An Assessment of Alternative Transports for Future Mobility Planning

Myron Hura, John Matsumura, Richard Robinson

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PREFACE

The aim of this study is to help the Office of the Under Secretary of Defense for Acquisition identify attractive sealift and airlift candidates for planning FY 1999 mobility programs. To do so, the work examines existing strategic mobility programs and then projects their capabilities into the late 1990s. Taking these projected capabilities into account, it identifies and assesses alternative combinations of sealift and airlift options in postulated future deployments. The focus of the study is on sealift and airlift options for carrying combat unit equipment and support.

The initial motivation for this research, which began in 1990, arose from the then-important Conventional Forces in Europe (CFE) reduction talks between the former Soviet Union and the United States. The objective of the study was to determine the implications of CFE on future mobility programs. Because of the revolutionary changes in Eastern Europe and the disintegration of the Soviet Union, the focus of the study shifted to postulated potential deployments to Southwest Asia, Northeast Asia, and to a representative third world austere destination. This study was done independently of the classified Mobility Requirements Study.

This work builds on some of the work done in RAND's Future Distribution System Study. That work is helping DoD to formulate a long-range plan to coordinate the design, positioning, and transport of military unit equipment and sustainment materiel. This report addresses near-term options for airlift and sealift programs for deploying unit equipment. The Future Distribution System Study considers some of the same options from a longer-term perspective.

This research was conducted for the Office of the Under Secretary of Defense for Acquisition, within the Acquisition and Support Policy Program of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and the Joint Staff.

SUMMARY

Existing U.S. strategic mobility programs were planned to support the deployment of large forces from the United States to Europe and regions on the periphery of the former Soviet Union, in the context of a global conflict with the Soviet Union and its allies. To support these demanding requirements, DoD made substantial investments in government-controlled transportation programs. The procurement of C-5s, Fast Sealift Ships, Maritime Prepositioning Ships, and Afloat Prepositioning Ships and the creation of the Ready Reserve Force are the most visible examples. In Operation Desert Shield, these programs, augmented by commercial charter ships and commercial aircraft in the Civil Reserve Air Fleet program, allowed the United States to deploy the combat unit equipment of 4 and 2/3 Army divisions, two Marine expeditionary brigades, and a large number of Air Force tactical and support squadrons to Saudi Arabia in roughly 90 days.

Now, however, the end of the Cold War and the increasing need to solve economic problems are likely to limit DoD expenditures on mobility programs. Yet the ability to project forces rapidly to distant places remains central to U.S. national security. To assist the Office of the Under Secretary of Defense for Acquisition (OUSD (A)) in planning future mobility programs that will respond to this dramatically changed environment, this analysis identifies cost-effective airlift and sealift candidates to augment projected FY 1999 capabilities of existing mobility assets and suggests alternative strategies for planning future mobility programs.

Because future deployment requirements are uncertain, alternative transport options were measured in postulated deployments of a notional major regional conflict force (MRCF), with either 900,000 or 1,000,000 stons of combat unit equipment (u/e) and combat service and combat service support (cs/css) to Southwest Asia (SWA), with and without use of the Suez Canal, and to Korea.[1] Four closure options for the MRCF, ranging from 50 to 90 days, were used in the analysis.[2] To ensure that transport combinations designed to deploy the MRCF were adequate to deploy a smaller force to austere loca-

[1]The notional MRCF consists of 4 and 2/3 Army divisions, two Marine expeditionary brigades, 24 Air Force aircraft squadrons, and three Navy carrier battle groups.

[2]Closure means the delivery of all MRCF unit equipment and cs/css to deployment destinations by a specified date.

tions, the analysis also examined the deployment of a notional low-intensity conflict force, with 60,000 stons of u/e and cs/css, to Zaire in 30 days.[3]

PREFERRED TRANSPORT CANDIDATES

Taking into account FY 1999 projected capabilities of existing mobility programs, as well as their actual performance in Operation Desert Shield, the analysis examined 11 alternative transport candidates. Four preferred candidates emerged from the analysis:

- The new C-17 military airlifter,[4]
- A new construction 30-knot fast sealift ship (NSL-7),
- A new-design large 24-knot roll-on/roll-off ship (950-ft. Ro/Ro), and
- A new-design large 24-knot prepositioning ship (Prepo).

