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FUEL LOGISTICS PLATFORM REQUIREMENTS TO SUPPORT DISTRIBUTED MARITIME OPERATIONS IN THE INDO-PACIFIC AREA OF RESPONSIBILITY

June 2023

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LIST OF ACRONYMS AND ABBREVIATIONS

AOR	area of responsibility
bbl	barrel of fuel (42 U.S. gallons)
CG	Ticonderoga-class guided-missile cruiser
CLF	Combat Logistics Force
CONSOL	fuel consolidation
CSG	Carrier Strike Group
CVN	Nimitz-class nuclear aircraft carrier
DDG	Arleigh Burke-class guided-missile destroyer
DF-21	medium-range anti-ship ballistic missile
DF-26	intermediate-range anti-ship ballistic missile
DLA	Defense Logistics Agency
DOD	United States Department of Defense
DMO	distributed maritime operations
DWT	deadweight tonnage (metric tons)
ESG	Expeditionary Strike Group
FAS	fuel-at-sea
F76	NATO designation for naval distillate fuel, complying with MIL-DTL-16884N for the U.S. Navy
FDNF	forward deployed naval forces
FUSED	Fuel Usage Study Extended Demonstration
JP5	aviation turbine fuel complying with MIL-DTL-5624W. NATO designation code F44
LHD	Wasp-class landing helicopter dock

LPD	San Antonio-class landing platform dock
LR Tanker	long range tanker (45-160 DWT)
LSD	Harper Ferry-class landing dock
MR Tanker	medium range tanker (25-45 DWT)
MSC	Military Sealift Command
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
RAS	replenishment at sea
RASP	Replenishment at Sea Planner
SFC	single fuel concept
T-AKE	dry cargo/ammunition ships
T-AO	underway replenishment oilers
T-AOE	fast combat support vessels
T-AOT	tankers
TCC	transportation component commands
USEUCOM	United States European Command
USINDOPACOM	United States Indo-Pacific Command
USNS	United States Naval Ship
USS	United States Ship

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I. INTRODUCTION

The *Fiscal Year 2020 Operational Energy Report*, released by the Office of the Under Secretary of Defense for Acquisition and Sustainment, highlighted the Chief of Naval Operations' (CNO) Operational Energy Component objectives to align the Navy energy network. The objectives are aimed at supporting the integrated naval force in distributed maritime operations (DMO) and Expeditionary Advanced Base Operations (EABO) by "prioritizing resupply capability and sources, weapons systems' operational reach, and energy command and control to enable the forward deployed integrated force to operate distributed in all domains in contested environments" (Under Secretary of Defense for Acquisition and Sustainment, 2021).

This thesis examines the sufficiency of strategic lift for naval consumption in the United States Indo-Pacific Command (INDOPACOM) area of operational responsibility. The research builds on previous thesis projects and capstones and has adopted many of their conclusions to base our model. As such, this project adopted the single fuel concept (SFC), which has been demonstrated to increase time between refueling, improving operational flexibility and endurance (Jimenez et al., 2020; Witt, 2022). Similarly, the model in this thesis utilizes the Fuel Usage Study Extended Demonstrated (FUSED) for fuel usage analysis. This is an NPS-accepted tool that is used to inform fuel burn rates based on speed and engine configurations, aviation flight time, and mission sets over time. The goal of the thesis is to examine operational fuel requirements, determine a concept of operations of strategic lift of bulk fuel into theater, and inform requirements develop for bulk fuel tankers.

The scenario for this thesis is a transit of a tanker carrying JP-5 from San Diego, CA to an arbitrary open ocean refueling point outside the second island chain in the western Pacific Ocean. The refueling point is located outside adversary long-range weapon engagement zone, but close enough to the second island chain to minimize transit times for tactical delivery by Military Sealift Command (MSC) vessels, shown in Figure 1. The analysis intentionally omits Hawaii due to the permanent closure of the Red Hill Bulk Fuel Storage Facility beginning in 2022 (Environmental Protection Agency, n.d.). The study-based fuel requirements on one Surface Action Groups (SAG), two Expeditionary Strike Groups (ESG), and two Carrier Strike Groups (CSG) conducting operations in vicinity of the steaming box shown in Figure 1. Two underway replenishment oilers (T-AOs) and two dry cargo/ammunition ships (T-AKEs) would make tactical fuel deliveries in a rotational schedule to the operational units from the bulk fuel tanker.

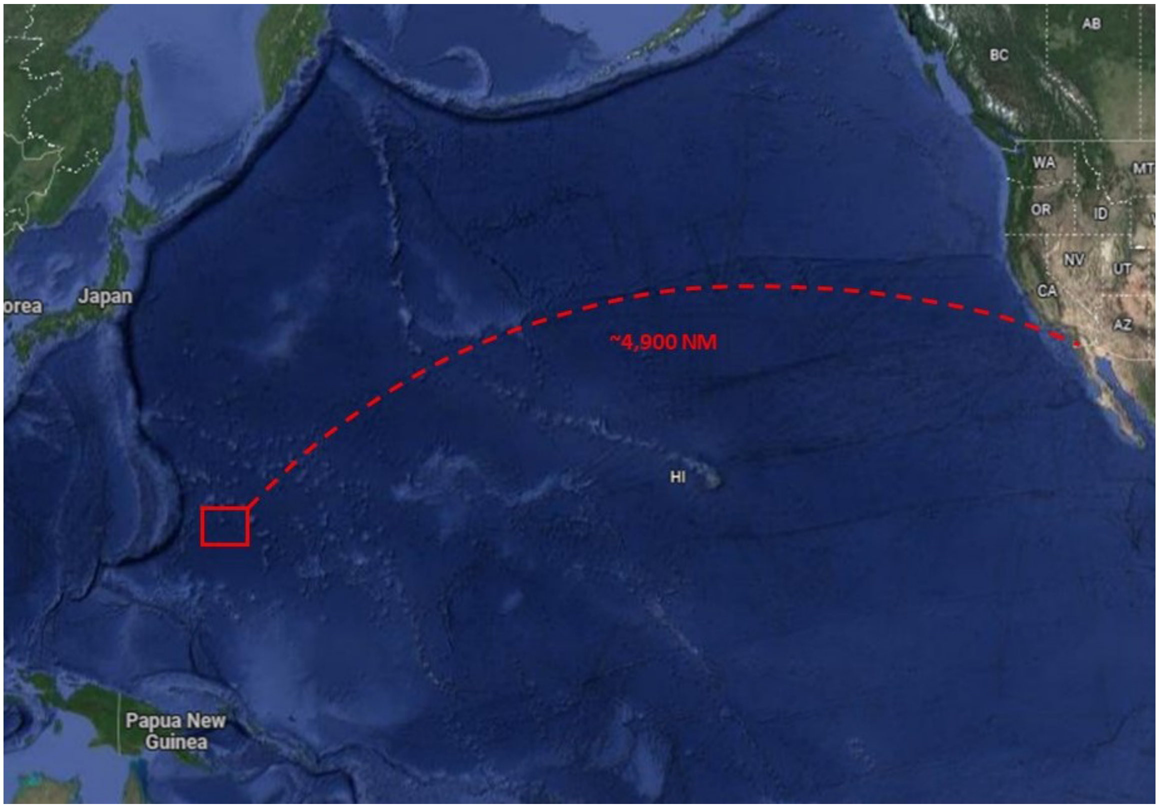

Figure 1. Scenario Transit of Chartered Oil Tanker from San Diego, CA to INDOPACOM AOR. Adapted from Google Maps. (n.d.).

The U.S. Navy and MSC currently operate T-AOs, T-AOEs, and T-AKEs to make tactical deliveries of multiple classes of supply following resupply at ports. The "hub-and-spoke" model in the western Pacific relies on traditional ports in mainland Japan and her islands, Guam, and Singapore, as well as non-traditional ports in Philippines, Australia, and Vietnam. However, when indications and warnings of hostile action are received as part of Phase I, these ports will become denied to logistics support vessels and combatants for a variety of reasons including threats from missiles, surface and subsurface enemy combatants, cyber-attacks against infrastructure, and geopolitical aversion to U.S. access. For these reasons, our research assumes accessibility to both traditional and nontraditional ports would not be guaranteed, and a model that maintains fuel distribution afloat is most feasible.

In this thesis, we seek to answer the following questions:

1. How many bulk fuel tankers are required to sustain distributed maritime operations in the western Pacific Ocean?

2. Are the contracts for bulk fuel tankers sufficient in quantity and time to meet operational requirements in the western Pacific Ocean during Phase I?

3. How would a switch to JP-5 improve efficiency over dual fuel during Distributed Maritime Operations in the western Pacific Ocean?

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II. BACKGROUND

This chapter establishes background context to include the area of responsibility (AOR), stakeholder responsibilities and available assets, Distributed Maritime Operations picture, single fuel concept, and bulk fuel transfer considerations.

A. INTRODUCTION TO INDOPACOM AOR

The United States Indo-Pacific Command (USINDOPACOM or INDOPACOM) AOR, as shown in Figure 2, is the largest of the six geographic combatant commands that surround the globe. According to Indo-Pacific Command (n.d.a), its mission is to "implement a combat credible deterrence strategy capable of denying our adversaries sustained air and sea dominance by focusing on posturing the Joint Force to win before fighting while being ready to fight and win." The AOR encompasses more than 35 different nations, to include over half of the world population, speaking over 3,000 languages (Indo-Pacific Command [INDOPACOM], n.d.a). The United States has many allied partners, and several well-established adversaries, which makes commanding this AOR very challenging at the strategic level. Maintaining freedom of navigation according to recognized international law is vital to ensuring that free trade continues throughout the INDOPACOM AOR. Allied and partner nation support is key to maintaining presence and security in the region to deter aggression and respond to threats accordingly, if required.

Figure 2. INDOPACOM AOR. Source: INDOPACOM (n.d.b).

B. DEFENSE LOGISTICS AGENCY ENERGY

Defense Logistics Agency (DLA) Energy is a major subordinate command of DLA, with a history dating back to World War II. Founded initially as the Army-Navy Petroleum Board, it was responsible for transporting fuel during WWII (Defense Logistics Agency [DLA] Energy, 2022). According to DLA Energy (2022), "the Secretary of Defense designated DLA as the Executive Agent for bulk petroleum in 2014" to promote efficiency and minimize supply chain redundancy. DLA Energy is headquartered in Virginia with regional offices throughout the world with Pacific locations in Hawaii, Japan, Guam, Okinawa, and South Korea. They service the military with fuel support, including JP5 and F76, fuel supply chains, storage and distribution infrastructure, and worldwide acquisitions of fuel-related services (DLA Energy, 2022).

C. UNITED STATES TRANSPORTATION COMMAND

United States Transportation Command (USTRANSCOM or TRANSCOM) is a combatant command established in 1987 within the Department of Defense (DOD). It provides transportation of personnel and material via sea, land, and air (Nicastro, 2022). Its headquarters is located at Scott Air Force Base. Serving as the DOD's primary logistics command, TRANSCOM is responsible for bulk fuel management and delivery through Transportation Component Commands (TCCs). Previously, DLA Energy was responsible for DOD bulk fuel management and delivery. However, the National Defense Authorization Act (NDAA) of FY 2022 shifted the responsibility to TRANSCOM. According to Braesch (2022), DLA Energy established a thorough plan and met established milestones and objectives, ultimately transferring overall responsibility of bulk fuel management and delivery to TRANSCOM in January 2023. Figure 3 shows TRANSCOM's current organization structure.

