MODELING THE PRE-POSITIONING OF AIR FORCE PRECISION GUIDED MUNITIONS

THESIS

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AFIT/GOR/ENS/02-09

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Abstract

The Air Force's ability to deploy, employ, and sustain operations in forward locations is a key to mission success. An integral part of this strategy is equipment pre-positioning, to include: vehicles, aircraft support, consumable inventory, and munitions. This research focuses on defining and developing a model to aid decision makers with the afloat pre-positioning and deployment of munitions in an effort to ensure that the right weapons are available when, and where needed. This research places a particular focus on the strategic, global pre-positioning of the Afloat Pre-positioning Fleet (APF) in an effort to minimize the overall response time involved with offloading these ships and transporting their cargo to the intended point of use.

The model developed in this study is a mixed integer program that was implemented using the General Algebraic Modeling System (GAMS). The model considers the various aspects of pre-positioning (forward operating locations, Standard Air Munitions Packages, and the APF) in order to optimally locate and configure each APF ship. The methodology for this model was tested and verified using precision-guided munitions data for a number of scenarios.

MODELING THE PRE-POSITIONING OF AIR FORCE PRECISION GUIDED MUNITIONS

1. Introduction

1.1. Background

The Expeditionary Air Force (EAF) concept spawned significant changes in the Air Force's combat support system. The EAF created the need for a flexible logistics system capable of supporting a wide range of United States Air Force (USAF) operations and scenarios. In response to this need, the Air Force developed an Agile Combat Support (ACS) system that varies depending on the scenario supported. The ACS system ensures that USAF forces respond to global challenges with flexibility, rapidity, and a decisive use of air power (Ammo Vision, 2000). Currently, the ACS network consists of various logistics hubs, which provide direct support to Air Force operations. These hubs include: forward operating locations, forward support locations, and CONUS support locations. These hubs are linked by both a transportation network and a command and control system. Due to the flexibility requirements of the ACS system, the resulting support mix may not be ideal for any particular contingency, but it should be robust enough to support the entire spectrum of contingencies faced by today's Air Force (Tripp, *et al.*, 2000).

Current USAF policies (rapid employment lines, high operations tempo, airlift constraints, etc.) dictate the need for a considerable amount of pre-positioned supplies and equipment. However, as the USAF strives to reduce its overseas footprint, it must reconsider current policies and procedures to ensure optimal resource handling and continued success in meeting its objectives.

Munitions are a key component of the ACS system and are absolutely critical to the success of the Air Force mission. As a result, a substantial amount of munitions are stockpiled at various locations. The Air Force also maintains a considerable amount of munitions aboard ships strategically positioned around the world (see Figure 1-1 from Federation, 2001). When a situation arises, and munitions are needed, these ships must steam to a port, dock, and have their munitions unloaded. Once on the ground, these munitions must be reloaded on freight trains or trucks and shipped to the requesting air bases. This process can be hampered by the availability of handling equipment, host nation approval, the need for qualified personnel, logistical capacities, etc. (Abell, *et al.*, 2000).

As the ACS system evolves, especially in terms of managing munitions, it must remain flexible and possess sound logistical practices so that it can ensure the timely transport of limited resources to meet rapid deployment, employment, sustainment, and reconstitution objectives. The Air Force has always relied upon global airlift capabilities to ensure rapid deployment of its equipment. However, by 2006 the Air Force will lose 135 airlifters from its fleet. The replacement of C-141 aircraft with fewer C-17 aircraft will not affect total airlift capacity, but the reduced number of aircraft represents a significant loss in global flexibility. In addition to the dwindling number of airlifters, the Air Force also faces competition for airlift requirements. In the early stages of a conflict, the Air Force has airlift responsibilities for both the Army and the Air Force. This competition for cargo space will tax already strained deployment requirements. The Air

Force has addressed this issue by employing the concept of an afloat pre-positioning fleet (APF), which transports war reserve materiel to where that materiel is needed. The Air Force currently leases three ships to store munitions and respond to crises all over the globe. The APF can meet worldwide munitions requirements in any theater of operations in 2 to 20 days, depending on a number of factors (Boley and Lyle, 2001). The ship's enormous cargo capacity, coupled with the flexibility of being able to pre-position these ships off of just about any coast in the world provides the Air Force with much of the flexibility and mobility it needs to respond to the wide range of crises the country currently faces. The Air Force must utilize strategic pre-positioning to ensure responsiveness and effectiveness in meeting objectives. Utilizing the APF to pre-position munitions is a giant step in the right direction.

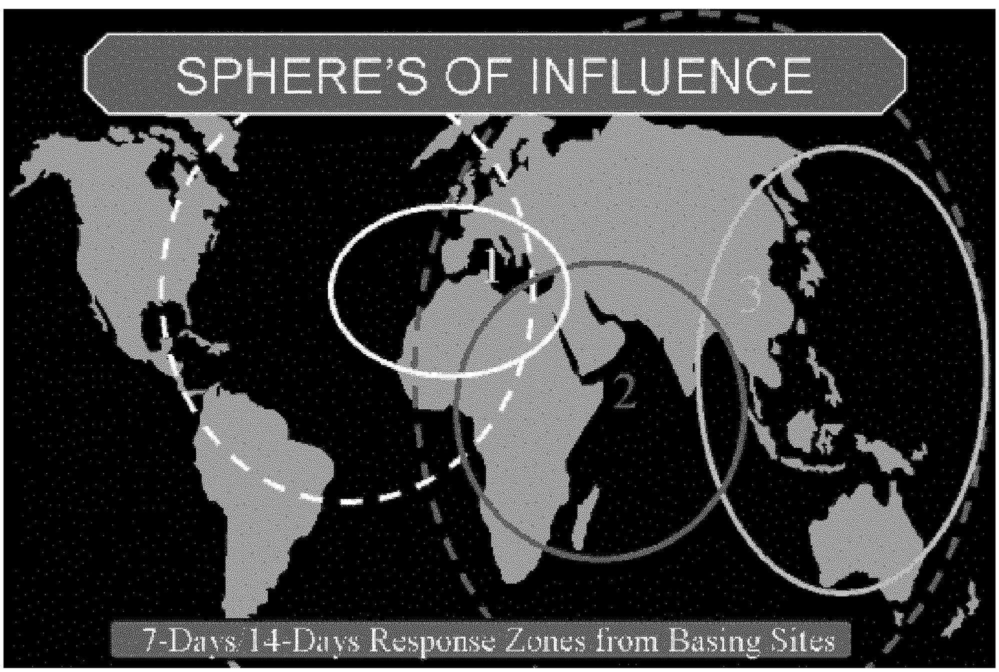


Figure 1-1. Sphere's of Influence for Pre-positioned Munitions Ships (Federation, 2001)

This figure displays both the 7 and 14 day response zones for an APF ship pre-positioned at each basing site.

1.2. Problem Statement

The USAF prides itself on its ability to rapidly respond to various contingencies throughout the world. However, the responsiveness is constrained by a number of factors including: economic considerations, political considerations, and logistical support.

The Air Force's success relies heavily on its ability to deploy the right weapons, people, and support to the right place, and in the proper time frame. This ability was tested during Operation Allied Force, the North Atlantic Treaty Organizations response to ethnic cleansing in the Balkans. During Operation Allied Force, munitions comprised the bulk of all Air Force logistical support (Peters, 2002). Planning models can help ensure that deployment plans are adequate to meet demand. Unfortunately, such planning models are limited in scope, and sometimes not even available.

This research focuses on defining and developing models to provide decision makers assistance in planning the afloat pre-positioning and deployment of munitions, in an effort to help planners ensure that the right weapons are available when needed and where needed.

1.3. Scope of Research

This research develops a mathematical modeling approach to improve upon current munitions pre-positioning practices. This thesis places a particular focus on the strategic, global pre-positioning of the afloat pre-positioning fleet (with an emphasis on precision guided munitions) in an effort to minimize the overall response time involved with moving these ships into theater, offloading them, and then transporting their cargo to the intended point of use. This research investigates the optimum pre-positioning strategy in order to maximize the Air Force's flexibility in responding to a number of Small Scale Contingencies (SSCs), as well as address military obligations in a major theater of war (MTW). The General Algebraic Modeling System (GAMS) is used to aid modeling and analysis of the effects of different pre-positioning scenarios. Microsoft Excel provides a flexible means of defining data specifics for the model.

1.4. Research Objective

The objective of this research is to define and develop a mixed integer program to model the effects of various pre-positioning scenarios. The integer program is implemented using GAMS. Specific data is read from Microsoft Excel and specified instances of the model are solved using a GAMS compliant solver package. The results of this model are analyzed to determine the options for strategic pre-positioning of munitions.

1.5. Overview of Thesis

The remainder of this document describes the concepts of pre-positioning and describes both the model and results in more detail. Chapter 2 provides some history on pre-positioning and describes the importance it plays in the Air Force's mobility capability. Chapter 3 describes the methodology and lists the assumptions that were used in the development of the model. Chapter 4 discusses the results of the munitions movement model and Chapter 5 outlines some limitations of the model as well as some opportunities for further research.

2. Literature Review

The turbulent international political environment has dramatically increased the number of potential hot spots where the President of the United States might commit U.S. military forces. However, as the U.S. military's overseas footprint shrinks, the Department of Defense must develop new strategies to ensure the success of military contingency operations. The military services' ability to deploy, employ, and sustain operations in forward locations is the elementary key to mission success. An integral part of this new strategy is equipment pre-positioning, to include: vehicles, aircraft support, consumable inventory, and munitions. This chapter briefly reviews the modern history of military pre-positioning, its role in contingency planning, some of the advantages and disadvantages of pre-positioning, and finally, the Air Force's future reliance on munitions pre-positioning as a means of supporting its wide range of missions.

2.1. Definition of Pre-positioning

For the purpose of this thesis, pre-positioning is defined as the "stockpiling of equipment and supplies at, or near the point of planned use (or point of debarkation)" (Compendium of Logistics Terms, 1981).

Pre-positioning makes equipment and supplies available to deploying forces in minimal time, improving the military's response/reaction to crises overseas (Military Pre-positioning, 1998), and ensuring the timely support of a specific force during the initial phases of a military operation (King, 1991). Without pre-positioned assets, the success of any deployment must rely heavily on extensive air and sealift from stateside locations. This significantly increases the long-range airlift required to support any time-phased force deployment. However, the relationship between the number of pre-positioned assets and airlift costs is not monotonic. If the number of pre-positioned assets increased dramatically, the Air Force would eventually reach a point where it is no longer fiscally, or operationally advantageous to pre-position assets compared with the alternative of using air and sealift (see Figure 2-1). The Air Force would be forced to ferry small amounts of assets from a number of different locations, scattered all over the globe. The USAF is currently investigating a number of different pre-positioning options for munitions to ensure that this balance is met. One way the Air Force addressed the issue of pre-positioning and airlifting munitions was with the advent of starter stock and swing stock. Starter stocks are munitions required at, or near the point of intended use and are used until a sustainable supply chain is established. The Air Force utilizes munitions storage areas (MSAs), located on or near a base, to house starter stocks. The MSAs are

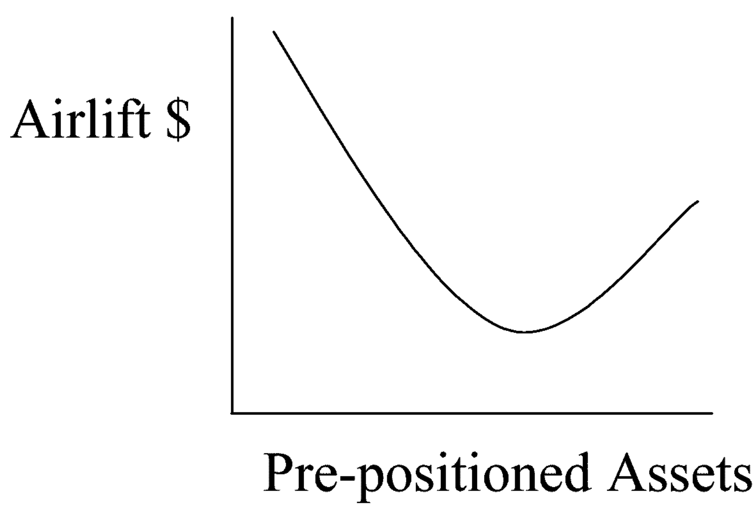


Figure 2-1. Relationship of Airlift $ to Number of Pre-positioned Assets

the first source of munitions utilized when a crisis arises. Swing stocks are the total munitions requirements minus the starter stocks. These specially designated swing stock munitions are pre-positioned to decrease the burden on the transportation network and provide quick access to vital assets.

