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Mission resource allocation in the Gulf of Guinea

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THESIS

MISSION RESOURCE ALLOCATION IN THE GULF OF GUINEA

by

Greta J. Spitz

March 2007

Thesis Advisor: Javier Salmeron
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Naval Forces Europe-Sixth Fleet (CNE-C6F) is responsible for the Gulf of Guinea (GOG) in Central-West Africa. CNE-C6F's goal is to provide persistent presence, pursuant the Global Fleet Station (GFS) concept, supporting U.S. Navy strategic priorities of Maritime Security and Theater Security Cooperation (TSC). Increased presence and developmental activities will assist host nations in developing their own maritime security. Limitations on USN capacity and logistics support present a challenge to scheduling, sustaining, and allocating mission resources in the GOG. This work presents an optimization model to aid in the mission planning and scheduling process. Specifically, we use notional data from the GFS prototype developed by CNE-C6F GOG Regional Planning Team which uses an LSD as the platform to accomplish almost 100 missions over six months. The problem is constrained by a budget, re-supply needs, and transit times between countries, among other logistical requirements. Our results show substantial improvements over current manual planning methods. For example, we demonstrate that 85% of the missions scheduled to be accomplished over the course of six months can be accomplished in three. Significant savings are realized by using a High Speed Vessel or by relaxing the request to achieve the maximum TSC value by 10%.

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MISSION RESOURCE ALLOCATION IN THE GULF OF GUINEA

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requirements for the degree of

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ABSTRACT

Naval Forces Europe-Sixth Fleet (CNE-C6F) is responsible for the Gulf of Guinea (GOG) in Central-West Africa. CNE-C6F's goal is to provide persistent presence, pursuant the Global Fleet Station (GFS) concept, supporting U.S. Navy strategic priorities of Maritime Security and Theater Security Cooperation (TSC). Increased presence and developmental activities will assist host nations in developing their own maritime security. Limitations on USN capacity and logistics support present a challenge to scheduling, sustaining, and allocating mission resources in the GOG. This work presents an optimization model to aid in the mission planning and scheduling process. Specifically, we use notional data from the GFS prototype developed by CNE-C6F GOG Regional Planning Team which uses an LSD as the platform to accomplish almost 100 missions over six months. The problem is constrained by a budget, re-supply needs, and transit times between countries, among other logistical requirements. Our results show substantial improvements over current manual planning methods. For example, we demonstrate that 85% of the missions scheduled to be accomplished over the course of six months can be accomplished in three. Significant savings are realized by using a High Speed Vessel or by relaxing the request to achieve the maximum TSC value by 10%.

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LIST OF ACRONYMS

AS	Submarine Tender
CARMA	Central-West Africa Resource and Mission Allocation model
CLF	Combat Logistics Force
CNE-C6F	Commander, Naval Forces Europe-Commander, Sixth Fleet
CNO	Chief of Naval Operations
CONOPS	Concept of Operations
DOD	Department of Defense
EBT	Effects-Based Thinking
EPT	Expeditionary Partnership Teams
EUCOM	U.S. European Command
FFG	Guided-Missile Frigate
GFS	Global Fleet Station
GMP	Global Maritime Partnership
GOG	Gulf of Guinea
HSV	High Speed Vessel
LCS	Littoral Combat Ship
LHD	Amphibious Assault Ship
LPD	Amphibious Transport Dock Ship
LSD	Landing Transport Dock Ship
MDA	Maritime Domain Awareness
MOE	Measure of Effectiveness
NAVSO	U.S. Naval Forces Southern Command
NECC	Naval Expeditionary Combat Command
NGO	Non-Government Organization
RPT	Regional Planning Team
SSTR	Security, Stability, Transition, and Reconstruction
TSC	Theater Security Cooperation
TSP	Traveling Salesman Problem
USCG	United States Coast Guard
USG	United States Government
USN	United States Navy
VRP	Vehicle Routing Problem

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EXECUTIVE SUMMARY

Naval Forces Europe-Sixth Fleet (CNE-C6F) is responsible for the Gulf of Guinea (GOG) in Central-West Africa. CNE-C6F's goal is to provide persistent presence, pursuant the Global Fleet Station (GFS) concept, supporting U.S. Navy (USN) strategic priorities of Maritime Security and Theater Security Cooperation (TSC). Increased presence and developmental activities will assist host nations in developing their own maritime security. It will also improve efficiency and viability of future logistical requirements in support of the GFS Concept, Maritime Domain Awareness, and the Global Maritime Partnership Initiative. The USN faces the challenge of weighing its resources against the value of a mission to TSC in Central-West Africa. However, the GOG is unlike any other in which the USN currently operates and limitations on USN capacity and logistics support present a challenge to scheduling, sustaining, and allocating mission resources.

This work presents the optimization model CARMA (Central-West Africa Resource and Mission Allocation) to aid in the mission planning and scheduling process. CARMA is designed to be a prototypic planning tool providing Fleet staffs the opportunity to examine the feasibility of future deployments and activities. The CARMA model identifies how one naval ship with embarked Expeditionary Partnership Teams (EPT) (previously known as Expeditionary Training Teams) can best meet the logistical requirements to provide training and support to West African nations around the GOG. The study provides possible solutions in the form of a deployment schedule and the combination of EPTs required to perform the missions. These results can guide planners in best utilizing current naval resources available in the region and provide insights for future planning.

Specifically, we use notional data from the Fall 2007 GOG GFS Demonstration developed by CNE-C6F GOG Regional Planning Team. This demonstration proposes a LSD (Landing Transport Dock Ship) as the platform to accomplish almost 100 missions over six months. Among several logistical requirements, the problem is constrained by a

budget, re-supply needs, transit times between countries, and the necessity to accomplish a minimum level of engagement in each GOG country it visits.

Our results show substantial improvements over current manual planning methods. Overall, we show that CARMA schedules missions resulting in increased TSC for the region with greater efficiency. For example, we demonstrate that 85% of the possible TSC value from a six month scenario is accomplished by missions scheduled over the course three months. Another scenario using a High Speed Vessel instead of a LSD renders a two-thirds reduction in cost. Finally significant savings are realized by relaxing the request to achieve the maximum TSC value by 10%.

CARMA can provide potential schedules and alternatives valuable to long-term planning in the GOG. Changing limitations on deployment time frame, ship or EPT availability, and budget offer opportunities to understand where tradeoffs can be made. CARMA can be used by planners to understand how different ship types may be used to accomplish similar missions. Exploration into EPT constraints can help the USN to determine team requirements: CARMA optimally allocates training teams to a ship to achieve the maximum TSC value, while accounting for berthing availability and satisfying a variety of other ship- and scenario-specific constraints.

I. INTRODUCTION

A. OVERVIEW

Over the past few years, the United States Navy (USN) has increased its focus on the region of Central West Africa known as the Gulf of Guinea (GOG). For several reasons, the nations surrounding the Gulf are becoming increasingly important and emerging as potential enduring partners. The role of engaging many of these nations in Theater Security Cooperation (TSC) falls under the responsibility of Admiral H. G. Ulrich, Commander U.S. Naval Forces Europe–Commander Sixth Fleet (CNE-C6F), the naval arm of U.S. European Command (EUCOM). While the U.S. military has been involved in this region for many years, only recently have the USN's coordinated and concerted efforts to improve maritime security and build partnerships become one of CNE-C6F's top priorities.

The USN has the challenge of weighing its resources against the value to TSC provided by missions accomplished in the GOG. This area of responsibility is unlike any other in which the USN currently operates. Severe logistical challenges exist, the most important of which are the lack of U.S.-owned bases within reasonable vicinity and limited local suppliers to provide dependable logistical support. These challenges are exacerbated by ungoverned spaces and immature host nation navies with limited operational and logistical capacity, creating great complexity for planners assigning forces to missions in this region. These missions include training maritime security forces in leadership, establishing communication and other infrastructures, developing security tactics and providing medical training, among others. All of these activities are important to the success of the GOG region, but requests for assistance and equipment exceed USN's capacity. As an example, the USN cannot give other nations financial aid or equipment, as this is the State Department's responsibility.

Planners must wrestle with prioritizing host nation requests to best meet their needs and U.S. strategic goals. Often these navies first need assistance with basic training and maintenance programs in order for other training programs to be beneficial in the long term. Due to limited availability and high costs of logistics resupply assets of the USN and of these developing nations, the Navy must be selective about the missions it conducts in order to provide the greatest benefit to the GOG nations and meet U.S. goals within the available budget. This thesis develops a mathematical optimization model, Central-West Africa Resource and Mission Allocation (CARMA), to aid in the planning process.

B. BACKGROUND

1. The Importance of the Gulf of Guinea to the United States

The GOG is an area of global concern for economic, political and military reasons. It lies in the "Arc of Instability," "...a swath of territory running from the Caribbean Basin through most of Africa, the Middle East, and Central and Southeast Asia. It is countries along this arc —often failed states— that U.S. officials argue have been left far behind as the rest of the world is brought into the global economy" [Military Reform Project 2003]. Piracy, drug and human trafficking, and fisheries poaching are just some of the everyday criminal threats which hinder economic advancement. Specifically for the U.S., the GOG is of economic concern because of the large amount of oil the U.S. imports from Africa. It is believed that oil imports from GOG nations will rise to 20% by 2010, up from 15% in 2005 [Council on Foreign Relations 2006].

Political and military concerns arise from lack of maritime security and instability in the region and the desire to aid safety measures for partner nations and protect sea lines of communication. Internal conflict spurred on by the struggle to control natural resources and power distribution has the potential to develop into cross-boarder crises in the GOG [Global Security 2006]. "A key mission for U.S. forces [in Africa] would be to ensure that Nigeria's oil fields, which in the future could account for as much as 25% of all U.S. oil imports, are secure," a senior Pentagon official told Greg Jaffe of the Wall Street Journal [Volman 2006]. The importance of the region is further supported by recent approval to create an additional combatant command for Africa. Secretary of Defense Robert Gates stated that Africa Command will "oversee security, cooperation, building partnership capability, defense support to nonmilitary missions, and if directed, military operations on the African continent" [CNN 2007]. A dedicated combatant command supports the idea that U.S. interests are protected through increased presence.

2. USN Presence in the Gulf of Guinea

The USN has the capacity and capability to provide increased presence and support the security efforts in Africa, specifically in the GOG, in accordance with its maritime strategy [Copp 2007]. However, USN efforts alone cannot accomplish this goal: coordination with the host nations is necessary. One possible way to obtain security and stability is to train and support regional nations to provide for their own maritime security. The Navy must help build their naval and maritime security forces with the correct capabilities and to appropriate capacity [Goldwyn and Morrison 2005, Miles 2006]. Recent military guidance suggests and directs these actions. The Department of Defense (DOD) Directive 3000.05, Military Support for Stability, Security, Transition and Reconstruction (SSTR) Operations orders the DOD to "develop greater means to help build other countries' security capacity to ensure security in their own lands" [DOD 2005]. Chief of Naval Operations (CNO) Guidance for 2006 states the CNO's vision for the future of the Navy includes "steadily deepening cooperation among the maritime forces of emerging partner nations" [CNO 2006].

The idea of improving maritime security for GOG nations is clearly a high priority and is further defined by the President's National Strategy for Maritime Security, EUCOM's Theater Security Cooperation Guidance, U.S. Naval Forces Europe Guidance for 2006, and CNO Strategic Studies Group XXV Report. Other concepts and initiatives which help to develop these capabilities and capacities are the Global Fleet Station (GFS), the Unclassified Maritime Domain Awareness (MDA) Initiative, and "The 1000 Ship Navy" [Morgan and Martoglio 2005] (now known as the "Global Maritime Partnership (GMP) Initiative"). Through these initiatives the Navy supports SSTR operations, builds partnerships, and promotes global maritime security. There is evidence that host nations welcome international cooperation when it is inclusive and transparent. Increased naval presence in the GOG must also be persistent and non-threatening to the host nations. This will require substantial logistics support, which is currently very limited [Ulrich 2006].

Naval leadership believes USN presence and activities in the GOG can help build the capability and capacity of West African nations to ensure security for the region in the future. Capacity building entails training military forces in order to improve their own security forces. This training ranges from small boat operations and force protection to vessel repair and ordnance disposal. It also extends to non-military areas where governmental and non-governmental organizations provide medical and educational training. The Navy can serve as an enabler for other services including reserves and U.S. Coast Guard (USCG), U.S. government (USG) organizations such as the State Department and U.S. Agency for International Development, and non-governmental organizations (NGO) or commercial entities by providing transport and hotel facilities, and security support. However, there are few bases and ports for logistical support in the GOG that can support the deployment of U.S. forces for the training and assistance requested by host nations. The closest U.S. owned bases that currently support Central-West Africa are located in Rota, Spain and the island of Diego Garcia in the Indian Ocean. Due to their great distances to the GOG, they are not practical for regional operations.[1]

3. Gulf of Guinea Nations and Maritime Security

CNE-C6F is responsible for most U.S. military affairs in Central-West Africa. They define the GOG as the following eleven countries (see Figure 1): Ghana, Togo, Benin, Nigeria, Cameroon, Gabon, Equatorial Guinea (EG), Sao Tome & Principe (STP), Congo (Brazzaville), Democratic Republic of Congo (Kinshasa), and Angola [Mittleman 2006]. Many of these countries' naval forces are in a state of grave deterioration or virtually nonexistent. Even the more advance navies carry out only coast guard-like missions including fisheries protection, counter-smuggling, and other law enforcement activities. They are considered secondary to army forces and therefore receive little funding [Cobble et al. 2006].

[1] Rota, Spain, is proposed to cover the West Africa region. The sailing path from Rota to Lagos, Nigeria, is about 3,500 nautical miles. To put this in perspective, if we intended to cover Lagos from Rio de Janeiro, Brazil, we would be over 150 miles closer. We might as well create the station in Norfolk, Virginia: the distance from Norfolk to Dakar, Senegal, is less than 3,400 nautical miles.