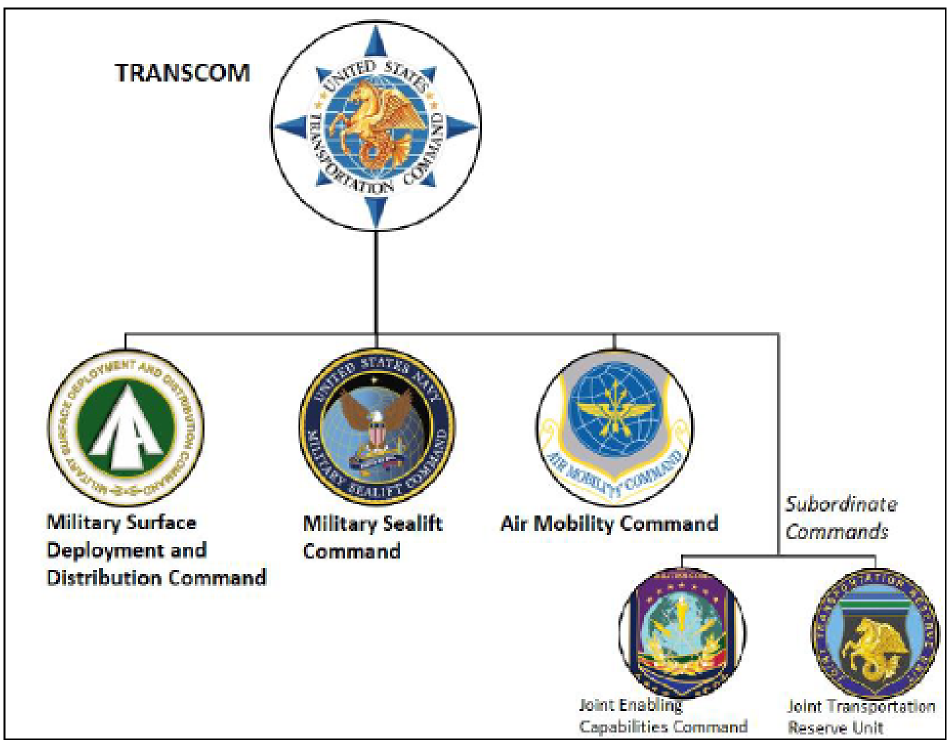

Figure 3. TRANSCOM Organizational Chart. Source: Nicastro (2022).

D. MILITARY SEALIFT COMMAND

Military Sealift Command (MSC) was founded in 1949 as the Military Sea Transportation Service due to the Department of Defense (DOD) requiring a central agency to manage all DOD oceanic transportation requirements (Military Sealift Command [MSC], (n.d.e). MSC currently operates over 120 active vessels that fall into eight categories, as shown in Figure 4:

- Fleet Oiler
- Special Mission
- Prepositioning
- Service Support
- Sealift Program
- Dry Cargo and Tankers
- Fleet Ordnance and Dry Cargo
- Expeditionary Fast Transport

Figure 4. MSC Ship Inventory. Source: Military Sealift Command (n.d.g).

For the purposes of this study, we focus on the capacities and capabilities of the Fleet Oilers, Dry Cargo and Tankers, Fleet Ordnance and Dry Cargo, and Expeditionary Fast Transport.

(1) Fleet Oilers

Fleet Oilers, designated as T-AOs, are the primary platform used by MSC to refuel U.S. Navy ships at sea. They provide several types of fuel to include F-76 for ship gas-turbine engines and generators, and JP-5 for aircraft fuel requirements. They are the largest category of the Navy's Combat Logistics Force (CLF) and can deliver food and other dry cargo to deployed forces to sustain their operations without having to enter port for replenishment (MSC, n.d.c). The Fleet Oilers typically operate with a Carrier Strike Group (CSG) or in the vicinity of major ports worldwide where U.S. Navy ships are operating.

(2) Dry Cargo and Tankers

According to MSC (n.d.a), there are currently five commercial tankers that have been contracted long-term by MSC, in addition to several other short-term contracted tankers. Their mission is to transport bulk petroleum from refineries, and storage and distribution facilities around the world as part of the DLA Energy mission. Dry cargo vessels are also on contract to MSC to transport large pieces of military equipment, vehicles, aircraft, and ammunition (MSC, n.d.a). MSC has the capability to contract additional commercial tankers and dry cargo vessels during times of war to support increased demand in potentially contested environments around the world.

(3) Fleet Ordnance and Dry Cargo

The Fleet Ordnance and Dry Cargo fleet is designed to carry cargo, food stores, ammunition and fuel to U.S. Navy ships and allied partners (MSC, n.d.d). Previously, this fleet was made up of ammunition ships and combat stores ships until the integration under one hull design, the T-AKE. Also in this category are the Fast Combat Supply Ships (T-AOEs), the largest logistics supply ships in the CLF. The primary mission of these vessels focuses on cargo and ammunition, with the ability to deliver fuel in smaller capacity compared to the Fleet Oilers.

(4) Expeditionary Fast Transport

According to MSC (n.d.b), the Expeditionary Fast Transport (T-EPFs) are high-speed ships with the ability to deliver personnel and cargo to smaller ports in potentially contested environments. They have a large cargo space that can be configured to conduct multiple mission sets, and a rear loading ramp to assist with loading and unloading cargo and military equipment. T-EPFs also have a flight deck for landing helicopters and seating for up to 312 passengers. It can reach speeds of 35 knots for rapid transport of conventional and special forces (MSC, n.d.b). Their versatility also allows them to assist with disaster, recovery, and humanitarian relief efforts.

E. DISTRIBUTED MARITIME OPERATIONS

Vice Admiral Sawyer described Distributed Maritime Operations (DMO) in *Seapower* Magazine as "a combination of distributed forces, integration of effects, and maneuver" meant to devastate the adversary and force them to make difficult strategic decisions (Lundquist, 2021). Logistics is an essential element of ensuring DMO is feasible and sustainable, particularly fueling dispersed forces across large distances. DMO's goal is to achieve sea control in a contested maritime environment. This situation would expose defenseless logistics vessels to a variety of enemy threats where the U.S. Navy might have lost sea control as operational units maneuver dynamically to avoid detection and targeting. Resupplying these units poses unique challenges as traditional replenishment at sea (RAS) events place both CLF and combatant in a vulnerable state for the duration of the event. In addition, if the RAS takes place in a contested area, the CLF's transit poses a risk to the vessel as well.

F. NAVY SINGLE FUEL CONCEPT

The U.S. Navy currently operates with two main sources of fuel: F-76 for non-nuclear ships and JP-5 for aircraft. There have been numerous studies and theses regarding the implementation JP-5 as a single fuel for shipboard and aviation use. The motivating factor for a single fuel is the flexibility it provides to logistics ships and operational units to only need to carry one fuel type and improved endurance because all fuel tanks could serve all needs. These two reasons combined result in fewer RAS events or port calls for CLF and operational units, allowing them to remain on mission for longer periods of time. Despite the potential benefits, there has been minimal traction for implementing the single fuel concept.

G. CONSOLIDATION OPERATIONS AND LIGHTERING

Fuel consolidation (CONSOL) operations occur between a large, specially outfitted tanker and smaller MSC CLF vessels. CONSOL allows CLF to refuel without pulling into port and support combatants on station for longer. Not only is the tanker able to travel to the CLF vessels and minimize transit times to ports, but also tankers are also able to refuel multiple CLF before needing to refuel themselves. Tankers will need to be outfitted with permanent fuel-at-sea (FAS) stations or modular CONSOL adapter kits.

Lightering is the process of transferring cargo, in this case fuel, between two vessels. Historically, lightering occurs to lessen the draft of laden vessels for their entrance into port. Lightering operations can occur at anchor or underway and involve pumping fuel from one vessel to another with fenders between the two vessels.

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III. LITERATURE REVIEW

This chapter reviews previous studies, and how they can inform our scenario. Several theses provided information on SFC, RASP, and CLF planning. Additionally, literature on the MSC contracting process, current U.S. regulations, and industry tanker availability is provided. Lastly, the closure of the bulk fuel storage facility at Red Hill in Hawaii is discussed, as this will have a major impact on strategic bulk fuel positioning.

a. Single Fuel Concept for Maritime Operations: Effects on Tactical and Operational Readiness and Sustainment through Simulation and Analysis

Jimenez et al. (2020) conducted an analysis including various scenarios utilizing SFC in the INDOPACOM AOR. Their results concluded that SFC would require a reduced requirement for T-AOs, fewer port visits for resupply and an increased fuel capacity for CLF. They also found that CLF fuel capacity under SFC resulted in a 20% increase for T-AKE and 12% increase for T-AO, even considering the loss of energy density of JP-5 compared to F-76. Additionally, the authors' modeled task group would increase its operational endurance by 1–3 days of supply (DOS), or 1080 nm or operational range.

b. Analysis for the Single Fuel Concept within the Eucom Area of Responsibility

Witt (2022) analyzed a potential movement of ships from Souda Bay, Greece to Loch Striven, Scotland and found that the SFC may be beneficial in the EUCOM AOR. During this transit, the ships would be conducting various operations for various durations. The ship configurations varied between two Carrier Strike Groups (CSGs), two Amphibious Readiness Groups (ARGs), and one CSG and one ARG considering aviation operations. The results from the 216 iterations found the single fuel model retained or reduced the number of CLF refueling events in port and the number of RAS events required for the operational units during the transit and provided the Combatant Commander increased flexibility and endurance of afloat units assigned to them. The research indicated there would be no benefit to maintaining dual fuels.

c. Replenishment at Sea Planner

Brown et al. (2018) developed the Replenishment at Sea Planner (RASP) model as a fuel saving planner to be utilized by resupply schedulers. RASP is particularly beneficial as it can forecast demand weeks into the future down to the hour and is able to optimize CLF fuel consumption by using an integer-linear optimization and a purpose-built heuristic. RASP was implemented in the 5^{th} Fleet AOR in 2013 and it is currently being used today with schedulers realizing its time savings, allowing them to consider alternatives.

d. Combat Logistics Force Planner

Brown and Carlyle (2008) examined the worldwide employment of "battle groups," a deployed group of ships supported by CLFs, and optimized the employment of CLF to sustain the battle groups. Their research explored different CLF compositions, scenarios, sea routes, and prepositioning to attempt to inform requirements development of future logistics forces. Their model can analyze the supportability of certain scenarios based on key considerations, such as port access, CLF availability, CLF supply variability, and future logistics force configurations. The CLF planner utilizes General Algebraic Modeling System (GAMS) to solve the scenario and permits the user to determine operational supportability.

e. MSC Contracting for Bulk Fuel Transportation

MSC utilizes time and voyage charters as the two main forms of contracting for bulk fuel transportation. When MSC undertakes to hire a vessel for a stated period of time that is a time charter. MSC pays the shipowner for the use of the vessel for a predetermined period, typically months or years, rather than paying for a specific voyage or transportation of goods. The benefit of a time charter is MSC usually has more control over the vessel's operations, including the selection of ports, routes, and cargo to be carried, while the shipowner retains ownership and overall management of the vessel. Under a time charter, MSC is responsible for covering the costs of the vessel's operation during the charter period, such as crew wages, fuel, and maintenance, as well as any port fees and other voyage expenses. A voyage charter is when MSC leases a vessel for transportation of goods or passengers for a particular voyage. Voyage charters give MSC some control over expenses related to the specific voyage and do not require a long-term commitment.

f. The Jones Act

The Jones Act, also known as the Merchant Marine Act of 1920, requires water-borne transportation between U.S. ports to be U.S. owned, crewed, registered, and built (DOT, 2023). Originally designed to promote shipbuilding to enhance national security, the provisions outlined in the Act have significant impact the pool of vessels the U.S. can contract and employ in the event of conflict. Internationally built vessels crewed by non-U.S. citizens operating to fuel U.S. vessels coming in and out of U.S. ports would be prohibited under the Jones Act.

g. Industry Tanker Availability Analysis

The international market for tankers is complex and has many national and business participants. The two main tankers are medium-range (MR) tankers and long-range (LR1) tankers. MR tankers make up most of the tanker fleet with approximately 1,700 vessels at an average age of 11.7 years while the LR1 tanker consists of less than 350 vessels and is slightly older with an average age of 13.6 years. Broekhuizen (2023) describes the following charter types:

- Voyage-charter: hiring of a vessel and crew for a voyage between a load port and a discharge port. The charterer pays the vessel owner on a per ton or lump sum basis. The owner pays the port costs (excluding stevedoring), fuel costs and crew costs.
- Time-charter: hiring of a vessel for a specific period. The owner still manages the vessel, but the charterer selects the ports and directs the vessel where to go. The charterer pays for all fuel the vessel consumes, port charges, and a daily 'hire' to the owner of the vessel.
- Bare boat charter: arrangement for the hiring of a vessel whereby no administration or technical maintenance is included as part of the agreement. The charterer pays for all operating expenses, including fuel, crew, port expenses and hull insurance. Sometimes, the charter period (normally years) ends with the charterer obtaining title (ownership) in the hull. In this case, the owners effectively finance the purchase of the vessel.
- Contract of Affreightment: a negotiated contract under which the shipowner agrees to carry a series of cargo parcels for a fixed price per

unit/volume or based on a floating rate index, generally without specifying the precise ship in which the cargo will be carried. However, the shipowner will be under obligation to provide the necessary cargo carrying capacity to serve the agreed cargo volume and destinations.