The Prepo candidate has the same hull and propulsion plant as the 950-ft. Ro/Ro, but is equipped with additional air-conditioning units and with environmental controls to support the long-term storage of military equipment. Thus, from a ship-construction perspective, only two new types of sealift candidates would have to be built.

Assuming that the C-17 meets design specifications to operate on austere airfields, its procurement would add flexibility to existing airlift programs. In the more demanding cases examined, the C-17 proved necessary for delivering required cargo to constrained aerial ports of debarkation (APODs). The choice among the preferred sealift candidates varies as a function of closure requirements and transit routes. NSL-7s and Prepo ships are the only sealift candidates capable of delivering cargo in 30 days or less to SWA, without access to the Suez Canal. They proved necessary to augment existing sealift programs to meet the requirements of the most demanding cases. The NSL-7s were also cost-effective in some of the less demanding cases. In the majority of cases examined, the 950-ft. Ro/Ro, maintained in reduced operating status, is the most cost-effective sealift candidate for meeting less time-demanding deployment options. The distinct capabilities of the preferred candidates suggest that combinations of these candidates be considered in planning future mobility programs.

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[3]The notional low-intensity conflict force consists of the 82nd Airborne Division, two Brigades of a light infantry division, six Air Force squadrons, a Special Forces unit, an amphibious Marine expeditionary brigade, and one Navy carrier battle group.

[4]The C-17 is in the initial stages of testing.

STRATEGIES FOR PLANNING FUTURE MOBILITY PROGRAMS

Because future deployments are uncertain, decisionmakers should probably consider a range of strategies in planning future mobility programs. At one extreme, they may choose to design mobility programs to meet the most demanding requirements. In the cases examined, this becomes the capability of closing the early air cargo of the MRCF in 12 days and 1 million stons of u/e and cs/css to SWA, without access to the Suez Canal, in 60 days, or to Korea in 50 days. To meet these demanding requirements, a combination of 80 C-17s,[5] 10 Prepo ships, 18 NSL-7s and 26 950-ft. Ro/Ro's have to be added to the baseline. The procurement of these new assets requires an estimated investment of about $30.5 billion, with C-17s accounting for over half of this total. Using foreign charter ships to deliver some of the late cs/css cargo decreases the number of 950-ft. Ro/Ro's by nine, and the required investment by roughly 8 percent.

At the other extreme, choosing to improve existing sealift capabilities only modestly and to maintain demonstrated airlift capabilities requires an investment of about $3.1 billion in 12 new 950-ft. Ro/Ro's. Using foreign charter ships to carry some of the late cs/css would decrease the number of 950-ft. Ro/Ro's by seven, the investment by roughly 60 percent. This strategy would allow closure of the early air cargo of the MRCF in about three weeks and of all cargo in 90 days to SWA, with and without Suez, or to Korea.

As an intermediate option, choosing to improve existing sealift capabilities only modestly and to improve airlift capabilities to deliver cargo to constrained APODs or austere locations requires an investment of about $19.5 billion in 80 C-17s and 12 new 950-ft. Ro/Ro's. This allows the closure of the early air cargo of the MRCF in 12 days and of all cargo in 90 days to SWA, with and without access to the Suez Canal, or to Korea. The added airlift capabilities are also sufficient to close the LICF in 30 days to Zaire.

In operations to constrained airfields, the estimated number of C-17s is highly sensitive to early cargo delivery requirements, and to APOD constraints, expressed as working maximum on the ground (MOG). A 10-percent increase in early cargo requirements, or a 10-percent decrease in MOG, increases the number of C-17s by roughly 40 to 60 percent. These results suggest that (1) in-depth analysis of early air-

[5]The quantity of C-17s is in terms of primary aircraft authorization, which may be 10 to 15 less than the total aircraft inventory.

cargo requirements is an essential element for sizing the C-17 buy, and (2) alternatives for reducing MOG constraints should be explored.

Clearly, the range of strategies—and of costs—is very wide. Choosing among them with confidence requires in-depth analyses of future threats to U.S. national interests and of DoD-planned responses to those threats. Until such analyses are completed, the choice of planning strategies will rely primarily on policymakers' perceptions of future threats and judgments as to what mobility capabilities are sufficient to meet those threats. Until detailed analysis can be completed, **this analysis suggests that initial investments be made to improve modestly the capabilities of existing mobility programs into the future.** If in-depth analysis verifies that rapid deployment requirements beyond the capabilities of existing programs are essential, the DoD should continue the procurement of C-17s and invest in a combination of 30-knot NSL-7s and 24-knot 950-ft. Ro/Ro's and Prepo ships.