2.2. History of Pre-positioning

The U.S. has never relied solely on forward basing or overseas access as a means of positioning forces and equipment to respond to regional crises (MPF 2010, 1998). In fact, as early as the mid-1960's, a joint Army-Navy study recommended building floating supply ships to pre-position equipment and supplies (Kampsen, 1998). The concept of Maritime Pre-positioning Forces (MPFs) and Afloat Pre-positioning Forces (APFs) stemmed from Congressional concerns over U.S. force projection capability and a lack of progress in acquiring basing rights in the Persian Gulf Region (Pasquarette, 1995). The Department of Defense's response to these concerns paid immediate dividends during the Gulf War in 1990. Afloat and ashore pre-positioning of equipment and munitions were required to sustain and project Gulf War forces. Pre-positioned supplies saved an estimated 1,800 airlift sorties to the Area of Responsibility (AOR) and provided direct support to 21 principal airfields (White Paper, 1991). The concept of pre-positioning continued to evolve throughout the 1990's. The Joint Staff's 1992 Mobility Requirements Study (MRS) stated its concern about the considerable risk faced by the earliest deployed troops. The MRS recommended a "gap filler" force be established for rapid response to a crisis (Kampsen, 1998). This gap filler provides essential assets and equipment during the early stages of a conflict until an adequate supply chain can be established. Pre-positioned assets are a major component of this "gap filler" and figured prominently in recent editions of both national security and national military strategies (Pasquarette, 1995). Despite this newfound support for pre-positioning assets, the Bottom-Up Review of U.S. defense policy, conducted during the Clinton Administration, confirmed that the U.S. military had major shortfalls in pre-positioned assets (Ships/Navy, 2001). Finally, although the 1996 Quadrennial Defense Review, completed in 1997, did not consider pre-positioned assets a major part of its scope, the concept was considered a critical part of a planned update to the MRS, beginning in 1999. Currently, the DOD spends over one billion dollars annually to manage pre-positioning programs (Military Pre-positioning, 1998).

The military's ability to deploy, employ, and sustain operations is vital to mission success. Employability is the ability to rapidly utilize equipment in its present location. Factors affecting employability include location, condition of equipment and supplies, and support facilities such as materiel handling equipment and port facilities. Deployability is the ability to move assets from their current location to a different theater. Afloat pre-positioned assets are considered to be the most deployable assets (Pasquarette, 1995). Sustainment is the process of establishing a supply chain capable of meeting mission requirements.

The DOD utilizes three main processes (the Mobility Triad) to aid deployment: strategic airlift, sealift, and pre-positioning (see Figure 2-2). Strategic airlift remains the fastest and most flexible means of deploying assets into a theater of operations. Airlift's ability to deliver assets very close to their required destination also justifies its use. However, airlift is the most expensive means of asset movement, and strategic airlift is limited by cargo capacity and size limitations. Strategic airlift capabilities may further decline in 2006, when the capable C-141s retire. Although the C-141 will be replaced by the C-17, and gross tonnage delivery capabilities will not diminish, the number of available mission aircraft will dramatically decrease from 270 (C-141s) to 135 (C-17s). Strategic sealift, which is managed by the Military Sealift Command (MSC), is relatively inexpensive, compared to airlift, and is capable of hauling large size assets and tonnage. Sealift is accomplished, in large part, by three types of vessels: container, roll-on/roll-off (RO/RO), and tankers. For deployment purposes, the DOD relies heavily on RO/RO vessels to move the majority of forces (Anderson, 1999). Unfortunately, sealift is not very fast and is limited to major seaports, or adequately equipped minor ports. Finally, strategically located pre-positioned assets can greatly reduce delivery time to the required location, and reduce the cost of potentially large shipping losses from submarine and air attacks (King, 1991). Unfortunately, afloat pre-positioning assets may take two to four days to offload once they reach a port. The military manages both land and sea-based pre-positioned assets. The APF contains Army, Marine, and Joint Service war materiel near locations of potential conflict. The MPF carries equipment for Marine Air Ground Attack Forces, and the Combat Pre-positioning Ships (CPS) carry enough equipment to support an Army Heavy Brigade Task Force. Finally, the Logistics Pre-positioning Ships (LPS) contain Joint Service supplies such as Air Force munitions and supplies (Anderson, 1999).

Since this research focuses on pre-positioning, it is important to delve a bit deeper into the advantages and disadvantages of this strategic tool. Pre-positioning may be divided into two major categories: land based and sea based.

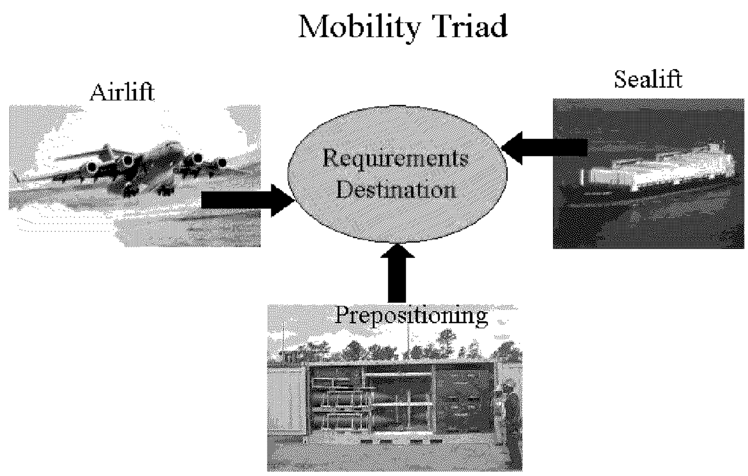


Figure 2-2. Mobility Triad: Airlift, Sealift, and Pre-positioning

2.3. Advantages of Pre-positioning

Two of the biggest advantages of pre-positioning are capacity and mobility. Relatively speaking, the capacity of APF ships is enormous. Depending on factors such as weight-to-volume ratio, and the configuration of a particular ship, one large ship can hold as much as 340 C-17 loads. Such capacities significantly ease the burden on strategic airlift assets. In addition to their enormous capacities, the APF ships also provide mobility. Ships can be positioned in response to constantly changing requirements or repositioned near potential hot spots. Once in position, the ships' inventories may be offloaded, or the ship may simply float offshore near the port of debarkation, awaiting further orders (Boley and Lyle, 2001). Pre-positioning also reduces the cost of potentially large shipping losses from submarine and air attacks, and strategically located pre-positioned assets can greatly reduce delivery time to the required location. This was demonstrated in the Gulf War when the pre-positioned equipment for three divisions in Europe reduced the divisions deployment time from 68 to 28 days. Pre-positioning of war reserve assets also reduces overseas manpower requirements during peacetime, and it can significantly reduce immediate demand on critical air and sea transportation resources. Pre-positioning serves as a viable alternative to rapid force deployment from another theater. Pre-positioning also plays an important role in foreign politics. The presence of pre-positioned stocks provides tangible proof of U.S. commitment to that particular region or host country (King, 1991).

2.4. Disadvantages of Pre-positioning

The concept and implementation of pre-positioning contains some imperfections. Obviously, the existence of pre-positioned stocks requires duplicate equipment and supplies, as well as additional training and maintenance. Pre-positioned stocks must also be available in operational condition. If not in operational condition, deploying units lose valuable time repairing or replacing equipment (Congress, 1989). These pre-positioned sites are vulnerable to attack, although some argue that afloat pre-positioned assets are safer and easier to defend than their land based counterparts (MPF 2010, 1998). As a result, fewer sites may be afforded better security. However, it would not be prudent, or strategically advantageous, to consolidate all assets under one roof, so these pre-positioned assets must be strategically "scattered". Finally, the number of pre-positioned assets are limited by asset availability and fiscal constraints (King, 1991).

2.5. Air Force Pre-positioning

In the midst of the Cold War, the USAF had an extremely large number of munitions caches scattered across Western Europe (see Figure 2-3). However, as tensions between the United States and the Soviet Union decreased, so did the number of overseas bases and, subsequently, munitions storage locations (see Figure 2-4).

Figure 2-3. Munitions Storage Locations During Cold War (Peters, 2001)

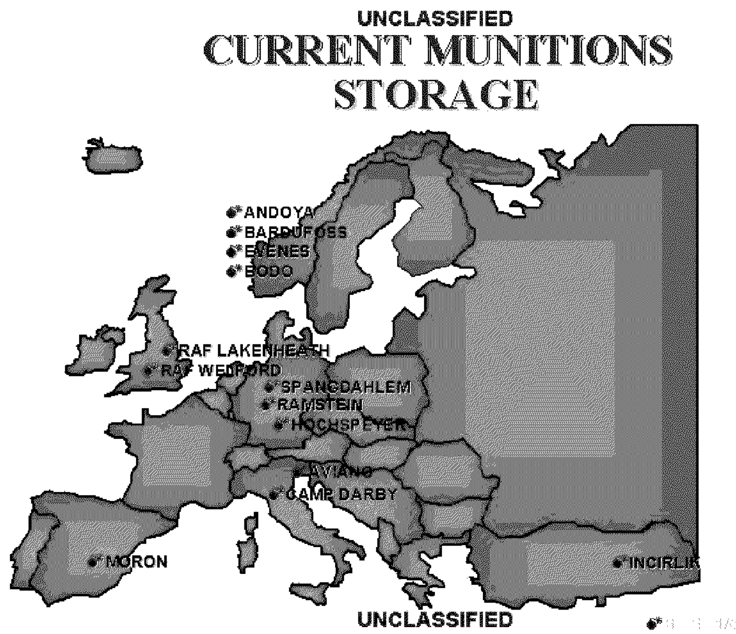


Figure 2-4. Current Munitions Storage in Europe

In the days leading up to the Gulf War, the Air Force had a large amount of munitions aboard pre-positioned ships (see Figure 2-5 below for an example of such a ship underway). At the onset of the hostilities, these ships steamed to a port and had their cargo offloaded to provide an initial combat capability. After the Gulf War, an enormous stockpile of munitions was left in the Persian Gulf region. The urgent need to reconstitute this stockpile led to a complete re-evaluation of the Air Force's global munitions positioning strategy. The pending reconstitution of thousands of munitions provided the Air Force with the perfect opportunity to re-think their global, munitions pre-positioning strategy. The Air Force wanted to develop a flexible munitions capability with an emphasis on *smart* munitions.

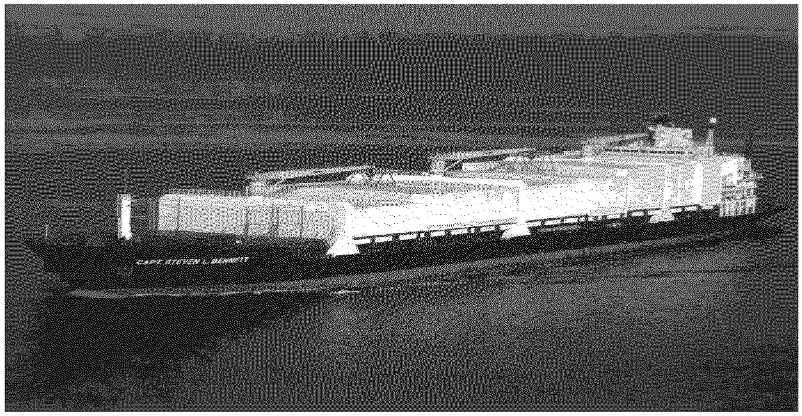


Figure 2-5. Member of the Afloat Pre-positioning Fleet

In 1994, the Chief of Staff of the Air Force, along with theater commanders in chief (CINCs) approved an afloat pre-positioning concept based on three munitions ships. The cargo on these ships was classified as swing stock and was designed to augment in theater munitions starter stocks (Boley and Lyle, 2001).

The advent of the Expeditionary Air Force (EAF) also spawned significant changes in the Air Force combat support system. Currently, the Air Force is developing the concept of an Agile Combat Support (ACS) system to support the wide range of USAF operations. ACS consists of forward operating locations (FOL), forward support locations (FSL), and CONUS support locations (CSL). FOLs contain resource allocations that support various employment timelines and are generally located at bases in "high threat" areas. FSLs are comprised of resources and support processes, and their locations depend on potential threats, geographic location, and cost benefits. The Air Force utilizes FSLs for munitions and War Reserve Materiel (WRM). Finally, CSLs are depots located in the U.S. and are designated to support overseas operations. An intricate command and control network links this system and organizes transportation and support to enable swift reactions to overseas crises (Tripp, *et al.*, 2000).

The Air Force must determine the tradeoffs associated with each support structure. Investment costs become extensive for pre-positioned support placed at numerous overseas locations. However, the employment timeline generally shrinks as the number of forward support locations increases. Today's high operations tempo and limited airlift capacity certainly favor increasing the number of FSLs, but the cost and risk of pre-positioning resources overseas support the notion of consolidated assets at established overseas and CONUS locations (Tripp, *et al.*, 2000).

To enable a quick response to requirements, the Air Force pre-positions its munitions stockpiles using the starter/swing concept. Swing stocks should be positioned to maximize flexibility and minimize overall response times to whatever crisis may develop. However, there is, often times, inadequate storage space or infrastructure in place, and these munitions must be malpositioned (stored at less than optimum locales) (Boley and Lyle, 2001).

