Supporting Air and Space Expeditionary Forces

Analysis of Combat Support Basing Options

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RAND PROJECT AIR FORCE

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Prepared for the United States Air Force

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The research reported here was sponsored by the United States Air Force under contract F49642-01-C-0003. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging-in-Publication Data

Supporting air and space expeditionary forces : analysis of combat support basing options / Mahyar A. Amouzegar ... [et al.].
p. cm.
"MG-261."
Includes bibliographical references.
ISBN 0-8330-3675-0 (pbk.)
1. Air bases, American—Foreign countries. 2. United States. Air Force—Supplies and stores. 3. United States. Air Force—Foreign service. 4. Airlift, Military—United States. I. Amouzegar, Mahyar A.

UG633.S8535 2004
358.4'1621'0973—dc22

2004019357

Published 2004 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
201 North Craig Street, Suite 202, Pittsburgh, PA 15213-1516
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Preface

This work evaluates a set of global forward support location (FSL) options for storing war reserve materiel (WRM). These option packages or "portfolios" have differing numbers and types of FSLs, e.g., land-based or afloat, and have differing allocations of WRM at the alternative sites. Evaluations of these packages address the effectiveness and efficiency of the options in meeting a wide variety of potential scenarios. In this monograph, we present capability-based analytic tools to evaluate the tradeoffs between various FSL options. A central element of our analytic framework is an optimization model that allows us to select the "best" mix of land- and sea-based FSLs for a given set of operational scenarios. Our formulation minimizes the peacetime costs for supporting training and deterrent exercises while accounting for the throughput and storage capacity necessary to support a range of contingency operations over several time periods. This monograph should be of interest to logisticians, operators, and mobility planners throughout the Department of Defense, especially those in the Air Force.

This research, conducted in the Resource Management Program of RAND Project AIR FORCE, is sponsored by the Air Force Deputy Chief of Staff for Installations and Logistics (AF/IL).

During the past six years, the RAND Corporation has studied options for configuring an Agile Combat Support (ACS) system that would enable the Air and Space Expeditionary Force (AEF) goals of rapid deployment, immediate employment, and uninterrupted sustainment from a force structure located primarily within the Conti-

nental United States (CONUS). This monograph is one of a series of RAND reports that address ACS options.

Other publications issued as part of the Supporting Air and Space Expeditionary Forces series include:

- *An Integrated Strategic Agile Combat Support Planning Framework*, Robert S. Tripp et al. (MR-1056-AF). This report describes an integrated combat-support planning framework that may be used to evaluate support options on a continuing basis, particularly as technology, force structure, and threats change.
- *New Agile Combat Support Postures*, Lionel Galway et al. (MR-1075-AF). This report describes how alternative resourcing of forward operating locations (FOLs) can support employment timelines for future AEF operations. It finds that rapid employment for combat requires some prepositioning of resources at FOLs.
- *An Analysis of F-15 Avionics Options*, Eric Peltz et al. (MR-1174-AF). This report examines alternatives for meeting F-15 avionics maintenance requirements across a range of likely scenarios. The authors evaluate investments for new F-15 Avionics Intermediate Shop test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at FSLs, or performing all maintenance at the home station for deploying units.
- *A Concept for Evolving to the Agile Combat Support/Mobility System of the Future*, Robert S. Tripp et al. (MR-1179-AF). This report describes the vision for the ACS system of the future based on individual commodity study results.
- *Expanded Analysis of LANTIRN Options*, Amatzia Feinberg et al. (MR-1225-AF). This report examines alternatives for meeting Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) support requirements for AEF operations. The authors evaluate investments for new LANTIRN test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at FSLs,

or performing all maintenance at CONUS support hubs for deploying units.

- *Lessons From the Air War over Serbia*, Amatzia Feinberg et al. (MR-1263-AF). This report describes how the Air Force's ad hoc implementation of many elements of an expeditionary ACS structure to support the air war over Serbia offered opportunities to assess how well these elements actually supported combat operations and what the results imply for the configuration of the Air Force ACS structure. The findings support the efficacy of the emerging expeditionary ACS structural framework and the associated but still-evolving Air Force support strategies. (This report is for official use only.)
- *Alternatives for Jet Engine Intermediate Maintenance*, Mahyar A. Amouzegar et al. (MR-1431-AF). This report evaluates the manner in which Jet Engine Intermediate Maintenance (JEIM) shops can best be configured to facilitate overseas deployments. The authors examine a number of JEIM support options, which are distinguished primarily by the degree to which JEIM support is centralized or decentralized. See also *Engine Maintenance Systems Evaluation (En Masse): A User's Guide*, Amouzegar and Galway (MR-1614-AF).
- *A Combat Support Command and Control Architecture for Supporting the Expeditionary Aerospace Force*, James Leftwich et al. (MR-1536-AF). This report outlines the framework for evaluating options for Combat Support Execution Planning and Control. The analysis describes the Combat Support Command and Control operational architecture as it is now, and as it should be in the future. It also describes the changes that must take place to achieve that future state.
- *Reconfiguring Footprint to Speed Expeditionary Aerospace Forces Deployment,* Lionel A. Galway et al. (MR-1625-AF). This report develops an analysis framework—as a footprint configuration—to assist in devising and evaluating strategies for footprint reduction. The authors attempt to define footprint and to establish a way to monitor its reduction.

- *Analysis of Maintenance Forward Support Location Operations,* Amanda Geller et al. (MG-151-AF). This report discusses the conceptual development and recent implementation of maintenance forward support locations (also known as Centralized Intermediate Repair Facilities [CIRFs]) for the United States Air Force. The analysis focuses on the years leading up to and including the AF/IL CIRF test, which tested the operations of centralized intermediate repair facilities in the European theater from September 2001 to February 2002.
- *Supporting Air and Space Expeditionary Forces: Lessons from Operation Enduring Freedom,* Robert S. Tripp et al., (MR-1819-AF). This report presents an analysis of combat support experiences associated with Operation Enduring Freedom and compares those experiences with those associated with Operation Allied Force.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is conducted in four programs: Aerospace Force Development; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine.

Additional information about PAF is available on our Web site at http://www.rand.org/paf.

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Summary

Background

The Air Force is committed to the Air and Space Expeditionary Force (AEF) concept and the transformation needed to enable the Air Force to project power quickly to any region of the world. Forward positioning of heavy war reserve materiel (WRM) resources in a well-chosen forward support location (FSL) posture is central to that concept. The focus of this report is on the presentation and discussion of an analytic framework that can be used to evaluate alternative FSL basing and transportation options for use in assessing WRM storage options in an uncertain world.

The presentation of this framework is important because it addresses how to assess alternative options in terms of the relevant programming costs. This formulation minimizes FSL operating, construction, and transportation costs associated with meeting training and deterrent exercises needed to demonstrate the U.S. military's capability to repeatedly project power to important regions around the world, thereby deterring aggression, while maintaining the FSL storage capacity and throughput necessary to engage in conflicts should deterrence fail. This concept is based on the notion that the United States can no longer know, with a high degree of accuracy, what nation, combination of nations, or non-state actors will pose a threat to vital U.S. interests. Consequently, the U.S. Air Force must be ready to deploy capable forces quickly across a wide range of potential scenarios.

Selecting Forward Support Locations to Provide Deterrence and to Meet Contingency Requirements

The aim of this work is to investigate FSL postures that are capable of meeting the WRM throughput requirements needed to win major regional conflicts and small-scale contingency operations, which are discussed in the Department of Defense (DoD) Strategic Planning Guidance and Defense Planning Scenarios. Perhaps more important, this study also addresses FSL postures that can act to deter aggression and coercion.

The FSL options should be selected from a feasible set of options in such a way that the costs of supporting deterrent exercises are minimized, while assuring that the selected FSLs have the storage capacity and throughput needed to meet potential future contingencies, if deterrence should fail. Thus, resources are programmed to support peacetime training and deterrent exercises and to support contingency operations should they eventuate. We do not include the cost of actually conducting contingency operations in our model. The reason for not including that cost is that Congress provides supplemental funding for conducting wartime or contingency operations if and when they occur; those costs are not included in budgeting for combat support locations. This is consistent with programming guidance and historical perspectives.[1]

Analysis Approach

In order to evaluate and select alternative forward basing options, we have developed capability-based models that can assess the cost of

[1] In the past, the United States would program for defense resources that would prevent nuclear war and provide for conventional forces to be used to defeat the Soviet Union and protect Korea from invasion from the north, with potential intervention by China to support the North Koreans. The programming assumptions were that these resources would be used once to defeat the enemy. It was assumed in programming for resources that contingency operations, if they were to arise, could be dealt with using a portion of the resources that were programmed for major theater wars.

various portfolios of forward support locations (FSLs) for meeting a wide variety of global force projection scenarios. The Department of Defense has made capability-based planning one of the core tenets of defense policy. This policy is a shift from a "threat-based" model (specific plans for a specific adversary) that had dominated defense planning in the latter part of the last century to a model in which the focus is on the capability of a potential adversary.[2]

In this capability-based approach, we examine the costs of alternative support basing options for the same levels of performance against a variety of deployment scenarios. The analyses show how various FSL options would perform under various degrees of stress to combat support while taking into account infrastructure richness, basing characteristics, deployment distances, strategic warning, and reconstitution conditions. These scenarios would include potential military and non-military operations in the Near East, the Asia-Pacific region, Central Asia, South America, Europe, and Northern and sub-Saharan Africa. In examining potential scenarios, we make a departure from Cold War planning and the early post-Cold War preparation for two major regional conflicts, and we present the cost surfaces for differing levels of performance across a set of scenarios that can potentially take place over a multiple-year time horizon of succeeding engagements and reconstitutions in a variety of geographical areas with differing degrees of operational intensity.

We coined the term *m-Period-n-Scenario* (MPNS) to describe a planning methodology that is in line with the expected deployment requirements, for which the Air Force must prepare to meet the high demand of multiple engagements of various sizes, with some (e.g., drug interdictions) occurring more than once in a short time horizon. This MPNS concept allows us to evaluate the requirements of several scenarios to determine the stresses that they place on WRM resources. These scenarios must be sequenced in order to determine their interdependency and their effect on the combat support re-

[2] Department of Defense, 2001.

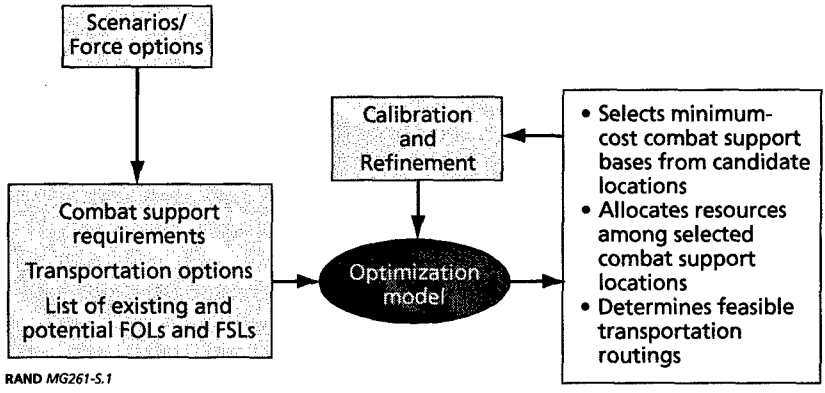
sources as well as to determine the maximum demands that a set of facilities must satisfy over the time period considered.

After the desired requirements in terms of combat support resources are determined, our optimization model selects a set of FSL locations that would minimize the peacetime costs of supporting deterrence against aggression while being able to support major regional conflicts should deterrence fail. This tool—the optimization model—essentially allows for the analysis of various "what-if" questions and assesses the solution set in terms of resource costs for differing levels of combat support capability.

There are several steps in our analytic approach (see Figure S.1):

1. A diverse set of scenarios that would stress the combat support system is selected. These scenarios would include small-scale humanitarian operations, continuous force presentation to deter aggression, and major regional conflicts. Each scenario would have a force mix of various weapon systems.
2. The scenarios and the force options drive the requirements for WRM, such as base operating support equipment, vehicles, and munitions.
3. These requirements, the potential FSLs and FOLs, and the options for transportation (e.g., allowing sealift or not) serve as the inputs to the optimization model.
4. The optimization model selects the FSL locations that minimize the FSL facility operating and transportation costs associated with planned operations, training missions, and deterrent exercises that take place over an extended time horizon and satisfy time-phased demands for WRM commodities at FOLs. The model also optimally allocates the programmed WRM resources and commodities to those FSLs. The model also computes the type and the number of transportation vehicles required to move the materiel to the FOLs. The result is the creation of a robust transportation and allocation network that connects a set of disjointed FSL and FOL nodes.

Figure S.1
Overview of the Analytic Process for the Optimization Model



5. The final step in our approach is to refine and recalibrate the solution set by applying political, geographical, and vulnerability constraints. This allows for reevaluation and reassessment of the parameters and options.

The end result of this analysis is a portfolio containing alternative sets of FSL postures, including allocations of WRM to the FSLs, which can then be presented to decisionmakers. This portfolio will allow policymakers to assess the merits of various options from a global perspective.

Combat Support Factors

Some of the important factors and parameters that affect the selection of a forward support location and how we address them are discussed next.

- **Airlift and airfield throughput capacity.** One of the major factors in selecting a forward support location is its transport capability and capacity. The parking space, the runway length and

width, the fueling capability, and loading and offloading equipment are all important factors in selecting an airfield to support an expeditionary operation. The maximum on ground (MOG) capability, for example, directly contributes to the diminishing return of deployment time as a function of available airlift. In other words, increasing the number air transporters by itself may not improve the deployment timelines (see page 22).

- **Forward operating location distance.** Distance from FSLs to FOLs can impede expeditionary operations. As the number of airlift aircraft increases, the difference in deployment time caused by distance becomes less pronounced. Adding more airlifters to the system will reduce the deployment time, albeit at a diminishing rate until the deployment time levels off due to MOG constraints (see page 23).
- **Base vulnerability.** In selecting regions and locations for forward support locations, we must consider the vulnerability of the candidate locations to attacks from adversaries in future conflicts. Forward support locations could be primary targets for adversaries with long-range fixed-wing aircraft, cruise missiles, or theater ballistic missiles (TBMs), as well as for special operations forces or terrorists (see page 25).
- **Base access.** This is an important issue that deserves careful consideration and one that must be addressed before each conflict or operation. Rather than taking the approach of eliminating some sites a priori due to political access problems, we let the model select the most desirable sites based on cost minimization. We then can "force" specific sites out of the solution set if they present access issues, and thereby provide the economic cost of restricting the solution to politically acceptable sites (see page 26).
- **Modes of transportation.** There are several advantages to using sealift or ground transportation in place of, or in addition to, airlift. Allowing for alterative modes of transportation might bring in some FSLs to the solution set that might have otherwise been deemed infeasible or too costly. Ships have a higher hauling capacity than any aircraft and can easily carry outsized or su-

per-heavy equipment. In addition, ships do not require overflight rights from any foreign government. Two attractive options are the Fast Sealift Ships (FSS), which have a speed of nearly 30 knots (versus 16 knots for conventional container ships) and a range of about 12,000 nautical miles, and the High-Speed Sealifts (HSS), which can achieve speeds of more than 60 knots lightship (400 metric tons). Trucks are, of course, cheaper and readily available in most locations through local contractors. Trucks do not require specialized airfield and, although they are much slower than aircraft, under certain circumstances they could contribute greatly to the delivery of materiel, especially when they are used in conjunction with airlift (see page 30).

Preliminary Results

To illustrate the MPNS planning concept and to demonstrate the potential of the optimization model, we present the results of an analysis dealing with collocating combat support materiel for the Army and the Air Force. Although this analysis highlights the value of the Eastern European basing as well the advantage of mixed modes of transportation, the results are preliminary and are for illustrative purposes only. In this analysis, we use the optimization model to select the locations of a set of FSLs that would be capable of meeting the storage and throughput requirements of a wide variety of scenarios at a minimum cost. The objective function minimizes the cost of the total number of exercises necessary to deter aggression while developing a capability to meet a potential regional conflict.

We assume that a small AEF package of fighters, bombers, refuelers, and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) assets is being deployed in various annual exercise and deterrence missions over the next ten years. The Army also participates in some of these exercises with a portion (a battalion size) of its Stryker Brigade Combat Team (SBCT). Table S.1 illustrates the various deployments and locations examined.

Table S.1
Deployment Location and Package

FOL	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Baghdad	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S
Bagram	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S
Cairo	A/S	A/S		A/S		A/S	A/S		A/S	
Incirlik	A/S	A/S		A/S		A/S	A/S		A/S	
Bishkek-Manas	A		A		A	A		A		A
Amman	A		A		A	A		A		A

NOTE: A=AEF; S = Stryker.

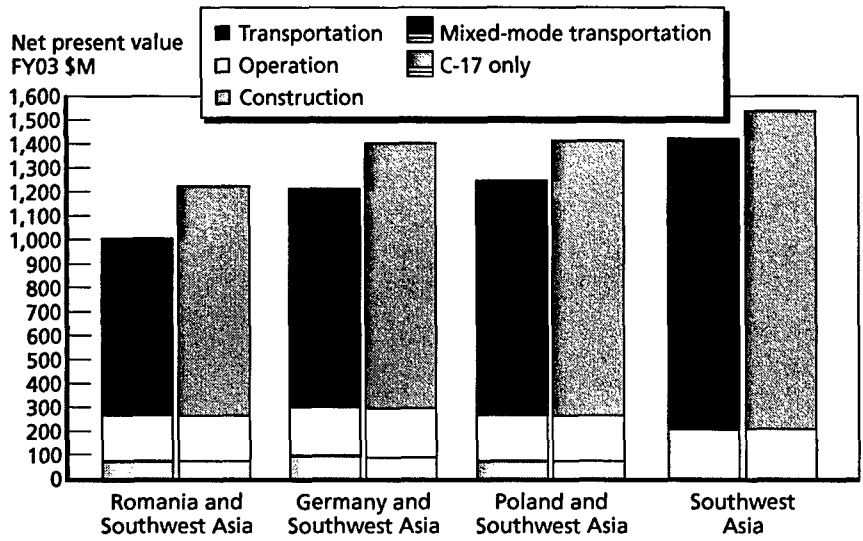
The potential FSLs that would support these deterrence exercises are Al Udeid (Qatar), Royal Air Force (RAF) Fairford (UK), Ramstein Air Base (AB) (Germany), Warsaw (Poland), and Constanta (Romania). The model was solved to determine the minimum cost set of FSLs that would meet all demand, achieving full operating capability within 12 days.

Figure S.2 presents the minimum cost attained for a mixed-mode transportation (air, sea, and land) given the 12-day full operation capability requirement (i.e., transporting all the combat support equipment and personnel). We also computed the air-only (C-17 only) transportation cost to show the cost of using a premium asset in case of a situation in which land or sea transportation is restricted. The minimum-cost solution has FSLs located in Southwest Asia (SWA) and in Romania, at a cost of $1 billion, a savings of slightly more than $200 million over the C-17-only solution (see page 60).

Although the Romania-SWA pairing is an optimal solution, there may be political or military factors that might prevent using Romania as an FSL site. By "forcing off" Constanta from the solution option, the model can show the economic cost of precluding the placement of an FSL in Romania. The second least-expensive option was to open FSLs in SWA and Germany (Poland and SWA provide a nearly identical solution). The savings realized through the use of multiple modes of transportation are greatly dependent upon the geography of the FSL posture in question. It is interesting to note that the Romania-SWA pairing offers about the same cost for air-only transportation (a premium choice) as the mixed—mode transportation for the Germany-SWA or Poland-SWA pairing (see page 60).

In addition to its economic savings, the Romania-SWA FSL posture also affords substantial savings in the use of strategic airlift to support these peacetime training missions. The use of trucks saved 250 C-17 sorties per year, while HSS saved an additional 150 C-17 sorties per year, a significant savings for a high-priority resource (see page 60).

Figure S.2
Cost of a Mixed-Transportation Strategy Versus an Air-Only Strategy



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Conclusions and Future Research

A global basing strategy can affect the ability to quickly deploy materiel in support of expeditionary forces. Prepositioning WRM at forward support locations reduces the distance between the points of storage, the FSLs, and the potential points of use—the FOLs. Deployment distances affect deployment times, but they are not the only factors. The number of airlifters and the quality of airfield infrastructure (e.g., MOG) interact with the flying distance to determine deployment time. As the number of airlifters increases, the effect of distance on deployment time becomes less pronounced, and the restriction on airfield capacity becomes more pronounced. However, one of the major tradeoffs is between the throughput capacity of the airfields and the number of airlifters. Finally, serious consideration must be given to a mixed-mode transport strategy.

FSL postures that are proposed without accounting for transport constraints may prove inferior once these transport considerations are included in the analysis. Our analytic approach offers a rational approach for selecting an appropriate FSL posture that is capable of meeting a wide range of potential scenarios.

Presently, we are collecting data and performing analysis of global basing options to recommend a set of alternative forward support locations that could support various types of deployment scenarios.

Acknowledgments

Many persons inside and outside the Air Force provided valuable assistance and support to our work. We thank Lieutenant General Michael Zettler and Ms. Susan O'Neal for initiating this study and for their ongoing support.

We are grateful to the project officers Major General Craig Rasmussen, AF/ILG, and Colonel Connie Morrow, AF/ILGX. At PACAF, Brigadier General Art Morrill, AF/ILP (formerly at PACAF/LG), and Colonel Russell Grunch, PACAF/ALOC, provided tremendous assistance in our data collection. At United States Air Forces in Europe (USAFE), we were fortunate enough to have great support from the USAFE/CC and his staff. In particular we would like to thank General Gregory Martin, AFMC/CC (formerly USAFE/CC); Brigadier General Dave Gillett, USAFE/LG; Colonel Gregory Foraker, USAFE/LGW; Colonel Charles Weiss, USAFE/LGO; Colonel Mark Jones, USAFE/LGX; Major Maria Garcia, USAFE/LGX; Captain Steven Sanders, USAFE/LGOPW; CMSgt John Hough, USAFE/LGWC; CMSgt Duane Mackey, USAFE/LGMA; and MSgt John Daigle, USAFE/LGWC. We also benefited from conversations with Major General Robert Elder CENTAF/CV; Major Dennis Long, CENTAF/A4; Colonel Duane Jones, CENTAF/A4; Lt Colonel Robert Michael Cleary, AF/ILGV; Lt Colonel Pat "Ten-Watt" Wathen, AF/XOOW; Lt Colonel Jeffrey W. Neuber, Air Force Logistics Management Agency (AFLMA)/LGX; Captain Joseph Skipper, AFLMA/LGX; Mr. Bob Lutz, DynCorp; and Mr. John Metzger, ACC/LGXW. In addition,

we thank Wing Commander Mark Leatham of the Royal Australian Air Force, who is presently serving at AF/ILI.