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ACRONYMS AND ABBREVIATIONS

ABN	Airborne
AF	Air Force
AMC	Air Mobility Command
APOD	Aerial port of debarkation
APOE	Aerial port of embarkation
APS	Afloat Prepositioning Ship
B/B	Breakbulk Ship
B-747	Boeing 747
B/C	Build and charter
C^3	Command, control, communications
CFE	Conventional Forces in Europe
CINC	Commander in chief
CONUS	Continental United States
CRAF	Civil Reserve Air Fleet
cs/css	Combat service and combat service support
CV BG	Carrier battle groups
DoD	Department of Defense
FSS	Fast Sealift Ship
+F	Plus foreign charter ships
kts	Knots
lb	Pound
LICF	Low intensity conflict force
MAC	Military Airlift Command
MARAD	Maritime Administration
MEB	Marine expeditionary brigade
MEF	Marine expeditionary force
MOG	Maximum on the ground
MPS	Maritime Prepositioning Ship
MRCF	Major regional contingency force
MSC	Military Sealift Command
NA	Not applicable
NCA	National Command Authorities
n mi	Nautical miles
ODS	Operation Desert Shield
O&S	Operations and support
OUSD (A)	Office of the Under Secretary of Defense for Acquisition
PAA	Primary aircraft authorization
Prepo	Prepositioning ship
Ro/Ro	Roll-on and roll-off
ROS	Reduced operating status

RRF	Ready Reserve Fleet
SAR	Selected Acquisition Report
SECDEF	Secretary of Defense
Sqdns	Squadrons
SPOD	Seaports of debarkation
SPOE	Seaports of embarkation
SRP	Sealift Readiness Program
SSS	Strategic Sealift Ship
sq. ft.	Square feet
stons	Short ton, 2000 lbs
SWA	Southwest Asia
T-ACS	Auxiliary crane ship
u/e	Unit equipment
UTE	Utilization, in hours per day

1. INTRODUCTION

The initial motivation in 1990 for our study of alternative mobility programs for the future arose from the then-important Conventional Forces in Europe (CFE) reduction talks between the former Soviet Union and the United States. The objective of the study was to determine the implications of CFE reductions for existing mobility program planning and to assist the Office of the Under Secretary of Defense for Acquisition (OUSD (A)) in developing alternative mobility programs for the near future. To take into account uncertainties about future deployments, the study was structured to examine the performance of alternative mobility programs not only to Europe but to other regions of potential interest as well—Southwest Asia; Northeast Asia; and a representative, austere, Third World destination.

The dissolution of the Warsaw Pact, the reunification of Germany, and the revolutionary changes in the former Soviet Union substantially diminished the importance of CFE reductions. Equally important, the recent revolutionary changes in Eastern Europe and the former Soviet Union changed the framework used in mobility program planning. Before these events, mobility programs were planned in the context of a global conflict with the Soviets and their Warsaw Pact allies, in which the United States had to deploy large forces to Europe and other regions on the periphery of the Soviet Union to counter a very large threat.

To support the large deployment requirements of the global conflict scenario, DoD has made substantial investments in mobility assets over the past 15 years. The procurement of C-5s, Fast Sealift Ships (FSSs), Maritime Prepositioning Ships (MPSs), and the creation of the Ready Reserve Force (RRF) being the most visible examples. Despite these improvements, major mobility studies indicated that existing assets were insufficient to meet existing requirements.[1] Results from such studies were used to design new transportation programs, and to provide rationale for funding requests to execute those programs. Currently, DoD has one major program in progress, the C-17, and a planned initiative, the Navy Strategic Sealift Implementation Plan. But because of the radical changes still taking place, DoD now faces major challenges in planning and justifying fu-

[1]Commission on Merchant Marine and Defense, *Second Report of the Commission on Merchant Marine and Defense: Recommendations*, December 30, 1987.

ture mobility programs. The characteristics and locations of future deployments are uncertain. Also, DoD faces declining budgets, which likely will limit investment in new mobility assets. An increased understanding of the contributions of these programs to a new planning framework is important.