Currently, the Air Force utilizes a triad of swing stock to rapidly respond to contingencies worldwide. The first, and preferred method is bomber flyaway, which are munitions assets directly available. This is the fastest method of response because the necessary munitions are stored right on base with their weapon delivery system. When a contingency arises, these munitions are loaded on the appropriate aircraft so the aircraft may complete its mission. The second leg of the triad is STAMP/STRAPP (Standard Air Munitions Package/Standard Tanks, Racks, Adapters, and Pylons Packages). STAMP/STRAPP assets are packages of munitions (bombs, kits, and tanks) that are configured onto 463L pallets. These pallets are built for airlift to facilitate intra-theater distribution once the assets reach the theater. STAMP is stored at two different locations in CONUS (McMillon, 2001). STAMP consists of mostly precision-guided munitions and “preferred” munitions (munitions with a certain level of accuracy, expected to minimize collateral damage) and enables selected tactical air units to deploy rapidly and operate from locations without pre-positioned munitions (AFI 21-201, 2000). Although munitions allocated as STAMP are not tied directly to specific operational plans (O-Plans), the intended use of the overall inventory is split between two major theaters of operations. The current location of the STAMP is designed to minimize response times but the storage and up-keep of this inventory is very resource intensive (i.e. manning and fiscal requirements). Replenishment of STAMP/STRAPP assets usually takes priority over all other pre-positioned assets.

The final leg of the swing stock triad is the APF. Munitions are stored aboard these ships in containers. Packaging capabilities allow subcomponents to be stored in a single container so that an all-up-round can be assembled while only opening one container. Unfortunately, containers that can accommodate all-up-rounds do not currently exist. Munitions may be transported from an APF ship to the point of use in as little as two days, depending on the location of the ship, but the average delivery time of afloat munitions is between eight and fifteen days.

Although the APF does not provide the fastest munitions employment times, it is appealing for a number of reasons. First of all, the APF is deemed a relatively safe and secure pre-positioning option. An APF ship can float undetected in the middle of the ocean and can visually detect oncoming threats or potential attacks. Maintenance costs of these ships are relatively low, and the ships environmentally controlled storage areas offer advantages over their land-based counterparts (see Figure 2-6). One of the biggest disadvantages of these ships is the loading/offloading constraint. These ships require certain port capabilities (i.e. water depth, equipment, personnel, etc.) and they often require an extraneous amount of offloading/rearranging to gain access to certain containers (Reavis, 2001). Finally, these ships are limited to certain ports because of net explosive weight (NEW) restrictions. APF ships may not be allowed to dock in certain ports because of the explosive hazard of the munitions onboard and the civilian population in proximity to the port.

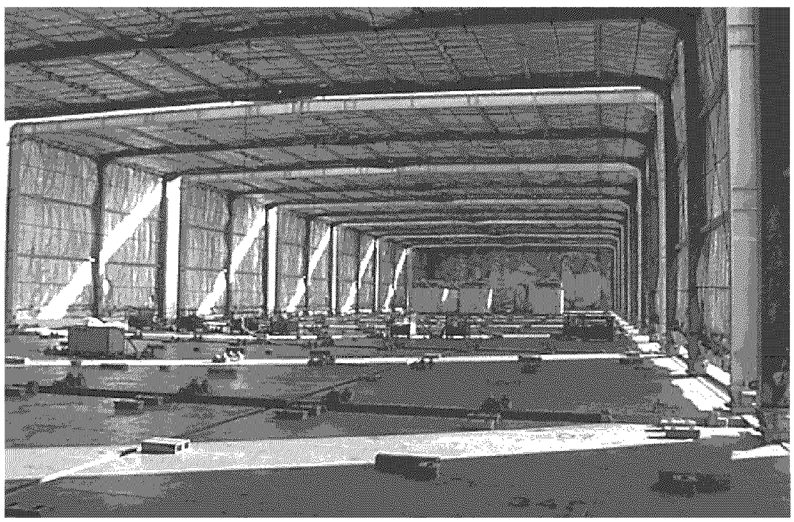


Figure 2-6. Environmentally Controlled Cocoon System Aboard a Munitions Ship

2.6. Munitions Requirements

The goal of airpower is to deny the enemy sanctuary. The Coalition Forces' success in the Gulf War was due, in large part, to their ability to project lethal force through airpower. Their ability to use the right weapon on the correct target shaped the outcome of the Gulf War. The Air Force utilized precision-guided munitions when decision makers deemed it important to avoid collateral damage, civilian casualties, or to directly hit a target. By the end of the conflict, the USAF had dropped over 90 percent of the 7,400 tons of precision-guided munitions used during the Gulf War and did so with deadly effectiveness (White Paper, 1991). More recently, the USAF has responded to the U.S. Embassy bombings in Kenya and Tanzania, Iraq's noncompliance with U.N. weapons inspectors, and Yugoslavia's ethnic cleansing in Kosovo. During each of these campaigns, the USAF relied heavily on precision-guided munitions to increase the probability of mission success while minimizing the risk of collateral damage.

Today, the Air Force's inventory is comprised of very advanced precision-guided munitions. These weapons offer increased lethality against enemy forces and reduce the risk of loss to U.S. forces. The Joint Chiefs of Staff establish the requirements for munitions inventories. These requirements are based on the specific nature and extent of the anticipated enemy threat, U.S. objectives, and expected enemy goals. Actual inventory levels are determined by daily demands during a contingency and the number of days expected to support that contingency (Congress, 1989). In addition to ensuring that the Air Force maintains the proper stocks of munitions, the Air Force must ensure that these munitions are available at the right location, in operational condition, and in the desired time frame to enhance the probability of mission success.

The Air Force utilizes war reserve materiel (WRM) munitions to support wartime activities listed in the War and Mobilization Plan (WMP) while the industrial base gears up to meet wartime demands. These WRM munitions are pre-positioned at operating bases, dispersed throughout an area of responsibility, aboard pre-positioning ships, and at selected locations and depots to ensure rapid air deployment.

The Air Force uses an involved process to move munitions from the requirements definition, through the placement stage to the actual point of use (see Figure 2-7). First, the CINC's apportion targets to the service components. After apportionment, Air Force officials calculate the proper mix of munitions using the Nonnuclear Consumables Annual Analysis (NCAA). The NCAA is the DOD process to determine annual conventional munitions requirements and associated war consumables for each theater. The WMP, Volume 4 (WMP-4), outlines planned aircraft activity used to implement each approved aircraft deployment, employment, and support operation. Once the NCAA process is complete, Air Force officials develop the air and ground munitions Detailed Logistics Allocation Report (DLAR) and the Tactical Air Missile Program (TAMP) documents. These documents allocate munitions to the theaters, APF, and STAMP. Following the development of the DLAR and TAMP, War Consumable Distribution Objectives (WCDO) are established. WCDOs tell the base level managers what assets should be positioned at their bases to support the OPlan. Next, positioning objectives are developed at the Global Asset Positioning (GAP) conference. GAP provides the war fighting CINCs with their initial starter stocks, rapid swing stock (with both APF and STAMP/STRAPP), and provides for swing stock positioning in theaters and in the continental United States. The GAP culminates in the development of the Munitions Movement Plan (MMP). The MMP is designed to move assets into theater storage, STAMP, and the APF to meet all theaters' requirements (AFI 21-201, 2000).

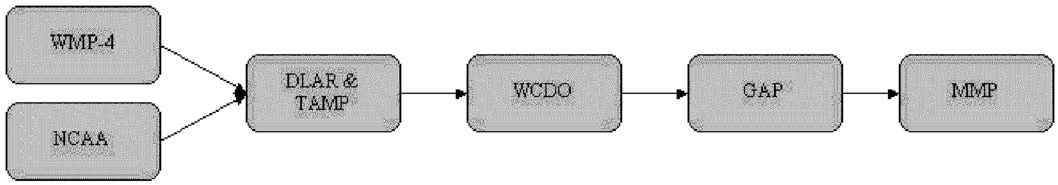


Figure 2-7. Munitions Requirements and Movement Process

2.7. Related Work

The recent interest in munitions pre-positioning has prompted several studies that investigate various aspects of this strategy. The Air Force Logistics Management Agency (AFLMA) conducted a study on pre-positioning munitions using the Joint Integrated Contingency Model (JICM). JICM is a "comprehensive, deterministic simulation in which higher level decisions and actions are specified by the user. Execution details are left to the adaptive logic of the program, which employs an extensive database of information about geography, military activities, and objects such as ships and aircraft" (Abell, *et al*., 2000). This model is used to determine day-to-day quantities of munitions delivered to operational bases. The study considered a number of potential conflicts of various sizes and in vastly different geographic locations. The bulk of the study, however, focused on Southwest Asia (SWA). The study produced a number of interesting recommendations, including: reduce war reserve materiel (WRM) munitions on the ground in SWA, increase the size of the afloat pre-positioning fleet, alter the composition of the afloat pre-positioning fleet, investigate the possibility of positioning a mix of WRM on fast, smaller, high speed sealifts (HSS), (Although these

HSS travel much faster than larger, more traditional sealift ships, they carry considerably less cargo), and investigate the possibility of strategic pre-positioning at forward operating locations.

In addition to the AFLMA study, a number of other studies that investigate munitions movement and positioning have recently been completed. Sentlinger developed a mixed integer program to look at the optimal weapons pre-positioning mix for established U.S. Naval weapon stations with a focus on minimizing shortfalls during a myriad of conflicts (Sentlinger, 2000). Anderson developed an optimization model that utilizes available shipping assets to redistribute weapons based on a pre-determined positioning plan for the Pacific Fleet. However, Anderson's optimization model only looks at the redistribution of weapons based on routine, scheduled deployments, and is not tied to any wartime scenario (Anderson, 1998). Synergy developed a simulation model to evaluate current munitions pre-positioning and provide alternative strategies for pre-positioning existing preferred munitions inventories. However, the Synergy model did not investigate alternative inventory mixes for the current APF (Synergy, 2001). Finally, Yost developed perhaps the most comprehensive optimization model, which investigates the optimal pre-positioning of USAF swing stock. The model may be run as a preemptive goal program with a main objective of minimizing munitions shortages and a secondary objective of minimizing operating costs while constrained to the level of shortages determined by the main objective. Yost looks at this process over a longer time horizon, and even incorporates new munitions purchases into the model (Yost, 2001). Unfortunately, with the exception of the Synergy study, these models do not include NEW restrictions and draft restrictions, or consider inland transportation options. These are critical components of any munitions movement process. Also, none of these models try to move munitions in an attempt to minimize delivery time. Precision guided munitions are such a critical component of mission success, and are usually required in the early stages of a conflict, and subsequently, the Air Force must ensure that these assets are available where needed, and in the proper time frame.

2.8. Summary

The end of the Cold War brought military downsizing and reductions in forward based infrastructure. These cuts have impeded the operational commanders' reach in projecting combat power and have constrained the logistics effort (Haviland, 1999). Unfortunately, these reductions will most likely continue in the future, resulting in an even greater need for more strategically pre-positioned assets. The military must determine the proper mix of land and afloat pre-positioning to complement strategic air and sea lift support of national security objectives as the U.S. enters an uncertain future with a smaller military based primarily in the continental United States (CONUS). In addition, each service must develop a sound pre-positioning program to complement the other services, as well as determine the proper balance of land and sea pre-positioning to optimize force projection capabilities (Kampsen, 1998). In particular, the Air Force, to achieve "Global Reach" and "Global Power", must utilize the benefits of pre-positioning, and hone the concept of ACS, to exploit the speed, range, flexibility, lethality, and precision of modern airpower.

3. Methodology

The previous two chapters detailed the importance of pre-positioning in meeting today's global munitions requirements. This chapter focuses on the technique/model used in this thesis to improve upon current pre-positioning concepts, specifically with regards to the Afloat Pre-positioning Fleet (APF).

3.1. GAMS

The model developed in this thesis was implemented using the General Algebraic Modeling System (GAMS). GAMS is a high-level modeling system for mathematical programming problems that consists of a language compiler and a number of integrated high-performance solvers. GAMS is tailored for complex, large scale modeling applications, and allows the user to build large maintainable models that can be adapted quickly to new situations (Brooke, *et al.*, 1998). XA, a GAMS compatible solver was used to solve the mixed integer program.

3.2. Mixed Integer Program

The model developed for this study is a mixed integer program (MIP). This mathematical model consists of a linear objective function and linear constraints with some variables required to be binary. By utilizing integer variables, the model can determine what is feasible and most efficient for meeting the munitions requirements within the confines of available resources. The parameters, variables, and equations of the model are discussed in this chapter.

3.3. Munitions Flow

In order to effectively model the flow of munitions, it is important to understand the many factors involved in this process. When a crisis arises, and starter stocks, bomber fly away, STAMP/STRAPP, and/or forward located stocks, cannot meet the munitions requirements for the crisis, the Air Force must use the Afloat Pre-positioning Fleet. Once requested, these ships (it may be all, or just one) steam to a port where their cargo may be offloaded (see Figure 3-1). Unfortunately, these ships cannot steam into just any port. These ships require certain water depths (draft), and must meet any Net Explosive Weight (NEW) restrictions. This usually prevents these ships from offloading their cargo in or near densely populated areas. Offload times depend upon manpower and equipment available, as well as the type of ship being offloaded. For example, a containerized vessel, where all goods are stored in ISO (International Standards Organization) containers, can be offloaded much faster than a break-bulk ship with all cargo packed in small, separable, and variably sized units (French and Rabey, 2001).

Figure 3-1. Containerized Vessel in Port -- Preparing to Offload

Once the ships are offloaded in port, the munitions are reloaded onto either rail cars (see figure 3-2) or truck convoys in order to transport the munitions to the requesting air base. Finally, once these munitions reach the proper air base, they are assembled into their usable form. These munitions are then loaded onto aircraft to conduct sorties against strategic targets in various theaters of operations. This process, as a whole, contains significant variation in the amount of time it takes to perform each of these tasks. However, in an effort to simplify the model, we consider these processes as deterministic with known completion times.

