chief of Naval Operations (CNO) Admiral John Richardson unveiled the Distributed Maritime Operations (DMO) doctrine, in Design for Maintaining Maritime Superiority 2.0 (Design 2.0) in 2018. Despite DMO being a relatively recent development, it has quickly risen to prominence as an effective form of fleet-level warfare. It capitalizes on the principles of distribution, integration, and maneuvering, enabling naval forces to amass an overwhelming amount of combat power at critical junctures (Filipoff, 2023). The DMO strategy operates at a theater level, strategically positioning distributed and networked assets to deliver offensive strikes against looming threats and hardened targets (Clark & Walton, 2019).

The heart of DMO lies in its decentralized nature. Through the deployment of a scattered naval force, the Navy can confound adversaries by making it challenging to identify which distributed targets warrant priority. This unique structure also allows our forces to strike first, imposing substantial operational dilemmas on the adversary (Filipoff, 2023).

Moreover, Distributed Maritime Operations have emerged as the guiding principle underpinning the conduct of EABO. This doctrine advocates for the dispersion of forces across a vast area, thereby bolstering resilience and minimizing vulnerability. In Design 2.0, Admiral Richardson emphasized the need for a robust refueling capability. We believe that the integration of the Single Fuel Concept (SFC) into this doctrine promises to yield substantial benefits.

The SFC proposes to streamline the logistical process by standardizing the type of fuel across all operations. Its integration within the DMO doctrine has the potential to yield significant dividends. With only one fuel type to manage, the supply chain simplifies. The complexity of managing multiple fuel types is eliminated, which translates into better efficiency and reduced logistical challenges.

In an environment where forces are distributed across a wide area, as in Distributed Maritime Operations, such simplification is a game-changer. It reduces the logistical footprint, minimizes the risk of supply disruptions, and thereby strengthens the overall operational flexibility. Garrett infers that the Single Fuel Concept's integration into contested areas does not just benefit logistics; it optimizes the execution of doctrines (1993, p. 20).

In essence, the Distributed Maritime Operations (DMO) and SFC's confluence represent a strategic and logistical innovation in naval warfare. By aligning the fluid and flexible strategy of DMO with the streamlined efficiency of SFC, we will create a robust and resilient logistical framework ready to face the challenges of EABO in the modern era. This unique synergy will not only respond to the demands of today's maritime operational environment—it will anticipate and surmount them.

### C. EXPEDITIONARY ADVANCED BASE OPERATIONS (EABO)

Expeditionary Advanced Base Operations (EABO) is a new operational concept and the latest addition to the naval concept family. EABO seeks to integrate the Fleet Marine Force (FMF) and Navy capabilities to offer a full range of skills to the warfighter, including support to sea denial and sea control, and sustainment of the fleet while operating in a contested environment (HQ USMC, 2021). EABO intends to support DMO by projecting the distribution of naval forces and capabilities inland in order to counter adversaries' Anti-Access/area-denial (A2/AD) in confined spaces (Corbett, 2018). Corbett also contends that EAB forces will be able to deny enemy forces access to land, air, and sea, by prepositioning "flotillas, UXX squadrons, land-based anti-ship missiles, logistics support, and other Navy capabilities forward to enable persistent naval presence and influence" (p. 22).

Expeditionary Advanced Bases (EABs) aim to create concepts of operations and bases with low signature forces flexible enough to quickly move from area to area within the enemy Anti-Access/area-denial (A2/AD) to prevent easy targeting, and at the same time enhance fleet support by assuring Command, Control, Communications, Computing, Cyber, Intelligence Surveillance, Reconnaissance and Targeting (C5ISRT) (Corbett, 2018). In a U.S. Naval Institute article, U.S. Marine Corps Commandant General David Berger (2020) describes the importance of the Marine Corps within a naval campaign and how integrating Anti-Submarine Warfare (ASW) and EABs complement each other. According to Berger ASW and EABs could "enable the joint force to sustain or widen its advantage in ASW" (para. 4). The Marine Commandant continued to explain that in addition to providing forward logistical, sensor, and strike capabilities "Marine expeditionary advance bases (EABs) could make a significant contribution to the undersea warfare campaigns, including holding Chinese and Russian submarines at risk" (para. 4).

EABO aims to project naval power to the littorals by integrating FMF into the larger naval campaign. EABO differs from traditional expeditionary operations in that it combines different expeditionary mission capabilities in a distributed and unpredictable way that persists inside the WEZ, limiting adversary targeting ability, and influencing the enemy's activities (HQ USMC, 2021). Some other tasks listed on the Tentative Manual for

EABO (2021) include but are not limited to conducting surveillance and reconnaissance, conducting operations in the information environment, conducting screen/guard/cover, denying or controlling key maritime terrain, conducting surface warfare operations, conducting air and missile defense, conducting strike operations, conducting sustainment operations, and conducting FARP operations.

#### **D. MARITIME LOGISTICS**

Design 2.0 prioritizes the implementation of the Distributed Maritime Operations and Expeditionary Advanced Base Operations concepts and necessitates a substantial transformation of the current maritime logistics structure. To ensure alignment with the National Defense Strategy the Navy must provide everything required to refuel, rearm, resupply, repair, and revive naval forces. Therefore, the logistics arm needs to facilitate maneuverability and deliver agile sustainment both ashore and afloat, particularly in contested environments.

Presently, the Navy operates with 31 Combat Logistics Force (CLF) ships at its disposal, designed to facilitate at-sea replenishment (U.S. Navy's Military Sealift Command, 2023). The CLF ships are critical to strategic operations as they enable naval vessels to remain on station, thereby extending the operational reach without necessitating a port of call. This is facilitated through a "hub and spoke" model that has served as an effective sustainment system for years, especially for an undistributed fleet in uncontested environments.

However, the emergent security landscape reveals the vulnerabilities of the current logistics model. Its fragility becomes evident when subjected to the demands of a widely distributed fleet under contest, proving it insufficient for upholding the objectives of DMO and EABO (Minding the Gap, 2021).

This is where the Naval Logistics Integration (NLI) becomes vital. The NLI serves to align and harmonize practices across the various logistical components of the Navy. By promoting a unified approach to procurement, transportation, storage, distribution, maintenance, and disposal of materials and services, the NLI can create a seamless,

efficient, and robust support structure tailored to the demands of the DMO and EABO concepts.

The marriage of the Single Fuel Concept (SFC) with the principle of Logistics Subsidiarity can create a potent combination for EABO. The simplicity and efficiency afforded by the SFC, in concert with the strategic benefits of resolving logistics issues at the local level, promise to enhance operational effectiveness and survivability and optimize integration. The path forward is clear: the DOD needs to embrace the SFC and the principle of Logistics Subsidiarity for more agile, resilient, and effective EABOs.

Thus, in this age of rapid transformation and dynamic security challenges, the integration of NLI and Maritime Logistics plays a crucial role. It aligns the Navy with the National Defense Strategy and sets the stage for innovative logistical solutions to support a widely distributed and contested fleet. This evolutionary shift is critical to ensuring that the Navy can sustain its operations, maintain its global reach, and fulfill its mission to defend the nation's interests at sea.

## **E. CONSOLIDATION OPERATIONS AND LIGHTERING**

Fuel consolidation (CONSOL) operations occur between a specifically outfitted large tanker and a smaller tanker. These operations allow Combat Logistics Force (CLF) ships to refuel without pulling into port and allow combatants to the ability to stay on station for a longer period of time (Smith, 2015). According to Smith, CONSOL operations allow the larger tanker to travel to CLF vessels to minimize transit time, and one tanker has the ability to refuel multiple CLF vessels before needing to refuel themselves. These types of operations can allow the U.S. Navy to set up specific CONSOL stations to allow for a preset latitude and longitude for CLF vessels to meet tankers to refuel.

Lightering is the process of transferring cargo or fuel between two vessels. Lightering operations can occur at anchor or underway. The process involves pumping fuel from one vessel to another with fenders between the vessels.

## **F. NEXT GENERATION LOGISTICS SHIPS (NGLS)**

The Navy and Marine Corps are exploring the concept of a common hull, multi-mission ship design. General Berger in Force Design 2030 explains the need for smaller ships (2020, p. 8). Herein lies the robust argument for the Single Fuel Concept (SFC) within Expeditionary Advanced Base Operations. Garrett in the abstract of his 1993 research states that, with the SFC, DOD simplifies logistics, enhances operational flexibility, and streamlines supply chains. One can draw from these revelations that SFC's provision for the same fuel type across all naval vessels, aircraft, and ground equipment can greatly reduce the logistical complexity inherent in maintaining diverse fuel supplies. In essence, this eases the burden on the naval logistics systems and enables it to dedicate more of its resources to critical operational tasks.

With this idea in mind, in 2020, the Navy and Marine Corps announced their intention to seek medium-sized amphibious ships designed to support a versatile and agile force that can consistently reposition, aligning with the requirements of Expeditionary Advanced Base Operations (EABO) and the broader Distributed Maritime Operations (DMO) concept (Eckstein, 2020). The original plan for the medium amphibious ships included the former NGLS family which was intended to be a family of smaller Combat Logistics Force (CLF) ships that would augment the existing larger CLF. O'Rourke's (2023) report states that these medium-sized CLF ships will be smaller and more agile than the current CLF family to provide logistics support in a contested environment and "more effectively counter the improving Anti-Access/area-denial (A2/AD) capabilities of China in particular" (p. 1). These ships are made with the intent to support the new Navy and Marine Corps initiatives of DMO and EABO. With the concept of DMO, the Navy intends to disperse its forces to prevent the enemy from attacking a group of large high-value targets concentrated nearby. EABO is a new Marine operational concept that will split marine expeditionary forces into small units and then disperse these units within the contested environment with the mission of achieving A2/AD. The author inferred that these units should be flexible enough to move these bases from one place to another, moving them quickly and often.

The original Next Generation Logistics Ships family consisted of three platforms: the fast supply vessel (FSV), the platform supply vessel (PSV), and the LAW. The latest programs are the Navy Light Replenishment Oiler (TAOL) which will consist of the PSV, FSV, and the Navy Medium Landing Ship (LSM) which replaced the LAW. Each of the three platforms takes advantage of industry innovation by incorporating commercially available off-the-shelf (COTS) ship designs to expedite the process of acquisition and deployment (O'Rourke, 2023). The same author states, "The program envisages building a new class of CLF ships (or a family of CLF ship designs) that would be smaller and individually less expensive to procure than the Navy's current CLF ships" (p.1)

The new family of TAOL ships is not intended to replace Combat Logistics Force (CLF) ships which are also called Underway Replenishment "UNREP" ships, but this paper will refer to them as CLF. The new TAOLs will only add to the current CLF family. Currently, the CLF family consists of large fleet oilers (TAOs) which are the supply lifeline to the U.S. Navy surface fleet, providing fuel and dry cargo to ships at sea (Military Sealift Command, 2020). According to Military Sealift Command, dry cargo ammunition ships (TAKEs) are versatile vessels designed to enhance delivery capabilities by providing a range of essential supplies, including food, fuel, spare parts, and ammunition, to the U.S. Navy and its allied forces. Finally, the fast combat support ships (TAOEs) are the largest of the ships in the CLF and provide parts, supplies, and fuel at sea (Military Sealift Command, 2020). The "T" on all these designations signifies that these ships are operated by the Military Sealift Command (MSC) or Merchant Marines (O'Rourke, 2023)

As highlighted by O'Rourke, (2023), the TAOL program represents a critical leap forward in the future of naval logistics. This ambitious program aims to develop a family of vessels comprising two unique variants – a PSV and an FSV. The author went on to say that both of these variants play significant roles in the logistics operations, fortifying logistical capability to provide prompt and efficient at-sea resupply. A notable aspect of these TAOL vessels is that they are expected to be smaller than the Navy's current CLF ships. This size differential affords these vessels greater maneuverability and access to shallower waters and tighter spaces, which can be critical in contested or congested maritime environments. Moreover, O'Rourke suggests that these ships are projected to be

less expensive to procure than the current CLF ships. This cost efficiency, combined with their significant functional utility, makes these vessels an attractive investment for the future of maritime logistics (2023).

The LSM is designed to be the principal littoral maneuver vessel of the littoral force. The vessels will be capable of embarking, transporting, landing, and subsequently reembarking small Marine Corps units and their supplies (O'Rourke, 2023). When properly postured, LSM will possess the range, endurance, and speed to support and conduct DMO and EABO.

### **1. Navy Light Replenishment Oiler (TAOL)**

The TAOL is strategically designed to enhance the capabilities of the traditional Combat Logistics Force (CLF), facilitating the critical functions of refueling, rearming, and resupplying naval warships in proximity to contested zones, thereby bolstering DMO and EABO. As per the architectural blueprint, the TAOL will encompass two distinct variants (O'Rourke, 2023). While both variants are aligned in mission objectives, the Fast Supply Vessel (FSV) variant distinguishes itself by being more compact and exhibiting greater speed. The report continues by saying the Navy has stated that COTS ship designs for the PSV and FSV are potential designs for the TAOL program, but they are not limiting potential solutions to those types.

O'Rourke, in his 2023 Congressional Research Service article outlines the TAOL program and it envisages the vessels revolutionizing the way naval logistics is managed by bringing forth a new generation of resupply vessels. With their specialized capabilities, increased flexibility, and cost efficiency, these vessels stand to enhance maritime operations and establish a robust and sustainable logistics support framework for the future.

The Navy's five-year shipbuilding plan had the first TAOL procurement in FY2026 for \$150 million (O'Rourke, 2023). According to the report, they have yet to determine the number of TAOLs they wish to procure, but the FY2023 30-year shipbuilding plan suggests they may want a dozen or so. The report goes on to say the Navy has awarded industry studies contracts to multiple companies in 2022 to inform the understanding of

cost capabilities and tradeoffs for the vessels. These vessels do not necessarily exist as of yet; however, the top-level requirements have been defined for the ideal vessels.

*a. Platform Supply Vessel (PSV)*

The PSV, specifically, is designed to provide petroleum, oils, and lubricants (POL) support to the fleet. These vessels will be equipped with the advanced technology and systems necessary to ensure seamless refueling operations in the open sea, thereby extending the naval forces' operational capabilities (SEACORE, n.d.). According to OPNAV N4, the PSV should have a sustained speed of 15–17 knots with a range of travel of about 3,500 nm (CAPT C. White, personal communication, October 23, 2023). OPNAV N4 also stated the fuel capacity will be around 1,575,000 gallons. The cargo capacity should be 800–900 short tons cargo capacity and a deck area of around 10,000 sq ft (Apte et al., 2020). Ideally, the PSV would be able to deliver about 210,000 gallons of fuel in under two hours at sea according to the presentation. Additionally, the presentation reported is engineered to achieve a high-efficiency delivery rate of 15 loads per hour encompassing both ammunition and cargo, simultaneously executing refueling operations. Its fundamental mission is intricately designed to offer comprehensive logistical support to maritime assets operating within the WEZ, thereby enhancing operational sustainability and effectiveness in critical maritime theaters. An example of a commercial PSV is shown in Figure 1.



Figure 1. Example of a Commercial PSV. Source: SEACORE (n.d.)

***b. Fast Supply Vessel (FSV)***

On the other hand, the FSV is the smaller and more agile design in the TAOL family. It is designed to offer a broader range of logistical support to the fleet, including the transportation of equipment, spare parts, and other supplies necessary to keep naval operations running smoothly (Swiftships, n.d.). The sustained speed of the FSV should be around 23 knots with a range of travel at around 100–1,000 nm (Apte et al., 2021). According to the presentation, the fuel storage capacity would be much smaller than the PSV at about 42,000 gallons and the deck area for ammunition and cargo would be around 2,500 sq ft. The FSV is required to demonstrate a minimum refueling capability of approximately 500 gallons per minute, utilizing a hose reel system as well as having the capacity to be able to resupply PSVs and LSMs with cargo, ammunition, and fuel (Apte et al., 2021). Its core mission would be to perform logistic runs within the WEZ. It is unclear as to whether or not the FSV variant will come to fruition, for this reason, we will not use this vessel in our scenario (CAPT C. White, personal communication, October 23, 2023). An example of a commercial FSV is shown in Figure 2.



Figure 2. Example of Commercial FSV. Source: Swiftships (n.d.).

**2. Medium Landing Ship**

The LSM is crafted to bridge the capability gap that exists between the Navy's amphibious warfare class ships and smaller, complementary landing craft (Amphibious Assault and Connectors Program [PMS 317], 2023). According to PMS 317, this vessel is designed to provide tactical maneuvers for Marine forces conducting EABO. The LSM is

not meant to be a single-mission ship according to the program office. It can support the day-to-day maneuvering of forces but also offers full protection for its crew and embarked forces (PMS 317, 2023). The LSM exchanges a sizable portion of cargo and fuel capacity for passenger space.

The Navy's LSM program envisions procuring somewhere between 18 – 35 vessels to support the Marine Corps concept of EABO. The Navy plans to procure the first LSM in FY2025 for approximately \$188 million (O'Rourke, 2023). The Navy will be awarded multiple contracts for concept studies in 2021. The LSM Program Officer is in the final stages of approval for the Capability Development Document and plans to release a request for proposals in quarter 4 of FY2023.

Once available, the LSM should have a sustained speed of 14 knots with a travel range of greater than 3,500 nm (PMS 317, 2023). According to the program office, the fuel storage capacity will be much larger than the FSV at greater than 90,000 gallons and can transfer fuel at a rate of 3,000 gallons per minute. The deck cargo area will be similar in size to the PSV at 8000–12,000 sq ft. Unlike the two TAOLs however, the LSM will have a ramp and crane to assist in loading and unloading cargo and ammunition. The vessel will be able to receive, store, and transfer both fuel and cargo at sea and will be capable of conducting up to 11 days of missions without replenishment. An example of one of the five preliminary designs is shown in Figure 3.



Figure 3. LSM Preliminary Design. Source: PMS 317 (2023).

### **3. Summary of Platforms**

Expeditionary Advanced Base Operations, executed by the new Marine Littoral Regiments, is designed to reinforce the U.S. Navy's sea control/sea-denial capabilities in the Western Pacific by diversifying the Navy's arsenal of lethal capabilities. This is achieved by deploying mobile, economical resources in forward, temporary locations, transcending traditional seagoing platforms' limitations, and becoming integral components of fleet/Force Movement Control Center operations (United States. Marine Corps (USMC), 2022). Within this framework, each vessel, including the PSV, FSV, and LSM, offers unique capabilities, though their mission sets are strikingly similar. The PSV, despite being capacity-rich, is unsuitable for extended missions within the WEZ. The FSV, with its speed and agility, is constrained by its limited capacity, making it suitable only for shorter missions. Meanwhile, the LSM, though capable of meeting all requirements, lacks the fuel capacity of the PSV, making it less effective for fuel transfers.

#### **G. LIBERTY LIFTER, DARPA CONCEPT**

Liberty Lifter is an innovative 21st-century strategic lift concept created by the Defense Advanced Research Project Agency (DARPA). This aircraft is designed as a floating and flying, long-range, low-cost plane capable of seaborne strategic and tactical lifts (Kent, 2022). This concept aircraft boasts fast flexible and survivable strategic lifts, efficient flight in ground effect and extended unrefueled ops according to the program manager, Dr. Kent. He also states the aircraft should have seaplane versatility with robust surface operations and a low-cost design. The Liberty Lifter is ideal for EABO operations with its notional range and speed that permits more flexible movement, can improve DMO by quickly moving forces with less refueling requirements, can rapidly reconfigure for a variety of missions and tasks and is more survivable due to reduced time spent at fixed targetable locations (Kent, 2022).

The Liberty Lifter program is currently in phase one of development according to the program manager (Kent, 2022). According to Kent, DARPA is working with two prime contractors to refine the design of the Liberty Lifter. Phase 1 contract awards are for 18 months, in which the program manager hopes the teams will perfect the conceptual design,

mature the design, and complete component and sub-scale testing. The Liberty Lifter team is scheduled to transition to Phase 2 in mid-2024, and Phase 3 in 2026, with an ultimate transition to the manufacturing and sustainment phase by the end of 2028 (Kent, 2022).

Once available, the Liberty Lifter will have a sustained speed of 145–180 Knots and a range of around 8,000 nm (Suggs, 2023). According to the program office, the carrying capacity will be 180,000 lbs over 1,440 sq ft. This will allow the Liberty Lifter to carry 12 463L pallets which could carry up to 20 SIXCON fuel storage tank modules, providing 18,000 gallons of fuel per load. With the same carry capacity, the Liberty Lifter would be able to carry loads of up to 300 passengers or two USMC Amphibious Combat Vehicles plus 32 crew members (Sugg, 2023). The program office also states the aircraft will have the capability to take off and land in a sea state of 4 and complete on-water operations in sea states up to 5. This makes the Liberty Lifter the ideal aircraft for strategic logistics to enable EABO logistical support. An example of a preliminary design is shown in Figure 4.

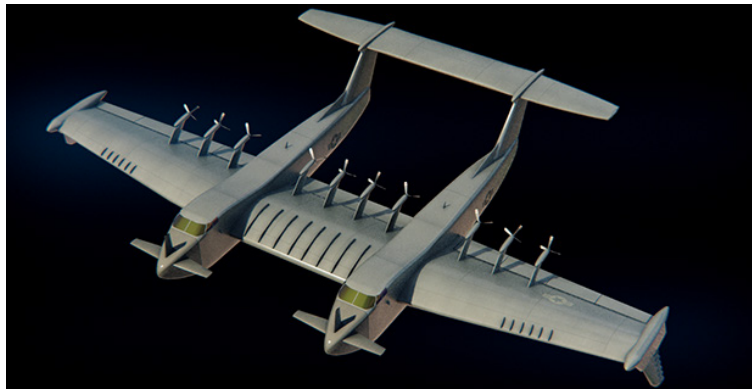


Figure 4. Liberty Lifter Concept Design. Source: Kent (2022)

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### **III. LITERATURE REVIEW**

This chapter reviews relevant studies and how they informed our scenario. These studies provided information on NGLS ships' ability to meet logistics demands for EABO and the benefits of using SFC and CONSOLs to support an MLR in the INDOPACOM AOR. Additionally, the literature on RASP and FUSED provides a summary of how these models are utilized in our study.

#### **A. NEXT GENERATION LOGISTICS SHIPS: REFUEL**

Loseke and Yarnell (2020) analyzed the optimal types and quantities of NGLS required to meet given in-theater logistics demands for Expeditionary Advanced Base Operations (EABO) as well as future joint naval concepts of distributed military operations (DMO). The study defines NGLS as being comprised of multiple platforms, a Platform Supply Vessel (PSV), a Fast Supply Vessel (FSV), and a LAW. To make their determinations, Loseke and Yarnell created a linear optimization model in Microsoft Excel using constraint and capacity data obtained from top-level requirements (TLRs) of each platform [using both the threshold (T) and objective (O) values] for each type of vessel as well as demand data EABO and DMO obtained from OPNAV N4. Their model uses the minimum number of deliveries as its objective function given the constraints and demand data previously mentioned. The analysis of their solution led to several determinations which they recommended to OPNAV N4. Some of these recommendations include: the capacity of the PSV should be targeted for the objective (O) value in the acquisition process, efforts should be made to eliminate or reduce delivery time constraints, and the LAW and FSV's performances are not enhanced by going above the threshold (T) level with delivery time constraints (Loseke & Yarnell, 2020).

#### **B. ANALYSIS OF FUEL LOGISTICS SUPPORT OF A MARINE LITTORAL REGIMENT OPERATING IN THE INDOPACOM AOR**

In their 2023 study, Tajudeen and colleagues conducted a comprehensive analysis of the deployment of Light Amphibious Warships (LAWs) and Next Generation Logistics Ships (NGLS), evaluating the strategic advantages of implementing a JP-5 single fuel

strategy to enhance the operational readiness of Marine Littoral Regiments (MLR) in contested environments. A scenario created by the same authors involving an MLR operating with U.S. Navy Ships in the INDOPACOM AOR contested environment and applied to the Naval Postgraduate School developed the Replenishment at Sea Planner (RASP) model. Using this model, they determined the best number of LAWs and NGLSs to support the needs of the MLR under a dual-fuel concept. They input the results mentioned above into the NPS-developed Fuel Usage Study Extended Demonstrations (FUSED) model to examine the benefits of switching from a dual fuel concept to a JP-5 Single Fuel Concept. The analysis of their solution led to the recommendation of the implementation of a JP-5 SFC due to the reduction in the number of replenishments at sea needed and the ability to extend operational reach when abroad (Tajudeen et al., 2023).

EABO 2045 analyzes the daily fuel consumption across different proposed EAB configurations. Scenarios were created to accurately capture the consumption rates of each EAB configuration, which aids in identifying the most effective methods to fulfill their fueling needs. This study also used the most up-to-date concepts for both the CLF assets, TAOL, as well as the new U.S. Navy Littoral Combat Ship, MLS. This information will serve as an update to the Analysis of Fuel Logistics Support of a Marine Littoral Regiment Operating in the INDOPACOM AOR by Tajudeen, Williamson, and Arnott, 2023.

### **C. FUEL LOGISTICS PLATFORM REQUIREMENTS TO SUPPORT DISTRIBUTED MARITIME OPERATIONS IN THE INTO-PACIFIC AREA OF RESPONSIBILITY**

In their 2023 research, Moore et al., conducted a detailed evaluation of the Naval force, assessing their current organic and contracted capabilities. Their objective was to propose a fuel distribution concept for transporting fuel into a theater. In the study, the authors compared the single fuel concept to the traditional dual-fuel concept while leveraging the fuel consumption tool FUSED. The authors then used the RASP model to optimize delivery schedules. The authors meticulously constructed a scenario that entailed the transference of fuel from the United States West Coast, utilizing a diverse fleet of commercial tankers, to the Combat Logistics Force (CLF). This operation was centered around a strategically positioned floating fuel consolidation station within the

INDOPACOM AOR. The analysis of their scenario led to numerous recommendations. Some of the recommendations included: Amending the Jones Act to allow contracts for other than U.S.-built, flagged, and crewed tankers, the use of tanker pool contracts to manage a pool of bulk fuel tankers with various shipowners to meet the requirements and configuring new ships for the SFC (Moore et al., 2023).

