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Optimization of combat logistics force required to support major combat operations

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

OPTIMIZATION OF COMBAT LOGISTICS FORCE REQUIRED TO SUPPORT MAJOR COMBAT OPERATIONS

by

Troy C. Morse

September 2008

Thesis Advisor:	W. Matthew Carlyle
Second Reader:	Gerald G. Brown

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13. ABSTRACT (maximum 200 words)

Military requirements development involves operational commanders conducting analyses of a variety of combat scenarios to assess force structure and material requirements to meet their military objectives. The naval component of each command determines the number of Combat Logistics Force (CLF) ships necessary to keep combatant vessels on station. Without sufficient CLF ships, naval forces are unable to sustain continued presence in theater, hampering their ability to support combat operations. Current practice uses spreadsheet-based average consumption models to estimate the CLF requirement. However, these models do not adequately account for surges in demand or coordination of shuttle ships between multiple battle groups. This thesis demonstrates an optimization model coupled with a spreadsheet interface to identify CLF requirements for campaign level analysis through the use of a fictional 60-day combat scenario. We determine that resupply port location is a key determinant of shuttle ship quantity and employment. We also demonstrate an all-shuttle-ship concept that eliminates the need for station ships and further reduces the number of CLF ships necessary to support the mission.

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OPTIMIZATION OF COMBAT LOGISTICS FORCE REQUIRED TO SUPPORT MAJOR COMBAT OPERATIONS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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ABSTRACT

Military requirements development involves operational commanders conducting analyses of a variety of combat scenarios to assess force structure and material requirements to meet their military objectives. The naval component of each command determines the number of Combat Logistics Force (CLF) ships necessary to keep combatant vessels on station. Without sufficient CLF ships, naval forces are unable to sustain continued presence in theater, hampering their ability to support combat operations. Current practice uses spreadsheet-based average consumption models to estimate the CLF requirement. However, these models do not adequately account for surges in demand or coordination of shuttle ships between multiple battle groups. This thesis demonstrates an optimization model coupled with a spreadsheet interface to identify CLF requirements for campaign level analysis through the use of a fictional 60-day combat scenario. We determine that resupply port location is a key determinant of shuttle ship quantity and employment. We also demonstrate an all-shuttle-ship concept that eliminates the need for station ships and further reduces the number of CLF ships necessary to support the mission.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOR	Area of Responsibility
ATF	Amphibious Task Force
BBLS	Barrels
BG	Battle Group
CG	Guided-Missile Cruiser
CJCS	Commander Joint Chiefs of Staff
CLF	Combat Logistics Force
CNA	Center for Naval Analyses
CNO	Chief of Naval Operations
COCOM	Combatant Commander
CINCLANTFLT	Commander, U.S. Atlantic Fleet
COMPACFLT N42	Commander, U.S. Pacific Fleet Logistics Planning
CONREP	Connected Replenishment
CONSOL	Consolidation (AKA "hit")
CSG	Carrier Strike Group
CTF-53	Commander Task Force 53
CVN	Aircraft Carrier (Nuclear)
DDG	Guided-Missile Destroyer
DFM	Distillate Fuel Marine (NATO F76)
ESG	Expeditionary Strike Group
FFG	Guided-Missile Frigate
GAMS	General Algebraic Modeling System
HIT	Replenishment of supplies by CLF ship (AKA "CONSOL")
INCHOP	Administratively gained by an operational fleet
JP5	Naval Aviation Fuel (NATO F44)
KTS	Nautical Miles per Hour (Knots)
LCS	Littoral Combat Ship
LHA	Amphibious Assault Ship
LHD	Amphibious Assault Ship
LPD	Amphibious Transport Dock Ship

LSD	Amphibious Dock Landing Ship
MCO	Major Contingency Operations
MSC	Military Sealift Command
NSS	Naval Simulation System
NWP 4-01.2	Naval Warfare Publication Sustainment at Sea
OPNAV N42	Navy Strategic Mobility and Combat Logistics
OPNAV N81	Assessment Division
SBF	Subic Bay Freeport
STONS	Short Tons
T-AE	Ammunition Ship
T-AFS	Combat Stores Ship
T-AKE	Auxiliary Dry Cargo and Ammunition Ship
T-AO	Fleet Oiler
T-AOE	Fast Combat Support Ship
TRANSCOM	United States Transportation Command
UNREP	Underway Replenishment
VBA	Visual Basic for Applications
VERTREP	Vertical Replenishment
ZBR	Zero Baseline Review

EXECUTIVE SUMMARY

Each Combatant Commander (COCOM) is responsible for contingency planning within his area of responsibility (AOR). This thesis provides a tool that will assist COCOM staffs in determining the Combat Logistics Force (CLF) required to support the naval component of each contingency operational plan and determine the overall CLF force necessary to support each AOR.

Commander Pacific Fleet N42 has been asked to participate in a CLF Zero Baseline review working group and is conducting analyses of third and seventh fleet requirements, which it will provide to OPNAV N42 for consolidation with input from other fleet logistics offices to determine the overall CLF fleet requirement. PACFLT N42 is currently attempting to build logistics elements into the Naval Simulation System (NSS) to capture logistics requirements during contingency planning simulation runs; they have requested that we perform parallel analysis with the CLF optimization model initially developed in a 2001 thesis by Borden, and further refined through several theses with the latest prior version developed in a 2006 thesis by Doyle, to provide insights into asset allocation and utilization for specific scenarios

The objective of this thesis is to show how the CLF planning tool, in conjunction with our newly developed scenario builder user interface, can be used to evaluate the CLF requirement for a particular AOR under combat conditions to determine the optimal allocation of CLF ships in support of a major combat operation. We develop a fictional scenario to simulate a convergence of a large naval force in a major theater of operations.

Our analyses offer several layers of insight on the use of optimization for theater level CLF planning. First we analyze the current CLF model to determine if the underlying sea routes network and scenario battle group tracks provide enough detail to adequately represent the employment of CLF assets in a particular AOR. We demonstrate how to improve the model and provide recommendations on future work to expand the sea routes network in areas of interest where resolution is lacking. Our primary analysis outlines how we determine resupply port requirements and CLF ship

composition and employment techniques. Subsequent analyses demonstrate the positive impact the T-AKE has on battle group inventory levels due to that ship's dual-commodity capability, and look at the influence of converting station ships into shuttle ships once in the condensed operating area of our scenario.

The most important finding in our study is the effectiveness of the CLF planning model and the flexibility provided by the scenario builder user interface. Together these tools provide decision support analysis to the operational commander in determining campaign-level CLF requirements. When conducted on several scenarios of interest, these analyses provide information that can then be aggregated to provide the fleet commander with a better understanding of his overall fleet requirement, and can aid force planners in developing future force structure concepts. The interface we develop provides an efficient way to update CLF composition, allowing an analyst to run several models and compare several compositions in a short period of time, and it minimizes the possibility of programming errors through automation of input data files.

In our first model play we demonstrate how the positions of resupply ports play an important role in the total number of CLF ships necessary to support combat operations. The longer the cycle time required for traveling to the port of resupply and back to the theater of operations, the greater the number of assets required to keep combatant ships at appropriate supply levels. The addition of nearby ports also allows for the elimination of station ships because the battle groups no longer need the extended capacity to subsist between shuttle ship CONSOLS. Our analysis of replacing the T-AFS and T-AE with the T-AKE demonstrates the added benefits of the T-AKE residual capacity even when these are loaded in T-AFS or T-AE configurations.

The process of conducting these analyses, from basic scenario construction, to ensuring network connectivity, adding resupply ports, and reconfiguring the CLF assets, helps logistics planners think through the logistics force requirements for any operation. These steps identify shortfalls and excesses in planned logistics support and suggest decisions to remedy these issues.

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I. INTRODUCTION

The Goldwater-Nichols Military Reorganization Act of 1986 places a greater emphasis on the role of the Combat Commander (COCOM) by establishing a direct line of communication between him and the President of the United States through the Chairman of the Joint Chiefs of Staff (CJCS). This relationship directly influences the way we develop and implement military strategy in line with the National Security Strategy [NSS, 2006]. Each COCOM is responsible for contingency planning within his areas of responsibility (AORs). CJCS develops the National Military Strategy which outlines military priorities as they relate to the National Security Strategy [NMS, 2004]. This document then guides the COCOM to develop comprehensive contingency operational plans (OPLAN) and determine what forces will be required to meet those demands. This thesis provides a tool that will assist the COCOM staff in determining the Combat Logistics Force (CLF) structure required to support the naval component of each OPLAN and develop the overall CLF force structure necessary to support the COCOM AORs.

A. PACIFIC FLEET COMPONENT FOR THE OPNAV N-42 COMBAT LOGISTICS FORCE ZERO-BASELINE REVIEW

Chief of Naval Operations Strategic Mobility and Combat Logistics (OPNAV N42) is currently conducting a Zero-Baseline Review (ZBR) of the CLF to ensure that the force structure and capabilities meet fleet requirements at the lowest cost and with acceptable risk. As a member of the ZBR working group, Commander Pacific Fleet N42 (COMPACFLT N42) is conducting analyses of third and seventh fleet requirements, which it will provide to OPNAV N42 for consolidation with input from other fleet logistics offices to determine the overall requirements of the force. COMPACFLT N42 is currently attempting to build logistics elements into the Naval Simulation System (NSS) [SPAWAR, 2001] to capture logistics requirements during contingency planning operations simulation runs. They have requested that we perform parallel analyses with the CLF optimization model initially developed in [Borden, 2001], and further refined through several theses with the most recent version developed in Doyle [2006], to provide additional insights into asset allocation and utilization for specific scenarios. The format of the data used in COMPACFLT's NSS simulation runs could not be easily extracted by COMPACFLT to build our scenario for the optimization model. Therefore, we developed a similar scenario located in the 7th Fleet AOR which is representative of the types of combat scenarios they are modeling. Through this fictional scenario we demonstrate how our system is used as a decision analysis tool and can be adapted to any scenario, fleet-specific or global, to provide CLF fleet planning analysis as well as operational CLF requirements planning.

B. CLF FORCE STRUCTURE AND T-AKE PHASED REPLACEMENT

The ability to provide logistic support to forward-deployed naval forces is essential in ensuring that these forces can remain on station indefinitely in any potential conflict. Military Sealift Command (MSC), a subordinate command of Transportation Command (TRANSCOM), provides logistics support to naval forces primarily through the CLF. The CLF is currently comprised of 31 vessels of five basic ship types, but it is currently undergoing a transformation to 30 ships of three basic types by 2014. This force is charged with the delivery of four basic commodities to the fleet; diesel fuel marine (DFM), aviation fuel (JP5), ordinance, and dry stores (the last of which includes spare parts, mail, dry goods, fresh fruits and vegetables, and frozen goods). Table 1 indicates the cargo capacities of each CLF ship type for each of the four basic commodities.

Ship Type	Speed (kts)	Range (nm)	POL Type	POL Capacity (bbls)	Cargo Type	Cargo Capacity (stons)
T-AO	16	3,000	**DFM**	72,000	**Stores**	220
			JP5	108,520	**Ordinance**	0
T-AKE	20	14,000	**DFM**	7,000	**Stores**	1,963*
			JP7	17,000	**Ordinance**	3,647*
T-AOE	26	3,000	**DFM**	62,400	**Stores**	952
			JP5	93,600	**Ordinance**	2,016
T-AE	20	10,000	**DFM**	8,674	**Stores**	0
			JP5	1,000	**Ordinance**	4,928
T-AFS	21	10,000	**DFM**	8,674	**Stores**	4,600
			JP5	10,000	**Ordinance**	0

* 5610 stons split between stores and ordinance in various proportions. 40/60 split shown.

Table 1. CLF Ship Capabilities (After NWP 4-01.2, 2007)

This table is read as follows: T-AKE has a maximum sustained speed of 20 kts, a maximum range without refueling of 14,000 nautical miles, a cargo DFM capacity of 7,000 bbls, a cargo JP5 capacity of 17,000 bbls, an ordinance capacity of 1,963 stons and a stores capacity of 3,647 stons. The stores-to-ordinance ratio is shown at 40/60, but is capable of multiple configurations.

The Kaiser Class (T-AO) is capable of carrying about 180,000 barrels of fuel oil, and 220 short tons of cargo lube oil, dry stores, and refrigerated containers, at 20 knots. Despite this residual dry stores capacity, it is rarely used to transfer dry goods to fleet customers. We will, therefore, ignore this small residual capacity in our analysis. The Supply Class (T-AOE) is the only remaining vessel in the CLF fleet capable of carrying significant amounts of all four commodities. Able to carry 156,000 barrels of fuel oil, 2,000 short tons of ordnance, 550 short tons of dry stores, and 400 short tons of refrigerated stores, at speeds exceeding 26 knots, it is also the only ship in the CLF fleet that can keep pace with a Carrier Strike Group (CSG) and is therefore often used as a station ship for those battle groups. The Kilauea Class Ammunition shuttle ship (T-AE) is a single commodity delivery ship capable of providing 4,900 short tons of ordinance to combat ships via connected or vertical replenishment (CONREP or VERTREP). Likewise, the Saturn Class Combat Stores shuttle (T-AFS) is a single-commodity vessel providing 4,600 short tons of dry stores via CONREP and VERTREP [MSC, 2008].