Figure 3-2. ISO Containers Being Loaded onto Railcars

There are a number of ports that the USAF currently employs to offload munitions from an APF ship. In addition, there are a number of over-the-land transportation options available at each port. The USAF also operates, and can establish, a significant number of airfields from which it can conduct operations. However, this initial model only looks at a small number of these ports and air bases. All potential ports not included in this model are within about one day steam time from at least one other port included in this study.

This model investigates the optimal pre-positioning of precision-guided munitions. The Air Force has an extensive inventory of such weapons, but this model only considers a sample of these munitions. The list of munitions modeled, and the quantity of munitions per APF ship, is found in Appendix B. Notional quantities of munitions required by each air base can also be found in Appendix B.

In order to accurately model the involvement of the APF in any conflict, the model must consider other sources of supply for munitions. This model considers two CONUS STAMP locations and a number of overseas munitions hubs. When a crisis arises, munitions flow from each of these sources to meet demand at each of the destinations. It is important to note that this model does not include the munitions storage areas (MSAs) that are located at each base.

3.4. Assumptions

Before discussing the model itself, it is important to clearly explain the assumptions inherent in the model. The following assumptions are not listed in order of importance or significance. The ships, which comprise the APF, are available for the duration of the scenario, and no breakdowns or enemy-inflicted incapacitation are modeled. Ships travel at a known, constant speed of advance throughout the scenario; however, each ship may have its own, unique speed. Ship steam times (like any other input data) can be changed prior to running the model, but not during model execution. The munitions, selected for use against certain target sets, are known, and no suitable substitutes may be requested or used during model execution. Offloading times at sea ports of debarkation are fixed. Transportation times, via rail line or truck convoy, from each port to each requesting air base, are considered deterministic. This model assumes that each port remains open for the duration of the scenario, and that all overland transportation infrastructures remain intact. Finally, although the ultimate goal of this model is to minimize the amount of response time to various crises throughout the world, this model is not concerned with the location of the targets themselves, just the location of the air base from which the munitions carrying sorties are launched.

3.5. Model Formulation

This section discusses the model in detail, including all the applicable indices, variables, and parameters used in the model.

Indices:

l	Starting Location of APF ship
d	Destinations (Requesting Air Bases)
a	APF Ship (source of munitions)
c	Conflict (MTW, SSC)
p	Ports of debarkation
t	Modes of over the land transportation (Rail, Truck)
m	Type of precision guided munitions moved in the scenario
h	Overseas Hubs for munitions
s	CONUS STAMP locations
k	Type of airlifters used to transport munitions

Variables:

X_{mpdc} = Number of PGMs m moved through port p to destination d for conflict c

F_{mhdc} = Number of PGMs m moved from Hub h to destination d for conflict c

ST_{msdc} = Number of PGMs m moved from STAMP location s to d for conflict c

$SHORT_{mdc}$ = Shortage of PGMs m to conflict c at destination d

$$W_{ap} = \begin{cases} 1 \text{ if APF ship a steams to port p} \\ 0 \text{ otherwise} \end{cases}$$

$$Y_{alp} = \begin{cases} 1 \text{ if APF ship a moves munitions from prepo location l to port p} \\ 0 \text{ otherwise} \end{cases}$$

$$N_{p} = \begin{cases} 1 \text{ if NEW restrictions are violated at port p} \\ 0 \text{ otherwise} \end{cases}$$

INV_{ma} = Number of PGMs m stored on APF ship a

$TRAN_{tpd}$ = Number of trips mode t makes between port p and destination d

$MOVE_{thd}$ = Number of trips mode t makes between Hub h and destination d

$AIRLIFT_{ksd}$ = Number of trips airlifter k makes between STAMP location s and destination d

Note: If infrastructure (e.g., highways or rail lines) were incapacitated, the corresponding variables could be set equal to zero to ensure the model would not select that particular option.

Parameters:

$AirTime_{ksd}$ = Time to move from STAMP location s to destination d via airlifter k

$APFCap_{a}$ = Capacity of APF ship a in terms of ISO containers (Volume)

$APFWt_{a}$ = Capacity of APF ship a in terms of weight in pounds

$$CanTx_{mpd} = \begin{cases} 1 \text{ if munition m can be moved from port p to destinatio n d} \\ 0 \text{ otherwise} \end{cases}$$

Dem_{mdc} = Demand for munitions m at destination d for conflict c

$$HubAor_{mhd} = \begin{cases} 1 \text{ if munitions can be moved from hub h to destinatio n d} \\ 0 \text{ otherwise} \end{cases}$$

$HubInv_{mh}$ = Inventory of munition type m at Hub h

M = Large Constant

$MaxNEW_{p}$ = Max NEW restriction listed for each port of debarkation

$MoveCap_{thd}$ = Number of 463L pallets that can be moved from hub h to destination d using mode t

$MoveWt_{thd}$ = Weight that can be moved from hub h to destination d using mode t

$Mper463L_{m}$ = Number of each PGM type fitted onto 463L pallet

$MperISO_{m}$ = Total number of each PGM type fitted into each ISO container

$MunWt_{m}$ = Weight of each PGM type ISO container in pounds

$NEWPen_{p}$ = Time penalty assessed for exceeding NEW restrictions in port p

$NEWperISO_{m}$ = NEW for ISO container full of PGM type m

$Offld_{ap}$ = Time to offload ship a at port p

Pen_{mdc} = Time penalty assessed for each munitions short at destination d for conflict c

$STAMPInv_{ms}$ = Inventory of munition type m at STAMP location s

$Steam_{alp}$ = Time to move APF ship a from prepo location l to port p

$TotInv_{m}$ = Total inventory of each PGM m across all APF ships

Tx_{tpd} = Time to move from port p to destination d via transportation mode t

$TxCap_{tpd}$ = Number of ISO containers that can be moved from port p to destination d using mode t

$TxTime_{thd}$ = Time to move from Hub h to destination d via transportation mode t

$TxWt_{tpd}$ = Weight capacity for each mode of transportation from port p to destination d

$Wtper463L_m$ = Weight of 463L pallet when loaded with munition m

Formulation:

Objective Function -- Min Response Time

$$\sum_{alp} Steam_{alp} * Y_{alp} + \sum_{mdc} Pen_{mdc} * SHORT_{mdc} + \sum_{tpd} Tx_{tpd} * TRAN_{tpd} + \sum_{ap} Offld_{ap} * W_{ap} + \sum_{p} NEWPen_p * N_p + \sum_{ksd} AirTime_{ksd} * AIRLIFT_{ksd} + \sum_{thd} TxTime_{thd} * MOVE_{thd} \qquad (1)$$

Objective Function -- Min Shortages

$$\sum_{mdc} SHORT_{mdc} \qquad (2)$$

The first objective of this model (1) is to minimize the total response time in meeting munitions demands at the various air bases. The time components used to determine this total time include steam times for various APF ships from determined pre-positioned locations to selected ports, offload times at the selected ports, a time penalty for violating any NEW restrictions at the port, inland transportation times from the selected ports to the requesting air bases, transportation times from overseas hubs to requesting air bases, airlift times from CONUS STAMP locations to requesting airbases, and a time penalty for any munitions shortages at the requesting air bases. The time penalty associated with each munitions shortage is considered to be a constant relational cost for each weapon, and each scenario. An alternative objective function (2) is to minimize the total shortages of munitions across requesting air bases, or destinations, for each conflict.

Subject To:

$$\sum_{p} CanTx_{mpd} * X_{mpdc} + \sum_{h} HubAOR_{mhd} * F_{mhdc} + \sum_{s} ST_{msdc} + SHORT_{mdc} = Dem_{mdc} \quad \forall m,d,c \tag{3}$$

$$\sum_{mdc} X_{mpdc} \le \sum_{mad} CanTx_{mpd} * W_{ap} * M \quad \forall p \tag{4}$$

$$\sum_{mpc} (X_{mpdc} \div MperIso_{m}) \le \sum_{tp} (TxCap_{tpd} * TRAN_{tpd}) \quad \forall d \tag{5}$$

$$\sum_{mpc} (X_{mpdc} \div MunWt_{m}) \le \sum_{tp} (TxWt_{tpd} * TRAN_{tpd}) \quad \forall d \tag{6}$$

$$\sum_{c} X_{mpdc} \le CanTx_{mpd} * INV_{ma} \quad \forall a,m,p,d \tag{7}$$

$$\sum_{a} INV_{ma} + \sum_{hdc} F_{mhdc} * HubAOR_{mhd} + \sum_{sdc} ST_{msdc} + \sum_{dc} SHORT_{mdc} \ge \sum_{dc} Dem_{mdc} \quad \forall m \tag{8}$$

$$\sum_{a} INV_{ma} = TotInv_{m} \quad \forall m \tag{9}$$

$$\sum_{dc} ST_{msdc} \le STAMPInv_{ms} \quad \forall m,s \tag{10}$$

$$\sum_{dc} F_{mhdc} \le HubInv_{mh} \quad \forall m,h \tag{11}$$

$$\sum_{c} (F_{mhdc} \div Mper463L_{m}) \le \sum_{t} (MoveCap_{thd} * MOVE_{thd} * HubAOR_{mhd}) \quad \forall m,h,d \tag{12}$$

$$\sum_{c} (F_{mhdc} \div Wtper463L_{m}) \le \sum_{t} (MoveWt_{thd} * MOVE_{thd} * HubAOR_{mhd}) \quad \forall m,h,d \tag{13}$$

$$\sum_{msc} (ST_{msdc} \div Mper463L_{m}) \le \sum_{ks} (AirVol_{ksd} * AIRLIFT_{ksd}) \quad \forall d \tag{14}$$

$$\sum_{msc} (ST_{msdc} \div Wtper463L_{m}) \le \sum_{ks} (AirWt_{ksd} * AIRLIFT_{ksd}) \quad \forall d \tag{15}$$

$$\sum_{m}(INV_{ma} \div MperISO_{m}) \leq \sum_{p}(APFCap_{a} * W_{ap}) \quad \forall a \tag{16}$$

$$\sum_{m}(INV_{ma} * MunWt_{m} \div MperISO_{m}) \leq APFWt_{a} \quad \forall a \tag{17}$$

$$\sum_{a} Y_{alp} = 1 \quad \forall l, p \tag{18}$$

$$\sum_{l} Y_{alp} = 1 \quad \forall a, p \tag{19}$$

$$\sum_{p} W_{ap} \leq 1 \quad \forall a \tag{20}$$

$$\sum_{l} Y_{alp} = W_{ap} \quad \forall a, p \tag{21}$$

$$\sum_{t} TRAN_{tpd} \leq \sum_{ma} CanTx_{mpd} * W_{ap} * M \quad \forall p,d \tag{22}$$

$$\sum_{mdc}(X_{mpdc} \div MperISO_{m}) * NEWperISO_{m} \leq MaxNEW_{p} + N_{p} * M \quad \forall p \tag{23}$$

$$X_{mpdc}, F_{mhdc}, ST_{msdc}, SHORT_{mdc}, TRAN_{tpd}, MOVE_{thd}, AIRLIFT_{ksd}, Inv_{ma} \geq 0 \tag{24}$$

$$W_{ap}, Y_{alp}, N_{p} = 0 \, or \, 1 \tag{25}$$

Equation (3) ensures that the model satisfies precision-guided munitions demand, across all destinations, for each conflict. Munitions may only be moved from a port to a destination if transportation modes are available. Any munitions not supplied from the APF ships, STAMP locations, or overseas hubs are considered shortages and must be provided by other means. Equation (4) indicates whether or not a particular APF ship steams to a particular port. M is an arbitrarily large number. Equations (5) and (6) determine the number of trips, based upon the volume and weight capacity of each mode of transportation, required by each transportation mode to move requested munitions from a given port to a requesting air base for each conflict. Equations (7) through (9) determine the proper inventory mix for each munitions type assigned to each APF ship. Equation (7) ensures that if an APF ship carries a certain weapon to support a conflict, inland transportation is available to move the munitions from the port to the final destination. Equation (8) ensures that the APF ships carry enough munitions (plus STAMP, hubs, and shortages) to meet total munitions demand, and Equation (9) forces the total munitions allocated across all APF ships to equal the munitions inventory currently available to the APF. Equations (10) and (11) ensure that the model does not exceed the available inventories at each of the STAMP locations and overseas hubs, respectively. Equations (12) and (13) prevent the number of munitions that are transported from the hubs from exceeding the volume and weight restrictions of each mode of transportation. Similarly, equations (14) and (15) constrain the number of munitions transported from each STAMP location to the volume and weight restrictions of each type of airlifter used. Equations (16) and (17) ensure that each APF ship's volume and weight capacities are not exceeded, while equations (18) and (19) ensure that only one APF ship is pre-positioned at each possible location. Equation (20) ensures that each APF ship only steams to one port and Equation (21) links the ships that steam to a given port to their initial pre-positioned location. Equation (22) ensures that munitions are only carried inland from a port if adequate transportation means and infrastructure are in place. Equation (23) ensures that the port NEW restrictions are not violated. If the restrictions are violated at a port, a time penalty is incurred. Finally, equations (24) and (25) list the restrictions on the variables used in the model.