Figure 1. Map of the Gulf of Guinea Region in Central West Africa [After Perry-Casteneda 2006]

By 2006, GOG countries made great strides to improve maritime safety and security in the region. A first step was their participation in a EUCOM-sponsored workshop in Accra, Ghana in early 2006. This set the stage for the "Communiqué of the Gulf of Guinea". This Communiqué or letter of intention was agreed upon in November 2006 at the Maritime Safety and Security Conference in Cotonou, Benin. The ministers and representatives of these nations agreed to improve MDA, implement legal and regulatory frameworks, sub-regional cooperation, and improve public awareness and political will to the benefit of maritime safety and security. The GOG countries' leadership urges greater collaboration to strengthen the relation with EUCOM and CNE-C6F [Gulf of Guinea Maritime Safety and Security Ministerial Conference 2006]. The door is open for increased engagement.

4. Persistent Presence and Logistical Challenges

Persistent presence is a key concept to building partnerships and capacity. A persistent presence allows familiarity through consistent interaction for both the USN and host nations. Relationships develop between those people who work together on a regular basis. The ability to routinely engage with partner navies, NGOs, and other organizations in the region is vital to the success of theater security and cooperation. In the past the Navy has been a fair-weather partner and inconsistent in participating in GOG exercises on a regular basis. Achieving the goal of persistent presence is dependent on logistics support from land or sea bases. Current USN presence is adequately supported for a limited period of time, but extended deployments over several months prove problematic [Fulkerson 2006].

Logistics support capabilities must be maximized to best meet the requirements of theater security cooperation and strategic regional goals for the nations in the GOG. A limited amount of the logistical requirements of fuel, maintenance support, training support and subsistence can be met through a combination of local ports and naval assets. By choosing to engage in activities which best help to improve TSC given the limited available resources, time spent on station will be utilized to the greatest extent possible. As operations become more frequent and infrastructure improves, more logistical assets provide by host nations will increase the feasibility of staying on station for longer periods of time. This increased time on station is believed to advance interoperability and relationships with the GOG nations. Increased presence will open the doors for improving the efficiency and viability of future logistical requirements in support of the GFS Concept, MDA, and GMP.

A possible sea base is the proposed GFS concept, which would link current naval bases around the world to local operations. The GFS concept proposes a ship or group of ships that would provide training and classroom space, operational support, and logistical services to enhance TSC. It would have onboard small training teams and units such as Riverine forces and helicopter detachments. It would be “a persistent sea base of operations from which to coordinate and employ adaptive force packages within a regional area of interest,” and sustaining USN, DOD, and USG assets as well as other coalition partners in a region [Hilburn 2006]. Teams from GFS ships would include

Naval Expeditionary Combat Command (NECC), USCG, and NGOs to will provide training and support. U.S. Naval Forces Southern Command (NAVSO) is using Swift, a High Speed Vessel (HSV-2), for a GFS pilot program in the Caribbean. However, in the Caribbean theater the distances are considerably less than in the GOG and there is sufficient shore-based logistical support. While there will be lessons that the Navy can learn from NAVSO's Caribbean demonstration, each region of the world in which the USN operates has different considerations and the same GFS platform is not the best solution for every region. The USS Fort McHenry (LSD-43) will demonstrate GFS capabilities in the GOG during late 2007 [Fulkerson 2007-A]. If successful, this demonstration will continue to aid in the development of continual presence. CARMA can be used to determine how a GFS platform can accomplish missions given current logistical support capabilities, which in turn can help prove the GFS concept.

The U.S. does not have any military bases on the African mainland. Instead, it relies on bilateral agreements with African countries to use their facilities [Volman 2006]. Even so, there is no core logistics port or full commercial logistics capability in the GOG. Additionally, USN combat logistics force (CLF) ships which usually provide sustainment for ships at sea are overextended with other commitments and cannot be guaranteed to be available in the region [Becker 2006]. At present, the U.S. is focusing on the GOG region to establish "bare-bones" facilities such as airstrips, basic communications links, and warehouses to be used for U.S. operations. Ghana and Gabon have signed agreements with the U.S. to allow American aircraft to refuel at local airbases [Volman 2006]. However, little analytical rigor has been used to determine the best way to achieve maximum mission accomplishment with the assets available while the specifications of a persistent sea base are being developed.

CNE-C6F has a Regional Planning Team (RPT) for the Gulf of Guinea and is organizing efforts to develop activities that support U.S. regional campaign plans, as well as the Theater Security Cooperation strategy [Mittleman 2006]. This RPT will play a significant role in the coordination of maritime security efforts between the GOG nations and the U.S. military. Despite the lack of military bases, the U.S. is involved with numerous countries for joint training exercises. Countries in the GOG region that have recently participated with the U.S. in exercises are Gabon, Ghana, Nigeria and

Cameroon. Exercises like West Africa Training Cruise and deployments by USS Emory S. Land (AS-39), USS Gunston Hall (LSD-44), and High Speed Vessel (HSV-2) Swift have provided opportunities for interoperability in the GOG. However, while these ships may be deployed several months for these training exercises, they are only able to support operations for a few weeks in the GOG [Volman 2006]. As seen in Figure 2, the effort to increase presence is apparent.

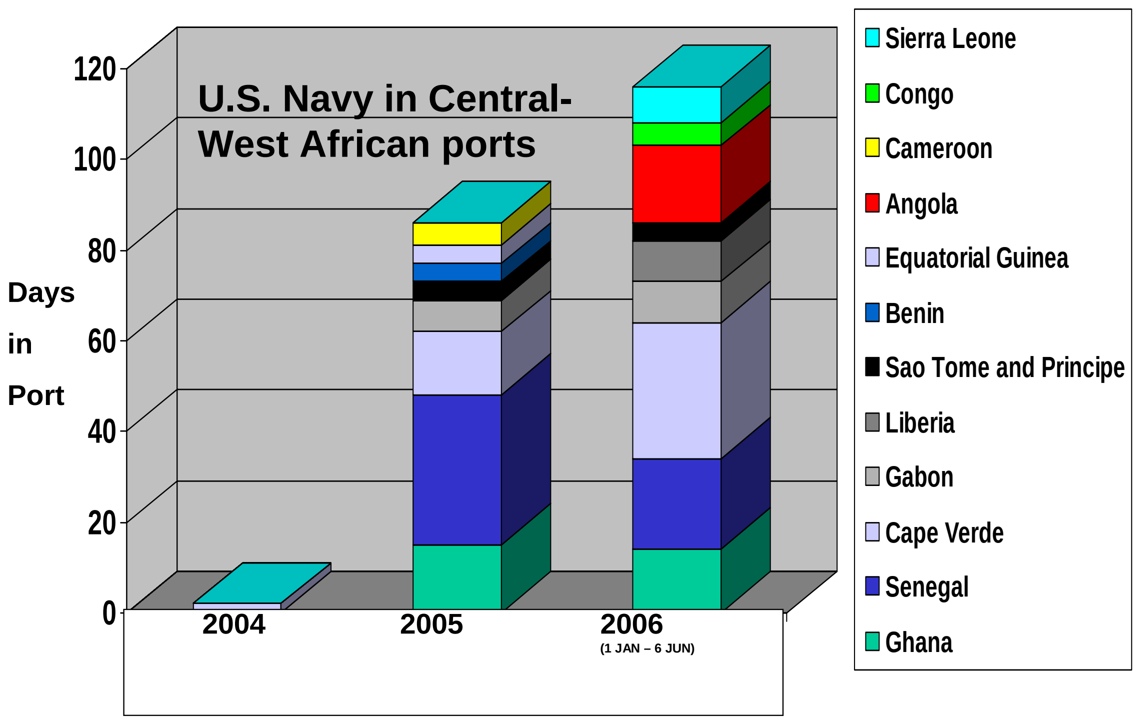

Figure 2. Number of days U.S. ships have been in GOG ports [From CNE-C6F RPT 2006]

How the forces will be supported for maritime operations in the GOG for a long-term basis needs to be decided. In the near term, U.S. naval presence will be achieved through the aforementioned exercises and GFS demonstrations similar to previous deployments to the region. Currently, some factors are hindering persistent training and presence by the Navy in the area, e.g.: (a) Minimal and expensive logistics support for resupply of food, fuel and support equipment; (b) lack of availability of dedicated and appropriate ship types that can support the training needed; (c) minimal maintenance and training facilities; and, (d) environmental constraints such as overboard discharges and potable water, which impact the flexibility to extend time on station or the ability to pull into certain ports [Trott 2006].

5. Current CNE-C6F RPT Planning

Previous deployments to the region have had very short term planning horizons, despite the best efforts of CNE-C6F. Many of the activities are a pick-up game of opportunity, where the underlying philosophy is "doing as much as can be done with short lead times and minimal resources" [Fulkerson 2006]. For example, the overall plans for the Emory S. Land's 2006 deployment were changed several times. The planning horizon was not sufficient to send in advance teams ahead of time to work with the host nations and determine their needs and coordinate with the defense attachés [Budney 2006]. Challenges in determining which missions could be accomplished due to funding issues were a large problem [Delaney 2007]. While the deployment was considered a success, more could have been accomplished.

The CNE-C6F RPT staff is using a planning method called Effects-Based Thinking (EBT), a methodology that brings together strategic priorities and measures of effectiveness (MOE), such as number of personnel trained or status of equipment to determine mission success over time. The latest deployments to the GOG have been planned using EBT [Ulrich 2006] as well as considering the requests of host nation countries. This process is proving useful, but there are thousands of possible mission-country combinations that the RPT planners do not have the time to consider. There is room for mathematical models to assist in this planning. Additionally, while much effort is being made to utilize EBT, MOEs are being developed in an area where there is little past experience of measuring and documenting the outcomes of engagements. For example, the teams designated to conducting many of the security evolutions are part of the NECC. NECC was created in 2006 and is still developing its concept of operations. As time progresses, more information will become available to help understand a complex environment where operations are not entirely familiar to the USN. There are a large number of resources, schedules, and logistical issues to manage and CARMA can provide planners with an insight into what is possible.

C. GOAL

This thesis uses the CARMA model to identify how one non-combatant type ship with embarked Expeditionary Partnership Teams (EPT) (previously known as Expeditionary Training Teams) can best meet the logistical requirements to provide training and support to West African nations around the GOG. The study provides possible solutions to guide planners in best utilizing current naval resources available in the region and provide insights for future planning.

Operations logistics techniques are used to model and optimize scheduling, sustainability, and other logistical problems. By identifying the constraints to mission accomplishment for U.S. naval assets while taking into account costs and benefits of these missions, mathematical models can be developed to help provide possible near-term solutions to resource allocation. This work uses optimization models to help identify the best possible allocation of available naval resources to achieve maximum mission accomplishment in the GOG. Specifically, CARMA maximizes the TSC value of all missions accomplished and then seeks a secondary goal based on minimizing cost. This adheres to the policy of doing as much as possible with minimal resources. The CARMA model is designed to demonstrate the capabilities of one USN ship and associated personnel to support increased engagement activity in the GOG.

Specific guidance that CARMA provides includes which EPTs may be onboard, and how the ship can best move from one port to another in order to drop off EPTs or other personnel which can accomplish missions. This is similar to the well-known "vehicle routing problem" (VRP). The VRP entails designing the optimal set of routes for a fleet of vehicles in order to serve a given set of customers. The interest in VRP is motivated by its practical relevance as well as by its considerable difficulty [Toth and Vigo 2002]. While there are considerable similarities between the VRP and the GOG problem, the GOG problem has important features not typically part of a standard VRP. For example, CARMA allows for EPTs to be dropped off at a location and for the ship to return to pick them up upon mission completion.

Work employing these techniques includes Naval Postgraduate School Master theses that have developed models contributing to USN aircraft carrier long-term deployment scheduling [Ayik 2000] and U.S. Marine Corps Combat Service Support resource, asset, and network route optimization [Lenhardt 2001, Ozkan 2005]. However, no work has yet been done to model the logistical constraints of ship movement and mission assignment while considering the objective of maximizing mission value. Additionally CARMA embeds two optimizations: first a maximization of the TSC value, then a minimization of the total cost of all the missions to produce the best mission set and schedule at minimum cost.

The initial measure of validity for the CARMA model is realized by comparing a number of test cases with past activities and current operational plans. This work will have proved successful if it helps operational planners to better plan activities in the GOG. CARMA should be used in conjunction with other judicious planning resources, and modified to accommodate new information and/or specifications as these are realized.

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II. MODELING APPROACHES

This chapter introduces the CARMA model which uses mathematical optimization to assign and schedule EPTs to missions that provide greatest value to TSC in Central-West African countries. The model also minimizes total cost in order to return the best combination of these missions at the lowest cost.

A. PROBLEM SPECIFICATIONS

CARMA is designed to be a prototypic planning tool providing Fleet staffs the opportunity to examine the feasibility of future deployments and activities. Its design allows changes in the majority of the data to reflect classified information and updates in resources and capabilities.