We benefited greatly during our project from the comments and constructive criticism of many RAND colleagues, including (in alphabetical order) Susan Bohandy, John Drew, Jim Masters, Patrick Mills, Don Snyder, and Tom Szayna. We also benefited from careful reviews by Rachel Rue and Christopher Paul.

As always, the analysis and conclusions are the responsibility of the authors.

Acronyms

AB	Air Base
a/c	Aircraft
ACL	Allowable Cabin Load
ACS	Agile Combat Support
ACN	Aircraft Classification Number
AEF	Air and Space Expeditionary Force
AEW	Air and Space Expeditionary Wing
AFB	Air Force Base
AFIL	Air Force Deputy Chief of Staff for Installations and Logistics
AFLMA	Air Force Logistics Management Agency
AF/XOX	Air Force Plans and Programs
AMC	Air Mobility Command
ANZUS	Australia-New Zealand-United States Partnership
AOR	Area of Responsibility
AWACS	Airborne Warning and Control System
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBP	Capability-Based Planning
CCDoTT	Center for Commercial Deployment of Transportation Technologies

CENTAF	U.S. Central Command Air Forces
CENTCOM	U.S. Central Command
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CIRF	Centralized Intermediate Repair Facility
CONUS	Continental United States
CRAF	Civil Reserve Air Fleet
CSC2	Combat Support Command and Control
CSL	Continental U.S. Support Location
DoD	Department of Defense
DPG	Defense Planning Guidance
EU	European Union
EUCOM	U.S. European Command
FOC	Full Operating Capability
FOL	Forward Operating Location
FSL	Forward Support Location
FSS	Fast Sealift Ships
GAMS	General Algebraic Modeling System
HSS	High-Speed Sealift
INCAT	International Catamaran
IOC	Initial Operating Capability
ISR	Intelligence, Surveillance, and Reconnaissance
JFAST	Joint Flow Analysis System for Transportation
JSTARS	Joint Surveillance Target Attack Radar System
LANTIRN	Low-Altitude Navigation and Targeting Infrared for Night
LCN	Load Classification Number
MAP	Membership Action Plan
MARAD	Maritime Administration
MIP	Mixed-Integer Programming

MOG	Maximum on Ground
MSC	Military Sealift Command
MPNS	m-Period-n-Scenario
MTW	Major Theater War
NATO	North Atlantic Treaty Organization
NEO	Noncombatant Evacuation Operation
nm	Nautical Mile(s)
OAF	Operation Allied Force
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PAF	Project Air Force
pax	Passenger
PCN	Pavement Classification Number
RAF	Royal Air Force
RO/RO	Roll-On/Roll-Off
RRDF	Roll-On/Roll-Off Discharge Facility
SOF	Special Operations Forces
SBCT	Stryker Brigade Combat Team
SEATO	Southeast Asia Treaty Organization
SWA	Southwest Asia
START	Strategic Tool for the Analysis of Required Transportation
SBCT	Stryker Brigade Combat Team
TBM	Theater Ballistic Missile
UK	United Kingdom
USAF	United States Air Force
USAFE	United States Air Forces in Europe
USTRANSCOM	United States Transportation Command
UTC	Unit Type Code
UTE	Utilization

VMB	Virtual Military Base
WRM	War Reserve Materiel

CHAPTER ONE

Introduction

The end of the Cold War and the associated realignment of power centers placed the United States and its allies in a new environment with vastly different security challenges than the one faced only a decade earlier. The early euphoria of the end of the Cold War was soon replaced with the realization that the United States, with the possible support of allied coalitions, would be expected to carry a substantial portion of security and peacekeeping responsibilities around the globe.[1] In today's environment, U.S. forces, and in particular the U.S. Air Force, have been called upon to make numerous overseas deployments, many on short notice, using downsized Cold War legacy force and support structures. The forces have had to satisfy a wide range of mission requirements associated with peacekeeping and humanitarian relief, while maintaining the capability to engage in major combat operations such as those associated with operations over Iraq, Serbia, and Afghanistan. A recurring challenge facing the post–Cold War Air Force has been its increasing frequency of deployments to increasingly austere locations.[2]

[1] For example, in fiscal year 1999, U.S. Air Force (USAF) operations included 38,000 sorties associated with Allied Force; 19,000 sorties to enforce the no-fly zones in Iraq; and about 70,000 mobility missions to more than 140 countries (see Sweetman, 2000). As of August 2003, of the Army's 33 combat brigades, 16 are operating in Iraq and, only about 7 percent of the coalition soldiers in Iraq are non-American.

[2] For a discussion of Air Mobility Command deployments from 1992–2000, see Brunkow and Wilcoxson, 2001.

U.S. defense policymakers can no longer plan for a particular scenario in a specific region of the world as the geopolitical divide of the last century has been replaced with a security environment that is more volatile. One of the many lessons of the past decade has been the unpredictability of the nature and the location of the conflicts. In the conflict in Serbia, the U.S. and coalition Air Forces in Operation Allied Force (OAF) played a major role in driving the Serbian forces from Kosovo. A common thought of the day was that all future conflicts would be air dominated.

The events of September 11, 2001, and the consequent U.S. reprisal against the Al-Qaeda in Afghanistan—Operation Enduring Freedom (OEF)—reemphasized the importance of asymmetric warfare and the fundamental role of Special Forces. These events, however, have not lessened the need for a powerful and agile aerospace force as the United States Air Force (USAF) flew long-range bombers to provide close air support to Special Operations Forces working with indigenous resistance ground forces in Afghanistan, far from existing U.S. bases. In Operation Iraqi Freedom (OIF), the U.S. Air Force played a substantial role throughout the conflict, from its initial role to suppress and disable the Iraqi command and control and the air defense system, to providing close air support in urban environments.[3]

Creation of the Air and Space Expeditionary Force

To meet current and anticipated challenges, the Air Force has developed an Air and Space Expeditionary Force (AEF) concept that has two primary goals. The first goal is to improve the ability to deploy quickly from the Continental U.S. (CONUS) in response to a crisis, commence operations immediately on arrival, and sustain those operations as needed. The second goal is to reorganize to improve readiness, better balance deployment assignments among units, and

[3] Tripp et al., 2003a and 2003b.

reduce uncertainty associated with meeting deployment requirements. The underlying premise is that rapid deployment from CONUS and a seamless transition to sustainment can substitute for an ongoing U.S. presence in theater, greatly reducing or even eliminating deployments the Air Force would otherwise stage for the purpose of deterrence.

To implement the AEF concept, the Air Force created ten Aerospace Expeditionary Forces,[4] each comprising a mixture of fighters, bombers, and tankers. These ten AEFs respond to contingencies on a rotating basis: for 90 days, two of the ten AEFs are "on-call" to respond to any crisis needing air power. The "on-call" period is followed by a 12-month period during which those two AEFs are not subject to short-notice deployments or rotations.[5] In the AEF system, individual wings and squadrons no longer deploy and fight as full and/or single units as they did during the Cold War. Instead, each AEF customizes a force package for each contingency consisting of varying numbers of aircraft from different units. This fixed schedule of steady-state rotational deployments promises to increase flexibility by enabling the Air Force to respond immediately to any crisis with little or no effect on other deployments.

The dramatic increase in deployments from CONUS, combined with the reduction of Air Force resource levels that spawned the AEF concept, have equally increased the need for effective combat support.[6] Because combat support resources are heavy and constitute a large portion of the weight of deployments (as shown in Figure 1.1),

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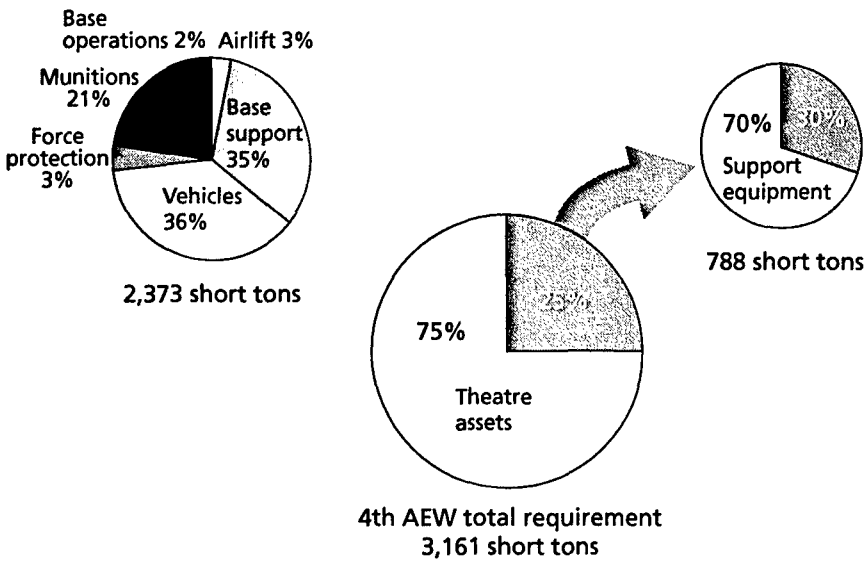
[4] Henceforth, when it is clear from the context, we will use AEF to represent both the concept and the force package.

[5] However, for many high-demand fields such as military police, the 90-day rotation has not been realized.

[6] Air Force Doctrine defines "combat support" to include "the actions taken to ready, sustain, and protect aerospace personnel, assets, and capabilities through all peacetime and wartime military operations."

Figure 1.1
Support Footprint for Air and Space Power Is Substantial



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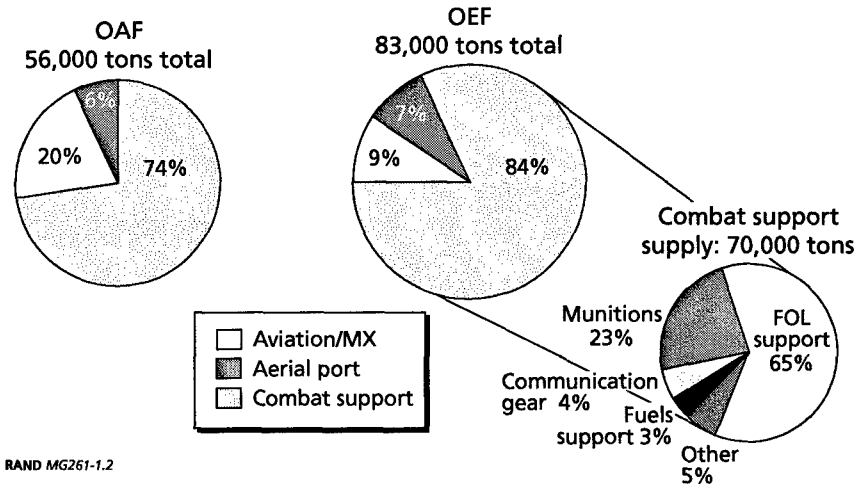
they have the potential to enable or constrain operational goals, particularly in today's environment, which is greatly dependent on rapid deployment.[7] Combat support continues to account for the bulk of assets in terms of lift requirements, as shown in Figure 1.2. Consequently, the Air Force is re-examining its combat support infrastructure, to focus on faster deployment, smaller footprint, greater personnel stability, and increased flexibility.

The AEF rapid global force projection goals and associated sustainment requirements create a number of support planning challenges in such areas as munitions and fuel delivery, engines and navigational equipment maintenance, and Forward Operating Locations (FOLs) development. Support is a particular challenge in expedition-

[7] Theater assets are provided by organizations outside the combat unit itself. In the case shown in Figure 1.1, most theater materiel was provided by U.S. Central Command Air Forces (CENTAF).

Figure 1.2
Combat Support Dominated in Operation Allied Force and Operation Enduring Freedom



ary operations, which are often conducted with little warning. The traditional assumption associated with Cold War–era support planning—that scenarios and associated support requirements could be fairly well developed in advance and materiel prepositioned at anticipated FOLs—no longer holds.

Much of the existing support equipment and processes are heavy and not easily transportable; deploying all of the support for almost any sized AEF from CONUS to an overseas location would be expensive in both time and airlifts. As a result, the Air Force has focused attention on streamlining deploying unit combat support processes, reducing the size of deployment packages, and evaluating different technologies for making deploying units more agile and able to be quickly deployed and employed. Decisions on where to locate intermediate maintenance facilities, such as Jet Engine Intermediate Maintenance shops, and non-unit heavy resources (i.e., those not associated with flying units, such as munitions, shelters, and vehicles) are significant drivers of employment timelines.

RAND's Concept of Agile Combat Support

Since the end of the Cold War, and the inception of the AEF concept, the RAND Corporation has worked with the Air Force to determine options for intermediate maintenance, and for combat support as a whole, that could meet the Air Force's changing needs.[8] RAND's research has resulted in what it calls an "Agile Combat Support (ACS)" network, consisting of five principal elements:[9]

1. **Forward Operating Locations** are sites in a theater, out of which tactical forces operate. FOLs can have differing levels of combat support resources to support a variety of employment timelines. Some FOLs in critical areas under high threat should have equipment prepositioned to enable aerospace packages designed for heavy combat to deploy rapidly. These FOLs might be augmented by other, more austere FOLs that would take longer to spin up. In parts of the world where conflict is less likely or humanitarian missions are the norm, all FOLs might be austere.
2. **Forward Support Locations** are sites near or within the theater of operation for storage of heavy combat support resources, such as munitions or war reserve materiel (WRM), or for consolidated maintenance and other support activities. The configuration and specific functions of FSLs depend on their geographic location, the threat level, steady state and potential wartime requirements and the costs and benefits associated with using these facilities.
3. **CONUS Support Locations (CSLs)** are support facilities in the continental United States. CONUS depots are one type of CSL, as are contractor facilities. Other types of CSLs may be analogous to FSLs. Such support structures are needed to support CONUS forces should repair capability and other activities be removed from units. These activities may be set up at major Air Force

[8] See, e.g., Tripp et al., 1999; Galway et al., 2000; Killingsworth et al., 2000; Peltz et al., 2000; Amouzegar, et al., 2001; Feinberg et al., 2001; and Amouzegar et al., 2004. For a comprehensive review of RAND agile combat support work see Rainey, et al., 2003.

[9] Tripp et al., 2000.

bases, appropriate civilian transportation hubs, or Air Force or other defense repair and/or supply depots.

4. **A transportation network** connects the FOLs and FSLs with each other and with CONUS, including locations providing en route tanker support. This is an essential part of an ACS system in which FSLs need assured transportation links to support expeditionary forces. FSLs themselves could be transportation hubs.
5. **A Combat Support Command and Control (CSC2) system** facilitates a variety of critical management tasks: (1) estimating support requirements, (2) configuring the specific nodes of the system selected to support a given contingency, (3) executing support activities, (4) measuring actual combat support performance against planned performance, (5) developing recourse plans when the system is not within control limits, and (6) reacting swiftly to rapidly changing circumstances.

This infrastructure can be tailored to the demands of any contingency. The first three parts—FOLs, FSLs, and CSLs—are variable; the Air Force configures them as deployments occur to best meet immediate needs. In contrast, the last two elements—a reliable transportation network and a CSC2 system—are indispensable ingredients in any configuration. Determining how to distribute responsibility for the support activities required for any given operation among CSLs, FSLs, and FOLs is an essential part of the strategic planning process. For example, in determining the number of FSLs to support a given operation, and their roles, the Air Force must carefully evaluate such factors as the support capability of available FSLs and the risks and costs of prepositioning specific resources at those locations.

The benefits of maintenance FSLs or centralized intermediate repair facilities (CIRFs) were made more evident by both an ad hoc implementation during the conflict in Kosovo and as a result of USAF formal testing of the CIRF in fall of 2001.[10] However, one of the outstanding issues in our analysis has been a strategic assessment

[10] See Geller et al., forthcoming, for more information.

of current and potential locations of supply Forward Support Locations, especially for munitions and non-munitions WRM, which is addressed in this document.

Operation Iraqi Freedom and Beyond

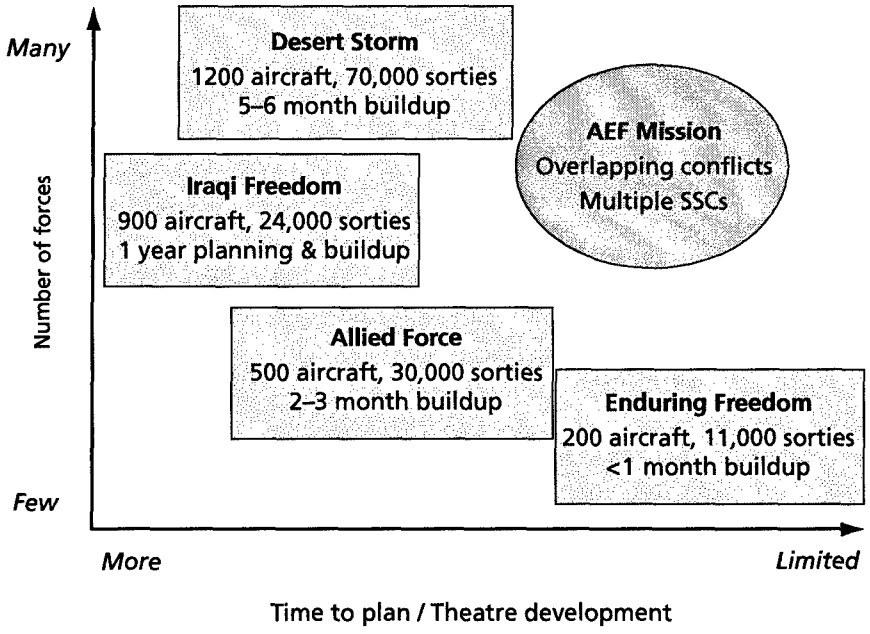
Figure 1.3 illustrates the relative size of engaged forces, the relative time required to plan, and the condition of any prior development in the theater for some recent conflicts. Operation Desert Storm, in the upper left quadrant of the figure, was a large operation that had the benefit of a long buildup time and a relatively good infrastructure. Operation Allied Force, in the lower left quadrant, had less time to plan, but was a smaller operation conducted from bases with good infrastructure. Operation Enduring Freedom, in the lower right quadrant, was a small operation, but was conducted on short notice in an immature theater. Operation Iraqi Freedom was similar to Operation Desert Storm in that it was sized like a major regional conflict (although with a much shorter duration) but had the benefit of long planning and buildup times.

The upper right quadrant of Figure 1.3 represents scenarios that the AEF must be ready to handle. The Air Force chief of staff recently said, "Our heightened tempo of operations is likely to continue at its current pace for the foreseeable future."

Although all of these conflicts are unique in certain ways, they do share certain elements—in particular, Operation Iraqi Freedom shares some attributes with both Operation Allied Force and Operation Enduring Freedom. OIF and OAF both involved a large fighter force and some bombers, a fairly long preparation time,[11] and deployment to known forward operating locations. OAF required minimum Special Operations Forces (SOF) and was supported with a relatively large coalition force (part of Operation Allied Force).

[11] Planning for OIF began as early as March 2002. One year later, Operation Iraqi Freedom began.

Figure 1.3
Characteristics of Recent Conflicts



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Whereas both OEF and OIF used SOF forces extensively, OEF required a large naval participation and made heavy use of tankers and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) assets.

Although OEF and OIF had very little direct coalition participation in their actual operations, the U.S. military enjoyed the participation of many of its "non-traditional" allies in supporting roles. In years past, we had recommended that a fresh look be taken at North Atlantic Treaty Organization (NATO) and European Union (EU) aspirant countries as potential sites for both permanent and virtual[12] maintenance and supply operations. The important roles that many

[12] "Virtual military bases" are staging grounds for USAF where there is no permanent U.S. presence.

of these countries played in Operation Allied Force, Operation Enduring Freedom, and Operation Iraqi Freedom have further enhanced their value as partners to the United States.

A New Combat-Support Planning Strategy for the 21st Century

The 21st century has ushered a new era in the national security arena in which the focus has shifted from the post–Cold War paradigm of preparing for nonrecurring major regional conflicts to ongoing and succeeding engagements and reconstitutions to deter aggression and coercion throughout the world by both state and stateless actors while preparing to engage and succeed in major theater wars (MTWs).[13]

The department of defense force planning has focused on four major categories:[14]

- Defense of the United States
- Deterrence of aggression and coercion in critical regions of the world
- Swift defeat of aggression in overlapping major conflicts
- Conducting a limited number of smaller-scale contingency operations.

The focus of our work is on the last three categories. However, in order to develop a robust combat support system for the Air Force, we must incorporate the temporal elements that have been missing in the earlier combat support planning studies. The Air Force's new role will inevitably include a commitment to multiple engagements in various geographical areas with differing degrees of operational intensity, with some (e.g., drug interdictions) occurring more than once in

[13] This shift can be mapped from the Cold War era of planning for a single war in Europe to post-Cold War two-MTW scenarios to the present state of the world with multiple and sometime shadowy adversaries.

[14] Department of Defense, 2001.

a short time horizon. This temporal dimension is captured in a new planning methodology in which several likely deployment scenarios, from small-scale humanitarian operations to major regional conflicts, are considered.

After a list of scenarios is generated, it is important to outline the *sequencing* and *recurrence* of these scenarios. For any given scenario, decisions should be made regarding its likelihood of occurrence over time (e.g., a given scenario may be highly unlikely over the next five years, but considerably more feasible 20 years out), its interrelationship with other scenarios (e.g., Scenario A may likely occur simultaneously with Scenario B), and its finality (e.g., a given scenario might repeat itself ten years out). We have coined the term *m-Period-n-Scenario* (MPNS) to describe this planning methodology, where "m" and "n" are placeholders for the number of time periods and the number of deployment scenarios, respectively. This is a major departure from the current war planning mindset. Previously, whether planning for nuclear warfare against the Soviet Union, or for large-scale conventional war in the Near East, U.S. analysts were planning for one great conflict that would occur only once, and that would change the defense environment so greatly as to invalidate plans for out-years following this conflict.

A Need for New Combat-Support Basing Options

The current overseas presence posture that is concentrated in Western Europe and Northeast Asia may be inadequate for the 21st century when potential threats have transcended the geopolitical divide of the Cold War era. The events in Southwest Asia prior to OIF, the difficulties of securing basing access in Turkey during OIF, and the denial of overflight rights from countries such as Austria, which opposed the war in Iraq, have further emphasized the importance of alternative forward operating and support locations.