4. Results

The previous three chapters discussed the importance of pre-positioning, the need for planning models to aid decision makers with pre-positioning policy, and finally, the assumptions and formulation for the model developed in this research. This chapter focuses on details of the model inputs, as well as the model results.

4.1. Scenario Inputs

In recent years, the Department of Defense has shifted its planning guidance from simultaneous major theaters of war to smaller scenarios ranging from small-scale contingencies to humanitarian operations. This thesis looked at three different scenarios including: a Major Theater of War in Southwest Asia (MTWS), a Small-Scale Scenario in Europe (SSCE), and a Small-Scale Scenario in Northeast Asia (SSCA).

To validate the model and illustrate the usefulness of its results, a sample problem was generated which incorporated data representative of real-world scenarios. This problem looked at three different simultaneous scenarios in three different theaters of operations. Each theater has a different support structure including different air bases, ports, and munitions hubs; however, the same APF ships could be used for each scenario. Eight different precision-guided munitions were considered in this study. Munitions demand data for this model was provided by CENTAF, and then notionalized.

Table 4-1 shows the air bases that were used to generate sorties for their respective theaters.

Table 4-1. Theater Breakdown of Air Bases Modeled

Theater	Air Base (Destination)
Europe	RAF Lakenheath
	Ramstein AB
	Aviano AB
	Incirlik AB
Southwest Asia	Prince Sultan Air Base (PSAB)
	Dhahran AB
	Al Jaber
	King Khalid Military City (KKMC)
Northeast Asia	Kadena AB
	Andersen AB
	Kunsan AB

Table 4-2 shows the ports which service each theater, and Table 4-3 shows various munitions hubs and the air bases included in their area of responsibility (AOR).

Table 4-2. List of Ports Used by APF for each Theater

Theater	Ports
Europe	Nordenham, Germany
	Livorno, Italy
	Iskenderun, Turkey
Southwest Asia	Ad Dammam, Saudi Arabia
	Al Jabail, Saudi Arabia
Northeast Asia	Apra, Guam
	Naha, Okinawa
	Chin Hae, South Korea

Table 4-3. List of Munitions Hubs and Their AOR, Listed by Theater

Theater	Munitions Hubs	Bases Included in AOR
Europe	Ramstein, Germany	Ramstein AB, Incirlik AB
	Darby, Italy	Aviano AB, Incirlik AB
	Welford, United Kingdom	RAF Lakenheath
Southwest Asia	None	None
Northeast Asia	Naha, Okinawa	Kadena AB

The ports, munitions hubs, and air bases used in these scenarios are not intended to be an exhaustive list. However, the facilities modeled provide an adequate sample to support the modeling of real-world scenarios and the model can be easily expanded to handle additional facilities as deemed necessary.

4.2. Results

The model was run twice with two different objectives. The first objective was to minimize munitions shortages for each scenario, at each destination. The second objective was to minimize the munitions delivery times to each destination. The following is a comparison of the results for these different objectives.

4.2.1 APF Movement

In order to validate the model, it is important to validate the movement of the APF ships, as well the flow of munitions from the ports to the final destinations. Depending on the objective function used, the model moves the APF in order to either minimize the overall response time in terms of providing munitions to a given scenario, or to minimize the total number of munitions shortages for a given scenario. Figures 4-1 and 4-2 show the movement of the APF ships from their pre-positioning location to their respective ports of debarkation for the scenarios used to test the model.

Figure 4-1 shows a rather random movement among the APF ships. One ship steams from the Mediterranean to Guam, while the other two steam from Saipan to the Persian Gulf and Germany, respectively.

Figure 4-2 displays a much more logical flow, and the travel distance and time is significantly decreased when the objective is to minimize delivery time. The first ship steams from the Mediterranean to Iskenderun, another travels from Diego Garcia to the Persian Gulf, and the final ship steams from Saipan to Guam. This represents a significant decrease in overall delivery time.

Figure 4-1. APF Movement When Objective is to Minimize Shortages

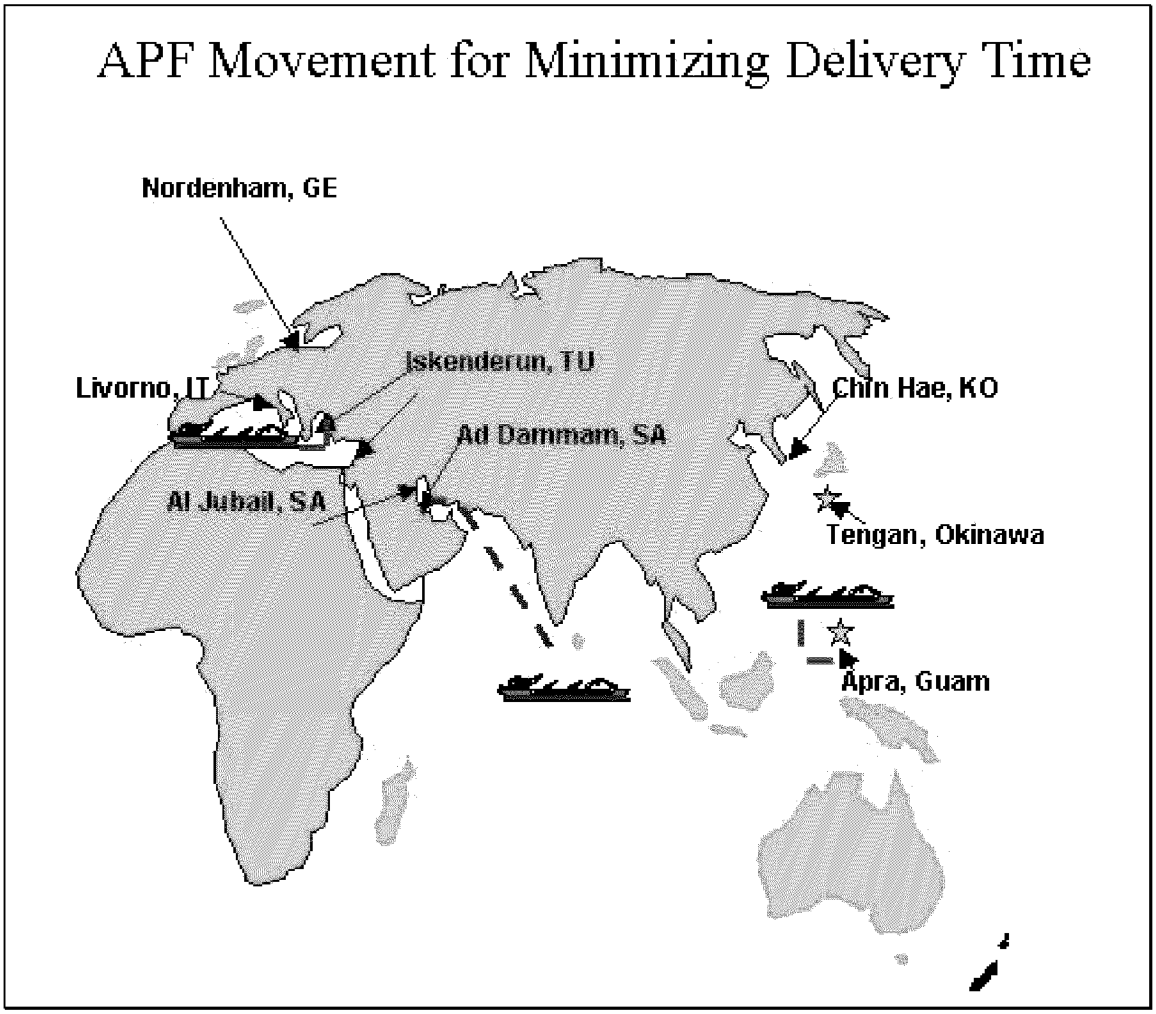


Figure 4-2. APF Movement When Objective is to Minimize Delivery Time

After comparing the APF movement for these two different objective functions, it became evident that minimizing overall response time, while including a relational penalty for shortages, produced more logical results. The following analysis stems from this model.

4.2.2 Volume of Munitions Provided by Each Source

The model provides a breakdown of the number of each munition provided to each destination, from each source. Munitions sources for each theater were designed to be unique to stress the model and ensure it performs as expected. Figures 4-3 to 4-5 show the aggregated percentage of munitions, for each scenario, that were supplied from each of the four sources. Obviously, the percentage will vary depending on factors such as the location of munitions hubs, or their inventories. However, for each of these scenarios, in an effort to minimize overall response time, the APF brings at least 26 percent of all munitions to the fight. This represents a significant amount of the overall munitions movement for the Air Force.

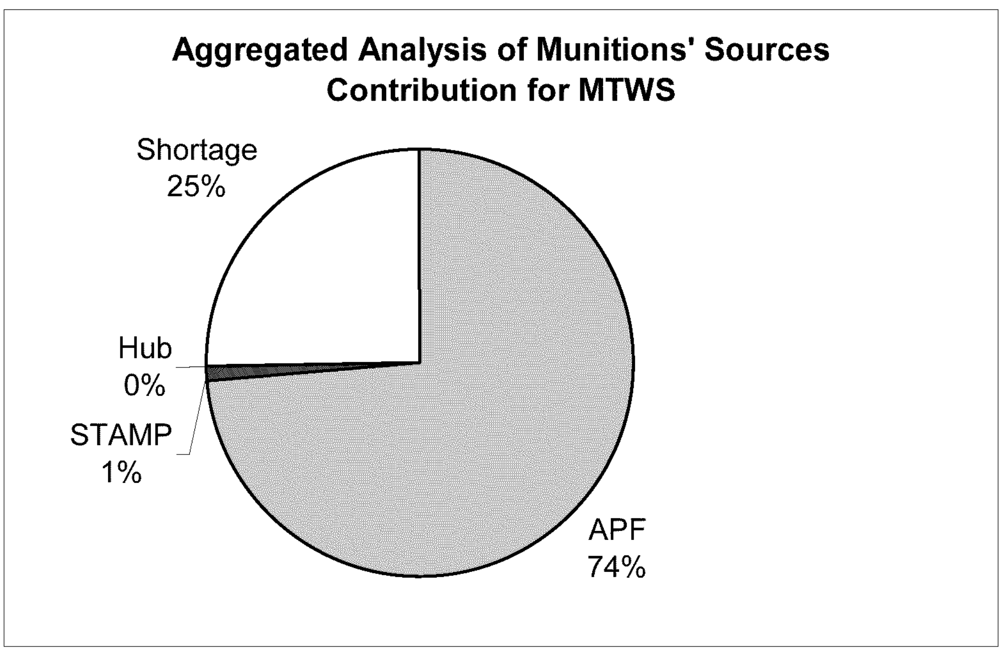


Figure 4-3. Aggregated Percentage of Munitions From Each Source for MTWS

Figure 4-3 may be the most revealing graph because it pertains to the largest scenario requiring the largest number of munitions. Over 74 percent of the munitions required for this scenario were supplied by the APF. Shortages also constitute a significant portion of the total munitions demand. However, if either hubs, or munitions storage areas (MSAs) were considered for this theater, this shortage level would be considerably smaller.

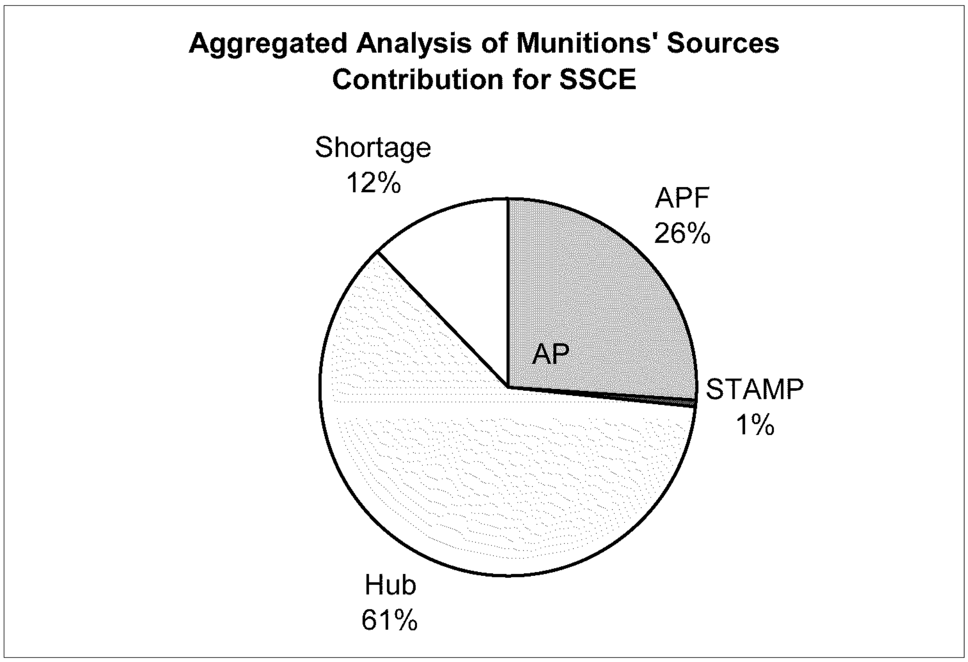


Figure 4-4. Aggregated Percentage of Munitions From Each Source for SSCE

Munitions movement for the SSCE scenario differs considerably from the other two scenarios. For this scenario, the munitions hubs play a critical part in supplying the air bases with their required munitions. The hubs can play a more significant role because the total demand is considerably less than in the MTWS scenario. Subsequently, STAMP is not relied upon too heavily because of the hubs' contributions.