#### **D. FUEL USAGE STUDY EXTENDED DEMONSTRATION (FUSED)**

The Fuel Usage Study Extended Demonstration (FUSED), an innovation of Mr. Brandon Naylor, is a deterministic simulator refined to decipher the complexities of naval fuel logistics with surgical precision. Developed in 2015, this Visual Basic for Applications (VBA) based model calculates fuel consumption for up to ten battle groups engaged in distinct operations. It facilitates real-time adjustments to an array of parameters, enabling tailored and efficient fuel consumption scenarios.

FUSED illuminates fuel consumption patterns, offering hour-by-hour insights backed by the ship class-specific fuel curves and other intricate variables. This tool ensures logistic ships meet fuel needs effectively and provides the coveted ability to restock at ports when reserves dip. In every operation, the synergy of accurate fuel estimates and timely restocking is vital but deeming this process ‘optimized’ may be an overstatement; FUSED focuses on deriving feasible solutions.

An innovative strategy is emerging, where data from FUSED aligns with the Replenishment at Sea Planner (RASP) to enhance naval logistics. FUSED offers robust fuel demand estimates for combatants, while RASP leverages this data to craft optimal logistics routes, offering a harmonious integration of data and logistics planning. Previous users of these models have attested to the streamlined logistics and operational efficiency achieved through this combination.

Naylor’s model does not just estimate fuel needs; it is an intricate system that records every aspect of fuel delivery with specificity. Each fuel delivery event, from quantity to date, is monitored, and initiation occurs when any unit hits a predefined fuel safety level. FUSED not only tracks fuel consumption but also meticulously analyzes the impacts of different operational policies. It predicts onboard fuel storage levels, determines

the optimal resupply times, and calculates the associated costs, thus serving as a strategic asset for operational decision-making.

The model's adaptability is evident in its accommodation of various adjustable parameters. FUSED is not just about tracking and estimating; it is a strategic asset for intricate decision-making and meticulous planning for naval operations. Its profound impact and utility resonate across logistics support staff, operation planners, and even the staff of Combined Task Forces or Geographical Combatant Commanders. High-ranking offices, including the Office of the Chief of Naval Operations Logistics Directorate, rely on FUSED for generating predictive models essential for cutting-edge logistics support planning.

Essentially, FUSED embodies a blend of precision, flexibility, and strategic insight, marking it as an indispensable asset in modern naval operations. Its capability to merge seamlessly with RASP underscores a future where naval logistics and operational efficiency reach unprecedented heights.

#### **E. REPLENISHMENT AT SEA PLANNER (RASP)**

In his 2013 article, Stewart remarked that planning optimal maritime routes for at-sea replenishment was their focus for creating the Replenishment at Sea Planner (RASP). The unparalleled capability of the U.S. Navy to remain at sea indefinitely sets it apart as the most formidable naval force in history. Few international navies can boast of this unique strength, a testament to our Navy's exceptionalism.

Stewart (2013) went on to liken the operation to another military marvel, stating, "Much like how the Air Force refuels midair, the Navy has its own equivalent through at-sea refueling (para. 5)."

Historically, naval forces docked at ports to restock fuel and supplies. In contrast, the U.S. Navy boasts a global forward deployment of supply vessels, facilitating replenishment while the fleet is still in motion. This strategic edge not only accelerates deployment but also yields substantial annual savings.

Furthermore, the Stewart (2013) concluded that the RASP is designed to enhance efficiency. RASP meticulously crafts a schedule that reduces the travel distance for supply ships, pinpointing routes that optimize both speed and fuel conservation.

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## **IV. METHODOLOGY, MODELING, AND RESULTS**

This chapter discusses how fuel demand was calculated for each Expeditionary Advanced Base (EAB) configuration as well as the base scenario, and how each asset and Fuel Consolidation (CONSOL) station was utilized. Moreover, this chapter discusses how both the Replenishment at Sea Planner (RASP) and the Fuel Usage Study Extended Demonstration (FUSED) model were applied to optimize the number and kind of assets to employ in order to recommend the best refueling strategy for the EABO base scenario during sustained and surge demands. Finally, this chapter discusses the results of the modeling.

### **A. FUEL DEMAND FOR EAB CONFIGURATIONS**

Demand was determined using a Mechanized Allowance List (MAL), provided by the Family of Expeditionary Fuel Systems, Headquarters, U.S. Marine Corps, Combat Development, and Integration (HQMC, CD&I). The equipment list was modified to reflect a “Modified Company,” or Expeditionary Advanced Base (EAB) Company+, and “Custom Platoons,” or EAB Platoons profiles. The EAB Company+ includes a Forward Arming and Refueling Point (FARP) equipped for refueling only. This study did not assess asset rearming capabilities. Aircraft fuel demand was constructed for the support of rotary wing aircraft based on an expeditionary aircraft squadron as per the Aircraft Squadron Fuel Consumption table shown in Appendix A.

The daily equipment consumption for the EAB Company+ and each EAB Platoon was calculated using each piece of equipment fuel consumption rate in gallons per hour (GPH), operating hours, and equipment quantity, taking into consideration an average readiness level of 80 percent. Daily aircraft fuel demand was based on each aircraft’s fuel consumption measured in GPH, the daily flight hours and the number of aircraft available based on 70 percent readiness. The EAB Platoons will only support organic ground equipment refueling and will keep minimum fuel on hand to support EABO’s agile base relocation concept.

The demand was evaluated accounting for two levels of burn rate: Sustained and Surge. The daily fuel demand and fuel capacity for each EAB are shown in Table 1.

Table 1. Fuel Demand and Holding Capacity Estimation in Gallons

|                  | <b>Sustained Demand</b> | <b>Surge Demand</b> | <b>Capacity</b> |
|------------------|-------------------------|---------------------|-----------------|
| <b>Company+</b>  | 52,646                  | 79,357              | 1,500,000       |
| <b>Platoon 1</b> | 1,839                   | 2,539               | 15,500          |
| <b>Platoon 2</b> | 1,839                   | 2,539               | 15,500          |
| <b>Platoon 3</b> | 1,839                   | 2,539               | 15,500          |
| <b>Platoon 4</b> | 1,839                   | 2,539               | 15,500          |

## **B. SCENARIO**

In this hypothetical scenario set in 2045, tensions in the South China Sea have been escalating for years due to Taiwan's pursuit of international recognition and self-determination. However, in a significant turn of events, China decided to use military force to reunify Taiwan with the mainland. In the lead-up to the conflict, China significantly enhanced its military capabilities, with a particular emphasis on naval and amphibious forces. Its intentions to reunify Taiwan with the mainland by force have become increasingly apparent. In a well-planned operation, China launched a large-scale amphibious assault on Taiwan with the aim of quickly overwhelming the island's defenses. This military operation is supplemented by cyberattacks that target Taiwan's command and control systems, further crippling its ability to respond effectively.

After the invasion, China implemented a maritime blockade around Taiwan, taking control of the island's territorial waters and disrupting vital shipping routes in the Taiwan Strait. To avoid being caught up in the conflict, cargo vessels from around the world are redirected away from the region, leading to major disruptions in the global maritime trade. These disturbances have significant economic and national security implications for the United States, supply chain disruptions, and shortages of essential goods, resulting in sharp fluctuations in prices of commodities.

Amidst Chinese aggression, the United States takes an active role in the situation by deploying naval assets to the region. The primary objective is to safeguard freedom of navigation and support Taiwan's defense. Consequently, joint U.S.-Taiwanese military operations were initiated to counter the Chinese invasion. Moreover, regional countries such as Japan, the Republic of Korea, the Philippines, and various Association of Southeast Asian Nations (ASEAN) nations expressed their deep concerns about the escalating situation.

The United States has tasked the Third Marine Logistics Regiment (3d MLR) to deploy into the second and first INDOPACOM island chains to conduct Expeditionary Advanced Base Operations (EABO) in support of U.S. coalition forces in the AOR. 3d MLR stands poised to dominate, generating formidable Combat Service Support (CSS) teams and sortie firepower, stretching its operational might across vast terrains. The MLR's tactical prowess is showcased in the construction of an intricate web of logistics—a dynamic framework of expeditionary-focused hubs, spokes, and nodes. This system does not merely connect; it breathes life into EABs, amplifying the range of the warfighters, assault aircraft, and light attack helicopters. It is the pulse, enabling the MLR to amplify and deploy Marine Corps combat forces with precision, right where the heart of the battle demands.

At the core, the hub pulses with energy. It is the stronghold of the MLR headquarters, casting an expansive presence robust enough to bolster multiple CSS units. Here, intricate logistic support merges seamlessly with the tactical command center, a nerve center from which the MLR commander orchestrates the battle symphony. All of this thrives under the impenetrable shield of theater ballistic missile defense systems.

Venturing further into the heart of the action, the EAB Company+ represents the secondary hub. Streamlined and, it demands a more refined logistic touch, typically orchestrated by a Company-level command team. Whether emerging from a well-established airfield replete with fuel repositories or an expeditionary airfield carved organically, the secondary hub stands ready.

Completing this tactical triad are the nodes, the EAB Platoons. Compact yet potent, these platoon-sized contact teams are the epitome of adaptability. Establishing their mark in the most austere terrains, nodes may emerge for mere hours or span a few days or weeks. Their mission is to serve as pivotal pit stops, facilitating rapid refueling and rearming for the aircraft fleet, inclusive of Joint Allied Partner aircraft, ensuring they soar unhindered deep into the action. To support DMO and EABO, EAB Platoons will carry a limited number of supplies and will have a limited fuel capacity to allow rapid relocation. The force laydown for resupply to company+ and platoons can be seen in figures 5 and 6 respectively.

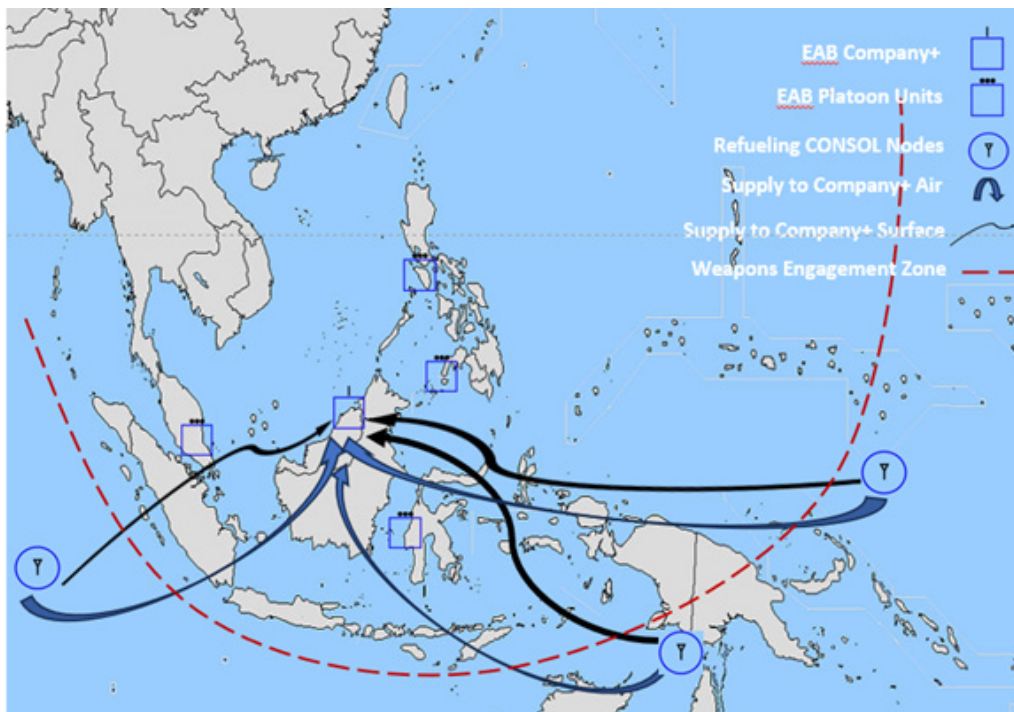


Figure 5. Force Laydown Resupply to Company+ via CONSOL

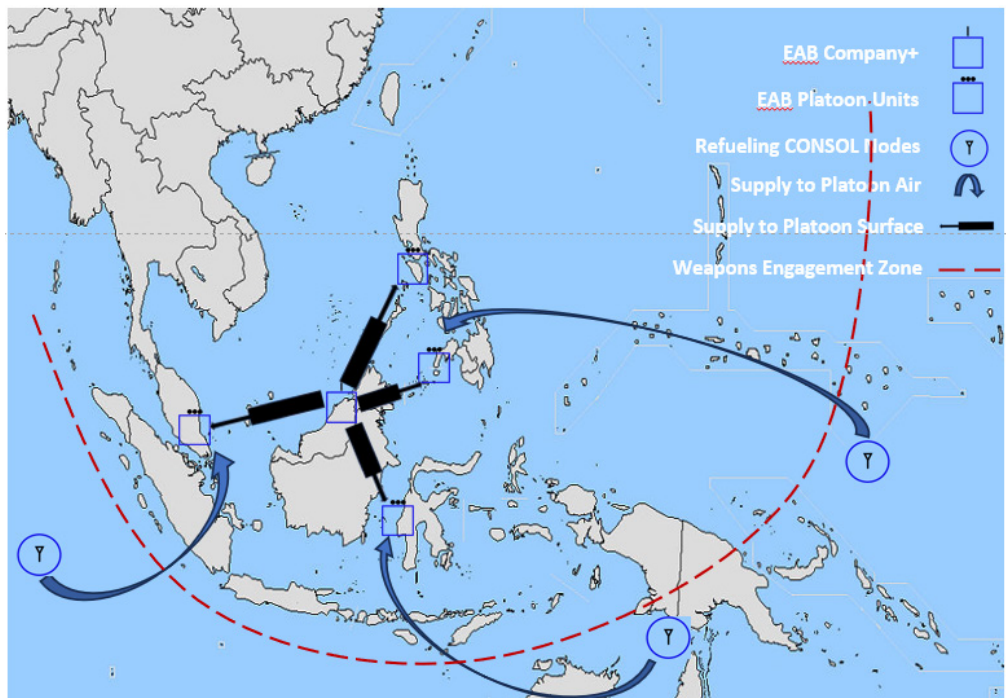


Figure 6. Force Laydown Resupply to Platoon via Company+ or CONSOL

The scope of this work is limited to the refueling support of the Company+, and the designated EAB Platoons for this notional scenario.

### C. REPLENISHMENT AT SEA PLANNER (RASP)

Efficient refueling is of utmost importance for naval units, and Replenishment at Sea Planner (RASP) is an advanced software that has been specifically designed to optimize refueling schedules. It is important to note that this thesis is the first to use an upgraded version of RASP, which employed the General Algebraic Modeling System (GAMS) to solve its optimization models. GAMS is an advanced software tool used for formulating and solving mathematical optimization problems. Its primary function is to take a defined optimization model, process it, and output the most effective solutions.

In our scenarios RASP defines the optimization model specific to naval logistics. This model includes variables (such as fuel amounts, locations of ships, timing of resupply operations), constraints (like fuel capacity, operational timelines, or maritime routes), and

an objective function (which could be minimizing the time for resupply or maximizing the efficiency of logistics operations).

RASP then uses GAMS to solve this optimization model. GAMS process the model provided by RASP, applying its advanced algorithms to find the optimal solution within the given constraints and towards the defined objective.

The output from GAMS, which is the optimal solution, can then be used by RASP to make informed decisions about naval logistics, such as when and where to refuel ships and how to best allocate logistical resources.

While RASP defines the optimization model based on specific naval logistical needs, GAMS acts as the solver, processing the model to find the best solution. This collaboration between RASP and GAMS enables sophisticated and efficient logistical planning in naval operations.

To achieve an optimal refueling schedule, RASP utilizes a specific type of mathematical optimization known as linear programming to generate the necessary data for its operations. This linear programming model is designed to address transportation problems, particularly those relevant to naval logistics, such as refueling schedules for ships. The linear programming model systematically processes various logistics variables (like fuel capacities, distances, and time frames) and constraints (such as operational limits or resource availability). Resolving the linear programming problem yields data indicative of optimal solutions for specific scenarios, notably in determining the most efficient fuel replenishment routes and schedules. The data generated from the linear programming solution, which includes details like optimal routing, scheduling, and resource allocation for refueling, is then fed into RASP through integration. RASP uses this data as a foundational layer for its more detailed and comprehensive logistical analysis.

Using the combined data, RASP can answer the pivotal question of how best to meet the demand for refueling. Through the leveraging of RASP, the logistic fleet can be scheduled to meet the refueling demands established by the linear programming model, thereby optimizing fuel deliveries.

RASP is designed to optimize the planning and scheduling of replenishment operations at sea. The tool's primary focus is to ensure that naval combatants can continue operations without unnecessary interruptions by optimizing the logistics tail that supports them. Below are the expected outputs from RASP and their potential applications:

**Optimized Schedules:** RASP provides a timetable indicating the best times for replenishment to ensure minimal disruption to naval operations. Beyond optimizing routes and reducing unnecessary travel, naval forces can conserve fuel and other resources, leading to financial savings.

**Route Planning:** Generates the most efficient routes for supply ships to minimize travel distance and time. This should enable naval operations to continue with fewer interruptions by ensuring timely replenishments.

**Demand Forecast and Fuel Conservation Analysis:** Offers a projection of the replenishment needs of various naval assets over a designated timeframe. The analysis recommends routes and speeds that allow supply vessels to operate at optimal fuel efficiency. We expect these outputs to help naval commanders and planners draft effective strategies that ensure ships remain supplied and ready for action.

**Asset Utilization:** Displays how various logistics assets, such as supply ships, will be utilized in the replenishment process. This output provides data to inform the allocation of logistics assets, ensuring they are positioned where they can be most effective.

**Risk Analysis:** Evaluates potential risks in the supply route, possibly accounting for threats like piracy or enemy naval activity. With insights into potential risks, naval forces can prepare for or avoid potential threats, ensuring the safety of both personnel and assets.

**Logistics Footprint:** Provides insights into the logistics assets required to support the naval fleet, including when and where they are needed. The outputs can facilitate coordination with allies and partners, especially in joint operations, by providing a clear plan for resupply.

**Geospatial Data:** Displays the spatial representation of replenishment operations, offering a clear visual of the naval logistics process.

This study is supported by all these features. Beyond offering a systematic approach to the complex challenge of at-sea replenishment, RASP ensures that naval forces can maintain prolonged operations, enhancing their effectiveness in both peacetime and conflict scenarios.

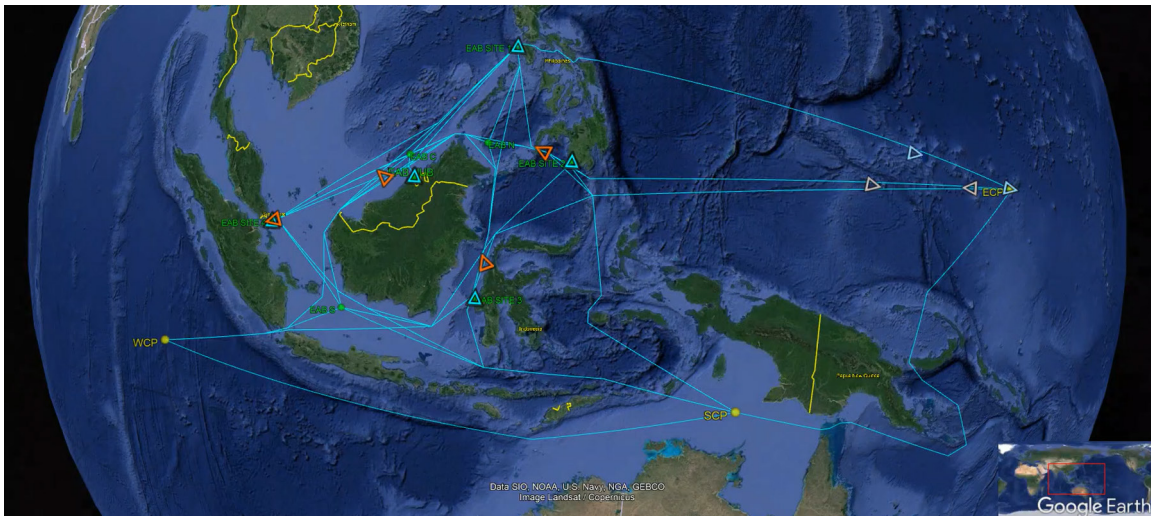


Figure 7. RASP Notional Resupply Network Design. Adapted from Google Maps (n.d.).

This study is a clarion call to reimagine our fuel supply chain strategies and operational efficiency in maritime operations. The study will bolster naval prowess through critical insights and recommendations, fortifying our preparedness and adaptability amidst ever-evolving global maritime landscapes.

#### **D. ASSUMPTION AND LIMITATIONS**

This study is limited to the supply and demand of one EAB Company+ and four EAB Platoons scattered across the AOR. It is assumed that all delivery assets will be carrying 100 percent JP-5.

##### **1. CONSOL Stations/Supply**

This EAB scenario includes three notional fuel supply consolidated (CONSOL) stations located outside the Weapons Engagement Zone (WEZ), named CONSOL East,

CONSOL South, and CONSOL West as related to the EAB Company+ location. These three locations can provide JP-5 to support all EABOs within the contested AOR.

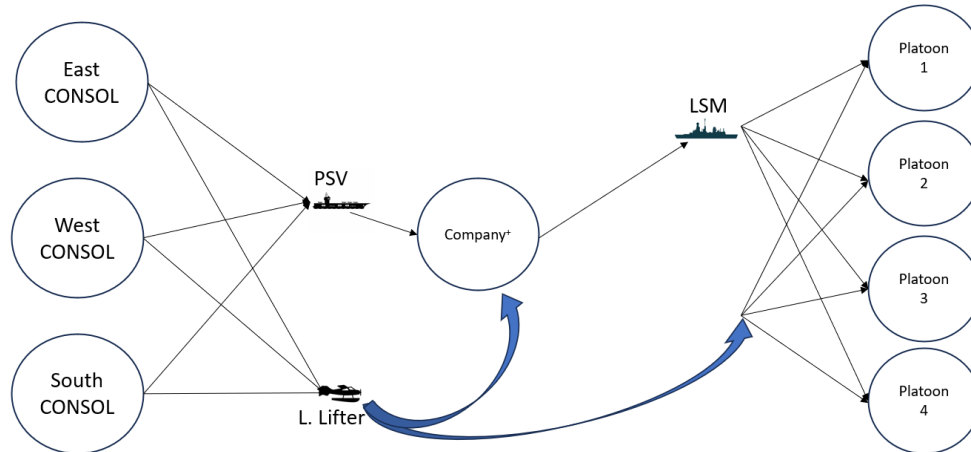


Figure 8. Notional Resupply Network Design

Each CONSOL station's distance affects the reach of each delivery asset to their destination. RASP results showed that delivery assets making deliveries from the further CONSOL Station, CONSOL Station East, showed challenges in achieving on time deliveries. The distances between stations are listed in Table 2.

Table 2. Distance Between Locations

|                 | WEST<br>CONSOL | SOUTH<br>CONSOL | EAST<br>CONSOL | EAB<br>CO+ | EAB<br>PL 1 | EAB<br>PL 2 | EAB<br>PL 3 | EAB<br>PL 4 |
|-----------------|----------------|-----------------|----------------|------------|-------------|-------------|-------------|-------------|
| WEST<br>CONSOL  | 0              | 2440            | 3978           | 1596       | 2161        | 2091        | 1477        | 1276        |
| SOUTH<br>CONSOL | 2440           | 0               | 2713           | 2022       | 1868        | 1329        | 1277        | 2031        |
| EAST<br>CONSOL  | 3978           | 2713            | 0              | 2708       | 2280        | 2011        | 2545        | 3271        |
| EAB Co +        | 1596           | 2020            | 2780           | 0          | 665.1       | 733.6       | 978         | 658.2       |
| EAB PL 1        | 2161           | 1868            | 2280           | 665.1      | 0           | 579.4       | 989.3       | 1206        |
| EAB PL 2        | 2091           | 1329            | 2011           | 733.6      | 579.4       | 0           | 658.4       | 1297        |
| EAB PL 3        | 1477           | 1277            | 2545           | 978        | 989.3       | 658.4       | 0           | 1017        |
| EAB PL 4        | 1276           | 2013            | 3271           | 658.2      | 1206        | 1297        | 1017        | 0           |

## 2. Delivery Assets/Duties

The study delves into the specifics of fuel demand by using simulations that cover a range of EABO missions. The analysis examines the effects of both sustained and surge demand while evaluating the impact of CLF's refueling capabilities. It is important to note that the study takes a cautious approach by keeping the high-capacity CONSOL stations and the CLF force outside the WEZ. The insights gained from this study are comprehensive and provide a better understanding of the implications of CLF's refueling capabilities.

The EAB Company+ receives support from two delivery assets, the PSV, and the Liberty Lifter (LL), which are stationed at the three CONSOL Stations. The LLs are not configured as tankers. It is assumed that the fuel delivered by the LLs will be stored in 20 SIXCON fuel storage tank modules and loaded on 463L pallets.

The LSM remains in the WEZ to support EAB Platoons and other EAB operations. EAB Platoons receive support through the LSM, while the LLs only assist individual EAB Platoons in extreme situations when there are not enough LSMs to support EAB Platoons (Except during Surge Demand). Delivery assets' fuel capacity, speed, and range are listed in Table 3.