In the European theater, there has been an interest among recent and aspirant NATO and EU member countries in being potential hosts for U.S. military combat and support forces. The Supreme

Allied Commander Europe, General James Jones, U.S. Marine Corps, has been interested in reevaluating bases in Europe for some time, and on February 26, 2003, the House Armed Services Committee heard testimonies on "U.S. Forward Deployed Strategy in the European Theater." At the same committee meeting, a representative of the American Enterprise Institute argued that some of the existing force bases in Germany should be moved to Poland, Romania, and Bulgaria.[15]

As was mentioned earlier, the idea of a new basing strategy has been circulated for some time both inside and outside of the Pentagon.[16] Current European bases—home to thousands of U.S. troops and their families—may be far from potential conflicts, from the combat support point of view. Furthermore, costs may be higher in Western Europe than in Eastern and Central European countries, and public support for U.S. presence may be eroding in Germany and to a lesser extent in the United Kingdom (UK).[17]

Arguably, the most dramatic effect of OIF will be felt in the Near East, where a major "threat" in that region has been eliminated and where an opportunity may have opened for transforming Iraq into the United States' chief regional ally. The Pentagon has announced its plan for withdrawing its forces from Saudi Arabia,[18] ending a 20-year military presence, and is looking for alternatives in the region to base some of its troops and support equipment. The U.S. Air Force has removed 50 warplanes from Incirlik, Turkey, ending the decade-long enforcement of the no-flight zone over northern Iraq, Operation Northern Watch. This new strategic realignment also includes Asia, where the Pentagon is considering shifting or has

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[15] "U.S. Forward Deployed Strategy in the European Theater," 2003.

[16] The RAND Corporation has had several internal discussions and has informally discussed examining new FSLs in Central and Eastern Europe in briefings to senior Air Force leaders in recent years.

[17] This was particularly true during OIF, an unpopular conflict in Western Europe.

[18] Burger, 2003.

already decided to shift[19] some troops from its long-time major bases in Japan and Korea in order to establish smaller bases in other countries such as Australia, Singapore, or Malaysia.[20]

This recent transformation is partly a continuation of a readjustment that began more than a decade ago at the end of the Cold War, partly due to the events of September 11, 2001, and their aftermath, and partly because of the new realignment in world security as the result of the operation in Iraq. But whatever the reason or cause, there is a spectacular change of strategy that requires thoughtful planning and analysis. The old alliances, such as NATO, the Australia-New Zealand-United States (ANZUS) partnership or the Southeast Asia Treaty Organization (SEATO) may survive for years to come, but their role and importance could diminish as the member nations assign differing, and most likely competing, values to the merits of various ventures that the United States places high on its agenda. Within this potentially fluid nature of threat coupled with potentially differing levels of support from allies, the USAF may wish to consider a host of new options in supporting its forces.

As mentioned earlier, one such strategy has been the establishment of virtual FSLs (for combat support) or, in general, virtual military bases (VMBs).[21] This scheme has the advantage of precluding any political ramifications for stationing American troops on foreign soil, as has been evidenced in Saudi Arabia and South Korea.[22] Other new facilities would be considerably smaller and more austere than current military bases, such as the one in Ramstein, Germany. As General Jones said on April, 28, 2003 in Washington, these will be

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[19] On June 5, 2003, the Pentagon announced the withdrawal of U.S. troops from the Demilitarized Zone in Korea.

[20] "U.S. To Realign Troops in Asia," 2003.

[21] As an example of such a base, 200 airmen from throughout Europe set up a temporary KC-135 tanker base in Bulgaria. The Bulgarian military and local police provided most of the security, local contractors provided fuel and meals, and the Air Force security forces guarded the planes (see Simon, 2003).

[22] Presently, the United States has troops in 156 countries and bases in 63 countries. Since September 11, 2001, U.S. military has opened 13 bases in seven new countries, leaving only 46 countries with no U.S. military presence.

locations "that you can go to in a highly expeditionary way, land a battalion, train for a couple of months with a host nation, if you will, or part of an operation, and then leave and then come back maybe six months later." [23]

Organization of This Report

In Chapter Two, we discuss the type of deployment scenarios should be used in the strategic assessment of current and potential locations of supply FSLs and then present the combat support factors that are essential in selection of alternative forward support locations. These factors include base accessibility, vulnerability, and capability. Chapter Two also presents alternative options to air transportation, including the use of High-Speed Sealift (HSS), and discusses the capabilities of U.S. and UK territorial basing options. Chapter Three presents a detailed discussion of our analysis methodology including the development of a large-scale optimization model. In Chapter Four, we illustrate the use of our analytic method by presenting an analysis of regional basing decisions, including a joint Army and Air Force combat support positioning option. This chapter should be used as a roadmap to our planned analysis of the global basing option. In Chapter Five, we present our conclusions and discuss the future direction of our FSL work.

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[23] Burger, 2003.

CHAPTER TWO

Strategies for Global Force Presentation

An effective combat support system should be responsive to various types of demands or stresses. Indeed, the unpredictability of the future security environment requires the evaluation of support concepts using a broad range of combat and non-combat scenarios with varying degrees of intensity.

We have developed capability-based models in order to assess the capacity of a combat support system in dealing with global force presentation. The Department of Defense (DoD) has made capability-based planning (CBP) part of its core tenets of defense policy goals, a major shift from an earlier "threat-based" planning model. This concept is based on the notion that the United States can no longer know, with a high degree of accuracy, what nation, combination of nations, or non-state actor will pose a threat to vital U.S. interests.[1]

The focus of this study is on war reserve materiel forward support locations, and, as such, we have evaluated capability options in terms of current and potential air base access, storage, throughput, and transportation options. As part of the development of an analytical architecture[2] for capability-based planning, we have assessed the capability needs by exploring the cost surfaces for providing equal

[1] Department of Defense, 2001.

[2] A recent RAND report reviewed and extended ideas developed over the past decades regarding capabilities-bases planning (Davis, 2002).

performance across a wide range of scenarios.[3] The scenarios may include small deployment of forces to support humanitarian operations, continuous and ongoing force presentation in various parts of the globe to deter aggression, various wargaming and exercises, and major regional conflicts. The scenarios we examine include various degrees of infrastructure richness, such as availability of fuel, communications, and transportation. These scenarios consider various basing options, such as basing availability, assurance of basing, and base security. Furthermore, the scenarios also present various strategic factors, such as the deployment distance, likely amount of strategic warning, and current Air Force reconstitution condition.

In the remainder of this chapter, we discuss in detail the combat support factors and their effect on the selection of the forward support locations.

Combat Support Factors

Each contingency and deterrence scenario presents a different set of combat support factors and requirements:

- Strategic factors, such as warning time, affect the amount of equipment that can be deployed before an operation begins.
- The reconstitution condition of the Air Force will impact the amount of airlift available.
- The deployment distance will impact the amount of airlift required and transportation time needed.
- The likely duration of the conflict would affect the amount of equipment required within the theater.
- The infrastructure richness determines the amount of materiel needed before desired capability is achieved.

[3] In developing these scenarios, we have relied on lessons learned from recent military activities while keeping in mind that the past conflicts are merely indicators and not predictors. Other sources of information are Air Force plans and programs (AF/XOX) scenarios, Defense Planning Guidance (DPG), and Khalilzad and Lesser, 1999.

- The distance from FOLs to potential FSLs or CSLs is an important factor in this equation because it affects tactical and strategic airlift requirements.
- The fuel, communications, and commercial transportation available would have a large impact on the amount of required equipment to be brought into the theater.
- The number of bases available in-theater, the assurance of gaining access, and the quality of the bases will also affect the ability to support aircraft in theater.

Forward Support Location Capability and Capacity

One of the major factors in selecting a forward support location is its transport capability and capacity. The parking space, the runway length and width, the fueling capability, and the capacity to load and offload equipment are all important factors in selecting an airfield to support an expeditionary operation.[4] Runway length and width are key planning factors and are commonly used as first criteria in assessing whether an airfield can be selected.

Table 2.1 outlines the airfield restrictions for some of the aircraft of interest.[5] The Aircraft Classification Number (ACN) values relate aircraft characteristics to a runway's load bearing capability, expressed as the Pavement Classification Number (PCN). An aircraft with an ACN equal to or less than the reported PCN can operate on the pavement subject to any limitation on the tire pressure.[6] The Load Classification Number (LCN) is a numeric value that determines how much weight a particular runway can hold without causing permanent damage. Each aircraft has a specified LCN that identifies how much stress it is expected to exert on the runway.

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[4] In our analysis some of these factors are computed parametrically in order to assess a minimum requirement of a potential field in order to meet a certain capability.

[5] For more information on airlifters and refuelers, see Appendix C.

[6] U.S. Air Force, 1998.

Table 2.1
Aircraft Airfield Restrictions

Aircraft Type	Minimum Runway Landing[a]		Minimum Taxiway (feet)	ACN (Rigid Pavement)		ACN (Flexible Pavement)		LCN	Ramp Space (square feet)
	Length	Width		High	Low	High	Low		
C-130	3,000	60	30	8-34	11-41	6-30	8-34	37	15,519
C-17	3,000	90	50	22-52	22-52	18-52	22-71	48	47,500
C-141	6,000	98	50	16-48	21-68	17-49	21-70	50	31,362
KC-10	7,000	148	75	12-48	15-68	14-58	21-75	77	34,800

[a] Minimum runway distance required for landing with a full load (maximum takeoff weight).

All of these factors combined dictate the type of aircraft that can be used at a base and the load capacity it can handle. The selection of each forward support location will be based heavily on the airfield restriction.

Airlift

The time it takes to deploy personnel and equipment to a forward operating location is a decreasing function of the number of available aircraft. As an example, we consider the deployment of 3,000 short tons of materiel, roughly the equivalent of one each of Harvest Falcon Housekeeping, Industrial Operations, and Initial Flight line sets, to an operating location at a distance of 1,600 nautical miles (nm).

Figure 2.1 shows the time necessary to deploy the Harvest Falcon set as a function of the number of C-17s. As the number of aircraft increases, the deployment time decreases, but at a diminishing rate. At some point in the curve, the addition of more C-17s does not decrease the deployment time.

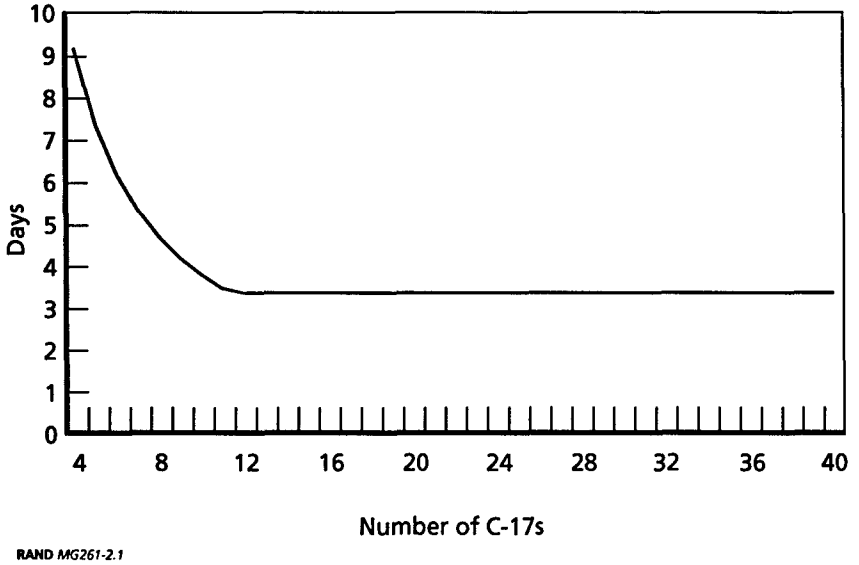
The time required to deliver combat support materiel is essential in an expeditionary operation because the conflict or the humanitarian operation may be slowed or halted by delayed combat support resources. However, as illustrated in Figure 2.1, an increase in the aircraft fleet size may not be the only solution. In the next section, we discuss the effect of throughput capacity on the deployment timeline.

Airfield Throughput Capacity

Another important factor in assessing the capacity of an airfield is the maximum on ground (MOG) capability.[7] MOG generally refers to the maximum number of parking spaces an airfield can provide (parking MOG), but it can be specialized to include the maximum

[7] Parking space, maintenance capacity, and the ramp space for storing and assembling the support equipment at an airbase are typically referred to as MOG for the aircraft (see Stucker et al., 1998). MOG and other factors determine the throughput of a base. In this report, we use the number of aircraft that can land, unload, be serviced, and take off per hour as a more effective measure of throughput constraint.

Figure 2.1
Deployment Time as a Function of the Number of Aircraft



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number of aircraft that can be served by maintenance, aerial port, or other facilities (working MOG). MOG could also refer to the fuel MOG, the maximum number of aircraft that can be refueled simultaneously. In our analysis, we used both working MOG and parking MOG to compute the airfield capability or throughput with the following equation,

$$Throughput = \frac{MOG * WorkDay}{ServiceTime},$$

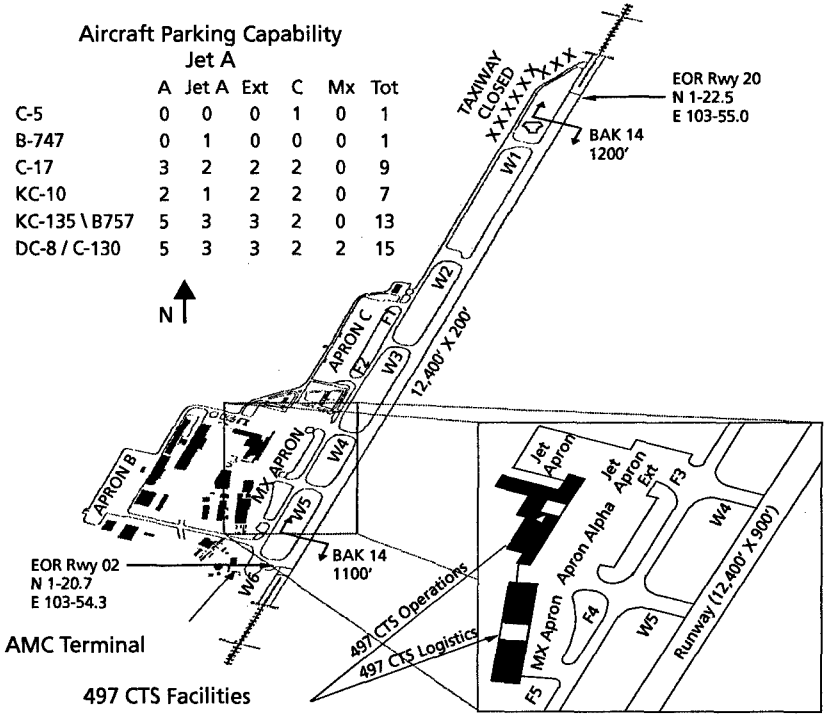
where *MOG* is the smaller of the working or parking MOG numbers,[8] *WorkDay* is the number of working hours in a day and *ServiceTime* is the required hours to load, unload, and service a particular aircraft. Thus, *Throughput* is the maximum number of aircraft that

[8] Lack of access to fuel MOG data prevented us from incorporating the fuel MOG in the equation.

can be processed through an airfield in one working day. Figure 2.2 illustrates the aircraft parking capability for Paya Lebar Airfield, Singapore.

The diminishing return illustrated in Figure 2.1 is a result of an airfield's throughput capacity. An airfield may have a relatively large parking MOG but a small working MOG, reflecting both parking spots available for aircraft to be processed and the availability of the personnel and equipment necessary to process the aircraft. These constraints hold at both the destination (i.e., FOL) and at the originating airfield (i.e., FSL).

Figure 2.2
Airfield Layout and Parking Capability at Paya Lebar Airfield, Singapore



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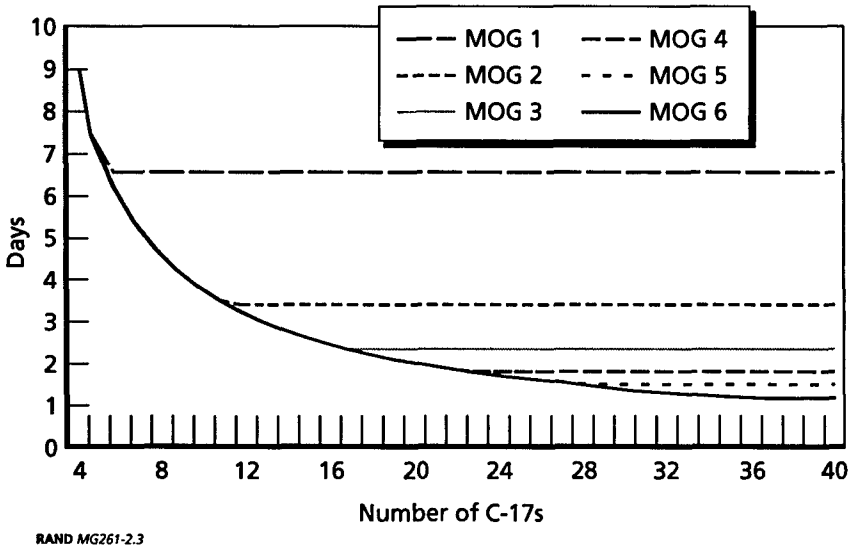
The smaller of the two MOGs will be the limiting factor. In the example above, we assumed that the constraining MOG was two C-17s. Assuming 24-hour operations and a standard 2.25-hour ground time, this configuration corresponds to a maximum airfield throughput of (24*2)/2.25, or just over 21 C-17s per day.

Figure 2.3 presents the same deployment as the example in Figure 2.1 (3,000 short tons of materiel over a distance of 1,600 nautical miles), as a function of the number of C-17s, for various levels of working MOG. The graph shows six somewhat overlapping curves, each representing the deployment time versus airlift tradeoff for a given MOG. As the number of airlifters increases, the corresponding decrease in deployment time occurs at a diminishing rate, as the curves in the figure show, until finally leveling off. This leveling off comes at a different point for each curve. For MOG 1, this point is reached at about six C-17s, and deployment time levels off at about 6.5 days. For MOG 2, deployment time continues to be reduced

Figure 2.3
Deployment Time as a Function of Airlift and MOG



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until roughly 3.3 days using 12 C-17s; for MOG 4, deployment time is reduced to 1.8 days using approximately 22 aircraft; and for MOG 6, deployment is reduced to 1.2 days using 34 aircraft.

To further illustrate the tradeoff between the airlift fleet and the throughput capacity of each base that is selected, we considered a five-FSL solution proposed in an earlier RAND study.[9] This study showed that five FSLs, located at Andersen Air Force Base (AFB), Diego Garcia,[10] Elmendorf AFB, Royal Air Force (RAF) Fairford UK, and Roosevelt Roads Puerto Rico could support the worldwide Air Force posture. Although it is true that from these locations, C-130s can reach almost any part of the world, they may not reach their destination in an expeditionary fashion. A simple calculation shows that if a three-day initial operating capability (IOC) is required to support 100 fighters and bombers, more than 150 dedicated C-17s with MOGs of two to four will be required, depending on the FOLs requirements.

Forward Operating Location Distance

As shown above, assigning greater numbers of aircraft alone may not reduce the deployment time. Investment in the infrastructure, personnel, and equipment at the airfields may also be required. We have shown that two factors that affect deployment time are the number of airlift aircraft and the airfield MOG. A third factor is the deployment distance. For example, consider what happens when an aircraft must fly a longer distance for a deployment. If multiple sorties are required by a single airlifter, the longer distance is compounded by the repeated round trips, so that the aircraft makes fewer round trips per unit time than it would if the distance were shorter. The additional flying time per sortie, multiplied by the number of sorties necessary, gives the total increase in deployment time.

Figure 2.4 shows deployment time for 3,000 tons of materiel, as a function of the number of C-17 aircraft conducting the deploy-

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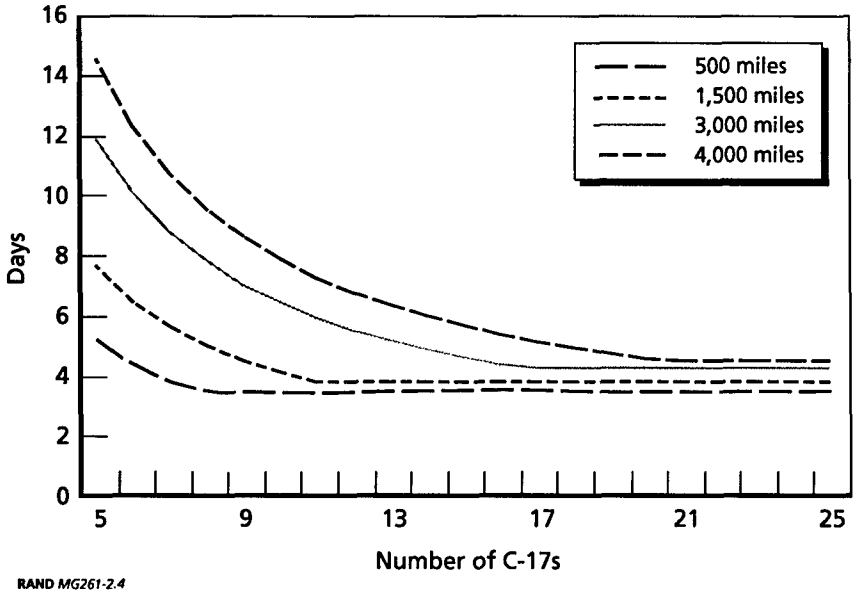
[9] Shlapak et al., 2002.

[10] Diego Garcia is a UK overseas territory leased to the United States until 2039.

ment, for various flying distances, under an assumed MOG of two. It shows that as the number of airlift aircraft increases, the difference in deployment time caused by distance becomes less pronounced. For example, with five C-17s, deploying a distance of 500 miles takes 5.2 days, while deploying a distance of 1,500 miles takes 7.5 days, and deploying a distance of 3,000 miles takes 11.8 days. With ten C-17s, the airlift pipeline for the 500-mile deployment becomes saturated with aircraft, and deployment time levels off at 3.5 days. The 1,500-mile deployment time also nearly levels off at four days, while the 3000-mile deployment requires 6.3 days. With 20 C-17s, the aircraft pipelines in all three deployments become saturated. Thus, 500 miles takes, at a minimum, 3.5 days; 1,500 miles takes 3.7 days; and 3,000 miles takes 4.1 days.

As the figure shows, adding more airlifters to the system will reduce the deployment time, albeit at a diminishing rate, until the de-

Figure 2.4
Deployment Time as a Function of Flying Distance



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ployment time levels off due to MOG constraints. The figure also demonstrates that the point at which the system is saturated—that is, the point at which adding additional airlift aircraft will not decrease deployment time—varies as a function of the distance flown.