- Consecutive Voyage Charter: like a Voyage Charter, but the ship is contracted to undertake a series of cargo carrying voyages on a defined route. This is used when the shipper has a well-defined schedule of cargoes to transport. To introduce some flexibility and allow for changing circumstances the charter party may incorporate options in terms of loading and/or discharge ports, quantities, and other contract terms. (Broekhuizen, 2023)

h. Red Hill Bulk Fuel Storage Facility Closure

The Red Hill Bulk Fuel Storage Facility (RHBFSF) was opened at the height of Pacific operations during World War II in 1943. The twenty tanks of the Red Hill facility hold a combined 250 million gallons of fuel and sit underground near Pearl Harbor, Hawaii. Following a drinking water emergency in November 2021 that traced back to leaks from the RHBFSF, the Secretary of Defense, in a memo dated 07 March 2022, ordered the Secretary of the Navy, in coordination with Commander, INDOPACOM, to defuel and permanently close the RHBFSF. A plan of actions and milestones (POAM) was provided, prior to 31 May 2022 as directed, and defueling commenced. The targeted completion date is forecasted to be within 12 months of commencement. The closure of RHBFSF will significantly lengthen the sea lines of refueling into the western Pacific AOR during conflict.

IV. MODEL AND METHODOLOGY

This chapter discusses in detail how fuel demand data is aggregated for the groups of ships, through the Fuel Usage Study Extended Demonstration (FUSED) model and then optimized using Replenishment at Sea Planner (RASP). Two different scenarios are presented using long range (LR) tankers only, and a combination of long range and medium range (MR) tankers, to provide bulk fuel to designated CONSOL locations.

A. MODEL

The FUSED model was utilized for fuel usage for our simulation. FUSED was developed in 2015 by Mr. Brandon Naylor, faculty staff at Naval Postgraduate School, and it has undergone several iterations and improvements. Using Visual Basic for Applications, it allows users to estimate fuel burned based on ship type, including Combat Logistics Force (CLF) ships, and different mission sets, engine configurations, and transit speeds. Figure 5 shows the FUSED integrates capacities of specific ports once the geographic theater has been defined to provide realistic timelines and location of refueling events. Once the user defines the inputs to include engine configuration, transit speed, aviation flight hours, and fuel safety levels, as shown in Table 1, a RAS event will be triggered. FUSED will then calculate fuel consumption on an hourly basis.

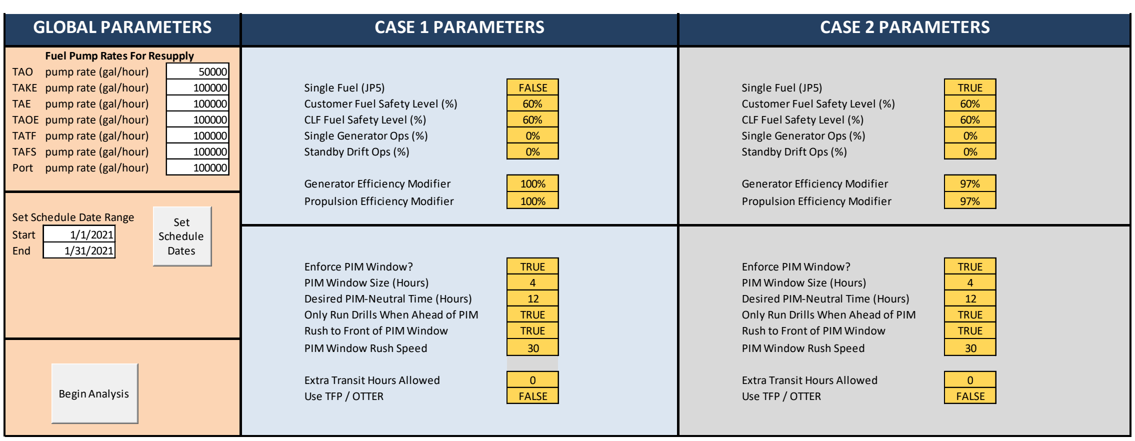


Figure 5. FUSED User Interface. Source: Naylor (2015)

Table 1. FUSED Input

	CSG	CSG	SAG	ESG	ESG
	Group 1	Group 2	Group 3	Group 4	Group 5
START	YOK	ECS	YOK	SCS	SAS
1	Transit	Transit	Transit	Transit	Transit
1.5	Transit	Transit	Transit	Transit	Transit
2	Transit	Transit	Transit	Transit	Transit
2.5	Transit	Transit	Transit	Transit	Transit
3	Transit	IVO Guam	Transit	Transit	Transit
3.5	Transit	Maintenance	Transit	Transit	Transit
4	Transit	Flight Ops	IVO Guam	Transit	Transit
4.5	Transit	Maintenance	ASW 3	IVO Papua	IVO CAROLINE ISL
5	IVO STANDOFF N	Flight Ops	ASW 3	Maintenance	Flight Ops
5.5	Flight Ops	Maintenance	ASW 3	Flight Ops	Maintenance
6	Maintenance	Flight Ops	Sustain	Maintenance	Flight Ops
6.5	Flight Ops	Maintenance	Sustain	Flight Ops	Maintenance
7	Maintenance	Flight Ops	ASW 1	Maintenance	Flight Ops
7.5	Flight Ops	Maintenance	ASW 1	Flight Ops	Sustain
8	Maintenance	Flight Ops	ASW 1	Maintenance	Sustain
8.5	Flight Ops	Maintenance	ASW 1	Flight Ops	Flight Ops
9	Maintenance	Flight Ops	ASW 4	Sustain	Maintenance
9.5	Flight Ops	Maintenance	ASW 4	Sustain	Flight Ops
10	Sustain	Flight Ops	ASW 4	Flight Ops	Maintenance

Based on these inputs, FUSED produces demand data as shown in Tables 2–4. FUSED also provides the number, location, date, and duration of Replenishment at Sea (RAS) events, in addition to quantity of fuel to be transferred per replenishment event. Due to the nature of CLF and battle group operations, it is assumed that if a specific unit within the battle group falls below the fuel safety level, all units within the battle group will receive fuel on the same day.

Table 2. FUSED Output Time in Transit. Source: Naylor (2015).

	Time in Transit	Fuel Burned in Transit (gal)		Jet Fuel Used in Transit (gal)	
Group	Days	Case 1	Case 2	Case 1	Case 2
1	2.29/2.29	221,595	228,448	0	0
2	2.54/2.54	539,193	555,869	0	0
3	25.71/25.71	3,718,938	3,833,957	0	0
4	4.04/4.04	785,434	809,726	0	0
5	4.04/4.04	853,524	879,922	0	0

Table 3. FUSED Output Time on Operations. Source: Naylor (2015).

	Time on Operations	Fuel Burned on Operations (gal)		Jet Fuel Used in Operations (gal)	
Group	Days	Case 1	Case 2	Case 1	Case 2
1	24.92/24.92	2,361,393	2,434,426	4,265,534	4,265,534
2	27/27	2,552,592	2,631,538	4,622,184	4,622,184
3	3.83/3.83	432,860	446,247	12,236	12,236
4	25.46/25.46	2,318,783	2,390,498	1,174,037	1,174,037
5	25.46/25.46	2,318,783	2,390,498	1,174,037	1,174,037

Table 4. FUSED Output Time on Standby. Source: Naylor (2015).

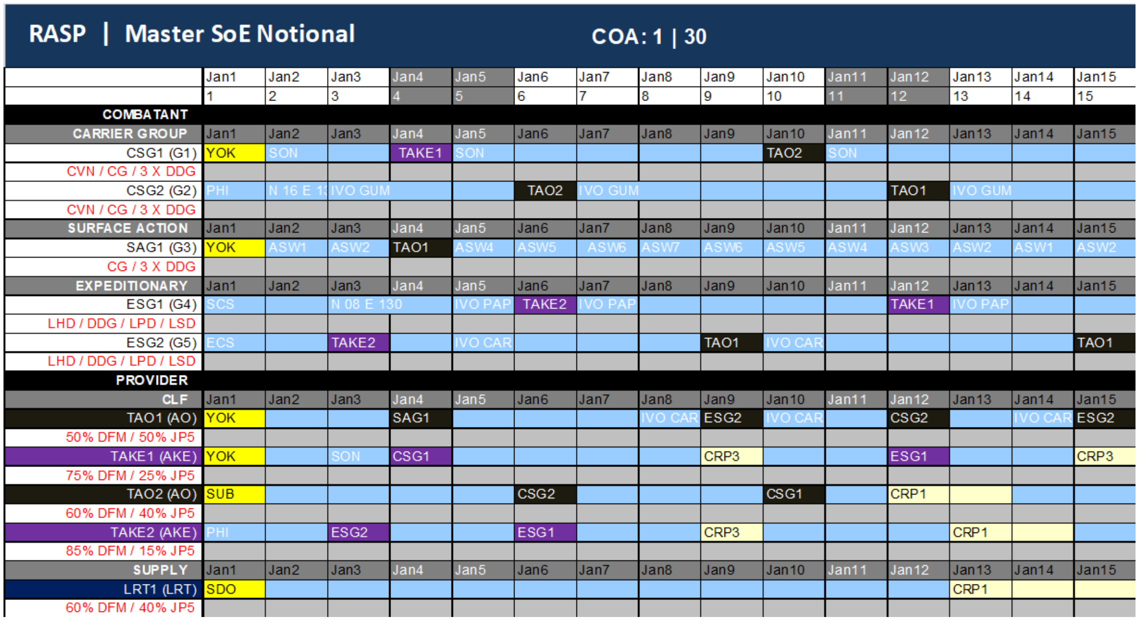
	Time on Standby	Ship Fuel Burned on Standby (gal)		Jet Fuel Used on Standby (gal)	
Group	Days	Case 1	Case 2	Case 1	Case 2
1	3.83/3.83	409,676	422,346	334,236	334,236
2	1.5/1.5	160,308	165,266	130,788	130,788
3	1.5/1.5	160,308	165,266	4,788	4,788
4	1.54/1.54	151,260	155,939	37,944	37,944
5	1.54/1.54	151,260	155,939	37,944	37,944

The demand data from FUSED was the input for RASP. Combatant demand data was then integrated with the two scenarios and two cases to determine the optimized schedule for replenishments. Holding all else constant in the scenarios and cases, RASP will then quantify the optimal number of MR and LR tankers to enable sufficient replenishment based on CLF limitation and combatant fuel usage. Figure 6 is a snapshot of the RASP control panel where parameters are entered to produce results, and Figure 7 is a notional schedule of events produced by RASP.