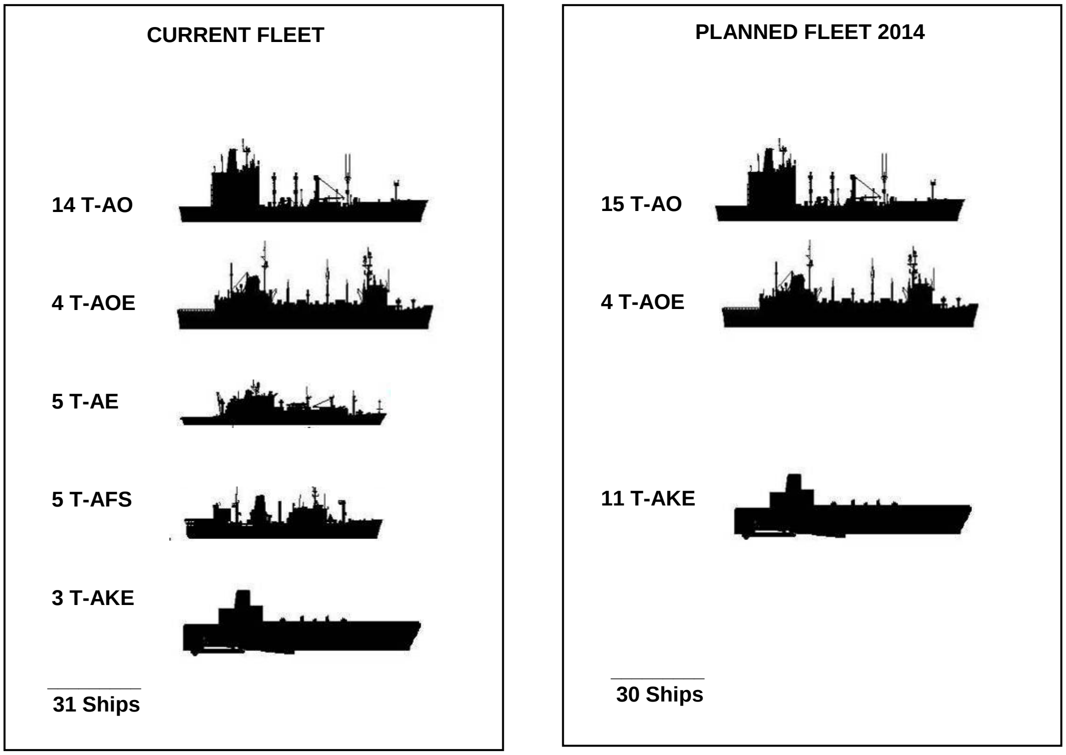


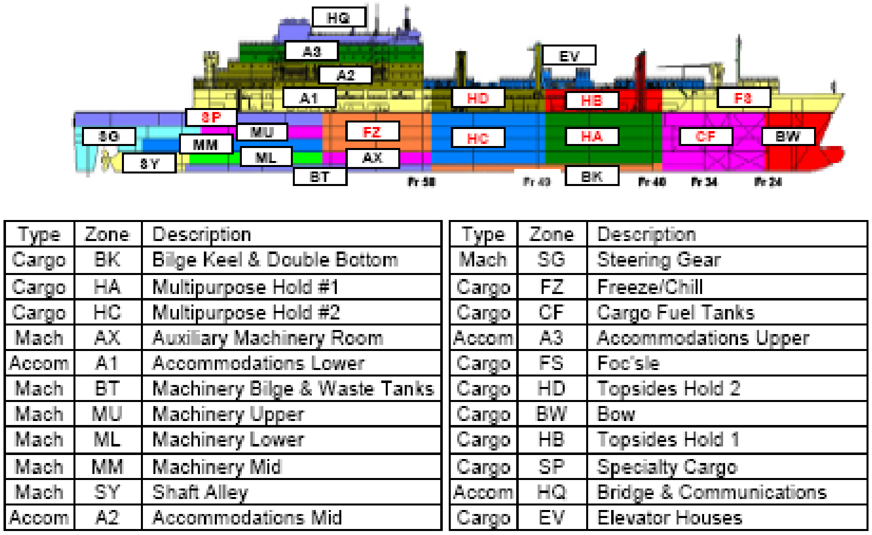
Figure 1. Current and Future CLF Configuration

As shown in Figure 1, the Auxiliary Dry Cargo Carrier (T-AKE), a multi-commodity delivery ship, will replace the T-AFS and T-AE which will be phased out as the new ships become operational. MSC is scheduled to take ownership of approximately two new vessels per year to reach its end strength of 11 total T-AKEs by 2012. The Combat Stores shuttle ships (T-AFS) should be completely replaced by the end of 2008 with the last Ammunition Shuttle Ship (T-AE) scheduled to depart active service by 2010.

The 30 vessels are divided among the six operational fleets based on several allocation studies conducted by the Center for Naval Analysis, OPNAV N42, the Naval Postgraduate School's Operations Research Department, and others. This allocation is continually reviewed and is currently being studied through the CLF ZBR at N42. This does not mean that all 30 ships are available for employment. Crew training, leave and scheduled depot maintenance remove 10 to 15 percent of the fleet from availability at any given time. This leaves approximately 25 to 27 vessels available to be shared in the global allocation pool. While this number has proved sufficient to cover the requirements of normal peacetime operations, the system becomes strained by combat operations, especially in geographically dispersed areas with longer sea lines of communication. It is, therefore, necessary to include analysis of the CLF requirements in planning for major combat operations to ensure that the system does not become overwhelmed.

C. T-AKE CONFIGURATION MANAGEMENT

T-AKE provides a dual commodity logistics lift of ammunition and dry stores to station ships and other ships operating with naval forces from supply sources, such as friendly ports, and at sea from merchant vessels. Unique in design, the T-AKE is capable of reconfiguring its dry storerooms to accommodate various load quantities of ammunition and dry stores. The Lewis and Clark Class T-AKE is designed to carry 63 percent of the combined load of the T-AE and the T-AFS dry stores and ammunition and 100 percent of the refrigerated stores. Through storeroom conversion of the Multi-Purpose dry cargo holds, indicated in Figure 2, she is able to achieve better than 100 percent of T-AE ammunition capacity or T-AFS stores capacity plus maintain full capacity for refrigerated stores. In addition, the refrigerated storerooms can be converted to dry storerooms further adding to the versatility of this platform.



Type	Zone	Description	Type	Zone	Description
Cargo	BK	Bilge Keel & Double Bottom	Mach	SG	Steering Gear
Cargo	HA	Multipurpose Hold #1	Cargo	FZ	Freeze/Chill
Cargo	HC	Multipurpose Hold #2	Cargo	CF	Cargo Fuel Tanks
Mach	AX	Auxiliary Machinery Room	Accom	A3	Accommodations Upper
Accom	A1	Accommodations Lower	Cargo	FS	Foc'sle
Mach	BT	Machinery Bilge & Waste Tanks	Cargo	HD	Topsides Hold 2
Mach	MU	Machinery Upper	Cargo	BW	Bow
Mach	ML	Machinery Lower	Cargo	HB	Topsides Hold 1
Mach	MM	Machinery Mid	Cargo	SP	Specialty Cargo
Mach	SY	Shaft Alley	Accom	HQ	Bridge & Communications
Accom	A2	Accommodations Mid	Cargo	EV	Elevator Houses

Figure 2. T-AKE Storeroom Configuration (From Schwaneke, 2004)

Multipurpose holds HA and HC can be reconfigured by deck to carry various amounts of dry stores and ordinance. In addition, the Freeze/Chill holds designated FZ can be converted for dry stores.

The ability to convert storerooms is of great benefit to the operational planner who can adjust the configuration to best meet the requirements of the specific operation. For the purposes of this thesis, we will consider five possible configurations of the T-AKE. These configurations, outlined in Table 2, are by no means the only combinations possible in the T-AKE, but they represent a range of configuration options and will give us insight into the general configurations that will provide the greatest level of support for the given scenario. Further analysis can then be done with these configurations as a baseline to determine an optimal mix of ordinance and stores.

Configuration	POL Type	POL Capacity (bbls)	Cargo Type	Cargo Capacity (stons)
T-AKE_AE_Load	**DFM**	7,000	**Stores**	682
	JP5	17,000	**Ordinance**	4,928
T-AKE_AFS_Load	**DFM**	7,000	**Stores**	4,600
	JP5	17,000	**Ordinance**	1,010
T-AKE_35_65_Load	**DFM**	7,000	**Stores**	1,963
	JP5	17,000	**Ordinance**	3,647
T-AKE_50_50_Load	**DFM**	7,000	**Stores**	2,805
	JP5	17,000	**Ordinance**	2,805
T-AKE_65_35_Load	**DFM**	7,000	**Stores**	3,647
	JP5	17,000	**Ordinance**	1,963

Table 2. T-AKE Scenario Configurations (After NWP 4-01.2, 2007)

For Example, T-AKE_35_65_Load represents the T-AKE configured with 35 percent of its capacity available for dry stores and 65 percent of its capacity available for ordinance. This vessel is capable of carrying a maximum of 7,000 bbls cargo DFM, 17,000 bbls cargo JP5, 1,963 stons stores, and 3,647 stons ordinance.

D. REVIEW OF PAST ANALYSIS FOR CLF FLEET SIZING

1. Optimizing the Number and Employment of Combat Logistics Force Shuttle Ships, with a Case Study of the T-AKE Ship

Borden [2001] initially developed a CLF optimization model in order to study the fleet composition of the Combat Logistics Force. He used that new model to evaluate a new ship class, the T-AKE, to provide recommendations on procurement quantities. Analysis over six different scenarios provided key information that aided in the Navy’s decision to procure 11 of the new class to recapitalize the aging fleet. In addition, he provided insight on how to best load and schedule supporting shuttle ships with the correct mix of fuel, ammunition, and consumable stores to resupply each of his distinctly different scenarios. His results show that it is better to reconfigure the T-AKE for each required load.

2. A Comparison of the Operational Potential and Capability of Two Combat Logistics Force Alternatives

Givens [2002] further developed Borden's model to evaluate two proposed CLF configurations. Alternative 1, developed by the Center for Naval Analyses, consists of three ship classes: T-AKE, T-AO, and T-AOE. Alternative 2, developed and approved by the Commander-in-Chief, U.S. Atlantic Fleet (CINCLANTFLT) [2001], utilizes these three classes, but adds a fourth ship class, the T-AOE(X), a next generation, triple commodity replenishment ship capable of high speeds that would allow it to keep up with its combatant customers. Givens' analysis reveals little difference between the two alternatives and assisted in the decision not to invest in the T-AOE(X).

3. Optimizing Global Operations Plans for the Combat Logistics Force

Cardillo [2004] examined a scenario representing CLF operations in support of the U.S. Navy's Fleet Response Plan [GlobalSecurity.org, 2008d]. His scenario consisted of world wide deployment of every available U.S. combatant vessel to support two major theater wars. Cardillo's work challenges the results of a spreadsheet employed by OPNAV N81, which evaluates the CLF requirement based on average daily demand. His analysis shows that by using an optimization model to determine CLF requirements based on forecasted daily demand instead of average daily demand, the CLF force recommendation is more robust and is able to account for large surges in demand due to the increase in activity in the major areas of operation.

4. Optimizing Global Combat Logistics Force Support for Sea Base Operations

DeGrange [2005] further embellished the CLF optimization to study support of a sea base during combat and follow-on humanitarian assistance operations. In his scenarios, the sea base becomes a large consumer of commodities as it pushes materiel ashore in support of combat operations. In addition, he studies the effects of adjusting inventory "safety" and "extremis" levels on consumer ships, and explores the effects of the Navy transitioning to a single fuel, rather than separate DFM and JP5.

5. Evaluation of Fleet Ownership versus Global Allocation of Ships in the Combat Logistics Force

Doyle [2006] evaluated two alternate ways to manage the CLF fleet, one in which each ship operates under a particular fleet ownership, and another in which the ships are centrally managed and globally deployed. He introduces an optimization-based scheduling tool, and uses it to evaluate a 181-day peacetime scenario tracking daily inventories of 13 battle groups to explore the best employment of CLF ships. Doyle also introduces the ability of a shuttle ship to consol more than one battle group prior to returning to port for resupply.

E. THESIS OBJECTIVES

All previous work conducted with the CLF planning model has been in support of fleet sizing and utilization studies for the entire CLF fleet. The objective of this thesis is to show how the CLF planning tool in conjunction with our new scenario builder user interface can be used to evaluate the CLF requirement for a particular area of operation under combat conditions to determine the optimal allocation of CLF ships in support of a major combat operation. The fictional scenario we use has been developed to simulate a convergence of a large naval force in a major theater of operations, and our analyses determine the minimum number of CLF ships necessary to meet the daily logistics demands. We also explore an optimal mix of CLF hull types, including several possible configurations of T-AKE, in order to provide the greatest level of support with the minimum number of assets. Finally, we discuss the tradeoffs associated with using CLF assets as station ships and as shuttle ships, and we show the benefits of a centrally managed CLF shuttle fleet in support of specific combat operations.

