Framework for Augmenting Current Fleet with Commercially Available Assets for Logistics Support in Contested Environment

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Background

China believes logistics in the contested environment is an Achilles's heel for the U.S. Navy.

The nine-dash line and surrounding countries

Chinese dredging vessels in the waters around Mischief Reef in the disputed Spratly Islands in the South China Sea

First and Second Island Chains

- We explore ways to develop capabilities to replenish potential combating forces through Next Generation Logistics Ships (NGLSs).
- The objective in this research is to study and analyze options for rearming, refueling, and resupplying in the contested and distributed environment.
- The framework created is flexible in terms of the scenarios.
- We develop mathematical models based on the scenarios approved by the sponsor to minimize number of deliveries.

This Research

- In this research, we offer a framework using mathematical models to refuel, rearm, and resupply for future logistics in contested environments to support the potential combat operations of the USN.

- The scenarios developed for this research are,
  - through discussions with the Sponsor
  - based on actual data, but those data are disguised by the authors.

At the foundation of the framework are the following research questions:

- Is the current fleet of vessels adequate to carry out the mission?
- Are there new vessels that can be modified or produced for the purpose of better sustainment through the three vectors of refuel, rearm, and resupply?
- If so, what type of vessels, and how many of each kind, should be acquired?

Description of the Next Generation Logistics Ships (NGLS)

Platform Supply Vessel (PSV)

- Vessel should have sustained speed of about 11–12 knots. The range of travel for PSV is about 3,500 nm.
- Its fuel capacity needs to be about 20,000 bbl.
- Ammunition and cargo capacity needs to be adequate for replenishing cargo, ammunition, and fuel at sea from Combat Logistics Force (CLF), specifically, about 800-900 short tons and deck area being about 10,000 sq ft.
- A major capability of the PSV is to be capable of delivering about 5,000 bbl of fuel under about 2 hours at sea.
- In addition, it needs to be able to deliver 15 loads/hour of ammunition and/or cargo in parallel with refueling.
- This vessel will be unmanned throughout the operational cycle with organic support only when necessary. Autonomously executing the mission is a required capability of PSV.

Description of the Next Generation Logistics Ships (NGLS)

Fast Supply Vessel (FSV)

- Much smaller than PSV but much faster, the sustained speed of an FSV is 23 knots, and the range of travel is about 800–1000 nm.
- The fuel capacity is required to be about 1,000 bbl. Deck area for ammunition and dry cargo is about 2,500 sq ft.
- A major capability of the FSV is to replenish PSV in littorals.
- It also needs to do water transfers with hose reel with roll-on/roll-off capabilities.
- On shore, FSV needs to be able to refuel at a minimum of about 500 gallons/minute with 2,000 ft hose reel.
- It also needs to be capable of conducting missions for 2–3 days without replenishment.
- Finally, it needs to be able to transfer cargo to a pier or ashore.

Description of the Next Generation Logistics Ships (NGLS)

Light Amphibious Warships (LAW)

- These lighter ships will help the Navy and Marine Corps meet new challenges, including sea-control-and-denial operations.
- The light amphibious warships will serve as maneuver and sustainment vessels to confront the changing character of warfare.
- The LAW will have beachability and ability to maneuver shore to shore.
- It will also be able to provide transfer of fuel and cargo from T-ships on beaches and ports (developed and undeveloped) to forces within contested environment.
- The idea is to have a risk-worthy vessel (defensible enough that risks are not excessive or cheap enough that we can afford to lose it) with priority for personnel survivability.

Assumptions

- A delivery is defined as carrying the commodities from a supply node to a demand node, on the given route by the vessel, designated to travel on that route.
- ‘Split 1’ transports commodities from CLF(Combat Logistics Force) to SAG(Surface Action Group) and Transshipment (PSV to LAW/FSV transfer point) nodes
- ‘Split 2’ transports commodities from Transshipment node to ASuW(Anti-Surface Warfare), FARP(Forward Arming and Refueling Point) and LOG(Logistics)
- The advantage of splitting the transshipment network into two transportation networks is twofold
  - One, ‘Split 1’ focuses on USN whereas ‘Split 2’ focuses on USMC.
  - This helps in maintaining the needs of Marines ashore and Navy forces afloat.
  - Second, splitting the network allows sequencing-of-shipment decisions to be separated from ship-capacity decisions, so that, if assets are available, shipments can be made in parallel to save time.