To assist OUSD (A) in planning future mobility programs, this analysis identifies cost-effective transport candidates for planning FY 1999 programs and suggests alternative strategies for future mobility planning. **Because of the uncertainties about future deployments, we postulate a reasonable range of deployment requirements that might be appropriate for the future.** The hypothetical deployment requirements were not derived from wargaming analysis. These notional deployments are used to assess the performance of existing programs and alternative transportation assets. From the analysis, we extract cost-effective transportation options for augmenting the projected FY 1999 capabilities of existing strategic mobility programs and provide rough-order-of-magnitude cost estimates for developing alternative capabilities.

The study focuses on transport options for deploying combat unit equipment and support. The study did not examine alternative transport options for ammunition and sustainment cargo. However, the analysis takes into consideration the effect of these requirements by reserving a percentage of transport assets to carry that cargo.

In assessing baseline capabilities, we relied on the experiences of Operation Desert Shield, which began two months after we started to examine the potential capabilities of alternative transportation assets in deploying a major regional conflict force (MRCF) to Southwest Asia. Because the Operation Desert Shield (ODS) deployment tested most of the existing sealift and airlift programs, we closely examined their demonstrated performance and compared it to their advertised potential capability. Section 2 presents the sealift analysis and the important implications for future sealift planning. Section 3 discusses the demonstrated performance of existing airlift assets in ODS and implications for future airlift planning.

Section 4 describes the analytical framework used in assessing alternative transportation programs and describes candidate transports. Section 5 evaluates the capabilities of existing and alternative transportation programs to support notional deployment capabilities to Southwest Asia (with and without use of the Suez Canal), Korea, and Zaire (chosen as a representative austere, Third World destination). Section 6 presents the conclusions and recommendations that emerge from the analysis.

2. EXISTING SEALIFT CAPABILITIES

This section of the report characterizes existing U.S. sealift assets and estimates the capabilities they provide. It does so by examining their performance in support of the Operations Desert Shield and Desert Storm. Their actual performance is compared to their potential capabilities, as derived from planning factors used in earlier strategic mobility analyses. From this comparison, we determine the factors that prevented the realization of the potential and draw implications on how they may affect future mobility planning. We also examine the role of commercial charter ships, both U.S. and foreign flag, in ODS and the implications for future sealift planning.

EXISTING U.S. SEALIFT PROGRAMS

Existing U.S. sealift programs can be divided into two general categories: (1) government-controlled ships and (2) U.S.-flag commercial ships. The next two sections present the characteristics and contrast the capabilities of ships in these two categories in terms of availability, speed, and cargo capacity.

U.S. Government-Controlled and U.S.-Flag Commercial Shipping

Government-controlled shipping includes both active and inactive ships controlled by the Military Sealift Command (MSC) and inactive ships maintained by the Maritime Administration (MARAD). DoD has ready access to these ships to support force deployments. As of September 1990, 112 out of a total of 263 U.S. dry-cargo sealift ships were in one of four government-controlled programs: (1) MPS, (2) Afloat Prepositioning Ship (APS), (3) FSS, and (4) the RRF (Table 1).[1]

Maritime Prepositioning Ships. MPSs support the early deployment of Marine Corps forces. There are 13 MPSs, divided into three squadrons, with each squadron carrying the equipment and 30 days of supplies for a Marine expeditionary brigade (MEB). These ships are manned and operated by commercial firms under charter to MSC. The squadrons are based on the East Coast of the United States,

[1]Maritime Administration, *RRF Ship Inventory*, MAR-745, January 1, 1991.

Table 1

Government-Controlled Dry-Cargo Ships

Program	MPS	APS	FSS	Ready Reserve Fleet			
				Ro/Ro	B/B[a]	Barge[b]	T-ACS[c]
Number	13	8	8	17	51	7	8
Speed (kts)	19	16–22	30	20	17	18	17
Cargo capacity (sq. ft.)	125,000	82,000	165,000	110,000	40,000	95,000	40,000
Activation (day)	1	1	4		5/10/20		

[a]Breakbulk ships.

[b]Ships designed to carry barges or lighters.

[c]Auxiliary crane ship.

Diego Garcia, and Guam. MPSs can sail on a day's notice in response to contingency orders. Their maximum sustained speed is slightly less than 20 knots. After delivering their prepositioned cargo, MPSs are available for common-user lift operations. The average cargo capacity of an MPS is about 125,000 sq. ft.[2]

Afloat Prepositioning Ships. Like MPSs, the 12 APSs are fully manned and loaded with cargo. The APSs are based overseas, one in the Mediterranean and 11 at Diego Garcia. Eight of the 12 APSs are dry-cargo ships, and four are tankers. The dry cargo ships carry ammunition, supplies, and port operating equipment. The APSs are operated by commercial firms under charter to MSC. They have maximum sustained speeds in the range of 16 to 22 knots. After delivering prepositioned cargo, APSs are typically used in delivering ammunition and sustainment cargo, but not in deploying combat equipment.