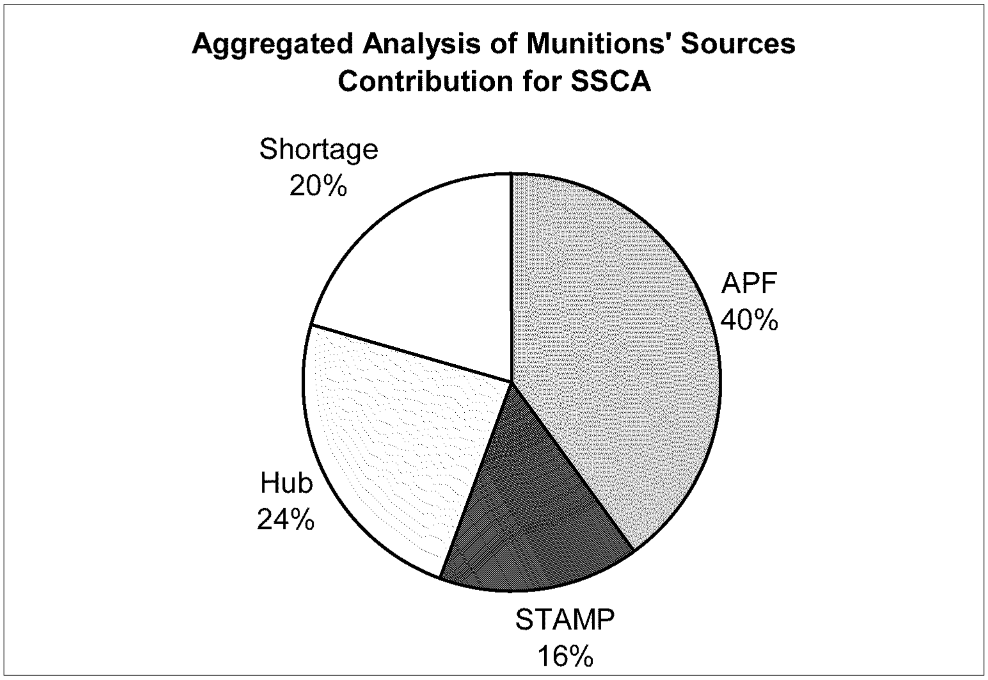


Figure 4-5. Aggregated Percentage of Munitions From Each Source for SSCA

The final scenario, SSCA, shows the largest balance in terms of the munitions sources used to meet total munitions demand. This also seems reasonable because of the geographic constraints in this region. All of the air bases included in this model, for this theater, are separated by water. Therefore, munitions cannot be moved over land between the air bases. The model results indicate that Andersen received the majority of their demand from the APF ship, while Kadena relied on both its hub and STAMP. Finally, because of its geographic separation and lack of a main munitions hub, Kunsan had to rely solely on STAMP from CONUS locations. Subsequently, Kunsan suffered considerable shortages.

4.2.3 Munitions Flow from Port to Final Destination

In addition to validating the movement of the APF ships, the flow of munitions from the ports to the final destinations was also validated. Figures 4-6 to 4-8 give a pictorial representation of the volume of munitions flow from each port utilized by the APF to the final destinations for each scenario. The weight of each line represents a relative volume of aggregated munitions that flow through the ports to the destinations. A thicker line represents a larger volume of munitions flow between the port and final destination. In addition to the figures, Tables 4-4 to 4-6 provide the numerical values of the aggregated munitions moved from each port to each destination.

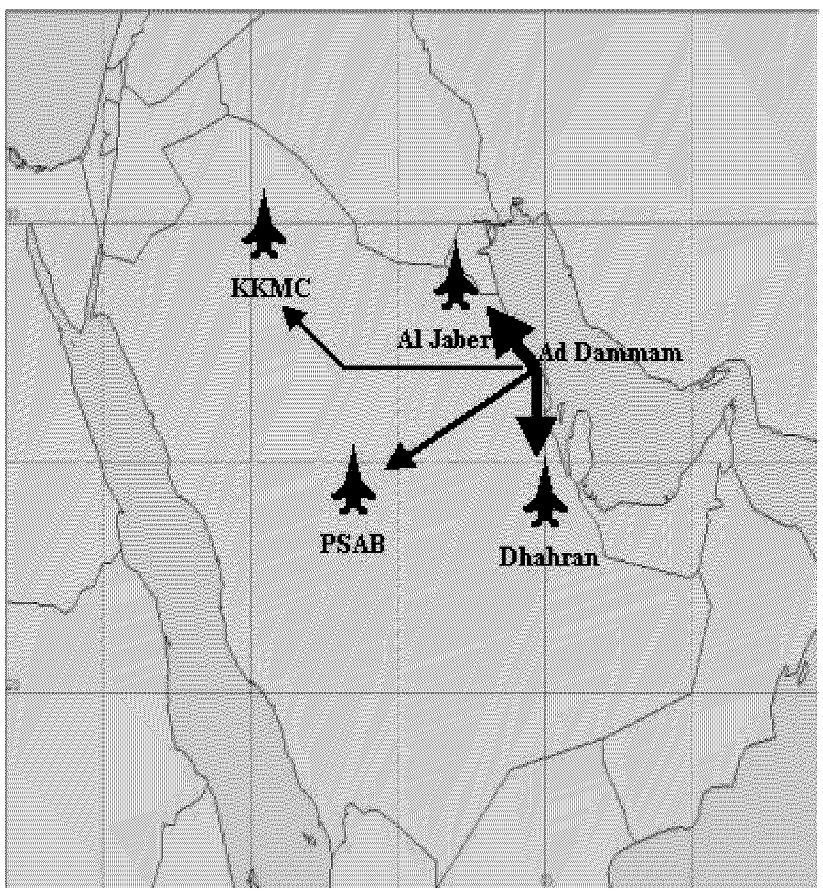


Figure 4-6. Munitions Volume from Port to Various Air Bases in Support of MTWS

Table 4-4 Aggregated Munitions Volume from Port to Destination for MTWS

Theater	Port	Destination	Aggregated Munitions Volume
SWA	**Ad Dammam**	Al Jaber	6951
		Dhahran	5401
		KKMC	2501
		PSAB	3305

Figure 4-6 shows a substantial amount of munitions being moved from an APF ship, through the port of Ad Dammam, and to the different destinations in the theater. The large number of munitions brought to the area by the APF makes sense as no munitions hubs were included in this theater. Therefore, all the munitions needed to support a MTW in SWA must be brought via APF ships or airlifted from the STAMP locations.

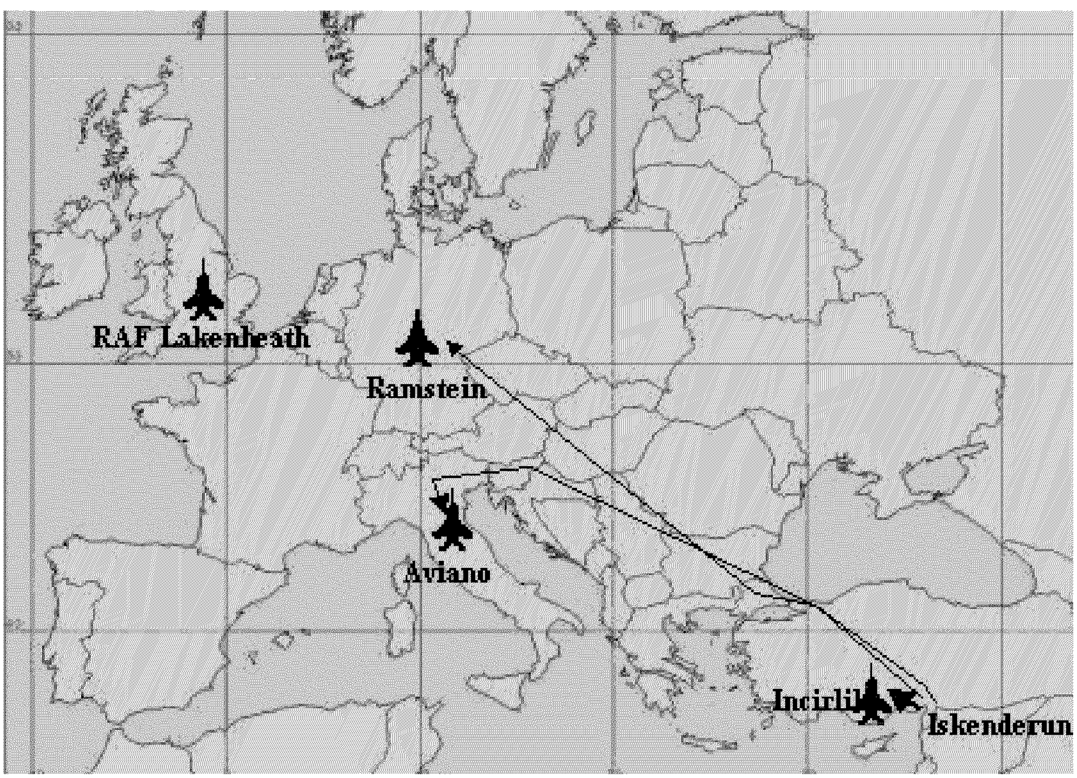


Figure 4-7. Munitions Volume from Port to Various Air Bases Support of SSCE

Table 4-5 Aggregated Munitions Volume from Port to Destination for SSCE

Theater	Port	Destination	Aggregated Munitions Volume
Europe	**Iskenderun**	Incirlik	2216
		Aviano	467
		Ramstein	100
		RAF Lakenheath	0

In the SSCE scenario, the APF ship steams into Iskenderun, Turkey to offload its munitions. The majority of its cargo is sent to Incirlik, with only nominal amounts of weapons sent to Ramstein and Aviano. This munitions flow seems reasonable as, in this scenario, the Air Force has large munitions hubs located very near the other three air bases in this theater. No munitions were sent from Iskenderun to Lakenheath because these two points are not entirely connected by land.

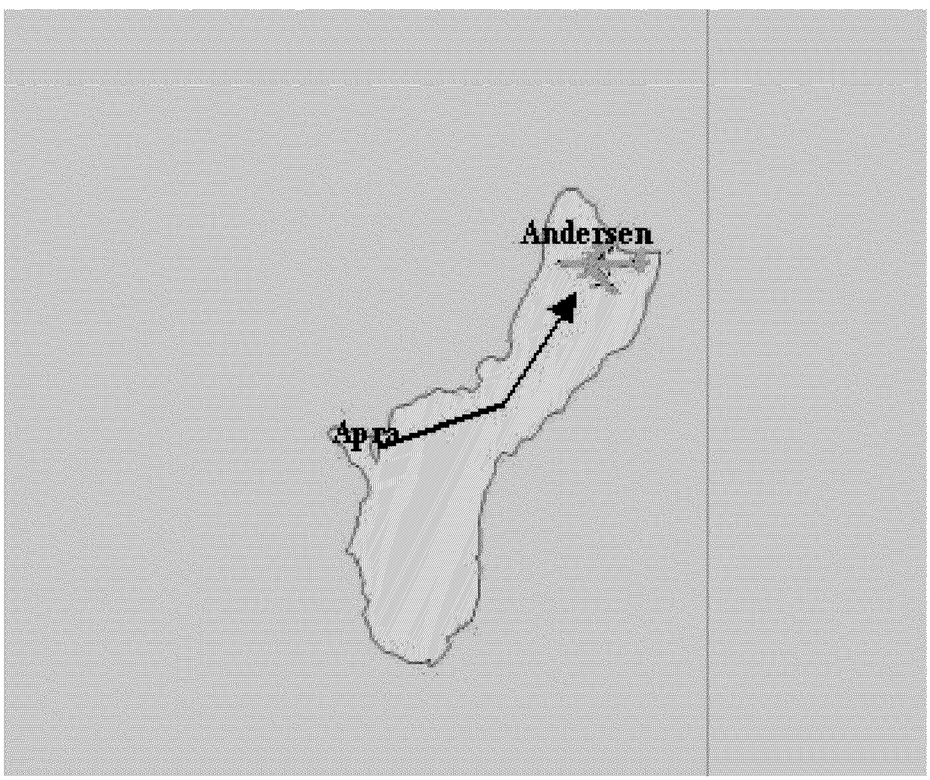


Figure 4-8. Munitions Volume from Port to Air Base in Support of SSCA

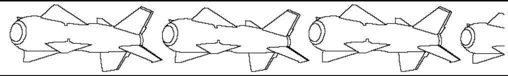
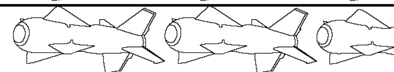
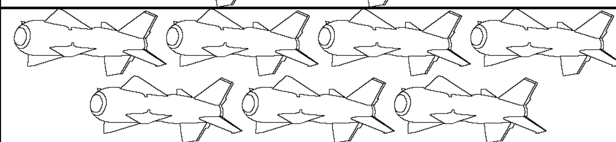
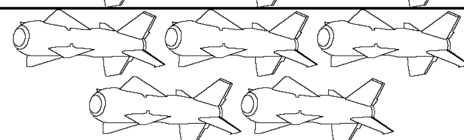
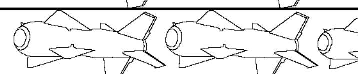
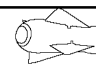
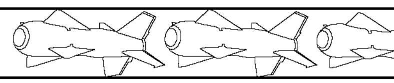
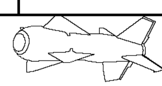
Table 4-6 Aggregated Munitions Volume from Port to Destination for SSCA

Theater	Port	Destination	Aggregated Munitions Volume
Asia	**Apra**	Andersen	2336
		Kadena	0
		Kunsan	0

For the final scenario, a SSC in northeast Asia, the model determined that the best option was to move the APF ship to Guam, and satisfy Andersen's munitions demand. Kadena can rely on both its munitions hub and some airlift support from STAMP locations. Unfortunately, Kunsan must rely solely on airlift support from CONUS STAMP locations, and subsequently suffers significant shortages. This problem stems from the fact that the model did not include any MSAs at, or near, the air bases in the scenario.