The scenario is developed using the Scenario Building interface and will serve as an example for the functionality of this interface. We aim to provide a useful tool to enable naval logistics planners to complete CLF asset optimization analysis for scenarios ranging from individual combat action to global fleet allocation and allow for CLF force sizing analysis which has been demonstrated by the aforementioned thesis work.

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II. SCENARIO DEVELOPMENT AND USER INTERFACE

A. OVERVIEW OF THE CLF PLANNING MODEL

The CLF planning model we use for our analyses, originally developed in [Borden , 2001], is a mixed integer program which minimizes the total number of short-ton-days that the combat fleet experiences stock levels below safety stock in four basic commodities. It optimizes the use of CLF shuttle ships along an underlying sea routes network to push the maximum amount of materiel out to the customer ships. The sea routes network is a conglomeration of identified waypoints, resupply ports, and tracks traveled by the battle groups built into the scenario. By overlaying the battle group tracks on the existing network, the sea routes program creates new waypoints and rhumb lines at intersection points, greatly increasing the fidelity of the network, especially in the area of operations. A Floyd-Warshall all-pairs shortest path algorithm is then used to find the optimal path for each class of shuttle ship from each customer, to the best resupply port, and then on to another customer over the entire network.

Data requirements for a scenario include, for each battle group, its composition, daily position and employment, daily consumption factors for the four basic commodities, and the composition of the CLF for the duration of the scenario. The primary decision variables are binary indicators, each of which indicates that a particular shuttle ship replenishes a specific battle group on a specific day. The objective function value is a representation of total short-ton-day shortage experienced by the combat fleet within the scenario, and contains increasing penalties for falling below the 50 percent safety stock, 25 percent extremis stock levels, and negative stock levels. An additional safety penalty is assessed for each occurrence of underway replenishment to encourage moving the maximum amount of materiel in the minimum number of required replenishments.

For further information on the development of the model or the underlying mathematics please see [Borden, 2001], [Givens, 2002], [Cardillo, 2004], [DeGrange, 2005], and [Doyle, 2006].

B. SCENARIO DEFINITION

1. Background

The notional, unclassified scenario we have developed to exercise the CLF planning model and demonstrate the usefulness of our scenario building tool is based on the highly contested chain of islands, rocks, and reefs in the South China Sea known as the Spratly Islands. This chain of geographic features is important to the surrounding nations due to its location along the world's second busiest international sea lane, the abundance of natural gas, oil and other resources, and the desire for nations surrounding the islands to increase their claims of territorial seas and archipelagic waters. With the increase in economic growth throughout Asia, the consumption of oil by Southeast Asian nations is increasing at an exponential rate. Therefore, many of the nations in the region are trying to control the resources in the Spratly Islands as well as the main trade route through which oil from the Middle East and Africa is delivered.

Figure 3. Spratly Islands Geography and Resources [From GlobalSecurity.org, 2008b]

Historical disputes over the island chain and its fossil fuel resources have included:

- Indonesia's ownership of the gas-rich Natuna Island group was undisputed until China released an official map indicating that the Natunas were in Chinese-claimed waters.
- The Philippines' Malampaya and Camago natural gas and condensate fields are in Chinese-claimed waters.
- Many of Malaysia's natural gas fields located offshore Sarawak also fall under the Chinese claim.
- Vietnam and China have overlapping claims to undeveloped blocks off the Vietnamese coast. A block referred to by the Chinese as Wan' Bei-21 (WAB-21) west of the Spratly Islands is claimed by the Vietnamese in their blocks 133, 134, and 135. In addition, Vietnam's Dai Hung (Big Bear) oil field is at the boundary of waters claimed by the Chinese.

- Maritime boundaries in the gas-rich Gulf of Thailand portion of the South China Sea have not been clearly defined. Several companies have been signed exploration agreements but have been unable to drill in a disputed zone between Cambodia and Thailand. [from GlobalSecurity.org, 2008c].

In our scenario, country red (the aggressor) invades several of the islands under Philippine control. The Philippines have requested U.S. assistance in accordance with the Mutual Defense Treaty of 1951 that states the United States will assist in the defense of Philippine armed forces, vessels, planes, and supply ships "that may be attacked, no matter where, by a hostile force" [DFA, 2008]. The United States has determined that it will send three Carrier Strike Groups (CSGs) and an Expeditionary Strike Group (ESG) from the 5th and 7th Fleet AORs to the area and will follow with a fourth CSG, 2nd ESG, and two Amphibious Task Forces (ATFs) in order to restore the territorial integrity of the Philippines and their island claims.

2. Scenario Assumptions

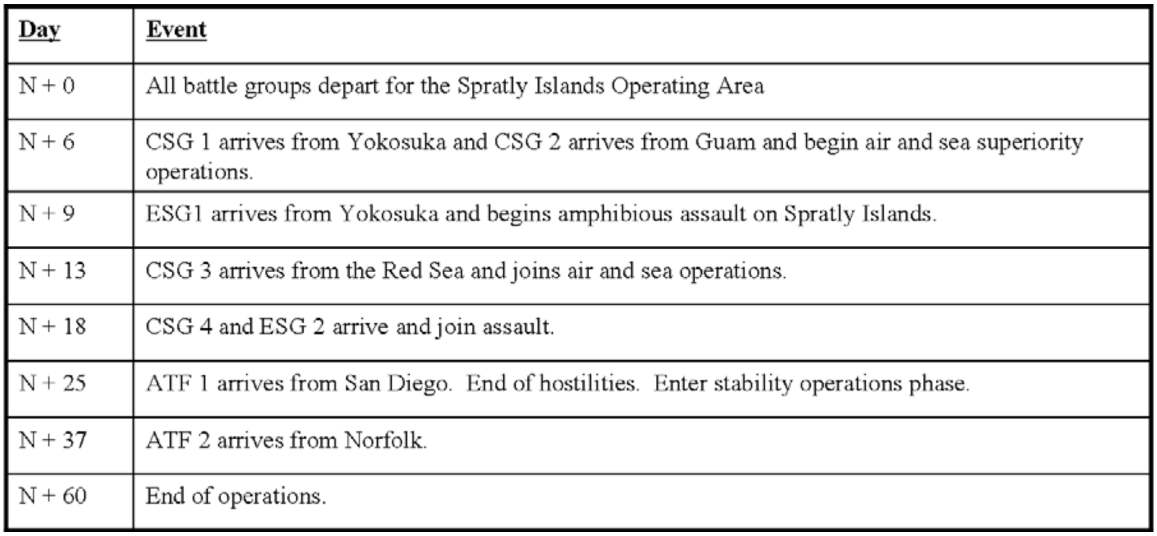
The following assumptions have been made in scenario development in order to concentrate our focus on the seventh fleet AOR and evaluate the effectiveness of the CLF assets assigned to support combat operations.

- Requirements outside of the operating area will not have an impact on the availability of assets in the area. This will allow assets to be allocated specifically for the operation and not pulled to fulfill other requirements.
- Minimum safety stock level for fuel and stores will be 50 percent of capacity and critical stock levels will be at 25 percent of capacity.
- All battle groups are available at N+0 day and will begin immediate transit to the area of operation. They will arrive in theater based on transit time from initial location and maximum transit speeds of 21 knots for CSGs and 13 knots for ESGs and ATFs.
- Shuttle ships will complete replenishment of one battle group prior to returning to port for resupply. When a battle group is scheduled for UNREP it will be refilled to the minimum of 100 percent of capacity or the amount of commodity available on the delivery ship.
- Ships already in the area of operation will begin the scenario at 100 percent of capacity in all commodities. Battle Groups transiting from outside the theater of operations will enter the theater at 70 percent capacity in all commodities. At this point the ships will fall under the administrative and operational chain of

command of seventh fleet. As demonstrated in [Doyle, 2006], fleet assignment becomes important if we restrict the CLF ships to only replenishing those ships assigned to the same fleet. As an example, a scenario in the central Pacific may include ships assigned to seventh fleet located in eastern Asia and third fleet located off the Pacific coast. In a fleet allocation of CLF ships, seventh fleet CLF ships would not be permitted to replenish 3rd Fleet combatants.

- On each day of the scenario, each Battle Group will be in exactly one of the following six employment states: “In Port,” “Pre-Assault,” “Assault,” “Sustain,” or “Disregard.” A Battle Group’s state determines its daily consumption of each of the four basic commodities, with the special states “In Port” and “Disregard” having no associated consumption and the other four states having consumptions as outlined in Figure 10, below.
- The combat fleet and CLF fleet will not suffer any losses, combat or mechanical, during the scenario. (Note that loss of a combatant makes the resulting logistical problem easier, and therefore, this provides conservative consumption for combatants. The loss of CLF ships can be evaluated by simply modifying the scenario to remove these ships.).

3. Fleet Composition and Timeline

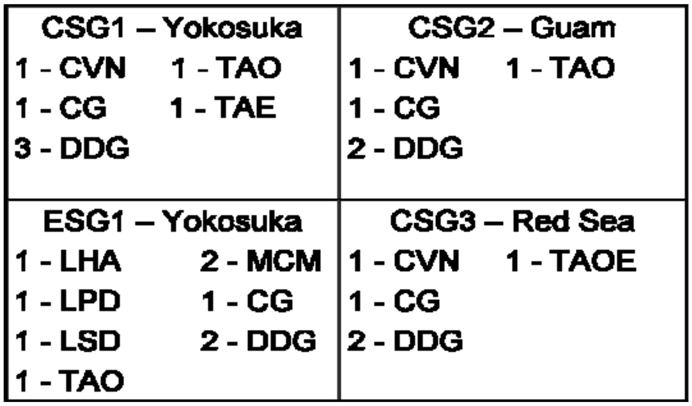


Day	Event
N + 0	All battle groups depart for the Spratly Islands Operating Area
N + 6	CSG 1 arrives from Yokosuka and CSG 2 arrives from Guam and begin air and sea superiority operations.
N + 9	ESG1 arrives from Yokosuka and begins amphibious assault on Spratly Islands.
N + 13	CSG 3 arrives from the Red Sea and joins air and sea operations.
N + 18	CSG 4 and ESG 2 arrive and join assault.
N + 25	ATF 1 arrives from San Diego. End of hostilities. Enter stability operations phase.
N + 37	ATF 2 arrives from Norfolk.
N + 60	End of operations.

Table 3. Scenario Timeline

This table represents the flow of ships into the theater of operation during our scenario. “N + 0” day is the date of notification for all units that will be involved in the operation. This day is then used as a point of reference for the remainder of the scenario.

The initial response force will consist of four battle groups, three CSGs and one ESG. CSG1 stationed at Yokosuka, Japan, has left port and will be in the operating area on day N+6. ESG 1, also operating near Yokosuka will be on station at N+9. CSG2 is transiting across the Pacific and is off the coast of Guam at day N+0 with a theater arrival date of N+6. CSG3 is transiting the Red Sea and will arrive in theater at N+13. These forces will enter combat operations upon arrival, shifting their consumption rates from pre-assault to assault levels, and will maintain this consumption until N+25 day at which time all groups will switch to sustaining rates. The initial response force battle group configurations are outlined in Figure 4.



CSG1 – Yokosuka 1 - CVN 1 - TAO 1 - CG 1 - TAE 3 - DDG	**CSG2 – Guam** 1 - CVN 1 - TAO 1 - CG 2 - DDG
ESG1 – Yokosuka 1 - LHA 2 - MCM 1 - LPD 1 - CG 1 - LSD 2 - DDG 1 - TAO	**CSG3 – Red Sea** 1 - CVN 1 - TAOE 1 - CG 2 - DDG

Figure 4. Battle Group Composition – Initial Response Force

Surges in demand will continue to be added to the system as four augmenting battle groups arrive on scene. These battle groups originate from the continental United States and Hawaii with time on station directly related to time-distance calculations utilizing the maximum speeds of 21 knots for the CSG and 13 knots for the ATFs and ESG. CSG4 from San Diego and ESG2 operating off the coast of Hawaii will arrive on station on day N+18 at which time they will shift to assault consumption rates until N+25. ATF1 departs San Diego and will arrive on N+25 followed by ATF2 from Norfolk which arrives on N+37. Both ATF forces will enter theater with a sustain consumption rate and maintain at that rate for the duration of the scenario. From N+38 day to N+60 we will maintain a steady state of demand and examine how well various CLF configurations are able to meet this demand. The configuration of the battle groups contained in the augmenting forces is listed in Figure 5.