1. Data

a. Gulf of Guinea Countries

The notional country network uses the physical location of the main port in which USN vessels have or plan to visit in each country. Each country is assigned a number of candidate missions and a minimum TSC level. Some countries are designated as being able to provide fuel and/or other provisions for the ship. Two other ports in addition to the GOG countries are designated part of the data set, but do not have missions or TSC levels assigned to them. These are Spain (Rota) and Senegal (Dakar). These countries provide re-supply opportunities for ships in transit to the GOG and are normal ports of call. Finally, there is a fictitious country designated “At Sea”, which provides a location for the ship to conduct exercises at sea or an opportunity to conduct underway replenishment if a refueling asset is available.

b. Missions

The missions are a subset of those designated by CNE-C6F’s engagement plan to be carried out in between 2007 and 2016. The missions are “discrete entities” and are paired with the countries where they can be executed. (By discrete entity it is meant that if the same mission is requested more than once it is given its own specific notation.) Each mission can be accomplished a maximum number of times in each country. Some missions may have precedence relationships with respect to other missions, i.e., one must be carried out in order for the other to be considered. The missions are then further designated as those which require the ship to remain in port, those where the ship must be at sea, or where the location of the ship is unrestricted. The ship must to drop EPTs off in order to complete missions and then later return for them upon completion of the missions.

c. TSC Values

Each mission is assigned a TSC value based on the benefit to theater security cooperation as determined by the Fleet staff. Each mission accomplished counts towards satisfying the minimum TSC level for the country where the mission is performed and the overall goal for the region. Often the exercises executed at sea involve a number of countries. Therefore for exercises conducted at sea, the TSC values are awarded to the fictitious "At Sea" country increasing overall TSC value for the region. This interaction increases coordination and understanding among the navies and maritime security forces in the region which in theory should add to TSC for all GOG countries.

d. Costs and Budget

A cost ($ amount) is assigned to each mission. The cost is determined by a cost per person-mission-day. There is also a cost associated with each port per day with the exception of Rota, Spain and the fictitious "At Sea" port for which there is no additional cost. The total cost of all missions performed and in port days cannot exceed the available budget.

e. EPTs

The EPTs are groups of people that can accomplish missions for which each EPT is capable. They range in capabilities and numbers of people. The EPTs can be organic to the ship or attached to the ship from another command, USG organization, or NGO. The number of teams attached to the ship is limited only by available living accommodations for these personnel. Additionally, the EPTs themselves are limited in availability by type. For instance, there may be a limited number of civil affairs EPTs. Finally, each team can only do one mission at a time.

f. Ship

The ship must be capable of carrying EPTs in addition to its regular crew. Ship specific data including available space for non-crew personnel, fuel capacity, and fuel consumption figures are used for each scenario. Not included in the model is the need for or use of other organic transportation like helicopters or LCUs (land craft, utility). A ship uses fuel at two rates, either underway or in port consumption. The underway rate equates to consumption at the average transit speed. The usage rate is calculated daily and is subtracted from the amount onboard at the end of the day. Fuel consumption from other consumers such as LCACs (landing craft air cushioned) and helicopters can be considered.

g. Distances

Distances are measured in nautical miles from one port to another and the speed of transit is measured in knots.

2. Assumptions

The CARMA model makes several assumptions in order to be tractable, i.e., computationally solvable. Like many naval missions, the number of people involved, the time to accomplish a mission and the resources consumed are not completely determined. These data figures are estimated averages and remain consistent: numbers of personnel on EPTs, length of mission, and fuel usage per day. It is assumed that these assumptions will have little impact on the overall results of the model. Planners then can use the results of the model to further define their schedule according to real-world specificities and other constraints not accounted for in the model.

a. Mission Support

It is assumed that for each mission-country pair there is adequate support, transportation, and/or training facilities to conduct the mission. Additionally, it is assumed that EPT resources and physical requirements needed to conduct the missions, including storage space, communications, etc., can be met by the ship or host nation. EPTs will be self-sufficient while conducting their missions, i.e., the ship does not have to remain in port unless the mission is so-designated.

b. *Fuel Usage*

One of the most important logistical constraints is fuel for the ship. Fleet policy states that most ships need to maintain 60% fuel onboard.[2] Many amphibious ships cannot physically have less than 50% fuel due to load instability problems. Other ships such as the HSV can drop to 25% fuel capacity. The model calculates fuel usage at an average speed which accounts for fluctuations in speed and fuel usage over a long period of time [Futcher 2006]. Ships can refuel at any of the designated refueling ports. The model requires one day at any refueling port (regardless of the amount refueled). We assume the fuel from the country is satisfactory for all ships and all necessary transfer equipment is available.

c. *Provisions*

Current support for food and other provisions is usually between 25-30 days. While fresh fruit and vegetables are obtainable at several ports, not all provisions are available. These other provisions must be flown in or received via CLF. Both options are very expensive and there is a lack of CLF assets. Therefore, it may not be economically feasible to provide ships provisions in countries where they are not available and ships only receive provisions at designated ports.

d. *Movement*

CARMA allows for only one ship to accomplish all the missions. When conducting missions not required to be done at sea or in port, the ship is free to move from one port to another as long as it returns to pick up the EPTs that it dropped off. It is not realistic that a ship would get underway with no purpose. Therefore, a small penalty has been assigned to each movement, which causes the model to move the ship only when it is going to refuel or accomplish a mission.

e. *Transit Time*

The fidelity of the model only allows for distances to be measured in units of days, e.g., a 2.3-day trip would be conservatively inputted in CARMA as a 3-day trip.

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[2] Fleet Policy uses a "stop light chart" designation to assess fuel levels:

Above 80% = green

>70-80 = yellow

>60-70 = red [Futcher F. (2006)]

3. Scope and Limitations

The CARMA model can be used as both a strategic and operational planning tool. It is strategic because it provides an overall value for theater security and cooperation in the GOG region while achieving target values for individual countries. It is operational because it assigns missions to a single ship over a specific time period. It is not intended to be used as a final scheduling tool. Instead, this tool should be used as a starting point for long-range planning. There is a number of planning factors like availability of assets, time of year, environmental constraints, and sensitivities of particular countries that operational and logistics planners must consider and if necessary these other planning factors can be addressed in CARMA.

B. MATHEMATICAL FORMULATION

This section describes the CARMA model, a two-objective integer linear programming model. CARMA first seeks to maximize the value of all missions conducted. It then minimizes the total cost (subject to an overall mission value target) of a set of missions with the same value.

1. Sets and Indices

U, EPT type, $u \in U$.

C, countries, $c \in C$. We include a fictitious country $c_0 \in C$ representing a location "At Sea."

T, time period, $t \in T = \{1, 2, ..., |T|\}$. Remark: we assume each time period represents one day.

M, missions, $m \in M$.

$J \subset M \times U$, subset of mission-EPT pairs (m,u) where mission *m* is carried out by EPT type *u*.

$K \subset M \times C$, subset of mission-country pairs (m,c) where mission *m* can be carried out in country *c*.

$M^p \subset M$, subset of missions in which the ship must remain in port for the duration of the mission.

$B \subset M \times M$, subset of missions-mission pairs (*m,m'*) where mission *m* must be carried out before mission *m'*.

$I \subset M^s \times C$, subset of mission-country pairs (*m,c*) where mission *m* is carried out at sea and is of value to country *c*.

$C^f \subset C$, subset of countries that can provide fuel.

$C^g \subset C$, subset of countries that can provide food and water.

2. Parameters (units)

$Uracks$, number of people for which space onboard the ship is available for EPT personnel (persons).

np_u, number of personnel in EPT type *u* (persons).

$maxN_u$, maximum number of EPTs type *u* that are available (teams).

d_m, duration of mission *m* (days).

$trip_{c,c'}$, duration of trip from country *c* to country *c'* (days).

tc, fuel tank capacity (gal).

$minFuel$, minimum fuel level allowed (gal).

$initFuel$, fuel onboard ship at the beginning of day 1 (gal).

b^m, fuel burn rate when transiting (gal/day).

b^w, fuel burn rate when in port (gal/day).

$resupplyT$, maximum time between ship re-supply for food and water (days).

$minEngage_c$, minimum value required for all missions in country *c* (value units).

$maxMission$, maximum number of each mission that can be conducted in each country.

$value_m$, value earned for accomplishing mission *m* (value units).

$cost_m$, cost of mission *m* ($).

$pCost_c$, cost of going in port country c ($).

budget , total amount of money allocated for all missions in the region ($).

$penalty_1$, penalty to discourage unnecessary movement for primary objective. Remark: For all examples, $penalty_1$ = 0.1.

$penalty_2$, penalty to discourage unnecessary movement for secondary objective. Remark: For all examples, $penalty_2$ = 100.

$\hat{TSC}$, TSC accomplishment (derived after the primary objective function has been optimized, see below) (value units).

α , fraction of $\hat{TSC}$ required to be accomplished when the secondary objective (cost) is optimized. $0 \le \alpha \le 1$. Note: $\alpha = 1$ unless otherwise specified.

3. Decision Variables

<u>Binary Decision Variables</u>

$X_{m.c.t.u}$, 1 if mission *m* in country *c* starts in day *t* by EPT *u*; 0 otherwise.

$W_{c,t}$, 1 if the ship is waiting in port at country *c* in day *t*; 0 otherwise.

$Q_{c,c',t}$, 1 if the ships starts a trip from country *c* to country *c'* in day *t*; 0 otherwise.

<u>Non-negative Continuous Decision Variables (units)</u>

F_t , amount of fuel onboard the ship at the end of day *t* (gal)

E_t , amount of fuel supplied to the ship at the beginning of day *t* (gal)

Non-negative Integer Decision Variables (units)

N_u , number of EPTs u onboard the ship (teams)

4. Mathematical Formulation of CARMA Model

Primary Objective Function: Maximize

$$\underset{X,Q,W,N,F,E}{Max} \sum_{\substack{m,c,t,u|c\neq c_0\\(m,u)\in J\\(m,c)\in K}} value_m X_{m,c,t,u} - \sum_{\substack{c,c',t|\\c\neq c'}} penalty1 Q_{c,c',t} \quad (1)$$

Secondary Objective Function: Minimize

$$\underset{X,Q,W,N,F,E}{Min} \sum_{\substack{m,c,t,u|\\(m,c)\in K\\(m,u)\in J}} cost_m X_{m,c,t,u} + \sum_{c,t} pCost_c W_{c,t} + \sum_{\substack{c,c',t|\\c\neq c'}} penalty2 Q_{c,c',t} \quad (2)$$

Constraints:

$$\sum_m value_m \sum_{\substack{t,u|(m,u)\in J\\(m,c)\in K}} X_{m,c,t,u} \geq minEngage_c \qquad \forall c \quad (3)$$

$$\sum_{u|(m,u)\in J} \sum_{t'=t}^{t-d_m} X_{m,c,t',u} \geq \sum_{u|(m',u)\in J} X_{m,c,t,u} \qquad \begin{array}{l}\forall t,m,m',c \mid (m,m')\in B,\\ (m,c)\in K,(m',c)\in K, t>d_m\end{array} \quad (4)$$

$$\sum_{t,u|(m,u)\in J} X_{m,c,t,u} \leq maxMission \qquad \forall m,c \mid (m,c)\in K \quad (5)$$

$$\sum_{\substack{c,m|\\(m',c')\in K\\(m',u')\in J}} \sum_{t'=t-d_m}^{t} X_{m,c,t',u} \leq N_u \qquad \forall t,u \quad (6)$$

$$\sum_u np_u N_u \leq Uracks \qquad \forall t \quad (7)$$

$$W_{c,t} + \sum_{c'|c'\neq c} Q_{c',c,t-trip_{c',c}+1} = W_{c,t+1} + \sum_{c'|c'\neq c} Q_{c,c',t+1} \qquad \forall c,t \mid t<|T| \quad (8)$$

$$\sum_{t'=t-d_m+1}^{t} X_{m,c,t',u} \leq W_{c,t} \qquad \forall m,c,t,u \mid (m,u)\in J,(m,c)\in K, m\in M^p \quad (9)$$

$$\sum_{\substack{m|(m,u)\in J\\(m,c)\in K,}} X_{m,c,t,u} \le W_{c,t} \qquad \forall c,t,u \qquad (10)$$

$$\sum_{\substack{m|(m,u)\in J\\(m,c)\in K}} X_{m,c,t,u} \le W_{c,t+d_m-1} \qquad \forall c,t,u \qquad (11)$$

$$\sum_{c\in C^g} \sum_{t'=t}^{t-resupplyT} W_{c,t'} \ge 1 \qquad \forall t \ge resupplyT \qquad (12)$$

$$E_t \le tc \sum_{c\in C^f} W_{c,t} \qquad \forall t \qquad (13)$$

$$F_t = intFuel + \sum_{t'=1}^{t} E_{t'} - \sum_{t'=1}^{t}\sum_{c} b^w W_{c,t'} - \sum_{c,c'}\sum_{t'=1}^{t}\sum_{n=1}^{\min\{trip_{c,c'},t-t'+1\}} b^m Q_{c,c',t'} \qquad \forall t \qquad (14)$$

$$E_t \ge 0, \qquad \forall t \qquad (15)$$

$$minFuel \le F_t \le tc, \qquad \forall t \qquad (16)$$

$$N_u \in \{0,1,...,maxN_u\} \qquad \forall u \qquad (17)$$

$$X_{m,c,t,u} \in \{0,1\}, \qquad \forall m,c,t,u \,|\, (m,c)\in K, (m,u)\in J \qquad (18)$$

$$W_{c,t} \in \{0,1\}, \qquad \forall c,t \qquad (19)$$

$$Q_{c,c',t} \in \{0,1\}, \qquad \forall c,c',t \qquad (20)$$

$$\sum_{\substack{m,c,t,u|\\(m,c)\in K\\(m,u)\in J}} cost_m X_{m,c,t,u} \le budget \qquad (21)$$

$$\sum_{\substack{m,c,t,u|\\(m,c)\in K\\(m,u)\in J}} value_m X_{m,c,t,u} \ge \alpha \hat{T}SC \qquad (22)$$

5. Optimization Models

Primary Model:

Maximize (1)

Subject to (3)-(21)

Let $\hat{TSC} = \sum_{\substack{m,c,t,u| \\ (m,c)\in K \\ (m,u)\in J}} value_m \hat{X}_{m,c,t,u}$,

where $\hat{X}_{m,c,t,u}$ is the result of the primary model.