RASP | Control Panel

Parameter	Value	Parameter	Value
Timeline:		Solver:	
Reporting Start Date	01-Jan-2025	Solve Type	Full
Retained History Days	0	Schedule Flex Days	0
Planning Start Date	01-Jan-2025	Existing Events	Preserve
Planning End Date	30-Jan-2025	Service Restrictions	All
Planning Horizon Days	60	Quick Solve:	
Report:		Solve Mode	Create Schedule
Reporting Classification	CUI	Max Delivery Days	10
Master SoE Notional Months	3	Overspeed Policy	Threshold
Master SoE Grid Days	1 to 30	Barrels To Avoid Early RAS	700
Consolidation Report Days	1 to 60	Barrels To Avoid Late RAS	1,500
Message:		Barrels To Avoid Tight RAS	2,000
Event Identifier Suffix	7	Barrels To Avoid Separate RAS	2,500
Master SoE Message Days	1 to 30	Full Solve:	
Change Threshold Days	3	Model Type	GAMS
Hull/Fill/Deck Lead Days	5	Solve Model	SOLVE
Routing:		Solve Engine	GUROBI
Routing Boundary Area	Global	Solve Threads	-1
Routing Logic Database	RASP-PAC-DEV-ROUTING	Solve Horizon	14
Routing Logic Imported	18-Feb-2022 @ 18:23	Solve Step	7
Metric:		Optimality Gap	0%
Fuel Cost Per Gallon	$2.50	Solve Timeout	30
CLF Planning Knots	12 To 18	Customer INREPs	No
Peak Demand Days	5	Region Overlap	500
Interface:		Priority Weight	3
Exported File Names	Automatic	Preference Weight	0.75
Magnification Zoom	100%	Safety Weight	0.4
		Extremis Weight	1.6

Figure 6. RASP Control Panel. Source: Rowe (2023).



RASP | Master SoE Notional COA: 1 | 30

	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
COMBATANT															
CARRIER GROUP	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
CSG1 (G1)	YOK	SON		TAKE1	SON					TAO2	SON				
CVN / CG / 3 X DDG															
CSG2 (G2)	PHI	N 16 E 1	IVO GUM			TAO2	IVO GUM					TAO1	IVO GUM		
CVN / CG / 3 X DDG															
SURFACE ACTION	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
SAG1 (G3)	YOK	ASW1	ASW2	TAO1	ASW4	ASW5	ASW6	ASW7	ASW6	ASW5	ASW4	ASW3	ASW2	ASW1	ASW2
CG / 3 X DDG															
EXPEDITIONARY	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
ESG1 (G4)	SCS		N 08 E 130		IVO PAP	TAKE2	IVO PAP					TAKE1	IVO PAP		
LHD / DDG / LPD / LSD															
ESG2 (G5)	ECS		TAKE2		IVO CAR				TAO1	IVO CAR					TAO1
LHD / DDG / LPD / LSD															
PROVIDER															
CLF	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
TAO1 (AO)	YOK			SAG1				IVO CAR	ESG2	IVO CAR		CSG2		IVO CAR	ESG2
50% DFM / 50% JP5															
TAKE1 (AKE)	YOK		SON	CSG1					CRP3			ESG1			CRP3
75% DFM / 25% JP5															
TAO2 (AO)	SUB					CSG2				CSG1		CRP1			
60% DFM / 40% JP5															
TAKE2 (AKE)	PHI		ESG2			ESG1			CRP3				CRP1		
85% DFM / 15% JP5															
SUPPLY	Jan1	Jan2	Jan3	Jan4	Jan5	Jan6	Jan7	Jan8	Jan9	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15
LRT1 (LRT)	SDO												CRP1		
60% DFM / 40% JP5															

Figure 7. RASP Example of Schedule of Events for All Units. Source: Rowe (2023).

B. NAVY SINGLE FUEL CONCEPT AND DUAL FUEL

The scenarios presented and concepts of operation examine both the Navy Single Fuel Concept (SFC) and dual fuel. Initially, RASP optimizes fuel distribution for traditional dual with the units identified in Table 5. The CLF is loaded based on routine, peacetime operations with varying ratios of F-76 to JP-5. Then, RASP is reconfigured for simulation Navy SFC using JP-5. We then compare the difference in fuel usage, number of RAS events, time units spent below the fuel safety threshold, and amount of fuel deficit the units incurred below the fuel safety threshold. By holding all variables constant, except for fuel types, we are able to analyze the potential benefits of SFC vs. dual fuel.

Table 5. Force Structure by Group

Forces	Group 1 CSG	Group 2 CSG	Group 3 SAG	Group 4 ESG	Group 5 ESG
CVN	1	1			
LHD				1	1
CG	1	1	1		
DDG	3	3	3	1	1
LPD				1	1
LSD				1	1

C. SCENARIO

The scenario for this simulation begins with normal daily maritime operations (DMO) (Phase 0) in the western Pacific with an abrupt transition to indications and warnings of potential conflict (Phase I) when the Navy initiates DMO. Force combat structure reflects a deployed CSG, Expeditionary Strike Group (ESG), and the sortied Forward Deployed Naval Forces (FDNF). Combined, we assumed two CSGs, two ESGs, and one Surface Action Group (SAG). The CLF structure consists of two T-AOs and two T-AKEs. Table 6 provides CLF and tanker capacities and capabilities. With the transition to Phase I, the Navy positions high value units (HVUs) outside the adversary's longest range weapon threat area, as shown in Figure 8. The simulation assumes that all FDNF and CLF forces were able to completely replenish their fuel before transiting beyond the second island chain. Due to the DF-21 surface to surface missile, DF-26 surface to surface missile, and undersea threats, traditional Navy ports at Yokosuka, Sasebo, Singapore, and Guam are assumed to be denied. This places significant constraints on logistics support to afloat units in the western Pacific with reliance on conducting logistics afloat by Military Sealift Command (MSC) vessels and chartered vessels.

Table 6. CLF and Tanker Capacities and Capabilities

Ship Type	Speed (kn)	Range (nm)	Capacity (bbls)
T-AO	18	10,000	180,000
T-AKE	18	14,000	23,450
MR Tanker	15	6,000	300,000
LR Tanker	17	15,000	500,000

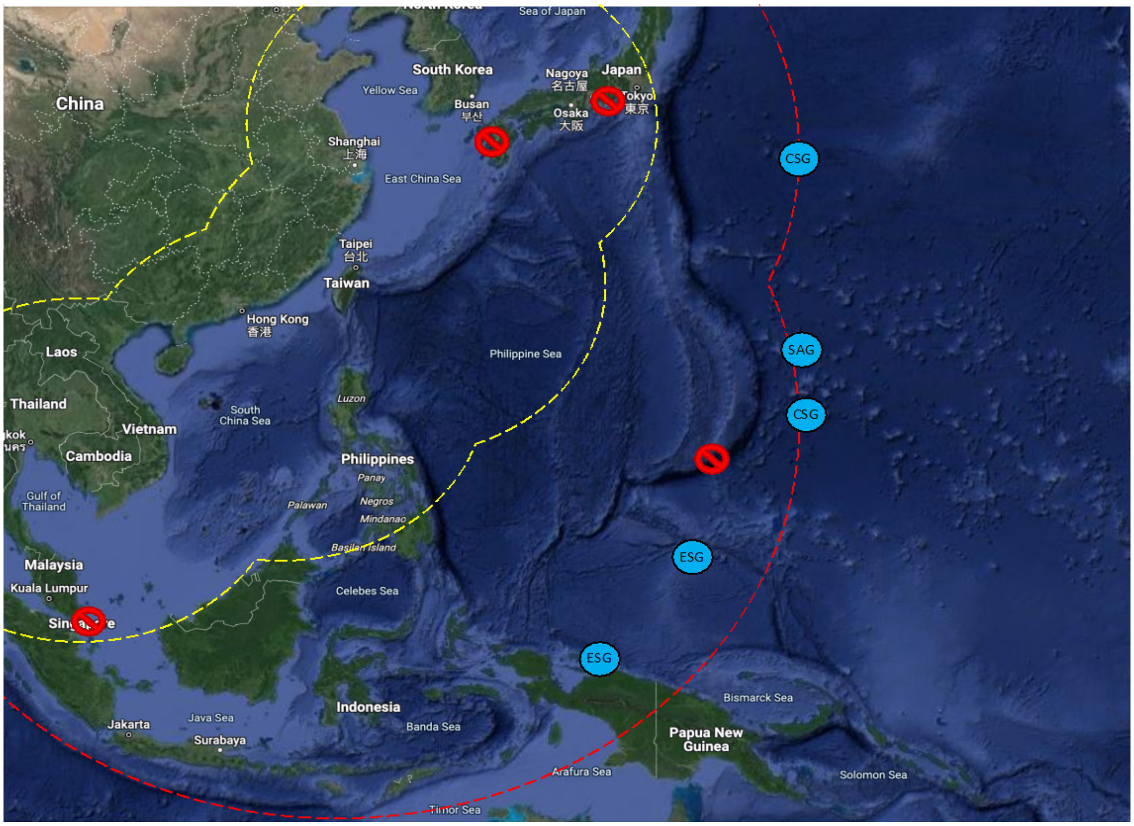


Figure 8. Phase I Distributed Maritime Operations. U.S. naval forces operating beyond second island chain and DF-26 range. Traditional Navy ports are denied. Adapted from Google Maps (n.d.).

Based on the scenario depicted, burn rates are calculated for these units during Phase I, assuming 30 days for CONUS units to surge and arrive in theater and the commencement of Phase II. The warships will be assigned a variety of mission sets. The two CSGs will conduct 12-hour alternating flight operations, pausing every 12 hours for maintenance and halting flight operations during replenishment for rest and maintenance.

The two ESGs will conduct the same operation schedule. The units of the SAG will conduct defensive screenings for the CSGs against subsurface and surface threats and ballistic missile defense of Guam. Based on these operations and their respective fuel compensation rates. We will then analyze multiple schemes of maneuver to optimize the configuration and quantity of tankers necessary to ensure sufficient fuel support to these units. Figures 9 and 10 are the proposed schemes of maneuver for which we will attempt to optimize.