Thus, long flying distances affect deployment time most when airlift aircraft are in short supply. With sufficient airlifters available, the effect of longer flying distances on deployment time can be minimal. Airfield throughput limitations appear to be the primary constraint on achieving more-rapid deployments.

Base Vulnerability

In selecting regions and locations for forward support locations, the vulnerability of the candidate locations to attacks from adversaries in future conflicts must be considered. Forward support locations could be primary targets for adversaries with long-range fixed-wing aircraft, cruise missiles, theater ballistic missiles (TBMs), or special operations forces, or primary targets of an attack by stateless actors.[11] Of these threats, theater ballistic missiles may be the easiest and least expensive for enemies to develop and deploy and the most difficult for the Air Force to defend against. The TBM threat is also the threat that is most sensitive to support location selection (due to the limited range of the majority of the world's ballistic missiles). We divided the ballistic missiles into four classes based on range: short range (less than 600 nautical miles), medium range (600 to 1,500 nautical miles), intermediate range (1,500 to 2,500 nautical miles), and intercontinental (greater than 2,500 nautical miles). Short-range ballistic missiles are the most plentiful of the missile threats; there are tens of thousands of short-range ballistic missiles around the world.[12]

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[11]The 1996 Khobar Tower and 2000 USS Cole attacks are two high-profile examples of attacks by stateless actors.

[12] Examples of short-range ballistic missiles include the Russian-designed SCUD and Chinese CSS-8. Short-range ballistic missiles are produced by more than 15 different countries and are openly sold through weapons dealers.

Medium-range ballistic missiles are less common than short-range missiles. Examples of medium-range missiles include the North Korean No-Dong and the Iranian-developed, Russian-designed Shihab-3.[13] Short- and medium-range ballistic missiles are the greatest threat to FSLs. Intermediate-range and intercontinental ballistic missiles are very expensive and a relatively small number of countries own them. For our vulnerability assessment, we will focus on the short- and medium-range ballistic missiles.

For a scenario in the Near East, most locations in Southwest Asia would be within reach of Iranian TBMs, while some locations in Turkey and all locations in the Eastern Balkans would remain out of reach.[14] In a Pacific scenario involving China, almost no location is safe from medium-range ballistic missiles, with the exception of Guam, Australia, and some parts of Japan. However, many of the potential forward support locations in these regions are outside the range of most short-range missiles.

Base Access

The Air Force is confronted with the daunting challenge of securing base access in every conflict or operation. Unfortunately, a solution that would address this challenge also curtails the force presentation greatly. In general, the U.S. military has had an excellent record of maintaining working relationships with other host nations, which has contributed to many military successes of recent years. However, these relationships vary greatly, and in our assessment of current and potential forward support locations we must also evaluate the possibility of denial of access and its effects on combat capability, as was demonstrated during Operation Iraqi Freedom.

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[13] In July 2000, Iran successfully tested its Shahab-3 missile and may have started limited production of it. See Blanche, 2000.

[14] For most scenarios that might involve United States Air Forces in Europe (USAFE) or CENTAF, Diego Garcia, Northern Europe and the United Kingdom are certainly the safest locations.

Arguably, one of the most important regions for potential forward support locations is Europe. European countries have been host to U.S. forces for more than 50 years. European forward bases have been used not only for local conflicts but also for operations in the Near East and Africa. The rich infrastructure, modern economies, stable democracies, and historical and cultural ties to the United States have made Europe an obvious choice for forward support and operating locations. Although there has been some political discontent regarding the resistance of France and Germany to supporting Operation Iraqi Freedom, such disagreement has by no means lessened the importance of European nations as host to U.S. forces.[15]

NATO has been expanded to include many of the former Soviet Bloc countries of Eastern and Central Europe. In 1999, NATO admitted Poland, Hungary, and the Czech Republic and also invited other countries with an outreach plan, the Membership Action Plan (MAP),[16] which includes Albania, Bulgaria, Estonia, Latvia, Lithuania, Macedonia, Romania, Slovakia, and Slovenia.[17] The new NATO members and other aspirant countries have started programs with various degrees of military relationships with the United States. Many of these countries played key supporting roles in OIF as well as in OEF and OAF.[18] Romania and Bulgaria are of particular interest in this study, as they are situated in proximity to regions of potential conflicts and have shown great interest in supporting U.S. forces in

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[15] Such disagreements, though disconcerting, should be expected even from the closest U.S. allies, as was demonstrated by the resistance of the United Kingdom, Spain, Italy, Greece, and Turkey to allow even over-flight rights during operation El Dorado Canyon (see Shlapak et al., 2002).

[16] Being part of MAP does not necessarily qualify a country for membership in NATO, but rather is only an expression of commitment by current NATO members (see Szayna, 2001).

[17] In addition to the current 19 NATO member countries and nine MAP countries, there are 37 additional countries that belong to the Euro-Atlantic Partnership Council (see www.nato.int).

[18] Feinberg et al., 2002; Tripp et al., 2003; and Tripp et al., forthcoming.

the recent conflicts.[19] Romania has significantly increased its defense spending to finance the radical restructuring of its military announced in 2000,[20] and Bulgaria has "adopted" the European and Euro-Atlantic defense and security values and considers its national security to be directly linked with regional and European security.[21] Both these countries have several airfields suitable to support various strategic aircraft. Romania, for example, may have up to four airfields capable of supporting C-5s.

The United States continues to maintain a strong and sizeable presence in Asia. Bilateral defense agreements with South Korea, Japan, Australia, Thailand, and the Philippines, along with other security commitments to some of the islands in the Pacific, ensure a continued presence of U.S. forces in the region. However, the bulk of U.S. forces are based primarily in South Korea and Japan in support of deliberate plans for that region. These forces are situated well for their primary mission in Korea, but their bases are remote from the Taiwan Strait and the South China Sea, where they may be needed for future regional conflicts. Guam is a valuable, well-developed U.S. territory in the Pacific, but the island is geographically distant from most potential conflict locations.

The U.S. Air Force keeps a small component in Singapore and Australia and regularly holds military exercises with the Thai military. Nevertheless, many countries in the region may be wary of openly supporting a large permanent U.S. presence in their territories, and others may not want to increase tension by taking sides in a conflict in which the United States, for example, aids Taiwan against the People's Republic of China. Therefore, regarding this region, we are concentrating dually on potential sites for more permanent U.S. bas-

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[19] Bulgaria allowed overflight rights during OAF despite domestic opposition. This was in contrast to Greece, a NATO member, who refused access to its airspace or airfields (Shlapak et al., 2002).

[20] According to the Romanian Defense ministry, $200 million will be spent on equipment in its effort to join NATO (see *The Military Balance,* 2001).

[21] According to General Nikola Kolev, Chief of General Staff of the Bulgarian Army, as reported in General Staff of the Bulgarian Army, 2002.

ing options (such as Darwin, Australia) and on virtual military bases or en-route support locations (such as U-Tapao, Thailand).

Bases, both virtual and permanent, in Australia, Thailand, Singapore, Malaysia, and the Philippines would greatly enhance the USAF combat support capabilities in support of a conflict in the Taiwan Strait, or operations against terrorism or insurgencies in Indonesia, the Philippines, or other critical regions in the Pacific Rim.

One of the most important regions in terms of security is the Near East, yet this region may be the most problematic in terms of base access. The United States military kept a sizeable presence in Saudi Arabia after Operation Desert Storm, but that decade-long arrangement was fraught with political and social issues,[22] and after OIF, the DoD decided to withdraw its troops from the kingdom. The United States has been successful in negotiating formal defense arrangements with Kuwait, Bahrain, Qatar, Oman, and the United Arab Emirates. However, as in the Asia-Pacific region, the granting of base and facility access does not necessarily mean guaranteed access to use them. This was clearly evident in the reluctance of some countries in the region to support U.S. forces openly in OIF. A "democratic" Iraq may provide for an improved bilateral agreement in the future. However, a large and visible permanent presence by the United States may, once again, be used by extremists to undermine and limit access to resources in the region.

Current United States and United Kingdom Bases

The vulnerability of some overseas bases combined with potential limitations in accessing bases has highlighted the value of overseas territories of the United States and of the close U.S. ally the United Kingdom. The United Kingdom has been a stalwart ally to the United States for many generations. For example, Britain enabled the 1986 raid on Libya, was the only other country that shared the bur-

[22] Whether justified or not, Osama Bin Laden used the U.S. presence in Saudi Arabia as a rallying cry among extremists in the region.

den of enforcing no-fly zones in Iraq,[23] and supported the U.S. forces fully in Iraq despite the unpopularity of the conflict among the UK public.

Some of the major U.S. bases outside of the continental United States are located in Guam and Alaska. These two locations, combined with bases in the United Kingdom and on the island of Diego Garcia, can put most of the world within C-130 range of U.S. power projection capability.[24] However, as we will demonstrate in this report, the maximum-on-ground constraint makes supporting even a moderately sized operation from this set of five FSLs impractical if speed of deployment and employment is a concern. Nevertheless, the access afforded by bases such as Diego Garcia and Guam makes them invaluable in any future operation, as evidenced by recent conflicts.

In fact, we might use Diego Garcia as a blueprint for future "acquisition" of readily accessible bases within other foreign territories. Countries such as the Philippines or Indonesia may, under certain circumstances,[25] be willing to allow a long-term lease of some of their isolated islands for permanent use by U.S. armed forces.

Alternative Modes of Transportation

Although most of the discussion in this chapter has focused on air transportation, the use of ground transportation and sealift play a major role in the forward support basing architecture. Moreover, constraining factors, such as throughput, fleet size, and load capacity, apply to all modes of transportation and are taken into consideration when there is an option to select an alternative mode.

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[23] Turkey also allowed the use of its bases for Operation Northern Watch.

[24] Shlapak et al., 2002.

[25] Arguably, circumstances that would compel a government to "cede" sovereignty of a portion of its territory are very rare. Nevertheless, the possibility that such an opportunity may arise should not be discounted.

There are several advantages to using sealift or ground transportation in place of, or in addition to, airlift. Ships have a higher hauling capacity than any aircraft and can easily carry outsized or superheavy equipment. Any water beyond 12 miles from the shore is considered international waters and thus can be navigated freely. Finally, ships do not require overflight rights from any foreign government.

Trucks are, of course, cheaper than aircraft or ships and are readily available in most locations through local contractors. They do not require specialized airfields and, although they are much slower than aircraft, under certain circumstances they could contribute greatly to the delivery of materiel, especially when they are used in conjunction with airlifts.

Figure 2.5 illustrates the advantage of using trucks in Southwest Asia (SWA). The graph shows that with only 200 trucks, 90 percent of 11 Harvest Falcon sets (about 11,000 pallets) can be delivered to various locations in SWA within 75 days. The same amount of materiel can be delivered in about 58 days using 24 C-17s or in 85 days using 47 C-130s. The best result, 40 days, is attained using approximately 400 trucks.[26]

Similarly, ships are slow relative to airplanes, and may require specialized ports and equipment for loading and offloading. Nevertheless, sealift can be an effective alternative to airlift. For example, in a notional 4,000-nautical-mile scenario comparing C-17s and the new large medium-speed roll-on/roll-off (RO/RO) ships, assuming no prepositioned ships in the theater, airlift could deliver only 72,000 tons of cargo in 36 days, whereas a sealift could deliver 3,960,000 tons in the same number of days.[27] In a recent RAND study,[28] it was estimated that it would take about 13 days to deploy a Stryker

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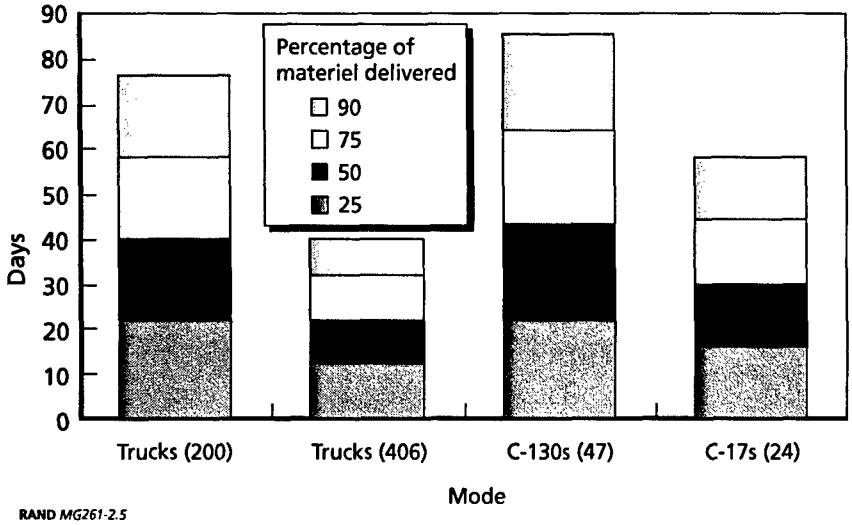
[26] Figure 2.5 is for illustrative purposes only, because other constraints such as throughput contribute greatly to the effectiveness of the transportation mode. In fact, a mixed strategy of 200 trucks and seven C-17s can achieve the same goal in 12 days.

[27] See "Sealift," Global Security.org website at www.globalsecurity.org/military/systems/ship/sealift.htm.

[28] Vick et al., 2002.

Figure 2.5
Materiel Delivery by Land Transport Versus Airlift



Brigade package (about 16,000 tons and 4,500 personnel) from Ft. Polk to Europe using 60 C-17 equivalents, at a throughput of two C-17s per hour, or using only two fast sealift ships at an average speed of 27 knots.

One of the modes of transportation that we are interested in is the Fast Sealift Ship (FSS), pictured in Figure 2.6, which is used by the Military Sealift Command (MSC). These ships are RO/RO, with a range of about 12,000 nautical miles. The noncombatant status of the FSSs makes them less costly to operate than combatant Navy ships, and because they lack onboard weapons, they require a smaller number of crew members.[29] The U.S. Navy owns eight Fast Sealift Ships, which are normally kept on reduced operating status but can fully activate and be under way to load ports within 96 hours. Table 2.2 outlines some of the characteristics of an FSS.

[29] The FSS has an average crew size of less than 40, while Navy ships of similar size generally have crews in the hundreds (see U.S. Navy Military Sealift Command, "Fact Sheet—Fast Sealift Ships," December 2003 (www.msc.navy.mil/factsheet/fss.htm; last accessed August 2004).

Figure 2.6
Roll-on/Roll-off Fast Sealift Ship

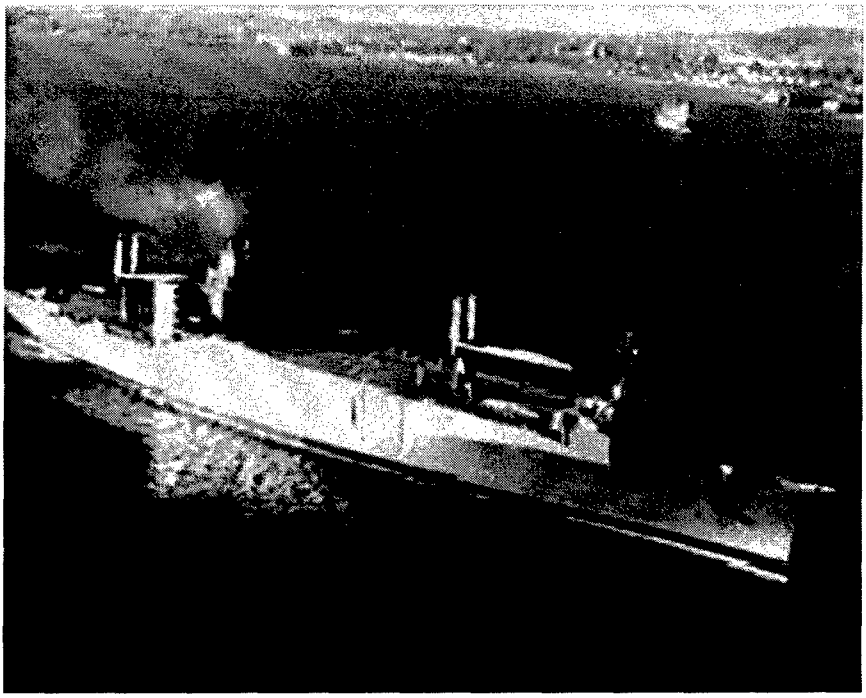


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Photo courtesy of International Catamaran (INCAT) at http://www.incat.com.au.

Table 2.2
Characteristics of Fast Sealift Ships

Speed	27 sustained; 33 maximum (knots)
Displacement	50,213 (short tons)
Length	946 feet
Beam	106 feet
Draft	35-37 feet
Miscellaneous	Roll-on/roll-off ramps; large open bay interiors

SOURCE: U.S. Navy Military Sealift Command, 2003.

One of the main requirements for this type of ship is a harbor that can accommodate a large MSC vessel. In the absence of an adequate harbor, a roll-on/roll-off discharge facility (RRDF) and lighterage (to bring the cargo ashore) are needed. The RRDF is a floating pier that is set up to receive cargo from vessels off the coast of a deployment location. The cargo is offloaded to the RRDF and then loaded to a smaller sea vessel for transportation to the shore.[30]

An alternative to FSS is the Navy's fast combat-support ship, a high-speed vessel designed as oiler, ammunition, and supply ship. This ship has the speed to keep up with the carrier battle groups. It rapidly replenishes Navy task forces and can carry more than 177,000 barrels of oil, 2,150 tons of ammunition, 500 tons of dry stores, and 250 tons of refrigerated stores.[31]

One particularly attractive option includes the High-Speed Sealifts such as 91-meter Wave Piercing Ferry International Catamaran (INCAT) 046 and the Revolution-120, a 120-meter Wave Piercing Catamaran.[32]

The HSS combines three attributes: light weight, high performance, and large payload. The INCAT 046 "Devil Cat" (see Figure 2.7), with a surface-piercing catamaran hull 91 meters long and beam of 23 meters, is capable of carrying 500 metric tons and reaching speeds of up to 43 knots. The U.S. Army, as part of the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) High-Speed Sealift program, and in cooperation with the United States Transportation Command (USTRANSCOM) and Maritime Administration (MARAD), sponsored an evaluation of the 91-meter INCAT.[33] The newest INCAT design, Revolution 120

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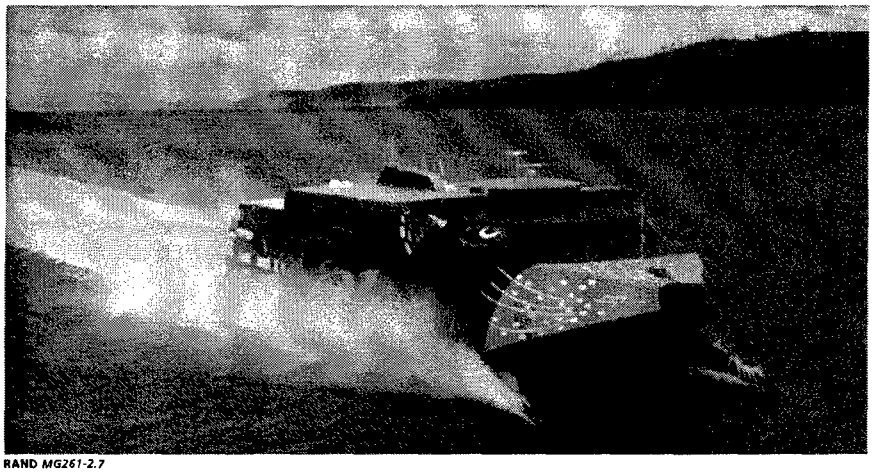
[30] For a detailed description of RRDF operation, see Vick et al., 2002, and the Military Sealift Command website (www.msc.navy.mil).

[31] U.S. Navy Military Sealift Command, "Fact Sheet—Fast Combat Support Ships—T-AOE," August 2002 (www.msc.navy.mil/factsheet/t-aoe.htm.

[32] These ships are manufactured by International Catamaran in its Australian shipyard.

[33] Dipper, 1998.

Figure 2.7
91-Meter Wave Piercing INCAT–046 Running at 43 Knots



RAND *MG261-2.7*

Photo courtesy of International Catamaran (INCAT) at http://www.incat.com.au.

with turbine-powered jets, is 120 meters long with a beam of 30 meters. It can achieve speeds of more than 60 knots lightship (400 metric tons) and 50 knots fully loaded (1,200 metric tons).

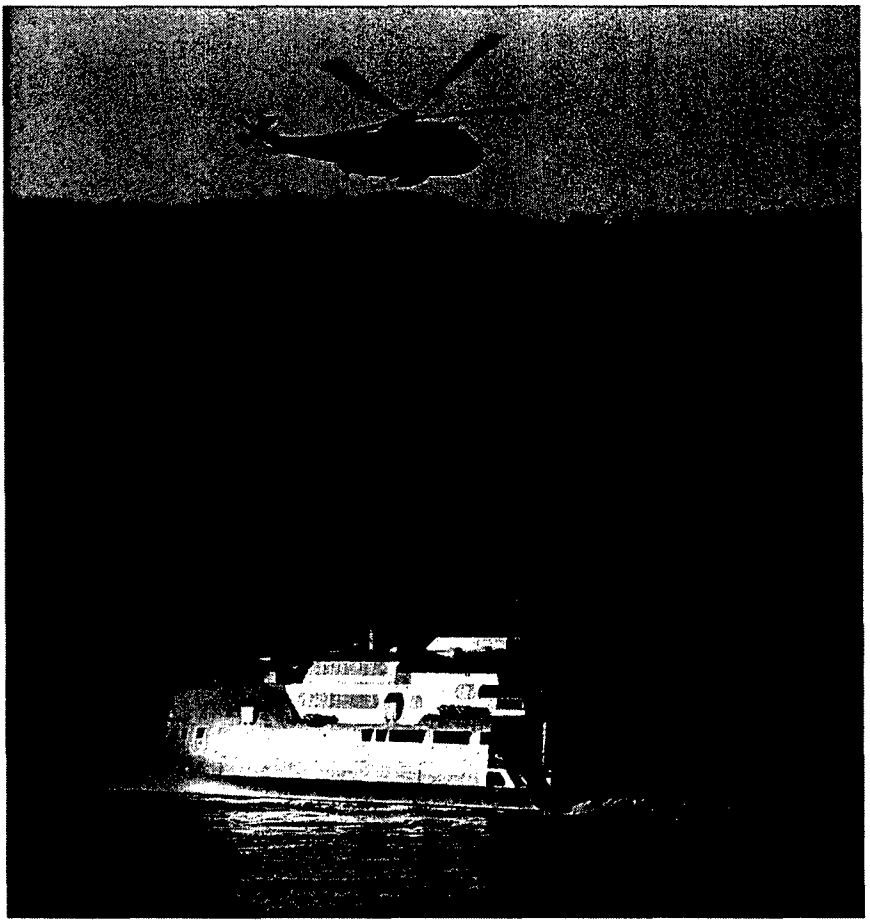
The Royal Australian Navy used an INCAT-built catamaran, the HMS Jarvis Bay (see Figure 2.8), to carry troops and vehicles to and from East Timor, a 430-mile run. This catamaran was used up to three times a week in runs between Darwin, Australia, and Dili, Indonesia. According to the commander of Jarvis Bay, the catamaran was a definite advantage, given the lack of a port or port service in Dili.[34]

In this chapter, we presented alternative modes of transportation that may play a major role in the selection of new forward support locations. The transportation options and combat support factors are both constraints and resources that are incorporated in the analytic framework that is discussed in the next chapter. Some of these factors

[34] Polson, William, "Navy Goes Down Under, Explores Future of Amphibious Warfare," cited in Vick et al., 2002.

are fixed (e.g., the location of a particular site), while others are parameters (e.g., throughput capacity) that may be changed in order to examine the cost and benefit of additional investment to improve the capability of a forward support location. There are, of course, other constraints, such as the political implications of regional imbalance, which should be considered, but are beyond the scope of this study.