Secondary Model

Minimize (2)

Subject to (3)-(20), (22)

6. Description of the Formulation

The primary objective function (1) maximizes the total TSC value to the region from all missions accomplished with a penalty for non-necessary movement, subject to constraints (3)-(21). In this first optimization, equation (21) ensures that the total cost of all missions conducted is within budget.

The secondary objective function (2) minimizes the cost of all missions conducted in the region with a penalty for non-necessary movement. This equation is subject to equations (3)-(20) and (22). In the second optimization, budget is no longer a constraint. Instead, equation (22) is needed to ensure that the level of TSC value is a fraction (typically close to 100%) of that achieved after the first objective.

Equations (3)-(7), and (17) allocate missions and EPTs. Equation (3) ensures the value of missions conducted in each country satisfies the minimum engagement level for that country. Equation (4) provides for precedence between associated missions. Equation (5) allows for a maximum number of each mission to occur in each country while equation (6) restricts each EPT to accomplishing only one mission at a time.

Equation (7) limits the number of EPTs to available rack space onboard the ship, where the number of each EPT type available is restricted by (17).

Equations (8)-(11) determine ship location: Equation (8) ensures the ship is either waiting in a country or underway at any time. Equation (9) makes the ship wait in port throughout the duration of a mission that needs to be carried out in port at country *c*. Equation (10) ensures the ship is in port at the start of the mission to drop off an EPT doing a mission, while equation (11) requires that the ship is in port to pick up the EPT at completion of the mission.

Equations (12)-(16) provide for replenishment. Equation (12) ensures that the ship obtains provisions and other supplies within a specified time period at a port that can provide these commodities and equation (13) ensures that the port can provide fuel if needed. Equation (14) keeps track of the fuel at time *t* through all that has been used and all taken on in refueling. Equation (15) prevents the ship from offloading fuel while equation (16) prevents the ship fuel level from going below the minimum required tank capacity and from exceeding tank capacity.

Equations (18)-(20) establish the domain for binary variables.

C. IMPLEMENTATION

The CARMA optimization model is implemented using a Mixed Integer Program (MIP) in GAMS [Brooke et al., 1996] and solved with GAMS/CPLEX [2006, GAMS Development Corps 2003].

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III. RESULTS AND ANALYSIS

A. SCENARIO DEVELOPMENT

In September, 2006, the Naval War College hosted a wargame for CNE-C6F to present their engagement plan for the GOG for 2007 through 2016. The proposed plan includes a number of missions which would take place over the course of 2007 performed by USN, DOD, USG, and NGOs. CNE-C6F has planned a six-month demonstration of GFS to accomplish these missions in Angola, Cameroon, Gabon, Ghana, Liberia, and STP. This thesis adopts this plan and produces a routing schedule for how these missions might be accomplished by the Navy. The following scenarios are built to demonstrate tradeoffs in total TSC value and cost due to a reduction of time, budget, and difference in ship types. Each subsequent scenario includes a ship, a set of possible missions to be conducted in each country, a number of training teams that can conduct those missions, and a time frame for the ship to make its deployment, among other data.

The first goal is to show that all of the missions can be accomplished within the six-month window allocated for the 2007 GOG GFS Demonstration. Secondly, it will be shown that EPT and mission assignment can be optimally scheduled. We also show that given a shorten time frame, CARMA can schedule and allocate EPTs to achieve the missions with the best TSC value at the least cost. Current operations in the region are slowly building in duration, but usually last for a couple months. This thesis compares a base case with alternatives to provide insight into options that may be available for ship's deployments.

Changes made to the scenarios can include the number of missions, the number of countries, ship type, missions' TSC values or cost, or the available budget. The ship's starting point can be at any country, including the fictitious "At Sea" node. This node is centrally located at approximately one-day transit from the majority of the ports in the GOG. In the data set used for the following scenarios, TSC values are determined through public information and are not fully indicative of USG intentions. However, CNE-C6F has divided the GOG countries into three tiers based on a number of factors. These factors include accessibility of the country, democratic governance, the number of

USG and NGO programs and activities already in existence [Voelker McQuaid 2006], and prior involvement with USN. The countries participating in the 2007 GOG GFS Demonstration considered to be in Tier 1 are Cameroon, Gabon, Ghana, and STP. Those in Tier 2 are Angola and Liberia.[3]

The majority of the EPTs come from the NECC. NECC is currently developing the concept of operations (CONOPS) for their different sub-commands. These CONOPS, when complete, will provide further information on how their teams are organized and assigned to missions. Other teams used in the model are organic to the ship or come from the USCG, the Maritime Partnership Program, and military medical teams.

One of the most significant challenges to operations in a region where there has been little previous experience is determining which ship can best achieve the assigned missions. The ship must have sufficient capacity to accomplish the majority of missions, but also not have significant excess of capability which is underutilized and could be better used elsewhere. Other characteristics must also be considered when determining which ship type to use. For instance, many larger ships are constrained by draft in shallower waterways while other smaller ships have short underway sustainment times. Several types of ships have operated in the region and several have been considered as the prototype for a GFS. These ship types include amphibious ships (LSD, LHD, and LPD), submarine tenders (AS), frigates (FFG), and high speed catamarans (HSV). All have deployed to the region, engaging the host nation navies and successfully accomplishing missions. The new littoral combat ship (LCS) has also been considered. For the scenarios in this thesis, the first choice is LSD, which has been designated by CNE-C6F as the GOG GFS Demonstration ship and will deploy in Fall 2007. At the request of CNE-C6F's RPT, the second ship modeled is HSV-2 Swift.

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[3] The GOG countries not included in the demonstration fall into the following categories:

Tier 1: Nigeria

Tier 2: Benin

Tier3: Democratic Republic of Congo (Kinshasa), Republic of Congo (Brazzaville), and Equatorial Guinea

1. The Solution Using Heuristic-CARMA

Given the size of the CARMA model for deployment (underway time more than 30 days) planning, we devise an approximating method that uses short-term time periods (typically months) and carries the information between consecutive periods. The mathematical size of the CARMA model results in long run times and therefore requires the use of shorter time frame models, yielding an approximate solution to the original, six-month problem. This procedure is called Heuristic-CARMA.

In order to use Heuristic-CARMA with our baseline case, Scenario 1, the data is set up such that the LSD can conduct missions in only one country per month, in accordance with the pre-specified route: During the first time period the ship departs from Rota, Spain and completes missions in Liberia. The next five time periods are dedicated to Ghana, Cameroon, Gabon, Angola, and STP, respectively. During the last time period, the ship completes its missions in STP and returns to Rota, Spain.

In subsequent scenarios, the ship is allowed to conduct missions in several countries during a time period. In addition, the ship conducts missions “At Sea” such as multinational exercises and embarking ship riders for training exercises. These missions occur during several of the time periods in accordance with when the respective countries would be participating in an activity that must be done while the ship is underway.

2. Bounding the Solution Using LR-CARMA

Since Heuristic-CARMA produces a suboptimal solution to the original CARMA model (with all periods in a single problem), we also run a linear relaxation of CARMA (LR-CARMA) which yields a bound on the true optimal solution to the problem.

For example, for Scenario 1, the LR-CARMA bound achieves the maximum TSC value of 369. Thus, it is only informative to confirm that the maximum TSC value could be possible. The LR-CARMA solution contains fractional values for some of the integer and/or binary variables, so we cannot tell whether this bound is achievable by a feasible solution without solving CARMA as a MIP or finding a heuristic solution that achieves that value. However, in other scenarios the LR-CARMA bound may give a better estimate of solution quality for the Heuristic-CARMA solution.

B. SCENARIO ONE: 2007 GOG GFS DEMONSTRATION

1. Scenario Description

CNE-C6F has scheduled a GOG GFS demonstration to commence in Fall 2007. A deployment similar to this is modeled in this scenario. USS Fort McHenry (LSD-43) is designated as the GOG GFS platform and will depart from and return to Rota, Spain. Its deployment includes scheduled logistics stop in Senegal, before continuing to the GOG for several months. The route shown in Figure 3 shows the entire deployment. The time frame for the 2007 GOG GFS Demonstration is six months, including transit time to and from the Mediterranean operating area. The exact dates and activities of the deployment are yet to be decided. Additionally, due to the sensitivity of some of the operations, the real-world schedule of some activities is classified. Thus, the scenario will consider the activities that were planned by CNE-C6F for their 2006 unclassified wargame. CARMA shows this route is sufficient and sustainable over a six month time frame given current logistical constraints.

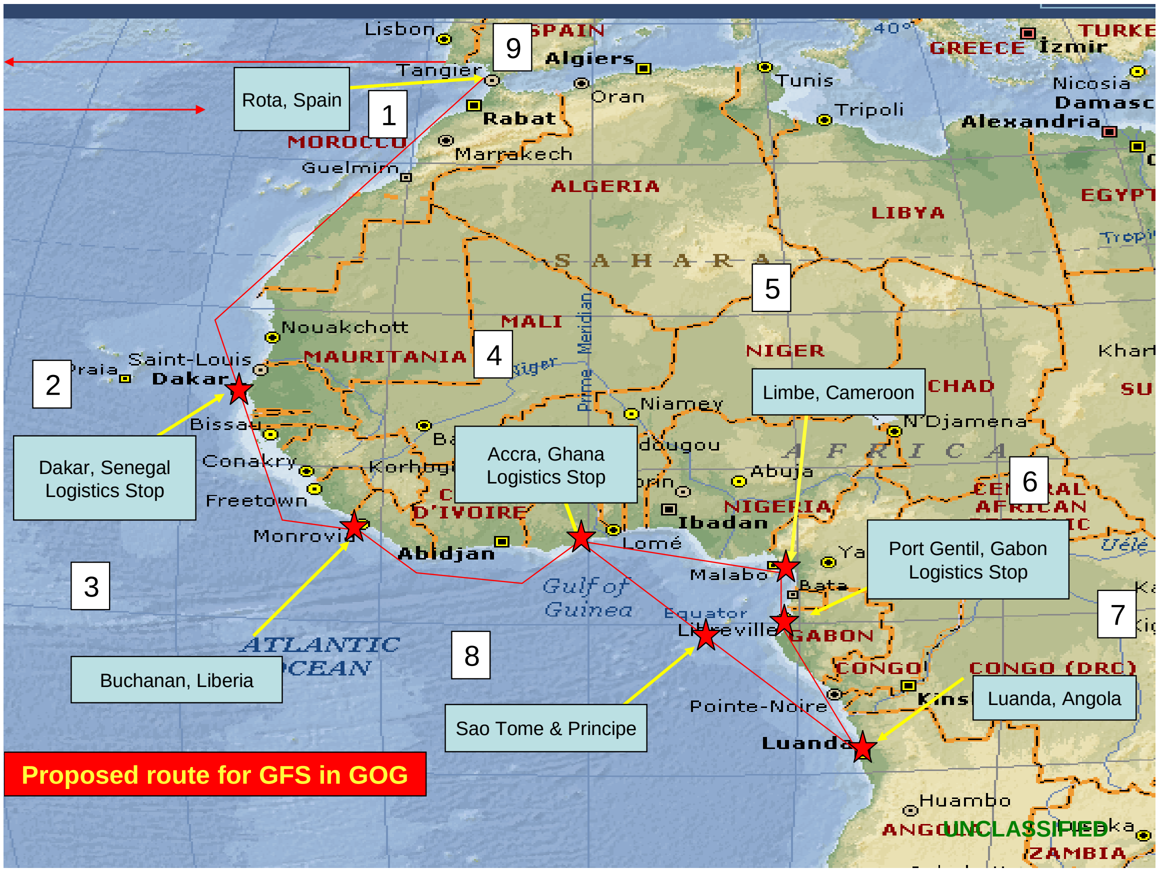

Figure 3. Proposed 2007 GOG GFS Demonstration route [After Fulkerson 2007-B]

The missions assigned to the countries are those designated by CNE-C6F (see Table 1). Only the countries set to provide logistics support as shown in Figure 3 (Senegal, Ghana, and Gabon) are designated to provide provisions, although USN has contracts in place to get fuel from other countries like Angola and STP if needed.

GOG Country Missions - 2007	Tier 1				Tier 2		
ACTIVITIES	GHANA	GABON	STP	CAM	ANGOLA	LIBERIA	AT SEA
MEDICAL							
MEDICAL OPS/READINESS SMEE	X		X				
HA/DR OF INFECTIOUS DISEASES	X						
INFRASTRUCTURE							
ENG RECONSTRUCTION SMEE, DIG WELLS	X	X	X	X		X	
RENOVATE MEDICAL CLINICS		X	X				
RENOVATE SCHOOLS/YOUTH ORG FACILITIES		X	X				
AIRPORT INFRASTRUCTURE IMPROVEMENTS	X						
ROAD IMPROVEMENTS	X	X	X	X			
UTILITY IMPROVEMENTS	X	X	X	X			
PORT INFRASTRUCTURE IMPROVEMENTS						X	
INFRASTRUCTURE GAP ANALYSIS	X	X	X	X			
CIVIL/COMMUNITY AFFAIRS							
PUBLIC AFFAIRS SMEE	X	X	X	X	X	X	
BAND LESSONS	X	X	X	X			
COMREL					X	X	
SURFACE MARITIME ACTIVITIES							
PORT SECURITY MTT	X					X	
RIVERINE OPS SMEE							
MULTINATIONAL EXERCISE							X
SHIPRIDER EMBARKS	X			X			X
SMALL BOAT / PATROL BOAT MAINTENANCE MTT	X		X				
ISPS ASSIST/CERT VISIT	X	X	X	X			
HYDRO SURVEY MTT	X		X				
MINE CLEARANCE					X		
MILITARY & LEADERSHIP TRAINING							
COMMUNICATIONS MTT	X	X		X			
OFFICER LEADERSHIP MTT	X			X			
NCO PROFESSIONAL DEVELOPMENT SMEE/MTT	X						
MARITIME DOMAIN AWARENESS ACTIVITIES							
SHIP VISIT					X	X	
MDA SITE SURVEY			X				
AIS RECIEVER SITES CONSTRUCTED	X		X			X	
COOPERATIVE SECURITY LOCATION	X						
GFS DEMO	X	X	X				X
LOGISTICS							
LOGISTICS STOP							

Table 1. Missions assigned to GOG countries for the 2007 GFS Demonstration

Table 2 shows mission attributes. The ship's location for each mission is either at sea, in port, or unconstrained. Mission duration is based on previous deployments. The number of personnel is reflective of the size of various EPTs predicted by NECC. The costs of each mission are calculated from average mission costs at a per-person, per-day rate for the total.