Table 3. Delivery Assets

|                       | Fuel Capacity (Gals) | Speed (Knots) | Range (NM)  |
|-----------------------|----------------------|---------------|-------------|
| <b>PSV</b>            | 1,575,000            | 15-17         | 3,500       |
| <b>Liberty Lifter</b> | 18,000               | 145-180       | 4,000-8,000 |
| <b>LSM</b>            | 90,000               | 14            | 3,500       |

## E. RASP OPTIMIZATION RESULTS

The RASP optimization model allocated the LSMs, PSVs, and LLs to meet two operational demand scenarios, surge, and sustained demand. The goal was to determine the optimal mix of these assets to meet sustained and surge operations demand requirements while keeping determined storage safety levels at each station while optimizing delivery routes, and costs. Efficiency was measured by determining the least amount of delivery

assets necessary to achieve the highest percentage of on time deliveries possible resulting in zero percent deliveries below maximum capacity.

Optimization runs were executed for different combinations of the three asset types under sustained and surge demand modes. Sustained demand assumed continuous supply needs and the surge introduced a constant spike in demand due to increased operational tempo. The model optimized asset allocation over a 30-day period to minimize requirement shortfalls, and each optimization run was limited to 10 minutes. In some scenarios, the 10-minute constraint caused the model to yield less than optimal results with increased delivery assets after a better solution was found with lesser assets.

A different combination of asset allocations was executed with PSVs and LLs departing from each CONSOL station outside the WEZ (CONSOLS West, South, and East). All LSMs departed from the EAB Company + and were the primary assets to supply EAB Platoons, with the LLs only used as last resort assets. The LLs were only used to deliver to EAB Platoons when critically low on fuel in sustain scenarios. This restriction was lifted during surge scenarios to be able to achieve optimal results. The distance between all locations is shown in Table 2.

The delivery asset's location at the start of the optimization runs was the designated CONSOL stations for the PSVs and LLs, and the EAB Company+ for all LSMs. Optimization runs with this setup were successful in scenarios with sustained demand, but not successful during surge demand scenarios. To correct the deficiency during surge demand scenarios two LSMs were prepositioned closer to the EAB Platoons, one to the north and one to the south. Additionally, the LLs restrictions to only be used as emergency assets when delivering to EAB Platoons were removed, and LLs would offer constant support to EAB Platoons.

### **1. Late Delivery Percentage**

Late delivery percentage represents the performance metrics of deliveries arriving at destinations after their total storage capacity was below their safety level threshold. The safety level threshold was 40 percent in sustained scenarios and 50 percent in surge.

**a. Sustained Demand Late Delivery Percentage**

The sustained demand for the EAB Company+ was 52,646 gallons per day and 1,839 for each EAB Platoon. The sustained demand late deliveries graph in Figure 9 shows deliveries from the West and South CONSOL stations with one PSV. These optimization results showed zero late deliveries when the scenario was run with six, five, and four LSMs regardless of the number of LLs used. Additionally, a combination of two LLs, one PSV, and two LSMs showed zero late deliveries, except for the CONSOL East scenario. One PSV was not able to keep up with maintaining the EAB Company+ safety level above 40 percent capacity, resulting in late deliveries. An additional run with two PSVs corrected this deficiency. Results with two PSVs are shown in Figure 11.

The first spike in late delivery percentages occurred with the combination of three LSMs, one PSV and zero LLs, where late deliveries increased from zero to 22 percent when delivering from CONSOL locations West, and South. See Figure 9.

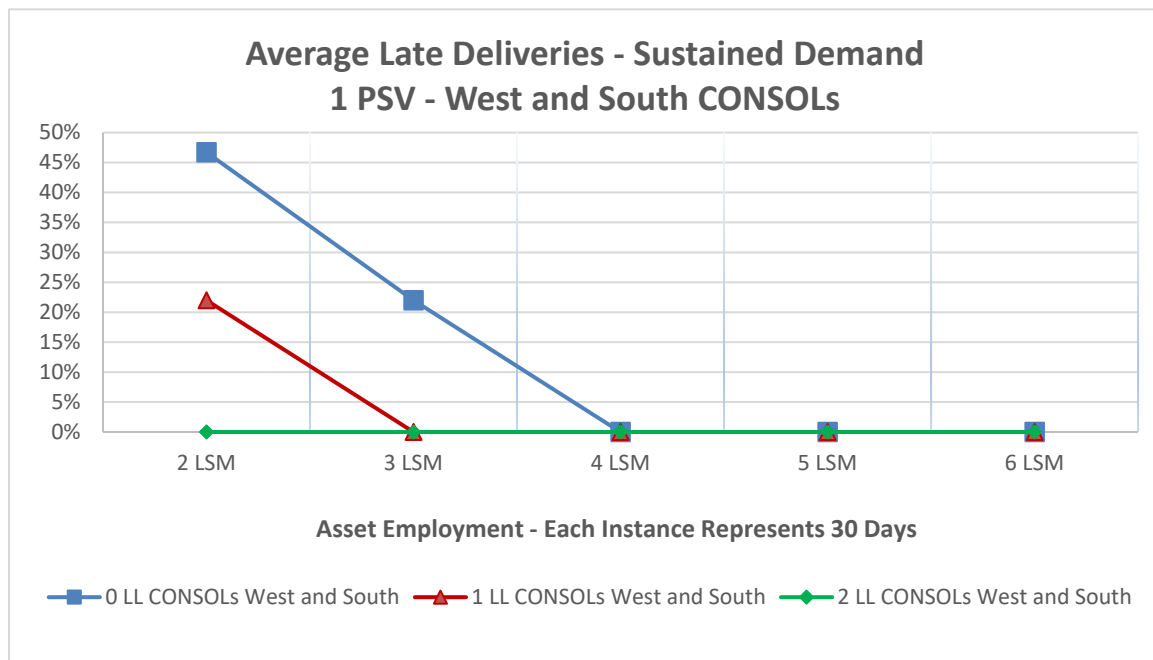


Figure 9. Sustained Demand Average Late Deliveries Chart—West and South CONSOLs One PSV

The RASP optimization tool could not find a solution to yield zero late deliveries with one PSV during the sustained demand scenario when the PSV operated out of the East CONSOL. One PSV could not make the round trip on time to keep the EAB Company+ above the 40 percent safety threshold. Figure 10 shows the results for the sustained demand scenario with one PSV operating from the East CONSOL.

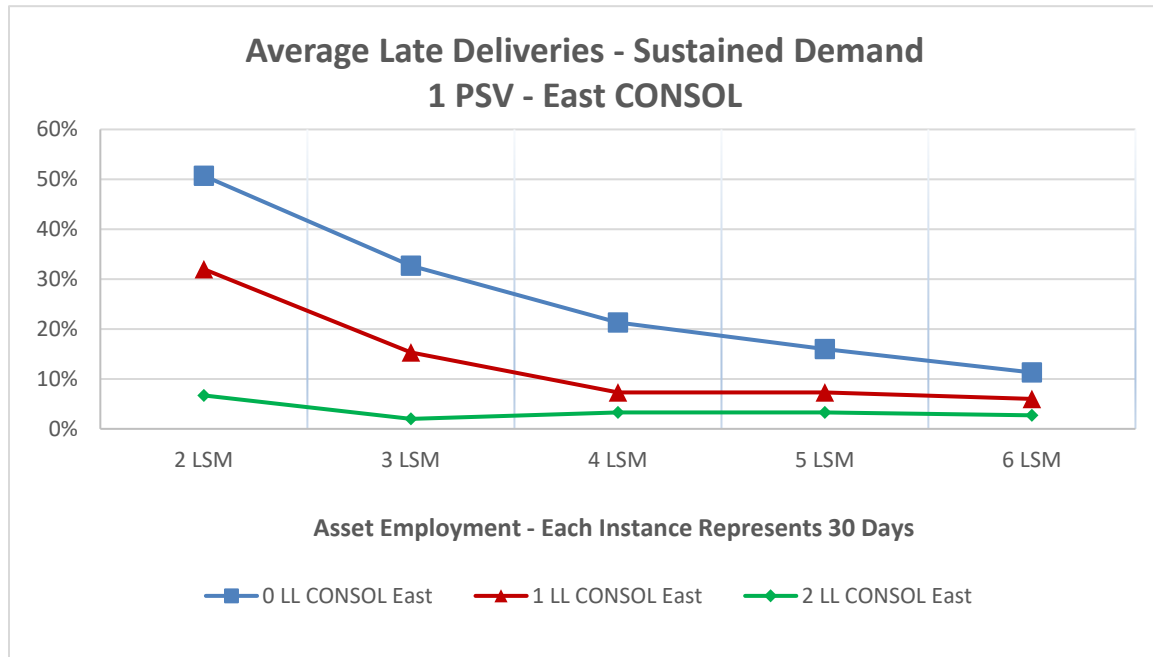


Figure 10. Sustained Demand Average Late Deliveries Chart—East CONSOL One PSV

The sustained demand average late deliveries with two PSVs from the East CONSOL, shown in Figure 11, yielded similar results as the optimization results from the West and South CONSOLs with one PSV in Figure 9. These optimization results also showed zero late deliveries when the scenario was run with six, five, and four LSMs regardless of the number of LLs used. Additionally, a combination of two LLs, two PSVs, and two LSMs showed zero late deliveries. See Figure 11.

Scenarios with 0 LLs required at least one LSM per EAB Platoon to stay above safety thresholds during the sustained scenario.

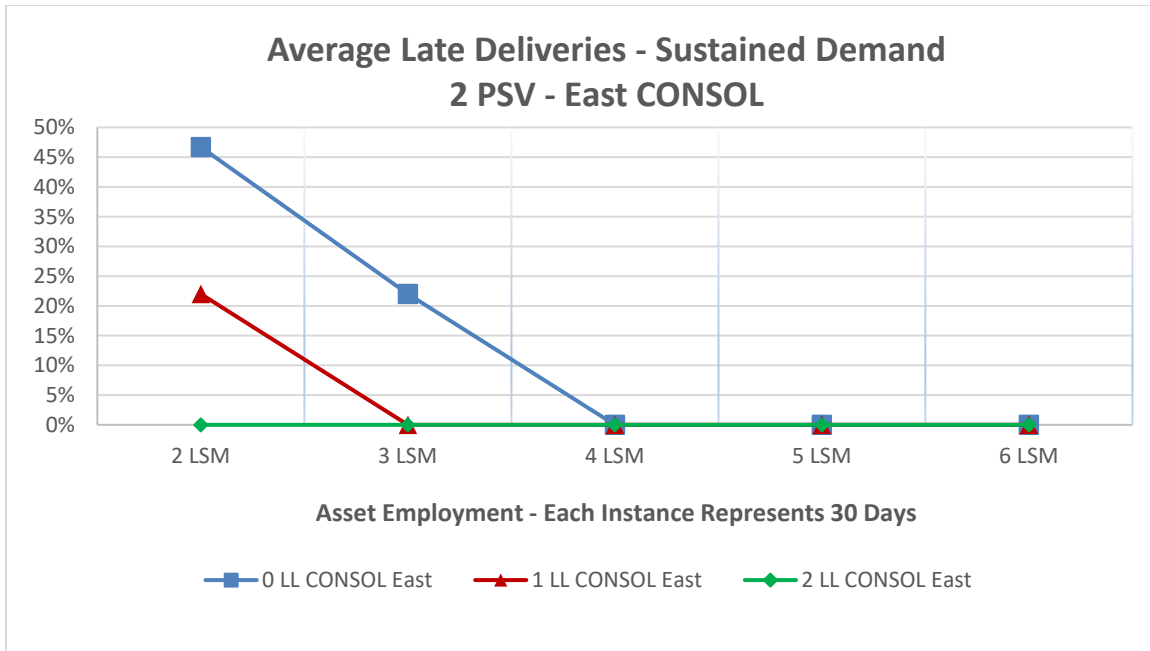


Figure 11. Sustained Demand Average Late Deliveries Chart—East CONSOL  
Two PSVs

Overall, the speed of the liberty lifter maintained EAB Platoons above their safety threshold when three LSMs were not enough to get to all the EAB Platoons on time deliveries. One LL in combination with two LSMs were not able to maintain the EAB Platoons safety thresholds above 40 percent.

#### ***b. Surge Demand Late Delivery Percentage***

The surge demand for the EAB Company+ was 79,357 gallons per day, a 50.7 percent increase compared to sustained demand, and 2,539 for each EAB Platoon, representing a 38 percent increase in demand when compared with sustained demand. This increase in demand affected the on-time delivery due to the decrease in the periodicity of delivery requirements caused by the increased demand and the safety storage threshold which increased from 40 to 50 percent of the total storage capacity at all locations.

The Average Late Deliveries Surge Demand graph with one PSV in Figure 12 shows that none of the RASP optimization solutions yielded zero late deliveries results, but all the results improved whenever LLs were present. The optimization model solutions

from the East and South CONSOL stations yielded similar results. Note that the worsening of any outputs after the addition of assets is caused by the RASP model time limitation. The model is limited to 10 minutes per scenario. On some occasions 10 minutes was not enough time for the optimization tool to find the best solution for the number of assets provided. The full results listing for the Sustained and Surge scenarios can be found in Appendix B.

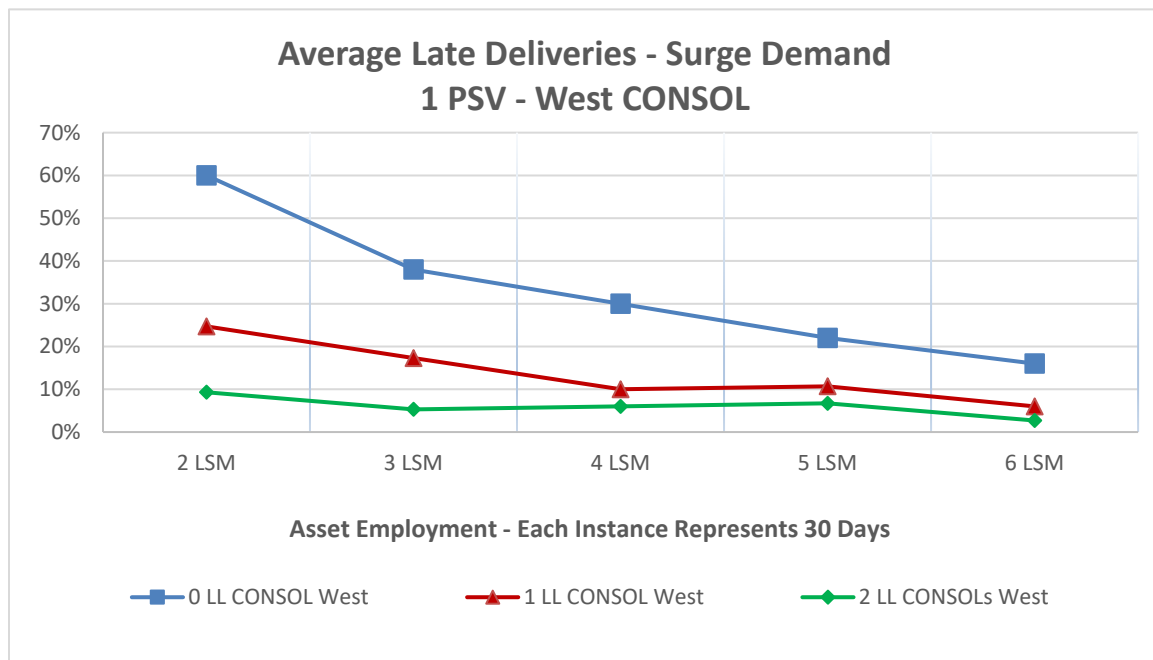


Figure 12. Surge Demand Average Late Deliveries Chart—West COSOL One PSV

Unlike in the sustained scenario, increasing the PSVs did not achieve significant improvements to the surge demand average late deliveries results. The Average Late Deliveries Surge Demand graph with two PSVs in Figure 13 shows that none of the RASP optimization solutions yielded zero late deliveries results.

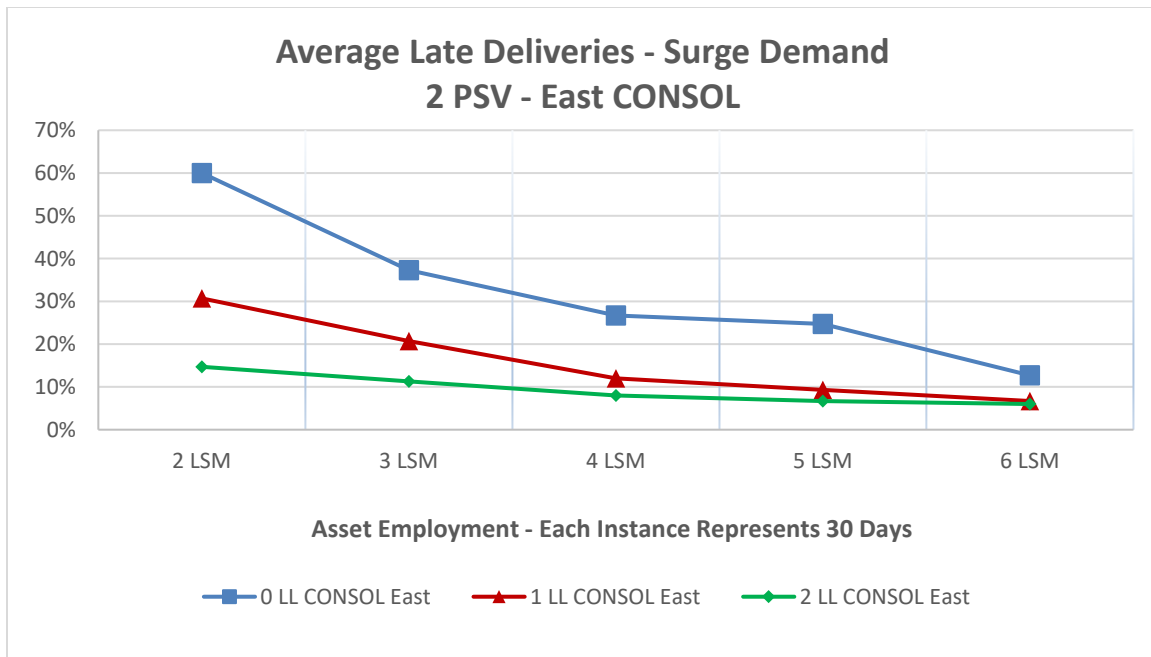


Figure 13. Surge Demand Average Late Deliveries Chart—East CONSOL  
Two PSVs

During surge demand scenarios, it was not possible to achieve a combination of assets that would result in zero percent late deliveries for the surge scenario, while matching the initial conditions of the sustained scenario, and RASP time limitation.

To achieve zero percent average late deliveries in the surge demand scenario two LSMs were prepositioned closer to the EAB Platoon locations during the start of the optimization run, one to the north and another to the south with reference to the EAB Company +. Additionally, a restriction where the LLs would only deliver fuel from outside the WEZ to EAB Platoons as a last resort was lifted, and LLs were allowed to conduct deliveries as needed. Optimization runs for the surge demand scenarios with prepositioned assets were conducted with one and two PSVs. See graphs on Figures 14–17 below.

These changes resulted in improved results across all locations. With one PSV, RASP achieved schedules with zero late deliveries from the West and South CONSOLs with a combination of six LSMs, one PSV, and two LLs. Zero late deliveries were also achieved from the West CONSOL location with a combination of three LSMs, one PSV, and two LLs.

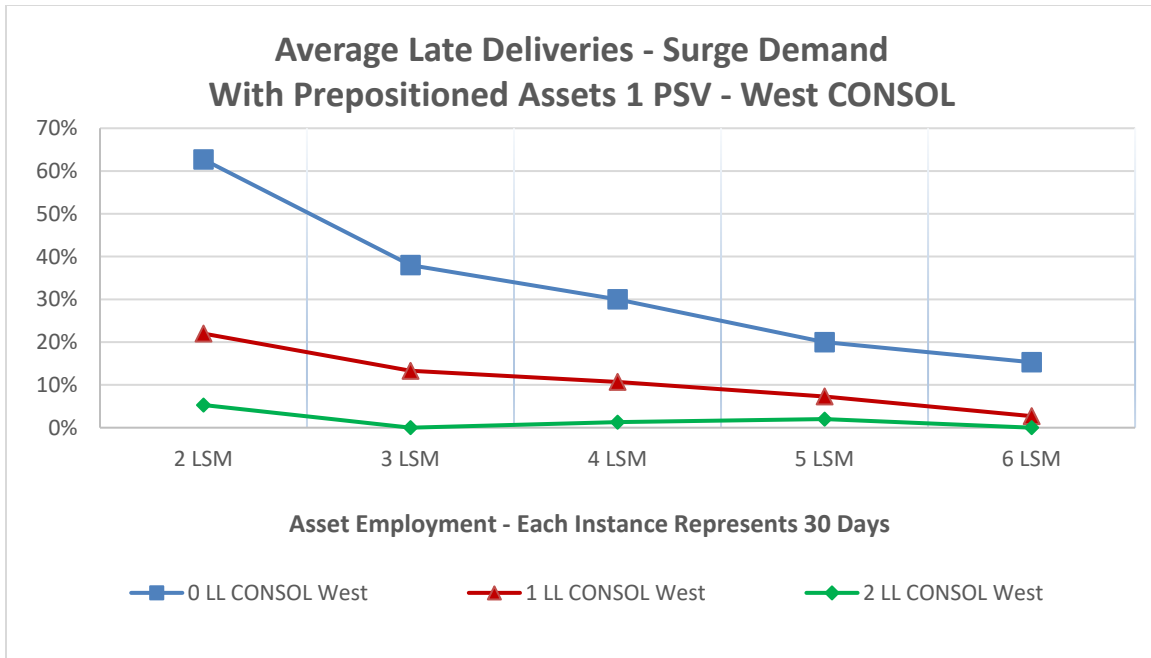


Figure 14. Surge Demand Average Late Deliveries Chart—West CONSOL  
One PSV with Prepositioned Assets

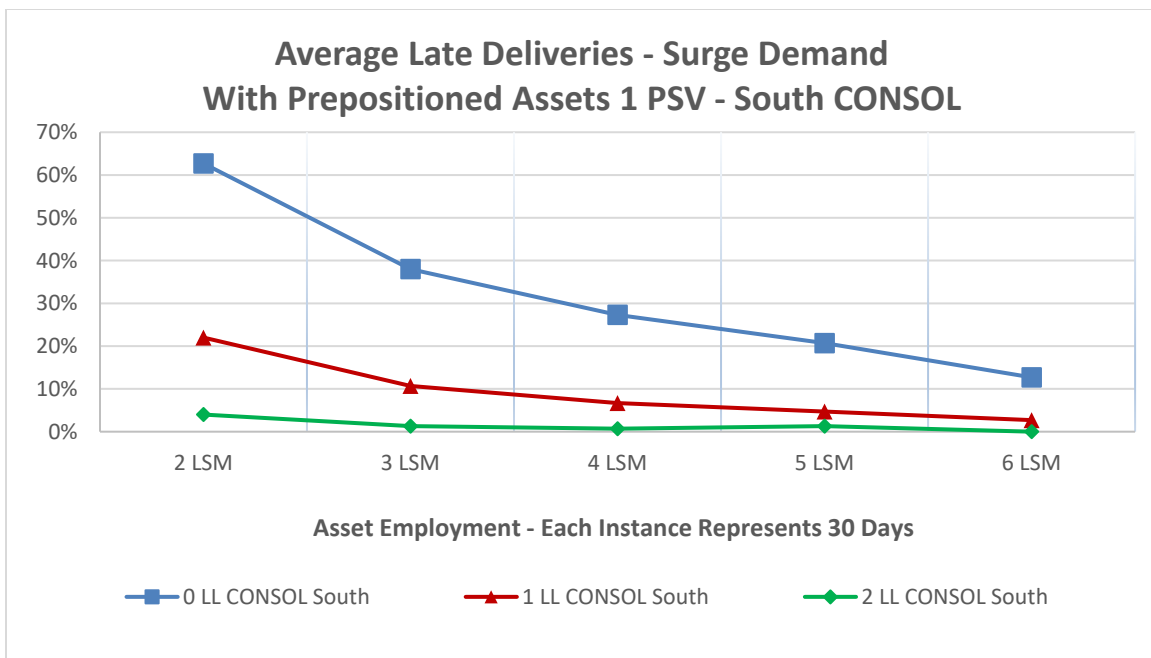


Figure 15. Surge Demand Average Late Deliveries Chart—South CONSOL  
One PSV with Propositioned Assets

As in the sustained demand scenario, the East CONSOL location could not achieve zero late deliveries with one PSV.