CSG4 – San Diego	**ESG2 – Hawaii**
1 – CVN 1 - FFG 1 - CG 1 - TAOE 3 - DDG	1 - LHA 1 - LPD4 2 - LSD
ATF1 – San Diego	**ATF2 – Norfolk**
1 - LHD 1 - LPD4 3 - LSD	1 - LHA 1 - LSD 1 - LPD4 1 - LPD17

Figure 5. Battle Group Composition – Augmenting Force

C. THE SCENARIO DEVELOPMENT TOOL

Figure 6. Scenario Building Tool Initialization Screen

The scenario development tool we have developed is a Microsoft Excel – Visual Basic for Applications (Excel/VBA) [Microsoft, 2008] product that, when paired with the GAMS, [GAMS, 2008], CLF planning model, provides an extremely powerful and planner-friendly mechanism for operational or strategic planners. Building each scenario requires the planner to determine the daily position and employment of each battle group over the span of the planning horizon. This information can be input into the graphical user interface that automatically builds data tables for each battle group and CLF ship that will be assigned. The true power of the tool lies in its ability to create the data files needed to run the GAMS CLF model at the push of a button. This allows the planner to make modifications to the scenario, create new GAMS input files, and then run the scenario without having to modify the code of the underlying optimization model, and with a much lower risk of transcription errors.

1. Logistics Planning Factors

The logistics planning factors used in our scenario come directly from the Naval Warfare Publication Sustainment at Sea [NWP, 2007]. These factors are used in determining the aggregate daily consumption rates and maximum aggregate capacities of each battle group in each of the four commodities. In addition, this document contains the speed, range, and capacities of each class of CLF ship.

The scenario builder allows the planner to change these consumption factors and ship capabilities through a menu located on the standard tool bar at the top of the spreadsheet. The drop down menu, displayed in Figure 7 offers the options to change CLF capabilities, ship capacities, or ship consumption planning factors. The planner may also change the NWP 4-01.2 data to conform with any future changes to the logistics planning factors. Changes to the NWP data will change the default settings for logistics planning factors. The complete list of logistics planning factors used can be found in the Appendix.

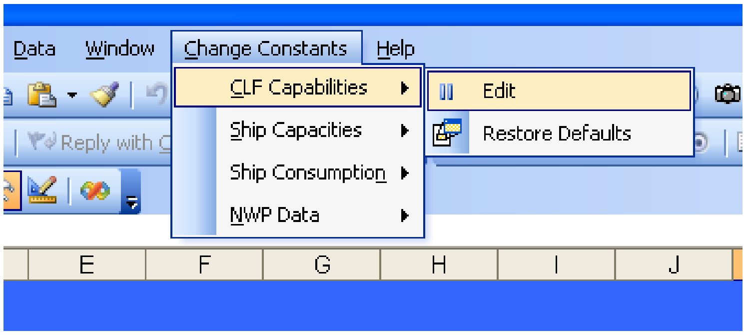
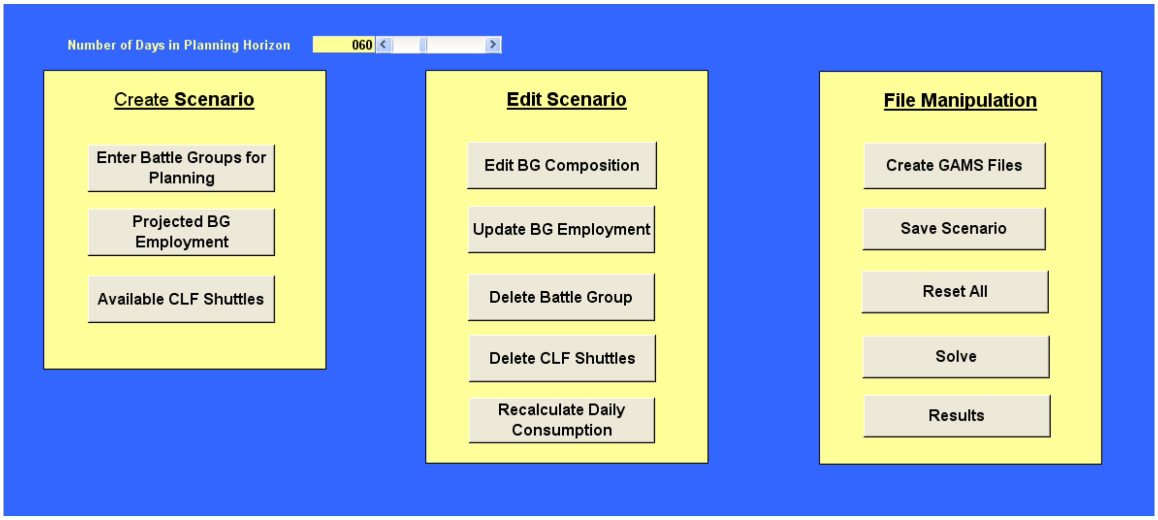


Figure 7. Editing Logistics Planning Factors

2. Creating a New Scenario

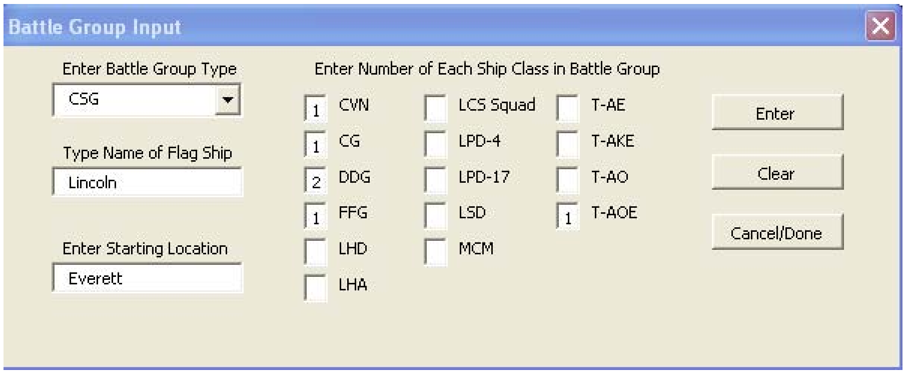


Number of Days in Planning Horizon 060

Figure 8. User Input Screen

After selecting the “Start New Scenario” button on the initialization page (Figure 6), you will be taken to the main user interface screen shown in Figure 8. This screen contains all of the buttons necessary for a planner to build, edit, and run a scenario in the GAMS model. The functionality for saving and loading scenarios has not yet been developed so planners save each scenario as a separate Excel workbook.

The planner must first create the battle groups that will be involved in the scenario. A battle group is defined as any ship or group of ships that will operate together. Capacities and consumption rates will be aggregated for the ships in the battle group and the battle group will be considered a single entity for replenishment purposes. Battle groups will be identified by type (CSG, ESG, independent operations, etc.), name of flagship, and place of origin or location at the start of the scenario. A hull number or other identifier may be used in place of the flagship name. The planner also needs to provide the number of each ship type attached to the group. An example of the battle group input form can be found in Figure 9. Note that any CLF ships added to the battle groups are considered station ships and will not be used as shuttle ships in the scenario, but will increase the overall capacity of the battle group in the commodities they carry.



Enter Battle Group Type: CSG

Type Name of Flag Ship: Lincoln

Enter Starting Location: Everett

1 CVN

1 CG

2 DDG

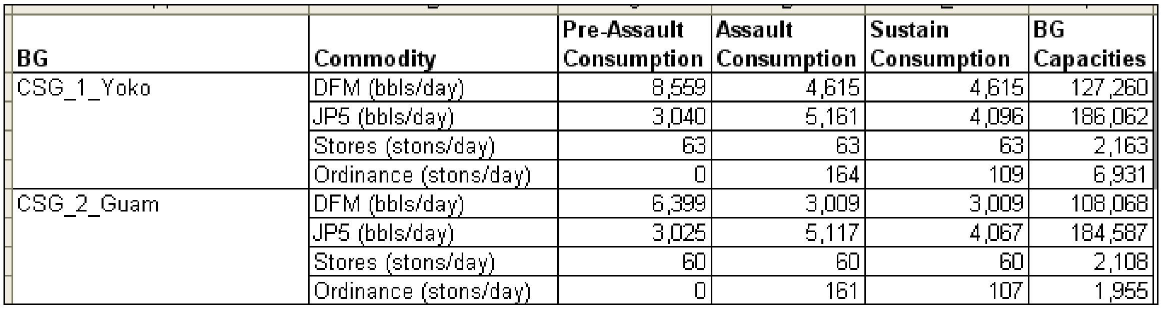
1 FFG

1 T-AOE

Figure 9. Battle Group Input Form

CSG Lincoln based in Everett, Washington consists of 1 CVN, 1 CG, 2 DDGs, 1 FFG, and 1 T-AOE station ship. The battle group configuration is used to calculate aggregate consumption and capacity for each of the basic commodities.

Completion of this step results in the creation of a new employment worksheet for each of the battle groups entered. The program also calculates the aggregate consumption and capacity numbers for each of the battle groups in each of the basic commodities and places that information in a separate table, an example of which can be seen in Figure 10 below.

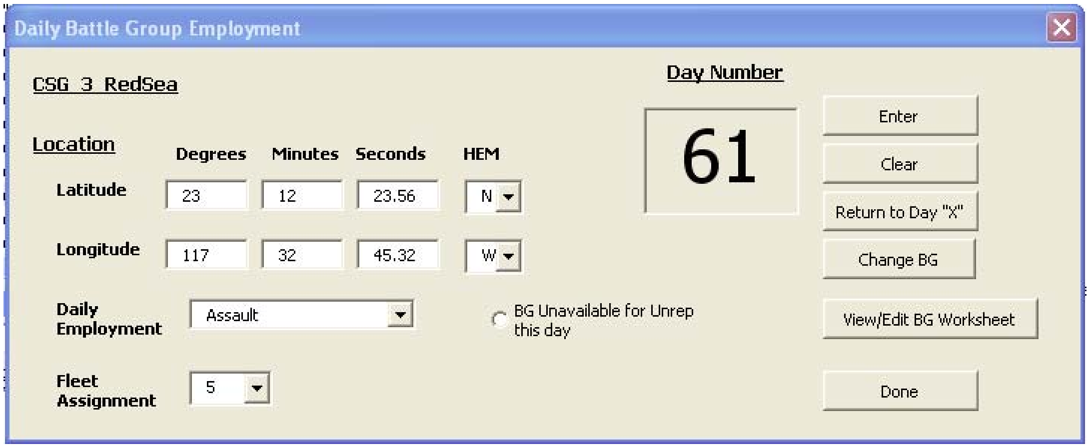


BG	Commodity	Pre-Assault Consumption	Assault Consumption	Sustain Consumption	BG Capacities
CSG_1_Yoko	DFM (bbls/day)	8,559	4,615	4,615	127,260
	JP5 (bbls/day)	3,040	5,161	4,096	186,062
	Stores (stons/day)	63	63	63	2,163
	Ordinance (stons/day)	0	164	109	6,931
CSG_2_Guam	DFM (bbls/day)	6,399	3,009	3,009	108,068
	JP5 (bbls/day)	3,025	5,117	4,067	184,587
	Stores (stons/day)	60	60	60	2,108
	Ordinance (stons/day)	0	161	107	1,955

Figure 10. Battle Group Daily Consumption and Capacities

Table reads as follows: The aggregate consumption for CSG_1_Yoko of DFM is 8,559 bbls/day at the pre-assault consumption rate, 4,615 bbls/day at the assault rate, and 4,615 bbls/day at the sustain rate. The battle group has an aggregate capacity of 127,260 bbls.

After entering the battle groups for the planning scenario, the planner must input the projected daily employment information into the workbook. This information includes daily position by latitude and longitude, daily employment state (In Port, Pre-Assault, Assault, Sustain, or Disregard), fleet assignment, and whether the battle group is available for UNREP on that day. This information must be entered for each day of the planning horizon and for each battle group in the scenario in the form shown in Figure 11. If the planner exits prior to completing entries for the entire spanning horizon, he is given the option to auto fill the remaining days with the last entered position and employment, disregard the battle group for the remainder of the scenario, return to the entry form to complete entering employment data, or leave the data blank. If the planner chooses to leave the data blank, then he must return and fill in that data prior to creating GAMS files and running the model or the model will not run properly.



CSG_3_RedSea

Day Number: 61

Location

	Degrees	Minutes	Seconds	HEM
Latitude	23	12	23.56	N
Longitude	117	32	45.32	W

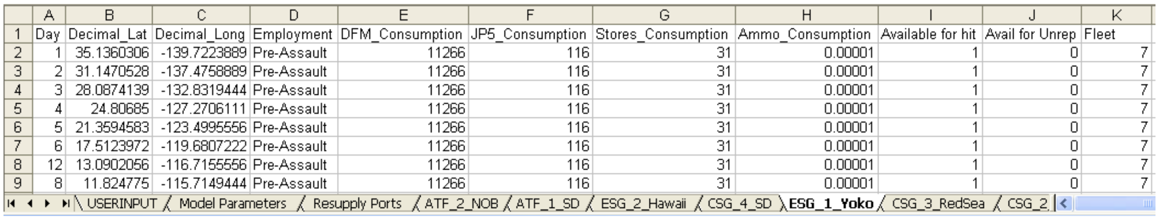
Daily Employment: Assault

○ BG Unavailable for Unrep this day

Fleet Assignment: 5

Figure 11. Battle Group Employment Form

Completion of this form will calculate and display the position, employment, daily consumption, fleet assignment and availability for replenishment on the spreadsheet for each battle group as seen in Figure 12. Availability for replenishment defaults to “Available” unless the “BG Unavailable” button is selected for that day. (Note that ordinance consumption for Pre-Assault has been modified to .00001 in order to prevent division by zero errors in the model but present no impact on the overall results.)