The available budget is set at $10 million, which will cover all the missions and two weeks of in-port days in each country. The TSC values are estimated based on information on previous mission feedback and public information, but do not necessarily reflect actual CNE-C6F planning figures.

GOG Country Missions - 2007 ACTIVITIES	mission location	duration (days)	# persons	cost ($) / mission	TSC value
MEDICAL					
MEDICAL OPS/READINESS SMEE		5	2	$5,000	3
HA/DR OF INFECTIOUS DISEASES		3	5	$7,500	4
INFRASTRUCTURE					
ENG RECONSTRUCTION SMEE, DIG WELLS		10	13	$65,000	5
RENOVATE MEDICAL CLINICS		3	7	$10,500	2
RENOVATE SCHOOLS/YOUTH ORG FACILITIES		3	7	$10,500	2
AIRPORT INFRASTRUCTURE IMPROVEMENTS		15	13	$97,500	6
ROAD IMPROVEMENTS		10	13	$65,000	4
UTILITY IMPROVEMENTS		10	13	$65,000	5
PORT INFRASTRUCTURE IMPROVEMENTS		20	13	$130,000	9
INFRASTRUCTURE GAP ANALYSIS		5	13	$32,500	5
CIVIL/COMMUNITY AFFAIRS					
PUBLIC AFFAIRS SMEE		3	6	$9,000	5
BAND LESSONS		2	4	$4,000	1
COMREL	in port	2	1	$1,000	3
SURFACE MARITIME ACTIVITIES					
PORT SECURITY MTT		5	18	$45,000	8
RIVERINE OPS SMEE		20	40	$400,000	9
MULTINATIONAL EXERCISE	"At Sea"	5	1	$2,500	10
SHIPRIDER EMBARKS	in port	5	1	$2,500	7
SMALL BOAT / PATROL BOAT MAINTENANCE MTT	"At Sea"	5	3	$7,500	6
ISPS ASSIST/CERT VISIT		10	4	$20,000	8
HYDRO SURVEY MTT		10	4	$20,000	8
MINE CLEARANCE		10	12	$60,000	7
MILITARY & LEADERSHIP TRAINING					
COMMUNICATIONS MTT		5	4	$10,000	4
OFFICER LEADERSHIP MTT		5	3	$7,500	7
NCO PROFESSIONAL DEVELOPMENT SMEE/MTT		3	1	$1,500	6
MARITIME DOMAIN AWARENESS ACTIVITIES					
SHIP VISIT	in port	5	1	$2,500	5
MDA SITE SURVEY		5	4	$10,000	7
AIS RECIEVER SITES CONSTRUCTED		10	13	$65,000	9
COOPERATIVE SECURITY LOCATION		5	4	$10,000	10
GFS DEMO	"At Sea"	3	4	$6,000	7
LOGISTICS					
LOGISTICS STOP	in port	1	1	$500	1

Table 2. Mission characteristics specific to GOG countries for the 2007 GFS Demonstration

The port-cost, per-day data is an average of previous port costs for a number of ships similar to LSDs or HSVs (see Table 3).

PORT	LSD	HSV
Angola	$200,000	$70,000
Cameroon	$145,000	$10,000
Gabon	$190,000	$70,000
Ghana	$72,000	$16,000
Liberia	$115,000	$40,000
Senegal	$185,000	$17,000
STP	$45,000	$10,000

Table 3. Average port-cost, per-day data for both LSD and HSV

2. Results

CARMA shows that six months are sufficient to carry out all of the activities assigned to each country. The total TSC value of all 69 missions conducted is 369 at a cost of $8,368,500. This provides an achievable target value from which to compare alternative scenarios.

Tables 4 through 9 show notional schedules to achieve this solution by optimally scheduling resources to accomplish missions. The tables show when the ship is in port, when it is underway, and when and which teams are assigned to missions. Missions that are designated to be conducted at sea are inputted in the model as being conducted at the fictitious "At Sea" node. As mentioned above, the scenario starts with the ship in Rota and conducts its first missions in Liberia as shown in Table 4.

	MISSIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	INPORT	Rota										Liberia					Senegal			Liberia				At Sea					Liberia
	UNDERWAY																												
At Sea	MULTINATIONAL EXERCISE																												
	SHIPRIDER EMBARKS																												
	GFS DEMO																												
Liberia	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS														NCF2														
	PORT INFRASTRUCTURE IMPROVEMENTS																		NCF1										
	PUBLIC AFFAIRS SMEE										MCAG																		
	COMREL												SHIP																
	PORT SECURITY MTT											USCG																	
	SHIP VISIT											SHIP																	
	AIS RECIEVER SITES CONSTRUCTED																							NCF3					
Senegal	LOGISTICS STOP																SHIP												

Table 4. Schedule of missions completed during days 1-28 in Liberia for Scenario 1: 2007 GOG GFS Demonstration

The ship is forced to conduct a logistics stop in Senegal (see Table 4). However, in order to achieve a greater number of missions accomplished, the ship drops off several EPTs in Liberia before heading back to Senegal. This is not a conventional or necessarily practical schedule; however, it does allow for an important mission of improving port infrastructure to be accomplished.

	MISSIONS	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	INPORT	Liberia			Refueling			Ghana				At Sea			Ghana					At Sea				Refueling	
	UNDERWAY																								
At Sea	MULTINATIONAL EXERCISE																								
	SHIPRIDER EMBARKS																			SHIP					
	GFS DEMO																				SHIP				
Ghana	MEDICAL OPS/READINESS SMEE						EXMED1																		
	HA/DR OF INFECTIOUS DISEASES							EXMED2																	
	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																			NCF2					
	AIRPORT INFRASTRUCTURE IMPROVEMENTS											NCF3													
	ROAD IMPROVEMENTS																NCF4								
	UTILITY IMPROVEMENTS																		NCF1						
	INFRASTRUCTURE GAP ANALYSIS						NCF1																		
	PUBLIC AFFAIRS SMEE					MCAG																			
	BAND LESSONS				RES1																				
	PORT SECURITY MTT						NWC1																		
	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT						NWC2																		
	ISPS ASSIST/CERT VISIT									RES2															
	HYDRO SURVEY MTT									USCG															
	COMMUNICATIONS MTT							ETC																	
	OFFICER LEADERSHIP MTT						SHIP																		
	NCO PROFESSIONAL DEVELOPMENT SMEE/MTT						SHIP																		
	AIS RECIEVER SITES CONSTRUCTED									NCF2															
	COOPERATIVE SECURITY LOCATION							MDA																	

Table 5. Schedule of missions completed during days 29-52 in Ghana for Scenario 1: 2007 GOG GFS Demonstration

The ship travels from Liberia to Ghana. Within 20 days it is able to accomplish all of its missions in Ghana. Refueling only takes one day, but two days are allocated here (see Table 5) because in CARMA the ship is not required to fill its tanks to 100%.

	MISSIONS	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	INPORT	Ghana				At Sea					Cameroon				Cameroon		At Sea			Cameroon	
	UNDERWAY																				
At Sea	MULTINATIONAL EXERCISE																				
	SHIPRIDER EMBARKS					SHIP															
	GFS DEMO																				
Cameroon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																NCF3				
	ROAD IMPROVEMENTS													NCF1							
	UTILITY IMPROVEMENTS														NCF2						
	INFRASTRUCTURE GAP ANALYSIS													NCF4							
	PUBLIC AFFAIRS SMEE																			MCAG	
	BAND LESSONS									RES											
	ISPS ASSIST/CERT VISIT														USCG						
	COMMUNICATIONS MTT											ETC									
	OFFICER LEADERSHIP MTT																SHIP				

Table 6. Schedule of missions completed during days 53-72 in Cameroon for Scenario 1: 2007 GOG GFS Demonstration

Table 6 shows that all of Cameroon's missions are completed in twelve days. The "At Sea" mission where the ship rider embarks represents a mission where Cameroonian personnel would embark the GFS. The timing of this event is not realistic, but the idea that there is sufficient time for the mission to be accomplished is represented. Additionally, CARMA does not address the availability of helicopters to transport personnel to and from shore to the GFS.

	MISSIONS	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
	INPORT	Cameroon			Gabon	Gabon	Gabon		At Sea	At Sea	At Sea	At Sea		Gabon	Gabon	Gabon	Gabon	Gabon
	UNDERWAY		X	X				X					X					
At Sea	MULTINATIONAL EXERCISE																	
At Sea	SHIPRIDER EMBARKS																	
At Sea	GFS DEMO								SHIP	SHIP	SHIP							
Gabon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS				NCF2	NCF2	NCF2	NCF2	NCF2	NCF2	NCF2	NCF2	NCF2	NCF2				
Gabon	RENOVATE MEDICAL CLINICS (ASST)														NCF1	NCF1	NCF1	
Gabon	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)															NCF2	NCF2	NCF2
Gabon	ROAD IMPROVEMENTS						NCF3	NCF3	NCF3	NCF3	NCF3	NCF3	NCF3	NCF3	NCF3	NCF3		
Gabon	UTILITY IMPROVEMENTS				NCF1	NCF1	NCF1	NCF1	NCF1	NCF1	NCF1	NCF1	NCF1	NCF1				
Gabon	INFRASTRUCTURE GAP ANALYSIS													NCF4	NCF4	NCF4	NCF4	NCF4
Gabon	PUBLIC AFFAIRS SMEE															MCAG	MCAG	MCAG
Gabon	BAND LESSONS															RES	RES	
Gabon	ISPS ASSIST/CERT VISIT				USCG	USCG	USCG	USCG	USCG	USCG	USCG	USCG	USCG	USCG				
Gabon	COMMUNICATIONS MTT													ETC	ETC	ETC	ETC	ETC

Table 7. Schedule of missions completed during days 73-89 in Gabon for Scenario 1: 2007 GOG GFS Demonstration

	MISSIONS	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
	INPORT	Refueling		At Sea	At Sea	At Sea	At Sea	At Sea				Angola	Angola	Angola	Angola	Angola					Angola			Refueling
	UNDERWAY		X						X	X	X						X	X	X	X		X	X	
At Sea	MULTINATIONAL EXERCISE			SHIP	SHIP	SHIP	SHIP	SHIP																
At Sea	SHIPRIDER EMBARKS																							
At Sea	GFS DEMO																							
Angola	PUBLIC AFFAIRS SMEE											MCAG	MCAG	MCAG										
Angola	COMREL														SHIP	SHIP								
Angola	MINE CLEARANCE											EOD	EOD	EOD	EOD	EOD	EOD	EOD	EOD	EOD	EOD			
Angola	SHIP VISIT											SHIP	SHIP	SHIP	SHIP	SHIP								

Table 8. Schedule of missions completed during days 90-112 in Angola for Scenario 1: 2007 GOG GFS Demonstration

Tables 7 and 8 show that all missions in Gabon and Angola are accomplished. This ship conducts a multinational exercise during days 92-96 that provides TSC benefit to all countries in the region. The ship returns to Gabon on day 112 to refuel and resupply within the required 25 days as shown in Table 8.

	MISSIONS	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147
	INPORT	Gabon			STP			At Sea							STP					At Sea			Gabon		STP											Rota
	UNDERWAY																																			
At Sea	MULTINATIONAL EXERCISE																																			
	SHIPRIDER EMBARKS																																			
	GFS DEMO																			SHIP																
STP	MEDICAL OPS/READINESS SMEE														EXMED																					
	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS							NCF1																												
	RENOVATE MEDICAL CLINICS (ASST)														NCF1																					
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)															NCF2																				
	ROAD IMPROVEMENTS				NCF2																															
	UTILITY IMPROVEMENTS									NCF3																										
	INFRASTRUCTURE GAP ANALYSIS														NCF4																					
	PUBLIC AFFAIRS SMEE															MCAG																				
	BAND LESSONS			RES																																
	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT														SHIP																					
	ISPS ASSIST/CERT VISIT									RES																										
	HYDRO SURVEY MTT								USCG																											
	MDA SITE SURVEY														MDA																					
	AIS RECIEVER SITES CONSTRUCTED																			NCF3																

Table 9. Schedule of missions completed during days 113-147 in STP for Scenario 1: 2007 GOG GFS Demonstration

The ship completes its assigned missions in STP and returns to Rota as shown in Table 9. The six months allotted for the GFS demonstration are sufficient to accomplish the missions; however, the total cost may be improved upon if the ship is able to spend fewer days in port. The total time is 147 days. Due to the fact that Heuristic-CARMA is used for this scenario, for each iterative time period the ship is forced to stay in port during the first time period at the country it ended in during the previous time period. This means that there are presumably five extra days in which the ship is waiting in port and no missions are being conducted.

Table 10 shows the EPTs that are used in the GOG GFS demonstration. If all personnel remained onboard for the entire duration of the deployment, then the ship would have to provide additional berthing for 126 people (a LSD has sufficient berthing space). However, this also shows that personnel from EPTs could embark and disembark the GFS in countries where other transportation to the GOG is possible and according to the time periods where they are needed.