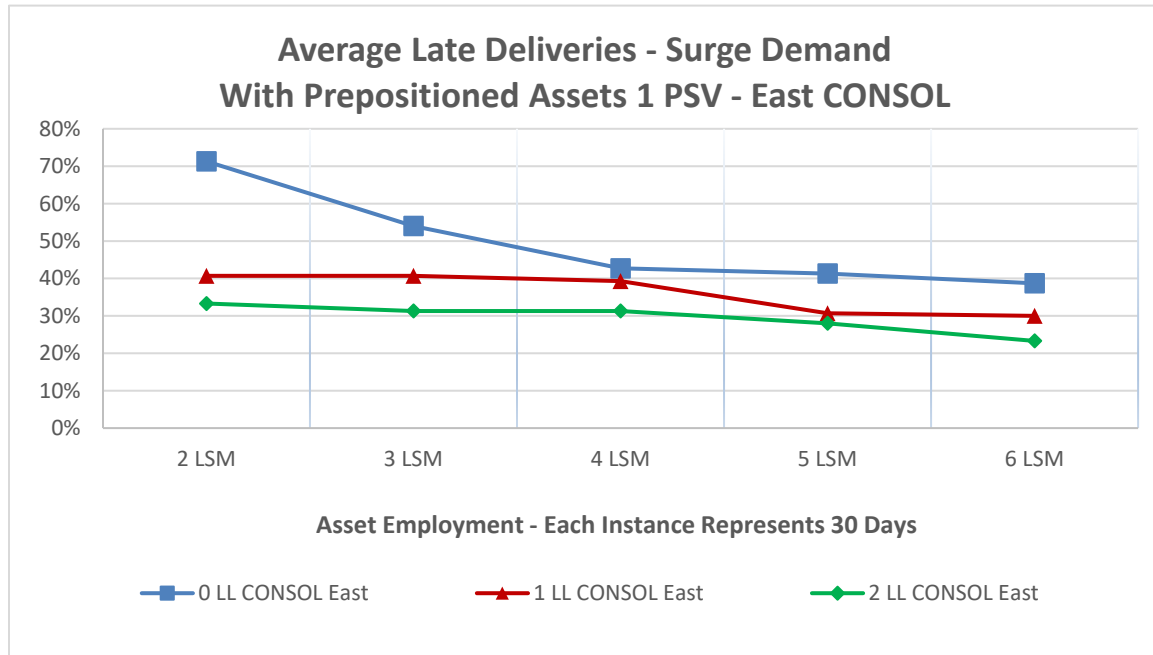


Figure 16. Surge Demand Average Late Deliveries Chart—East CONSOL  
One PSV with Prepositioned Assets

Adding two PSVs to the surge scenario further improved the results. Zero late deliveries were achieved from all CONSOL locations with a mixture of five, four, and three LSMs when combined with two PSVs, and two LLs as shown in Figure 17.

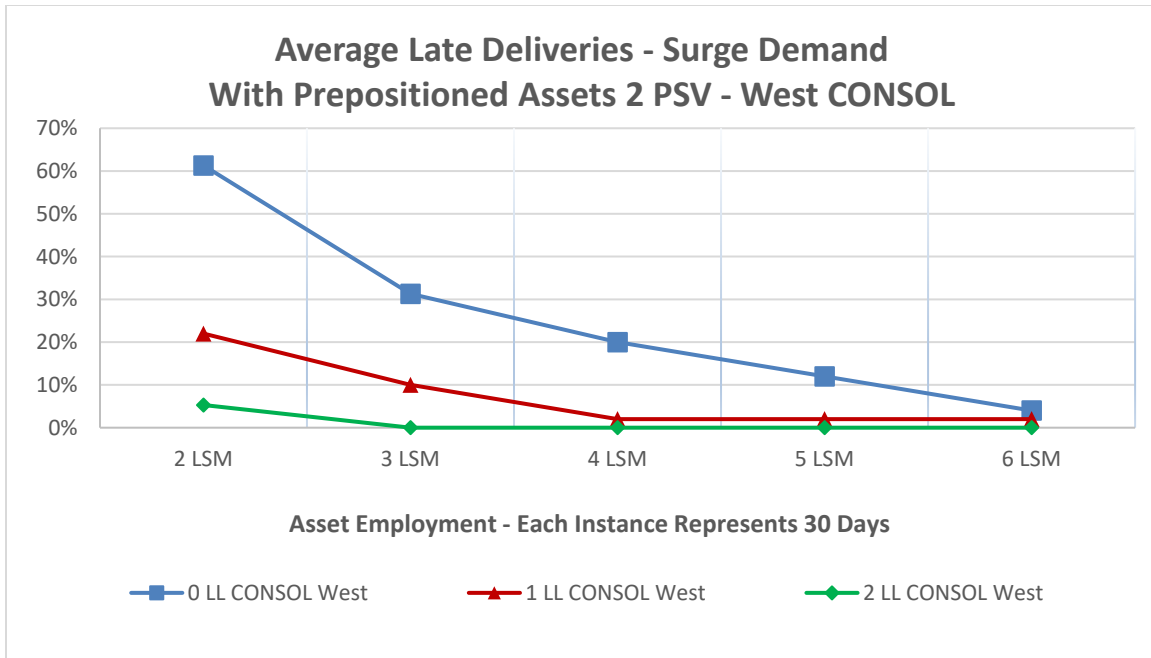


Figure 17. Surge Demand Average Late Deliveries Chart – West CONSOL  
Two PSVs with Prepositioned Assets

The optimization results from CONSOL station west were almost identical as the results from CONSOL station south with prepositioned assets except for the datapoint of two PSVs, two LSMs, and two LLs where CONSOL station west resulted in 10 percent late deliveries, and station south resulted in 11 percent late deliveries.

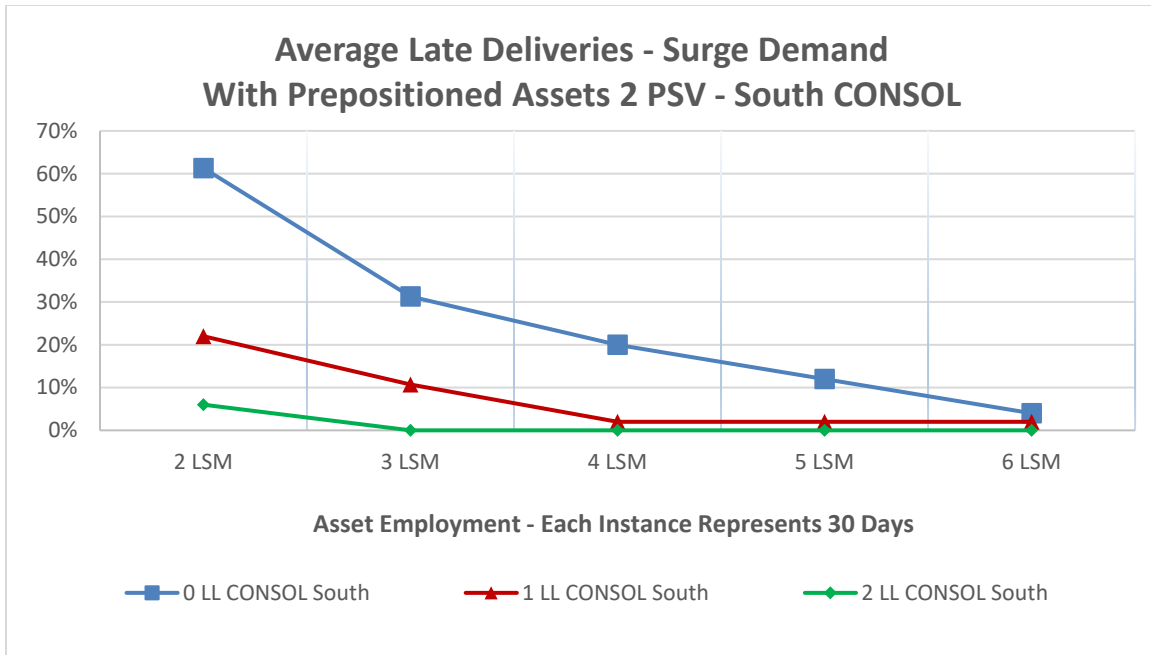


Figure 18. Surge Demand Late Deliveries Chart—South CONSOL Two PSVs with Prepositioned Assets

One hundred percent on-time delivery was also achieved with a combination of six LSMs, two PSVs, and two LLs, but only from CONSOL locations West and South. The optimization tool could not find a solution with this combination of assets from location East as shown in Figure 19. Possibly due to the RASP model 10-minute optimization run limitation utilized during these scenarios. CONSOL station East achieved 100 percent on-time deliveries with 3–5 LSMs, 2 PSVs, and 2 LLs.

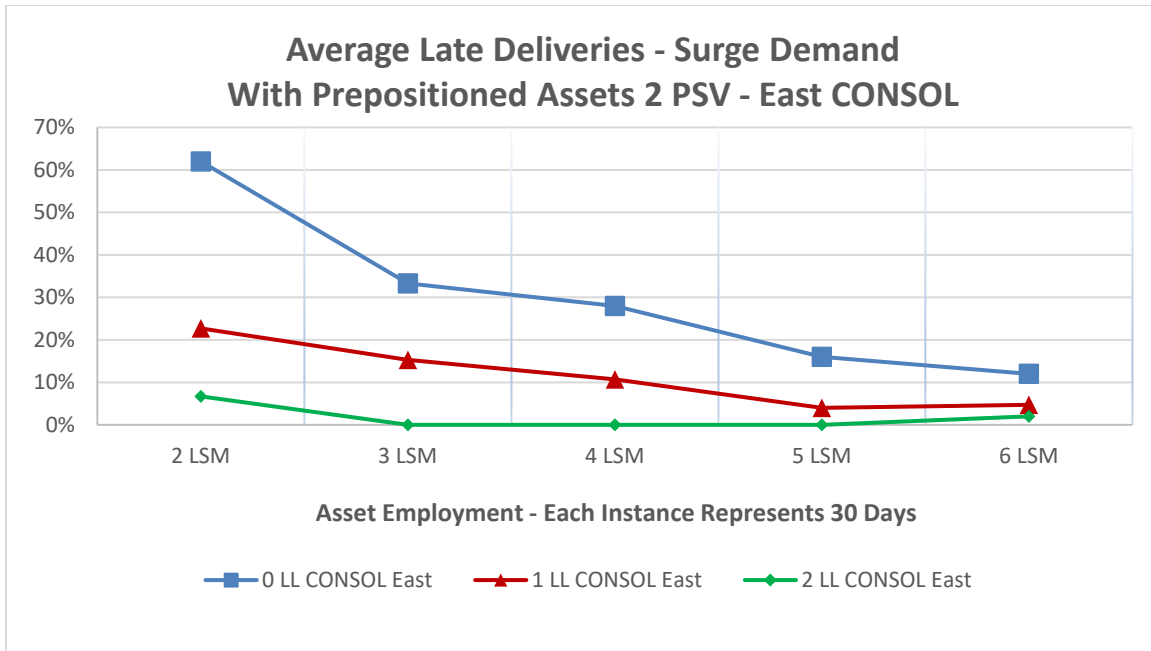


Figure 19. Surge Demand Average Late Deliveries Chart—East CONSOL  
Two PSVs with Prepositioned Assets

## 2. Below Maximum Capacity Delivery

The previous section discussed the Average Late Deliveries, which represents the average instance that at least one receiving station received a delivery after reaching its safety threshold. The Below Maximum Capacity Delivery metric shows how low any one of the receiving stations reached before receiving a late delivery. This is a cumulative metric, and it represents the lowest level of storage capacity any given station experienced below its safety threshold. This value represents the lowest percentage that at least one of the receiving stations experienced during an optimization run. Any value below zero percent signifies that one or more receiving stations were left with no fuel, which equates to mission failure. The values above zero denote the lowest state of any given station before receiving fuel in reference to their safety threshold.

As mentioned above, any negative value represents that one or more of the receiving stations reached zero percent capacity and could not continue to operate due to lack of fuel. The lowest the number below zero, the greater the cumulative impact on the receiving stations. Any metric with zero value represents that all receiving stations

achieved 100 percent on time deliveries, or deliveries at or above their specific safety thresholds.

**a. Sustained Demand Below Maximum Capacity Delivery**

The below maximum capacity delivery results for the sustained demand scenario with one PSV in Figure 20 showed that receiving stations were filled before reaching their safety thresholds with a combination six, five, and four LSMs regardless of the number of LLs used when utilizing the West, and South CONSOL stations. Additionally, a combination of two and three LSMs, two LLs, and one PSV resulted in zero deliveries below threshold from CONSOL stations West and South.

The optimization run with one PSV from CONSOLs West and South resulted in mission failure when the asset mix was three LSMs, one PSV, and zero LL. In addition, stations were out of fuel before replenishment with a combination of two LSMs, one PSV, and one LL, and two LSM, one PSV and zero LL.

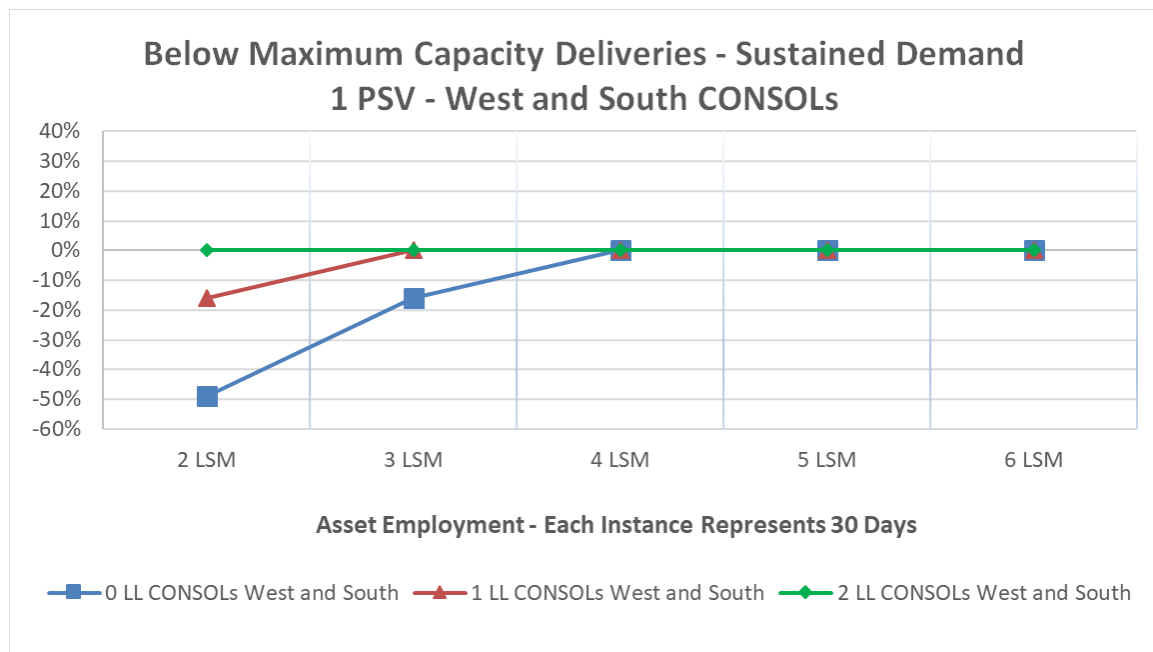


Figure 20. Sustained Demand Below Maximum Capacity Deliveries Chart—  
West and South CONSOLs One PSV

In the scenario coming out of the East CONSOL station one PSV was not able to keep up with maintaining the EAB Company+ safety level above 40 percent capacity. None of the data points were at zero percent as shown in Figure 21. All results above zero percent represent the lowest any receiving station reached before receiving fuel. All results below the zero percent mark represent that one or more receiving units ran out of fuel for one or more days, resulting in mission failure.

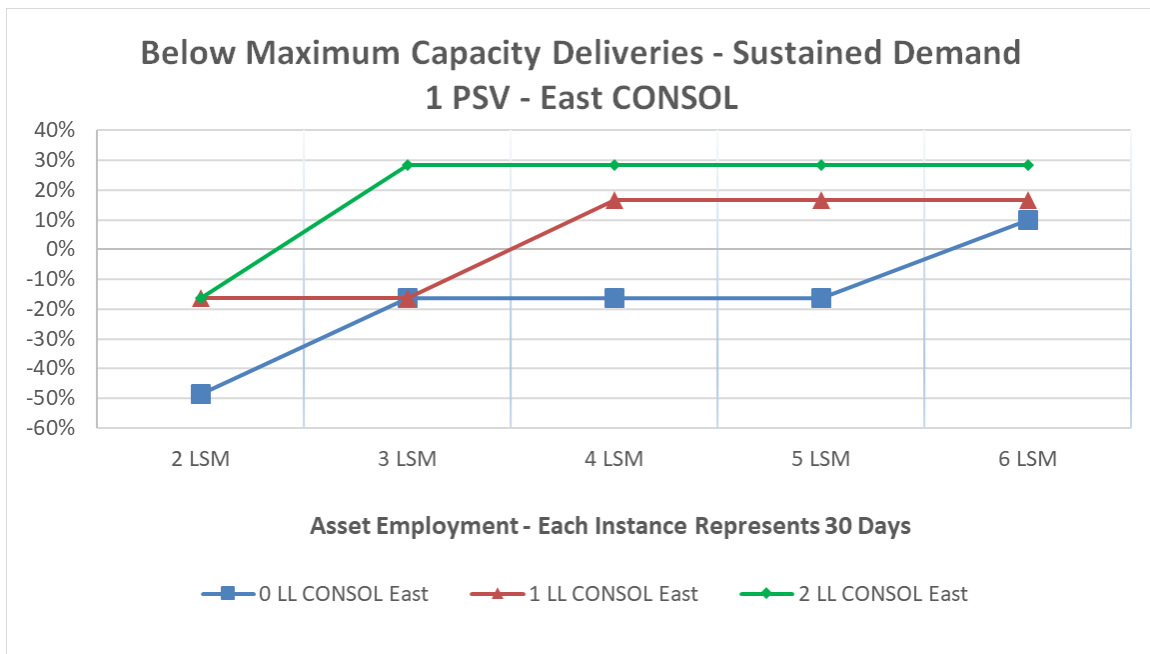


Figure 21. Sustain Demand Below Maximum Capacity Deliveries Chart—  
East CONSOL One PSV

The RASP optimization tool could not find a solution to achieve zero below maximum capacity deliveries with one PSV during the sustained demand scenario when the PSV and LLs operated out of the East CONSOL station. An additional run with two PSVs corrected this deficiency as shown in Figure 22. When using two PSVs with six, five, and four LSMs regardless of the number of LLs all receiving stations were filled before reaching their safety threshold. Additionally, a combination of two and three LSMs, two LLs, and one PSV also showed zero deliveries below threshold. All other combinations

resulted in mission failure. Without the LLs, stations experienced zero percent capacity after when utilizing three or less LSMs and two PSVs.

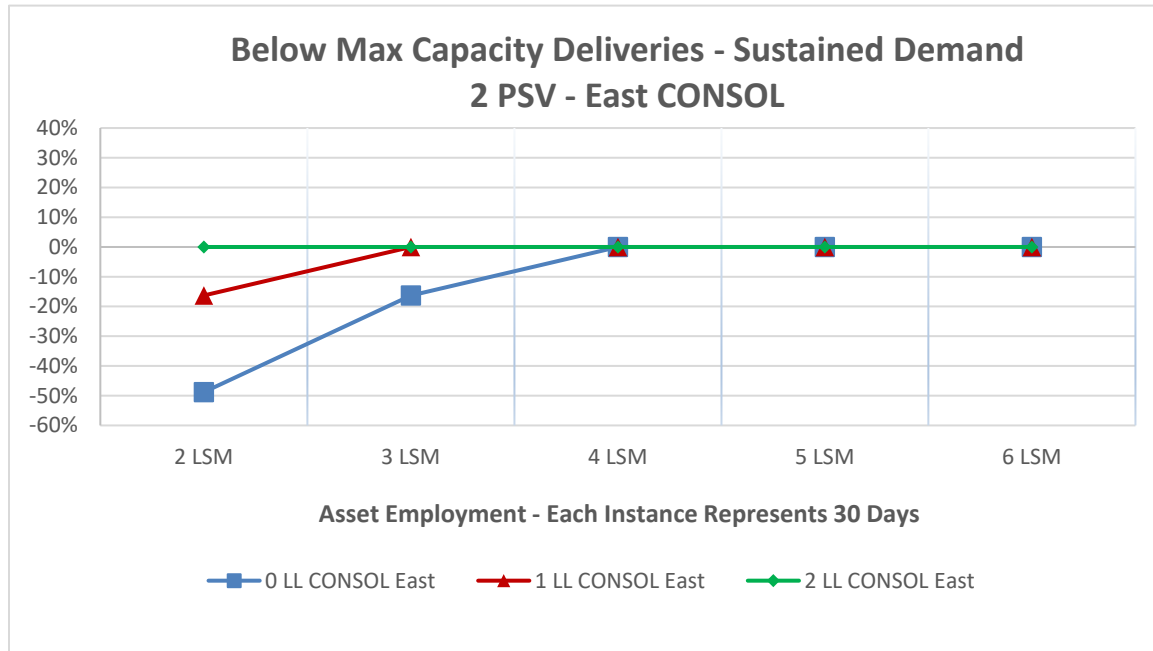


Figure 22. Sustained Demand Below Maximum Capacity Deliveries Chart—East CONSOL Two PSVs

***b. Surge Demand Below Maximum Capacity Delivery***

Optimization runs with surge demand yielded zero instances where any station received fuel below their safety threshold. During every optimization run at least one station received fuel below 50 percent. See Figures 23–26. This situation worsened during runs from CONSOL station East with one PSV, where receiving stations completely ran out fuel in ten out of fifteen scenarios, experiencing mission failure. See Figure 25. Adding one additional PSV from CONSOL East improved the results with only one scenario resulting in mission failure after the addition, but none achieved zero percent below maximum capacity delivery.

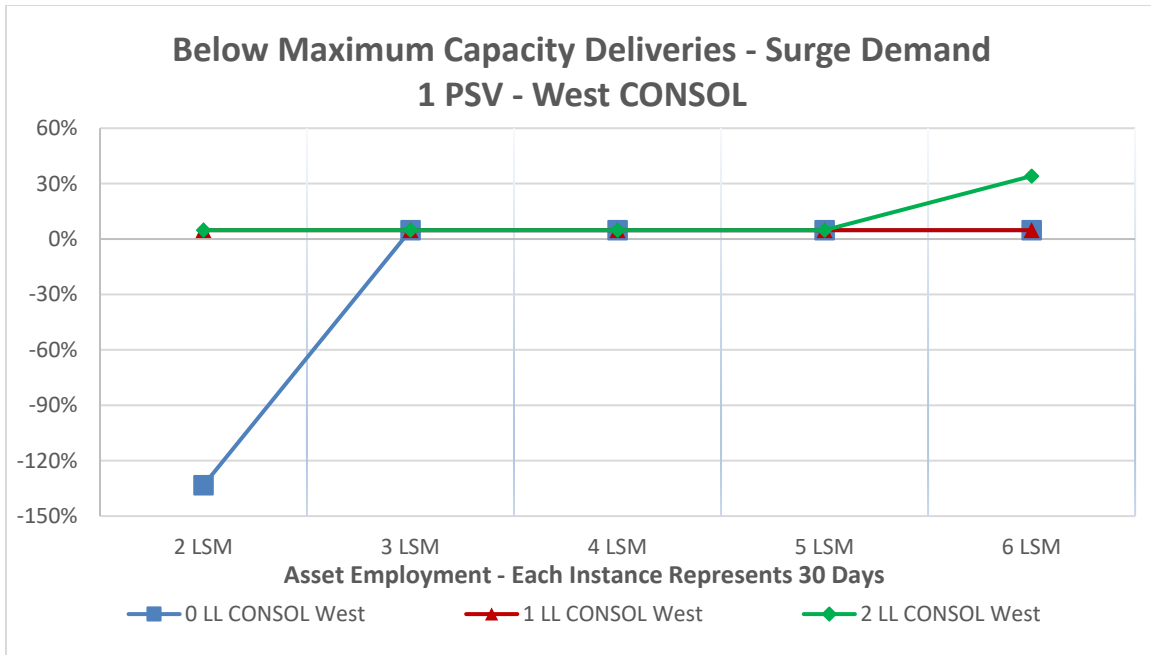


Figure 23. Surge Demand Below Maximum Capacity Deliveries Chart—West CONSOL One PSV

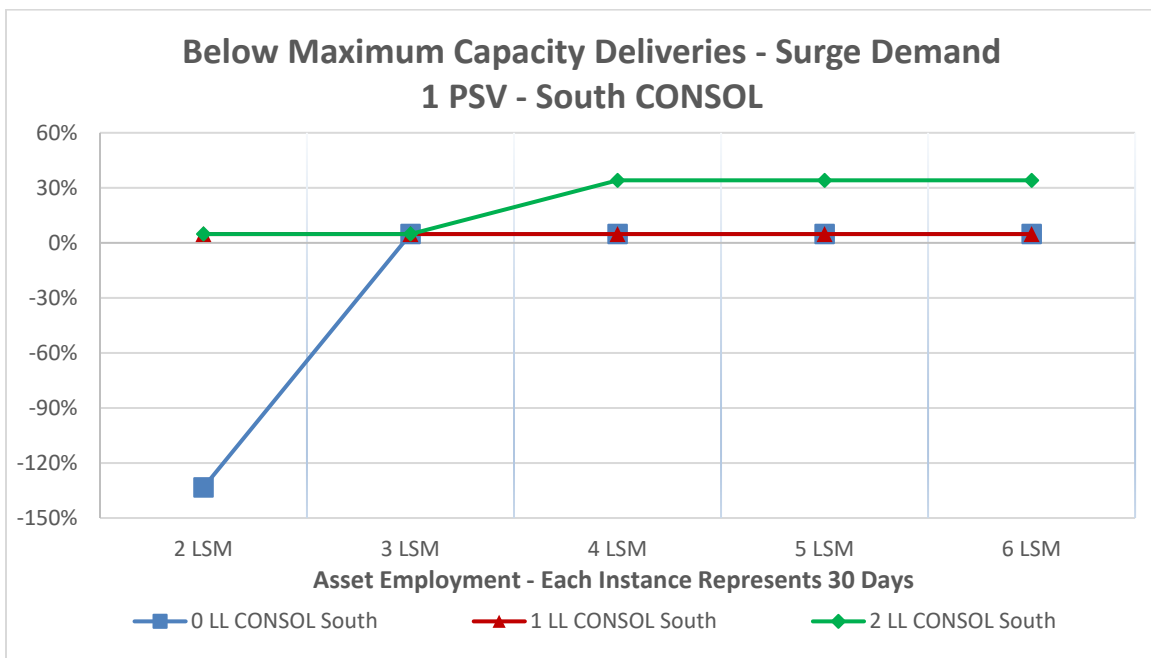


Figure 24. Surge Demand Below Maximum Capacity Deliveries Chart—South CONSOL One PSV