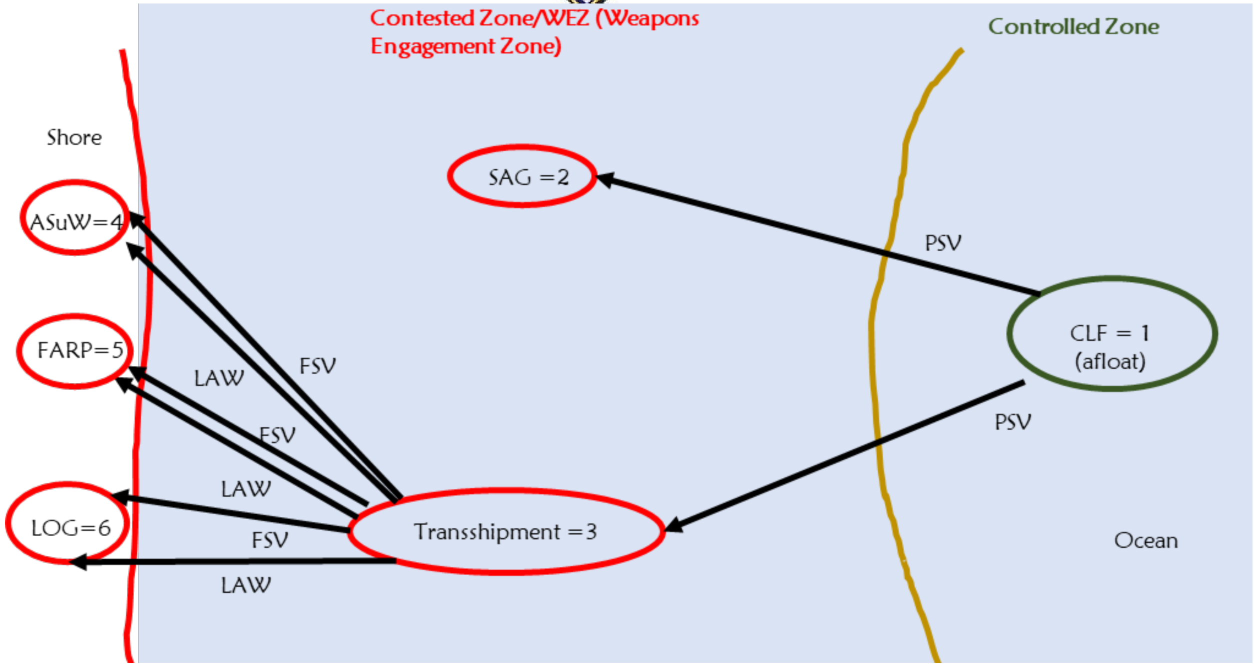

Figure 1: Scenario Based on Subject Matter Expert (SME) Feedback

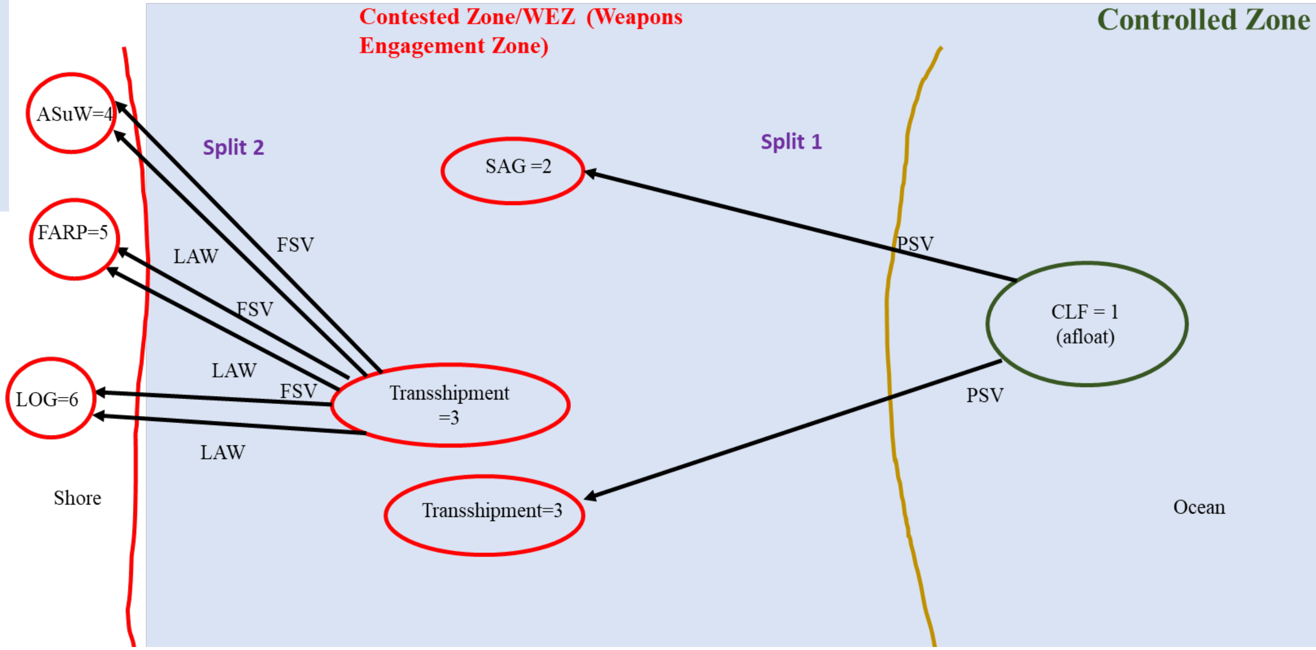

Figure 2: Scenario Based on SME Feedback with Split 1 and Split 2

Results and Interpretation

	Fuel in BBL			Ammunition and Supplies in Pallets		
	Combined Deliveries	Split 1 Deliveries	Split 2 Deliveries	Combined Deliveries	Split 1 Deliveries	Split 2 Deliveries
PSV from CLF 1 to SAG 2	4	4		2	2	
PSV from CLF 1 to Trans 3	2	2		1	1	
FSV from Trans 3 to ASuW 4	1		0	1		0
FSV from Trans 3 to FARP 5	0		0	0		0
FSV from Trans 3 to LOG 6	1		1	0		0
LAW from Trans 3 to ASuW 4	0		1	0		1
LAW from Trans 3 to FARP 5	3		3	1		1
LAW from Trans 3 to LOG 6	0		0	1		1
Total	11	6	5	6	3	3

- Six deliveries by PSV does not necessarily mean six ships. In either scenario results can be thought of as six PSVs making one delivery each, or two PSVs making three deliveries each or….
- Three deliveries by LAWs in either scenario can be thought of as three LAWs making one delivery each or two LAWs, one making two deliveries and the other making one delivery or…..
- The combined network models deliveries to the forward bases as sequential, potentially overstating the resupply time.
- The resupply time to the forward bases, as only the 'split model makes clear, can be as short as the maximum of the round-trip time of *either* the PSV transit from the transshipment point to the CLF and back *or* the FSV/LAW transit from the transshipment-point to the forward base and back.