	A	B	C	D	E	F	G	H	I	J	K
1	Day	Decimal_Lat	Decimal_Long	Employment	DFM_Consumption	JP5_Consumption	Stores_Consumption	Ammo_Consumption	Available for hit	Avail for Unrep	Fleet
2	1	35.1360306	-139.7223889	Pre-Assault	11266	116	31	0.00001	1	0	7
3	2	31.1470528	-137.4758889	Pre-Assault	11266	116	31	0.00001	1	0	7
4	3	28.0874139	-132.8319444	Pre-Assault	11266	116	31	0.00001	1	0	7
5	4	24.80685	-127.2706111	Pre-Assault	11266	116	31	0.00001	1	0	7
6	5	21.3594583	-123.4995556	Pre-Assault	11266	116	31	0.00001	1	0	7
7	6	17.5123972	-119.6807222	Pre-Assault	11266	116	31	0.00001	1	0	7
8	12	13.0902056	-116.7155556	Pre-Assault	11266	116	31	0.00001	1	0	7
9	8	11.824775	-115.7149444	Pre-Assault	11266	116	31	0.00001	1	0	7

Figure 12. Battle Group Daily Employment Worksheet

This figure reads as follows: On day 1, ESG_1_Yoko is located at 35.1360 degrees latitude, -139.7223 degrees longitude and is operating at the Pre-Assault level of consumption. At this level, ESG_1_Yoko consumes 11,266 bbls of DFM, 116 bbls of JP5, 31 stons of stores, and 0 stons of ordinance. The ship is available for replenishment indicated by the 1 in the “Available for hit” column and is assigned to the 7th Fleet AOR. The “Available for Unrep” column is not currently used at this time but is included for further expansion of the model and defaults to 0.

The final step in scenario development is identifying the CLF shuttle ships that will be available for scheduling during the scenario. Shuttle ships are identified by CLF ship type (T-AE, T-AFS, etc.), and a name identifier which can be any alphanumeric combination. It is also necessary to identify the fleet assignment of the shuttle ship. This designation will restrict the shuttle ship from being scheduled to replenish ships outside of its operational fleet. Each added ship is placed on a CLF assets worksheet and the speed, range and commodity capacities are filled in based on ship type. In addition, the ship is added to the CLF-Battle Group commodities matrix that indicates which commodities each customer battle group can receive from each delivery ship. For the purpose of our analysis T-AOs only deliver DFM and JP5, T-AEs deliver ordinance, T-AFS deliver stores, T-AKEs deliver stores and ordinance, and T-AOEs deliver all commodities.

3. Scenario Editing

Figure 13. Scenario Editing Options

The scenario editing functions allow the planner to make modifications to the current scenario once initial data has been entered. “Edit BG Composition” (Figure 13) will automatically recalculate aggregate consumption numbers and capacities for the battle group and update the battle group daily employment worksheet with these figures.

Updating battle group employment allows the planner to either amend existing data or to add additional days of employment. Amending data will prompt the planner to choose a day on which to start amending. If the planner does not continue changes through the end of the planning horizon, he is prompted for auto fill options. If the planner does not wish to change the remaining data in the spreadsheet, he selects "Leave Blank." Appending data will take the planner to the next available day for scheduling. If the planner adds data outside of the planning horizon, this data will be ignored upon creation of data files.

Deleting a battle group completely removes it from the workbook. The daily employment worksheet is removed and all entries in other worksheets are purged. Likewise, deleting CLF shuttles removes the CLF shuttle ship from the CLF assets worksheet and the CLF-Battle Group commodities matrix.

The "Recalculate Daily Consumption" button should be used any time the planner makes changes to the battle group daily employment worksheets directly without going through the user form. It will loop through the existing battle groups and ensure that the daily consumption factors match the employment consumption level selected for each day.

4. File Manipulation

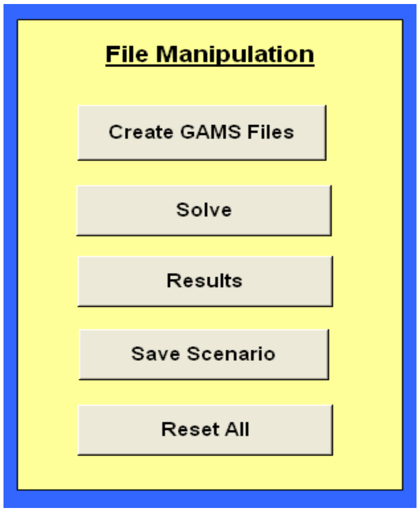


Figure 14. File Manipulation Options

The “Create GAMS Files” button (see Figure 14) will create 15 comma-separated-value (CSV) files which are read into the GAMS model prior to model execution. This relieves the planner from having to manipulate each occurrence of a battle group or CLF ship in the GAMS code with each change in the scenario. Run this function prior to your GAMS model play, accomplished by pushing the “Solve” button. The results, read into a separate worksheet in the workbook, are created in a separate file by the GAMS solver and formatted to allow quick graphing of the saw-tooth inventory state charts for each commodity. This file contains information on daily inventory levels, replenishment events, and consumption for each battle group in each of the four commodities. The “Results” button reads this data into your workbook and opens the worksheet to allow further analysis of results.

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III. ANALYSIS OF RESULTS

A. SYNOPSIS

This analysis reveals several insights from the use of optimization for theater level CLF planning.

Initially, we analyze the current CLF model to determine if the underlying sea routes network and scenario battle group tracks will provide enough fidelity to adequately support modeling movements of CLF ships (that must stay on our sea-routes, rather than steam on arbitrary tracks) in a particular AOR. We demonstrate how to improve the model and provide recommendations on future work to expand the sea routes network in areas of interest where fidelity is lacking.

Our primary analysis will outline how we determine resupply port requirements and CLF ship composition and employment techniques. Although the analysis here is based on a fictional combat scenario, the same methods apply to any scenario. This affords operational staffs the ability to conduct analysis on all scenarios of interest and aggregate the results to form recommendations on overall force structure requirements while also defining specific requirements for the contingency operation.

Additional analyses demonstrate the positive contribution the T-AKE makes to battle group inventory levels due to its dual-commodity capability, and also evaluates the influence of converting station ships into centrally controlled shuttle ships once forces are in the condensed operating area of the combat theater.

B. SEA ROUTES NETWORK AND BATTLE GROUP TRACK INTEGRATION

The underlying sea routes network, as discussed in the brief summary of the model, is comprised of ports and waypoints throughout the globe that are connected by fast and slow arcs. Slow arcs are found between nodes passing through known geographic slow transit areas such as the Suez Canal or the Straits of Malacca, and transit of such an arc takes a fixed amount of time, regardless of ship class. These areas increase the time it takes for any ship to traverse through the geographically restricted area. Fast arcs allow CLF ships to travel at the top speed indicated in the model for each type. Full layout of the sea routes network is illustrated in [Doyle, 2006].

The battle group track integrator expands the sea routes network under the assumption that any track over which the battle group traverses may also be used by a CLF ship. This expansion is accomplished by adding additional nodes and arcs in the network wherever a battle group track crosses the existing sea routes network.

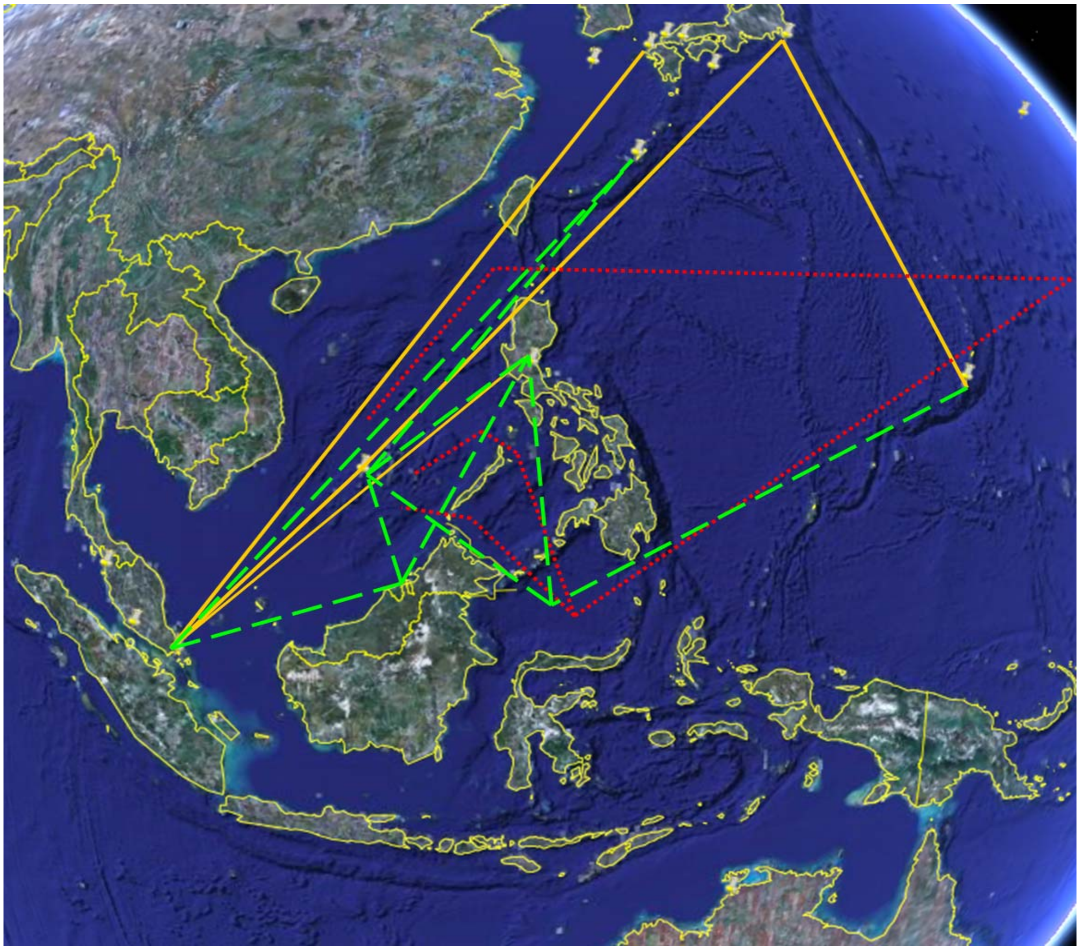


Figure 15. Sea Routes and Battle Group Tracks for Spratly Island Scenario

Solid lines represent existing sea routes arcs from [Doyle, 2006]. Dotted Lines indicate battle group tracks entering from the Pacific Ocean to the east. Dashed lines are added sea route arcs which increase the fidelity of the network and ensure integration of battle group tracks.

Figure 15 shows the sea routes network in the area of the Spratly Islands as it existed prior to our study, depicted by solid lines. The dotted lines indicate the tracks of three of the battle groups that arrive from the west and enter the theater of operations following three different lines of approach. Close examination of these two sets of lines reveals that the last intersection of the two southern battle group tracks and the existing sea route arc is in the vicinity of Guam. Had we run the model without additional arcs added, CLF ships would have had to traverse from a port of resupply to this intersection point and then follow the battle group track back to the theater of operations, adding needless, unrealistic days of transit to the model.

To avoid these artificial increases in turn-around time, we have added several arcs to the existing network in the theater of operations as shown by the dashed lines in Figure 15. This ensures that our battle group tracks and sea routes network are well connected and integrated allowing for freedom of navigation throughout the AOR. Changes of this nature currently require modification to the existing GAMS model but changes to the graphical user interface would allow arc and node adjustments as necessary.