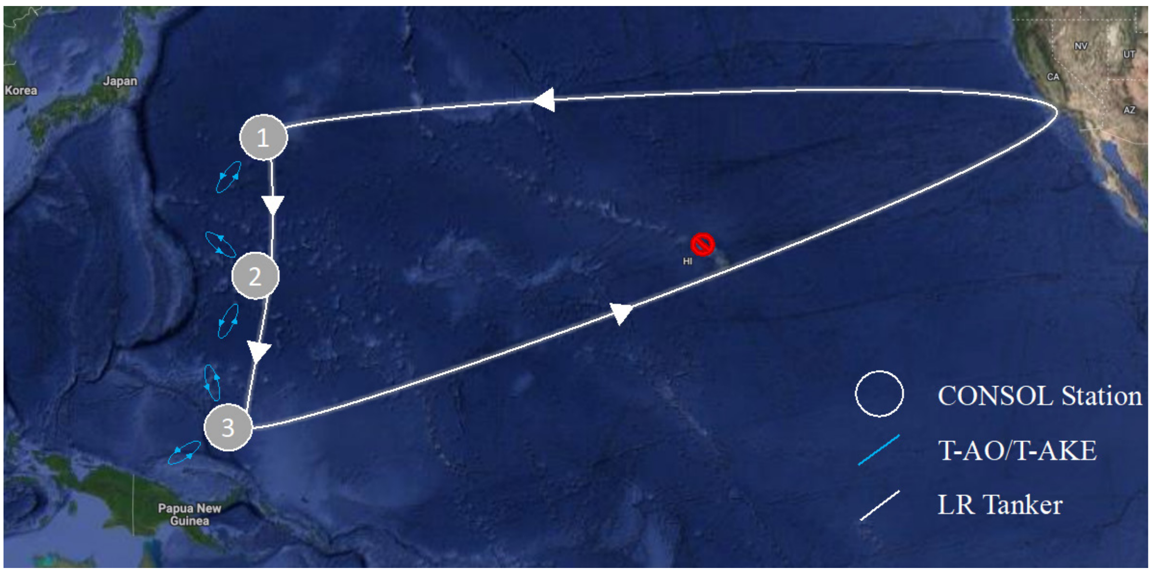


Figure 9. Scheme of Maneuver of LR Tankers from CONUS to CONSOL Stations in Theater. Source: Adapted from Google Maps (n.d.).

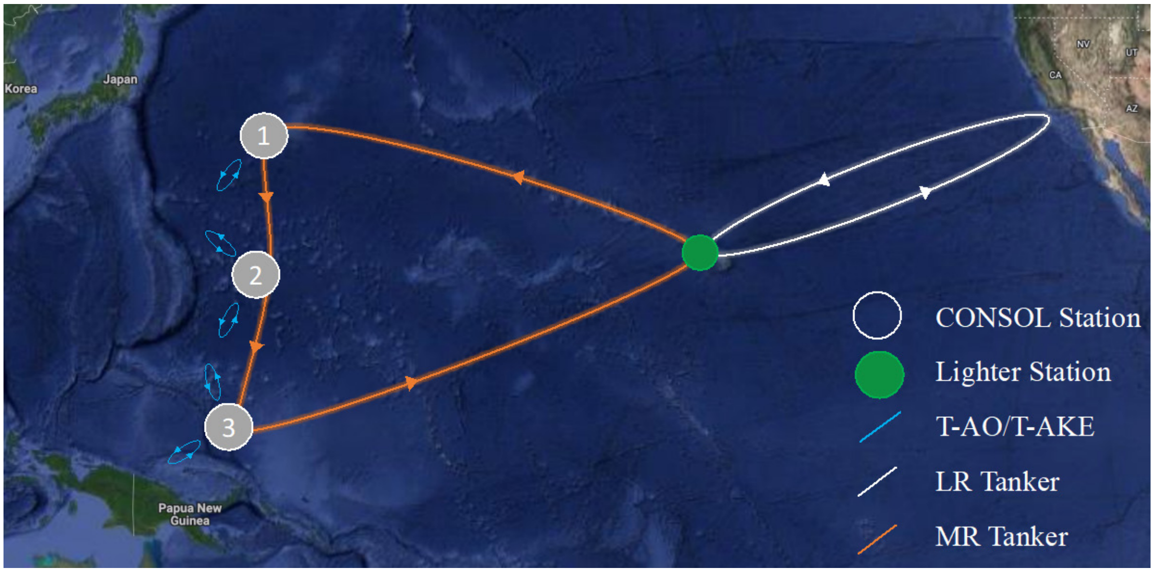


Figure 10. Scheme of Maneuver of LR Tankers from CONUS to a Lightering Station Near Hawaii. Source: Adapted from Google Maps (n.d.). LR tankers will transfer fuel to MR tankers in protected waters to further transport bulk fuel to three CONSOL stations in theater.

The two scenarios attempt to optimize tanker schemes of maneuver utilizing commercially available MR and LR tankers. The tankers are chartered by MSC at the start of contingency and immediately begin sustainment operations. For both scenarios, the MR and LR tankers simulate CONSOL, which takes 12 hours to complete, and lightering operations, which take one day to complete. The assumed capacity for LR tankers is 500,000 bbl and MR tankers 300,000 bbl.

In scenario 1, multiple LR tankers begin their transit from the west coast continental United States and travel the nearly 5,000 nm to a CONSOL station where they transfer their fuel to the CLF ships at a designated station east of the second island chain in the western Pacific. Once their fuel storage has been depleted, the LR tanker then begins the transit back to CONUS to be refueled and start the transit again.

In scenario 2, multiple LR tankers begin the transit from the west coast continental United States and travels to Hawaii where they will lighter with the smaller, more commercially available, MR tankers. The LR tankers will lighter with as many MR tankers until their fuel storage is depleted and then begin the transit back to CONUS for refuel, ensuring an LR tanker is always on station to refuel MR tankers. The MR tankers will then begin their transit to predetermined CONSOL stations east of the second island chain where they will conduct CONSOL operations with CLF ships until their fuel storage is depleted at such time the MR tankers will transit back to Hawaii to lighter with LR tankers.

D. ASSUMPTIONS

Within the above scenarios, we assume the following:

4. Daily fuel demand was combined for the whole task group.
5. Time for T-AO and T-AKE CONSOL operations is twelve hours.
6. Time for lightering operations is one day.
7. Fuel safety levels were set to 60% of total capacity. Each task group will replenish every six days.
8. All combatants and CLF were able to load fuel to their total capacity before sortieing out of port or transit to their operational area.
9. Source of supply for JP-5 and F-76 is San Diego. Access to Red Hill Bulk Fuel Storage Facility is not accessible.
10. LR and MR tankers begin the simulations without fuel.

E. LIMITATIONS

The model is limited by the following:

1. CLF attrition is not considered.
2. Fuel consumption and replenishment is the only class of supply considered in the model.

V. RESULTS

The results are based on FUSED fuel demand data that has been optimized by RASP to provide various solutions to the stated problem sets. Scenario schemes of maneuver and RASP output tables are provided to visually show how RASP optimized solutions to the problem sets.

A. DATA

FUSED estimated fuel demand data for the end users on the identified in our Phase I scenario which included two CSGs, two ESGs, and one SAG. Supporting the combatants are two T-AOs and two T-AKEs. The units were designated specific mission sets in accordance with DMO concepts at the start of contingency in the western Pacific Ocean. FUSED captured the demand data by fuel burned, fuel delivered, RAS events, and the number of CONSOL events to refuel the CLF vessels. FUSED then ran the same scenario twice, once under Case 1: Dual Fuel (JP-5 and F-76) and once under Case 2: SFC (JP-5 only).

RASP improvements permitted multiple iterations of the two scenarios and two cases until the ideal starting conditions were identified. Although both scenarios examined the fuel requirements for a 30-day Phase I, RASP modeling halted tanker support once CLF vessels were sufficiently loaded with fuel to complete exactly 30 days of operations. Only when the simulation was modified to 45 days was the model able to capture the supply and demand for the entirety of Phase I operations. For this reason, demand data for combatants reflect 30 days, but the simulation is solved for a 45-day scenario. Additionally, for scenario 1, the LR tanker schedule is manually input into RASP because the model is overburdened with options that cannot be determined to be optimal due to the size and scale of the scenario. To alleviate this issue, an additional assumption is made that an LR tanker would have a predetermined schedule, including an 11-day trip from San Diego to CONSOL Station 1. Figure 11 shows all possible routes that RASP produced as it solved various scenarios.

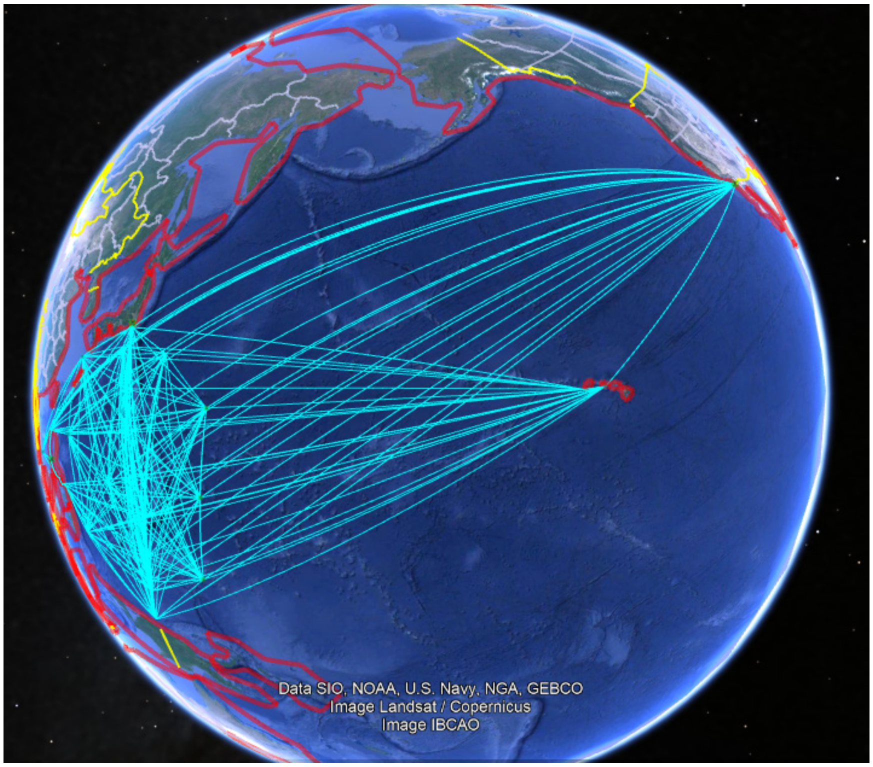


Figure 11. All Potential Routes Based on RASP Routing Table Inputs. Source: Rowe (2023).

B. FUSED OUTPUTS

The total fuel demand is summarized in Table 1 for all units for the 30-day Phase 1 operations. The fuel demand shown in Table 7 and Table 8 are FUSED outputs showing the fuel demand separated by Case (Dual vs. SFC). The total fuel usage for Case 1 is 28,026,634 gallons and Case 2 is 29,459,611 gallons. The data does indicate an increase in fuel usage due to the decreased efficiency. However, as previously demonstrated, it reduces the frequency of RAS events due to the decreased variability in demand generation. That is, both ship and aviation operations generate demand for JP-5 only.

Table 7. Case 1 Dual Fuel Demand Data Displayed by Group and Fuel Type. Source: Rowe (2023).

Dual Fuel					
	Transit	Operations		Standby	
Group	DFM	DFM	JP5	DFM	JP5
G1	5,276	56,224	101,560	9,754	7,958
G2	12,838	60,776	110,052	3,817	3,114
G3	88,546	10,306	291	3,817	114
G4	18,701	55,209	27,953	3,601	903
G5	20,322	55,209	27,953	3,601	903

Table 8. Case 2 Single Fuel Demand Data Displayed by Group. Source: Rowe (2023).

Single Fuel					
	Transit	Operations		Standby	
Group	JP5	JP5		JP5	
G1	5,439	57,963	101,560	10,056	7,958
G2	13,235	62,656	110,052	3,935	3,114
G3	91,285	10,625	291	3,935	114
G4	19,279	56,917	27,953	3,713	903
G5	20,951	56,917	27,953	3,713	903

C. RASP OUTPUTS

Scenario 1: One LR Tanker

Figure 12 illustrates the scheme of maneuver (SOM) for one LR tanker. In this SOM, the only LR tanker begins in San Diego on Day 1 of Phase I. The LR tanker departs San Diego for CONSOL Station 1, taking eleven days to transit the Pacific Ocean. Due to capacity constraints, the LR tanker can only transfer fuel at CONSOL Station 1, and the model relies on all CLF to transit to CONSOL Station 1. After two days and four CONSOL operations with all CLF in the AOR, the LR tanker departs for an 11-day return trip to San Diego for refueling and repeats the transit. RASP outputs indicate this SOM has a below time of 35% and below max of 60%. This demonstrates that combatants experienced a significant amount of time below the 60% Fuel Safety Threshold. One LR tanker cycle lasts 23 days.