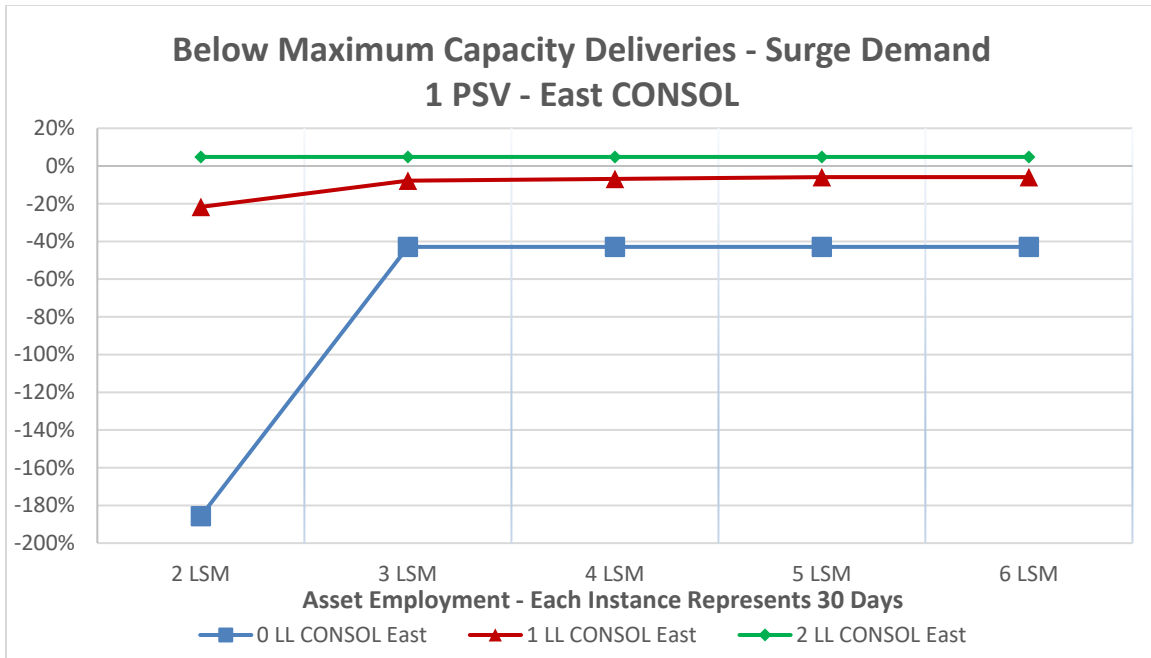


Figure 25. Surge Demand Below Maximum Capacity Deliveries Chart—East CONSOL One PSV

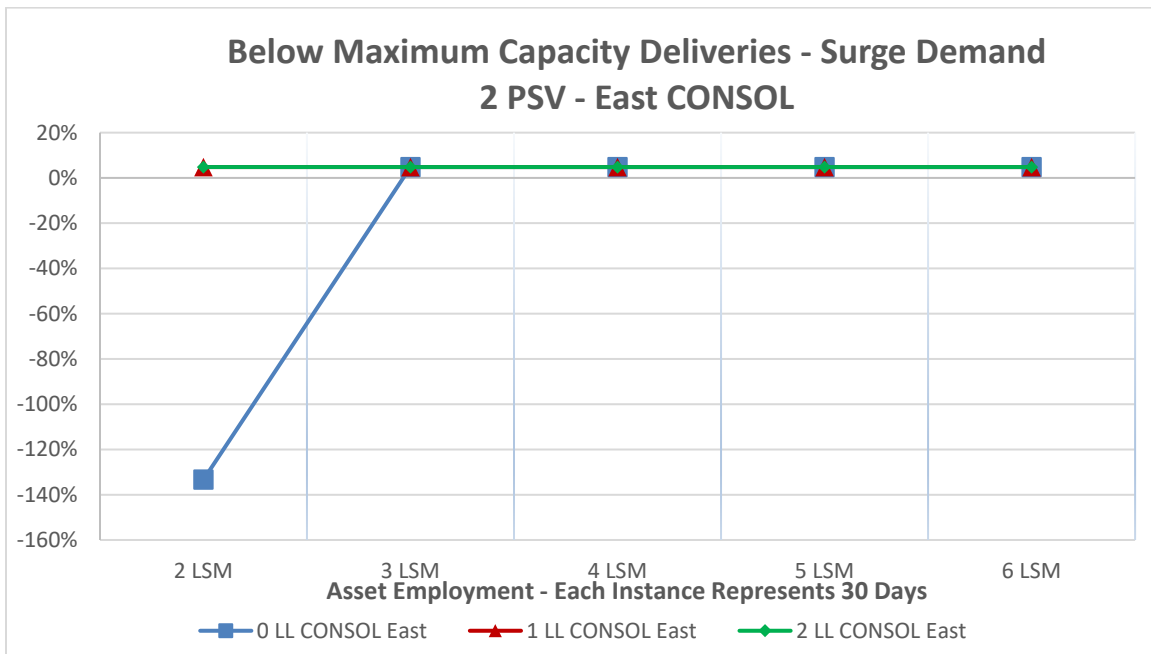


Figure 26. Surge Demand Below Maximum Capacity Deliveries Chart—East CONSOL Two PSVs

To achieve zero percent below maximum capacity deliveries in the surge demand scenario, two LSMs were prepositioned closer to the EAB Platoon locations during the start of the optimization run, one to the north and another to the south. Additionally, a restriction where the LLs would only deliver fuel from outside the WEZ to EAB Platoons as a last resort was lifted, and LLs were allowed to conduct deliveries as needed. Optimization runs for the surge scenarios with prepositioned assets were conducted with one and two PSVs. See Figures 27–31 below.

These changes resulted in improvements across all locations. With one PSV zero below maximum capacity deliveries were achieved from the West and South CONSOL locations with a combination of six LSMs, and two LLs. Additionally, RASP achieved schedules with zero below maximum capacity deliveries from the West CONSOLs with a combination of three LSMs, one PSV, and two LLs. As in the sustained demand scenario, the East CONSOL location could not achieve zero deliveries below maximum capacity with one PSV and none of the values showed zero in Figure 29.

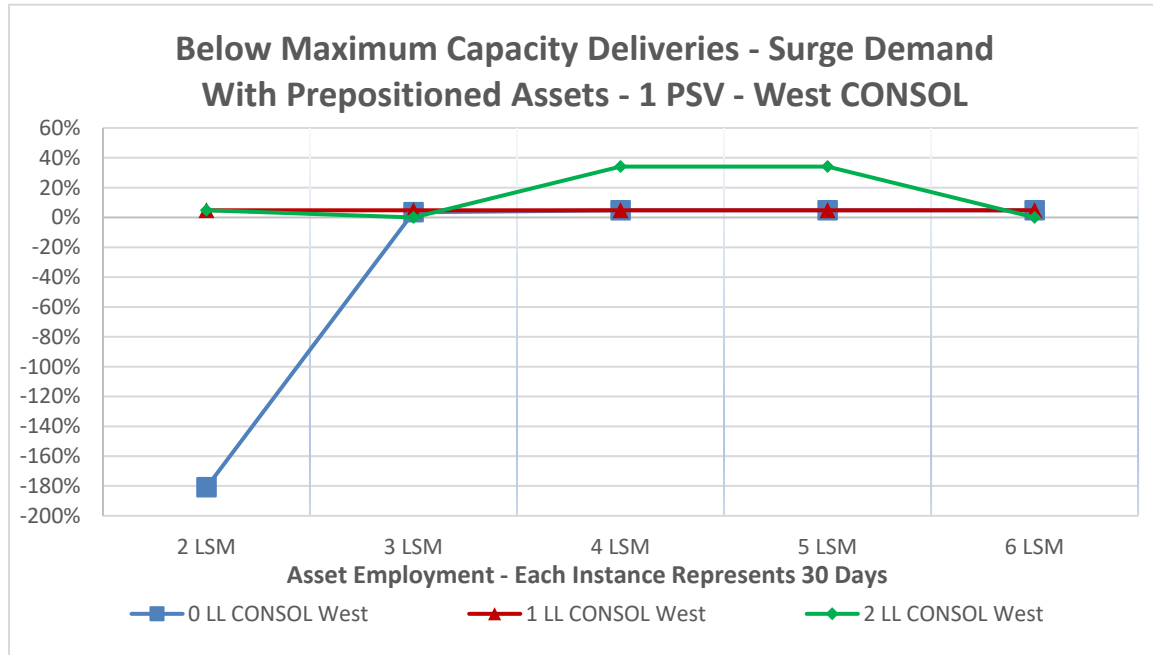


Figure 27. Surge Demand Below Maximum Capacity Deliveries Chart—West CONSOL One PSV with Prepositioned Assets

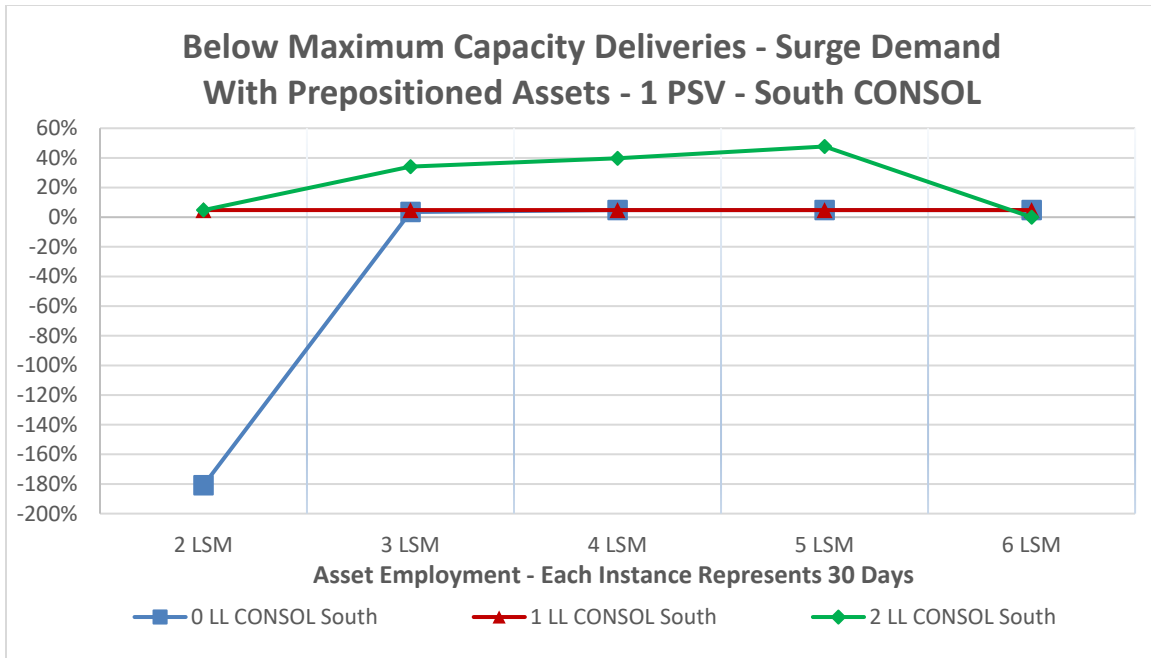


Figure 28. Surge Demand Below Maximum Capacity Deliveries Chart—South CONSOL One PSV with Prepositioned Assets

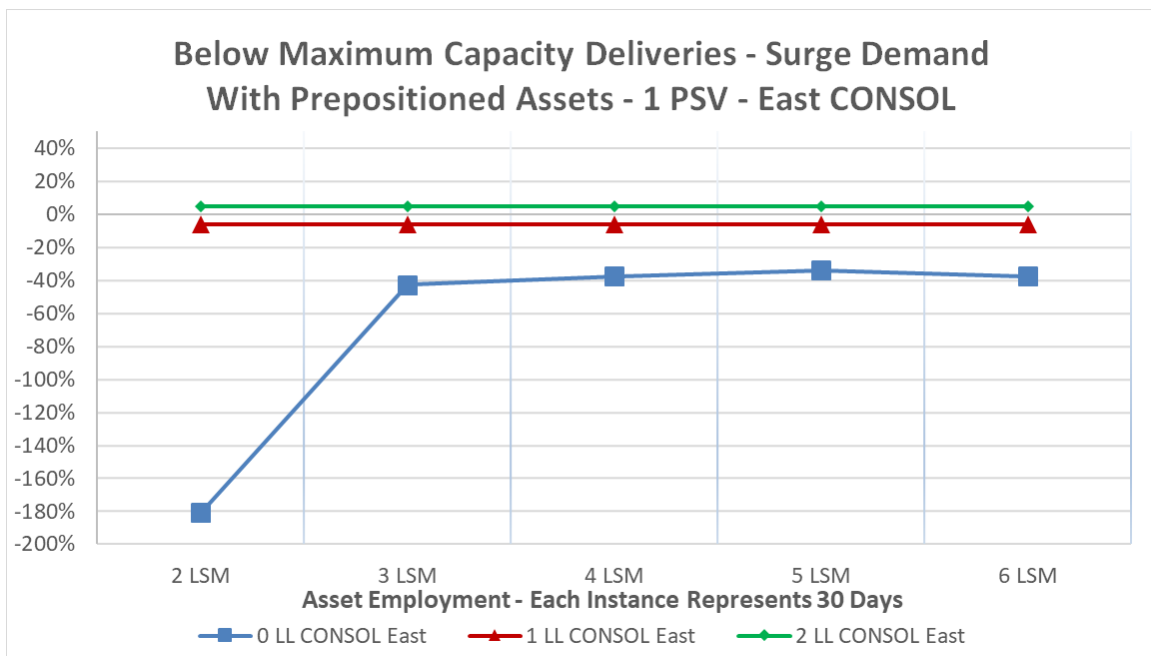


Figure 29. Surge Demand Below Maximum Capacity Chart—East CONSOL One PSV with Prepositioned Assets

Adding two PSVs to the surge scenarios further improved the results. Zero deliveries below maximum capacity were achieved from all CONSOL locations with a mixture of six, five, four, and three LSMs when combined with two PSVs, and two LLs, except for CONSOL East.

The optimization tool could not find a solution with this combination of assets from CONSOL East. RASP allocated 10 minutes per optimization run. This time was not enough for the model to find a solution for the six LSM, two LLs scenario from CONSOL East. CONSOL East achieved zero percent below maximum capacity deliveries with a combination of three, four, and five LSMs, two PSVs and two LLs as shown in Figure 31.

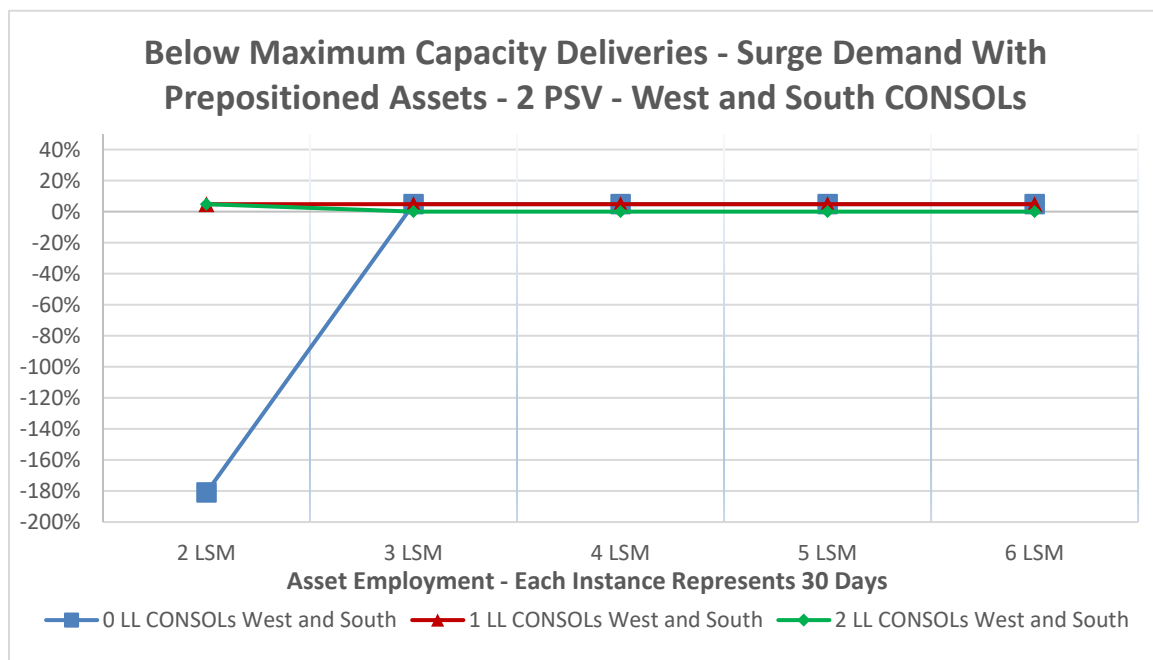


Figure 30. Surge Demand Below Maximum Capacity Deliveries Chart—West and South CONSOL Two PSV with Prepositioned Assets

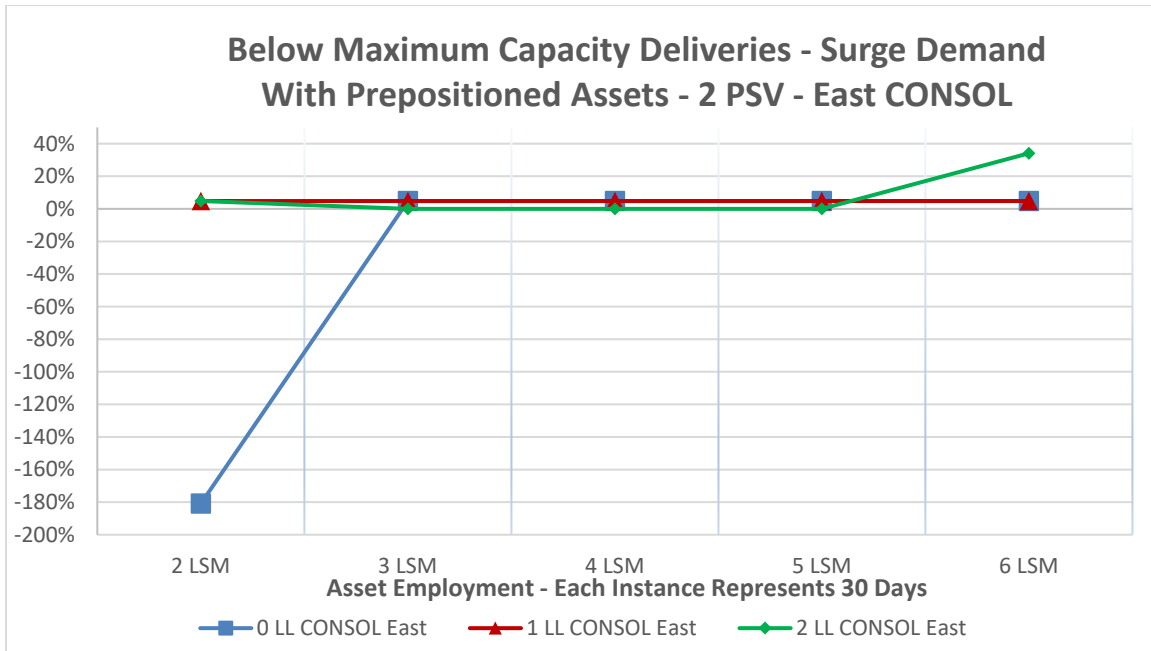


Figure 31. Surge Demand Below Maximum Capacity Deliveries Chart—East  
CONSOL Two PSVs with Prepositioned Assets

## **V. CONCLUSION AND RECOMMENDATIONS**

From the RASP model results, we were able to draw several conclusions and make some recommendations as well as propose follow-on studies for future work.

### **A. CONCLUSION**

In conclusion, this study demonstrates how fuel demand can impact fuel deliveries across different Expeditionary Advanced Base (EAB) configurations. During sustained operations, the EAB Company+ required 45,172 gallons of fuel, while each EAB Platoon needed 1,794 gallons. However, during surge conditions, the Company+ demand jumped over 50 percent to 69,045 gallons daily, and each Platoon's requirement increased nearly 40 percent to 2,477 gallons a day. These variations in fuel consumption were significantly influenced by the operational tempo and the readiness level of equipment and aircraft. This highlights how fuel consumption is heavily influenced by the size and composition of the EAB units and whether operations are ongoing or intensifying.

Fuel consumption patterns can shift significantly based on operational scenarios, the scale of EAB units, and equipment use. By leveraging modeling tools like Replenishment at Sea Planner (RASP), naval planners can determine the right combinations of replenishment ships and dynamic deployment approaches to sustain EABOs across a range of demanding, real-world conditions. This study provides a framework to enhance the responsiveness, resilience, and effectiveness of naval logistics.

The RASP optimization model provides data-driven asset allocation recommendations to meet varying operational requirements while keeping EABs at or above safety capacity thresholds.

To meet these variable demands, the analysis points to optimal mixes of replenishment assets. During sustained operations, as few as 2 Liberty Lifters and 2 LSMs, alongside 1 PSV, could satisfy requirements from the East and South Fuel Consolidation (CONSOL) stations, assuming 100 percent delivery asset availability. However, meeting the spike in surge demands necessitated pre-positioning LSMs closer to EAB Platoons and utilizing Liberty Lifters more dynamically to share the replenishment burden. Under these

conditions, the model showed that 3 to 6 LSMs, 2 Liberty Lifters, and 2 PSVs were optimal for on-time deliveries from all CONSOL stations. Key insights include:

- LLs are essential for meeting periodic surge demands.
- LSMs and PSVs efficiently meet continuous sustainment needs. (The optimal combination of PSV and LSM will maintain EABO continuously supplied with sufficient fuel to operate within a contested area).
- Distance between stations could require the need of additional delivery assets regardless of assets load capacity. The EAB Platoons frequent demand intervals could require dedicated assets to each Platoon station.

The study resulted in the following asset mix recommendations to enable the logistics force to meet both sustained and surge demands:

- 4 LSMs – Provide sustenance lift capacity from EAB Company+ to 4 EAB Platoons.
- 1 PSV -- Will suffice to maintain one hub (EAB Company+) with a 1.5-million-gallon storage capacity at the stated sustained and surge demands when the CONSOL station is within 2,300 nautical miles of the hub. Distances greater than 2,300 nautical miles require at least two PSVs to maintain the EAB Company+ within the capacity safety thresholds during sustained and surge scenarios.
- 2 LLs – Enable rapid response to sustain and surge demands. The LL speed makes it a great asset to make quick drops to EAB Platoons in remote areas. The LLs were vital to maintain the surge scenario demand capacity within the safety threshold.
- Prepositioned assets greatly improved the optimization model to be able to meet surge demand.

## **B. RECOMMENDATIONS**

Based on the scenario and analysis presented in the thesis, here are some potential recommendations for optimal asset combinations to support Expeditionary Advanced Base Operations (EABO) in the INDOPACOM AOR:

Most Efficient Combination:

- 4 LSMs – Provide sustenance lift capacity from EAB Company+ to 4 EAB Platoons.
- 1 PSV – Will suffice to maintain the EAB Company+ hub when the CONSOL station is within 2,300 nautical miles. Beyond this distance, 2 PSVs are needed.
- 2 Liberty Lifters – Enable rapid response to sustainment and surge demands. Their speed makes them well-suited for quick deliveries to remote EAB Platoons.

This combination utilizes the minimum number of assets needed to meet on-time delivery thresholds during both sustained and surge conditions, based on the modeling results. The PSV and LSMs handle routine sustainment, while the Liberty Lifters provide flexible surge capacity.

The optimal combination was:

- 5 LSMs
- 2 PSVs
- 2 Liberty Lifters

This configuration builds in more redundancy with an extra LSM and PSV compared to the ‘most efficient’ option. The extra PSV ensures the EAB Company+ hub can be maintained within capacity thresholds even from the furthest East CONSOL station. The additional LSM provides more lift capacity and flexibility in reaching EAB Platoons.

The most conservative combination was:

- 6 LSMs
- 2 PSVs
- 2 Liberty Lifters

This combination includes maximum capacity with 6 LSMs, offering the most lift assets to handle sustainment and surge demands. With two PSVs, it also ensures robust support for the EAB Company+ hub even from distant CONSOL stations. The Liberty Lifters still provide rapid flexible lift. This conservative mix ensures fuel delivery requirements can be met under the widest range of challenging conditions and allows for efficient asset prepositioning in the AOR.

In summary, the modeling and analysis point to an optimal balance utilization of delivery assets to support this scenario based on the INDOPACOM AOR, employing between 4 and 6 LSMs, 1 or 2 PSVs, and 2 Liberty Lifters to provide both efficient routine sustainment and flexible surge capacity for EABO fuel resupply. The exact mix can be tailored based on factors like operational demands, geography, and risk tolerance.

## **C. FUTURE STUDIES**

The journey of refining the Fuel Usage Study Extended Demonstration (FUSED) model for this study encountered a significant hurdle due to the intricate complexity involved in updating its Visual Basic for Applications (VBA) code which was originally coded to solve fuel deliveries between CFLs and U.S. Navy ships. This challenge inevitably meant that the FUSED model could not be sufficiently modified in time to be utilized effectively and deliver meaningful results in our current analysis. The modification process faced constraints in producing an in-depth analysis that could be resolved with more time for future studies. Our current progress with FUSED is promising, yet it is not complete. From our analysis thus far, it is evident that without an additional external factor influencing the model the LSMs will behave as described above as represented by the RASP model results. This insight underscores the need for continued development and refinement of our logistical models to ensure they accurately reflect the complexities and dynamics of real-world operations.