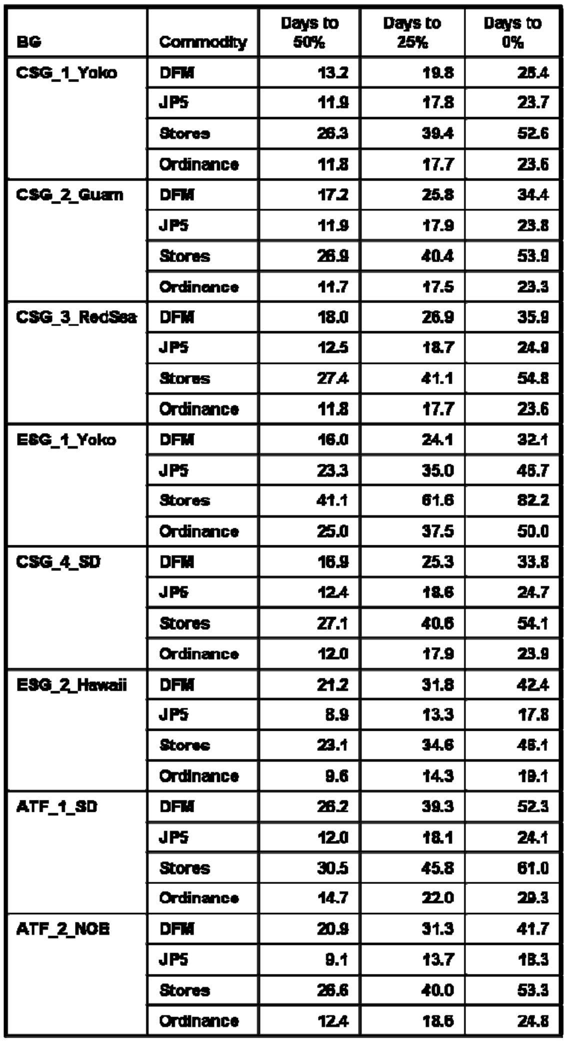
C. IDENTIFYING LOGISTICS BASE SHORTFALLS

Positions of logistics resupply ports play a key role in the overall performance of our CLF composition. For our initial run of the model we utilized a baseline mix of CLF ships containing three T-AFSs, one T-AO, and one TAE. As expected, this mix of assets did not perform particularly well for our scenario for two reasons. First, the Spratly Islands AOR is geographically removed from the key logistics ports of Singapore, Okinawa, Yokosuka, and Guam identified in the sea routes network used in previous thesis work. Second, the mix of five CLF ships is inadequate to support a combat fleet of 47 ships operating under combat and sustaining consumption levels. We will explore the later in section E of this chapter.

The two major sea ports utilized by CLF assets in our initial run are Singapore and Okinawa. Singapore lies approximately 800 nautical miles from the nearest battle group's assigned operating box, and Okinawa is approximately 1,000 nautical miles removed. To illustrate the impact this has on force requirements, consider our T-AO.

Capable of maximum sustained speeds of 16 knots, the T-AO can travel a maximum of 384 nautical miles per day. Port turnaround time is set at two days for each port giving the T-AO a complete turnaround time of roughly seven days for Singapore and eight days for Okinawa. Given the assumption that the T-AO only consoles with one battle group before returning to port to resupply and given the presence of eight battle groups in our scenario, each of the battle groups should experience a cycle time of between 64 and 72 days between fuel replenishments.

An initial review of the daily consumption planning factors indicates that JP-5 and ordinance are the driving factors in determining the frequency of replenishment events required. CSG_1_Yoko containing one CVN, one CG, three DDGs, one T-AO, and one T-AE, has a DFM assault consumption rate of 4,615 barrels of fuel per day and a capacity for 122,029 barrels. By simple division, this yields 26.4 days before the battle group completely exhausts its DFM supply. Furthermore, CSG_1_Yoko will fall below the 50 percent safety stock level in 13.2 days and will hit the 25 percent extremis level in 19.8 days, demonstrating the inadequacy of a 64-day cycle time. To meet the demand and maintain stock above safety levels for each battle group requires a dedicated T-AO ship for each of the eight groups. The sustainability cycles for each battle group in each commodity are listed in Table 4.



BG	Commodity	Days to 50%	Days to 25%	Days to 0%
CSG_1_Yoko	DFM	13.2	19.8	26.4
	JP5	11.9	17.8	23.7
	Stores	26.3	39.4	52.6
	Ordinance	11.8	17.7	23.6
CSG_2_Guam	DFM	17.2	25.8	34.4
	JP5	11.9	17.9	23.8
	Stores	26.9	40.4	53.9
	Ordinance	11.7	17.5	23.3
CSG_3_RedSea	DFM	18.0	26.9	35.9
	JP5	12.5	18.7	24.9
	Stores	27.4	41.1	54.8
	Ordinance	11.8	17.7	23.6
ESG_1_Yoko	DFM	16.0	24.1	32.1
	JP5	23.3	35.0	46.7
	Stores	41.1	61.6	82.2
	Ordinance	25.0	37.5	50.0
CSG_4_SD	DFM	16.9	25.3	33.8
	JP5	12.4	18.6	24.7
	Stores	27.1	40.6	54.1
	Ordinance	12.0	17.9	23.9
ESG_2_Hawaii	DFM	21.2	31.8	42.4
	JP5	8.9	13.3	17.8
	Stores	23.1	34.6	46.1
	Ordinance	9.6	14.3	19.1
ATF_1_SD	DFM	26.2	39.3	52.3
	JP5	12.0	18.1	24.1
	Stores	30.5	45.8	61.0
	Ordinance	14.7	22.0	29.3
ATF_2_NOB	DFM	20.9	31.3	41.7
	JP5	9.1	13.7	18.3
	Stores	26.6	40.0	53.3
	Ordinance	12.4	18.6	24.8

Table 4. Days Sustainability without Resupply per Commodity

For CSG_1_Yoko, DFM will reach minimum safety level of 50 percent in 13.2 days, minimum extremis level of 25 percent in 19.8 days, and will completely exhaust fuel supply by 26.4 days without receiving a CONSOL.

To further emphasize the importance of geographically local resupply ports, we added Subic Bay, Philippines and Muara, Brunei, to the model as full service ports. Subic Bay Freeport (SBF) lies approximately 350 nautical miles from AOR and has long been recognized for its strategic location at the center of the fastest growing markets in Asia. It is at the hub of the region and all major cities in Asia are within easy reach by sea or air. Aside from its strategic location, SBF has a deepwater seaport that is capable of handling the largest ships ever built, demonstrated by its history of supporting the U. S.

7th Fleet [SBF, 2008]. Muara, Brunei, lays 200 miles south of the Spratly Islands. The dedicated container terminal at Muara Port is equipped with up-to-date machinery and operated by experienced and skilled manpower that delivers a high level of efficiency and productivity [BPD, 2008]. After adding these two ports we run the model again maintaining our baseline CLF configuration of three T-AFSs, one T-AO, and one T-AE.

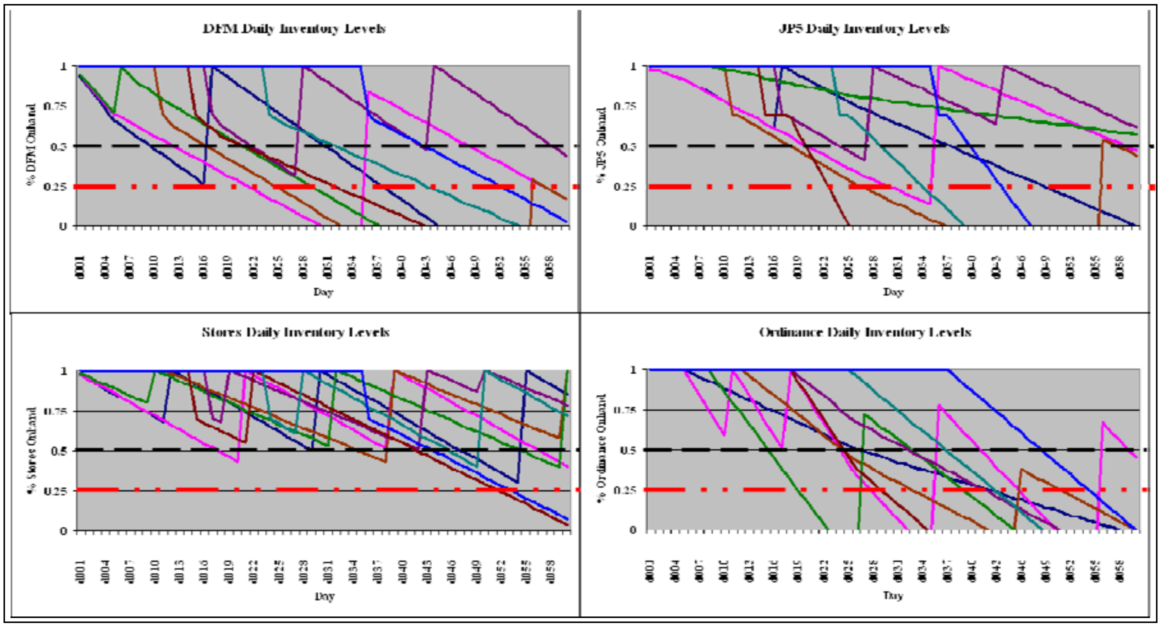


Figure 16. Inventory Levels for 3 T-AFS/1 T-AO/1 T-AE without Subic Bay and Maura available

Examining the “DFM Daily Inventory Levels” chart, the dashed line located at .5 represents the minimum safety stock level of 50 percent for this commodity. The dotted and dashed line at .25 represents the extremis stock level of 25 percent. Each of the sawtooth lines represents the daily stock position of a battle group in our scenario. The goal is to get all of these lines above the 50 percent threshold. This representation will remain consistent throughout our analyses.

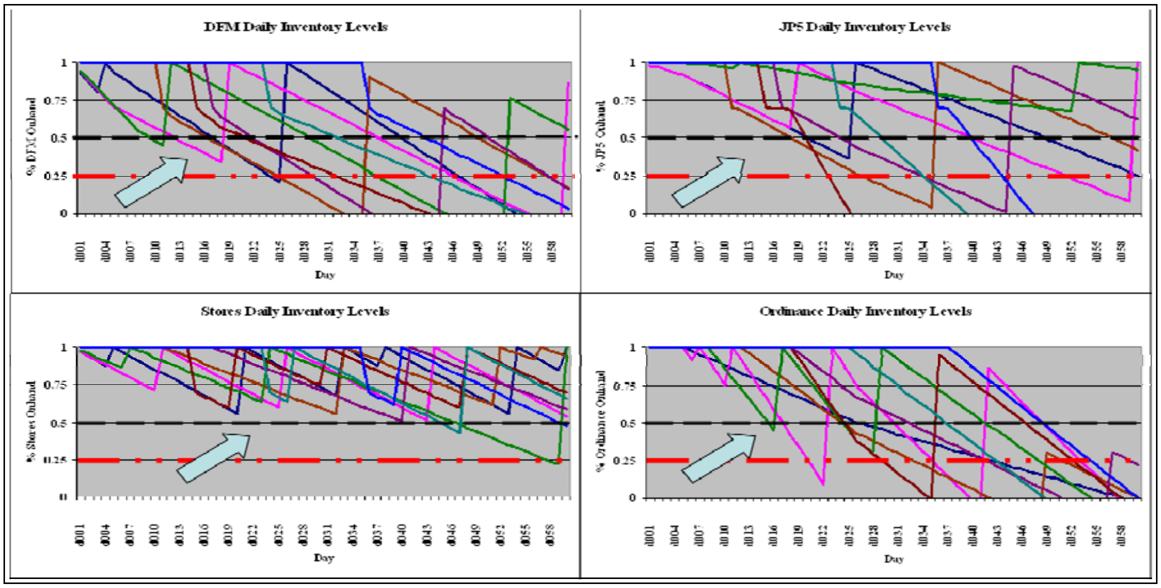


Figure 17. Inventory Levels for 3 T-AFS/1 T-AO/1 T-AE with Subic Bay and Maura available

The arrows illustrate the shift of the inventory position lines up and to the right indicating an overall improvement in CLF cycle time and overall inventory levels.

Comparing the two sets of graphs above it is apparent that in either case the CLF ships are inadequate to meet the demands in the scenario. However, there is a noticeable shift up and to the right in the graphs of Figure 17, particularly in stores, once the ports of Subic Bay and Muara are added to the system. This indicates that the ships are able to maintain stock levels for a longer period of time after scenario initiation and are able to maintain higher stock levels for each battle group throughout the campaign. All ships are now capable of a maximum of four days turn-around time, reducing the fuel cycle time for the battle groups in the previous example from 64 to 32 days. This result verifies the benefit of establishing local ports of resupply whenever practicable. The ports of Subic Bay and Muara will remain in our network for the remainder of our analyses.

D. THE T-AKE EFFECT

Due to its scheduled replacement of the T-AE and T-AFS by the year 2010, we swap T-AKEs into the scenario for the three T-AFS and one T-AE in our baseline run. We conduct a one-for-one swap of assets configuring three of the T-AKEs to carry 100 percent of the T-AFS load and one to carry 100 percent of the T-AE load. This gives us an overall CLF mix of three T-AKE_AFS, one T-AKE_AE and one T-AO.