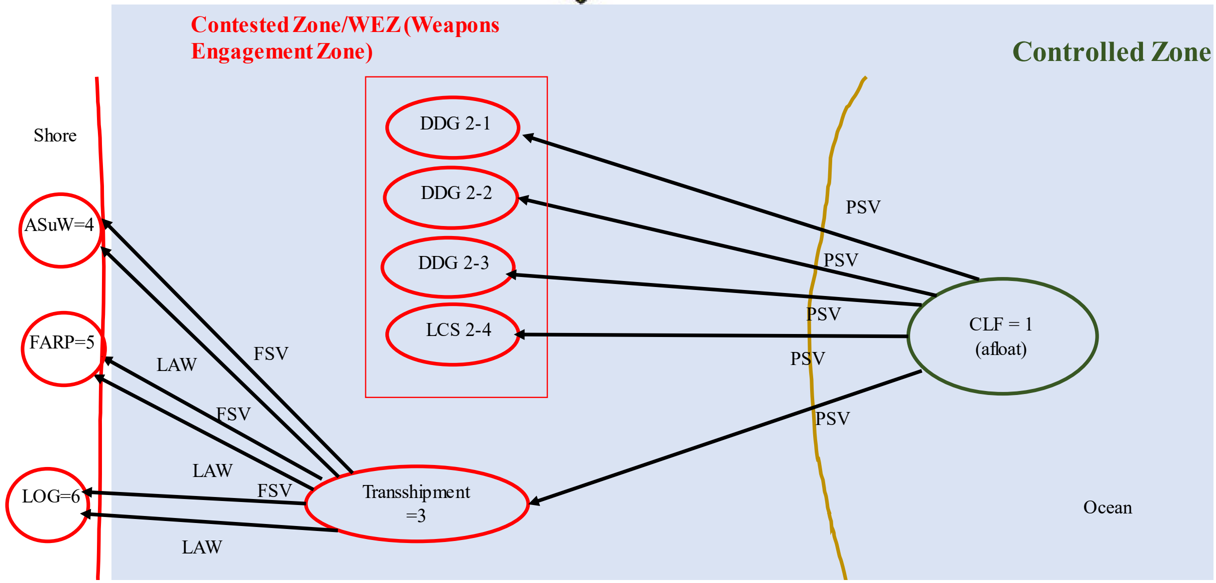

Figure 3: Scenario Based on Separated SAG: Three DDGs and One LCS

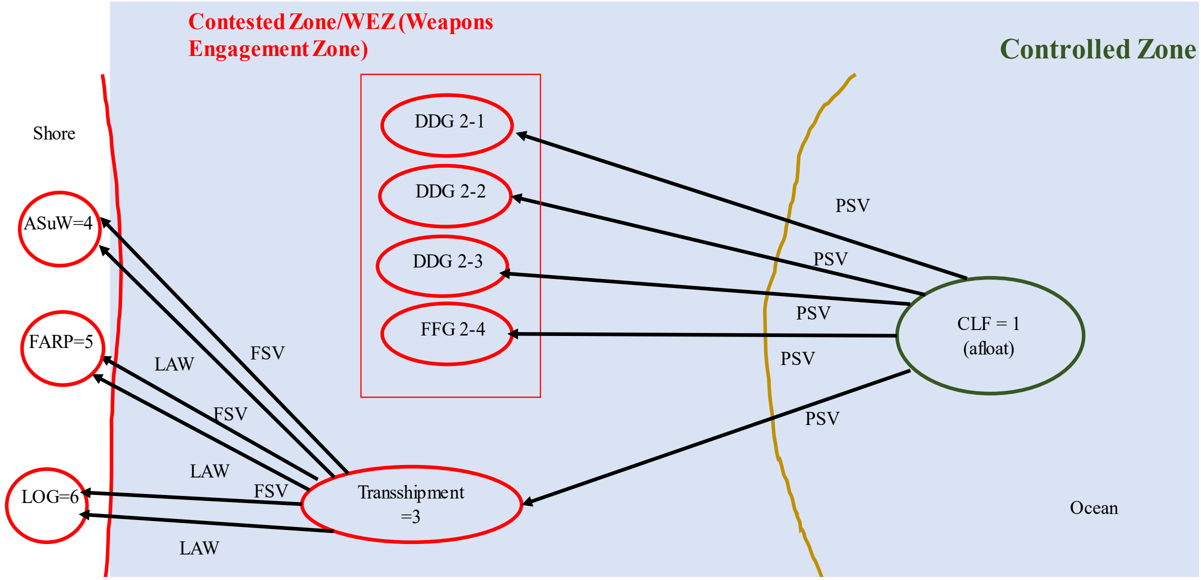

Figure 4: Scenario Based on Separated SAG: Three DDGs and One FFG

Assumptions for Sustained Scenario: Separated SAG

- DDG can sustain for eight days without refueling
- FFG must be refueled every seven days
- LCS must be refueled every four days
- We incorporated this by changing the corresponding demands
- Number of deliveries are the deliveries made by a specific vessel on a specific route for a specific commodity

Results

Minimum Number of Deliveries for Transportation of Fuel in BBL and Ammunition and Supplies in Pallets: Three DDGs and One LCS