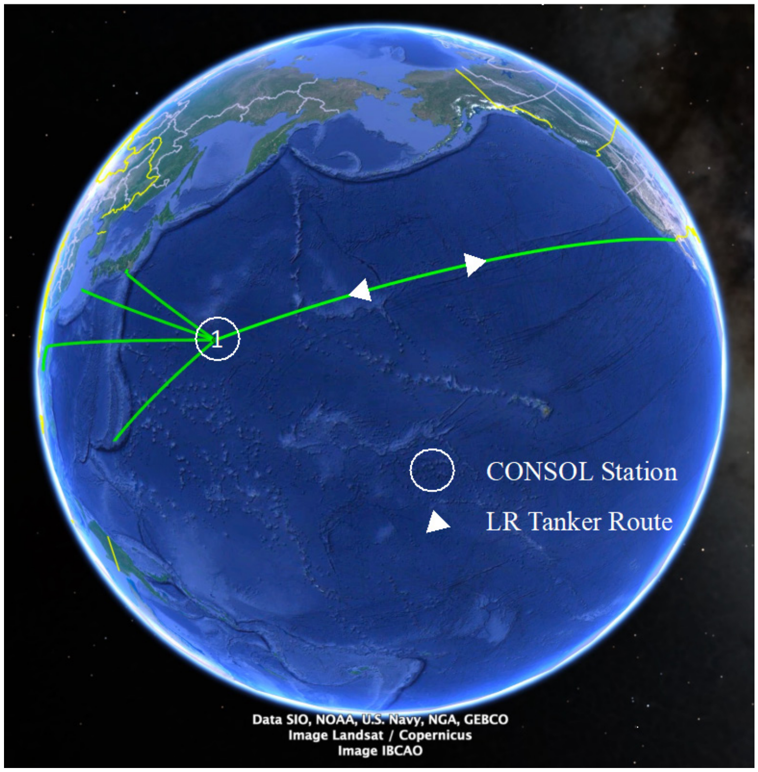


Figure 12. Scenario 1. One LR Tanker Scheme of Maneuver. Adapted from Google Earth (n.d.).

Scenario 1: Two LR Tankers

Figure 13 illustrates the SOM for two LR tankers. In this SOM, one LR tanker departs San Diego on Day 1 of Phase I. The LR tanker departs San Diego for CONSOL Station 1, taking 11 days to transit the Pacific Ocean. After one day and two CONSOL operations, the LR tanker departs for a 2-day transit to CONSOL Station 2 and begins two more CONSOL operations. Once complete at CONSOL Station 2, the LR tanker departs for San Diego, and the second LR tanker departs San Diego to conduct the same underway as the first LR tanker. Once the second LR tanker completes operations at CONSOL Station 2, the first LR tanker repeats the underway, and the cycle continues. One LR tanker cycle lasts 28 days. RASP outputs indicate this SOM has a below time of 16% and a below max of 38%, a marked improvement from only one LR tanker.

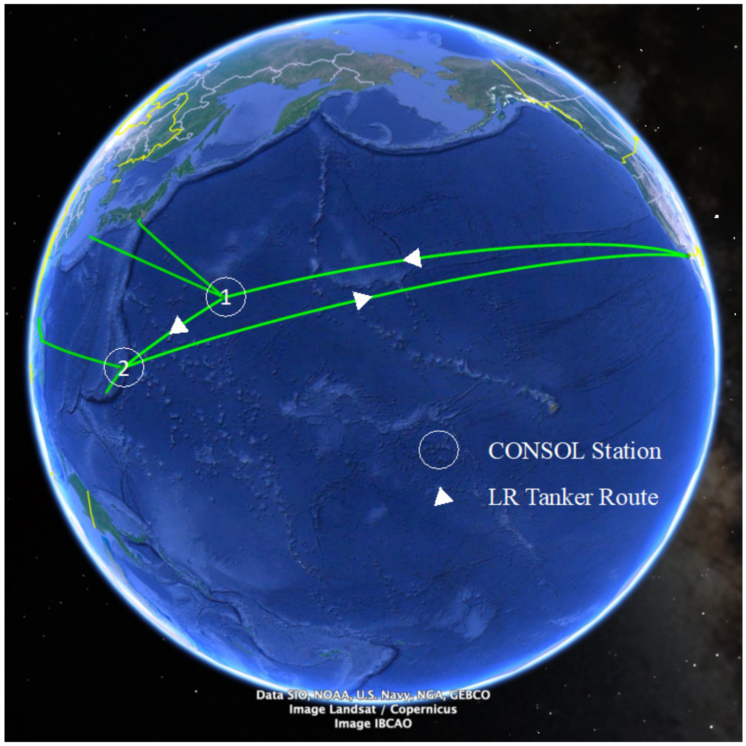


Figure 13. Scenario 1. Two LR Tankers Scheme of Maneuver. Adapted from Google Earth (n.d.).

Scenario 1: Three LR Tankers

Figure 14 illustrates the SOM for three LR tankers. In this SOM, one LR tanker departs San Diego on Day 1 of Phase I. The LR tanker departs San Diego for CONSOL Station 1, taking eleven days to transit the Pacific Ocean. After one day and two CONSOL operations, the LR tanker departs for a 3-day transit to CONSOL Station 2 and begins two more CONSOL operations on Day 16. Once complete, the LR tanker departs for another 3-day transit to CONSOL Station 3 and begins two more CONSOL operations on Day 20. The LR tanker then departs CONSOL Station 3 to return to San Diego. The second LR tanker departs San Diego on Day 14, while the first LR tanker is transiting from CONSOL Station 1 to CONSOL Station 2. The third LR tanker departs San Diego on Day 26 when the first LR tanker is transiting back to San Diego and the second LR tanker is transiting from CONSOL Station 1 to CONSOL Station 2. One LR tanker cycle lasts 33 days. RASP outputs indicate a below time of 8% and a below max of 18%, a significant improvement from two LR tankers and a significant improvement from one LR tanker.

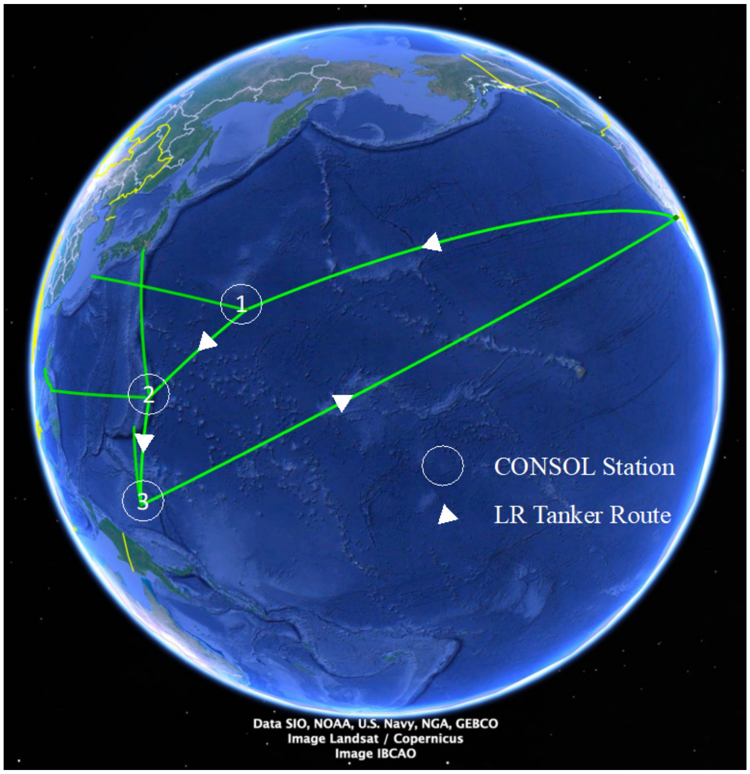


Figure 14. Scenario 1. Three LR Tankers Scheme of Maneuver. Adapted from Google Earth (n.d.).

Scenario 1 in Summary

Table 9 shows the results based on the number of LR tankers supporting the CLF. Our research shows that effectiveness increases as the number of LR tankers increases. The effects are shown in the below time, time below the fuel Safety threshold of 60%, and the below max, the number of units below the fuel safety threshold of 60%. There is an inverse relationship between the number of LR tankers and the amount of time combatants stay above the fuel safety threshold and how much the combatants fall below the fuel safety threshold.

Table 9. Scenario 1 RASP Output. Source: Rowe (2023).

INPUT SETS				SCENARIO SUMMARY					
Provider Ships ACTIVE LRT	Provider Ships FUEL STUDY	Customer Ships FUEL STUDY	Control Panel SOLVE DAYS	Planned RAS	Below Time	Below Max	Provider LOAD	Estimated Provider Fuel (gal)	Optimality Gap
1 LRT	DUAL	DUAL	45 DAYS	29	35%	60%	2	3,413,851	58%
2 LRT	DUAL	DUAL	45 DAYS	32	16%	38%	2	4,192,380	19%
3 LRT	DUAL	DUAL	45 DAYS	35	8%	18%	3	4,532,099	20%

As demonstrated in Figure 15, the more LR tankers are input, the more fuel the LR tankers can pass on to the CLF. Similarly, the number of planned RAS events increases as the number of LR tankers increases, demonstrating the increased fuel transferred to the CLF to support the combatants. The increase from one LR tanker to two LR tankers marks a 22.8% increase in fuel transferred to CLF. Additionally, the increase from two LR tankers to three LR tankers marks an 8.1% increase in fuel transferred to CLF. There is a diminishing return on the input, and we would likely continue to see the increase of fuel transferred to CLF decline with each additional LR tanker input.

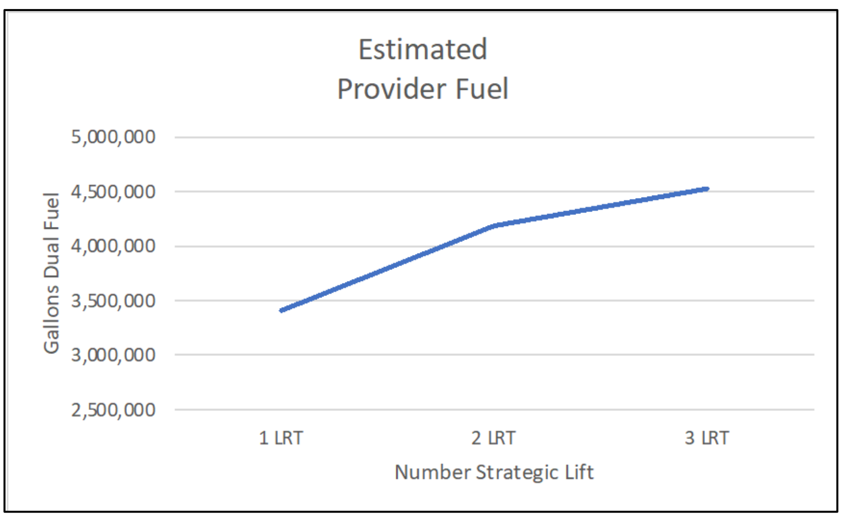


Figure 15. Relationship between Amount of Fuel Provided and Number of LR Tankers

Another metric to consider is the optimality gap which measures the model's ability to deconflict all possible routes and schedules to determine the most effective and efficient distribution model. An ideal optimality gap is below 50%, where RASP has likely found an optimal distribution model but could not prove the solution. This would indicate that the dual fuel model utilizing one LR tanker is not the optimal solution, and further consideration would need to be made if one LR tanker with dual fuel could support the total fuel requirement.