Figure 2.8
HMS Jarvis Bay



RAND *MG261-2.8*

Photo courtesy of International Catamaran (INCAT) at http://www.incat.com.au.

CHAPTER THREE

Analysis Methodology

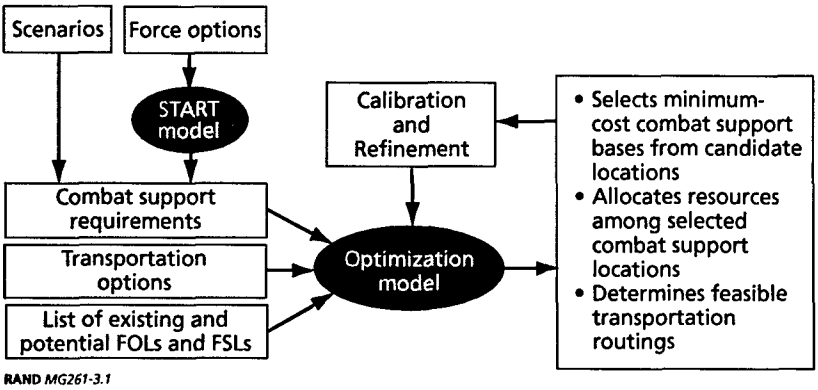
In this chapter, we present the capability-based models that are used to evaluate the effectiveness of alternative forward support basing architecture. These tools are designed to explore the cost surfaces of alternative FSL postures for providing the same level of performance considering many constraints, such as deployment time and transportation availability. The result is a collection of tools that may be used to answer questions ranging from the costs for various portfolios of FSLs that are needed on a global scale to support contingencies around the world, to the optimal placement and transportation of materiel within a theater. This set of tools can also be used to explore the costs associated with eliminating otherwise desirable sites due to political or other factors. Figure 3.1 illustrates our methodology for evaluating alternative FSL sites.

The step-by-step approach of this methodology is as follows:

1. A diverse set of scenarios is selected, including force options that stress the system in various ways, as described in Chapter Two.
2. The combat support requirements, such as base operating support equipment, vehicles, and munitions, are calculated using a RAND model, the Strategic Tool for the Analysis of Required Transportation (START).[1]

[1] See Snyder and Mills, 2003.

Figure 3.1
Overview of Analytic Process for the Optimization Model



3. The combat support requirements, the set of potential FSLs and FOLs that are derived from the scenarios, and the availability of various types of transportation, such as sealifts or C-17s, serve as the inputs to the optimization model.
4. The mixed-integer programming model determines an optimal set of FSL locations, the inventory allocations for those locations, transportation requirements, and the deployment timeline.

- The objective is to minimize construction, operating costs, and transportation costs associated with planned operations, training missions, and deterrent exercises that take place over an extended time horizon.
- The above objective is constrained by time-phased demands for WRM commodities at FOLs, throughput and storage capacity of FSLs, and other combat support requirements, which are listed in the previous chapter.
- Although the costs are based on "peacetime" operations and do not include the actual cost of contingency operations, the facil-

ity size and throughput are designed to support such contingencies.
- The result is the creation of a robust transportation and allocation network that connects a set of disjointed FSL and FOL nodes to support deterrent exercises while having the capability to support major regional conflicts.

5. The solution set is refined and recalibrated by applying political, geographical, and vulnerability constraints. This allows for re-evaluation and reassessment of the parameters and options.

The end result of this analysis is a set of FSL portfolios, including allocations of WRM to those FSLs, which can be presented to decisionmakers. These alternative FSL postures will allow policymakers to assess the merits of various options from a global perspective.

Scenario Construction

One of the tenants of force presentation as stated in the Quadrennial Defense Review[2] is the notion of deterring aggression and coercion. We stated earlier that the underlying principle in this study is the concept of MPNS—evaluating a series of possibly recurring contingencies across a time horizon. As such, this study is oriented toward investigating FSL postures that are capable of meeting the WRM throughput requirements needed to win major regional conflicts and small-scale contingency operations, which are discussed in the Department of Defense (DoD) Strategic Planning Guidance and Defense Planning Scenarios. Perhaps more important, this study also addresses FSL postures that can act to deter aggression and coercion. The deterrent posture is, of course, related to the contingency posture, in that the FSLs that provide materiel to support deterrent exercises may be used to support likely future contingencies. Likewise, the FOLs used in deterrent exercises should be closely aligned, to the

[2] U.S. Department of Defense, 2001.

greatest extent possible, to the FOLs that would be used to prosecute contingency operations in various areas of responsibility.[3]

The major regional scenarios posit one conflict in northeast Asia and one in southwest Asia. These operations include the deployment of fighters, bombers, tankers, and Intelligence, Surveillance, and Reconnaissance (ISR) aircraft. In parts of Central America, South America, and Africa, we used SOF and humanitarian operations involving ISR, helicopters, and support aircraft.[4]

The objective in our scenario selection process was to ensure that FSL postures had the capacity and throughput necessary to support forces around the globe that are engaged in various-sized conflicts. Our intent here is to demonstrate *how* the method can be used to make such determinations in the future, not to provide specific basing recommendations.[5]

Demand Generation

For any given scenario, we estimate the requirements for non-unit commodities needed to support the war fighter. As mentioned above, this estimation is done using a rule-based commodity demand generator, the Strategic Tool for the Analysis of Required Transportation (START). START is a prototype analysis tool, developed by RAND and designed for strategic planners, that estimates the total amount of materiel and manpower needed in a theater to achieve a certain operational capability. It converts the operational capability desired at a deployed location into a list of materiel and manpower needed to generate that capability. The START model operates at the base level,

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[3] In a forthcoming RAND follow-up study of global FSL options, the following scenarios are being examined to determine overall FSL capacity and throughput requirements: major regional conflicts; several deterrence exercises; and Central American, South American, and African SOF and humanitarian operations.

[4] Some of our hypotheses are based on publicly available documents, such as Barnett, 2003.

[5] Our forthcoming work will address the specifics of scenarios that are of current and future interest to the Air Force and Joint communities.

computing which resources are needed at a given base for that base to achieve an organic capability, then adding theater needs (such as theater-level command and control equipment), and finally subtracting whatever benefits may be gained by economies of scale and centralization of supply and repair (such as CIRFs).[6] Theater requirements are calculated by summing requirements at multiple bases.

The START model builds requirements at the level of Unit Type Codes (UTCs),[7] and with the exception of munitions, it does not estimate consumables (e.g., food and fuel).[8] The UTC is a natural unit to quantify movement requirements, because it forms the components of deployment time-phased force deployment data sets. START combines the output list of UTCs with the Manpower and Equipment Force Packaging movement characteristics for each UTC.

Inventory and Location Optimization

We developed a Mixed-Integer Programming (MIP) model to determine FSL locations and optimally allocate currently programmed WRM resources to those FSLs. There are many optimization models that allocate resources, or supply-chain planning models that allow for distribution schemes for alternative supply sources. In the military arena, there are allocation models, such as munitions planning[9] or force assessment[10] for aircraft and weapons systems. A simulated annealing approach has been used in locating and allocating munitions.[11] Although each of these models covers aspects of WRM basing

[6] Tripp et al., 1999; Peltz et al., 2000; Feinberg et al., 2001; Amouzegar et al., 2002.

[7] Some commodities do not have a UTC (e.g., most general-purpose vehicles) or are commonly shipped as **Z99 UTCs (e.g., munitions). In these cases, each item is listed individually as a "**Z99" UTC. See Galway et al., 2002.

[8] Munitions are included because they require a considerable amount of airlift due to their weight, and unlike many consumables, cannot be procured off the local market.

[9] Brown et al., 1994.

[10] Yost, 1996.

[11] Bell, 2003.

options, they do not include all the relevant factors that are discussed in this report.

The following section presents the mathematical programming formulation of the optimization model. The Forward Support Location Site Selection and Transportation Model includes a detailed representation of transporters, throughput constraints, and deployment times. This model was developed using the General Algebraic Modeling System (GAMS).[12]

Forward Support Location Site Selection and Transport Model

A traditional approach to such problems has been to use the Set Cover formulation. However, this type of modeling does not consider transportation constraints. In general, with set cover modeling, an unlimited number of transport vehicles, unlimited vehicle throughput at each facility, and an unlimited amount of storage space at the FSLs are each assumed.[13] To overcome some of these difficulties, we developed a new optimization model—the Forward Support Location Site Selection and Transportation Model.

This new optimization model is constrained by throughput, storage space, and authorized resources and is driven by the time-phased demand for commodities at FOLs. The result of this optimization is the creation of a network that connects a set of disjointed FSL and FOL nodes. It allocates resources to a particular FSL and dictates the movement of WRM resources, munitions, and personnel from FSLs to FOLs. The model also computes the type and the number of transportation vehicles required to move materiel to FOLs.

The following mathematical model presents a somewhat simplified overview of the Forward Support Location Site Selection and

[12] Brooke et al., 2003.

[13] For more information on Set Covering models, see Daskin, 1995.

Transportation Model. A detailed formulation of the model is in Appendix A.

We begin by defining the following variables:

q_{jm}	Number of mode m vehicles available at FSL j at the beginning of time 1
p_{jkmt} u_{jkmt} y_{jkmt}	Number of mode m vehicles tasked to transport personnel, p, munitions cargo, u, and non-munitions cargo, y, from FSL j to FOL k, beginning loading on time, t
v_{jmt}	Number of mode m vehicles available at FSL j at the end of time t

Constraints satisfying the limits on the total number of available vehicles system-wide, equal to the initial number of available vehicles C_m plus the variable r_m denoting the additional mode m vehicles procured, and the total vehicles available for loading at each FSL are defined as:

$$\sum_j q_{jm} \leq (C_m + r_m) \qquad \forall m$$

$$\sum_k [p_{jkmt} + u_{jkmt} + y_{jkmt}] \leq v_{jm(t-1)} \qquad \forall j,m;t \geq 2$$

FSL MOG constraints are defined in such a way as to account for both vehicle "space on the ground" and vehicle "ground time." The MOG at each FSL is modeled separately for each of three "classes" of vehicles, because these three classes—air vehicles, ground vehicles, and sea vehicles—are assumed to use a disjointed set of loading equipment. Each FSL is assumed to have a maximum number of vehicle spaces allowed for loading for each class at any one time. Within a class of vehicles, different modes of transport are assumed to consume differing fractions of this loading space. For example, the parking space for one C-5A is equal to the parking space

for four C-130s.[14] Each of these differing modes of transport is also assumed to consume the loading space for a different length of time. Using the same example, the wartime-planning loading time for a C-130 is 90 minutes, while that of a C-5A is 255 minutes. Thus, each loaded C-5A will consume four times the loading space for nearly three times as long as will each loaded C-13.

Consider one *class* of vehicles (e.g., air), comprising multiple *modes* (e.g., C-17, C-5), and let A_j be the MOG capacity for this class at FSL j. Then, defining α_m as the number of time periods necessary to load a mode m vehicle, the MOG constraints are defined over all modes m in the current class as:

$$\sum_{km} \sum_{g=0}^{\alpha_m - 1} \left(p_{jkm(t-g)} + u_{jkm(t-g)} + y_{jkm(t-g)} \right) \leq A_j \qquad \forall j,t$$

The FOL maximum on ground constraints similarly restrict the FOLs based on the unload space available at each FOL.

Next, define the variables:

w_j Binary variable indicating FSL j status, $w_j = 1$ if open, $w_j = 0$ otherwise

x_{ijkmt} Quantity of commodity i sent from FSL j to FOL k via mode m, beginning loading at time t

n_j Additional square feet of storage space needed beyond E_j at FSL j

A demand constraint requires the cumulative arrivals by time t to satisfy at least a pre-specified percent of the cumulative demand by time t. This constraint requires the declaration of parameter ϖ_{jkm}, equal to the number of time periods necessary to load a mode m vehicle at FSL j, transit to FOL k, and unload at FOL k. FSL storage constraints limit the space available for munitions and nonmunitions.

[14] U. S. Air Force, 1998.

The demand requirement and storage capacity are satisfied by the following constraints, respectively,

$$\sum_{jm,g\le t} x_{ijkm(g-\varpi_{jkm})} \ge D_{ikt} \qquad \forall i,k,t$$

$$\sum_{ikmt} x_{ijkmt} \le E_j w_j + n_j \qquad \forall j$$

$$n_j \le (F_j - E_j) w_j \qquad \forall j$$

where D_{ikt} is the cumulative demand, in tons, for commodity i at FOL k by time t, E_j is the minimum square footage needed for an economically feasible FSL at location j, and F_j is the maximum potential square feet of storage space at FSL j. Note that two versions of the storage-space constraints exist for each potential FSL, one for munitions commodities and one for nonmunitions commodities, because separate storage is assumed for each. These constraints also control the opening and closing of FSLs.

A final necessary variable is the following:

z_{jkmt} Number of mode m vehicles tasked to make the return trip from FOL k to FSL j, departing at time t.

After vehicles p, u, and y finish unloading at FOL k (assuming that n represents the sum of the loading, transport, and unloading times), the following constraint reassigns those vehicles to return trips to FSLs:

$$\sum_j z_{jkmt} = \sum_j \left(p_{jkm(t-\varpi_{jkm})} + u_{jkm(t-\varpi_{jkm})} + y_{jkm(t-\varpi_{jkm})} \right) \qquad \forall k,m,t$$

Note that this model formulation does not assign an individual transport vehicle to a single FSL, to a single FOL, or to a single commodity type. Instead, a given C-17 may transport munitions from FSL A to FOL B, and then make the return trip from FOL B to FSL C, where it will be loaded with a personnel cargo. Note also that individual FOLs are not necessarily "covered" by a single FSL. Instead, multiple FSLs may send commodities to a given FOL, if the optimal solution requires it.

The following constraint limits the average fleet-wide utilization over the duration of the entire scenario to be less than the planning factor for each transport mode:

$$\sum_{jkt} (p_{jkmt} + u_{jkmt} + y_{jkmt} + z_{jkmt}) \leq \sigma_m (C_m + r_m) \qquad \forall m$$

where σ is the utilization rate, expressed (for airlift) as the average flying hour goal per day divided by 24 hours for mode m.

The model is solved by finding a set of p_{jkmt}, q_{jm}, u_{jkmt}, v_{jmt}, w_j, x_{ijkmt}, y_{jkmt}, z_{jkmt} that first satisfies the set of contingency requirements, and then minimizes the costs of conducting training and deterrent exercises over a given time horizon. That is, the FSL posture should be selected from a feasible set such that the costs of supporting deterrent exercises are minimized, and yet have the storage capacity and throughput needed to meet potential future contingencies, if deterrence should fail. Thus, resources are programmed to support peacetime training and deterrent exercises and to provide for resources necessary to support contingency operations should they eventuate. Supplemental funding, approved by the Congress, provides the money for conducting wartime or contingency operations if and when they occur. This is consistent with programming guidance and historical perspectives.[15]

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[15] In the past, the United States would program for defense resources that would prevent nuclear war and provide for conventional forces to be used to defeat the Soviet Union and protect Korea from invasion from the north, with potential intervention by China to support the North Koreans. The programming assumptions were that these resources would be used once to defeat the enemy. It was assumed in programming for resources that contingency

Specifically, the formulation minimizes the net present value of facility openings, if any are needed, and operating costs over a specific time horizon. The Forward Support Location Site Selection and Transportation Model outputs a transportation plan and reports the time needed for forward operating locations to achieve initial and final operational capabilities.

It should also be noted that if the marginal cost of facility construction or expansion is nearly identical across the various sites, then the problem is essentially converted to minimizing the number of FSLs opened. Similarly, if the marginal price of transportation is a constant, then the problem is converted to minimizing the total pallet-mile problem.

Size and Complexity of the Model

The Forward Support Location Site Selection and Transportation Model allows for a more accurate representation of the combat support system through its consideration of transport variables and constraints. The model does have a few weaknesses, such as its representation of time. Time is modeled as a discrete parameter, i.e., every action taken in this system consumes a time interval equal to an integer multiple of one unit of the time period. If the time periods are small enough, the degree of error will be insignificant. Suppose, for example, that the time period is equal to one second. In the current context (strategic combat support), the difference between 0.01 second and 1.0 second is of little consequence. However, if the time periods are larger, the accuracy of the model will diminish. For example, if the time period were assumed to be equal to one day, then a sortie with a flying time of 45 minutes is considered to be equal to a sortie with a flying time of 24 hours.

Thus, the loss of precision due to time representation is not an issue in using the model if the time periods are defined as being suffi-

operations, if they were to arise, could be dealt with using a portion of the resources that were programmed for major theater wars.

ciently short. However, shorter time periods significantly increase the running time of the model. The Forward Support Location Site Selection and Transportation Model can very rapidly grow to an enormous size. For example, a model with three commodities, two modes of transport, 30 FOLs, 25 FSLs, and 100 time periods can have more than 300,000 constraints and more than 1,000,000 variables. If the problem parameters are not sufficiently restricted, the model can grow to a size that is beyond the memory and processing capabilities of current personal computers. Therefore, the time period will need to be long enough that a reasonably small number of total time periods is generated (over the interval from the start of the first contingency to the finish of the last contingency), which will allow the model to remain tractable.[16]

A final caveat regarding this model needs to be stated with respect to the input data. The solutions returned are sensitive to the set of scenarios that are provided. A vastly different set of input scenarios will likely return a very different solution set of FSLs. However, it is important to note that this model is not specific to any one set of input scenarios, and changes to the inputs can be made easily if it is decided that a given set of scenarios does not take into account some important consideration.

Post-Optimization Analysis

Before the final portfolio of FSL options is generated, refinement and calibration of the potential portfolio needs to be done from a political point of view. The result may alter the FSL list and thereby affect the results of the optimization process. Some FSLs suggested by the model may be deemed to be impossible due to politics, practicality, or risk. Other FSLs not suggested by the model may merit consideration due to those same factors. These considerations may inform the

[16] For this study, we selected three hours as the duration of the time period. This time period is small enough to capture the nuances of the process (e.g., loading an aircraft) without overly prolonging the running of the model.

inputs to another iteration of model runs. This post-optimality analysis can then be run iteratively until an acceptable set of portfolios is achieved.

The results of our analysis yield global "portfolio options" of FSL structures and WRM allocations that will include tables of metrics (such as policies, locations, technologies, and costs), which will allow policymakers to assess the merits of the various options. Ultimately, policymakers would be able to consider various mixes of FSLs with their respective capabilities and effectiveness. In the next chapter, we present a series of deployment scenarios across a ten-year time horizon to illustrate the use of our methodology.

CHAPTER FOUR

Regional Analysis

In this chapter, we present an analysis that focuses on the Eastern European and Southwest Asian regions as an illustration of how our analytic framework can be used to assist in the forward support location decisionmaking process. Through this example, we examine FSL posture options against a multi-year set of regularly scheduled peacetime training and deterrence missions to support joint Army-Air Force exercises, while sizing the FSL facilities to support a major theater war.[1]

For this analysis, we assume that small Air Force and Army forces will be permanently stationed in Europe and in Southwest Asia. Therefore, the United States will need to deploy forces to SWA on a continuing basis. This needs to be done to demonstrate power-projection capabilities so that potential adversaries are aware of the United States' ability to project power quickly to the SWA region and so that the United States does not need to have a large force structure permanently positioned in SWA as well as in Europe. The operating locations that we use for such deployments (training and exercise) are shown in Table 4.1.

[1] This sizing is achieved by including a constraint requiring combat support for an equivalent of 100 fighters and bombers.

Table 4.1
Operating Locations for Training and Exercise

Country	Forward Operating Location (Air Base)
Egypt	Cairo
Turkey	Incirlik
Kyrgyzstan	Bishkek-Manas
Jordan	Amman
Iraq	Baghdad
Afghanistan	Bagram

Collocated Air Force and Army FSL Assessment

In our deterrent exercises, we deploy an AEF package of 18 fighters consisting of a mix of F-15Cs, F-15Es, and F-16Cjs; three B-52Hs; ten KC-10s; one Airborne Warning and Control System (AWACS); and one Joint Surveillance Target Attack Radar System (JSTARS) to each operating location listed in Table 4.1. The START model was used to determine support requirements for this AEF package, computing a requirement of 924 supporting personnel, 3,211 short tons of bare base, and 1,073 short tons of munitions (see Table 4.2). The combat support needed for this size deployment is referred to henceforth as the AEF (WRM) package.

The Army's force consists of the Stryker Brigade Combat Team (SBCT), an interim force designed to fill the gap between the current legacy force of light and heavy forces. SBCTs are equipped with a family of Interim Armored Vehicles, including command, mobile gun, infantry carriers, and anti-tank vehicles, built on the commercially available Light Armored Vehicles.[2] For this analysis, we deploy one-third of an Army Stryker Brigade (approximately a

[2] See Vick et al., 2002, for a full description of the SBCT package and the analysis related to deploying SBCT.

Table 4.2
AEF and SBCT Combat Support Package

Package	Equipment (Short Tons)	Personnel
AEF (WRM) 18 fighters 3 bombers 10 refuelers 2 command and control systems	4,284	924
Stryker 100 vehicles: command, mobile gun, infantry carriers, anti-tank vehicles	5,150	1,167

battalion-sized force) with the AEF (WRM) package. This portion of the package is referred to henceforth as a Stryker package. A battalion-size Stryker would require 1,167 supporting personnel, 600 short tons of bare base, 4,300 short tons of vehicles, and 250 short tons of munitions.