	Fuel	Ammunition and Supplies
	Deliveries	Deliveries
PSV from CLF 1 to DDG 2-1	1	1
PSV from CLF 1 to DDG 2-2	1	1
PSV from CLF 1 to DDG 2-3	1	1
PSV from CLF 1 to LCS 2-4	1	1
PSV from CLF 1 to Trans 3	2	1
FSV from Trans 3 to ASuW 4	1	1
FSV from Trans 3 to FARP 5	0	0
FSV from Trans 3 to LOG 6	1	0
LAW from Trans 3 to ASuW 4	0	0
LAW from Trans 3 to FARP 5	3	1
LAW from Trans 3 to LOG 6	0	1
Total	11	8

Minimum Number of Deliveries for Transportation of Fuel in BBL and Ammunition and Supplies in Pallets: Three DDGs and One FFG

	Fuel	Ammunition and Supplies
	Deliveries	Deliveries
PSV from CLF 1 to DDG 2-1	1	1
PSV from CLF 1 to DDG 2-2	1	1
PSV from CLF 1 to DDG 2-3	1	1
PSV from CLF 1 to LCS 2-4	2	1
PSV from CLF 1 to Trans 3	2	1
FSV from Trans 3 to ASuW 4	1	0
FSV from Trans 3 to FARP 5	0	0
FSV from Trans 3 to LOG 6	1	0
LAW from Trans 3 to ASuW 4	0	1
LAW from Trans 3 to FARP 5	3	1
LAW from Trans 3 to LOG 6	0	1
Total	12	8

Recommendations

Based on our analysis we recommend following

- the time-allowed-per-delivery constraint for PSV engaging with SAG in WEZ should be investigated,
- the binding constraint on capacity to transfer is the time-allowed-per-delivery
- capacity of PSV for carrying fuels is much larger than what it can deliver in the time-allowed-per-delivery
- So, if the time-allowed-per-delivery cannot be altered, then increase the rate of transfer
- tweaking at the TLRs and some platform modification so that sustainment can be made much faster and with fewer deliveries

Increased Demand Nodes: Minimum Deliveries for Fuel in BBL and Ammunition and Supplies in Pallets

Scenarios	Three SAGs		Two ASuWs		Three SAGs, Two ASuWs	
	Deliveries		Deliveries		Deliveries	
	Fuel	Ammunition and Supplies	Fuel	Ammunition and Supplies	Fuel	Ammunition and Supplies
PSV from CLF 1 to SAG 2	12	5	4	2	12	5
PSV from CLF 1 to Trans 3	2	1	2	1	2	1
FSV from Trans 3 to ASuW 4	0	0	0	0	0	0
FSV from Trans 3 to FARP 5	0	0	0	0	0	0
FSV from Trans 3 to LOG 6	0	0	1	0	0	0
LAW from Trans 3 to ASuW 4	1	1	1	1	1	1
LAW from Trans 3 to FARP 5	3	1	3	1	3	1
LAW from Trans 3 to LOG 6	1	1	0	1	1	1
Total	19	9	11	6	19	9

Deliveries by FSV and LAW

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

Recommendations

Deliveries by FSV and LAW through all scenarios suggest,

- the most FSVs needed for each of these scenarios to transport fuel are two whereas for the same scenarios five LAWs are also needed
- the most FSVs needed for each of these scenarios to transport ammunition and supplies is one, however, for the same scenarios three LAWs are also needed
- There are no scenarios in which the substitution of a LAW for an FSV would result in a requirement for additional number of ships (1-for-1)
- So, results and our analysis suggest that acquisition of LAWs is preferred to FSVs
- the FSV does not look very useful in these scenarios, since these scenarios did not require the TLRs in which that ship dominated the others (primarily, speed)

Back up Slides

Motivation for the New Vessels

- To optimize its future fleet logistics platforms, the USN is exploring the concept of a common hull, multi-mission auxiliary ship design.
- Acting Secretary of the Navy Modly announced that, *"there are certain ship classes that don't even exist right now that we're looking at that will be added into that mix, but the broad message is, it's going to be a bigger fleet, it's going to be a more distributed fleet, it's going to be a more agile fleet. And we need to figure out what that path is and understand our topline limitations. (Congressional Research Service, 2020)"*
- General David H. Berger, the commandant of the Marine Corps, states, "We must also explore new options, such as inter-theater connectors and commercially available ships and craft that are smaller and less expensive, thereby increasing the affordability and allowing acquisition at a greater quantity. We recognize that we must distribute our forces ashore given the growth of adversary precision strike capabilities, so it would be illogical to continue to concentrate our forces on a few large ships. The adversary will quickly recognize that striking while concentrated (aboard ship) is the preferred option. We need to change this calculus with a new fleet design of smaller, more lethal, and more risk-worthy platforms. (Congressional Research Service, 2020)"