RASP modeling also optimized replenishment schedules based on CLF proximities, CONSOL station locations, and fuel remaining in the LR tanker. To streamline RASP simulations, the model could only match the number of available CONSOL stations with the number of LR tankers in the simulation. For example, when scenario 1 simulated only one available LR tanker, only the most northerly CONSOL station, labeled CONSOL Station 1 in Figure 7, was used for CONSOL operations. Only when a second LR tanker was input to RASP did CONSOL Station 2 become operational; the same held for the third LR tanker and CONSOL Station 3.

Scenario 2: One LR Tanker and Two MR Tankers

Figure 16 illustrates the SOM for one LR tanker and two MR tankers. In this SOM, two MR tankers begin in vicinity of Hawaii, and one LR tanker begins in San Diego. The LR tanker begins its transit to Hawaii on Day 1 of Phase I and arrives on Day 8. The LR tanker then lighters with the MR tanker. The MR tanker begins its transit from Hawaii to CONSOL Station 1 on Day 9, taking six days to transit the Pacific Ocean. On Day 15, the MR tanker conducts two CONSOL operations, then transits for three days to CONSOL Station 2. After completing one CONSOL operation, the MR tanker transits back to Hawaii. The second MR tanker departs Hawaii on Day 16 and arrives at CONSOL Station 1 on Day 22, conducting a single CONSOL operation. The second MR tanker arrives at CONSOL Station 2 on Day 26 and conducts two CONSOL operations. After completing the CONSOL operations, the MR tanker departs for Hawaii. The LR tanker remains staged in Hawaii until the first MR tanker arrives back in Hawaii on Day 29 to lighter with the MR tanker, and the cycle repeats. Due to the capacity of the LR tanker, it remains in Hawaii for the second MR tanker to return to Hawaii to lighter before returning to San Diego to refuel. RASP outputs indicate a below time of 15% and below max of 36%.

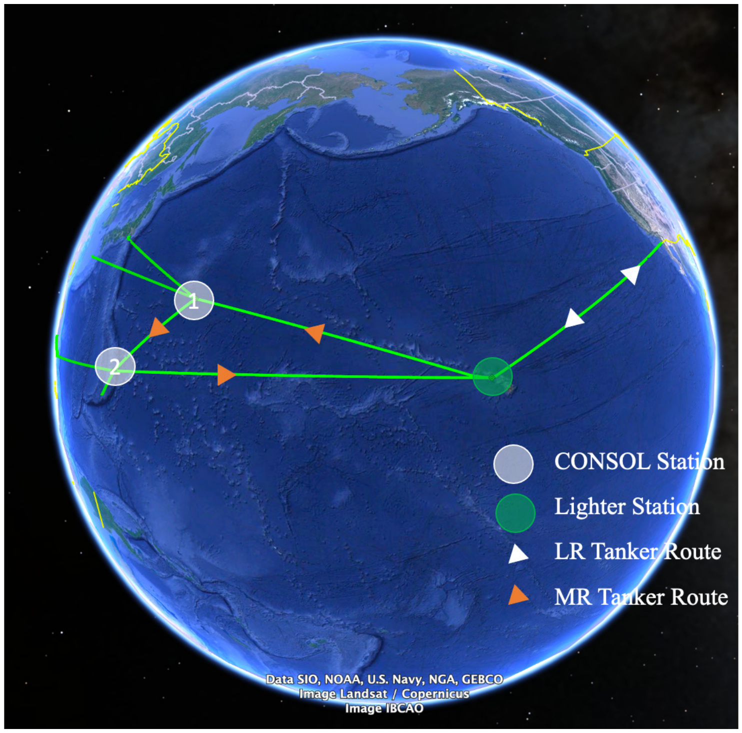


Figure 16. Scenario 2. One LR Tanker and Two MR Tankers Scheme of Maneuver. Adapted from Google Earth (n.d.).

Scenario 2: Two LR Tankers and Three MR Tankers

Figure 17 illustrates the SOM for two LR tankers and three MR tankers. In this SOM, three MR tankers begin in vicinity of Hawaii, and two LR tankers begin in San Diego. The first LR tanker departs San Diego for Hawaii and lighters with the first MR tanker upon arrival on Day 8. The MR tanker departs for a 6-day transit to CONSOL Station 1, where it conducts one CONSOL operation and departs for CONSOL Station 2. At CONSOL Station 2 on Day 19, the MR tanker conducts two CONSOL operations and begins the transit to CONSOL Station 3. The MR tanker departs the AOR on Day 23. The second MR tanker lighters with the LR tanker already in Hawaii and departs on Day 17 to conduct another cycle of the same CONSOL schedule as the first MR tanker. At this point, the second LR tanker departs San Diego for Hawaii. Once the second LR tanker arrives and stages in Hawaii on Day 22, the first LR tanker departs for San Diego. The third MR tanker departs Hawaii on Day 25, arriving at CONSOL Station 1 after Day 30. RASP outputs indicate a below time of 13% and below max of 33%, showing marginal improvements from one LR tanker and two MR tankers.

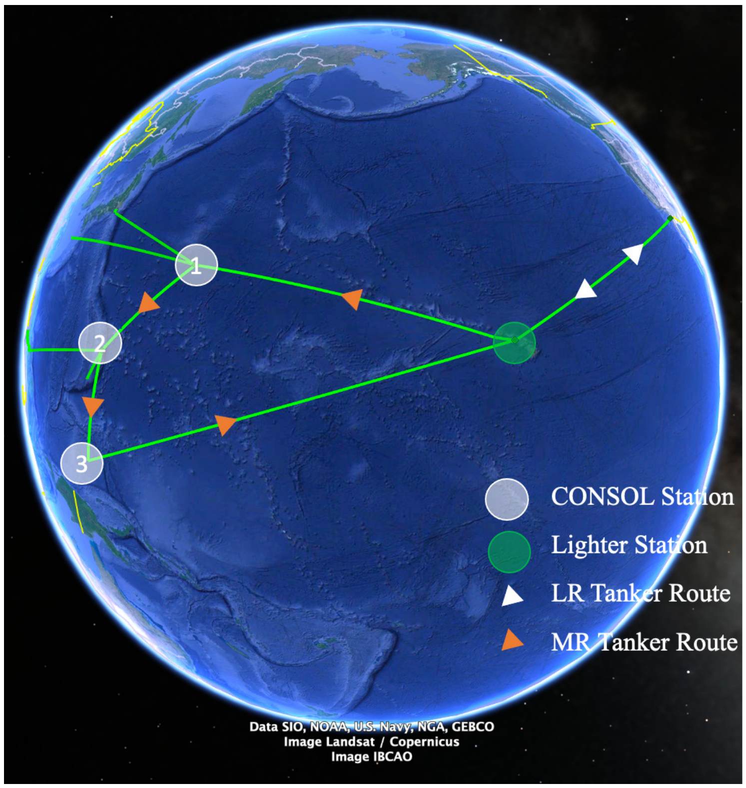


Figure 17. Scenario 2. Two LR Tankers and Three MR Tankers Scheme of Maneuver. Adapted from Google Earth (n.d.)

Scenario 2: Two LR Tankers and Four MR Tankers

Figure 18 illustrates the SOM for two LR tankers and four MR tankers. In this SOM, four MR tankers begin in vicinity of Hawaii, and two LR tankers begin in San Diego. The first LR tanker departs San Diego for Hawaii and lighters with the first MR tanker upon arrival on Day 8. The MR tanker departs for a 6-day transit to CONSOL Station 1, where it conducts one CONSOL operation on Day 15 and departs for CONSOL Station 2. At CONSOL Station 2 on Day 19, the MR tanker conducts two CONSOL operations and begins the transit to CONSOL Station 3, which conducts one CONSOL operation on Day

22. The MR tanker then departs the AOR and arrives in Hawaii just after the 30-day Phase I. The second MR tanker begins the cycle on Day 15, arriving at CONSOL Station 1 on Day 21. The second LR tanker departs San Diego on Day 16 and arrives in Hawaii to relieve the first on Day 22. The first LR tanker returns to San Diego to refuel on Day 28. The third MR tanker begins the cycle on Day 21, arriving at CONSOL Station 1 on Day 27. The fourth MR tanker begins the cycle on Day 27 and arrives in the AOR after Phase I. RASP outputs indicate a below time of 10% and below max of 20%, a marked improvement over the previous simulations within scenario 2.

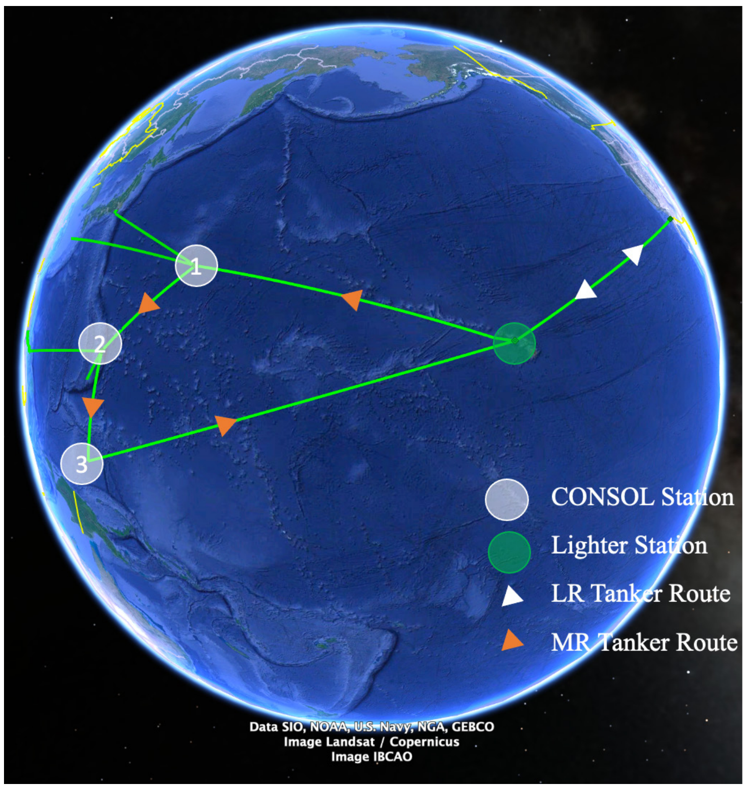


Figure 18. Scenario 2. Two LR Tankers and Four MR Tankers Scheme of Maneuver. Adapted from Google Earth (n.d.).

Scenario 2 in Summary

Table 10 shows the results based on the number of MR and LR tankers supporting the CLF. Our research shows that as the number of MR tankers increases, effectiveness also increases. The effects are shown in the below time and the below max. Like scenario 1, there remains an inverse relationship between the number of MR tankers and the amount of time combatants stay above the fuel safety threshold, and how much the combatants fall below the 60% fuel safety threshold.

Table 10. Scenario 2 RASP Output. Source: Rowe (2023).