The Air Force is assumed to deploy to each FOL, while the Stryker force is assumed to deploy to Cairo, Incirlik, Baghdad, and Bagram only. We are considering a ten-year time horizon with various types of deployment locations and packages (see Table 4.3). Within each year, the Baghdad and Bagram exercises occurred simultaneously (i.e., they had the same contingency start and demand deadline dates), while the applicable set of the remaining four exercises occurred simultaneously but at a different point in the year than the Baghdad-Bagram exercises occurred. The simultaneous nature of these deployments requires the FSLs to be sized to support an equivalent of four AEF (WRM) and four Stryker packages at the same time. Therefore, the optimal solution has the capacity to support a major deployment in the region.

A set of potential FSLs was assumed to support these training missions for this analysis. Existing installation locations at Al Udeid, Qatar, RAF Fairford, UK, and Ramstein Air Base (AB), Germany,

Table 4.3
Deployment Location and Package

FOL	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Baghdad	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S
Bagram	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S	A/S
Cairo	A/S	A/S		A/S		A/S	A/S		A/S	
Incirlik	A/S	A/S		A/S		A/S	A/S		A/S	
Bishkek-Manas	A		A		A	A		A		A
Amman	A		A		A	A		A		A

NOTE: A=AEF; S = Stryker.

were allowed as potential FSLs. Additionally, locations in Warsaw, Poland, and Constanta, Romania, were allowed to provide an evaluation of future location options.[3]

The Forward Support Location Site Selection and Transportation Model was solved to determine the minimum-cost set of FSLs that would meet all demands, achieving Full Operating Capability (FOC), within 12 days.[4]

Model Parameter Settings

The following parameter settings were used for the computational testing. We used trucks, HSS, and C-17s for meeting the transportation needs. An inventory of 80 C-17s was assumed, with no additional procurement of transport vehicles permitted. The airlifters were not assumed to be assigned to any one base or theater, but instead were allowed to fly between any series of bases as needed. For example, a C-17 that flew a shipment of munitions from Ramstein AB to a SWA FOL could then make the return trip from SWA to Sanem, Luxembourg, before departing from Sanem carrying bare base supplies to the FOL in Turkey.

Using Air Force planning factors, we allowed a maximum of 45 tons of cargo or 90 personnel per C-17 sortie.[5] The goal for the planning factor contingency USE rate, expressed as the average flying hour per day, was assumed to be 11.7. Although the planning factor value for C-17 load and unload times is 2.25 hours, because our model utilizes three-hour time intervals, we assumed load and unload times of three hours, a slightly pessimistic assumption. Travel times

[3] The focus of this analysis was to assess the value of new Eastern European sites. We selected Romania and Poland because they both played a role in OIF. Other countries, such as Bulgaria, are also good candidates.

[4] The selection of 12 days is for illustration purposes only. A very short time period would make the problem infeasible (i.e., current fleet size and throughput capacity could not support the deployment).

[5] U.S. Air Force, 1998.

were computed by dividing the port-to-port flying distances (obtained via the Joint Flow Analysis System for Transportation [JFAST]) by the C-17's flying speed of about 500 statute miles per hour. These times were then rounded up to the next multiple of three hours. For example, the distance from Ramstein, Germany, to Kyrgyzstan is about 2,685 nautical miles. Dividing this distance by 500 miles per hour gives a flying time of 5.37 hours. However, because our model assumes three-hour time intervals, this flying time is increased to six hours. The MOG at each potential FSL was assumed to be 5.0 C-17s. A MOG of 4.0 C-17s was assumed for each FOL that did not have a collocated potential FSL. For those FOLs that had a collocated potential FSL, the FSL MOG of 4.0 C-17s was assumed.

A minimum square footage of storage space necessary for an economically feasible FSL was needed for both munitions and nonmunitions WRM. Because of the unavailability of reliable numbers on the maximum potential inside storage space available at each potential FSL, it was assumed that each FSL had a maximum of 100,000 square feet for munitions (approximately 20 igloos) and 335,000 square feet for nonmunitions (the inside storage space at Thumrait, Oman, the largest current storage FSL in southwest Asia). It was assumed that each ton of bare-base supplies converted into 28.344 square feet of storage space, each ton of vehicles converted into 29.497 square feet of storage space, and each ton of munitions converted into 20.592 square feet of storage space.[6]

The transport costs were assumed at the Air Mobility Command (AMC) contingency channels rate of $1.43162 per short ton per nautical mile.[7] We used the current discount rate of 3.0 percent to compute the net present value of transportation and operating costs over the ten-year time horizon.[8]

While transport and operating costs should be discounted for future years, the FSL facilities are assumed to be built and ready for

[6] These numbers were computed from representative START model outputs.

[7] See "U.S. Department of Defense Airlift Rates," 2003.

[8] See Office of Management and Budget, n.d.

operation at the start of period one. Thus, the construction cost is based on year-zero dollars, and no discount rate is appropriate. However, reliable cost estimates were difficult to obtain for each potential FSL location. Therefore, construction costs for opening new FSLs were based on the *Historical Air Force Construction Cost Handbook*.[9] After estimating the base cost for two minimally sized warehouses at a given location, one having 100,000 square feet for nonmunitions and the other having 5,000 square feet for munitions, this cost was multiplied by the handbook's Area Cost Factors to reflect variations in local construction costs. The cost per additional square foot of storage space beyond the minimum size was estimated in a similar manner for each warehouse type. However, several of the locations examined as potential FSLs did not appear in this Area Cost Factor listing, because they are not sites with major current Air Force facilities. Thus, for the potential FSLs at Constanta, Romania, an area cost factor of 1.0 (equal to, e.g., Richards AFB in Missouri) was assumed. It should be noted that the weakness of the facility costs is a recognized shortcoming of this analysis. Nevertheless, these numbers should provide good order-of-magnitude costing estimates.[10]

Modeling Results

The minimum cost solution returned by the model had FSLs opened in Romania and Southwest Asia at a total cost of about $1.2 billion (see Figure 4.1). Although the Romania and SWA pairing is an optimal mathematical solution, there may be political or military factors that might prevent using Romania as an FSL site. By forcing off Constanta from the solution option, the model can show the economic cost of precluding the placement of an FSL in Romania. The second least-expensive option was to open FSLs in both SWA and

[9] See Air Force Civil Engineer Support Agency (AFCESA), 2000.

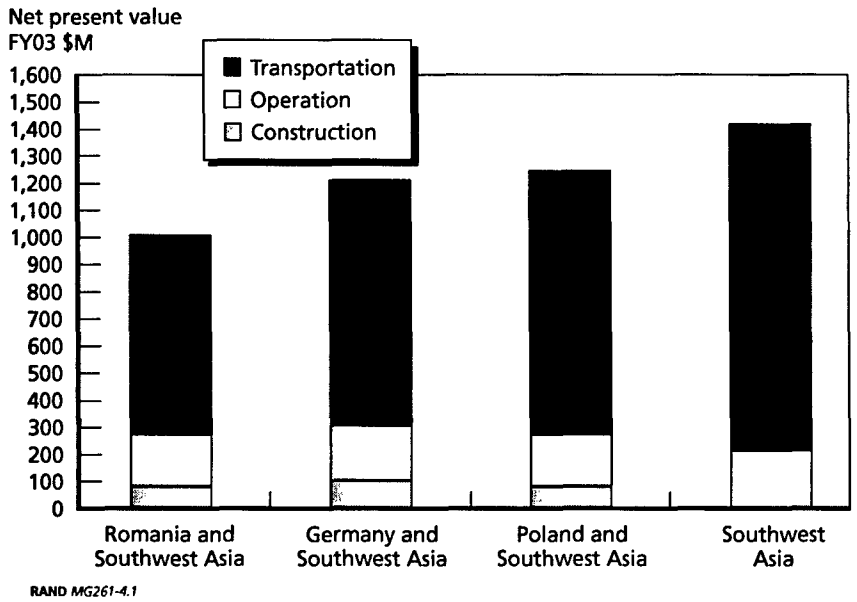
[10] RAND is currently conducting a sensitivity analysis of the country factor, which will be reported at a later date.

Germany at a cost of $1.4 billion (close behind Poland and SWA at a cost of $1.42 billion).

Finally, it should be noted that each of these solutions places one FSL within Europe (within the U.S. European Command [EUCOM]), whereas almost all of the FOLs in this analysis are located within the U.S. Central Command (CENTCOM) area of responsibility. A solution that is more regional in scope, and considers only the CENTCOM for FSL locations, would return the solution presented in the rightmost bar in Figure 4.1, with all FSLs located in SWA, at a cost of $1.5 billion.

A key feature of the FSL Site Selection and Transportation Model is its ability to model multiple modes of transport. Given the geography of the region under consideration, the impact of land transport and sealift on the FSL posture was studied next. For the land transport option, trucks were assumed to have a range of 500

Figure 4.1
Solution for Minimum-Cost and Alternative FSL Locations (Air Only)



nautical miles per day, with one day added for each required border crossing. A roadmap of the region was obtained through JFAST, and the highway distance between each FSL-FOL pair was computed. It was assumed that trucks were a feasible transport option only for routes having a length of less than 1,500 nautical miles. Using these rules, only three FSL-FOL routes were feasible: Romania-Incirlik, Al Udeid-Amman, and Al Udeid-Baghdad. A maximum load of 20 tons or 40 personnel was assumed for trucks. Truck transport costs were set to about $0.07 per ton per nautical mile. An inventory of 200 trucks was allocated, and each FSL and FOL had a throughput of 24 trucks per day.

High-speed sealift catamarans were used as the sealift option for this study. This study assumed a maximum range of 4,000 nautical miles at a speed of 30 knots. An additional day was added to the transport time for each Suez Canal crossing. We assumed a maximum load of 400 short tons and 370 personnel.

The land transport from each FSL and FOL to their nearest seaports was also taken into consideration. Only those FSLs and FOLs located within 900 nautical miles of a seaport were permitted to use sealift, eliminating the FOLs at Bishkek-Manas and Bagram from sealift consideration. Similarly, the 4,000-nautical-mile range limit between seaports precluded several FSL-FOL routes from consideration. Thus, the only routes permitted for sealift were Cairo, Incirlik, and Amman, each of which could be served by Fairford, Ramstein, Constanta, or Al Udeid; additionally the Al Udeid-Baghdad route was permitted.

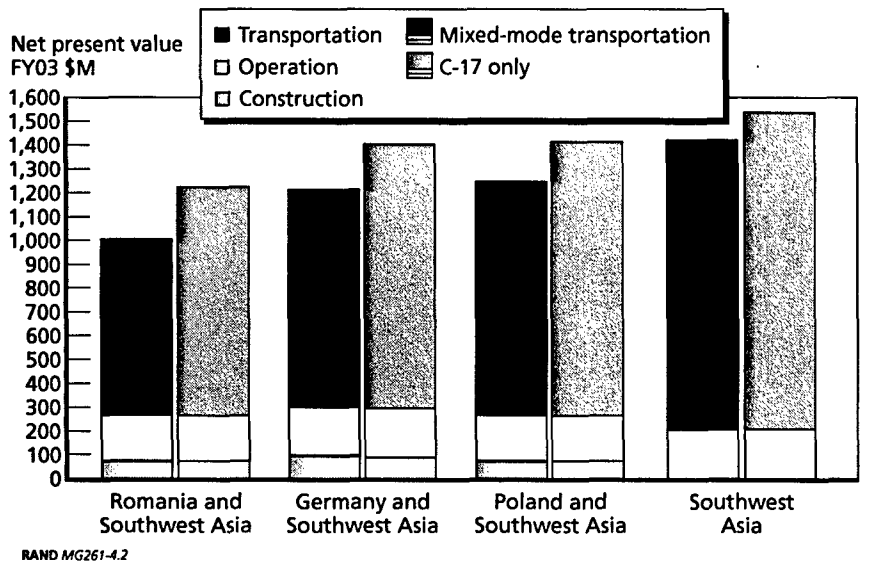
We allocated two HSS to the theater, with each seaport capable of handling one HSS at a time. Sealift costs were assumed at the U.S. Navy's Military Sealift Command rates,[11] increased by 50 percent to reflect the higher fuel consumption of HSS. Finally, we note that the trucks required for the road march from FSLs and FOLs to their nearest seaport were assumed to travel at a rate of 500 nautical miles per day, and these trucks were not subtracted from the trucks used for

[11] See www.msc.navy.mil.

FSL-FOL ground transport but were assumed to be available from the seaports as needed.

Figure 4.2 presents the minimum cost attained for a mixed mode of transportation given a 12-day deadline to achieve full operation capability (i.e., transporting all the combat support equipment and personnel). The air-only results (represented by the right-hand bar in each pair of bars in the figure) are stacked against the mixed-mode results (shown in the left-hand bars) for comparison. Again, the minimum cost solution has FSLs located in SWA and in Romania, at a cost of $1.0 billion, a savings of slightly more than $200 million over the C-17-only solution. The SWA-Germany and SWA-Poland solutions each realize a savings of slightly less than $200 million, while the single AOR solution having FSLs in SWA realizes a savings of roughly $100 million compared with their C-17-only solutions.

Figure 4.2
A Mixed-Transportation Strategy Option



As expected, we see that the savings realized through the use of multiple modes of transportation are greatly dependent upon the geography of the FSL posture in question. It is interesting to note that the Romania-SWA pairing offers about the same cost for air-only transportation (a premium choice) as the mixed-mode transportation for Germany-SWA and Poland-SWA pairings.

In addition to its economic savings, the Romania-SWA FSL posture also affords a substantial savings in the use of strategic airlift to support these peacetime training missions. The use of trucks saved 250 C-17 sorties per year, while HSS saved an additional 150 C-17 sorties per year, a significant savings for a high-priority resource.

Alternative Transportation Modes

We performed several analyses using notional scenarios to assess the value of Fast Sealift Ships and High-Speed Sealift as compared with airlift (both C-17s and C-130s). In this analysis, we deployed a full Stryker Brigade package and a larger-sized AEF package supported by the equipment and personnel listed in Table 4.4, using distances ranging from 500 nautical miles to 5,000 nautical miles. High-speed ships perform well in short-range deployment, doing better than both strategic and tactical lifts (see Figure 4.3). In moderate to long ranges, the high-speed ships continue to do as well as C-17s. FSS tend to have a long setup time, resulting in relatively poor performance for short-range deployment. HSS has a range of 1,000-2,000 nautical miles (possibly up to 4,000 nautical miles with some modifications), and therefore Figure 4.3 as it relates to HSS beyond the range of 4,000 nautical miles is notional and possible only with sea refueling or further technological advances.

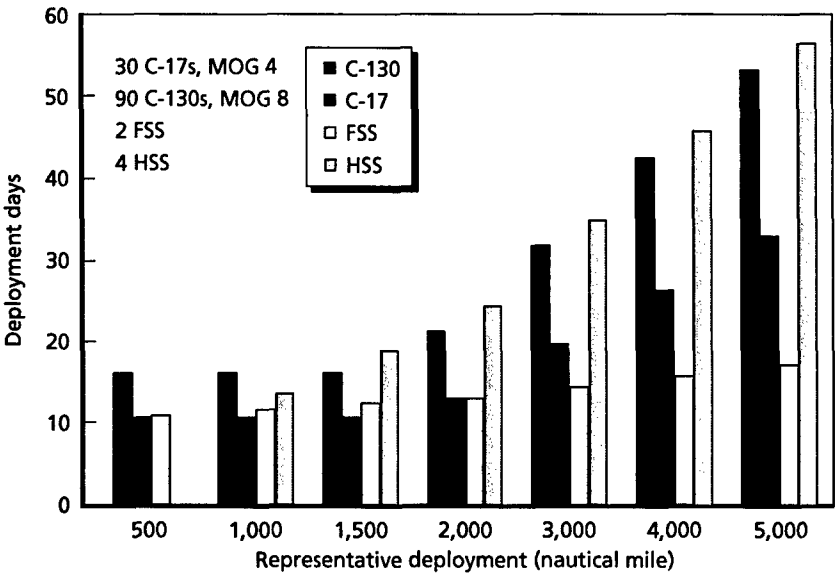
Finally, it should be noted that these results are based on the inventory and throughput assumptions[12] used for Figure 4.3, and any

[12] The throughput assumption for airlift is about two C-17s per hour (i.e., MOG 4) or four C-130s per hour (i.e., MOG 8).

Table 4.4
Bare Base and Munitions Support Equipment and Personnel

Package	Equipment (Short Tons)	Personnel
AEF (WRM) 36 fighters 6 bombers 10 refuelers 4 command and control systems	6,572	1,000
Stryker 300 vehicles	14,490	4,050

Figure 4.3
Deployment Using HSS and FSS



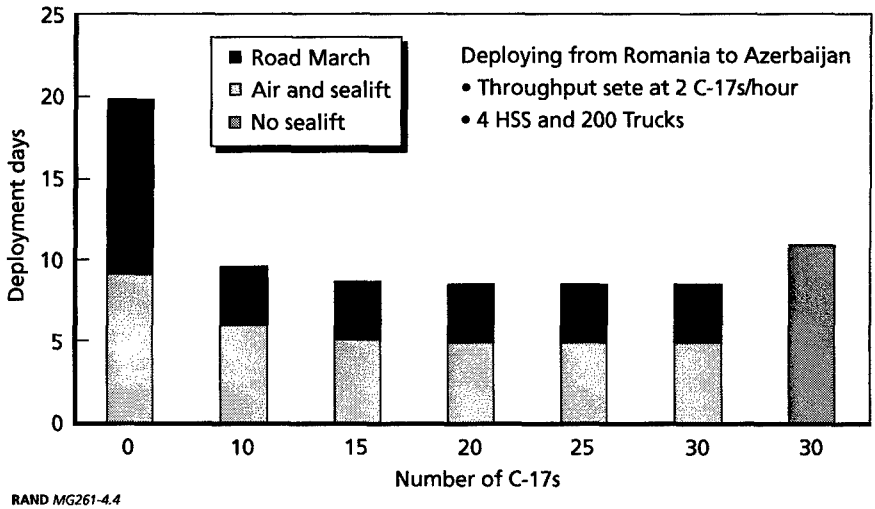
RAND *MG261-4.3*

changes in the throughput and the fleet size would affect the results. Certainly, strategic airlift is the preferred mode, and if the number of

C-17s and their associated throughput capability are increased sufficiently, then they will present the best transportation option. However, given the severe constraints on such airlift, HSS and FSS can provide viable and sometimes better options.

The benefits of high-speed sealift are further illustrated in the following notional deployment from Romania to Central Asia (Azerbaijan) in support of a small operation. As shown in Figure 4.4, with 30 C-17s at MOG 4, all support materiel for Stryker and AEF (WRM) packages can be deployed in about 12 days. However, using four HSS and 200 trucks (with no airlift), the same materiel can be transported in about 20 days via the Black Sea and some land travel (road march) from an eastern port of the Black Sea to the destinationin Azerbaijan.[13] The sealift alone takes less than ten days and the remaining time is devoted to the road march.

Figure 4.4
Results of A Mixed-Transportation Strategy Option



RAND *MG261-4.4*

[13] We assumed a 170-miles-per-day limit as a reflection of poor road conditions. However, it should be noted that the roads in Georgia are severely restricted and may in fact be impassable.

However, a mixed strategy of sealift and airlift shows better performance than using a single transport mode. In fact, an optimal mixture is reached (i.e., adding more C-17s would not improve the performance) at about 15 C-17s and with the initial four HSS and 200 trucks. All materiel and personnel can be fully deployed in less than ten days, including four days of road march.

CHAPTER FIVE

Conclusions

The geopolitical divide that defined the Cold War era has ceased to exist and has been replaced with an international system that is more fluid and unpredictable. The Air Force has responded to this changing security environment by transforming itself into an expeditionary force. The Air Force is now fully committed to the Air and Space Expeditionary Force concept and the transformation that is needed to enable the Air Force to project power quickly to any region of the world. Forward positioning of heavy war reserve materiel in a well-chosen FSL posture is central to that concept.

This report focuses on the development of an analytic framework that can be used to evaluate alternative FSL basing and transportation options for WRM storage. This framework is important to capabilities planning because it addresses how to assess alternative options in terms of the relevant programming costs. As this study shows, an optimal formulation resulting from the use of this analytical tool should minimize FSL operating, construction, and transportation costs associated with training and deterrent exercises, which are needed to demonstrate the U.S. military's capability to repeatedly project power to regions around the world, thereby deterring aggression. An optimal formulation should also maintain the FSL storage capacity and throughput necessary for the United States to engage in major conflicts should deterrence fail. Given that the United States can no longer know, with a high degree of certainty, what nation, combination of nations, or non-state actors will pose a threat to vital

U.S. interests, the U.S. Air Force must be ready to deploy capable forces quickly across a wide range of potential scenarios.

As discussed in Chapter One, there is concern about how quickly even small air and space forces can deploy to austere locations, at least with current equipment and support processes. A global basing strategy can affect the Air Force's ability to quickly deploy materiel in support of expeditionary forces. Prepositioning WRM at forward support locations reduces the distance between the points of storage—the FSLs, and the potential points of use—the FOLs. Deployment distances affect deployment times, but they are not the only factors. The number of airlifters and the quality of the airfield infrastructure (e.g., MOG) interact with flying distance to determine deployment times. As the number of airlifters increases, the effect of distance on deployment time becomes less pronounced, and the restriction on airfield capacity becomes more pronounced. However, as we demonstrate in a number of examples in this report, one of the major tradeoffs that must be made is between the throughput capacity of the airfields and the number of airlifters. In the final examples in this report, we showed the advantage of a mixed-transport strategy.

FSL postures that are proposed without accounting for transport constraints may prove to be inferior after the above transport considerations are included in the analysis. For example, earlier studies have indicated that a set of five FSLs—located at Andersen AFB, Diego Garcia, Elmendorf AFB, RAF Fairford, and Roosevelt Roads Puerto Rico—can support nearly the entire world. However, for a global set of scenarios, we found that this base-case set of five FSLs was unable to support a three-day IOC timeline. One potential negative impact of smaller sets of FSLs is the increased risk of potential denial-of-access difficulties, along with reduced potential for more rapid employment.