The examination of cross-docking should be studied during future work. Cross-docking is a practice in logistics of unloading materials from an incoming vehicle and loading these materials directly into outbound vehicles, with little or no storage in between (Apte & Mason, 2006). Integrating cross-docking as a strategy in a transshipment multimodal fuel delivery system, particularly in a military context or contested environments. Using platforms like the Liberty Lifter is undoubtedly advantageous in terms of efficiency, safety, and operational flexibility. Moreover, cross-docking introduces new complexities and requirements that could drive beneficial enhancements to both the Fuel Usage Study Extended Demonstrations (FUSED) and Replenishment at Sea Planner (RASP) models. However, it is also crucial to explore and develop alternate designs for delivery operations, particularly in complex and varied operational environments such as Expeditionary Advance Base Operations (EABO).

In Expeditionary Advance Base Operations, the essence of time cannot be overstated. The implementation of cross-docking, characterized by the swift transition of fuel from incoming transports, such as supply ships or tankers, directly to outbound units, exemplifies a paradigm shift towards heightened operational efficiency. This approach not only substantially mitigates the typical dwell time associated with traditional storage practices but also accelerates the entire delivery process.

The Liberty Lifter plays a crucial role in this context, offering high mobility that enables dynamic and responsive fuel supply chains, essential for maintaining operational readiness in varied and contested environments. Cross-docking not only accelerates supply but also minimizes the risks inherent in fuel storage in conflict zones, reducing vulnerability to enemy attacks.

The flexibility of cross-docking allows for the establishment of temporary fuel transfer stations, particularly useful in scenarios where permanent infrastructure is impractical. This approach optimizes resource utilization, balancing the demands of rapid mobility with the need for efficient logistics in both small and large-scale operations.

Furthermore, integrating cross-docking into the FUSED and RASP models introduces a new dimension of complexity and potential enhancement. For FUSED, this

would involve incorporating parameters for the throughput rates of temporary transfer stations and forecasting fuel transfer needs. RASP, on the other hand, could benefit from dynamic routing algorithms that account for the logistics of cross-docking operations.

Future endeavors in refining logistical models must pivot towards enhancing the integration and functionality of cross-docking, crucial for an agile and efficient military fuel supply chain. This involves developing sophisticated algorithms that enable flexible location transfer stations, coupled with advanced machine learning techniques for more accurate demand forecasting. Achieving this level of integration would markedly optimize cross-docking, a vital component in modern military logistics. Concurrently, it is essential to address operational aspects such as the refueling needs of logistics vessels like LSMs due to their own fuel consumption. Additionally, we are exploring innovative concepts like float storage, which would empower these vessels to discharge fuel at lighterage or berth locations. This strategy not only improves the flexibility of fuel distribution but also ensures a more responsive and robust logistical framework, aligning with the dynamic needs of military operations.

The impacts of operating delivery assets with dual fuel should be analyzed in future studies. The work on this study was conducted with the assumption of a single fuel carried by all delivery assets. The impacts of delivery assets carrying dual fuel should be considered to determine how it would affect these scenarios.

Additionally, exploring innovative approaches like floating storage, which would allow these vessels to discharge fuel at lighterage or berth locations, significantly augmenting the flexibility and efficiency of fuel distribution, should be studied.

## APPENDIX A. FUEL CONSUMPTION DATA

Table 4. TAMCN Fuel Burning Equipment List for EAB Company +. Adapted from Family of Expeditionary Fuel Systems, HQMC, CD&I (email to authors, 23 March 2023).

| EAB Company+                                                                      |         |                                                                                                                       |               |                   |                                      |                                          |                              |           |           |          |                                       |           |     |                               |                                   |
|-----------------------------------------------------------------------------------|---------|-----------------------------------------------------------------------------------------------------------------------|---------------|-------------------|--------------------------------------|------------------------------------------|------------------------------|-----------|-----------|----------|---------------------------------------|-----------|-----|-------------------------------|-----------------------------------|
| USMC Update TAMCN Fuel Burning Equipment List for ICIS Update (10 September 2019) |         |                                                                                                                       |               |                   |                                      |                                          |                              |           |           |          |                                       |           |     |                               |                                   |
| ***Modified to calculate fuel demand for EABO 2045 notional scenario***           |         |                                                                                                                       |               |                   |                                      |                                          |                              |           |           |          |                                       |           |     |                               |                                   |
| 5-Char<br>TAMCN                                                                   | TAMCN   | TAMCN NOMENCLATURE                                                                                                    | Fuel Consumed |                   | Operating<br>Hours<br>Surge<br>Daily | Operating<br>Hours<br>Sustained<br>Daily | Fuel Tank<br>Capacity (Gals) | Fuel Type |           |          | Comments                              |           |     | SURGE<br>DAILY<br>CONSUMPTION | SUSTAINED<br>DAILY<br>CONSUMPTION |
|                                                                                   |         |                                                                                                                       | GPH           | MPG               |                                      |                                          |                              | Primary   | Alternate | Tertiary |                                       | READINESS | QTY |                               |                                   |
| A0021                                                                             | A00217G | COMMUNICATIONS DATA: AN/TYQ-101A, COMMUNICATION DATA LINK SYSTEM (CDLS)                                               | 5.85          | 10.26             | 24.00                                | 24.00                                    | 25                           | F-24      | JP-5/8    | Diesel   | 1 X M1152 HMMWV SL-3                  | 80%       | 1   | 112                           | 112                               |
| A0033                                                                             | A00337G | OPERATIONS CENTRAL; PROCESSING AND DISPLAY SYSTEM WITH MULTIFUNCTIONAL INFORMATION DISTRIBUTION SYSTEM (MIDS) TRAILER | 5.85          | 10.26             | 24.00                                | 24.00                                    | 25                           | F-24      | JP-5/8    | Diesel   | 1 X M1152 HMMWV SL-3                  | 80%       | 1   | 112                           | 112                               |
| A0153                                                                             | A01537G | RADIO SET; AN/MRC-142C                                                                                                | 5.85          | 10.26             | 24.00                                | 24.00                                    | 25                           | F-24      | JP-5/8    | Diesel   | 1 X M1123 HMMWV SL-3                  | 80%       | 1   | 112                           | 112                               |
| A0254                                                                             | A02547G | COMBAT OPS CENTER, SET III, AN/TSQ-239(V)4                                                                            | 3.53          | N/A               | 24.00                                | 24.00                                    | 41.6                         | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 68                            | 68                                |
| A1440                                                                             | A14407G | RADAR SET, AN/TPQ-46B, FIREFINDER RADAR                                                                               | 2.75          | 9.44              | 24.00                                | 24.00                                    | 25                           | F-24      | JP-5/8    | Diesel   | 3 X M1152 HMMWV, 1 X M1151 HMMWV SL-3 | 80%       | 1   | 53                            | 53                                |
| A1957                                                                             | A19577G | RADIO SET, AN/MRC-145A                                                                                                | 4.3           | 11                | 24.00                                | 24.00                                    | 25                           | F-24      | JP-8      | Diesel   | 1 X M1123 HMMWV SL-3                  | 80%       | 1   | 83                            | 83                                |
| A2600                                                                             | A26007G | COMMAND SYSTEM TACTICAL; COMPOSITE TRACKING NETWORK (CTN)                                                             | 5.85          | 10.26             | 24.00                                | 24.00                                    | 25                           | F-24      | JP-5/8    | Diesel   | 1 X M1152 HMMWV SL-3                  | 80%       | 1   | 112                           | 112                               |
| B0038                                                                             | B00387B | ALL TERRAIN CRANE (ATC) MAC-50                                                                                        | 9.5           | No data available | 24.00                                | 12.00                                    | 148                          | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 182                           | 91                                |
| B0039                                                                             | B00397B | AIRFIELD DAMAGE REPAIR (ADR) KIT                                                                                      | 3.25          | N/A               | 24.00                                | 12.00                                    | 42.17                        | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 62                            | 31                                |
| B0971                                                                             | B09717B | GENERATOR SET, SKID MTD, 30KW/400HZ, TQG (MEP-815B)                                                                   | 2.75          | N/A               | 24                                   | 24                                       | 23                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 2   | 106                           | 106                               |
| B1016                                                                             | B10167B | GENERATOR SET, 60KW, 400HZ, SKID-MTD (MEP-816B)                                                                       | 5.37          | N/A               | 24                                   | 24                                       | 43                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 103                           | 103                               |
| B1135                                                                             | B11357B | REFUELING SYSTEM, EXPEDIENT, HELO                                                                                     | 0.4           | N/A               | 12                                   | 8                                        | 1.3                          | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 2   | 8                             | 5                                 |
| B1570                                                                             | B15707B | PUMP ASSEMBLY, EXPEDIENT REFUELER, FUEL DISPENSING                                                                    | 0.52          | N/A               | 12                                   | 8                                        | 1.03                         | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 5                             | 3                                 |
| B1580                                                                             | B15807B | PUMP MODULE, FUEL (SIXCON)                                                                                            | 0.52          | N/A               | 12                                   | 8                                        | 1.04                         | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 5                             | 3                                 |
| B1583                                                                             | B15837B | PUMP, FUEL, 600 GPM                                                                                                   | 4.9           | N/A               | 12                                   | 8                                        | 20                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 2   | 94                            | 63                                |
| B1620                                                                             | B16207B | PUMP UNIT SET                                                                                                         | 0.25          | N/A               | 12                                   | 8                                        | 0.92                         | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 2   | 5                             | 3                                 |
| B1785                                                                             | B17857B | ROLLER, COMPACTOR, VIBRATORY                                                                                          | 4             |                   | 18                                   | 12                                       | 60                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 58                            | 38                                |
| B1922                                                                             | B19227B | SCRAPER-TRACTOR, WHEELED                                                                                              | 6             |                   | 18                                   | 12                                       | 135                          | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 86                            | 58                                |
| B1951                                                                             | B19517B | SHOP EQUIPMENT SET, GP, #1                                                                                            | 0.99          | N/A               | 24                                   | 24                                       | 9                            | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 19                            | 19                                |
| B2127                                                                             | B21277B | SWEEPER, ROTARY, VEHICLE MOUNTING                                                                                     | 8             |                   | 18                                   | 12                                       | 50                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 115                           | 77                                |
| B2394                                                                             | B23947B | PUMP, WATER 600 GPM                                                                                                   | 4.9           | N/A               | 24                                   | 24                                       | 23                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 2   | 188                           | 188                               |
| B2460                                                                             | B24607B | TRACTOR, FT, W/ANGLE BLADE                                                                                            | 4             |                   | 18                                   | 12                                       | 52                           | F-24      | JP-5/8    | Diesel   |                                       | 80%       | 1   | 58                            | 38                                |

| EAB Company+                                                                                |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          |                                            |     |                               |                                   |
|---------------------------------------------------------------------------------------------|---------|-----------------------------------------------------------------------------------------|---------------|-------------------|-----------------------------|---------------------------------|---------------------------------|-----------|-----------|----------|----------|--------------------------------------------|-----|-------------------------------|-----------------------------------|
| USMC Update TAMCN Fuel Burning Equipment List for ICIS Update (10 September 2019) Continued |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          |                                            |     |                               |                                   |
| ***Modified to calculate fuel demand for EABO 2045 notional scenario***                     |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          |                                            |     |                               |                                   |
| 5-Char<br>TAMCN                                                                             | TAMCN   | TAMCN NOMENCLATURE                                                                      | Fuel Consumed |                   | Operating<br>Hours<br>Surge | Operating<br>Hours<br>Sustained | Fuel<br>Tank<br>Capacity (Gals) | Fuel Type |           |          | Comments |                                            |     | SURGE<br>DAILY<br>CONSUMPTION | SUSTAINED<br>DAILY<br>CONSUMPTION |
|                                                                                             |         |                                                                                         | GPH           | MPG               |                             |                                 |                                 | Primary   | Alternate | Tertiary |          | READINESS                                  | QTY |                               |                                   |
|                                                                                             |         |                                                                                         |               |                   | Daily                       | Daily                           |                                 |           |           |          |          |                                            |     |                               |                                   |
| B2464                                                                                       | B24647B | TRACTOR, FT, W/MULTIPURPOSE BUCKET                                                      | 12            |                   | 18                          | 12                              | 52                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 173                           | 115                               |
| B2483                                                                                       | B24837B | LOADER, BACKHOE (BHL) MODEL 420D                                                        | 4             |                   | 18                          | 12                              | 33.8                            | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 58                            | 38                                |
| C0035                                                                                       | C00357B | ENHANCED HEATING SYSTEM                                                                 | 1.49          | N/A               | 24                          | 24                              | 14                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 57                            | 57                                |
| C7909                                                                                       | C79092B | SHOP EQUIPMENT, GENERAL PURPOSE (COMMON #32)<br>MODEL USMC23-1100                       | 1.03          | N/A               | 24                          | 24                              | 10                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 20                            | 20                                |
| D0005                                                                                       | D00057K | MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR) ARMOR<br>SYSTEM (MAS), AMK27/AMK27A1         | 13.3          | 3.85              | 18                          | 12                              | 78                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 383                           | 255                               |
| D0009                                                                                       | D00097K | MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR),<br>TRACTOR, MK31/AMK31                      | 13.3          | 4.5               | 18                          | 12                              | 80                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 383                           | 255                               |
| D0022                                                                                       | D00227K | TRUCK, UTILITY, EXPANDED CAPACITY, ENHANCED, M1152                                      | 5.85          | 10.26             | 18                          | 12                              | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 168                           | 112                               |
| D0031                                                                                       | D00317K | TRUCK, UTILITY, COMMAND AND CONTROL/GENERAL<br>PURPOSE VEHICLE, M1165                   | 5.85          | 10.26             | 18                          | 12                              | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 84                            | 56                                |
| D0032                                                                                       | D00327K | TRUCK, UTIL, ECV, TOW CARRIER, ARMORED                                                  | 4.3           | 14                | 18                          | 12                              | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 62                            | 41                                |
| D0036                                                                                       | D00367K | MINE RESISTANT AMBUSH PROTECTED, ALL TERRAIN<br>VEHICLE (M-ATV)                         | 6             | 6.6               | 18                          | 12                              | 40                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 86                            | 58                                |
| D0053                                                                                       | D00537K | TRUCK, TRACTOR, ARMORED, 10X10, LOGISTICS VEHICLE<br>SYSTEM REPLACEMENT (LSVR), AMKR16  | 20            | 2.31              | 18                          | 12                              | 166                             | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 576                           | 384                               |
| D0198                                                                                       | D01987K | MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR),<br>MK23/MK25, MK23A1/MK25A1                 | 13.3          | 3.85              | 18                          | 12                              | 78                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 383                           | 255                               |
| D0211                                                                                       | D02117K | FLATRACK REFUELER, 2500 GAL                                                             | 2             |                   | 10                          | 8                               | 7                               | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 16                            | 13                                |
| D1001                                                                                       | D10017K | TRUCK, AMBUL, 4-LTR, ARMD,<br>2 1/4T, HMMWV M997A2                                      | 4.3           | 14                | 12                          | 8                               | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 41                            | 28                                |
| D1063                                                                                       | D10637K | TRUCK, CARGO, RE-SUPPLY F/HIGH MOBILITY ARTILLERY<br>ROCKET SYSTEM (HIMARS), MK37       | 13.3          | 4.5               | 18                          | 12                              | 80                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 192                           | 128                               |
| D1073                                                                                       | D10737K | TRUCK, DUMP, 7T, W/WINCH (MTVR) MK29                                                    | 13.3          | 4.5               | 18                          | 12                              | 78                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 192                           | 128                               |
| D1158                                                                                       | D11587K | TRUCK, UTILITY, CARGO/TROOP, M998                                                       | 4.3           | 14                | 18                          | 12                              | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 62                            | 41                                |
| D1162                                                                                       | D11627K | INTERNALLY TRANSPORTABLE VEHICLE, PRIME MOVER<br>(ITV-PM)                               | 2.3           | 19.41             | 18                          | 12                              | 17                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 1   | 33                            | 22                                |
| E0067                                                                                       | E00677B | ELECTRO OPTICAL MAINTENANCE SHELTER COMPLEX                                             | 5.06          | N/A               | 24.00                       | 24.00                           | 43                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 194                           | 194                               |
| E0942                                                                                       | E09427M | LAV, ANTI-TANK (LAV-ATA1)                                                               | 11.01         | 5.63              | 18.00                       | 12.00                           | 71                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 317                           | 211                               |
| E0948                                                                                       | E09487B | LAV, LOGISTICS (LAV-LA1)                                                                | 11.01         | 5.63              | 18.00                       | 12.00                           | 71                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 317                           | 211                               |
| E0949                                                                                       | E09497M | LAV, MORTAR (LAV-MA1)                                                                   | 11.01         | 5.63              | 18.00                       | 12.00                           | 71                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 317                           | 211                               |
| E1500                                                                                       | E15007M | ROCKET SYSTEM, ARTY, HIGH MOB (HIMARS) (M142)                                           | 5.1           | NO data available | 24.00                       | 24.00                           | 58                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 196                           | 196                               |
| E1839                                                                                       | E18397M | GUIDED MISSILE BATTERY CONTROL CENTRAL, VEHICLE<br>MOUNTED, AN/TWQ-2 (ADVANCED MANPADS) | 5.85          | 10.26             | 24.00                       | 24.00                           | 25                              | F-24      | JP-5/8    | Diesel   |          | 80%                                        | 2   | 225                           | 225                               |
|                                                                                             |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          | Company + Demand                           |     | 6,281                         | 4,736                             |
|                                                                                             |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          | Aviation Squadron Demand                   |     | 62,763                        | 40,436                            |
|                                                                                             |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          | Total with Company+, Aviation & 4 Platoons |     | 78,952                        | 52,348                            |
|                                                                                             |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          | Total with Company+ & Aviation Support     |     | 69,045                        | 45,172                            |
|                                                                                             |         |                                                                                         |               |                   |                             |                                 |                                 |           |           |          |          |                                            |     | SURGE                         | SUSTAINED                         |

Table 5. TAMCN Fuel Burning Equipment List for EAB Platoons. Adapted from Family of Expeditionary Fuel Systems, HQMC, CD&I (email to authors, 23 March 2023).

| EAB Platoon                                                                       |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           |       |                               |                                   |
|-----------------------------------------------------------------------------------|---------|------------------------------------------------------------------------------|---------------|-------|--------------------------------------|------------------------------------------|---------------------------------|-----------|-----------|----------|-----------------------|-----------|-------|-------------------------------|-----------------------------------|
| USMC Update TAMCN Fuel Burning Equipment List for ICIS Update (10 September 2019) |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           |       |                               |                                   |
| ***Modified to calculate fuel demand for EABO 2045 notional scenario***           |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           |       |                               |                                   |
| 5-Char<br>TAMCN                                                                   | TAMCN   | TAMCN NOMENCLATURE                                                           | Fuel Consumed |       | Operating<br>Hours<br>Surge<br>Daily | Operating<br>Hours<br>Sustained<br>Daily | Fuel<br>Tank<br>Capacity (Gals) | Fuel Type |           |          | Comments              |           |       | SURGE<br>DAILY<br>CONSUMPTION | SUSTAINED<br>DAILY<br>CONSUMPTION |
|                                                                                   |         |                                                                              | GPH           | MPG   |                                      |                                          |                                 | Primary   | Alternate | Tertiary |                       | READINESS | QTY   |                               |                                   |
|                                                                                   |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           |       |                               |                                   |
| A1954                                                                             | A19547G | RADIO TERMINAL SET, AN/MRC-142B                                              | 4.3           | 11    | 24.00                                | 24.00                                    | 25                              | F-24      | JP-8      | Diesel   | 1 X M1123 HMMWV SL-3  | 80%       | 1     | 83                            | 83                                |
| A2179                                                                             | A21797G | RAD TERM DGTL TROPOSCAN AN/TRC-170A(v)5                                      | 5.85          | 10.26 | 24.00                                | 24.00                                    | 25                              | F-24      | JP-5/8    | Diesel   | 1 X M1152 HMMWV SL-3  | 80%       | 1     | 112                           | 112                               |
| A3232                                                                             | A32327G | SECURE MOBILE ANTI-JAM RELIABLE TACTICAL-TERMINAL (SMART-T)                  | 5.85          | 10.26 | 24.00                                | 24.00                                    | 25                              | F-24      | JP-5/8    | Diesel   | 1 X M1152 HMMWV SL-3  | 80%       | 1     | 112                           | 112                               |
| B0730                                                                             | B07307B | GENERATOR SET, 3KW, 60HZ, SKID-MTD (MEP-831A)                                | 0.5           | N/A   | 24.00                                | 24.00                                    | 4                               | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 10                            | 10                                |
| B0980                                                                             | B09807B | GEDNERATOR SET, DIESEL ENGINE, 2 KW, 60 HZ (MEP-531A)                        | 0.3           | N/A   | 24.00                                | 24.00                                    | 1.6                             | F-24      | JP-5/8    | Diesel   |                       | 80%       | 2     | 12                            | 12                                |
| B1135                                                                             | B11357B | REFUELING SYSTEM, EXPEDIENT, HELO                                            | 0.4           | N/A   | 12.00                                | 8.00                                     | 1.3                             | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 4                             | 3                                 |
| B1570                                                                             | B15707B | PUMP ASSEMBLY, EXPEDIENT REFUELER, FUEL DISPENSING                           | 0.52          | N/A   | 12.00                                | 8.00                                     | 1.03                            | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 5                             | 3                                 |
| B1580                                                                             | B15807B | PUMP MODULE, FUEL (SIXCON)                                                   | 0.52          | N/A   | 12.00                                | 8.00                                     | 1.04                            | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 5                             | 3                                 |
| C7110                                                                             | C71107G | TACTICAL IMAGERY PRODUCTION SYSTEM (TIPS03)                                  | 5.2           | N/A   | 24.00                                | 24.00                                    | 46                              | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 100                           | 100                               |
| D0007                                                                             | D00077K | MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR) ARMOR SYSTEM (MAS), AMK29/AMK29A1 | 13.3          | 3.85  | 18.00                                | 12.00                                    | 78                              | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 192                           | 128                               |
| D1161                                                                             | D11617K | INTERNALLY TRANSPORTABLE VEHICLE, LIGHT STRIKE VARIANT (ITV-LSV)             | 3.3           | 13.64 | 18.00                                | 12.00                                    | 22.2                            | F-24      | JP-5/8    | Diesel   |                       | 80%       | 1     | 48                            | 32                                |
| D0045                                                                             | D0045   | JOINT LIGHT TACTICAL VEHICLE (JLTV)                                          | 8.13          | 8     | 18.00                                | 12.00                                    | 40                              | F-24      | JP-5/8    | Diesel   | Recently fielded item | 80%       | 1     | 117                           | 78                                |
| E0856                                                                             | E08567K | ASSAULT AMPHIBIOUS VEHICLE, RECOVERY (AAVR7A1)                               | 21.38         | 1.17  | 12.00                                | 8.00                                     | 171                             | F-24      | JP-5/8    | Diesel   |                       | 80%       | 2     | 410                           | 274                               |
| E0948                                                                             | E09487B | LAV, LOGISTICS (LAV-LA1)                                                     | 11.01         | 5.63  | 18.00                                | 12.00                                    | 71                              | F-24      | JP-5/8    | Diesel   |                       | 80%       | 8     | 1,268                         | 846                               |
|                                                                                   |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           | Total | 2,477                         | 1,794                             |
|                                                                                   |         |                                                                              |               |       |                                      |                                          |                                 |           |           |          |                       |           |       | SURGE                         | SUSTAINED                         |

Table 6. Aircraft Squadron Fuel Consumption. Adapted from Family of Expeditionary Fuel Systems, HQMC, CD&I (email to authors, 23 March 2023).

| Aircraft Squadron Fuel Consumption                                      |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|-------------------------------------------------------------------------|----------------|------------------|-------------------------------|---------------|-------------------|----------------|--------------------------------|--------------------------------|--------------------------|-----------|---------------|-----------------|--------------------------|-----------------------------------|
| ***Modified to calculate fuel demand for EABO 2045 notional scenario*** |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
| SQUADRON<br>TYPE                                                        | AIRCRAFT NAME  | AIRCRAFT<br>TYPE | FUEL<br>CONSUMPTIO<br>N (GPH) | SORTIE DATA   |                   |                | FLIGHT<br>HRS/DA<br>Y          | SUSTAINED<br>FLIGHT<br>HRS/DAY | QUANTITY PER<br>SQUADRON |           | READINES<br>S | AIRCRAFT<br>QTY | DAILY<br>CONSUMPTIO<br>N | SUSTAINED<br>DAILY<br>CONSUMPTION |
|                                                                         |                |                  |                               | SURGE<br>RATE | SUSTAINED<br>RATE | LENGTH<br>(HR) |                                |                                | ASSUALT                  | SUSTAINED |               |                 |                          |                                   |
| HMH                                                                     | Super Stallion | CH-53E/K         | 573.5                         | 3.0           | 2.0               | 3.0            | 9                              | 6                              | 16                       | 12        | 70%           | 8               | 28,904                   | 19,270                            |
| VMM                                                                     | Osprey         | MV-22            | 330                           | 4.0           | 2.5               | 3.0            | 12                             | 7.5                            | 12                       | 10        | 70%           | 4               | 11,088                   | 6,930                             |
| HMLA                                                                    | Huey           | UH-1Y            | 110                           | 4.0           | 2.5               | 3.0            | 12                             | 7.5                            | 9                        | 7         | 70%           | 12              | 11,088                   | 6,930                             |
| HMLA                                                                    | Cobra          | AH-1Z            | 231                           | 4.0           | 2.5               | 1.2            | 4.8                            | 3                              | 18                       | 16        | 70%           | 15              | 11,642                   | 7,277                             |
| VMU                                                                     | Blackjack      | M/RQ-21A         | 0.3                           | 2.0           | 1.5               | 12.0           | 24                             | 18                             | 12                       | 10        | 70%           | 8               | 40                       | 30                                |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | 47            |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                | TOTAL FUEL CONSUMPTION PER DAY |                                |                          |           | GAL           | 62,763          | 40,436                   | GAL                               |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP8)     | 420,513         | 270,923                  | lbs (JP8)                         |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP5)     | 407,960         | 262,836                  | lbs (JP5)                         |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                | WEEKLY FUEL CONSUMPTION        |                                |                          |           | GAL           | 439,342         | 283,054                  | GAL                               |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP8)     | 2,943,590       | 1,896,464                | lbs (JP8)                         |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP5)     | 2,855,722       | 1,839,853                | lbs (JP5)                         |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                | MONTHLY FUEL CONSUMPTION       |                                |                          |           | GAL           | 1,882,894       | 1,213,090                | GAL                               |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP8)     | 12,615,387      | 8,127,704                | lbs (JP8)                         |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           |               |                 |                          |                                   |
|                                                                         |                |                  |                               |               |                   |                |                                |                                |                          |           | lbs (JP5)     | 12,238,808      | 7,885,086                | lbs (JP5)                         |