INPUT SETS				SCENARIO SUMMARY					
Provider Ships ACTIVE LRT	Provider Ships FUEL STUDY	Customer Ships FUEL STUDY	Control Panel SOLVE DAYS	Planned RAS	Below Time	Below Max	Provider LOAD	Estimated Provider Fuel (gal)	Optimality Gap
2M 1L	DUAL	DUAL	45 DAYS	35	15%	36%	1	3,963,759	46%
3M 2L	DUAL	DUAL	45 DAYS	35	13%	33%	1	4,599,940	39%
4M 2L	DUAL	DUAL	45 DAYS	34	10%	20%	2	5,066,127	26%

As observed in scenario 1, as the quantity of MR tankers increases, the more fuel the MR tankers can transfer to the CLF. However, the number of Planned RAS events fluctuates, remaining relatively steady compared to scenario 1. Figure 19 shows the quantity of fuel provided based on the amount of the different strategic lift assets. The increase from two MR tankers and one LR tanker to three MR tankers and two LR tankers marks a 16.1% increase in fuel transferred to CLF, and the addition from three MR tankers and two LR tankers to four MR tankers and two LR tankers marks a 10.1% increase in fuel transferred to CLF. The optimality gap for all solutions remained below the 50% target, where RASP likely found the optimal solution but may not have been able to prove the solution.

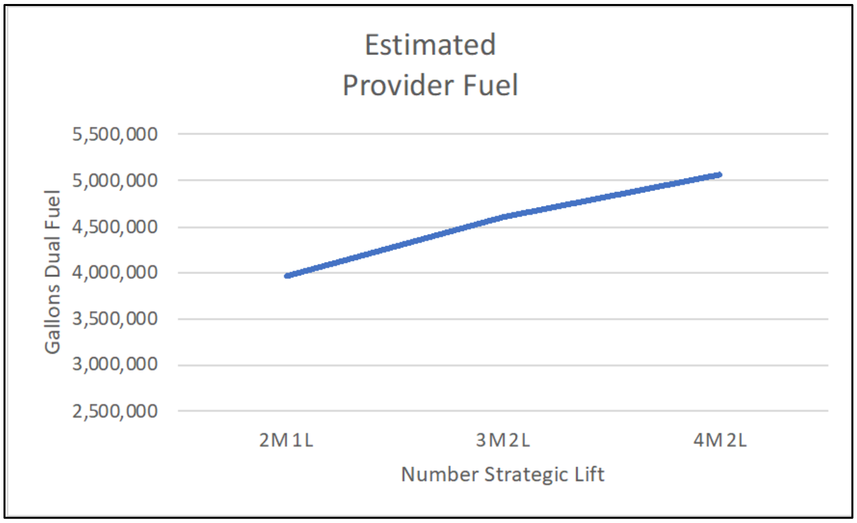


Figure 19. Relationship between Amount of Fuel Provided and Number of Strategic Lift

RASP modeling utilized all units in every model in scenario 2 in a cyclical pattern. Apart from two MR tankers and one LR tanker model, RASP ensured an MR tanker went to all three CONSOL stations, regardless of a required CONSOL operation. This result indicates that RASP inadvertently built-in redundancy to the scenario, an important aspect of readiness and sustainment but not the most efficient.

D. SINGLE VS. DUAL FUEL RESULTS

To compare the effects of SFC vs. dual fuel, the below time and below max of each scenario will be compared against the same strategic lift amounts and configurations. Tables 11 and 12 compare RASP outputs for each scenario. As demonstrated, nominal benefits were realized between the SFC and dual for each respective configuration in the below time metrics. However, greater effects were exhibited in the below max. Because the SFC can be used for both ship propulsion and aviation operations, it allows for a greater quantity of one fuel for both operations. This is due to the capacity augmentation improvements realized due to inventory expansion in both the CLF and combatant, improving endurance for both asset types.

Table 11. Scenario 1 RASP Single vs. Dual Fuel Outputs. Source: Rowe (2023).

INPUT SETS				SCENARIO SUMMARY					
Provider Ships ACTIVE LRT	Provider Ships FUEL STUDY	Customer Ships FUEL STUDY	Control Panel SOLVE DAYS	Planned RAS	Below Time	Below Max	Provider LOAD	Estimated Provider Fuel (gal)	Optimality Gap
1 LRT	DUAL	DUAL	45 DAYS	29	35%	60%	2	3,413,851	58%
1 LRT	SINGLE	SINGLE	45 DAYS	28	34%	60%	2	3,393,711	0%
2 LRT	DUAL	DUAL	45 DAYS	32	16%	38%	2	4,192,380	19%
2 LRT	SINGLE	SINGLE	45 DAYS	32	12%	20%	2	4,204,790	7%
3 LRT	DUAL	DUAL	45 DAYS	35	8%	18%	3	4,532,099	20%
3 LRT	SINGLE	SINGLE	45 DAYS	33	6%	13%	2	4,527,829	11%

Table 12. Scenario 2 RASP Single vs. Dual Fuel Outputs. Source: Rowe (2023).

INPUT SETS				SCENARIO SUMMARY					
Provider Ships ACTIVE LRT	Provider Ships FUEL STUDY	Customer Ships FUEL STUDY	Control Panel SOLVE DAYS	Planned RAS	Below Time	Below Max	Provider LOAD	Estimated Provider Fuel (gal)	Optimality Gap
2M 1L	DUAL	DUAL	45 DAYS	35	15%	36%	1	3,963,759	46%
2M 1L	SINGLE	SINGLE	45 DAYS	34	12%	20%	2	3,913,898	41%
3M 2L	DUAL	DUAL	45 DAYS	35	13%	33%	1	4,599,940	39%
3M 2L	SINGLE	SINGLE	45 DAYS	32	18%	20%	2	4,683,753	44%
4M 2L	DUAL	DUAL	45 DAYS	34	10%	20%	2	5,066,127	26%
4M 2L	SINGLE	SINGLE	45 DAYS	34	6%	13%	1	5,036,957	14%

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Our analysis sought to answer three research questions by utilizing FUSED and RASP. FUSED estimated fuel demand data for two CSGs, two ESGs, and one SAG for two scenarios. While RASP streamlined a replenishment schedule that compared MR and LR tanker configurations and movement.

(1) Optimal Tanker Configuration

The optimal bulk fuel tanker configuration to sustain DMO in our scenarios in the western Pacific Ocean is three LR tankers, as depicted in scenario 1. One LR tanker has an unacceptable 60% below max and 35% below time. This would leave the combatant ships running dangerously low on fuel for a significant time. Although two LR tankers significantly decreased the below max to 38% and below time to 18%, there would need to be a rigorous adherence to the schedule with very few deviations. Three LR tankers keep the combatant ships within an acceptable below max of 18% and below time of 8% while providing maximum fuel. Also, this allows redundancy into the pattern. If one of the tankers must pull into a port for maintenance or is delayed due to weather, two LR tankers can still perform the mission without significantly effecting operations.

The various combinations of MR and LR tankers in Scenario 2 did not yield results that proved significant advantages over three LR tankers. The most effective combination proved to be four MR tankers and two LR tankers. The four MR and two LR tanker combination provided 534,029 gallons more fuel than three LR tankers, but it had a slightly higher below time and below max, as you can see in Table 13. Even though the four MR and two LR combination can provide more fuel, the combatant ships spent slightly more time under the fuel safety threshold than with three LR tankers.

Table 13. Scenario RASP Output Comparison. Source: Rowe (2023).

INPUT SETS				SCENARIO SUMMARY					
Provider Ships ACTIVE LRT	Provider Ships FUEL STUDY	Customer Ships FUEL STUDY	Control Panel SOLVE DAYS	Planned RAS	Below Time	Below Max	Provider LOAD	Estimated Provider Fuel (gal)	Optimality Gap
3 LRT	DUAL	DUAL	45 DAYS	35	8%	18%	3	4,532,099	20%
4M 2L	DUAL	DUAL	45 DAYS	34	10%	20%	2	5,066,127	26%

In scenario 2, four MR and two LR tanker combination, there are more bulk fuel tankers utilized which would increase cost to charter and operate, but the tankers would have almost half the distance to travel for their roundtrip portions. This could decrease maintenance and crew delays. However, the location for the lightering is not an efficient location and takes the bulk fuel tankers an extra 1–2 days to transit as opposed to the straight path from San Diego for the three LR tankers. Due to those constraints in scenario 1, three LR tanker configuration provides the most stability and redundancy for DMO in the western Pacific Ocean. Although, the four MR and two LR tanker combination is a viable alternative and if a more efficient lightering location can be established could be the most effective option.

(2) Contract Requirements

To sustain bulk fuel tanker requirements during Phase I operations, the current contracts can be used depending on the availability of the requested tanker configuration. However, tankers will need to be outfitted with permanent fuel-at-sea (FAS) stations or modular CONSOL adapter kits. The availability of U.S. built, flagged, and crewed tankers would determine if there are enough charters and time to contract for Phase I operations. Contracting for LR tankers may be an obstacle as there are less than 350 vessels worldwide, with few being US built, flagged, and crewed which is a requirement under the Jones Act. Typically, MSC uses time or voyage charters to contract bulk fuel tankers. A time charter would be most logical for this requirement as it allows MSC to have more control over the vessel's operation throughout a specified period and options to extend the term can be added to the contract. Since the tanker market is highly fragmented, a contract would have to be in place for each shipowner. There would be separate pre-award, award, administration, and close-out procedures for each contract. If the tankers can be chartered, another obstacle is having them on station in time for operations. Tankers operate consistently on charters to maintain profitability and may be in the middle of, or completing, a charter when we need them. The ship's location at the time of the contract may not be near our required location. It may take a ship time to get from its last charter location to where MSC requires it to be. Contracting bulk fuel tankers may be hindered by vessel availability and location.

(3) Single Fuel Efficiency

Switching to JP-5 for a single fuel concept does not improve fuel usage efficiency over dual fuel, however it does increase capacity while decreasing RAS frequencies. The capacity that is gained from using a single fuel overcomes the fuel usage inefficiency. It allows for units to stay on mission longer while reducing below time and below max.

B. RECOMMENDATIONS

Given our analysis and results, the following are recommended:

- *Jones Act Amendment.* The use of only US built, flagged, and crewed ships is a limiting factor in responding to a conflict. It currently allows exceptions with a waiver requested by the Secretary of Defense and granted by the Secretary of Homeland Security when national defense is at risk. It would be more efficient to have a built-in clause specifically citing war or conflicts as an exception so contracts can be authorized at the speed of relevance before a conflict.

- *Tanker pool contracts.* These are currently being used in the commercial industry and would provide potential benefit to MSC contracting efforts. The time charter would be with a contract administrator that manages a pool of bulk fuel tankers with various shipowners to meet the requirement. The administrator can determine how many tankers are needed to meet the demand requirement of three LR tankers. They may decide to use six tankers to allow for maintenance issues and ships being in different locations at the start of the conflict. If a conflict arises, having a pool of tankers on contract that exceeds the tanker demand could increase response time, create redundancy, and give tankers flexibility while staying profitable. Also, if the Jones Act was amended it could increase the pool by having a variation of non-U.S. built, flagged, or crewed tankers.

- *Configure new ships.* As there seems to be a hesitancy to switch current combatant ships to JP-5 for a SFC, then consideration should be given to having newly built U.S. Navy ships configured for the SFC.

C. FURTHER RESEARCH

Given our analysis and results, we recommend several topics for future thesis or research projects. Research should be conducted on consolidating DOD-wide fuel logistics for Phases 1 and 2 operations in the INDOPACOM AOR to provide a complete picture of fuel demand and capacity. Future projects should explore Navy Expeditionary, Naval Special Warfare, Expeditionary Advanced Basing Operations, United States Air Force, and United States Army requirements.

Further research should also investigate worldwide fuel and lubricant refinery capacities to support the United States, allies, and adversaries in a conflict and the impact on maintaining civilian demands. Additionally, if the U.S. Navy switches to a SFC would refineries be able to meet demand in normal and prolonged combat operations and how would this affect pricing. This thesis focuses solely on fuel logistics, but future research should consider ammunition, parts, and food to create more optimized schedules. Lastly, further research into testing and establishing multiple lightering locations in the Pacific Ocean outside of the second island chain to provide alternative ways to support the fleet.

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