We used the regional scenario to illustrate how an optimal FSL posture can support peacetime exercises and deterrence operations while meeting potential demands for large-scale contingencies. The Forward Support Location Site Selection and Transportation Model (discussed below) showed that FSL postures, which cut across regional AORs, can allow for substantial reductions in cost. We pre-

sented another key feature of the model regarding the measurement of the potential impact of varying modes of transport, including sealift, land transport, and airlift—i.e., the ability of the model to take into account tradeoffs between various transportation options. Adding multiple modes of transport was shown to significantly reduce the total cost of the training exercises.

An important tradeoff occurs between the total FSL posture cost and the time allowed to deployment. A nonstressing closure time will enable the FSL throughput constraints to be less binding, allowing for potentially fewer FSLs to be opened, and creates less load balancing among FSLs, enabling shipments to be transported over the least-expensive routes. A stressing closure time requirement, on the other hand, makes the FSL throughput constraints more binding, potentially requiring more FSLs to be opened, and it creates greater load balancing across FSLs. Another observed impact of closure time is on the number of transport vehicles that are needed, because extremely stressing closure times may require additional vehicles to be procured.

Creation of Analytic Models

Optimization tools can be used to examine the location and allocation of WRM FSLs. With this in mind, we developed a new large-scale, mixed-integer optimization model, called the Forward Support Location Site Selection and Transportation Model, which includes transportation, throughput, storage space, and time-phased demand constraints. This model not only selects a set of FSL locations but also allocates resources to those facilities and develops a robust transportation system while minimizing the total cost of construction and maintenance, transportation, and procurement.

Qualitative Factors

As the flow chart in Figure 3.1 in Chapter Three illustrates, a post-optimal solution analysis is needed to factor in the qualitative issues

that must be considered in the evaluation of an FSL architecture. The following qualitative issues are especially relevant:

- Political concerns need to be addressed in any decision on the location of WRM FSLs. Although the focus of this report is not on the political issues associated with selecting an FSL location, our analyses showed that for a global set of scenarios, limiting potential FSLs to U.S. and UK territories precludes satisfying the demand for a three-day IOC worldwide. The operational metrics, such as IOC, are presented in Chapter Two in an attempt to quantify the capability sacrificed or added by various government policies. We allude to the effect of various policies in the regional analysis in Chapter Four by showing the "political" cost of eliminating Romania from the solution set.
- The Department of Defense has different security policies for each region of the world with some regions requiring the most immediate attention (e.g., Afghanistan in OEF). It may also be the case that for certain regions or situations, defense planners are willing to accept an inability to employ rapidly. Such factors would have a significant impact on the selection of an "optimal" FSL posture, which can affect the Air Force's capability to meet unplanned demands.

The modeling approach presented in this report provides a sound basis for examining FSL WRM storage options. However, much of the data used in our computational testing, most notably the data on available storage space, throughput values at FSLs and FOLs, and construction costs, need further refinement. In the follow-up stage of this study, which is underway as of this writing, RAND will be working with the Air Force to collect more data on throughput and construction costs as well as scenario concepts. These scenarios will be used to develop recommendations to the Air Force on new forward support basing options that will be robust across a host of deployment scenarios.

APPENDIX A

FSL Site Selection and Transportation Model Formulation

The Forward Support Location Site Selection and Transportation Model was developed for this study as a tool for optimally allocating currently programmed WRM resources to FSLs. In this appendix, we present the mathematical formulation of the model. For further discussion, see Chapter Three.

Sets and Set Indices

$i \in \mathrm{I}$	commodities; $\mathrm{I} = \{PAX, BOS, VEH, MUN, ...\}$
AMM(I)	munitions; $\mathrm{AMM(I)} \subseteq \mathrm{I}$; $\mathrm{AMM(I)} = \{MUN, ...\}$
NAM(I)	non-munitions; $\mathrm{NAM(I)} \subseteq \mathrm{I}$; $\mathrm{NAM(I)} = \{BOS, VEH, ...\}$
$j \in \mathrm{J}$	FSL index; $\mathrm{J} = \{FSL1, FSL2, ...\}$
$k \in \mathrm{K}$	FOL index; $\mathrm{K} = \{FOL1, FOL2, ...\}$
$m \in \mathrm{M}$	mode of transport; $\mathrm{M} = \{C\text{-}130, C\text{-}17, C\text{-}5, B747, TRUCK, HSS, ...\}$
AIR(M)	aircraft; $\mathrm{AIR(M)} \subseteq \mathrm{M}$; $\mathrm{AIR(M)} = \{C\text{-}130, C\text{-}17, C\text{-}5, B747, ...\}$

LAN(M)	land vehicles; $\text{LAN(M)} \subseteq \text{M}$; $\text{LAN(M)} = \{TRUCK,...\}$
SEA(M)	sea vehicles; $\text{SEA(M)} \subseteq \text{M}$; $\text{SEA(M)} = \{HSS,...\}$
PER(M)	personnel transport vehicles; $\text{PER(M)} \subseteq \text{M}$; $\text{PER(M)} = \{B747, HSS,...\}$
$h \in \text{H}$	phase; $\text{H} = \{1,2,...\}$
$t \in \text{T}$	time periods which divide up each phase h; $\text{T} = \{1,2,...\}$

Data Parameters: Coefficients

Δ_j	fixed cost incurred to open FSL j with $E_{\aleph j}$ square feet of storage space for commodity class $\aleph\ [\text{AMM(I)} = 1, \text{NAM(I)} = 2]$
Θ_{mh}	cost of obtaining an additional vehicle of mode m at the beginning of phase h
$\Xi_{\aleph j}$	variable cost per square foot of storage space needed beyond $E_{\aleph j}$ for commodity class $\aleph\ [\text{AMM(I)} = 1, \text{NAM(I)} = 2]$ at FSL j
Ψ_{ik}	shortfall cost per time unit per ton (or per passenger [PAX]) of commodity i not fulfilled at FOL k
Ω_{ijkm}	cost per ton (or per PAX) of commodity i transported from FSL j to FOL k via mode m
α_m	number of time periods necessary to load a mode m vehicle
β_m	number of time periods necessary to unload a mode m vehicle
γ_m	maximum load in tons per mode m vehicle

ζ_k contingency start date at FOL k

η_k contingency finish date at FOL k

λ_m maximum load in PAX per mode m vehicle

μ_k phase of contingency occurrence associated with FOL k

π_{km} additional time needed following unloading for commodities to reach FOL k via mode m

ρ_m conversion factor for parking space for mode m

σ_m utilization rate, expressed (for airlift) as the average flying-hour goal per day divided by 24 hours, for mode m

τ_{jkm} one-way transportation time from FSL j to FOL k (or in opposite direction) via mode m

ϕ_i conversion factor for commodity i from tons to square feet of storage space (= 0 for PAX).

Data Parameters: Right-Hand Sides

$A_{\aleph j}$ max on ground, in class $\aleph$ [AIR(M) = 1, LAN(M) = 2, SEA(M) = 3] equivalent vehicles, at FSL j

$B_{\aleph k}$ max on ground, in class $\aleph$ [AIR(M) = 1, LAN(M) = 2, SEA(M) = 3] equivalent vehicles, at FOL k

C_{mh} planned systemwide inventory of mode m vehicles at the beginning of phase h

D_{ikt} cumulative demand, in tons (or PAX), for commodity i at FOL k by time t

$E_{\aleph j}$ minimum square footage needed for an economically feasible FSL at location j for commodity class $\aleph\,[\mathrm{AMM(I)}=1, \mathrm{NAM(I)}=2]$

$F_{\aleph j}$ maximum potential square feet of storage space at FSL j for commodity class $\aleph\ [\mathrm{AMM(I)}=1, \mathrm{NAM(I)}=2]$.

Variables

n_j additional square feet of storage space needed beyond $E_{\aleph j}$ for commodity class $\aleph\,[\mathrm{AMM(I)}=1, \mathrm{NAM(I)}=2]$ at FSL j

p_{jkmt} number of mode m vehicles tasked to transport personnel from FSL j to FOL k, beginning loading on time t. Integer

q_{jmh} number of mode m vehicles available at FSL j at the start of time $t=1$ during phase h

r_{mh} additional mode m vehicles obtained at the beginning of phase h

s_{ikt} shortfall below demand, in tons (or PAX), for commodity i at FOL k not fulfilled by time t

u_{jkmt} number of mode m vehicles tasked to transport solely munitions from FSL j to FOL k, beginning loading on time t. Integer

v_{jmth} number of mode m vehicles available at FSL j at the end of time t during phase h

w_j binary variable indicating status of FSL j x_{ijkmt} tons (or PAX) of commodity i sent from FSL j to FOL k via mode m, beginning loading on time t

y_{jkmt} number of mode m vehicles tasked to transport some nonmunitions from FSL j to FOL k, beginning loading on time t. Integer

z_{jkmt} number of mode m vehicles tasked to make the return trip from FOL k to FSL j, departing on time t. Integer

Note: There is an implicit assumption throughout the entire model that terms having an index value $t \leq 0$ are not considered.

Objective Function

$$\min \sum_{j} \left(\Delta_j w_j + \Xi_{"1"j} n_{"1"j} + \Xi_{"2"j} n_{"2"j} \right) + \sum_{ijkmt} \Omega_{ijkm} x_{ijkmt} + \sum_{mh} \Theta_{mh} r_{mh} + \sum_{ikt} \Psi_{ik} s_{ikt} \tag{A.1}$$

Constraints

$$\sum_{j} q_{jmh} \leq \left(C_{mh} + r_{mh} \right) \qquad \forall m,h \tag{A.2}$$

$$\sum_{k \ni \mu_k = h} \left[p_{jkmt} + u_{jkmt} + y_{jkmt} \right] \leq v_{jm(t-1)h} \qquad \forall j,m,h;t \geq 2 \tag{A.3}$$

$$\sum_{k \ni \mu_k = h} \sum_{m \in \mathrm{AIR(M)}} \sum_{n=0}^{\alpha_m - 1} \left[\rho_m \left(p_{jkm(t-n)} + u_{jkm(t-n)} + y_{jkm(t-n)} \right) \right] \leq A_{"1"j} \qquad \forall j,t,h \tag{A.4}$$

$$\sum_{k \ni \mu_k = h} \sum_{m \in \text{LAN(M)}} \sum_{n=0}^{\alpha_m - 1} [\rho_m (p_{jkm(t-n)} + u_{jkm(t-n)} + y_{jkm(t-n)})] \leq A_{"2"j} \qquad \forall j,t,h \tag{A.5}$$

$$\sum_{k \ni \mu_k = h} \sum_{m \in \text{SEA(M)}} \sum_{n=0}^{\alpha_m - 1} [\rho_m (p_{jkm(t-n)} + u_{jkm(t-n)} + y_{jkm(t-n)})] \leq A_{"3"j} \qquad \forall j,t,h \tag{A.6}$$

$$\sum_{j} \sum_{m \in \text{AIR(M)}} \sum_{n=0}^{\beta_m - 1} [\rho_m (p_{jkm(t-\tau_{jkm}-\alpha_m-n)} + u_{jkm(t-\tau_{jkm}-\alpha_m-n)} + y_{jkm(t-\tau_{jkm}-\alpha_m-n)})] \leq B_{"1"k} \qquad \forall k;\ \zeta_k \leq t \leq \eta_k \tag{A.7}$$

$$\sum_{j} \sum_{m \in \text{LAN(M)}} \sum_{n=0}^{\beta_m - 1} [\rho_m (p_{jkm(t-\tau_{jkm}-\alpha_m-n)} + u_{jkm(t-\tau_{jkm}-\alpha_m-n)} + y_{jkm(t-\tau_{jkm}-\alpha_m-n)})] \leq B_{"2"k} \qquad \forall k;\ \zeta_k \leq t \leq \eta_k \tag{A.8}$$

$$\sum_{j} \sum_{m \in \text{SEA(M)}} \sum_{n=0}^{\beta_m - 1} [\rho_m (p_{jkm(t-\tau_{jkm}-\alpha_m-n)} + u_{jkm(t-\tau_{jkm}-\alpha_m-n)} + y_{jkm(t-\tau_{jkm}-\alpha_m-n)})] \leq B_{"3"k} \qquad \forall k;\ \zeta_k \leq t \leq \eta_k \tag{A.9}$$

$$\sum_{j,m} \sum_{n=1}^{t} x_{ijkm(n-\tau_{jkm}-\alpha_m-\beta_m-\pi_{km})} \geq D_{ikt} - s_{ikt} \qquad \forall i,k;\ \zeta_k \leq t \leq \eta_k \tag{A.10}$$

$$\sum_{k \ni \mu_k = h} \sum_{i \in \text{AMM(I)}} \sum_{m,t} \phi_i x_{ijkmt} \le E_{"1"j} w_j + n_{"1"j} \qquad \forall j,h \tag{A.11}$$

$$n_{"1"j} \le \left(F_{"1"j} - E_{"1"j}\right) w_j \qquad \forall j \tag{A.12}$$

$$\sum_{k \ni \mu_k = h} \sum_{i \in \text{NAM(I)}} \sum_{m,t} \phi_i x_{ijkmt} \le E_{"2"j} w_j + n_{"2"j} \qquad \forall j,h \tag{A.13}$$

$$n_{"2"j} \le \left(F_{"2"j} - E_{"2"j}\right) w_j \qquad \forall j \tag{A.14}$$

$$\sum_{k,m,t} x_{"PAX"jkmt} \le \left(\sum_{k,t} D_{"PAX"kt}\right) w_j \qquad \forall j \tag{A.15}$$

$$\sum_{k \ni \mu_k = h} \sum_{j} \left(\left[\sum_{t} \tau_{jkm} \left(p_{jkmt} + u_{jkmt} + y_{jkmt} \right) \right] + \left[\sum_{t=1}^{\|\mathrm{T}\| - \tau_{jkm}} \tau_{jkm} z_{jkmt} \right] + \left[\sum_{t=\|\mathrm{T}\| - \tau_{jkm}+1}^{\|\mathrm{T}\|-1} \left(\|\mathrm{T}\| - t\right) z_{jkmt} \right] \right) \le \|\mathrm{T}\| \left(C_{mh} + r_{mh}\right) \sigma_m \qquad \forall m,h \tag{A.16}$$

$$\sum_{i \in \text{AMM(I)}} x_{ijkmt} \le \gamma_m u_{jkmt} \qquad \forall j,k;\ m \notin \text{SEA(M)};\ \zeta_k \le t \le \eta_k \tag{A.17}$$

$$\sum_{i \in \text{NAM(I)}} x_{ijkmt} \le \gamma_m y_{jkmt} \qquad \forall j,k;\ m \notin \text{SEA(M)};\ \zeta_k \le t \le \eta_k \tag{A.18}$$

$$\sum_{i \in \text{AMM(I)} \cup \text{NAM(I)}} x_{ijkmt} \le \gamma_m y_{jkmt} \qquad \forall j,k;\ m \in \text{SEA(M)};\ \zeta_k \le t \le \eta_k \tag{A.19}$$

$$x_{"PAX"jkmt} \le \lambda_m y_{jkmt} \qquad \forall j,k;\ m \in (\mathrm{SEA(M)} \cap \mathrm{PER(M)});\ \zeta_k \le t \le \eta_k \tag{A.20}$$

$$x_{"PAX"jkmt} \le \lambda_m p_{jkmt} \qquad \forall j,k;\ m \in \mathrm{PER(M)}; m \notin \mathrm{SEA(M)};\ \zeta_k \le t \le \eta_k \tag{A.21}$$

$$\sum_j z_{jkmt} = \sum_j [p_{jkm(t-\tau_{jkm}-\alpha_m-\beta_m)} + u_{jkm(t-\tau_{jkm}-\alpha_m-\beta_m)} + y_{jkm(t-\tau_{jkm}-\alpha_m-\beta_m)}] \qquad \forall k,m;\ \zeta_k \le t \le \eta_k + 1 \tag{A.22}$$

$$v_{jmth} = v_{jm(t-1)h} + \sum_{k \ni \mu_k = h} [z_{jkm(t-\tau_{jkm})} - p_{jkmt} - u_{jkmt} - y_{jkmt}] \qquad \forall j,m,h; t \ge 2 \tag{A.23}$$

$$v_{jm"1"h} = q_{jmh} + \sum_{k \ni \mu_k = h} [-p_{jkm"1"} - u_{jkm"1"} - y_{jkm"1"}] \qquad \forall j,m,h \tag{A.24}$$

$$x_{ijkmt} = 0 \qquad t < \zeta_k;\ t > \eta_k \tag{A.25}$$

$$n_{"1"j}, n_{"2"j}, p_{jkmt}, q_{jmh}, r_{mh}, s_{ikt}, u_{jkmt}, v_{jmth}, x_{ijkmt}, y_{jkmt}, z_{jkmt} \ge 0 \tag{A.26}$$

$$p_{jkmt}, u_{jkmt}, y_{jkmt}, z_{jkmt} \qquad \text{integer} \tag{A.27}$$

$$w_j \in \{0,1\} \tag{A.28}$$

The objective function (A.1) minimizes the total cost, equal to the sum of the FSL opening costs, the transport cost, the cost of

procuring new vehicles, and the shortfall cost for not satisfying demand requirements. Constraint (A.2) limits the total number of available vehicles systemwide. Constraint (A.3) limits the total number of vehicles that begin loading for transport at FSL j at time t to be no greater than the vehicles available there at the end of time $t-1$. Note that $v_{jm"1"} \geq 0$ and constraint (A.24), taken together, eliminate the need for a version of constraint (A.3) at $t=1$. The FSL Maximum on Ground constraints (A.4), (A.5), and (A.6) are defined in such a way as to account for both vehicle "space on the ground" and vehicle "ground time."

The FOL MOG constraints (A.7), (A.8), and (A.9) similarly restrict the FOLs based on the unload space available at each FOL. A demand constraint (A.10) compares the cumulative arrivals by time t against the cumulative demand by time t, with unmet demand recorded in the shortfall variable s. FSL storage is limited through constraints (A.11) and (A.12) for munitions, through constraints (A.13) and (A.14) for non-munitions, and through constraints (A.15) for personnel. This set of five constraint types also controls the decision of whether to open an FSL at location j. Constraint (A.16) limits the average fleetwide utilization over each phase to be less than the planning factor.

The remaining constraints are necessary for mathematical "bookkeeping." Note the assumptions that (1) excluding sea vehicles, no vehicle may simultaneously transport both munitions and nonmunitions, and (2) personnel must be transported, for land and air vehicles, on dedicated sorties that carry no other commodities. Constraints (A.17) and (A.18) translate tons of commodities transported via non-sea transport modes into transport vehicles for munitions and transport vehicles for nonmunitions, respectively. Constraint (A.19) similarly translates into sea vehicles all non-personnel commodities transported via sea vehicles. Constraint (A.20) translates into sea vehicles personnel transported via sealift. Constraint (A.21) translates into personnel transport vehicles personnel transported via land and air vehicles. After vehicles p, u, and y finish unloading at FOL k, constraint (A.22) reassigns those vehicles to return trips to FSLs. Constraints (A.23) and (A.24) are

flow balance equations for the number of available vehicles, at time periods $t \geq 2$ and $t = 1$, respectively. Vehicles available at FSL j at the end of time period t are equal to the vehicles available at the end of time period $t = 1$, less those that begin loading for transport at the beginning of time period t, plus those that return at the beginning of time period t.

Several implicit assumptions are worth noting here: The forward support location configuration will be determined and in place at the beginning of phase 1, and this FSL configuration (i.e., the number, location, and size of FSL facilities) will then remain static across all phases. The number of transport vehicles may vary across phases, but within any one phase the number of transport vehicles may not vary. Idle vehicles at the FSL are assumed to be able to "sit" somewhere and not consume MOG space at the FSL. Vehicles returning to an FSL do not consume MOG space at that FSL, and vehicles departing an FOL for return to an FSL do not consume MOG space at that FOL. The more complicated terms associated with z in constraint (A.16) are necessary due to the fact that the travel time associated with a return trip to an FSL might occur over some period of time later than the maximum time period $\|T\|$, if a vehicle arrives at an FOL sufficiently close to this final time period. The implicit assumption that $\eta_k \leq \|T\|$, together with constraint (A.10), precludes this consideration for variables p, u, and y. There is an implicit assumption that vehicles may not "sit" at an FOL; rather, immediately following unloading a vehicle, the vehicles must depart on a return trip to some FSL. Vehicles returning to an FSL at time t are not available to begin loading for an FOL delivery until time $t + 1$. For all transport modes, no $j \rightarrow k$ route has transit time 0.

If an FOL is also a potential FSL, this collocation must be modeled such that no transportation or throughput resources are consumed to meet the FOL's demand if the collocated FSL is opened. This can be accomplished through the use of a "dummy" vehicle. The dummy vehicle has transit time $\tau = 1$ from FSL j to its collocated FOL, with $\tau = \infty$ over all other routes. For all other "non-dummy" vehicles, the transit time $\tau = \infty$ is assumed from FSL j to its

collocated FOL. This dummy vehicle is assumed to consume no throughput, to incur no transport cost, and to have an infinite maximum load, with a utilization rate $\sigma = 1$. The fleetwide inventory of dummy vehicles can be set equal to the number of potential forward support locations.

APPENDIX B

General Algebraic Modeling System for FSLs and Their Attributes

The following GAMS statements implement the optimization model described in this report. (Some tables and parameters are abbreviated for space reasons.)