Mathematical Model for Fuel (Figure 2)

Total supply at node i for fuel = S_{Fi} ,**Total demand at node j** for fuel = D_{Fj}

Shared volume capacity for fuel **on vessel** *k* enroute *ij* = cF_{kij}

Modes of transportation: *PSV =1, FSV = 2, LAW = 3*

Split 1

Decision Variables:

X_{Fkij} = flow of **fuel** from source *i* to node *j* on vessel *k, i=1, j= 2, 3, k = 1*

Y_{kij} = *# of deliveries by vessels of type k from node i to j and l*

Objective Function: Minimize Number of Deliveries

$$\min(y_{112} + y_{113})$$

Constraints:

Supply at CLF = 1, $(x_{F112} + x_{F113}) \le SF_1$

Demand at SAG = 2, $x_{F112} \ge DF_2$

at Transshipment = 3, $x_{F113} \ge DF_3$

Capacity Fuel Volume

$$(cF_{112})Y_{112} - X_{F112} \ge 0$$
$$(cF_{113})Y_{113} - X_{F113} \ge 0$$

Y_{kij}*'s integer,* X*'s* ≥ 0

Mathematical Model for Fuel (Figure 2)

Split 2

Decision Variables:

X_{Fkjl} = flow of **fuel** from transshipment node *j* to sink *l* on vessel *k, j=3, l=4, 5, 6, k = 2, 3*

Y_{kij} *= # of deliveries by vessels of type k from node i to j and l*

Objective Function: Minimize Number of Deliveries

$$\min(y_{234} + y_{235} + y_{236} + y_{334} + y_{335} + y_{336})$$

Constraints:

Supply *at Transshipment = 3,*

$$x_{F234} + x_{F235} + x_{F236} + x_{F334} + x_{F335} + x_{F336} \le SF_3$$

Demand *at ASuW = 4,* $x_{F234} + x_{F334} \ge DF_4$

at FARP = 5, $x_{F235} + x_{F335} \ge DF_5$

at LOG = 6, $x_{F236} + x_{F336} \ge DF_6$

Capacity Fuel Volume

$$(cF_{234})Y_{234} - X_{F234} \ge 0$$
$$(cF_{235})Y_{235} - X_{F235} \ge 0$$
$$(cF_{236})Y_{236} - X_{F236} \ge 0$$
$$(cF_{334})Y_{334} - X_{F334} \ge 0$$
$$(cF_{335})Y_{335} - X_{F335} \ge 0$$
$$(cF_{336})Y_{336} - X_{F336} \ge 0$$

Y_{kij}*'s integer,* X_{kij}*'s* ≥ 0

Assumptions

	Fuel in BBL	Ammunition and Supplies in Pallets
	Supply/Demand	Supply/Demand
Supply at CLF 1	1000000	100000
Supply at Trans 3	6500	750
Demand at DDG 2-1	5000	25
Demand at DDG 2-2	5000	25
Demand at DDG 2-3	5000	25
Demand at LCS 2-4	3000	20
Demand at Trans 3	6500	750
Demand at ASuW 4	100	50
Demand at FARP 5	6300	350
Demand at LOG 6	100	350
	Capacity	Capacity
PSV from CLF 1 to DDG 2-1	5500	60
PSV from CLF 1 to DDG 2-2	5500	60
PSV from CLF 1 to DDG 2-3	5500	60
PSV from CLF 1 to DDG 2-4	5500	60
PSV from CLF 1 to Trans 3	5500	800
FSV from Trans 3 to ASuW 4	1000	250
FSV from Trans 3 to FARP 5	1000	250
FSV from Trans 3 to LOG 6	1000	250
LAW from Trans 3 to ASuW 4	2200	1000
LAW from Trans 3 to FARP 5	2200	1000
LAW from Trans 3 to LOG 6	2200	1000