Fast Sealift Ships. The eight FSSs are large container ships, purchased by DoD from Sealand Corporation and converted to partial roll-on/roll-off (Ro/Ro) ships. Their capacity, 165,000 sq. ft.,[3] makes them the largest dry cargo sealift ships in the U.S. inventory. FSSs are maintained by partial crews in reduced operating status (ROS), with a readiness to sail within four days. When new, the SL-7s were

[2]This is the average cargo carried by the MPSs of the Diego Garcia squadron in Operations Desert Shield and Desert Storm. Source: R. Rost et al., *Sealift Operation Desert Shield/Desert Storm: 7 August 1990 to 17 February 1991*, Center for Naval Analysis, Alexandria, Virginia, May 1991.

[3]This capacity reflects the application of a 0.75 cargo-stowage factor to the 220,000 sq. ft. of the nominal usable area of an FSS.

capable of a maximum speed of about 33 kts. Conversion to FSSs reduced their nominal maximum speed to about 30 kts.

Ready Reserve Force. In 1990 the RRF consisted of 96 ships, of which 83 were dry-cargo ships. The dry-cargo ships can be subdivided into four general categories: Ro/Ro's, breakbulks, heavylift barge ships, and auxiliary crane ships (T-ACS). In Operations Desert Shield and Desert Storm, RRF Ro/Ro's carried roughly 110,000 sq. ft. of cargo or more than double the capacity of breakbulks and T-ACS.[4] The maximum sustained speeds of RRF ships are 17 to 20 kts.

RRF ships are laid up and maintained under the control of MARAD in one of three advertised readiness conditions: (1) The bulk are in 5-day readiness, (2) others are in 10-day readiness, and (3) the remaining small fraction in 20-day readiness.[5] After orders are issued, RRF ships have to be towed to repair facilities for activation and have to be manned by personnel drawn primarily from the Merchant Marine. Consequently, the RRF cannot respond as rapidly as the MPSs, APSs, or FSSs to emergent requirements.

Commercial U.S.-Flag Shipping

To support military operations, MSC can also charter commercial ships. However, the future availability of commercial ships is difficult to predict. Trade patterns, economic considerations, and contractual agreements between shippers and customers may substantially affect the availability of commercial ships. For example, commercial shipping companies may be reluctant to disrupt scheduled civilian-sector operations to support DoD requirements for fear of losing long-term customers.

If DoD cannot charter sufficient ships, it can call up commercial ships in the Sealift Readiness Program (SRP). All U.S. shipping companies that received construction differential subsidies, or receive operating differential subsidies, have to commit at least half of their ships to the SRP. Moreover, shipping companies that compete for Department of Defense cargo must commit half of their U.S.-flag ships to the SRP. The Secretary of Defense, in conjunction with the Secretary of Transportation, can call ships in the SRP to support military operations.

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[4]R. Rost et al., *Sealift Operation Desert Shield/Desert Storm: 7 August 1990 to 17 February 1991*, Center for Naval Analysis, Alexandria, Virginia, May 1991.

[5]At the start of Operation Desert Shield, roughly 75 percent of the ships activated were listed in the 5-day readiness category.

Commercial U.S.-flag dry-cargo ships that are used in carrying military cargo can be subdivided into four general classes: breakbulk, Ro/Ro, container ships, and car carriers. As shown in Table 2, in January 1989, there were 151 privately owned dry-cargo ships in the U.S.-flag fleet; 93, or about 60 percent, of those were in the SRP.[6] Container ships constitute roughly 60 percent of the U.S. commercial dry-cargo fleet. Because they are configured with open cells for carrying containers and lack decks, container ships cannot, without modification, carry the bulk of military equipment.[7] Moreover, DoD relies on container ships for resupply and sustainment cargo operations.[8] Consequently, only a small number of container ships are likely to be used in deploying unit equipment.