Table 4-7 provides one more representation of the volume of munitions that flow from the APF ships to each destination. From this table, it is easy to see that SWA receives the bulk of munitions from the APF. This coincides with the large munitions requirement associated with the MTW scenario in that theater. The other two theaters do not receive as much support from the APF due to such factors as existing munitions hubs and geographic constraints.

Table 4-7. Volume of Munitions Flow From APF in Each Theater

Theater	Port	Air Base (Destination)	Aggregated Munitions Movement
Southwest Asia	**Ad Dammam**	**PSAB**	
		KKMC	
		Al Jaber	
		Dhahran	
Europe	**Iskenderun**	**Incirlik**	
		Aviano	
		Ramstein	
		Lakenheath	
Northeast Asia	**Apra**	**Andersen**	
		Kadena	
		Kunsan	
KEY			 = 1000 Aggregated Munitions

Based on the sample scenarios used, this model produced logical results in terms of APF movement, munitions volume from the munitions sources available in each theater, and the munitions flow from the ports to the final destinations.

5. Conclusions

This chapter reviews some of the limitations of the munitions movement model, proposes potential improvements for the model, and finally discusses the conclusions that may be drawn from the model.

5.1. Model Limitations

Producing a model that completely represents every aspect of the contingency munitions movement process is beyond the scope of this study. However, there are a number of changes that would enhance this model, and result in a more complete and valuable product. First of all, the inputs for this model are considered known, or deterministic. In any real-world situation, however, there is variability in the factors used by this model. Subsequently, the model should be enhanced to accept and process stochastic inputs for data such as time factors and the number of resources available to transport munitions. Secondly, the model used in this study assumes that all munitions requirements are known at the beginning of each conflict. A time-phased model that coincides with the different phases of actual operational plans (O-Plans) may prove to be more effective. Finally, the model may be improved by incorporating either a preemptive goal programming or a multi-objective programming approach that may be modified depending on the importance of the competing objectives: minimizing delivery time, or minimizing munitions shortages. The current model uses a constant relational cost for munitions shortages and does not take into account the significance of the weapon to the success of the given scenario.

5.2. Suggested Improvements

In addition to the suggested modeling improvements in the previous section, there are some other changes that would streamline data input, and enhance output analysis. Changes to model inputs could be handled easier if there was a database interfaced with the model as opposed to the current spreadsheet format. Currently, when model parameters are added or deleted, all Excel worksheets that contain data related to that parameter need to be manually updated. The input file should be automated to prompt the user to input all applicable data, and then automatically generate the applicable data worksheets. This program should also update the cell ranges to be read from the GAMS program. This would significantly decrease the time associated with modifying model inputs. An automated database could also be used to control the output ranges, so the user would not have to manually update the output ranges each time the input data changes.

5.3. Additional Validation

The model was validated based on notionalized scenarios and expert judgment. A classified study would examine actual scenarios and compare model outputs to operational plans, munitions movement expert opinions, or operational histories.

5.4. Conclusion

The model created in this study optimizes the pre-positioning of the Afloat Pre-positioning Fleet based on the factors and parameters used in the model. In order to meet this objective, the model had to consider factors that would mirror the real-world movement of munitions. As a result, this model investigated a limited number of air bases, ports, STAMP locations, and munitions hubs to provide weapons in response to three different scenarios. All three legs of the mobility triad, airlift, sealift, and pre-positioning, were modeled to move munitions from their respective sources to the proper destinations in order to either minimize overall delivery time, or minimize the total number of munitions shortages at each destination. The scenarios, although not real, are representative of conflicts the USAF may expect to encounter in the near future. The munitions demand data used in the development of this model were notionalized for security reasons.

The intent of this study was to show that a mixed integer program could be used to aid decision makers in determining an optimal strategy for pre-positioning the APF. This study shows, although to a limited capacity, that indeed, the contingency munitions movement process can be modeled, and the results can be used to optimize the location of the APF.

Appendix A

```
*This model finds the min time associated with moving pre-positioned munitions
*from different ships to various requesting air bases.
*
*This model uses three different sources of munitions to meet demand at the
*different destinations:  APF, overseas munitions hubs, and CONUS STAMP locations.
*
*The model reads input from an Excel File, and outputs the results into another Excel
File

$TITLE Prepo Munitions Movement Problem

SETS
      l     prepo locations /R, D, S/
      d     destinations /L, A, R, P, J, D, M, I, G, O, K/
      a     APF ship /1,2,3/
      c     Conflict /MTWS, SSCA, SSCE/
      p     Ports /L, N, I, J, D, O, C, A/
      t     Modes of Tx /1, 2/
      m     munitions type /1 * 8/
      h     Hubs for munitions /Wford, Ram, Dar, Kad/
      s     STAMP locations /1,2/
      k     Airlifters /C5, C130, C17/;

*The following commands read in parameter values from an Excel Spreadsheet
PARAMETER TotInvAPF(m) Total Inventory of Each Munition across all APF Ships
$libinclude xlimport  TotInvAPF Input.xls TotalInvAPF!b3:j4 ;

PARAMETER HubInv(m,h) Inventory of munition type m at Hub H
$libinclude xlimport  HubInv Input.xls HubInv!b3:f11 ;

PARAMETER STAMPInv(m,s) Inventory of munition type m at STAMP location s
$libinclude xlimport  STAMPInv Input.xls STAMPInv!b3:d11 ;

PARAMETER MperISO(m) Total number of each Munitions type fitted into ISO
containers
$libinclude xlimport  MperISO Input.xls MperISO!b3:j4 ;

PARAMETER Mper463L(m) Number of munitions m that fit onto 463L pallet
$libinclude xlimport  Mper463L Input.xls Mper463L!b3:j4 ;

PARAMETER MaxNEW(p) Max NEW restriction listed for each port of debarkation
$libinclude xlimport  MaxNEW Input.xls MaxNEW!b3:j4 ;
```

```
PARAMETER NEWPen(p) Time penalty for violating NEW restrictions at a given port
$libinclude xlimport  NEWPen Input.xls NEWPen!b3:j4 ;

PARAMETER Offld(a,p)  Time to offload ships at each port
$libinclude xlimport  Offld Input.xls Offld!b3:j4 ;

PARAMETER NEWperISO(m) NEW for ISO full of munitions type m
$libinclude xlimport  NEWperISO Input.xls NEWperISO!b3:j4 ;

PARAMETER MunWt(m)  Weight of each Munitions type ISO container in lbs
$libinclude xlimport  MunWt Input.xls MunWt!b3:j4 ;

PARAMETER Wtper463L(m) Weight of 463L when loaded with munition type m
$libinclude xlimport  Wtper463L Input.xls Wtper463L!b3:j4 ;

PARAMETER APFCap(a) Capacity of each APF Ship in terms of ISO containers
$libinclude xlimport  APFCap Input.xls APFCap!b3:e4 ;

PARAMETER APFWt(a)  Capacity of each APF Ship in terms of Weight in lbs
$libinclude xlimport  APFWt Input.xls APFWt!b3:e4 ;

PARAMETER Steam(a,l,p) Time to transport munitions from l to p using APF ship a
$libinclude xlimport  Steam Input.xls Steam!b3:k12 ;

PARAMETER Tx(t,p,d) Time to transport munitions from p to d using tx mode t
$libinclude xlimport  Tx Input.xls Tx!b4:n20 ;

PARAMETER TxTime(t,h,d) Time to transport munitions from p to d using tx mode t
$libinclude xlimport  TxTime Input.xls TxTime!b4:n12 ;

PARAMETER AirTime(k,s,d) Time to transport munitions from s to d using airlifter k
$libinclude xlimport  AirTime Input.xls AirTime!b3:n9 ;

PARAMETER Dem(m,d,c) Demand for each munitions at each location for each conflict
$libinclude xlimport  Dem Input.xls Dem!b3:f91 ;

PARAMETER Pen(m,d,c) Time Penalty for shortages of munitions at each destination
$libinclude xlimport  Pen Input.xls Pen!b4:f92 ;

PARAMETER TxCap(t,p,d) # ISOs that can be moved from p to d using mode t
$libinclude xlimport  TxCap Input.xls TxCap!b4:n20 ;

PARAMETER TxWt(t,p,d) Weight that can be moved from p to d using mode t
$libinclude xlimport  TxWt Input.xls TxWt!b4:n20 ;
```

```
PARAMETER MoveCap(t,h,d) # 463Ls that can be moved from h to d using mode t
$libinclude xlimport  MoveCap Input.xls MoveCap!b4:n12 ;

PARAMETER MoveWt(t,h,d) Weight that can be moved from h to d using mode t
$libinclude xlimport  MoveWt Input.xls MoveWt!b4:n12 ;

PARAMETER CanTx(m,p,d) Equals 1 if OLT Tx is available and 0 otherwise
$libinclude xlimport  CanTx Input.xls CanTx!b3:n67 ;

PARAMETER HubAOR(m,h,d) Equals 1 if d is within Hub's AOR and 0 otherwise
$libinclude xlimport  HubAOR Input.xls HubAOR!b4:n36 ;

PARAMETER AirVol(k,s,d) Volume capacity of airlifter k from s to d
$libinclude xlimport  AirVol Input.xls AirVol!b3:n9 ;

PARAMETER AirWt(k,s,d) Weight Capacity of airlifter k from s to d
$libinclude xlimport  AirWt Input.xls AirWt!b3:n9 ;

VARIABLES
      X(m,p,d,c)        # of munitions of type m moved from l to d for conflict c
      F(m,h,d,c)        # of munitions of type m moved from h to d for conflict c
      ST(m,s,d,c)       # of munitions of type m moved from s to d for conflict c
      Y(a,l,p)          equals 1 if munitions moved from l to port p by APF a and zero ow
      W(a,p)            indicator vbl that equals 1 if APF a is in port p
      TRAN(t,p,d)       # of trips with mode t needed to move munitions from p to d
      AIRLIFT(k,s,d)    # sorties of airlifter k needed to move munitions from s to d
      MOVE(t,h,d)       # of trips with mode t needed to move munitions from f to d
      SHORT(m,d,c)      # of munitions short at d for conflict c
      INV(m,a)          # of munitions stored on APF ship a
      N(p)              equals 1 if NEW restrictions are violated and 0 otherwise
      Z                 total time to move munitions from ship to requesting bases ;

*Following variables are constrained to be greater than or equal to 0
POSITIVE VARIABLES X, F, ST, INV, SHORT, TRAN, MOVE, AIRLIFT;

*Following variables are constrained to equal 0 or 1
BINARY VARIABLES Y, W, N;

*Description of Constraints
EQUATIONS
      TIME                  define obj fn (min total transport time of munitions)
      DEMAND(m,d,c)         satisfy demand for each munitions at each site
      IND(p)                turns on indicator if APF ship moves to port
      STOCK(m,a,p,d)        determine inventory of APF ships
      STAMPSUPPLY(m,s)      ensure STAMP supply is not exceeded
```