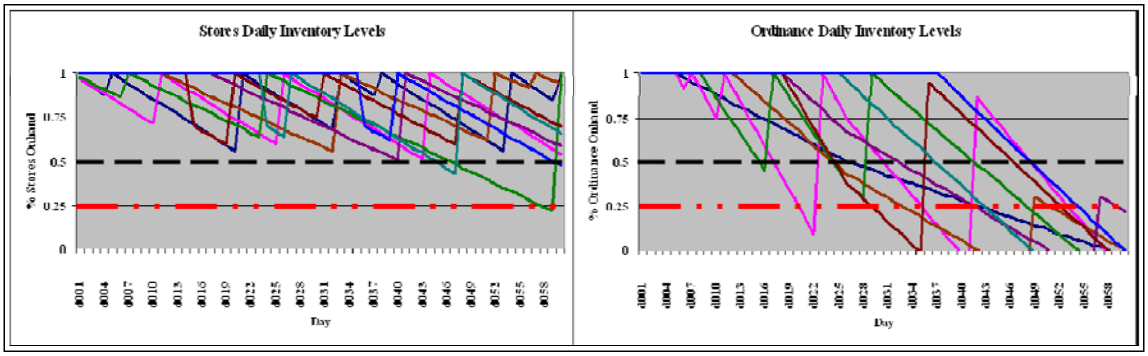


Figure 18. Stores and Ordinance Inventory Levels 3 T-AFS/1 T-AE/1 T-AO

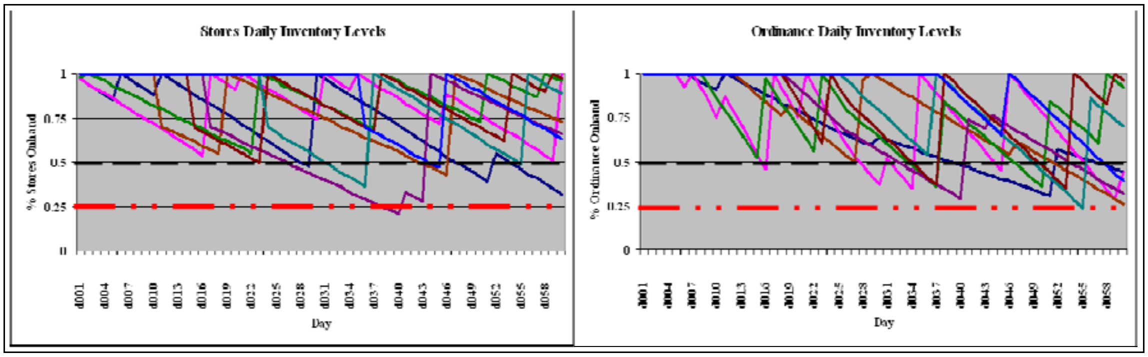


Figure 19. Stores and Ordinance Levels 3 T-AKE_AFS/1 T-AKE_AE/1-TAO

The inventory levels of ordinance in the Figures 18 and 19 shows a strong improvement when converting to T-AKEs, but there appears to be a slight decline in the stores inventory levels for several of the battle groups. The increase in ordinance levels is directly related to the residual capacity of the T-AKE in a T-AFS configuration which allows it to carry 1,010 short tons of ordinance in addition to 100 percent of the dry stores load of the T-AFS. The decline in stores inventory is caused by the change in CLF utilization to try to minimize the time that the battle groups spend below extremis in ordinance inventory. In practice the model is trading the lower penalty associated with a drop below safety stock of stores to avoid the higher penalty awarded for a drop into extremis of ordinance. If the employment schedule of CLF assets remained the same in both runs of the model we would expect to see a slight increase in stores inventory levels due to the residual capacity of a T-AKE in a T-AE configuration of an additional 682 short tons for stores.

E. OPTIMIZING THE CONFIGURATION OF CLF ASSETS

To optimize the total CLF configuration, we use an iterative process. First we run the model for a baseline mix of assets that we think will meet the overall demand. We then analyze the sawtooth inventory level diagrams for this run to determine what shortfalls are present. From the baseline run shown in Figure 17, our initial configuration is deficient in DFM, JP5, and ordinance with several battle groups completely running out of each commodity. Stores inventory levels are satisfactory for six of the eight battle groups because we have three T-AFSs operating on a four-day cycle that allows for each battle group to be hit once every eight days. The information contained on these charts not only shows inventory deficiencies, but also allows the decision maker to assess the risk of ships falling below the safety and extremis threshold. In this case we decided that the stores levels provided by the three T-AKEs in a T-AFS configuration is acceptable and so we did not add any additional assets specifically for the delivery of stores.

Our analysis of the fuel levels for the battle group caused us to add an additional two T-AOs to the CLF composition for our second iteration but this number was also inadequate to improve the overall inventory levels of DFM or JP5. For our third iteration we ran the model with a composition of three T-AKE_AFSs, one T-AKE_AE, and four T-AOs. The resulting inventory levels can be seen in the Figure 20 below.

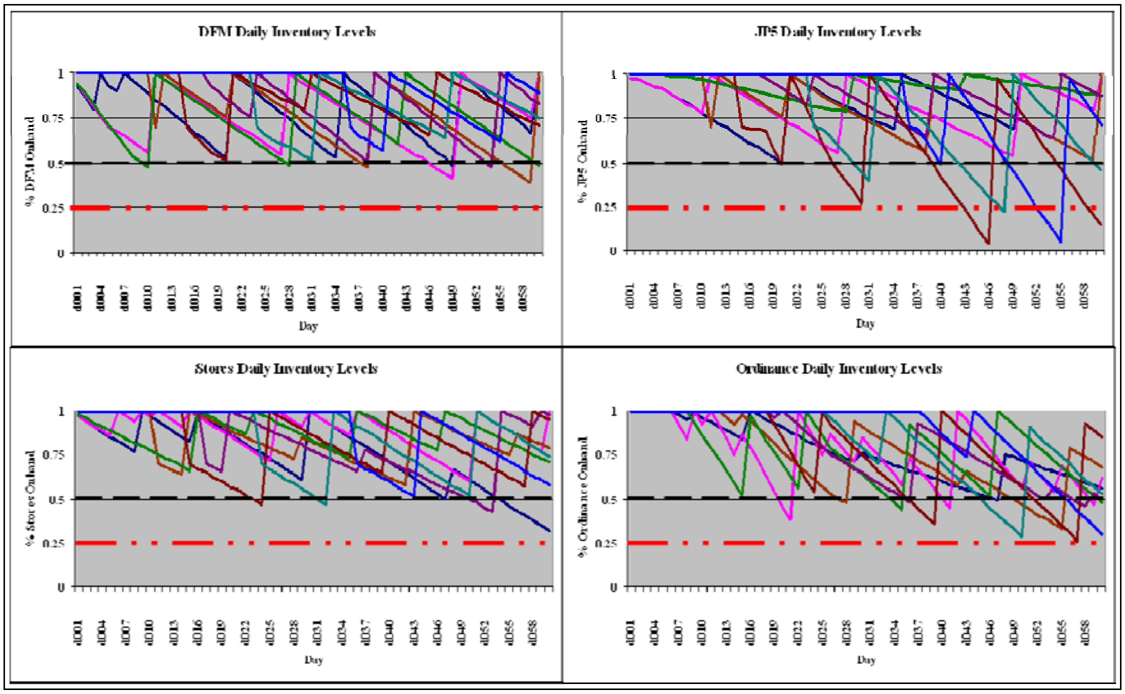


Figure 20. Inventory Levels for 3 T-AKE_AFS/1 T-AKE_AE/4 T-AO

After completion of this iteration, we assess JP5 levels as still dangerously low for our amphibious battle groups which may be an issue unless we can assume that all amphibious borne aircraft will be shore based during this portion of the operation. If this is the case, then we should modify the JP5 consumption planning factors for these battle groups to reflect this and re-run the model to see if the problem is resolved. Assuming that the amphibious ships are acting as lily pad refueling stations for marine aircraft, it appears that we will need an additional one to two refueling assets along with an additional T-AKE. Our DFM inventory levels are acceptable but our JP5 numbers are not. Therefore, configuring an asset to carry a larger ratio of JP5 to DFM may be more beneficial to the overall system. A final confirmation run could then be used to verify the appropriate levels are reached.

Considering the levels for stores and ordinance in Figure 20, the shortages appear more severe for ordinance. This information is useful in trying to determine which configuration of T-AKE is appropriate to try to increase both of these commodities simultaneously. In this case it may be beneficial to attempt adding a T-AKE in a 35 percent stores and 65 percent ordinance configuration to augment the existing force. While we did not conduct the model run for this mix of assets, we would expect an improvement in each of the commodities. We may find, however, that a T-AKE with a 50/50 stores-to-ordinance load or in an AE configuration may perform better. The benefit of the user interface is the ability to quickly change CLF asset composition and rerun the model to provide the comparisons for these varying configurations of the T-AKE.

F. IMPACT OF ALLOWING BATTLE GROUP STATION SHIPS TO ACT AS SHUTTLE SHIPS

Revisiting the battle group composition defined in the scenario in Figure 4 and Figure 5 there are a total of six station ships assigned to the battle groups. The CLF model sees these assets as an integrated part of the battle group that adds to the overall capacity of the group in the commodities carried by the shuttle. When you consider the three T-AKE_AFS/1 T-AKE_AE/4 T-AO composition that we ran previously, we utilize eight shuttle ships and six station ships, approximately half of the total CLF fleet. This raises the question: How important is the added capacity of the station ships?

To answer this question, we started with the extreme case of removing all station ships from their battle groups and not augmenting the CLF shuttle ship force. This results in little change in the overall performance of the system although we did see an increase in the frequency of UNREP events that each battle group experienced. Superficially this may seem like a restriction impeding the battle groups mission capability more often for replenishment. However, the battle groups with station ships had to receive replenishments from their station ships on a regular basis to distribute the added capacity. Station ship replenishment is not captured in the current CLF model. The locality of resupply ports also plays an important role in this negligible difference because the battle groups do not require the extra capacity of the shuttles to carry them between shuttle ship consoles.

Our next step was to reintroduce two T-AOEs that had been removed. Traditionally, these assets accompany carrier battle groups as station ships, but provide the greatest overall impact as shuttle ships due to the increased speed and capacity for all four commodities. This practice is common in the 5th Fleet AOR where station ships are detached from their battle groups upon arrival and report to CTF-53 who schedules all replenishments in theater. The resulting composition for our scenario run is three TAKE_AFSs, one T-AKE_AE, four TAOs and two T-AOEs for a total of 10 CLF assets.

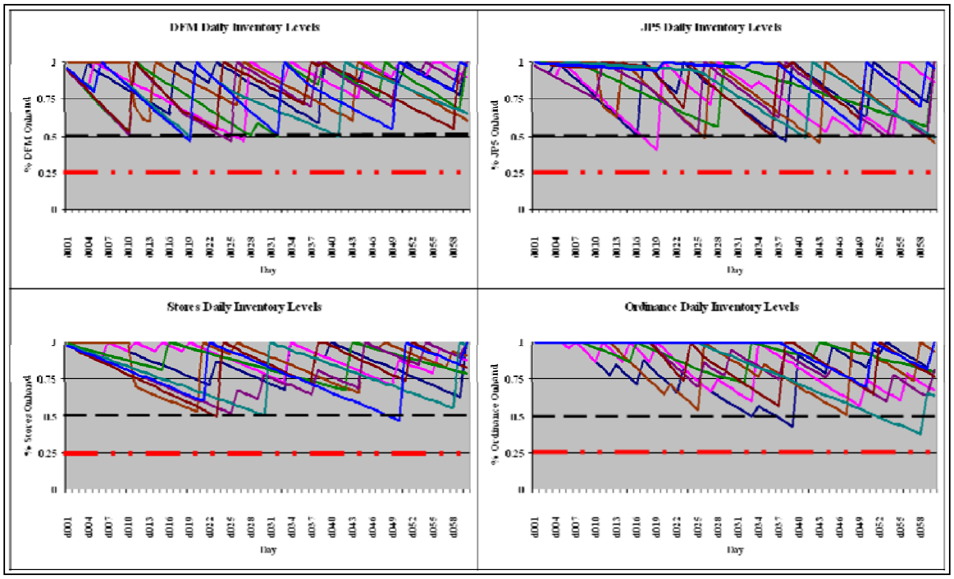


Figure 21. Inventory Levels for 3 T-AKE_AFS/1 T-AKE_AE/4 T-AO/2 T-AOE

Compared to the inventory levels achieved by our battle groups with accompanying station ships shown in Figure 20, the overall performance of the system without station ships and with two T-AOEs acting as shuttles improves in each of the four commodities with particularly large improvements found in JP5 and ordinance. This result demonstrates that for a confined area of operations such as the Spratly Islands, it is far more effective to use your CLF assets as shuttle ships if we have resupply ports close enough to eliminate the need for added station ship capacity. Furthermore, the addition of the T-AOEs as multi-commodity shuttles provide a greater service level to the combat fleet while allowing a total CLF asset reduction of four vessels (three T-AOs/one T-AE station ships) bringing the total needed to support the operation to ten.

IV. CONCLUSIONS AND FOLLOW-ON STUDIES

A. WHAT CONCLUSIONS CAN WE DRAW?

The most important finding in our study is the effectiveness of the CLF planning model and the planner's scenario builder interface to provide decision support to the operational commander in determining campaign level CLF requirements. Conducted on several scenarios of interest, the information gained from this tool can then be aggregated to provide the fleet commander with a better understanding of his overall fleet requirement and can aid force planners in developing future force structure decisions. The interface provides an efficient way to update the CLF composition allowing several model plays to be done and various compositions to be compared and contrasted.