Commercial car carriers are designed to carry smaller and lighter vehicles than most of those used by the military. Therefore, their utility in military cargo operations is limited—with some modifications, they may carry jeep-type vehicles. Because of these limitations, car carriers are not typically counted on for deploying military equipment. Subtracting container ships and car carriers, the U.S.-flag commercial fleet in the near future may provide, at most, 50 ships to support the deployment of military equipment. The maximum speed of these ships is in the range of 16 to 20 kts. In ODS the average commercial Ro/Ro carried roughly 75,000 sq. ft. of cargo, or slightly less than twice the cargo carried by breakbulks.

Table 2

Commercial U.S.-Flag Dry-Cargo Ships

Class	Ro/Ro	Breakbulk	Container	Car Carriers
Number	20	31	95	5
Speed (kts.)	20	16–20	20	18
Cargo Capacity (sq. ft.)	75,000	40,000	NA	NA

[6]Military Sealift Command, *1990 Sealift Readiness Program (SRP) Data*, electronic message to U.S. Commander-in-Chief, Transporation Command, 131807Z, February 1990.

[7]Flatracks and seasheds may be inserted in container ship cells to provide deck space on which to carry military vehicles and other equipment.

[8]In ODS, container ships under the Special Mid-East Shipping Agreement between the MSC and U.S. commercial ship owners were used to deliver most of the nonammunition sealifted sustainment supplies.

DEMONSTRATED PERFORMANCE OF SEALIFT IN ODS

The deployment operations in support of Operations Desert Shield and Desert Storm involved all existing government-controlled programs and extensively used domestic and foreign commercial ships. In examining the sealift operations, we focus on the deployment of unit equipment (u/e) and combat service and combat service support equipment (cs/css) during the first 90 days of the deployment. During this period, with the exception of a helicopter brigade, the u/e and cs/css of major units deployed from CONUS. Given the ongoing contraction of forward-based U.S. forces we consider this case to be more representative of future operations. Then we briefly discuss follow-on ODS force deployments, in which sealift moved u/e and cs/css from the Continental United States (CONUS) and Europe. We did not examine sustainment operations, because they relied primarily on container ships not used in deploying u/e and cs/css.

Early Cargo Deliveries in ODS

In the first 90 days, sealift delivered roughly 10 million sq. ft. of u/e and cs/css to Saudi Arabia. U.S. government–controlled ships accounted for about 70 percent of these deliveries. Foreign and U.S. charter ships carried the remaining 30 percent, with foreign charter ships delivering the bulk of this fraction (Figure 1).

The initial deliveries were made by MPSs, which began unloading cargo on the eighth day of the operation. APSs began making deliveries shortly thereafter. These initial deliveries were followed by FSSs, which began delivering cargo 20 days into the deployment. U.S. commercial charter ships began delivering cargo on day 32, and foreign charter ships began significant deliveries roughly 45 days into the operation.

The delivery profiles depicted in Figure 1 underline the distinct capabilities of various sealift programs. MPSs and APSs, because of their high readiness and forward positioning, began delivering cargo within the first two weeks of ODS. FSSs, because of their high readiness and high speed, began delivering cargo within three weeks. RRF and commercial charters did not make initial deliveries in the first 30 days.

Demonstrated Performance of MPSs

The full potential of MPSs was not realized during ODS, primarily because of two factors: (1) policy decisions to delay sailing of MPSs and