Sets

```
I commodities /PAX,BOS,VEH,MUN/
AMM(I) munitions /MUN/
NAM(I) non-munitions /BOS,VEH/
J FSL index /Okec,...,AlUd/
K FOL index /Cair,...,Bagrm8/
M mode of transport /C-17,Truck,HSS/
AIR(M) aircraft /C-17/
LAN(M) land vehicles /Truck/
SEA(M) sea vehicles /HSS/
PER(M) personnel transport vehicles /C-17,Truck,HSS/
H phase /H1*H16/
T time periods which divide up each phase /T1*T73/;

ALIAS (T,N);
```

TABLE **THETA(M,H)** cost of obtaining an additional vehicle of mode M at the beginning of phase H

	H1	...	H16
C-17	0	...	0
⋮			
HSS	0	...	0;

TABLE **PSI(I,K)** shortfall cost per time unit per ton (or per pax) of commodity I not fulfilled at FOL K

	Cair	...	Bagrm8
PAX	0	...	0
⋮			
MUN	0	...	0;

TABLE **OMEGA(I,J,K,M)** cost per ton (or per pax) of commodity I transported from FSL J to FOL K via mode M

	Cair.C-17	...	Bagrm8.HSS
PAX.Okec	732.00	...	80798283.67
⋮			
MUN.AlUd	2988.00	...	80798283.67;

TABLE **PI(K,M)** additional time needed following unloading for commodities to reach FOL K via mode M

	C-17	...	HSS
Cair	0	...	1
⋮			
Bagrm	80	...	12;

TABLE **TAU(J,K,M)** one-way transportation time from FSL J to FOL K (or in opposite direction) via mode M

	Cair.C-17	...	Bagrm8.HSS
Okec	2	...	99999999
⋮			
AlUd	1	...	99999999;

TABLE **C(M,H)** planned systemwide inventory of mode M vehicles at the beginning of phase H

	H1	...	H16
C-17	80	...	80
⋮			
HSS	2	...	2;

TABLE **D(I,K,T)** cumulative demand in tons (or pax) for commodity I at FOL K by time T

PAX.Cair	2091
⋮	
MUN.Bagrm8	1323;

Parameters

DELTA(J) fixed cost incurred to open FSL J with E1(J) and E2(J) square feet of storage space for munitions and non-munitions commodities, respectively

/Okec	9245000.00	
⋮		
AlUd	11463800.00	/

XI1(J) variable cost per square foot of storage space needed beyond E1(J)for munitions commodities at FSL J

/Okec 192.28
⋮
AlUd 238.43 /

XI2(J) variable cost per square foot of storage space needed beyond E2(J)for non-munitions commodities at FSL J

/Okec 75.44
⋮
AlUd 93.55 /

ALPHA(M) number of time periods necessary to load a mode M vehicle

/C-17 1
⋮
HSS 1 /

BETA(M) number of time periods necessary to unload a mode M vehicle

/C-17 1
⋮
HSS 1 /

GAMMA(M) maximum load in tons per mode M vehicle

/C-17 45
⋮
HSS 400 /

ZETA(K) contingency start date at FOL K

```
/Cair          1
  ⋮
Bagrm8   1   /
```

ETA(K) contingency finish date at FOL K

```
/Cair          73
  ⋮
Bagrm8   73   /
```

LAMBDA(M) maximum load in pax per mode M vehicle

```
/C-17    90
  ⋮
HSS      370   /
```

MU(K) phase of contingency occurrence associated with FOL K

```
/Cair          2
  ⋮
Bagrm8   15   /
```

RHO(M) conversion factor for parking space for mode M

```
/C-17    1
  ⋮
HSS      1   /
```

SIGMA(M) utilization rate expressed (for airlift) as the average flying-hour goal per day divided by 24 hours for mode M

```
/C-17     0.4875
  ⋮
HSS       1          /
```

PHI(I) conversion factor for commodity I from tons to square feet of storage space

```
/BOS      28.344
  ⋮
MUN       20.592     /
```

A1(J) max on ground in AIR equivalent vehicles at FSL J

```
/Okec     5
  ⋮
AlUd      5    /
```

A2(J) max on ground in LAN equivalent vehicles at FSL J

```
/Okec     8
  ⋮
AlUd      8    /
```

A3(J) max on ground in SEA equivalent vehicles at FSL J

```
/Okec     0
  ⋮
AlUd      1    /
```

B1(K) max on ground in AIR equivalent vehicles at FOL K

```
/Cair          4
  ⋮
Bagrm8   4   /
```

B2(K) max on ground in LAN equivalent vehicles at FOL K

```
/Cair          8
  ⋮
Bagrm8   8   /
```

B3(K) max on ground in SEA equivalent vehicles at FOL K

```
/Cair          1
  ⋮
Bagrm8   0   /
```

E1(J) minimum square footage needed for an economically feasible FSL at location J for munitions commodities

```
/Okec    5000
  ⋮
AlUd     5000    /
```

E2(J) minimum square footage needed for an economically feasible FSL at location J for non-munitions commodities

```
/Okec    100000
  ⋮
AlUd     100000    /
```

F1(J) maximum potential square feet of storage space at FSL J for munitions commodities

/Okec 100000

⋮

AlUd 100000 /

F2(J) maximum potential square feet of storage space at FSL J for non-munitions commodities

/Okec 800000

⋮

AlUd 800000 /;

Free Variables

OBJ objective;

Positive Variables

N1(J) additional square feet of storage space needed beyond E1(J) for munitions commodities at FSL J

N2(J) additional square feet of storage space needed beyond E2(J) for non-munitions commodities at FSL J

Q(J,M,H) number of mode M vehicles available at FSL J at the start of time T = 1 during phase H

R(M,H) additional mode M vehicles obtained at the beginning of phase H

S(I,K,T) shortfall below demand in tons (or pax) for commodity I at FOL K not fulfilled by time T

V(J,M,T,H) number of mode M vehicles available at FSL J at the end of time T during phase H

X(I,J,K,M,T) tons (or pax) of commodity I sent from FSL J to FOL K via mode M beginning loading on time T;

Binary Variables

W(J) binary variable indicating status of FSL J;

Integer Variables

P(J,K,M,T) number of non-sea mode M vehicles tasked to transport personnel from FSL J to FOL K beginning loading on time T

U(J,K,M,T) number of non-sea mode M vehicles tasked to transport munitions from FSL J to FOL K beginning loading on time T

Y(J,K,M,T) number of non-sea mode M vehicles tasked to transport non-munitions (or total sea mode M vehicles) from FSL J to FOL K beginning loading on time T

Z(J,K,M,T) number of mode M vehicles tasked to make the return trip from FOL K to FSL J departing on time T;

Equations

OBJECTIVE objective function

TOTALNUMBERVEHICLES(M,H) constraint on the total number of mode M vehicles during phase H

FSLVEHAVAIL(J,M,T,H) constraint on mode M vehicle availability at FSL J during time T>1 for phase H

FSLMOGAIR(J,T,H) constraint on MOG of FSL J for air vehicles during time T for phase H

FSLMOGLAN(J,T,H) constraint on MOG of FSL J for land vehicles during time T for phase H

FSLMOGSEA(J,T,H) constraint on MOG of FSL J for sea vehicles during time T for phase H

FOLMOGAIR(K,T) constraint on MOG of FOL K for air vehicles during time T

FOLMOGLAN(K,T) constraint on MOG of FOL K for land vehicles during time T

FOLMOGSEA(K,T) constraint on MOG of FOL K for sea vehicles during time T

DEMANDCONSTRAINT(I,K,T) constraint on meeting cumulative demand for commodity I at FOL K by time T

FSLSTORAMM(J,H) constraint on munitions storage space at FSL J during phase H

FSLSTORAMM2(J) additional constraint on munitions storage space at FSL J

FSLSTORNAM(J,H) constraint on non-munitions storage space at FSL J during phase H

FSLSTORNAM2(J) additional constraint on non-munitions storage space at FSL J

FSLSTORPAX(J) constraint on personnel space at FSL J

UTERATE(M,H) constraint limiting the average fleetwide utilization of mode M vehicles over phase H

BOOKVEHAMM(J,K,M,T) translates tons of munitions transported from FSL J to FOL K beginning loading on time T into mode M non-sea vehicles

BOOKVEHNAM(J,K,M,T) translates tons of non-munitions transported from FSL J to FOL K beginning loading on time T into mode M non-sea vehicles

BOOKVEHSEA(J,K,M,T) translates total tons transported from FSL J to FOL K beginning loading on time T into mode M sea vehicles

BOOKVEHSEAPAX(J,K,M,T) translates personnel transported from FSL J to FOL K beginning loading on time T into mode M sea vehicles

BOOKVEHPAX(J,K,M,T) translates personnel transported from FSL J to FOL K beginning loading on time T into non-sea mode M vehicles

RETURNTRIPVEHICLES(K,M,T) assigns mode M vehicles to return trips following delivery and unloading to FOL K at time T

```
FLOWBALANCEVEH(J,M,T,H) tracks the number of
    mode M vehicles available at FSL J at the end of time
    T>1 for phase H
INITFLOWBALANCEVEH(J,M,H) tracks the number of
    mode M vehicles available at FSL J at the end of time
    T=1 for phase H;
OBJECTIVE.. OBJ =E=
    SUM(J,DELTA(J)*W(J)+XI1(J)*N1(J)+XI2(J)*N2(J))+
    SUM(I,SUM(J,SUM(K,SUM(M,SUM(T,OMEGA(I,J,K
    ,M)*X(I,J,K,M,T))))))+SUM(M,SUM(H,THETA(M,H)
    *R(M,H)))+SUM(I,SUM(K,SUM(T,PSI(I,K)*S(I,K,T)))
    );
TOTALNUMBERVEHICLES(M,H).. SUM(J,Q(J,M,H))
    =E= C(M,H)+R(M,H);
FSLVEHAVAIL(J,M,T,H)$(ORD(T)>1)..
    SUM(K$(MU(K)=ORD(H)),(P(J,K,M,T)+U(J,K,M,T)+
    Y(J,K,M,T))) =L= V(J,M,T-1,H);
FSLMOGAIR(J,T,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(M$AIR(M),SUM(N
    $(ORD(N)<=ALPHA(M)),RHO(M)*(P(J,K,M,N+CEIL
    (ORD(T)-2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1)))))) =L= A1(J);
FSLMOGLAN(J,T,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(M$LAN(M),SUM(
    N$(ORD(N)<=ALPHA(M)),RHO(M)*(P(J,K,M,N+
    CEIL(ORD(T)-
    2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1)))))) =L= A2(J);
FSLMOGSEA(J,T,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(M$SEA(M),SUM(N
    $(ORD(N)<=ALPHA(M)),RHO(M)*(P(J,K,M,N+CEIL
    (ORD(T)-2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    2*ORD(N)+1)))))) =L= A3(J);
```

```
FOLMOGAIR(K,T)$((ORD(T)>=ZETA(K)) AND
    (ORD(T)<=ETA(K)))..
    SUM(J,SUM(M$AIR(M),SUM(N$(ORD(N)
    <=BETA(M)),RHO(M)*(P(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-2*ORD(N)+1)))))) =L=
    B1(K);
FOLMOGLAN(K,T)$((ORD(T)>=ZETA(K)) AND
    (ORD(T)<=ETA(K)))..
    SUM(J,SUM(M$LAN(M),SUM(N$(ORD(N)<=BETA(
    M)),RHO(M)*(P(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-2*ORD(N)+1)))))) =L=
    B2(K);
FOLMOGSEA(K,T)$((ORD(T)>=ZETA(K)) AND
    (ORD(T)<=ETA(K)))..
    SUM(J,SUM(M$SEA(M),SUM(N$(ORD(N)<=BETA(
    M)),RHO(M)*(P(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+U(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-
    2*ORD(N)+1))+Y(J,K,M,N+CEIL(ORD(T)-
    TAU(J,K,M)-ALPHA(M)-2*ORD(N)+1)))))) =L=
    B3(K);
DEMANDCONSTRAINT(I,K,T)$((ORD(T)>=ZETA(K))
    AND (ORD(T)<=ETA(K)))..
    SUM(J,SUM(M,SUM(N$(ORD(N)<=ORD(T)),
    X(I,J,K,M,N)-
    CEIL(TAU(J,K,M)+ALPHA(M)+BETA(M)+PI(K,M)))))
    =G= D(I,K,T)-S(I,K,T);
```

```
FSLSTORAMM(J,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(I$AMM(I),SUM(M,
    SUM(T,PHI(I)*X(I,J,K,M,T))))) =L= E1(J)*W(J)+N1(J);
FSLSTORAMM2(J).. N1(J) =L= (F1(J)-E1(J))*W(J);
FSLSTORNAM(J,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(I$NAM(I),SUM(M,
    SUM(T,PHI(I)*X(I,J,K,M,T))))) =L= E2(J)*W(J)+N2(J);
FSLSTORNAM2(J).. N2(J) =L= (F2(J)-E2(J))*W(J);
FSLSTORPAX(J)..
    SUM(K,SUM(M,SUM(T,X('PAX',J,K,M,T)))) =L=
    SUM(K,SUM(T,D('PAX',K,T)))*W(J);
UTERATE(M,H)..
    SUM(K$(MU(K)=ORD(H)),SUM(J,SUM(T,TAU(J,K,
    M)*(P(J,K,M,T)+U(J,K,M,T)+Y(J,K,M,T)))+
    SUM(T$(ORD(T)<=(CARD(T)-
    TAU(J,K,M))),TAU(J,K,M)*Z(J,K,M,T))+SUM(T$((O
    RD(T)>=(CARD(T)-TAU(J,K,M)+1)) AND
    (ORD(T)<=(CARD(T)-1))),(CARD(T)-
    ORD(T))*Z(J,K,M,T)))) =L=
    CARD(T)*(C(M,H)+R(M,H))*SIGMA(M);
BOOKVEHAMM(J,K,M,T)$((NOT SEA(M)) AND
    (ORD(T)>=ZETA(K)) AND (ORD(T)<=ETA(K)))..
    SUM(I$AMM(I),X(I,J,K,M,T)) =L=
    GAMMA(M)*U(J,K,M,T);
BOOKVEHNAM(J,K,M,T)$((NOT SEA(M)) AND
    (ORD(T)>=ZETA(K)) AND (ORD(T)<=ETA(K)))..
    SUM(I$NAM(I),X(I,J,K,M,T)) =L=
    GAMMA(M)*Y(J,K,M,T);
BOOKVEHSEA(J,K,M,T)$(SEA(M) AND
    (ORD(T)>=ZETA(K)) AND (ORD(T)<=ETA(K)))..
    SUM(I$(AMM(I)+NAM(I)),X(I,J,K,M,T)) =L=
    GAMMA(M)*Y(J,K,M,T);
BOOKVEHSEAPAX(J,K,M,T)$(SEA(M) AND PER(M)
    AND (ORD(T)>=ZETA(K)) AND
    (ORD(T)<=ETA(K))).. X('PAX',J,K,M,T) =L=
    LAMBDA(M)*Y(J,K,M,T);
```

```
BOOKVEHPAX(J,K,M,T)$((NOT SEA(M)) AND PER(M)
    AND (ORD(T)>=ZETA(K)) AND
    (ORD(T)<=ETA(K))).. X('PAX',J,K,M,T) =L=
    LAMBDA(M)*P(J,K,M,T);
RETURNTRIPVEHICLES(K,M,T)$((ORD(T)>=ZETA(K)
    ) AND (ORD(T)<=ETA(K))).. SUM(J,Z(J,K,M,T)) =E=
    SUM(J,P(J,K,M,T-
    CEIL(TAU(J,K,M)+ALPHA(M)+BETA(M)))+
    U(J,K,M,T-
    CEIL(TAU(J,K,M)+ALPHA(M)+BETA(M)))+Y(J,K,M,
    T-CEIL(TAU(J,K,M)+ALPHA(M)+BETA(M))));
FLOWBALANCEVEH(J,M,T,H)$(ORD(T)>1)..
    V(J,M,T,H) =E= V(J,M,T-
    1,H)+SUM(K$(MU(K)=ORD(H)),Z(J,K,M,T-
    CEIL(TAU(J,K,M)))-P(J,K,M,T)-U(J,K,M,T)-
    Y(J,K,M,T));
INITFLOWBALANCEVEH(J,M,H).. V(J,M,'T1',H) =E=
    Q(J,M,H)+SUM(K$(MU(K)=ORD(H)),-P(J,K,M,'T1')-
    U(J,K,M,'T1')-Y(J,K,M,'T1'));
X.FX(I,J,K,M,T)$((ORD(T)<ZETA(K)) OR
    (ORD(T)>ETA(K))) = 0.0;

MODEL board  /ALL/;
SOLVE board USING MIP MINIMIZING OBJ;
.
.
.
P.FX(J,'Ande2',M,T)$(ORD(T)<1) = 0.0;

P.FX(J,'Algi',M,T)$(ORD(T)<25) = 0.0;
.
.
.
P.UP(J,'Ande2',M,T)$((ORD(T)>=1) AND
    (ORD(T)<=25)) = 1000.0;

P.UP(J,'Algi',M,T)$((ORD(T)>=25) AND (ORD(T)<=49))
    = 1000.0;
.
.
.
```

```
P.FX(J,'Ande2',M,T)$(ORD(T)>25) = 0.0;

P.FX(J,'Algi',M,T)$(ORD(T)>49) = 0.0;
.
.
.
U.FX(J,'Ande2',M,T)$(ORD(T)<1) = 0.0;

U.FX(J,'Algi',M,T)$(ORD(T)<25) = 0.0;
.
.
.
U.UP(J,'Ande2',M,T)$((ORD(T)>=1) AND
    (ORD(T)<=25)) = 1000.0;

U.UP(J,'Algi',M,T)$((ORD(T)>=25) AND (ORD(T)<=49))
    = 1000.0;
.
.
.
U.FX(J,'Ande2',M,T)$(ORD(T)>25) = 0.0;

U.FX(J,'Algi',M,T)$(ORD(T)>49) = 0.0;
.
.
.
Y.FX(J,'Ande2',M,T)$(ORD(T)<1) = 0.0;

Y.FX(J,'Algi',M,T)$(ORD(T)<25) = 0.0;
.
.
.
Y.UP(J,'Ande2',M,T)$((ORD(T)>=1) AND
    (ORD(T)<=25)) = 1000.0;

Y.UP(J,'Algi',M,T)$((ORD(T)>=25) AND (ORD(T)<=49))
    = 1000.0;
.
.
.
Y.FX(J,'Ande2',M,T)$(ORD(T)>25) = 0.0;

Y.FX(J,'Algi',M,T)$(ORD(T)>49) = 0.0;
Z.UP(J,K,M,T) = 1000.0;
* separate the facility construction and transport costs
```

```
PARAMETERS
FACCOST facility construction cost
TRANCOST transport cost
FROMTO(I,J,K,M) tons (or pax) of commodity I shipped
    from FSL J to FOL K via mode M;
FACCOST =
    SUM(J,DELTA(J)*W.L(J)+XI1(J)*N1.L(J)+XI2(J)*N2.L
    (J));
TRANCOST =
    SUM(I,SUM(J,SUM(K,SUM(M,SUM(T,OMEGA(I,J,
    K,M)*X.L(I,J,K,M,T))))));
FROMTO(I,J,K,M) = SUM(T,X.L(I,J,K,M,T));
```

APPENDIX C

Air Lifter and Refueler Characteristics

One of the major factors in selecting a forward support location is its transport capability and capacity, and that capability and capacity can dictate the type of aircraft that can be used at a base and the load capacity it can handle. The tables in this appendix present the characteristics of various aircraft of interest.[1]

Table C.1
Aircraft Size

Aircraft	Length (feet)	Width (feet)[a]	Maximum Weight (feet)	Parking Spots (C-141 = 1)
C-130	99.50	132.60	175,000	0.5
C-141	168.40	160.00	343,000	1.0
C-17	173.92	169.75	585,000	1.13[b]
C-5A/B	247.80	222.70	840,000	2.0
KC-10	181.60	165.30	593,000	1.1
KC-135	136.25	130.85	322,500	0.7
B-747	231.83	195.67	836,000	1.7
DC-10	182.25	165.33	593,000	1.1

[a] Wingtip clearance: ten feet on each side with wing walker, 25 feet on each side without wing walker. (The restrictions do not apply to the Civil Reserve Air Fleet.)
[b] With a wing walker, the C-17 can park in a C-141 spot.

[1] All data in this appendix are from U.S. Air Force, 1998.

Table C.2
Aircraft Payloads

Aircraft	Pallet	Cargo (short tons)		Passengers		NEO
	Position	ACL[a]	Planning[b]	ACL	Planning	Passengers
C-130	6	17	12	90	80	92/74[c]
C-141	13	30	19	153	120	200/153
C-17	18	65	45	102	90	102
C-5A/B	36	89	61.3	73	51	73
KC-10[d]	25	60	32.6	75	68	75
KC-135	6	18	13	53	46	53
B-747	44	100	86	335	335	390
DC-10	30	72	62	210	210	280

NOTE: Cargo and passenger payload (except for the C-5) are exclusive of one another.
[a] Organic cargo is calculated as the maximum allowable cabin load (ACL) for a 3,200-nautical-mile leg; CRAF is calculated for a 3,500-nautical-mile leg.
[b] These numbers represent the historical average.
[c] The lower noncombatant evacuation operation (NEO) numbers reflect life-raft capacity.
[d] Includes KC-10 (airlift) and KC-135 (airlift).

Table C.3
Aircraft Block Speeds

Aircraft	500 nm	1,000 nm	1,500 nm	2,000 nm	3,000 nm	4,000 nm	5,000 nm
C-130	185	208	246	262	—	—	—
C-141	227	332	370	386	399	414	—
C-17	243	348	386	402	415	430	—
C-5A/B	242	347	385	401	414	429	429
KC-10	267	372	410	426	439	454	454
KC-135	252	357	395	411	424	439	439
B-747	287	392	430	446	459	474	474
DC-10	277	381	420	436	449	464	464

Table C.4
Ground Times

Aircraft	Passenger and Cargo Operations Wartime Planning Times (hours plus minutes)				Minimum Crew Rest Times (hours plus minutes)
	Onload	Enroute	Offload	Expedited[b]	
C-130	1 + 30	1 + 30	1 + 30	0 + 45	15 + 15
C-141	2 + 15	2 + 15	2 + 15	1 + 15	16 + 00
C-17	2 + 15	2 + 15	2 + 15	1 + 45	16 + 00
C-5A/B	4 + 15	3 + 15	3 + 15	2 + 00	17 + 00
KC-10	4 + 15	3 + 15	3 + 15	3 + 15	17 + 00
KC-135	3 + 30	2 + 30	3 + 30	2 + 30	17 + 00
B-747	3 + 30/ 5 + 00[a]	1 + 30	2 + 00/ 3 + 00[a]	—	—
DC-10	2 + 30/ 5 + 00[a]	1 + 30	3 + 00	—	—

[a] Includes passengers and cargo.
[b] Includes onload or offload operations only. Does not include refueling or reconfiguration operations.

Table C.5
Aircraft Utilization

Aircraft	UTE Rate[b]		Contingency	Inventory[c]	
	Surge	Sustain	USE Rate	2003	2012
C-130	6.0	4.0	6.0	514	361[d]
C-141	12.1	9.7	7.4	74	0
C-17	15.15	13.9	11.7	109	109[e]
C-5A/B	10.0/11.4	8.4/8.4	5.8/7.5	126	112
KC-10[a]	12.5	10	7.9	59	59
KC-135[a]	—	—	5.6	547	486
B-747	10	10	10	—	—
DC-10	10	10	10	—	—

[a] KC-10 and KC-135 UTE rates apply in the airlift role.
[b] Surge UTE rates apply for the first 45 days (C-130s surge for 30 days).
[c] Inventory data are from Capt. Steven Oliver, AFLMA/LGM.
[d] Does not include the potential buy of an additional 94 C-130Js.
[e] Does not include the potential buy of an additional 71 C-17s.

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