APPENDIX B. RASP SCENARIO OUTPUT

Table 7. West CONSOL—Sustained and Surge

| RASP   Scenario Dashboard CONSOL West - Sustained & Surge |            |              |                  |                 |                 |                 |                    |               |                     |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
|-----------------------------------------------------------|------------|--------------|------------------|-----------------|-----------------|-----------------|--------------------|---------------|---------------------|----------------|-------------|------------|-----------|-----------|-------------------|---------------|------------------|------------------|-------------------------|----------------|-----------------|
| SOLVE INFO                                                |            |              | INPUT SETS       |                 |                 |                 |                    |               | SCENARIO SUMMARY    |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| Solver Generated                                          |            |              | Combatant Assets | Provider Assets | Provider Assets | Provider Assets | Logistics Services | Control Panel | Performance Metrics |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| CoA Index                                                 | Solve Time | Solve Status | DEMAND MODE      | LSM AVAIL       | PSV AVAIL       | LL AVAIL        | SUPPLY LOC         | SOLVE DAYS    | Capacity Days       | Fronthaul Days | Planned RAS | Below Time | Below Avg | Below Max | Below Max Ammount | Provider LOAD | Provider UW Days | Provider Max Cap | Estimated Provider Fuel | Optimality Gap | Objective Value |
| 1                                                         | 00:10:09   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 78.2%            | 100.0%           | 1,449,157               | 0.0%           | -6,351          |
| 2                                                         | 00:10:08   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 85.7%            | 100.0%           | 1,437,030               | 0.0%           | -6,216          |
| 3                                                         | 00:10:09   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 94.7%            | 100.0%           | 1,424,902               | 0.0%           | -6,081          |
| 4                                                         | 00:10:09   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 78.2%            | 100.0%           | 1,449,157               | 0.0%           | -5,668          |
| 5                                                         | 00:10:09   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 85.7%            | 100.0%           | 1,437,030               | 0.0%           | -5,533          |
| 6                                                         | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 94.7%            | 100.0%           | 1,424,902               | 0.0%           | -5,398          |
| 7                                                         | 00:05:41   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 76.4%            | 100.0%           | 1,195,277               | 0.0%           | -5,037          |
| 8                                                         | 00:07:52   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 84.4%            | 100.0%           | 1,183,149               | 0.0%           | -4,902          |
| 9                                                         | 00:10:09   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 94.2%            | 100.0%           | 1,171,022               | 0.6%           | -4,767          |
| 10                                                        | 00:10:09   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 77.9%            | 100.0%           | 951,551                 | 0.5%           | -5,132          |
| 11                                                        | 00:03:06   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 86.7%            | 100.0%           | 939,424                 | 0.0%           | -4,998          |
| 12                                                        | 00:02:32   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 80.7                | 30.6           | 19          | 22%        | 23%       | 56%       | -16%              | 1             | 93.4%            | 100.0%           | 927,081                 | 0.0%           | -8,764          |
| 13                                                        | 00:03:43   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 7             | 79.6%            | 100.0%           | 707,831                 | 0.0%           | -5,228          |
| 14                                                        | 00:06:04   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 80.7                | 30.6           | 18          | 22%        | 23%       | 56%       | -16%              | 4             | 85.0%            | 100.0%           | 695,489                 | 0.0%           | -8,995          |
| 15                                                        | 00:00:11   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 80.7                | 30.6           | 20          | 47%        | 32%       | 89%       | -49%              | 1             | 92.8%            | 100.0%           | 683,566                 | 0.0%           | -21,773         |
| 16                                                        | 00:10:11   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 51.7                | 30.6           | 40          | 3%         | 9%        | 16%       | 34%               | 9             | 86.4%            | 100.0%           | 1,757,174               | 15.9%          | -9,161          |
| 17                                                        | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 51.7                | 30.6           | 38          | 6%         | 20%       | 45%       | 5%                | 6             | 92.0%            | 100.0%           | 1,714,070               | 15.8%          | -9,180          |
| 18                                                        | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 51.7                | 30.6           | 33          | 16%        | 22%       | 45%       | 5%                | 2             | 97.5%            | 100.0%           | 1,732,408               | 17.2%          | -9,651          |
| 19                                                        | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 51.7                | 30.6           | 39          | 7%         | 16%       | 45%       | 5%                | 11            | 87.2%            | 100.0%           | 1,523,603               | 18.6%          | -9,126          |
| 20                                                        | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 51.7                | 30.6           | 38          | 11%        | 17%       | 45%       | 5%                | 8             | 93.0%            | 100.0%           | 1,511,476               | 18.2%          | -9,127          |
| 21                                                        | 00:10:08   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 51.7                | 30.6           | 30          | 22%        | 22%       | 45%       | 5%                | 2             | 97.3%            | 100.0%           | 1,498,837               | 20.4%          | -9,828          |
| 22                                                        | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 51.7                | 30.6           | 39          | 6%         | 16%       | 45%       | 5%                | 10            | 88.1%            | 100.0%           | 1,260,085               | 14.7%          | -8,778          |
| 23                                                        | 00:10:09   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 51.7                | 30.6           | 36          | 10%        | 21%       | 45%       | 5%                | 9             | 93.4%            | 100.0%           | 1,247,446               | 15.2%          | -8,688          |
| 24                                                        | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 51.7                | 30.6           | 26          | 30%        | 22%       | 45%       | 5%                | 2             | 98.6%            | 100.0%           | 1,248,461               | 16.8%          | -9,804          |
| 25                                                        | 00:10:08   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 51.7                | 30.6           | 39          | 5%         | 18%       | 45%       | 5%                | 12            | 89.0%            | 100.0%           | 1,026,003               | 13.7%          | -8,642          |
| 26                                                        | 00:10:08   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 51.7                | 30.6           | 33          | 17%        | 22%       | 45%       | 5%                | 11            | 92.7%            | 100.0%           | 1,013,876               | 11.0%          | -8,548          |
| 27                                                        | 00:06:10   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 51.7                | 30.6           | 22          | 38%        | 23%       | 45%       | 5%                | 2             | 96.7%            | 100.0%           | 970,514                 | 0.0%           | -10,869         |
| 28                                                        | 00:10:08   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 2 LL            | W                  | 30            | 51.7                | 30.6           | 37          | 9%         | 20%       | 45%       | 5%                | 13            | 88.7%            | 100.0%           | 761,973                 | 7.6%           | -8,459          |
| 29                                                        | 00:10:08   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 1 LL            | W                  | 30            | 51.7                | 30.6           | 29          | 25%        | 23%       | 45%       | 5%                | 11            | 92.2%            | 100.0%           | 749,717                 | 6.9%           | -8,825          |
| 30                                                        | 00:00:17   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 0 LL            | W                  | 30            | 51.7                | 30.6           | 25          | 60%        | 63%       | 183%      | -133%             | 2             | 96.3%            | 100.0%           | 736,943                 | 0.0%           | -67,737         |

Table 8. South CONSOL—Sustained and Surge

| RASP   Scenario Dashboard CONSOL South - Sustained & Surge |            |              |                  |                 |                 |                 |                    |               |                     |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
|------------------------------------------------------------|------------|--------------|------------------|-----------------|-----------------|-----------------|--------------------|---------------|---------------------|----------------|-------------|------------|-----------|-----------|-------------------|---------------|------------------|------------------|-------------------------|----------------|-----------------|
| SOLVE INFO                                                 |            |              | INPUT SETS       |                 |                 |                 |                    |               | SCENARIO SUMMARY    |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| Solver Generated                                           |            |              | Combatant Assets | Provider Assets | Provider Assets | Provider Assets | Logistics Services | Control Panel | Performance Metrics |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| CoA Index                                                  | Solve Time | Solve Status | DEMAND MODE      | LSM AVAIL       | PSV AVAIL       | LL AVAIL        | SUPPLY LOC         | SOLVE DAYS    | Capacity Days       | Fronthaul Days | Planned RAS | Below Time | Below Avg | Below Max | Below Max Ammount | Provider LOAD | Provider UW Days | Provider Max Cap | Estimated Provider Fuel | Optimality Gap | Objective Value |
| 1                                                          | 00:10:08   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 79.1%            | 100.0%           | 1,461,427               | 0.0%           | -6,378          |
| 2                                                          | 00:10:09   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 86.6%            | 100.0%           | 1,449,300               | 0.0%           | -6,243          |
| 3                                                          | 00:10:09   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 95.8%            | 100.0%           | 1,437,172               | 0.0%           | -6,108          |
| 4                                                          | 00:10:12   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 79.1%            | 100.0%           | 1,461,427               | 0.0%           | -5,695          |
| 5                                                          | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 86.6%            | 100.0%           | 1,449,300               | 0.0%           | -5,560          |
| 6                                                          | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 95.8%            | 100.0%           | 1,437,172               | 0.0%           | -5,425          |
| 7                                                          | 00:06:47   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 77.4%            | 100.0%           | 1,207,547               | 0.0%           | -5,064          |
| 8                                                          | 00:08:36   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 85.4%            | 100.0%           | 1,195,419               | 0.0%           | -4,929          |
| 9                                                          | 00:05:51   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 95.4%            | 100.0%           | 1,183,292               | 0.0%           | -4,794          |
| 10                                                         | 00:10:08   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 78.9%            | 100.0%           | 963,821                 | 0.2%           | -5,160          |
| 11                                                         | 00:02:28   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 87.9%            | 100.0%           | 951,694                 | 0.0%           | -5,026          |
| 12                                                         | 00:01:28   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 19          | 22%        | 23%       | 56%       | -16%              | 1             | 94.8%            | 100.0%           | 939,351                 | 0.0%           | -8,791          |
| 13                                                         | 00:02:20   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 7             | 80.7%            | 100.0%           | 720,101                 | 0.0%           | -5,255          |
| 14                                                         | 00:06:08   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 18          | 22%        | 23%       | 56%       | -16%              | 4             | 86.3%            | 100.0%           | 707,759                 | 0.0%           | -9,022          |
| 15                                                         | 00:00:14   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 20          | 47%        | 32%       | 89%       | -49%              | 1             | 94.3%            | 100.0%           | 695,836                 | 0.0%           | -21,800         |
| 16                                                         | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 40          | 1%         | 10%       | 16%       | 34%               | 9             | 87.6%            | 100.0%           | 1,773,017               | 15.4%          | -9,111          |
| 17                                                         | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 39          | 6%         | 16%       | 45%       | 5%                | 5             | 93.0%            | 100.0%           | 1,760,895               | 12.8%          | -9,034          |
| 18                                                         | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 33          | 18%        | 22%       | 45%       | 5%                | 2             | 98.8%            | 100.0%           | 1,748,768               | 15.0%          | -9,801          |
| 19                                                         | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 40          | 3%         | 13%       | 16%       | 34%               | 9             | 88.4%            | 100.0%           | 1,509,498               | 14.5%          | -8,833          |
| 20                                                         | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 37          | 9%         | 20%       | 45%       | 5%                | 5             | 93.5%            | 100.0%           | 1,527,836               | 13.9%          | -8,844          |
| 21                                                         | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 31          | 20%        | 22%       | 45%       | 5%                | 2             | 98.7%            | 100.0%           | 1,515,197               | 12.4%          | -9,647          |
| 22                                                         | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 40          | 6%         | 9%        | 16%       | 34%               | 9             | 89.4%            | 100.0%           | 1,306,398               | 12.9%          | -8,671          |
| 23                                                         | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 36          | 11%        | 21%       | 45%       | 5%                | 9             | 94.8%            | 100.0%           | 1,263,295               | 13.8%          | -8,714          |
| 24                                                         | 00:10:11   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 27          | 29%        | 23%       | 45%       | 5%                | 2             | 98.6%            | 100.0%           | 1,251,038               | 14.5%          | -9,708          |
| 25                                                         | 00:10:09   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 38          | 7%         | 18%       | 45%       | 5%                | 11            | 89.8%            | 100.0%           | 1,041,852               | 11.2%          | -8,456          |
| 26                                                         | 00:10:11   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 32          | 17%        | 23%       | 45%       | 5%                | 11            | 94.2%            | 100.0%           | 1,030,236               | 11.3%          | -8,647          |
| 27                                                         | 00:03:38   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 22          | 38%        | 23%       | 45%       | 5%                | 2             | 98.4%            | 100.0%           | 986,874                 | 0.0%           | -10,906         |
| 28                                                         | 00:10:08   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 2 LL            | S                  | 30            | 80.7                | 30.6           | 35          | 11%        | 23%       | 45%       | 5%                | 15            | 90.1%            | 100.0%           | 777,822                 | 7.4%           | -8,477          |
| 29                                                         | 00:10:09   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 1 LL            | S                  | 30            | 80.7                | 30.6           | 29          | 23%        | 23%       | 45%       | 5%                | 11            | 93.9%            | 100.0%           | 765,565                 | 7.0%           | -8,861          |
| 30                                                         | 00:00:16   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 0 LL            | S                  | 30            | 80.7                | 30.6           | 25          | 60%        | 63%       | 183%      | -133%             | 2             | 98.2%            | 100.0%           | 753,303                 | 0.0%           | -67,774         |

Table 9. East CONSOL—Sustained and Surge One PSV

| RASP   Scenario Dashboard CONSOL East - Sustained & Surge (1 PSV) |            |              |                  |                 |                 |                 |                    |               |                     |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
|-------------------------------------------------------------------|------------|--------------|------------------|-----------------|-----------------|-----------------|--------------------|---------------|---------------------|----------------|-------------|------------|-----------|-----------|-------------------|---------------|------------------|------------------|-------------------------|----------------|-----------------|
| SOLVE INFO                                                        |            |              | INPUT SETS       |                 |                 |                 |                    |               | SCENARIO SUMMARY    |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| Solver Generated                                                  |            |              | Combatant Assets | Provider Assets | Provider Assets | Provider Assets | Logistics Services | Control Panel | Performance Metrics |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| CoA Index                                                         | Solve Time | Solve Status | DEMAND MODE      | LSM AVAIL       | PSV AVAIL       | LL AVAIL        | SUPPLY LOC         | SOLVE DAYS    | Capacity Days       | Fronthaul Days | Planned RAS | Below Time | Below Avg | Below Max | Below Max Ammount | Provider LOAD | Provider UW Days | Provider Max Cap | Estimated Provider Fuel | Optimality Gap | Objective Value |
| 1                                                                 | 00:10:08   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 3%         | 10%       | 12%       | 28%               | 10            | 85.6%            | 100.0%           | 1,614,364               | 18.8%          | -8,684          |
| 2                                                                 | 00:10:08   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 6%         | 14%       | 23%       | 17%               | 9             | 93.2%            | 100.0%           | 1,724,102               | 19.6%          | -8,758          |
| 3                                                                 | 00:10:08   | SOLVED       | SUSTAIN          | 6 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 11%        | 16%       | 30%       | 10%               | 1             | 97.0%            | 100.0%           | 1,590,114               | 19.9%          | -11,410         |
| 4                                                                 | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 3%         | 8%        | 12%       | 28%               | 11            | 85.5%            | 100.0%           | 1,421,419               | 20.3%          | -8,106          |
| 5                                                                 | 00:10:11   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 7%         | 15%       | 23%       | 17%               | 10            | 93.8%            | 100.0%           | 1,286,604               | 26.3%          | -8,751          |
| 6                                                                 | 00:10:09   | SOLVED       | SUSTAIN          | 5 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 21          | 16%        | 18%       | 56%       | -16%              | 1             | 96.8%            | 100.0%           | 1,397,169               | 27.4%          | -11,642         |
| 7                                                                 | 00:10:09   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 3%         | 10%       | 12%       | 28%               | 12            | 85.1%            | 100.0%           | 1,253,372               | 23.4%          | -7,533          |
| 8                                                                 | 00:10:10   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 7%         | 15%       | 23%       | 17%               | 9             | 92.8%            | 100.0%           | 1,190,469               | 26.1%          | -8,145          |
| 9                                                                 | 00:10:08   | SOLVED       | SUSTAIN          | 4 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 19          | 21%        | 21%       | 56%       | -16%              | 1             | 96.6%            | 100.0%           | 1,204,224               | 31.0%          | -12,006         |
| 10                                                                | 00:10:09   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 2%         | 8%        | 12%       | 28%               | 14            | 85.4%            | 100.0%           | 937,478                 | 22.8%          | -7,395          |
| 11                                                                | 00:10:09   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 21          | 15%        | 20%       | 56%       | -16%              | 9             | 92.0%            | 100.0%           | 972,626                 | 33.3%          | -9,080          |
| 12                                                                | 00:10:08   | SOLVED       | SUSTAIN          | 3 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 18          | 33%        | 22%       | 56%       | -16%              | 1             | 96.1%            | 100.0%           | 960,284                 | 29.5%          | -17,239         |
| 13                                                                | 00:10:09   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 7%         | 20%       | 56%       | -16%              | 17            | 86.4%            | 100.0%           | 743,543                 | 26.4%          | -8,432          |
| 14                                                                | 00:10:09   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 19          | 32%        | 22%       | 56%       | -16%              | 9             | 89.6%            | 100.0%           | 681,625                 | 24.3%          | -13,446         |
| 15                                                                | 00:00:16   | SOLVED       | SUSTAIN          | 2 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 20          | 51%        | 31%       | 89%       | -49%              | 1             | 94.1%            | 100.0%           | 669,492                 | 0.0%           | -30,327         |
| 16                                                                | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 37          | 18%        | 22%       | 45%       | 5%                | 19            | 92.6%            | 100.0%           | 1,728,887               | 39.9%          | -23,946         |
| 17                                                                | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 33          | 30%        | 23%       | 56%       | -6%               | 12            | 95.5%            | 100.0%           | 1,691,862               | 38.9%          | -36,198         |
| 18                                                                | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 28          | 37%        | 32%       | 93%       | -43%              | 1             | 97.7%            | 100.0%           | 1,471,493               | 23.1%          | -91,731         |
| 19                                                                | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 36          | 23%        | 21%       | 45%       | 5%                | 19            | 91.6%            | 100.0%           | 1,525,782               | 38.9%          | -22,742         |
| 20                                                                | 00:10:10   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 30          | 34%        | 23%       | 56%       | -6%               | 12            | 95.1%            | 100.0%           | 1,397,367               | 36.5%          | -35,744         |
| 21                                                                | 00:10:18   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 26          | 41%        | 31%       | 93%       | -43%              | 1             | 97.6%            | 100.0%           | 1,359,783               | 21.0%          | -91,416         |
| 22                                                                | 00:10:09   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 33          | 30%        | 22%       | 45%       | 5%                | 21            | 92.1%            | 100.0%           | 1,261,746               | 32.3%          | -21,811         |
| 23                                                                | 00:10:09   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 30          | 35%        | 23%       | 57%       | -7%               | 12            | 95.8%            | 100.0%           | 1,224,168               | 36.1%          | -36,583         |
| 24                                                                | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 24          | 45%        | 31%       | 93%       | -43%              | 1             | 97.5%            | 100.0%           | 1,217,613               | 19.3%          | -91,117         |
| 25                                                                | 00:10:09   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 29          | 33%        | 23%       | 45%       | 5%                | 21            | 91.8%            | 100.0%           | 1,028,181               | 28.7%          | -21,779         |
| 26                                                                | 00:10:09   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 25          | 43%        | 23%       | 58%       | -8%               | 12            | 94.9%            | 100.0%           | 960,004                 | 22.4%          | -36,724         |
| 27                                                                | 00:10:08   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 21          | 53%        | 29%       | 93%       | -43%              | 1             | 97.2%            | 100.0%           | 953,449                 | 0.9%           | -93,200         |
| 28                                                                | 00:10:09   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 28          | 31%        | 23%       | 45%       | 5%                | 23            | 92.3%            | 100.0%           | 763,588                 | 25.4%          | -21,584         |
| 29                                                                | 00:10:09   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 24          | 40%        | 24%       | 72%       | -22%              | 11            | 95.8%            | 100.0%           | 727,002                 | 29.5%          | -41,833         |
| 30                                                                | 00:01:50   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 22          | 66%        | 70%       | 236%      | -186%             | 1             | 96.7%            | 100.0%           | 689,150                 | 0.0%           | -141,780        |

Table 10. East CONSOL—Sustained and Surge Two PSV

| RASP   Scenario Dashboard CONSOL East - Sustained & Surge (2 PSVs) |            |              |                  |                 |                 |                 |                    |               |                     |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
|--------------------------------------------------------------------|------------|--------------|------------------|-----------------|-----------------|-----------------|--------------------|---------------|---------------------|----------------|-------------|------------|-----------|-----------|-------------------|---------------|------------------|------------------|-------------------------|----------------|-----------------|
| SOLVE INFO                                                         |            |              | INPUT SETS       |                 |                 |                 |                    |               | SCENARIO SUMMARY    |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| Solver Generated                                                   |            |              | Combatant Assets | Provider Assets | Provider Assets | Provider Assets | Logistics Services | Control Panel | Performance Metrics |                |             |            |           |           |                   |               |                  |                  |                         |                |                 |
| CoA Index                                                          | Solve Time | Solve Status | DEMAND MODE      | LSM AVAIL       | PSV AVAIL       | LL AVAIL        | SUPPLY LOC         | SOLVE DAYS    | Capacity Days       | Fronthaul Days | Planned RAS | Below Time | Below Avg | Below Max | Below Max Ammount | Provider LOAD | Provider UW Days | Provider Max Cap | Estimated Provider Fuel | Optimality Gap | Objective Value |
| 1                                                                  | 00:10:10   | SOLVED       | SUSTAIN          | 6 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 73.6%            | 100.0%           | 1,603,635               | 0.0%           | -6,770          |
| 2                                                                  | 00:10:11   | SOLVED       | SUSTAIN          | 6 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 80.0%            | 100.0%           | 1,591,507               | 0.1%           | -6,635          |
| 3                                                                  | 00:10:11   | SOLVED       | SUSTAIN          | 6 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 87.6%            | 100.0%           | 1,579,380               | 0.0%           | -6,500          |
| 4                                                                  | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 73.6%            | 100.0%           | 1,603,635               | 0.0%           | -6,087          |
| 5                                                                  | 00:10:08   | SOLVED       | SUSTAIN          | 5 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 80.0%            | 100.0%           | 1,591,507               | 0.0%           | -5,952          |
| 6                                                                  | 00:10:09   | SOLVED       | SUSTAIN          | 5 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 87.6%            | 100.0%           | 1,579,380               | 0.0%           | -5,817          |
| 7                                                                  | 00:09:52   | SOLVED       | SUSTAIN          | 4 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 71.6%            | 100.0%           | 1,349,754               | 0.0%           | -5,456          |
| 8                                                                  | 00:07:44   | SOLVED       | SUSTAIN          | 4 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 78.4%            | 100.0%           | 1,337,627               | 0.0%           | -5,321          |
| 9                                                                  | 00:08:35   | SOLVED       | SUSTAIN          | 4 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 1             | 86.5%            | 100.0%           | 1,325,499               | 0.0%           | -5,186          |
| 10                                                                 | 00:06:46   | SOLVED       | SUSTAIN          | 3 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 72.6%            | 100.0%           | 1,106,029               | 0.0%           | -5,552          |
| 11                                                                 | 00:01:09   | SOLVED       | SUSTAIN          | 3 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 4             | 80.0%            | 100.0%           | 1,093,901               | 0.0%           | -5,418          |
| 12                                                                 | 00:02:13   | SOLVED       | SUSTAIN          | 3 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 19          | 22%        | 23%       | 56%       | -16%              | 1             | 84.9%            | 100.0%           | 1,081,559               | 0.0%           | -9,183          |
| 13                                                                 | 00:01:12   | SOLVED       | SUSTAIN          | 2 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 80.7                | 30.6           | 22          | 0%         | 0%        | 0%        | 0%                | 7             | 73.6%            | 100.0%           | 862,873                 | 0.0%           | -5,648          |
| 14                                                                 | 00:01:30   | SOLVED       | SUSTAIN          | 2 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 80.7                | 30.6           | 18          | 22%        | 23%       | 56%       | -16%              | 4             | 77.7%            | 100.0%           | 850,530                 | 0.0%           | -9,414          |
| 15                                                                 | 00:00:14   | SOLVED       | SUSTAIN          | 2 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 80.7                | 30.6           | 20          | 47%        | 32%       | 89%       | -49%              | 1             | 83.7%            | 100.0%           | 838,043                 | 0.0%           | -22,192         |
| 16                                                                 | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 39          | 6%         | 17%       | 45%       | 5%                | 6             | 81.6%            | 100.0%           | 1,905,402               | 16.8%          | -9,708          |
| 17                                                                 | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 38          | 7%         | 18%       | 45%       | 5%                | 6             | 89.0%            | 100.0%           | 1,906,695               | 14.8%          | -9,344          |
| 18                                                                 | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 35          | 13%        | 21%       | 45%       | 5%                | 2             | 91.6%            | 100.0%           | 1,897,953               | 17.1%          | -9,802          |
| 19                                                                 | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 39          | 7%         | 14%       | 45%       | 5%                | 9             | 83.7%            | 100.0%           | 1,659,232               | 18.8%          | -9,424          |
| 20                                                                 | 00:10:08   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 37          | 9%         | 21%       | 45%       | 5%                | 7             | 86.8%            | 100.0%           | 1,677,073               | 15.7%          | -9,181          |
| 21                                                                 | 00:10:10   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 29          | 25%        | 23%       | 45%       | 5%                | 2             | 91.0%            | 100.0%           | 1,664,382               | 22.0%          | -10,164         |
| 22                                                                 | 00:10:09   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 38          | 8%         | 19%       | 45%       | 5%                | 9             | 82.0%            | 100.0%           | 1,424,607               | 13.7%          | -9,223          |
| 23                                                                 | 00:10:09   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 36          | 12%        | 20%       | 45%       | 5%                | 7             | 88.9%            | 100.0%           | 1,413,539               | 14.3%          | -9,170          |
| 24                                                                 | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 28          | 27%        | 22%       | 45%       | 5%                | 2             | 92.5%            | 100.0%           | 1,401,412               | 19.1%          | -10,064         |
| 25                                                                 | 00:10:09   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 35          | 11%        | 22%       | 45%       | 5%                | 9             | 82.4%            | 100.0%           | 1,161,631               | 7.7%           | -8,776          |
| 26                                                                 | 00:10:08   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 31          | 21%        | 22%       | 45%       | 5%                | 10            | 86.2%            | 100.0%           | 1,148,879               | 14.4%          | -9,515          |
| 27                                                                 | 00:03:43   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 22          | 37%        | 23%       | 45%       | 5%                | 2             | 91.4%            | 100.0%           | 1,106,653               | 0.0%           | -10,680         |
| 28                                                                 | 00:10:09   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6           | 35          | 15%        | 21%       | 45%       | 5%                | 12            | 82.9%            | 100.0%           | 927,571                 | 8.0%           | -9,514          |
| 29                                                                 | 00:10:09   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6           | 25          | 31%        | 23%       | 45%       | 5%                | 10            | 87.5%            | 100.0%           | 885,909                 | 4.4%           | -9,488          |
| 30                                                                 | 00:00:29   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6           | 25          | 60%        | 63%       | 183%      | -133%             | 2             | 90.6%            | 100.0%           | 873,083                 | 0.0%           | -67,173         |