	Fuel in BBL	Ammunition and Supplies in Pallets
	Supply/Demand	Supply/Demand
Supply at CLF 1	1000000	100000
Supply at Trans 3	6500	750
Demand at DDG 2-1	5000	25
Demand at DDG 2-2	5000	25
Demand at DDG 2-3	5000	25
Demand at FFG 2-4	7000	25
Demand at Trans 3	6500	750
Demand at ASuW 4	100	50
Demand at FARP 5	6300	350
Demand at LOG 6	100	350
	Capacity	Capacity
PSV from CLF 1 to DDG 2-1	5500	60
PSV from CLF 1 to DDG 2-2	5500	60
PSV from CLF 1 to DDG 2-3	5500	60
PSV from CLF 1 to DDG 2-4	5500	60
PSV from CLF 1 to Trans 3	5500	800
FSV from Trans 3 to ASuW 4	1000	250
FSV from Trans 3 to FARP 5	1000	250
FSV from Trans 3 to LOG 6	1000	250
LAW from Trans 3 to ASuW 4	2200	1000
LAW from Trans 3 to FARP 5	2200	1000
LAW from Trans 3 to LOG 6	2200	1000

Mathematical Model for Fuel (Figures 3 and 4)

Modes of transportation: *PSV =1, FSV = 2, LAW = 3*

Decision Variables:

X_{Fkij} = flow of **fuel** from source *i* to node *j* on vessel *k, i=1, j= 2-1, 2-2, 2-3, 2-4, and 3, k = 1*

X_{Fkjl} = flow of **fuel** from transshipment node *j* to sink *l* on vessel *k, j=3, l=4, 5, and 6, k = 2, 3*

Y_{kij} *= # of deliveries by vessels of type k from node i to j and l*

Objective Function: Minimize Number of Deliveries

$$\min(y_{112-1} + y_{112-2} + y_{112-3} + y_{112-4} + y_{113} + y_{234} + y_{235} + y_{236} + y_{334} + y_{335} + y_{336})$$

Constraints:

Supply *at CLF = 1,* $(x_{F112-1} + x_{F112-2} + x_{F112-3} + x_{F112-4} + x_{F113}) \le SF_1$

at Transshipment = 3,

$$x_{F234} + x_{F235} + x_{F236} + x_{F334} + x_{F335} + x_{F336} \le SF_3$$

Demand *at DDG = 2-1,* $x_{F112-1} \ge DF_{2-1}$

at DDG = 2-2, $x_{F112-2} \ge DF_{2-2}$

at DDG = 2-3, $x_{F112-3} \ge DF_{2-3}$

at LCS or FFG = 2-4, $x_{F112-4} \ge DF_{2-4}$

at Transshipment = 3, $x_{F113} \ge DF_3$

at ASuW = 4, $x_{F234} + x_{F334} \ge DF_4$

at FARP = 5, $x_{F235} + x_{F335} \ge DF_5$

at LOG = 6, $x_{F236} + x_{F336} \ge DF_6$

Transshipment (Flow Balance)

$$x_{F113} - (x_{F234} + x_{F235} + x_{F236} + x_{F334} + x_{F335} + x_{F336}) \ge 0$$

Capacity Fuel Volume

$$(cF_{112-1})Y_{112-1} - X_{F112-1} \ge 0$$
$$(cF_{112-2})Y_{112-2} - X_{F112-2} \ge 0$$
$$(cF_{112-3})Y_{112-3} - X_{F112-3} \ge 0$$
$$(cF_{112-4})Y_{112-4} - X_{F112-4} \ge 0$$
$$(cF_{113})Y_{113} - X_{F113} \ge 0$$
$$(cF_{234})Y_{234} - X_{F234} \ge 0$$
$$(cF_{235})Y_{235} - X_{F235} \ge 0$$
$$(cF_{236})Y_{236} - X_{F236} \ge 0$$
$$(cF_{334})Y_{334} - X_{F334} \ge 0$$
$$(cF_{335})Y_{335} - X_{F335} \ge 0$$
$$(cF_{336})Y_{336} - X_{F336} \ge 0$$

Y_{kij}*'s integer,* X_{kij}*'s* ≥ 0