Scenario 1								
EPT type used	# personnel	Days 1-28 # teams	Days 29-52 # teams	Days 53-72 # teams	Days 73-89 # teams	Days 90-112 # teams	Days 113-147 # teams	Max # of personnel
SHIP	1	2	2	1	1	2	1	2
USCG	4	1	1	1	1		1	4
NWC	25		1					25
EOD	12					1		12
NCF	13	3	4	4	3		4	52
MCAG	6	1	1	1	1	1	1	6
ETC	4		2	1	1			8
EXMED	5		1				1	5
RESERVE	4		1	1	1		2	8
MDA	4		1				1	4
# EPT personnel onboard		51	110	71	58	20	80	126

Table 10. EPTs employed in Scenario 1: 2007 GOG GFS Demonstration

Scenario 1 represents the most optimistic schedule in terms of time flexibility and mission accomplishment. For comparison to other scenarios, it provides an upper bound on the total TSC value.

C. SCENARIO TWO: 90-DAY GOG GFS DEMONSTRATION

1. Scenario Description

The same scenario as the GOG GFS demonstration described in Scenario 1 was run over a compressed timeline of 90 days. The budget remains the same as at $10 million. While persistent presence is the goal, the reality of limited resources means that one option will be for a number of ships to make shorter deployments to the region. Also, extenuating circumstances that may require a ship to respond to another situation may mean that there is less time than originally planned for the deployment. In this case it is valuable to see what percentage of the total TSC value can be accomplished as well as how many of the original missions.

2. Results

Initial results show that, overall, 58 missions can be conducted in 90 days, almost half the time of Scenario 1. This is a completion rate of 84% with respect to Scenario 1. The total TSC value returns a similar result: 82% of the maximum TSC value is achieved. Additionally, the cost is only 72% of the total for the six-month demonstration (see Table 11).

	Scenario 1 180-day demo	Scenario 2 90-day demo
Missions Completed	69 (100%)	58 (84%)
TSC Value	369 (100%)	304 (82%)
Cost	$8,268,500	$5,987,500 (72%)

Table 11. Results from the Scenario 2: 90-day GOG GFS Demonstration

Remark: Since we use Heuristic-CARMA it is important to bound the best possible solution under the conditions of Scenario 2. In this case, LR-CARMA yields a TSC value of 348, which indicates our heuristic solution is within 14% of optimality.

Tables 12 through 14 show a notional schedule which allocates EPTs and schedules missions during 90 days (optimal within any 30-day period).

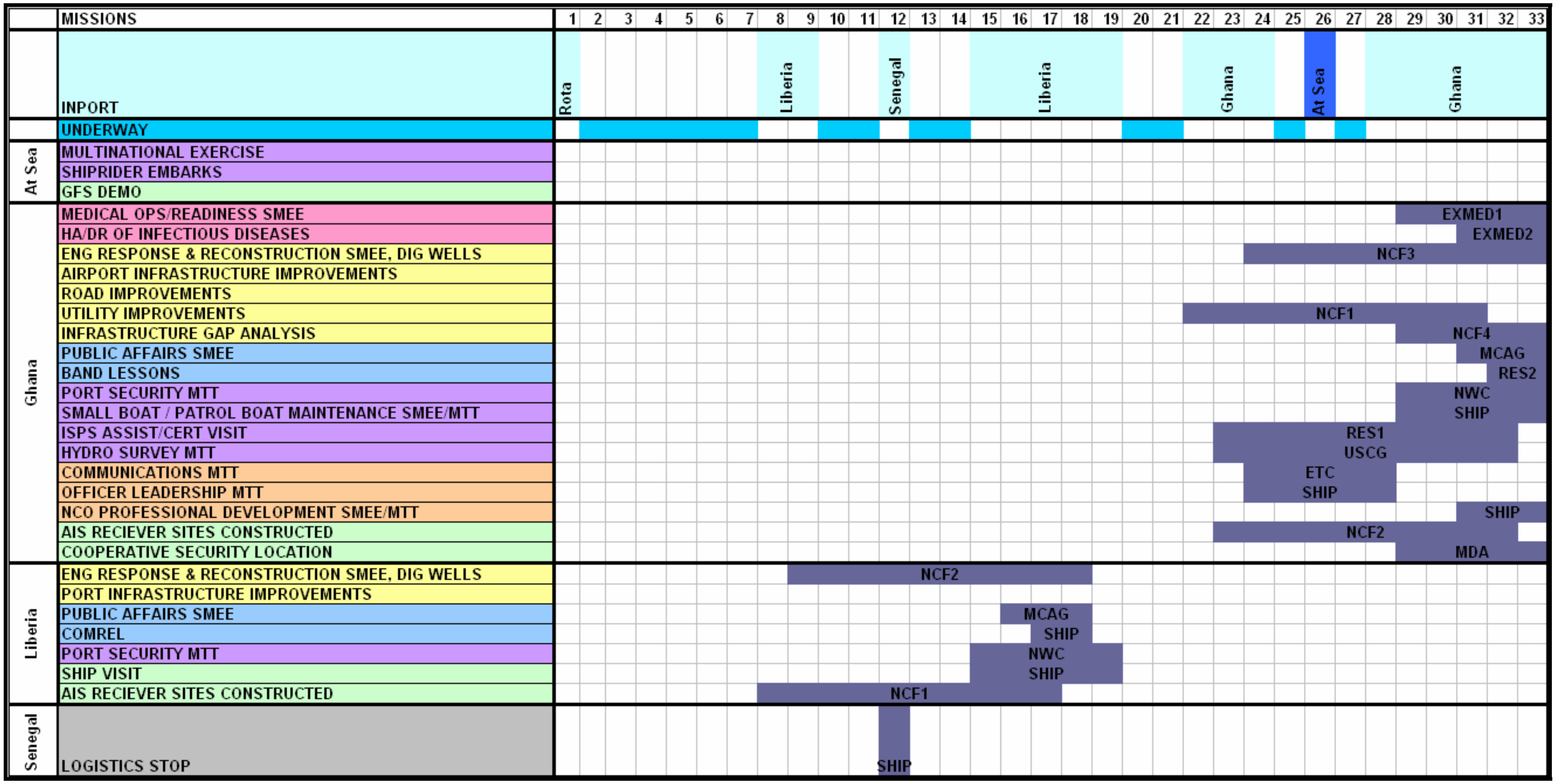

Table 12. Schedule of missions completed during days 1-33 in Ghana and Liberia for Scenario 2: 90-day GOG GFS Demonstration

Table 12 shows that in 33 days, the ship is able to conduct the majority of the missions assigned to Liberia and Ghana. Only five missions that are completed in the six month demonstration are not accomplished in this scenario. Similar to Scenario 1, the ship drops off EPTs at Liberia before heading to Senegal for its logistics stop. Also, in order to minimize cost, the ship goes to sea rather than stay in port Ghana because there are no port costs for being "At Sea."

	MISSIONS	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
	INPORT	Refueling				At Sea				Cameroon		Gabon					Cameroon					Gabon		Refueling	
	UNDERWAY																								
At Sea	MULTINATIONAL EXERCISE																								
	SHIPRIDER EMBARKS					SHIP																			
	GFS DEMO					SHIP																			
Gabon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS															NCF2									
	RENOVATE MEDICAL CLINICS (ASST)																							NCF3	
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																						NCF2		
	ROAD IMPROVEMENTS																								
	UTILITY IMPROVEMENTS																NCF3								
	INFRASTRUCTURE GAP ANALYSIS																						NCF1		
	PUBLIC AFFAIRS SMEE																							MCAG	
	BAND LESSONS																							RES	
	ISPS ASSIST/CERT VISIT																USCG2								
	COMMUNICATIONS MTT																						ETC		
Cameroon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																								
	ROAD IMPROVEMENTS																								
	UTILITY IMPROVEMENTS													NCF1											
	INFRASTRUCTURE GAP ANALYSIS																NCF4								
	PUBLIC AFFAIRS SMEE																MCAG								
	BAND LESSONS																	RES							
	ISPS ASSIST/CERT VISIT													USCG1											
	COMMUNICATIONS MTT																ETC								
	OFFICER LEADERSHIP MTT																SHIP								

Table 13. Schedule of missions completed during days 34-57 in Cameroon and Gabon for Scenario 2: 90-day GOG GFS Demonstration

During days 34-57 CARMA demonstrates how the GFS can drop EPTs off in one country then move to another to conduct missions before returning to the first country to pick up the teams it first dropped off (see Table 13). Cameroon and Gabon are relatively close in distance and this schedule could also represent when helicopter or small boat transfer teams ashore.

	MISSIONS	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
	INPORT	Gabon		STP				Angola						STP				Gabon				At Sea												Rota
	UNDERWAY																																	
At Sea	MULTINATIONAL EXERCISE																						SHIP											
	SHIPRIDER EMBARKS																					SHIP												
	GFS DEMO																						SHIP											
STP	MEDICAL OPS/READINESS SMEE													EXMED																				
	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
	RENOVATE MEDICAL CLINICS (ASST)													NCF4																				
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)														NCF1																			
	ROAD IMPROVEMENTS																																	
	UTILITY IMPROVEMENTS							NCF1																										
	INFRASTRUCTURE GAP ANALYSIS													NCF3																				
	PUBLIC AFFAIRS SMEE												MCAG																					
	BAND LESSONS			RES1																														
	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT													ETC																				
	ISPS ASSIST/CERT VISIT								RES2																									
	HYDRO SURVEY MTT							USCG																										
	MDA SITE SURVEY													MDA																				
	AIS RECIEVER SITES CONSTRUCTED								NCF2																									
Angola	PUBLIC AFFAIRS SMEE																																	
	COMREL							SHIP																										
	MINE CLEARANCE																																	
	SHIP VISIT																																	

Table 14. Schedule of missions completed during days 61-90 in Angola and STP for Scenario 2: 90-day GOG GFS Demonstration

In the remaining 32 days, the ship conducts only one mission in Angola. The tradeoff between conducting more missions in Angola and conducting more valuable missions "At Sea" is seen here (Table 14). Greater TSC value is gained within the available time frame by conducting the missions "At Sea".

Since fewer missions are conducted, fewer personnel and EPTs are needed than in Scenario 1, as shown in Table 15. On average, more EPTs are employed at any one time meaning that it would be more practical for them to remain onboard for the duration of the deployment.

Scenario 2					
EPT type used	# personnel	Days 1-33 # teams	Days 34-57 # teams	Days 58-90 # teams	Max # of personnel
SHIP	1	2	2	3	3
USCG	4	1	2	1	8
NWC	25	1			25
EOD	12				0
NCF	13	4	4	4	52
MCAG	6	1	1	1	6
ETC	4	1	1	1	4
EXMED	5	2		1	10
RESERVE	4	2	1	2	8
MDA	4	1		1	4
Personnel onboard		115	76	86	120

Table 15. EPTs employed 90-day GOG GFS Demonstration

However, while there are six fewer people than in the Scenario 1, more missions are being conducted at any one time, therefore, there are tradeoffs in the composition of the EPTs used. As shown in Table 16, EOD is not used in the 90-day scenario, but one additional USCG and EXMED team are now used.

	Scenario 1 180-day demo	Scenario 2 90-day demo
EPT type used	Max # of personnel	Max # of personnel
SHIP	2	3
USCG	4	8
NWC	25	25
EOD	12	0
NCF	52	52
MCAG	6	6
ETC	8	4
EXMED	5	10
RESERVE	8	8
MDA	4	4
Personnel onboard	126	120

Table 16. Comparison of the number of EPTs needed to conduct missions in 180-day versus 90-day GOG GFS Demonstration scenarios

D. SCENARIO THREE: 90-DAY GOG GFS DEMONSTRATION WITH HSV

1. Scenario Description

U.S. Naval Forces South is using an HSV for its GFS demonstration in 2007. Since the HSV had been identified as a viable platform for GFS, CNE-C6F requested that it also be modeled. The same mission data is used as Scenario 2 (the 90-day GOG GFS Demonstration) while the ship specific data such as fuel usage, fuel capacity, and berthing space for EPTs is changed to reflect the different characteristics of the HSV. A comparison of the characteristics between LSD and HSV ship types is shown in Table 17.

	berthing capacity (persons)	fuel tank capacity (gal)	minimum fuel capacity (gal)	underway burn rate (gal/day)	in port fuel burn rate (gal/day)
LSD	454	804300	60%	12902	4173
HSV	107	138600	25%	8316	2772

Table 17. LSD and HSV Ship type characteristics

2. Results

The most significant result of the HSV scenario is the reduction in cost of the GOG GFS demonstration. This is mostly due to the lower average port costs of the HSV as compared to the LSD and is not a reflection of the missions themselves. There are slight differences in the schedules, but both ship types achieve the same mission accomplishment rates and total TSC values in the 90-day time frame. Table 18 shows the difference in cost between the LSD and HSV. The most important conclusion is that using the HSV for the demonstration costs $2,339,500, almost 40% less than Scenario 2 which uses an LSD.

	Scenario 2 90-day with LSD	Scenario 3 90-day with HSV
Missions Completed	58	58
TSC Value	304	304
Cost	$5,987,500	$2,339,500

Table 18. Mission, TSC value, and cost comparison of 90-day GOG GFS Demonstration with LSD versus with HSV

The LR-CARMA results for Scenario 3 are the same as for Scenario 2, finding a maximum TSC value of 348, which indicates our heuristic solution is within 14% of optimality.

Tables 19 through 21 show the schedule for the HSV scenario. There are some slight differences from the Scenario 2 due to the fact that the HSV needs to refuel more often than the LSD.