HUBSUPPLY(m,h)	ensure HUB supply is not exceeded
SUPPLY(m)	ensure ships inventory don't exceed available munitions
DEMD(m)	Meet demand
TRANCAP(d)	ensure transportation volume capacity not exceeded (p to d)
TRANWT(d)	ensure transportation weight capacity not exceeded (p to d)
TRANCAP2(m,h,d)	ensure transportation volume capacity not exceeded (h to d)
TRANWT2(m,h,d)	ensure transportation weight capacity not exceeded (h to d)
AIRCAP(d)	ensure airlifters vol capacity not exceeded
AIRWGT(d)	ensure airlifters weight capacity not exceeded
CAPACITY(a)	ensure ship's storage capacity not exceeded
WTCAP(a)	ensure ship's weight capacity not exceeded
LOCATION(l,p)	only 1 ship at each location
LOCATION1(a,p)	only 1 ship at each location
PORT(a)	Ensures each ship only moves to one port
LINK(a,p)	Links W and Y vbls
LINK2(p,d)	Links W and TRAN vbls
NEW(p)	ensure ships don't exceed NEW restrictions in port;

```
*Objective Function:  Minimize overall munitions delivery time
TIME..
Z =E= SUM((a,l,p), Steam(a,l,p)*Y(a,l,p)) + SUM((m,d,c), Pen(m,d,c)*SHORT(m,d,c))
+ SUM((t,p,d), Tx(t,p,d)*TRAN(t,p,d)) + SUM((a,p), W(a,p)*Offld(a,p))+ SUM(p,
N(p)*NEWPen(p)) + SUM((k,s,d), AIRLIFT(k,s,d)*AirTime(k,s,d)) + SUM((t,h,d),
MOVE(t,h,d)*TxTime(t,h,d));

*Constraints:
DEMAND(m,d,c)..
SUM((p), X(m,p,d,c)*CanTx(m,p,d))+ SUM(h, F(m,h,d,c)*HubAOR(m,h,d)) +
SUM(s, ST(m,s,d,c)) + SHORT(m,d,c) =e= Dem(m,d,c);

IND(p)..
SUM((m,d,c), X(m,p,d,c)) =l= SUM((m,a,d), W(a,p)*CanTx(m,p,d)*999999);

STOCK(m,a,p,d)..
SUM(c, X(m,p,d,c)) =l= INV(m,a)*CanTx(m,p,d);

STAMPSUPPLY(m,s)..
SUM((d,c), ST(m,s,d,c)) =l= STAMPInv(m,s);
HUBSUPPLY(m,h)..  SUM((d,c), F(m,h,d,c)) =l= HubInv(m,h);

SUPPLY(m)..
SUM(a, INV(m,a)) =e= TotInvAPF(m);

DEMD(m)..
```

```
SUM(a, INV(m,a))+ SUM((h,d,c), F(m,h,d,c)*HubAOR(m,h,d)) + SUM((s,d,c),
ST(m,s,d,c)) + SUM((d,c), SHORT(m,d,c)) =g= SUM((d,c),Dem(m,d,c));

TRANCAP(d)..
SUM((m,p,c), X(m,p,d,c)/MperISO(m)) =l= SUM((t,p), TxCap(t,p,d)*TRAN(t,p,d));

TRANWT(d)..
SUM((m,p,c), X(m,p,d,c)/MunWt(m)) =l= SUM((t,p), TxWt(t,p,d)*TRAN(t,p,d));

TRANCAP2(m,h,d)..
SUM((c), F(m,h,d,c)/Mper463L(m)) =l= SUM((t), MoveCap(t,h,d) *MOVE(t,h,d)
*HubAOR(m,h,d));

TRANWT2(m,h,d)..
SUM((c), F(m,h,d,c)/Wtper463L(m)) =l= SUM((t), MoveWt(t,h,d)*MOVE(t,h,d)
*HubAOR(m,h,d));

AIRCAP(d)..
SUM((m,s,c), ST(m,s,d,c)/Mper463L(m)) =l= SUM((k,s), AirVol(k,s,d)*
AIRLIFT(k,s,d));

AIRWGT(d)..
SUM((m,s,c), ST(m,s,d,c)/Wtper463L(m)) =l= SUM((k,s), AirWt(k,s,d)*
AIRLIFT(k,s,d));

CAPACITY(a)..
SUM((m), INV(m,a)/MperIso(m)) =l= SUM(p, APFCap(a)*W(a,p));

WTCAP(a)..
SUM(m, INV(m,a)*MunWt(m)/MperISO(m)) =l= APFWt(a);

LOCATION(l,p)..
SUM(a, Y(a,l,p)) =l= 1;

LOCATION1(a,p)..
SUM(l, Y(a,l,p)) =l= 1;

PORT(a)..
SUM(p, W(a,p)) =e= 1;

LINK(a,p)..
SUM(l, Y(a,l,p)) =e= W(a,p);

LINK2(p,d)..
SUM((t), TRAN(t,p,d)) =l= SUM((m,a), W(a,p)*CanTx(m,p,d)*10);
```

```
NEW(p)..
SUM((m,d,c), X(m,p,d,c)*NEWperISO(m)/MperISO(m))=l=MaxNEW(p) +
N(p)*999999999;

MODEL    Prepo /ALL/;
OPTIONS  OPTCR=.01, ITERLIM=1000000, MIP=XA ;
SOLVE    Prepo USING MIP MINIMIZING Z;

DISPLAY  X.L , X.M;

*The following commands output model results into an Excel Spreadsheet

$libinclude xlexport X.l Output.xls APF_Munitions!a4:f196
$libinclude xlexport Y.l Output.xls Prepo_Port!a4:e13
$libinclude xlexport F.l Output.xls Hub_Munitions!a4:f164
$libinclude xlexport ST.l Output.xls STAMP_Munitions!a4:f116
$libinclude xlexport SHORT.l Output.xls Shortages!a4:f64
$libinclude xlexport INV.l Output.xls APF_Inventory!a4:d12
```

Appendix B

This appendix lists some of the important input parameters used for this model.

B.1. Munitions Demand for MTWS

Scenario	Destination	Munition	Demand
MTWS	Dhahran	1	150
		2	1000
		3	500
		4	0
		5	3000
		6	100
		7	2200
		8	500
	Incirlik	1	100
		2	200
		3	0
		4	100
		5	500
		6	0
		7	0
		8	0
	Al Jaber	1	100
		2	500
		3	150
		4	0
		5	3500
		6	1800
		7	0
		8	2500
	KKMC	1	0
		2	0
		3	0
		4	0
		5	100
		6	1500
		7	0
		8	1000
	PSAB	1	500
		2	2000
		3	750
		4	500
		5	1500
		6	350
		7	800
		8	15

B.2. Calculated Munitions Inventory Levels for Each APF Ship

APF Ship	Munitions Type	Inventory Level
1	1	402.33
	2	806.667
	3	786
	4	133.33
	5	3500
	6	1800
	7	393.33
	8	901
2	1	402.33
	2	806.667
	3	750
	4	133.33
	5	3500
	6	7082
	7	393.33
	8	901
3	1	402.33
	2	806.667
	3	750
	4	133.33
	5	8372
	6	1800
	7	393.33
	8	901

B.3. Munitions Inventory for Each Hub

Munitions Type	RAF Welford	Ramstein	Darby	Kadena
1	100	150	150	150
2	200	300	200	300
3	200	300	200	300
4	30	48	48	50
5	1200	1800	1800	2000
6	1000	1500	1500	1800
7	100	150	150	200
8	200	300	300	350

B.4. Munitions Inventory for Each STAMP Location

Munitions Type	Medina	Hill
1	100	50
2	100	0
3	100	0
4	100	50
5	350	300
6	300	200
7	120	0
8	250	100

Appendix C

Additional Scenario

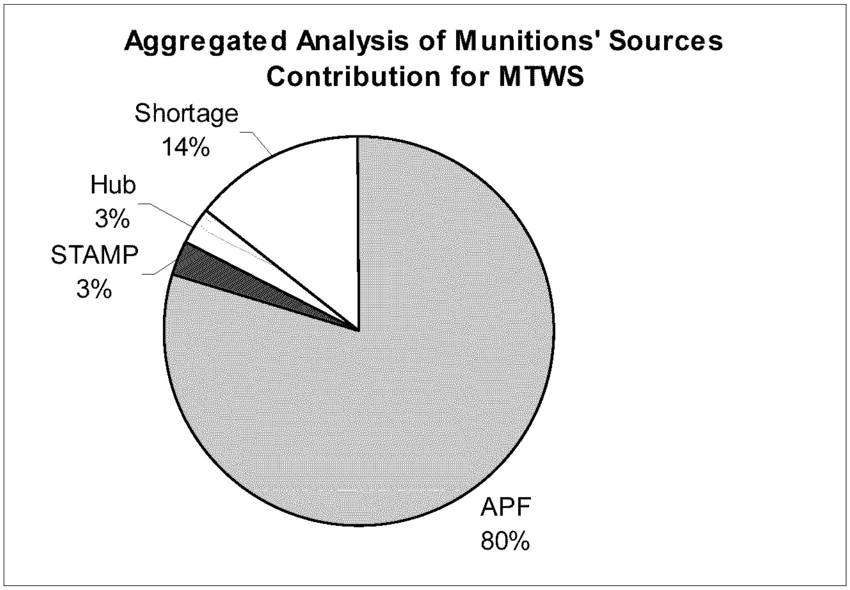
This appendix includes the results of one additional scenario to further validate the model. The likelihood of the USAF being involved in a MTW scenario in conjunction with simultaneous SSCs in three different theaters is fairly remote. Therefore, the model was run to determine the optimal munitions flow for the MTWS scenario, only.

APF Movement

For this scenario, two of the ships were pre-positioned in the Indian Ocean and the third was pre-positioned in the western Mediterranean. The two ships from the Indian Ocean steamed to Ad Dammam and Al Jubail, Saudi Arabia, respectively. The third ship steamed to Livorno, Italy, where it offloaded a small number of munitions to meet demand at Incirlik AB in Turkey.

Volume of Munitions from Each Source

As in the multiple scenario model run, the APF proved to be by far, the largest source of munitions for this scenario. The APF provided almost 80 percent of the total munitions requirements. The APF could play a larger role because more ships could be allocated to this scenario. Despite an even larger contribution from the APF, the other sources also increased their contributions to the scenario. The munitions hubs in the European theater played a critical role in this scenario. Since the hubs were not relied upon to support a European scenario, they were used to meet demand at Incirlik AB and provided over three percent of the total munitions requirements for this scenario. Similarly, since STAMP was not so heavily taxed by the northeast Asian scenario, it could provide a larger number of munitions in support of this scenario and provided just less than three percent of the total munitions requirements. The remaining 14 percent of munitions shortages were not a result of munitions movement limitations, but simply inventory limitations. The USAF does not own enough precision guided munitions to meet all requirements.



Conclusion

The execution of this additional scenario further validates the capabilities of this model.

Glossary of Acronyms

ACS:	Agile Combat Support
APF:	Afloat Pre-positioning Fleet
CINC:	Command In Chief
CONUS:	Continental United States
CPS:	Combat Pre-positioning Ship
CSL:	CONUS Support Location
DOD:	Department of Defense
EAF:	Expeditionary Air Force
FOL:	Forward Operating Location
GAMS:	General Algebraic Modeling System
GAP:	Global Asset Positioning
HSS:	High Speed Sealifts
ISO:	International Standards Organization
JICM:	Joint Integrated Contingency Model
LPS:	Logistics Pre-positioning Ship
MIP:	Mixed Integer Program
MMP:	Munitions Movement Plan
MPF:	Military Pre-positioning Fleet
MRS:	Mobility Requirements Study
MSC:	Military Sealift Command
MTMC:	Military Transportation Management Command

MTW: Major Theater of War

NCAA: Non-Consumables Annual Analysis

NEW: Net Explosive Weight

O-Plans: Operational Plans

RO/RO: Roll On/Roll Off

SSC: Small Scale Contingency

STAMP: Standard Air Munitions Packages

STRAPP: Standard Tanks, Racks, Adapters, and Pylons Packages

SWA: Southwest Asia

USAF: United States Air Force

WCDO: War Consumables Distribution Objective

WMP: War Mobilization Plan

WRM: War Reserve Materiel

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Vita

Daniel Paul Johnstone was born in Hartford, Connecticut. After graduating from Simsbury High School in 1993, he accepted an Air Force ROTC scholarship to attend the Rochester Institute of Technology, and pursue a degree in Industrial and Manufacturing Engineering.

Daniel graduated from RIT and was commissioned into the United States Air Force as a 2d Lieutenant in May of 1998. After completing Supply/Fuels Officer Training School at Lackland AFB, TX, in 1998, Lt Johnstone was stationed at McConnell AFB in Wichita, KS. While stationed at McConnell, Lt Johnstone served as Officer in Charge of Combat Operations Support, Executive Officer to the 22d Logistics Group Commander, and finally as Commander of the 22d Fuels Management Flight.

In 2000, Lt Johnstone was selected to pursue a Master's of Science degree in Operations Research from the Air Force Institute of Technology at Wright-Patterson AFB, OH. Upon graduation, Lt Johnstone will be assigned to the Air Force Logistics Management Agency (AFLMA) at Gunter AFB, AL.

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14. ABSTRACT The Air Force's ability to deploy, employ, and sustain operations in forward locations is a fundamental key to mission success. An integral part of this strategy is equipment pre-positioning, to include: vehicles, aircraft support, consumable inventory, and munitions. This research focuses on defining and developing a model to aid decision makers with the afloat pre-positioning and deployment of munitions in an effort to ensure that the right weapons are available when, and where needed. This research places a particular focus on the strategic, global pre-positioning of the Afloat Pre-positioning Fleet (APF) in an effort to minimize the overall response time involved with offloading these ships and transporting their cargo to the intended point of use.

The model developed in this study is a mixed integer program that was implemented using the General Algebraic Modeling System (GAMS). The model considers the various aspects of pre-positioning (forward operating locations, Standard Air Munitions Packages, and the APF) in order to optimally locate and configure each APF ship. The methodology for this model was tested and verified using precision-guided munitions data for a number of scenarios.

15. SUBJECT TERMS
Munitions, Prepositioning, Afloat Prepositioning Fleet, Mixed Integer Program

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