In our first model run, we demonstrated how the positions of resupply ports play an important role in the total number of CLF ships necessary to support combat operations. The longer the cycle time required for traveling to the port of resupply and back to the theater of operations, the greater the number of assets required to keep combatant ships at appropriate supply levels. The addition of nearby ports also allows for the elimination of station ships because the battle groups no longer need the extended capacity to subsist between shuttle hits. This further reduces the total number of CLF ships required for the operation.

Our analysis of replacing the T-AFS and T-AE with the T-AKE demonstrates the added benefits of the residual capacity even when these ships are loaded out in T-AFS or T-AE configurations. While we only examine the T-AFS and T-AE configurations in our model runs, the ability to split these ships into multiple configurations provides an added layer of flexibility not available in previous classes of ship

Perhaps the most interesting result is eliminating station ships from the battle groups and creating an all shuttle ship CLF support force. This practice, common in the smaller region of the 5th Fleet AOR, is only practical given a condensed AOR with local ports of resupply, but greatly reduces the number of CLF ships required to meet the overall demand of combatants in the scenario. This result should lead operational planners to explore an all shuttle ship force where the preconditions are met.

B. FURTHER RESEARCH OPPORTUNITIES AND MODEL IMPROVEMENTS

1. Modeling CLF UNREP Boxes (Gas Station Model)

The original PACFLT scenario required that battle groups transit to designated UNREP boxes for security and maneuverability reasons. The current model requires shuttle ships to travel to the battle group to provide resupply. Additional work should be done to allow the optimization of replenishment such that the CLF asset time distance calculation would account for the distance of the battle group to the UNREP box and the distance of the CLF ship to the same box.

2. Changes to Battle Group Composition Mid-Scenario

Currently our user interface calculates static capacity and consumption numbers based on the composition of the battle group when initially added to the scenario. The model itself allows ships to pass in and out or between battle groups as the scenario progresses. User interface modifications for this would allow, for example, modeling the transition of station ships to shuttle ships as they check in (INCHOP) to 5th Fleet AOR.

3. Expansion of the Sea Routes Network

Our scenario identified some deficiencies in the robustness of the sea routes network near a particular AOR. It would be beneficial to look at the probable areas of operation for U. S. naval forces and expand the network in those areas to ensure that the paths of shuttle ships are consistent with the paths likely to be taken and that battle groups are unable to enter an area of operations are guaranteed to intersect the underlying sea routes network.

4. Determining Optimal T-AKE Configurations

Part of the power of the dual commodity T-AKE is its ability to convert storage into any of multiple configurations in order to provide the right mix for the given scenario. In our scenario we arbitrarily chose five T-AKE configurations and only used two in our analysis. Additional scenario analyses could help determine an optimal configuration of the T-AKE that provides the greatest flexibility across a wide range of possible future events.

5. Combat Scenario Development

Each combatant commander has a list of Major Contingency Operations (MCOs) that he must plan towards and develop requirements to support. It would be beneficial to develop a catalogue of scenarios based on these MCOs that could accompany this tool for analysis in each major theater. This work would most likely become classified, and would require the installation of the GAMS model and user interface on a classified computer system.

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APPENDIX. LOGISTICS PLANNING FACTORS

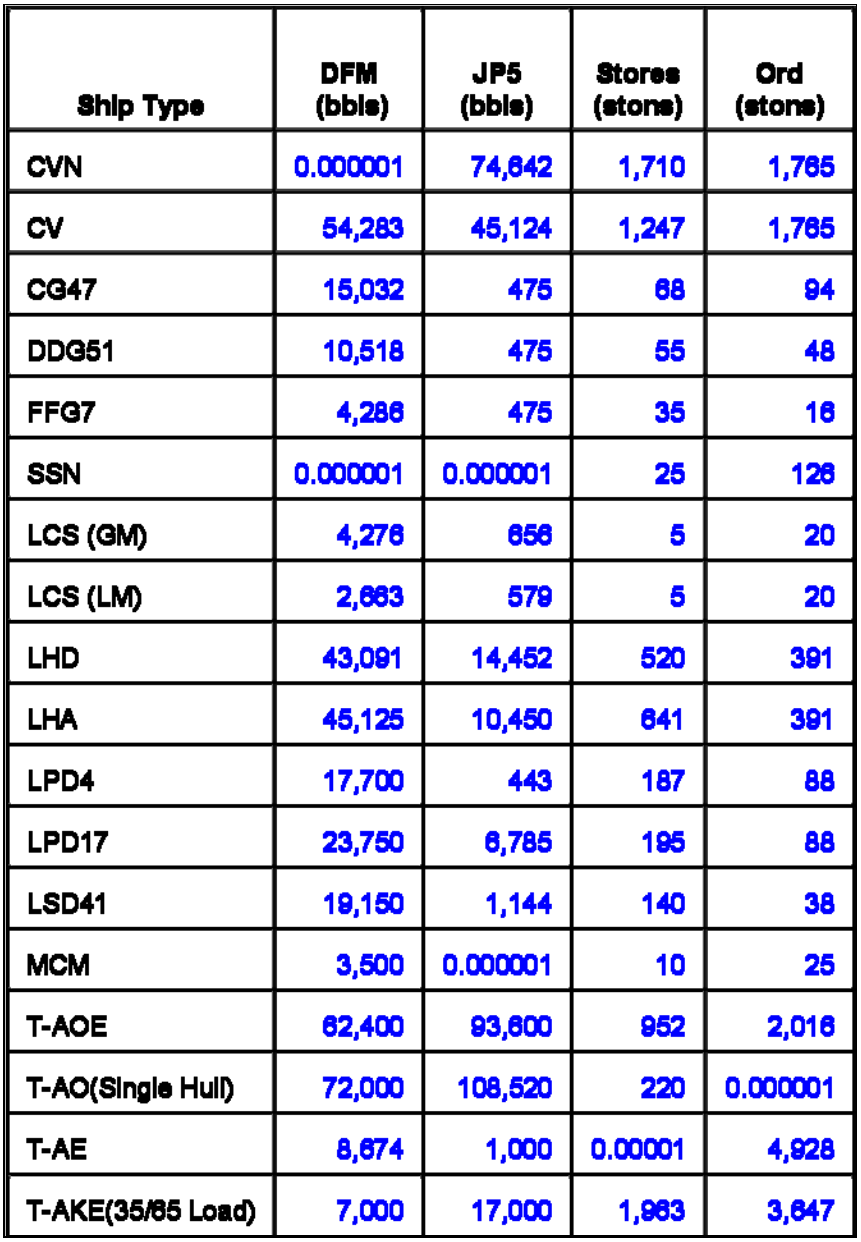
A. CLF CAPABILITIES BY SHIP TYPE

Ship Type	Speed (kts)	Range (nm)	POL Type	POL Capacity (bbls)	Cargo Type	Cargo Capacity (stons)
TAO_Single_Hull	16	3,000	DFM	72,000	Stor	220
			JP5	108,520	ordn	0.000001
TAO_Double_Hull	16	3,000	DFM	61,800	stor	220
			JP5	92,520	ordn	0.000001
T5	15	6,000	DFM	118,500	stor	0.000001
			JP5	118,500	ordn	0.000001
TAKE_AE_Load	20	14,000	DFM	7,000	stor	682
			JP5	17,000	ordn	4,928
TAKE_AFS_Load	20	14,000	DFM	7,000	stor	4,600
			JP5	17,000	ordn	1,010
TAKE_35_65_Load	20	14,000	DFM	7,000	stor	1,963
			JP5	17,000	ordn	3,647
TAKE_50_50_Load	20	14,000	DFM	7,000	stor	2,805
			JP5	17,000	ordn	2,805
TAKE_65_35_Load	20	14,000	DFM	7,000	stor	3,647
			JP5	17,000	ordn	1,963
TAOE	26	3,000	DFM	62,400	stor	952
			JP5	93,600	ordn	2,016
TAE	20	10,000	DFM	8,674	stor	0.000001
			JP5	1,000	ordn	4,928
TAFS	21	10,000	DFM	8,674	stor	4,600
			JP5	10,000	ordn	0.000001
JHSV	35	1,250	DFM	0.000001	stor	360
			JP5	0.000001	ordn	240

Table 5. CLF Capabilities and Capacity for each Commodity (After NWP 4-01.2)

T-AO_Single_Hull has a maximum sustained speed of 16 knots, a maximum unreplenished range of 3,000 nautical miles and capacities of 72,000 barrels for DFM, 108,520 barrels for JP5, 220 short tons of stores and 0 short tons of ordinance.

B. SHIP CAPACITIES



Ship Type	DFM (bbls)	JP5 (bbls)	Stores (stons)	Ord (stons)
CVN	0.000001	74,642	1,710	1,765
CV	54,283	45,124	1,247	1,765
CG47	15,032	475	68	94
DDG51	10,518	475	55	48
FFG7	4,286	475	35	16
SSN	0.000001	0.000001	25	126
LCS (GM)	4,276	656	5	20
LCS (LM)	2,663	579	5	20
LHD	43,091	14,452	520	391
LHA	45,125	10,450	641	391
LPD4	17,700	443	187	88
LPD17	23,750	6,785	195	88
LSD41	19,150	1,144	140	38
MCM	3,500	0.000001	10	25
T-AOE	62,400	93,600	952	2,016
T-AO(Single Hull)	72,000	108,520	220	0.000001
T-AE	8,674	1,000	0.00001	4,928
T-AKE(35/65 Load)	7,000	17,000	1,963	3,647

Table 6. Ship Capacities for each Commodity (After NWP 4-01.2)

The CVN has a capacity for 0 barrels of DFM, 74,642 barrels of JP5, 1,710 short tons of stores and 1,765 short tons of ordinance.

C. SHIP CONSUMPTION FACTORS

Ship Type	Commodity	Pre-Assault Consumption	Assault Consumption	Sustain Consumption
CVN	DFM (bbls/day)	0.000001	0.000001	0.000001
	JP5 (bbls/day)	3,000	6,000	4,000
	Stores (stons/day)	60	60	60
	Ordinance (stons/day)	0.000001	150	100
CG47	DFM (bbls/day)	1,430	757	757
	JP5 (bbls/day)	6	30	16
	Stores (stons/day)	2	2	2
	Ordinance (stons/day)	0.000001	6	3
DDG51	DFM (bbls/day)	1,200	646	646
	JP5 (bbls/day)	6	34	16
	Stores (stons/day)	2	2	2
	Ordinance (stons/day)	0.000001	3	2
FFG7	DFM (bbls/day)	304	304	304
	JP5 (bbls/day)	0.000001	30	16
	Stores (stons/day)	1	1	1
	Ordinance (stons/day)	0.000001	1	0.75
LCS Squadron	DFM (bbls/day)	350	450	350
	JP5 (bbls/day)	0.000001	20	16
	Stores (stons/day)	0.25	0.25	0.25
	Ordinance (stons/day)	0.000001	2	1
LHD	DFM (bbls/day)	2,000	1,071	1,071
	JP5 (bbls/day)	72	759	612
	Stores (stons/day)	16	16	16
	Ordinance (stons/day)	0.000001	33	16
LHA	DFM (bbls/day)	2,000	1,071	1,071
	JP5 (bbls/day)	72	759	612
	Stores (stons/day)	16	16	16
	Ordinance (stons/day)	0.000001	33	16
LPD4	DFM (bbls/day)	1,142	626	629
	JP5 (bbls/day)	17	324	221
	Stores (stons/day)	5	5	5
	Ordinance (stons/day)	0.000001	6	4
LPD17	DFM (bbls/day)	1,142	1,071	1,071
	JP5 (bbls/day)	17	759	612
	Stores (stons/day)	6	6	6
	Ordinance (stons/day)	0.000001	6	4
LSD41	DFM (bbls/day)	725	346	346
	JP5 (bbls/day)	2	61	66
	Stores (stons/day)	4	4	4
	Ordinance (stons/day)	0.000001	2	1
MCM	DFM (bbls/day)	600	600	600
	JP5 (bbls/day)	0.000001	0.000001	0.000001
	Stores (stons/day)	0.5	0.5	0.5
	Ordinance (stons/day)	0.000001	0.000001	0.000001
T-AOE	DFM (bbls/day)	2,570	960	960
	JP5 (bbls/day)	10	10	10
	Stores (stons/day)	1	1	1
	Ordinance (stons/day)	0.000001	0.000001	0.000001
T-AO	DFM (bbls/day)	2,570	960	960
	JP5 (bbls/day)	10	10	10
	Stores (stons/day)	1	1	1
	Ordinance (stons/day)	0.000001	0.000001	0.000001
T-AE	DFM (bbls/day)	960	960	960
	JP5 (bbls/day)	10	10	10
	Stores (stons/day)	1	1	1
	Ordinance (stons/day)	0.000001	0.000001	0.000001
T-AKE	DFM (bbls/day)	960	960	960
	JP5 (bbls/day)	10	10	10
	Stores (stons/day)	1	1	1
	Ordinance (stons/day)	0.000001	0.000001	0.000001

Table 7. Ship Consumption by Employment (After NWP 4-01.2)

A DDG51 consumes an average of 1,200 barrels/day of DFM when in pre-assault employment, 646 barrels/day in assault employment, and 646 barrels/day in sustain employment.

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