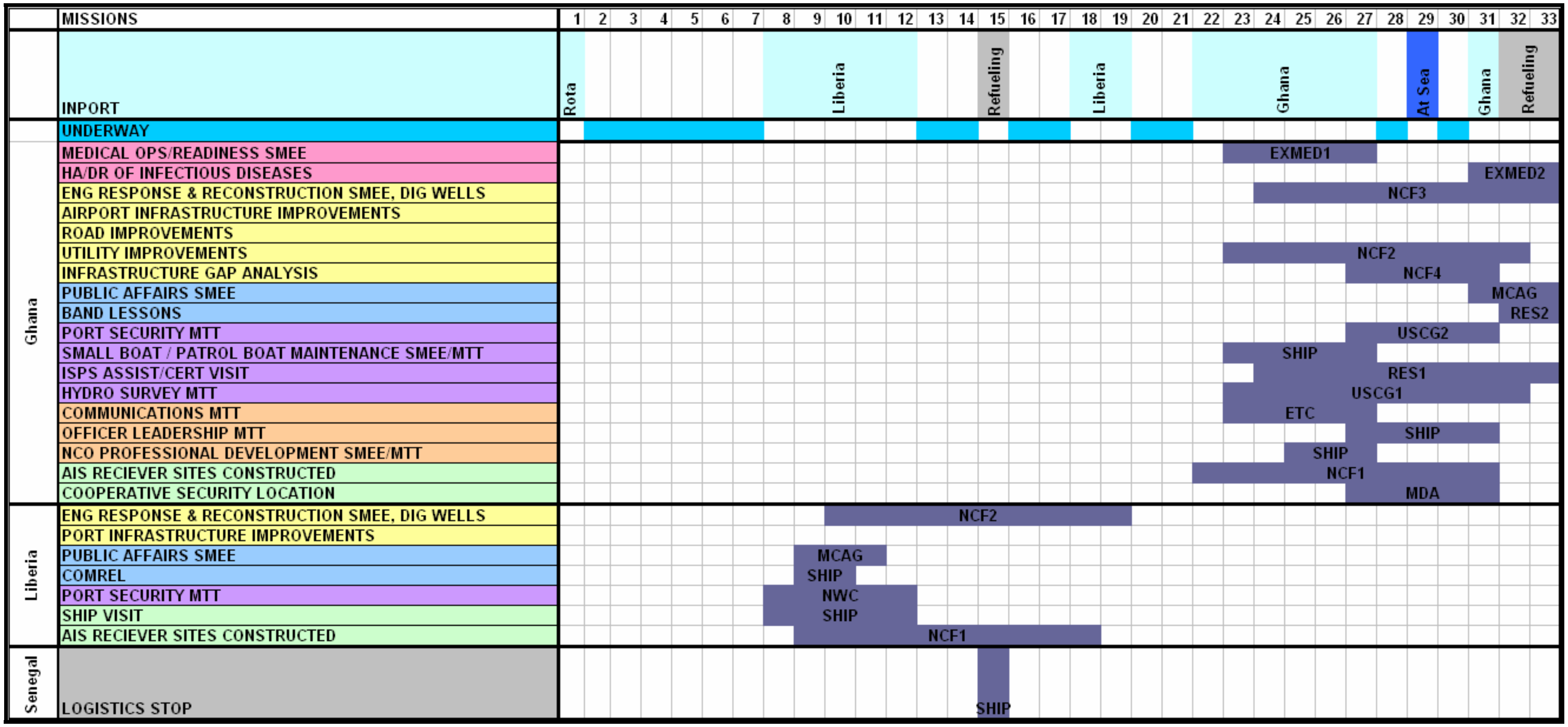

Table 19. Schedule of missions completed during days 1-33 in Ghana and Liberia for Scenario 3: 90-day GOG GFS Demonstration with HSV

The HSV refuels and resupplies in Senegal on day 15 (see Table 19) as compared to day 12 where (see Table 12) we observe that the LSD only needs to resupply.

	MISSIONS	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
	INPORT	Refueling				At Sea				Cameroon		Gabon					Cameroon					Gabon		Refueling	
	UNDERWAY																								
At Sea	MULTINATIONAL EXERCISE																								
At Sea	SHIPRIDER EMBARKS					SHIP																			
At Sea	GFS DEMO					SHIP																			
Gabon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS															NCF2									
Gabon	RENOVATE MEDICAL CLINICS (ASST)																							NCF3	
Gabon	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																						NCF2		
Gabon	ROAD IMPROVEMENTS																								
Gabon	UTILITY IMPROVEMENTS																NCF3								
Gabon	INFRASTRUCTURE GAP ANALYSIS																						NCF1		
Gabon	PUBLIC AFFAIRS SMEE																							MCAG	
Gabon	BAND LESSONS											RES													
Gabon	ISPS ASSIST/CERT VISIT																USCG2								
Gabon	COMMUNICATIONS MTT																						ETC		
Cameroon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS									NCF1															
Cameroon	ROAD IMPROVEMENTS																								
Cameroon	UTILITY IMPROVEMENTS													NCF1											
Cameroon	INFRASTRUCTURE GAP ANALYSIS																NCF4								
Cameroon	PUBLIC AFFAIRS SMEE															MCAG									
Cameroon	BAND LESSONS														RES										
Cameroon	ISPS ASSIST/CERT VISIT													USCG1											
Cameroon	COMMUNICATIONS MTT																ETC								
Cameroon	OFFICER LEADERSHIP MTT																SHIP								

Table 20. Schedule of missions completed during days 34-57 in Cameroon and Gabon for Scenario 3: 90-day GOG GFS Demonstration with HSV

	MISSIONS	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
	INPORT	Refueling		STP				Angola						STP				Refueling				At Sea												Rota
	UNDERWAY																																	
At Sea	MULTINATIONAL EXERCISE																						SHIP											
	SHIPRIDER EMBARKS																					SHIP												
	GFS DEMO																						SHIP											
STP	MEDICAL OPS/READINESS SMEE													EXMED																				
	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
	RENOVATE MEDICAL CLINICS (ASST)													NCF4																				
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)														NCF1																			
	ROAD IMPROVEMENTS																																	
	UTILITY IMPROVEMENTS							NCF1																										
	INFRASTRUCTURE GAP ANALYSIS													NCF3																				
	PUBLIC AFFAIRS SMEE												MCAG																					
	BAND LESSONS														RES																			
	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT													ETC																				
	ISPS ASSIST/CERT VISIT								USCG2																									
	HYDRO SURVEY MTT							USCG1																										
	MDA SITE SURVEY													MDA																				
	AIS RECIEVER SITES CONSTRUCTED								NCF2																									
Angola	PUBLIC AFFAIRS SMEE																																	
	COMREL							SHIP																										
	MINE CLEARANCE																																	
	SHIP VISIT																																	

Table 21. Schedule of missions completed during days 58-90 in Angola and STP for Scenario 3: 90-day GOG GFS Demonstration with HSV

Tables 20 and 21 show Gabon as a major refueling port. Similar to the LSD scenario, the model does not require the ship to refuel to its maximum level; therefore, the ship is shown refueling for three days. In reality, the ship would require only one day refueling and the remaining days would be spent waiting in port for the EPTs to complete their missions.

Another distinction between the LSD and the HSV is the number of additional berthing spaces that are available for EPTs. The HSV has only 107 excess spaces; therefore, because the LSD scenario required 120 personnel it would appear that the HSV would not be able to conduct all the missions the LSD could. Instead, CARMA chooses a different EPT configuration which accomplishes the same TSC value. The difference between the 95 EPT members on the HSV and the 122 on the LSD may provide additional savings (see Table 22). This is important as it may not be obvious by manual inspection. Table 23 shows which EPTs are used during each time period.

	Scenario 2 LSD	Scenario 3 HSV
EPT type used	Max # of personnel	Max # of personnel
SHIP	3	3
USCG	8	8
NWC	25	0
EOD	0	0
NCF	52	52
MCAG	6	6
ETC	4	8
EXMED	10	10
RESERVE	8	4
MDA	4	4
Personnel onboard	120	95

Table 22. Comparison of the number of EPTs needed to conduct missions when using LSD versus HSV

Scenario 3					
EPT type used	# personnel	Days 1-33 # teams	Days 34-57 # teams	Days 58-90 # teams	Max # of personnel
SHIP	1	2	2	3	3
USCG	4	1	2	2	8
NWC	25				0
EOD	12				0
NCF	13	4	4	4	52
MCAG	6	1	1	1	6
ETC	4	1	2		8
EXMED	5	2		1	10
RESERVE	4	1	1	1	4
MDA	4	1		1	4
Personnel onboard		86	80	82	95

Table 23. Number of EPTs employed during each time period of Scenario 3: 90-day GOG GFS Demonstration with HSV

The most obvious benefit of using an HSV is the cost savings. While the number of EPT personnel onboard remains well-below the maximum allowed, if more missions were added, berthing capacity on the HSV may become an issue. Also, the HSV had to refuel much more frequently (approximately every 15 days as compared to every 30 days for the LSD); however, it is shown that this can be accommodated given the availability of refueling ports.

E. SCENARIO FOUR: 90-DAY GOG GFS DEMONSTRATION WITH 75% BUDGET

1. Scenario Description

This scenario takes Scenario 2 (the 90-day GOG GFS Demonstration with an LSD) and reduces the budget for each time period by 25%. For example, the budget used in Scenario 2 (after hierarchically maximizing TSC value and then minimizing cost) for days 1-33 was $2,142,000. We constrain the available budget for the same time period in this scenario to 25% less, resulting in $1,606,500 being available. This is done to see how tradeoffs are made between mission accomplishment and total TSC value when the budget is constrained.

2. Results

The overall result is that the ship spends more time "At Sea" than in previous scenarios. Fewer missions are completed, but the TSC value remains high. As shown in Table 24, reducing the budget by 25% only reduces the total TSC value by 17%.

	Scenario 2 100% budget	Scenario 4 75% budget
Missions Completed	58	42
TSC Value	304	251
Cost	$5,987,500	$4,475,500

Table 24. Mission, TSC value, and cost comparison of 90-day GOG GFS Demonstration and the same with 75% budget

The solution using LR-CARMA provides an upper bound of 341 for the maximum TSC value, which indicates our heuristic solution is within 37% of optimality. It may be possible to develop a different heuristic model which based on previous scenarios can provide a better solution. The scenario limits the budget to 75% for each time period. However, different excursions into allocating the budget in different ways for each time period may provide a larger TSC value while still constraining the budget to 75%.

In comparison to the schedule for Scenario 1 shown in Table 12, Table 25 shows that the ship conducts missions at sea instead of in Liberia. The missions “Shiprider Embarks” and the “GFS Demo” have a slightly lower TSC value (see Table 2), but come at a much lower cost, including port-cost savings.

	MISSIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
	INPORT	Rota						Senegal				Liberia				Ghana					Liberia					Ghana						At Sea		
	UNDERWAY																																	
At Sea	MULTINATIONAL EXERCISE																																	
At Sea	SHIPRIDER EMBARKS																															SHIP		
At Sea	GFS DEMO																															SHIP		
Ghana	MEDICAL OPS/READINESS SMEE																									EXMED1								
Ghana	HA/DR OF INFECTIOUS DISEASES																										EXMED2							
Ghana	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
Ghana	AIRPORT INFRASTRUCTURE IMPROVEMENTS																																	
Ghana	ROAD IMPROVEMENTS																				NCF3													
Ghana	UTILITY IMPROVEMENTS																					NCF4												
Ghana	INFRASTRUCTURE GAP ANALYSIS																									NCF1								
Ghana	PUBLIC AFFAIRS SMEE																								MCAG									
Ghana	BAND LESSONS																							RES2										
Ghana	PORT SECURITY MTT																									NWC								
Ghana	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT																									ETC								
Ghana	ISPS ASSIST/CERT VISIT																				RES1													
Ghana	HYDRO SURVEY MTT																					USCG												
Ghana	COMMUNICATIONS MTT																																	
Ghana	OFFICER LEADERSHIP MTT																									SHIP								
Ghana	NCO PROFESSIONAL DEVELOPMENT SMEE/MTT																										SHIP							
Ghana	AIS RECIEVER SITES CONSTRUCTED																			NCF2														
Ghana	COOPERATIVE SECURITY LOCATION																									MDA								
Liberia	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
Liberia	PORT INFRASTRUCTURE IMPROVEMENTS																																	
Liberia	PUBLIC AFFAIRS SMEE											MCAG																						
Liberia	COMREL										SHIP																							
Liberia	PORT SECURITY MTT																																	
Liberia	SHIP VISIT																																	
Liberia	AIS RECIEVER SITES CONSTRUCTED															NCF1																		
Senegal	LOGISTICS STOP							SHIP																										

Table 25. Schedule of missions completed during days 1-33 in Ghana and Liberia for Scenario 4: 90-day GOG GFS Demonstration with 75% budget

While conducting missions in Gabon and Cameroon, the ship goes back and forth between the two countries dropping off and picking up EPTs instead of staying in port for the duration of the mission (see Table 26). This increased underway time accounts for fewer total in port costs, but does not allow for enough time to conduct the missions at sea that are shown in the schedule of Scenario 2 (Table 13).