Table 11. West CONSOL—Surge Prepositioned Assets

| RASP   Scenario Dashboard CONSOL West - Surge - Prepositioned Assets |               |                 |                         |                    |                    |                    |                       |                  |                     |                   |                |               |              |              |                         |                  |                    |                     |                               |                       |                    |
|----------------------------------------------------------------------|---------------|-----------------|-------------------------|--------------------|--------------------|--------------------|-----------------------|------------------|---------------------|-------------------|----------------|---------------|--------------|--------------|-------------------------|------------------|--------------------|---------------------|-------------------------------|-----------------------|--------------------|
| Solve Info                                                           |               |                 | Input Sets              |                    |                    |                    |                       |                  | Scenario Summary    |                   |                |               |              |              |                         |                  |                    |                     |                               |                       |                    |
| Solver Generated                                                     |               |                 | Combata<br>nt<br>Assets | Provider<br>Assets | Provider<br>Assets | Provider<br>Assets | Logistics<br>Services | Control<br>Panel | Performance Metrics |                   |                |               |              |              |                         |                  |                    |                     |                               |                       |                    |
|                                                                      |               |                 |                         |                    |                    |                    |                       |                  |                     |                   |                |               |              |              |                         |                  |                    |                     |                               |                       |                    |
| CoA<br>Index                                                         | Solve<br>Time | Solve<br>Status | DEMAND<br>MODE          | LSM<br>AVAIL       | PSV<br>AVAIL       | LL<br>AVAIL        | SUPPLY<br>LOC         | SOLVE<br>DAYS    | Capacity<br>Days    | Fronthaul<br>Days | Planned<br>RAS | Below<br>Time | Below<br>Avg | Below<br>Max | Below<br>Max<br>Ammount | Provider<br>LOAD | Provder<br>UW Days | Provider<br>Max Cap | Estimated<br>Provider<br>Fuel | Optimalit<br>y<br>Gap | Objective<br>Value |
| 1                                                                    | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 10               | 89.4%              | 100.0%              | 1,740,880                     | 11.0%                 | -8,244             |
| 2                                                                    | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 3%            | 19%          | 45%          | 5%                      | 9                | 95.4%              | 100.0%              | 1,588,516                     | 10.0%                 | -8,191             |
| 3                                                                    | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 36             | 15%           | 19%          | 45%          | 5%                      | 2                | 98.8%              | 100.0%              | 1,715,597                     | 18.9%                 | -9,116             |
| 4                                                                    | 00:10:07      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 2%            | 6%           | 16%          | 34%                     | 8                | 86.8%              | 100.0%              | 1,523,603                     | 5.0%                  | -7,290             |
| 5                                                                    | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 7%            | 14%          | 45%          | 5%                      | 9                | 94.8%              | 100.0%              | 1,450,546                     | 10.4%                 | -7,745             |
| 6                                                                    | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 33             | 20%           | 23%          | 45%          | 5%                      | 2                | 97.3%              | 100.0%              | 1,498,837                     | 15.1%                 | -8,667             |
| 7                                                                    | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 1%            | 12%          | 16%          | 34%                     | 10               | 88.1%              | 100.0%              | 1,251,679                     | 5.1%                  | -6,796             |
| 8                                                                    | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 11%           | 16%          | 45%          | 5%                      | 9                | 94.4%              | 100.0%              | 1,247,446                     | 9.5%                  | -7,201             |
| 9                                                                    | 00:10:07      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 28             | 30%           | 22%          | 45%          | 5%                      | 2                | 98.2%              | 100.0%              | 1,262,487                     | 12.9%                 | -8,718             |
| 10                                                                   | 00:10:08      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 10               | 88.5%              | 100.0%              | 1,026,003                     | 2.6%                  | -6,219             |
| 11                                                                   | 00:10:08      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 35             | 13%           | 21%          | 45%          | 5%                      | 10               | 93.1%              | 100.0%              | 1,013,876                     | 3.8%                  | -6,848             |
| 12                                                                   | 00:10:07      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 24             | 38%           | 23%          | 47%          | 4%                      | 2                | 98.4%              | 100.0%              | 984,302                       | 10.3%                 | -9,406             |
| 13                                                                   | 00:10:07      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 38             | 5%            | 22%          | 45%          | 5%                      | 12               | 88.7%              | 100.0%              | 761,973                       | 4.2%                  | -6,072             |
| 14                                                                   | 00:10:07      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 29             | 22%           | 23%          | 45%          | 5%                      | 10               | 91.9%              | 100.0%              | 749,717                       | 2.5%                  | -7,121             |
| 15                                                                   | 00:01:22      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 25             | 63%           | 64%          | 231%         | -181%                   | 1                | 98.3%              | 100.0%              | 720,649                       | 0.0%                  | -69,794            |
| 1                                                                    | 00:10:09      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 4                | 78.1%              | 100.0%              | 1,906,257                     | 1.2%                  | -7,758             |
| 2                                                                    | 00:10:08      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                      | 3                | 83.7%              | 100.0%              | 1,894,130                     | 1.1%                  | -7,787             |
| 3                                                                    | 00:10:08      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 38             | 4%            | 23%          | 45%          | 5%                      | 2                | 90.2%              | 100.0%              | 1,881,491                     | 0.5%                  | -7,818             |
| 4                                                                    | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 5                | 78.7%              | 100.0%              | 1,642,222                     | 1.3%                  | -7,313             |
| 5                                                                    | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                      | 5                | 84.7%              | 100.0%              | 1,630,094                     | 1.2%                  | -7,343             |
| 6                                                                    | 00:10:09      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 34             | 12%           | 23%          | 45%          | 5%                      | 2                | 89.5%              | 100.0%              | 1,648,432                     | 4.0%                  | -7,893             |
| 7                                                                    | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 7                | 79.6%              | 100.0%              | 1,408,657                     | 1.1%                  | -6,878             |
| 8                                                                    | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                      | 7                | 86.1%              | 100.0%              | 1,396,529                     | 0.9%                  | -6,908             |
| 9                                                                    | 00:10:07      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 30             | 20%           | 23%          | 45%          | 5%                      | 2                | 88.7%              | 100.0%              | 1,414,356                     | 0.4%                  | -7,962             |
| 10                                                                   | 00:10:07      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                      | 10               | 82.5%              | 100.0%              | 1,187,156                     | 2.0%                  | -6,510             |
| 11                                                                   | 00:04:28      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 35             | 10%           | 23%          | 45%          | 5%                      | 7                | 85.0%              | 100.0%              | 1,163,470                     | 0.5%                  | -6,982             |
| 12                                                                   | 00:05:51      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 25             | 31%           | 23%          | 45%          | 5%                      | 2                | 87.4%              | 100.0%              | 1,150,191                     | 0.0%                  | -8,327             |
| 13                                                                   | 00:10:08      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 2 LL               | W                     | 30               | 51.7                | 30.6              | 38             | 5%            | 22%          | 45%          | 5%                      | 12               | 80.2%              | 100.0%              | 883,248                       | 3.9%                  | -6,414             |
| 14                                                                   | 00:10:07      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 1 LL               | W                     | 30               | 51.7                | 30.6              | 29             | 22%           | 23%          | 45%          | 5%                      | 10               | 83.2%              | 100.0%              | 898,289                       | 3.1%                  | -7,500             |
| 15                                                                   | 00:01:45      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 0 LL               | W                     | 30               | 51.7                | 30.6              | 25             | 61%           | 65%          | 231%         | -181%                   | 2                | 88.7%              | 100.0%              | 899,118                       | 0.0%                  | -69,785            |

Table 12. South CONSOL—Surge Prepositioned Assets

| RASP   Scenario Dashboard CONSOL South - Surge - Prepositioned Assets |               |                 |                         |                    |                    |                    |                       |                  |                     |                   |                |               |              |              |                        |                  |                    |                     |                               |                       |                    |
|-----------------------------------------------------------------------|---------------|-----------------|-------------------------|--------------------|--------------------|--------------------|-----------------------|------------------|---------------------|-------------------|----------------|---------------|--------------|--------------|------------------------|------------------|--------------------|---------------------|-------------------------------|-----------------------|--------------------|
| SOLVE INFO                                                            |               |                 | INPUT SETS              |                    |                    |                    |                       |                  | SCENARIO SUMMARY    |                   |                |               |              |              |                        |                  |                    |                     |                               |                       |                    |
| Solver Generated                                                      |               |                 | Combata<br>nt<br>Assets | Provider<br>Assets | Provider<br>Assets | Provider<br>Assets | Logistics<br>Services | Control<br>Panel | Performance Metrics |                   |                |               |              |              |                        |                  |                    |                     |                               |                       |                    |
| CoA<br>Index                                                          | Solve<br>Time | Solve<br>Status | DEMAND<br>MODE          | LSM<br>AVAIL       | PSV<br>AVAIL       | LL<br>AVAIL        | SUPPLY<br>LOC         | SOLVE<br>DAYS    | Capacity<br>Days    | Fronthaul<br>Days | Planned<br>RAS | Below<br>Time | Below<br>Avg | Below<br>Max | Below<br>Max<br>Amount | Provider<br>LOAD | Provder<br>UW Days | Provider<br>Max Cap | Estimated<br>Provider<br>Fuel | Optimalit<br>y<br>Gap | Objective<br>Value |
| 1                                                                     | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                     | 11               | 88.5%              | 100.0%              | 1,712,604                     | 8.3%                  | -8,087             |
| 2                                                                     | 00:10:08      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 3%            | 19%          | 45%          | 5%                     | 7                | 94.4%              | 100.0%              | 1,760,895                     | 8.3%                  | -8,119             |
| 3                                                                     | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 1 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 37             | 13%           | 21%          | 45%          | 5%                     | 2                | 98.9%              | 100.0%              | 1,749,279                     | 12.9%                 | -8,703             |
| 4                                                                     | 00:10:07      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 1%            | 1%           | 2%           | 48%                    | 11               | 88.1%              | 100.0%              | 1,539,452                     | 5.7%                  | -7,395             |
| 5                                                                     | 00:10:07      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 5%            | 16%          | 45%          | 5%                     | 9                | 95.6%              | 100.0%              | 1,496,860                     | 8.1%                  | -7,616             |
| 6                                                                     | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 1 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 36             | 21%           | 22%          | 45%          | 5%                     | 2                | 98.7%              | 100.0%              | 1,423,791                     | 14.0%                 | -9,007             |
| 7                                                                     | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 1%            | 10%          | 10%          | 40%                    | 11               | 88.7%              | 100.0%              | 1,244,957                     | 3.9%                  | -6,787             |
| 8                                                                     | 00:10:07      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 7%            | 15%          | 45%          | 5%                     | 8                | 95.8%              | 100.0%              | 1,262,087                     | 8.3%                  | -7,158             |
| 9                                                                     | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 1 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 28             | 27%           | 22%          | 45%          | 5%                     | 2                | 98.6%              | 100.0%              | 1,220,444                     | 9.1%                  | -8,603             |
| 10                                                                    | 00:10:07      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 1%            | 8%           | 16%          | 34%                    | 11               | 89.7%              | 100.0%              | 1,041,852                     | 3.2%                  | -6,293             |
| 11                                                                    | 00:10:08      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 35             | 11%           | 22%          | 45%          | 5%                     | 11               | 94.6%              | 100.0%              | 1,029,724                     | 2.6%                  | -6,814             |
| 12                                                                    | 00:10:07      | SOLVED          | SURGE                   | 3 LSM              | 1 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 24             | 38%           | 23%          | 47%          | 4%                     | 2                | 98.5%              | 100.0%              | 1,017,468                     | 1.7%                  | -9,509             |
| 13                                                                    | 00:10:09      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 38             | 4%            | 23%          | 45%          | 5%                     | 12               | 90.2%              | 100.0%              | 777,822                       | 3.5%                  | -6,062             |
| 14                                                                    | 00:10:07      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 29             | 22%           | 23%          | 45%          | 5%                     | 11               | 93.5%              | 100.0%              | 765,565                       | 2.8%                  | -7,158             |
| 15                                                                    | 00:00:57      | SOLVED          | SURGE                   | 2 LSM              | 1 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 25             | 63%           | 64%          | 231%         | -181%                  | 1                | 98.3%              | 100.0%              | 753,815                       | 0.0%                  | -69,902            |
| 1                                                                     | 00:10:08      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                     | 4                | 79.4%              | 100.0%              | 1,926,196                     | 1.2%                  | -7,803             |
| 2                                                                     | 00:10:08      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                     | 3                | 85.0%              | 100.0%              | 1,913,557                     | 1.4%                  | -7,834             |
| 3                                                                     | 00:10:07      | SOLVED          | SURGE                   | 6 LSM              | 2 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 38             | 4%            | 23%          | 45%          | 5%                     | 2                | 91.6%              | 100.0%              | 1,901,430                     | 0.9%                  | -7,862             |
| 4                                                                     | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                     | 5                | 80.1%              | 100.0%              | 1,662,161                     | 1.2%                  | -7,358             |
| 5                                                                     | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                     | 5                | 86.2%              | 100.0%              | 1,650,033                     | 1.0%                  | -7,388             |
| 6                                                                     | 00:10:08      | SOLVED          | SURGE                   | 5 LSM              | 2 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 35             | 12%           | 23%          | 45%          | 5%                     | 2                | 91.0%              | 100.0%              | 1,667,859                     | 0.1%                  | -7,935             |
| 7                                                                     | 00:10:08      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                     | 7                | 81.0%              | 100.0%              | 1,428,084                     | 1.2%                  | -6,923             |
| 8                                                                     | 00:10:09      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 39             | 2%            | 23%          | 45%          | 5%                     | 7                | 87.6%              | 100.0%              | 1,416,468                     | 1.4%                  | -6,953             |
| 9                                                                     | 00:10:07      | SOLVED          | SURGE                   | 4 LSM              | 2 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 30             | 20%           | 23%          | 45%          | 5%                     | 2                | 90.3%              | 100.0%              | 1,434,294                     | 0.1%                  | -8,008             |
| 10                                                                    | 00:10:08      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 40             | 0%            | 0%           | 0%           | 0%                     | 9                | 82.0%              | 100.0%              | 1,195,025                     | 1.0%                  | -6,488             |
| 11                                                                    | 00:10:08      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 35             | 11%           | 22%          | 45%          | 5%                     | 11               | 85.4%              | 100.0%              | 1,150,999                     | 2.7%                  | -7,157             |
| 12                                                                    | 00:01:41      | SOLVED          | SURGE                   | 3 LSM              | 2 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 25             | 31%           | 23%          | 45%          | 5%                     | 2                | 89.2%              | 100.0%              | 1,170,130                     | 0.0%                  | -8,372             |
| 13                                                                    | 00:10:09      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 2 LL               | S                     | 30               | 51.7                | 30.6              | 38             | 6%            | 20%          | 45%          | 5%                     | 12               | 81.5%              | 100.0%              | 899,097                       | 4.1%                  | -6,462             |
| 14                                                                    | 00:10:07      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 1 LL               | S                     | 30               | 51.7                | 30.6              | 29             | 22%           | 23%          | 45%          | 5%                     | 11               | 83.4%              | 100.0%              | 886,840                       | 2.7%                  | -7,500             |
| 15                                                                    | 00:01:01      | SOLVED          | SURGE                   | 2 LSM              | 2 PSV              | 0 LL               | S                     | 30               | 51.7                | 30.6              | 25             | 61%           | 65%          | 231%         | -181%                  | 2                | 91.2%              | 100.0%              | 923,147                       | 0.0%                  | -69,839            |

Table 13. East CONSOL—Surge Prepositioned Assets

| RASP   Scenario Dashboard CONSOL East - Surge - Prepositioned Assets |            |              |                  |                 |                 |                 |                    |               |                     |                  |             |            |           |           |                   |               |                 |                  |                         |                 |                 |
|----------------------------------------------------------------------|------------|--------------|------------------|-----------------|-----------------|-----------------|--------------------|---------------|---------------------|------------------|-------------|------------|-----------|-----------|-------------------|---------------|-----------------|------------------|-------------------------|-----------------|-----------------|
| Solve Info                                                           |            |              | Input Sets       |                 |                 |                 |                    |               |                     | Scenario Summary |             |            |           |           |                   |               |                 |                  |                         |                 |                 |
| Solver Generated                                                     |            |              | Combatant Assets | Provider Assets | Provider Assets | Provider Assets | Logistics Services | Control Panel | Performance Metrics |                  |             |            |           |           |                   |               |                 |                  |                         |                 |                 |
|                                                                      |            |              |                  |                 |                 |                 |                    |               | Capacity Days       | Fronthaul Days   | Planned RAS | Below Time | Below Avg | Below Max | Below Max Ammount | Provider LOAD | Provder UW Days | Provider Max Cap | Estimated Provider Fuel | Optimalit y Gap | Objective Value |
| CoA Index                                                            | Solve Time | Solve Status | DEMAND MODE      | LSM AVAIL       | PSV AVAIL       | LL AVAIL        | SUPPLY LOC         | SOLVE DAYS    | Capacity Days       | Fronthaul Days   | Planned RAS | Below Time | Below Avg | Below Max | Below Max         | Provider LOAD | Provder UW Days | Provider Max Cap | Estimated Provider Fuel | Optimalit y Gap | Objective Value |
| 1                                                                    | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 37          | 23%        | 22%       | 45%       | 5%                | 20            | 91.9%           | 100.0%           | 1,550,798               | 37.3%           | -18,032         |
| 2                                                                    | 00:10:07   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 34          | 30%        | 22%       | 56%       | -6%               | 9             | 93.8%           | 100.0%           | 1,526,931               | 42.8%           | -30,529         |
| 3                                                                    | 00:10:08   | SOLVED       | SURGE            | 6 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 29          | 39%        | 28%       | 88%       | -38%              | 1             | 97.8%           | 100.0%           | 1,634,414               | 32.2%           | -61,955         |
| 4                                                                    | 00:10:08   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 32          | 28%        | 22%       | 45%       | 5%                | 19            | 91.1%           | 100.0%           | 1,469,988               | 39.2%           | -18,028         |
| 5                                                                    | 00:10:08   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 29          | 31%        | 23%       | 56%       | -6%               | 10            | 95.8%           | 100.0%           | 1,361,524               | 38.9%           | -29,216         |
| 6                                                                    | 00:10:07   | SOLVED       | SURGE            | 5 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 26          | 41%        | 28%       | 84%       | -34%              | 1             | 97.5%           | 100.0%           | 1,329,060               | 28.2%           | -62,284         |
| 7                                                                    | 00:10:07   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 31          | 31%        | 23%       | 45%       | 5%                | 19            | 91.5%           | 100.0%           | 1,144,593               | 40.4%           | -18,591         |
| 8                                                                    | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 33          | 39%        | 24%       | 56%       | -6%               | 12            | 94.7%           | 100.0%           | 1,120,044               | 41.9%           | -29,130         |
| 9                                                                    | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 28          | 43%        | 30%       | 88%       | -38%              | 1             | 97.5%           | 100.0%           | 1,217,613               | 15.4%           | -60,115         |
| 10                                                                   | 00:10:07   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 33          | 31%        | 21%       | 45%       | 5%                | 18            | 92.0%           | 100.0%           | 971,824                 | 39.3%           | -18,662         |
| 11                                                                   | 00:10:08   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 25          | 41%        | 23%       | 56%       | -6%               | 12            | 95.4%           | 100.0%           | 947,967                 | 21.8%           | -23,860         |
| 12                                                                   | 00:10:07   | SOLVED       | SURGE            | 3 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 23          | 54%        | 32%       | 93%       | -43%              | 1             | 97.2%           | 100.0%           | 963,604                 | 18.6%           | -64,282         |
| 13                                                                   | 00:10:07   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 30          | 33%        | 22%       | 45%       | 5%                | 18            | 91.2%           | 100.0%           | 713,803                 | 31.8%           | -17,662         |
| 14                                                                   | 00:10:07   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 24          | 41%        | 23%       | 56%       | -6%               | 10            | 93.9%           | 100.0%           | 702,110                 | 31.9%           | -29,570         |
| 15                                                                   | 00:03:37   | SOLVED       | SURGE            | 2 LSM           | 1 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 25          | 71%        | 63%       | 231%      | -181%             | 1             | 96.7%           | 100.0%           | 689,150                 | 0.0%            | -112,935        |
|                                                                      |            |              |                  |                 |                 |                 |                    |               |                     |                  |             |            |           |           |                   |               |                 |                  |                         |                 |                 |
| 1                                                                    | 00:10:09   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 40          | 2%         | 11%       | 16%       | 34%               | 10            | 83.5%           | 100.0%           | 1,961,083               | 8.3%            | -8,473          |
| 2                                                                    | 00:10:07   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 39          | 5%         | 16%       | 45%       | 5%                | 8             | 89.4%           | 100.0%           | 1,910,895               | 11.4%           | -8,793          |
| 3                                                                    | 00:10:07   | SOLVED       | SURGE            | 6 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 36          | 12%        | 22%       | 45%       | 5%                | 2             | 93.6%           | 100.0%           | 1,869,111               | 14.2%           | -9,093          |
| 4                                                                    | 00:10:09   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 40          | 0%         | 0%        | 0%        | 0%                | 8             | 85.7%           | 100.0%           | 1,568,902               | 7.5%            | -7,923          |
| 5                                                                    | 00:10:08   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 39          | 4%         | 18%       | 45%       | 5%                | 7             | 88.2%           | 100.0%           | 1,689,930               | 6.4%            | -7,850          |
| 6                                                                    | 00:10:07   | SOLVED       | SURGE            | 5 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 34          | 16%        | 22%       | 45%       | 5%                | 2             | 95.7%           | 100.0%           | 1,723,264               | 8.8%            | -8,454          |
| 7                                                                    | 00:10:07   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 40          | 0%         | 0%        | 0%        | 0%                | 10            | 84.2%           | 100.0%           | 1,395,766               | 4.7%            | -7,261          |
| 8                                                                    | 00:10:07   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 38          | 11%        | 20%       | 45%       | 5%                | 7             | 87.7%           | 100.0%           | 1,425,336               | 11.1%           | -7,804          |
| 9                                                                    | 00:10:08   | SOLVED       | SURGE            | 4 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 29          | 28%        | 22%       | 45%       | 5%                | 2             | 92.5%           | 100.0%           | 1,401,976               | 8.3%            | -8,752          |
| 10                                                                   | 00:10:09   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 40          | 0%         | 0%        | 0%        | 0%                | 12            | 84.8%           | 100.0%           | 1,161,136               | 1.4%            | -6,914          |
| 11                                                                   | 00:10:07   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 34          | 15%        | 21%       | 45%       | 5%                | 9             | 86.8%           | 100.0%           | 1,179,473               | 7.1%            | -7,586          |
| 12                                                                   | 00:10:07   | SOLVED       | SURGE            | 3 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 25          | 33%        | 23%       | 45%       | 5%                | 2             | 89.6%           | 100.0%           | 1,162,447               | 16.9%           | -10,032         |
| 13                                                                   | 00:10:08   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 2 LL            | E                  | 30            | 51.7                | 30.6             | 38          | 7%         | 20%       | 45%       | 5%                | 11            | 85.6%           | 100.0%           | 927,571                 | 3.8%            | -6,933          |
| 14                                                                   | 00:10:07   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 1 LL            | E                  | 30            | 51.7                | 30.6             | 29          | 23%        | 23%       | 45%       | 5%                | 10            | 87.6%           | 100.0%           | 915,314                 | 2.8%            | -7,907          |
| 15                                                                   | 00:01:20   | SOLVED       | SURGE            | 2 LSM           | 2 PSV           | 0 LL            | E                  | 30            | 51.7                | 30.6             | 25          | 62%        | 64%       | 231%      | -181%             | 2             | 90.6%           | 100.0%           | 873,647                 | 0.0%            | -69,962         |

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