	MISSIONS	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
	INPORT	At Sea				Refueling		Cameroon		At Sea		Cameroon			Gabon		Cameroon		Gabon		Cameroon		Gabon	Refueling	
	UNDERWAY																								
At Sea	MULTINATIONAL EXERCISE																								
	SHIPRIDER EMBARKS																								
	GFS DEMO																								
Gabon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																								
	RENOVATE MEDICAL CLINICS (ASST)																							NCF3	
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																								
	ROAD IMPROVEMENTS									NCF1															
	UTILITY IMPROVEMENTS																		NCF4						
	INFRASTRUCTURE GAP ANALYSIS																				NCF2				
	PUBLIC AFFAIRS SMEE																						MCAG		
	BAND LESSONS																							RES	
	ISPS ASSIST/CERT VISIT																		USCG2						
	COMMUNICATIONS MTT																				ETC				
Cameroon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																								
	ROAD IMPROVEMENTS											NCF2													
	UTILITY IMPROVEMENTS															NCF3									
	INFRASTRUCTURE GAP ANALYSIS																		NCF1						
	PUBLIC AFFAIRS SMEE																								
	BAND LESSONS																								
	ISPS ASSIST/CERT VISIT															USCG1									
	COMMUNICATIONS MTT																		ETC						
	OFFICER LEADERSHIP MTT																		SHIP						

Table 26. Schedule of missions completed during days 34-57 in Cameroon and Gabon for Scenario 4: 90-day GOG GFS Demonstration with 75% budget

Several of the missions in STP are expensive infrastructure improvement missions. The ones that have a higher TSC value are conducted with the ship spending as little time as possible in STP. The ship makes its necessary stop for provisions in Gabon before returning to Rota.

	MISSIONS	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
	INPORT	Gabon			Angola				STP		At Sea							STP		Gabon		STP											Rota	
	UNDERWAY																																	
At Sea	MULTINATIONAL EXERCISE													SHIP																				
	SHIPRIDER EMBARKS												SHIP																					
	GFS DEMO														SHIP																			
STP	MEDICAL OPS/READINESS SMEE																			EXMED														
	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
	RENOVATE MEDICAL CLINICS (ASST)																																	
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																																	
	ROAD IMPROVEMENTS																																	
	UTILITY IMPROVEMENTS												NCF1																					
	INFRASTRUCTURE GAP ANALYSIS																			NCF3														
	PUBLIC AFFAIRS SMEE																																	
	BAND LESSONS																																	
	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT																																	
	ISPS ASSIST/CERT VISIT												RES2																					
	HYDRO SURVEY MTT												USCG																					
	MDA SITE SURVEY																			MDA														
	AIS RECIEVER SITES CONSTRUCTED																																	
Angola	PUBLIC AFFAIRS SMEE																																	
	COMREL				SHIP																													
	MINE CLEARANCE																																	
	SHIP VISIT																																	

Table 27. Schedule of missions completed during days 58-90 in Angola and STP for Scenario 4: 90-day GOG GFS Demonstration with 75% budget

An interesting finding in this scenario is that more EPT personnel are used than in Scenario 2 (see Table 28). One additional ETC team is used while the ship is completing missions in Cameroon and Gabon where the ship is going back and forth between the countries.

	Scenario 2 100% budget	Scenario 4 75% budget
EPT type used	Max # of personnel	Max # of personnel
SHIP	3	3
USCG	8	8
NWC	25	25
EOD	0	0
NCF	52	52
MCAG	6	6
ETC	8	4
EXMED	10	10
RESERVE	8	8
MDA	4	4
Personnel onboard	124	120

Table 28. Number of EPTs used during each period of the 90-day GOG GFS Demonstration with 75% budget

Scenario 4 shows an approximate optimal solution given constraints on the budget for each of the time periods in Scenario 2. However, there may be a more optimal solution if instead the TSC value is constrained and the total budget can be allocated throughout the entire 90-day time period.

F. SCENARIO FIVE: 90-DAY GOG GFS DEMONSTRATION WITH 90% TSC REQUIREMENT

1. Scenario Description

This fifth scenario explores the tradeoffs when a solution of at least 90% of the optimal TSC value optimal found in Scenario 2 is sought, while the cost is minimized.

2. Results

The results of this scenario prove better than the results in Scenario 4. When the budget was set at 75% of the original budget, the ship only accomplished 72% of the missions and achieved 83% of the total TSC value. Scenario 5 shows that when the TSC value is forced to remain at 90% of the original, 84% of the missions are completed at only 73% of the budget (see Table 29).

	Scenario 2 Max TSC	Scenario 5 90% TSC
Missions Completed	58	49
TSC Value	304	275
Cost	$5,987,500	$4,384,500

Table 29. Comparison between 90-day GOG GFS Demonstration and 90% TSC requirement scenario

Note: Using the LR-CARMA model for Scenario 5 does not provide any further insight.

The main difference between the schedule in Scenario 2 and the similar time frame for Scenario 5 is that two missions at sea are accomplished in place of a number of missions in Liberia (see Table 12 and Table 30). The ship conducts the same number of missions in Ghana, but five less in Liberia. Overall, only one less EPT is needed.

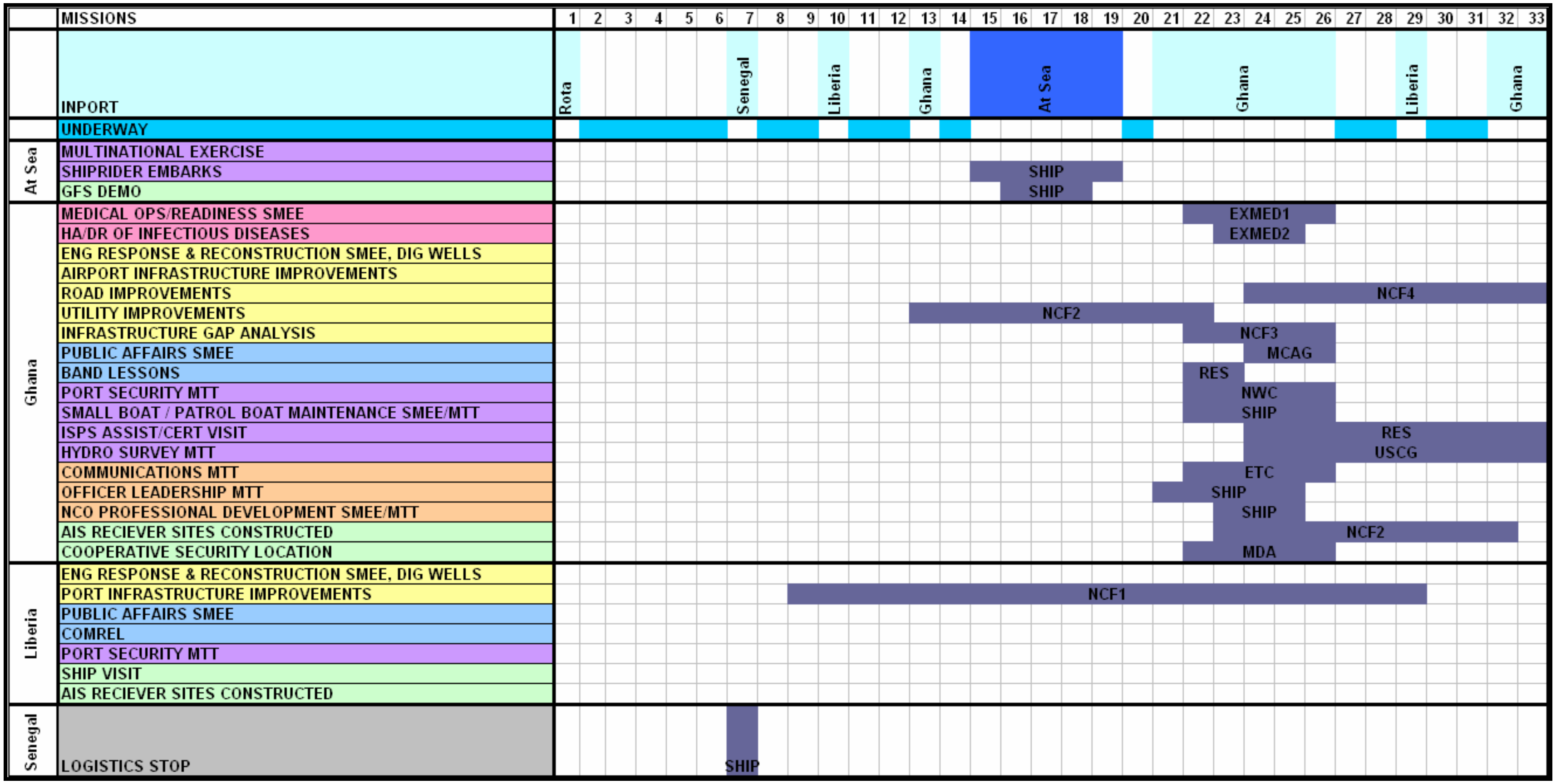

Table 30. Schedule of missions completed during days 1-33 in Ghana and Liberia for Scenario 5: 90-day GOG GFS Demonstration with 90% TSC requirement

The ship conducts the same number of missions at sea with one less mission in Gabon and three less in Cameroon. However, the same number of EPTs is needed. The ship also spends three more days at sea, reducing the overall cost (see Table 13 and 31).

	MISSIONS	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
	INPORT	Ghana				At Sea				Refueling		Cameroon		Gabon			Cameroon		At Sea		Cameroon		Gabon	Refueling	
	UNDERWAY																								
At Sea	MULTINATIONAL EXERCISE																								
	SHIPRIDER EMBARKS					SHIP																			
	GFS DEMO						SHIP																		
Gabon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																		NCF4						
	RENOVATE MEDICAL CLINICS (ASST)																							NCF2	
	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																								
	ROAD IMPROVEMENTS																								
	UTILITY IMPROVEMENTS																	NCF3							
	INFRASTRUCTURE GAP ANALYSIS											NCF1													
	PUBLIC AFFAIRS SMEE																							MCAG	
	BAND LESSONS																							RES	
	ISPS ASSIST/CERT VISIT																		USCG2						
	COMMUNICATIONS MTT											ETC													
Cameroon	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																								
	ROAD IMPROVEMENTS																								
	UTILITY IMPROVEMENTS															NCF2									
	INFRASTRUCTURE GAP ANALYSIS																		NCF1						
	PUBLIC AFFAIRS SMEE																								
	BAND LESSONS																								
	ISPS ASSIST/CERT VISIT															USCG1									
	COMMUNICATIONS MTT																		ETC						
	OFFICER LEADERSHIP MTT																		SHIP						

Table 31. Schedule of missions completed during days 34-57 in Cameroon and Gabon for Scenario 5: 90-day GOG GFS Demonstration with 90% TSC requirement

Finally, the number of missions conducted "At Sea" and in Angola remain the same as in Scenario 2, with two fewer accomplished in STP. There was little room to cut missions in this last time frame, and therefore the schedules are very similar (see Table 14 and 32).

	MISSIONS	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
	INPORT	Gabon				STP					Angola				STP			Gabon				At Sea												Rota
	UNDERWAY																																	
At Sea	MULTINATIONAL EXERCISE																						SHIP											
At Sea	SHIPRIDER EMBARKS																					SHIP												
At Sea	GFS DEMO																						SHIP											
STP	MEDICAL OPS/READINESS SMEE					EXMED																												
STP	ENG RESPONSE & RECONSTRUCTION SMEE, DIG WELLS																																	
STP	RENOVATE MEDICAL CLINICS (ASST)					NCF2																												
STP	RENOVATE SCHOOLS/YOUTH ORG FACILITIES (ASST)																																	
STP	ROAD IMPROVEMENTS									NCF3																								
STP	UTILITY IMPROVEMENTS									NCF4																								
STP	INFRASTRUCTURE GAP ANALYSIS					NCF1																												
STP	PUBLIC AFFAIRS SMEE					MCAG																												
STP	BAND LESSONS																																	
STP	SMALL BOAT / PATROL BOAT MAINTENANCE SMEE/MTT					ETC																												
STP	ISPS ASSIST/CERT VISIT									RES																								
STP	HYDRO SURVEY MTT									USCG																								
STP	MDA SITE SURVEY					MDA																												
STP	AIS RECIEVER SITES CONSTRUCTED																																	
Angola	PUBLIC AFFAIRS SMEE																																	
Angola	COMREL										SHIP																							
Angola	MINE CLEARANCE																																	
Angola	SHIP VISIT																																	

Table 32. Schedule of missions completed during days 58-90 in Angola and STP for Scenario 5: 90-day GOG GFS Demonstration with 90% TSC requirement

Often a 90% solution is all that is needed or can be done. CARMA shows that substantial cost savings can be realized if the requirement is not to achieve the maximum possible TSC value, but to come sufficiently close.

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IV. CONCLUSION AND FUTURE RESEARCH

This thesis creates and implements the CARMA model which can be used to optimally schedule its resources to accomplish USN missions in the GOG. CARMA takes into account logistical constraints and produces an optimal ship configuration and schedule for a given scenario. This thesis demonstrates CARMA to optimally select and schedule missions to achieve the greatest TSC value, given a number of constraints including time, budget, and ship characteristics, among other logistical constraints.

First, CARMA is used to demonstrate that current planning is adequate to meet the mission requirements and scheduling. Next CARMA is used to show how a majority of missions and TSC value can be achieved in a reduced time frame. In the first case, all of the missions are conducted in 147 days. Scenario 2 shows 82% of the original TSC value can be achieved despite a 40% reduction in time. The third scenario shows the high cost savings of using an HSV instead of an LSD. The cost is reduced by 60% due to port costs. The fourth scenario shows that by cutting the budget 25%, there is only a 17% reduction in the total TSC value of the missions. Finally, in Scenario 5, CARMA is used to show that there are alternative routes which can accomplish most of the possible TSC value at a fraction of the cost.

CARMA can be used by planners to understand how different ship types may be used to accomplish similar missions given different constraints of each. Exploration into EPTS constraints can help the USN determine numbers of teams that are required. Finally, CARMA can provide alternatives for long-term planning in the GOG.

Follow-on research can be done to improve the heuristic through a Fix-and-Relax approach to the model and/or other decomposition techniques. Other research can be done in conjunction with CNE-C6F and NECC to achieve greater fidelity in the data as well as comparing additional scenarios with the real world results of the actual 2007 GOG GFS Demonstration. This includes creating an Excel interface to provide for easier user accessibility and data recording. Finally, additions to the model might include in-port multinational missions, multiple ships, or aircraft drop-off and pick-up.

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