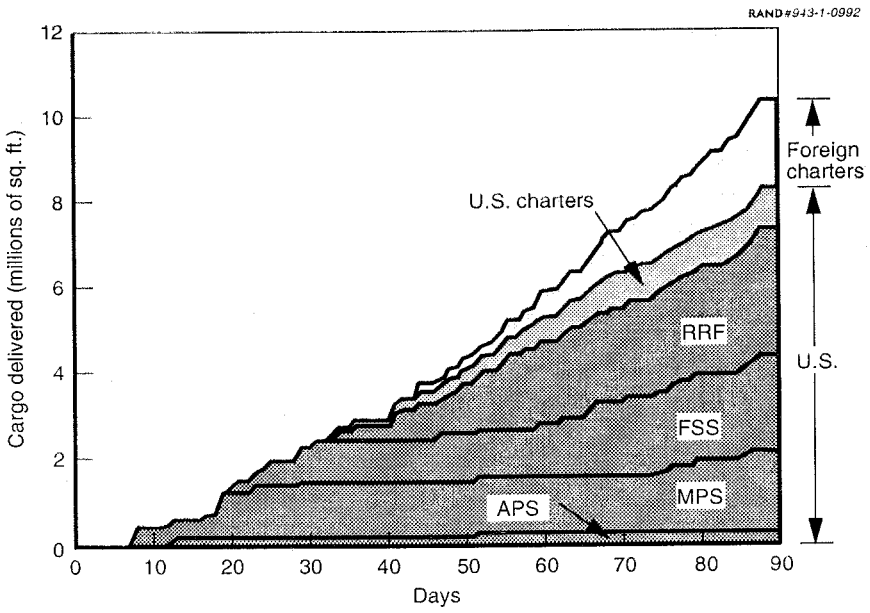

Figure 1—Cargo Deliveries in the First 90 Days of ODS

(2) management and coordination of MPSs. Policymakers chose not to sail MPSs from their forward positions to the Persian Gulf on August 2, 1991, the day that Iraq invaded Kuwait. Had this decision been made, ships from the Diego Garcia squadron could have arrived three days after ODS began, or 5 days earlier than their actual arrival (Figure 2). A similar delay is reflected in the performance of the Guam MPS Squadron (Figure 3).

In ODS, the delays in closure did not affect the outcome of the operation, but in future operations they might. Because MPSs are fully manned, loaded, and prepositioned at forward locations, they can be ordered to sail on warning and proceed to conduct operations in international waters in the vicinity of areas of potential conflict, well before hostilities commence. But if decisionmakers choose not to sail MPSs on warning, some of the advantage is lost.

The closure of both MPS squadrons was also delayed because not all ships were in their designated forward locations. One ship of the Diego Garcia squadron was in Norfolk, Virginia, on August 7 for scheduled maintenance. Before proceeding to Saudi Arabia, it had to

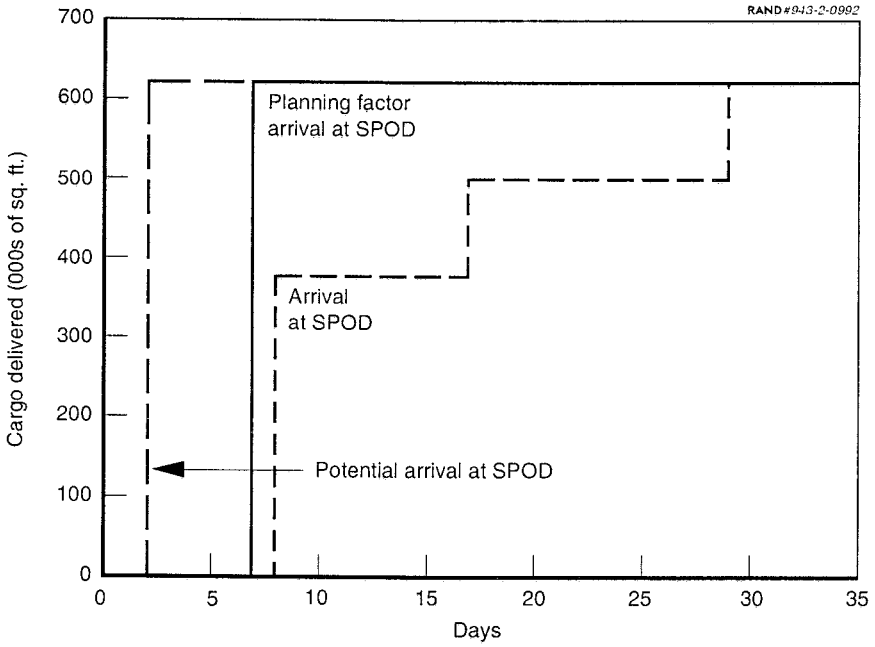

Figure 2—Potential and Actual Performance of the Diego Garcia MPS Squadron

sail to Blount Island, Florida, and load cargo. As a result, it did not arrive at the port of debarkation until day 29. A second Diego Garcia MPS was en route to CONUS and did not arrive in Saudi Arabia until day 16. The performance of the Guam squadron was closer to planning-factor expectations. Only one ship, returning from an exercise off the U.S. West Coast, was not in the vicinity of Guam when ODS began.

The above events suggest the need for improved management of MPS during peacetime operations. The departure of ships from forward locations for routine maintenance should be better coordinated. Studies suggest that, routinely, only one ship out of 13 should be off station for scheduled maintenance.[9] Moreover, exercises involving MPS ships could be conducted in their areas of operations to minimize closure delays.

[9]Naval Audit Service, *Logistics Planning for the Maritime Prepositioning Ships Program*, Falls Church, Virginia, February 29, 1989.

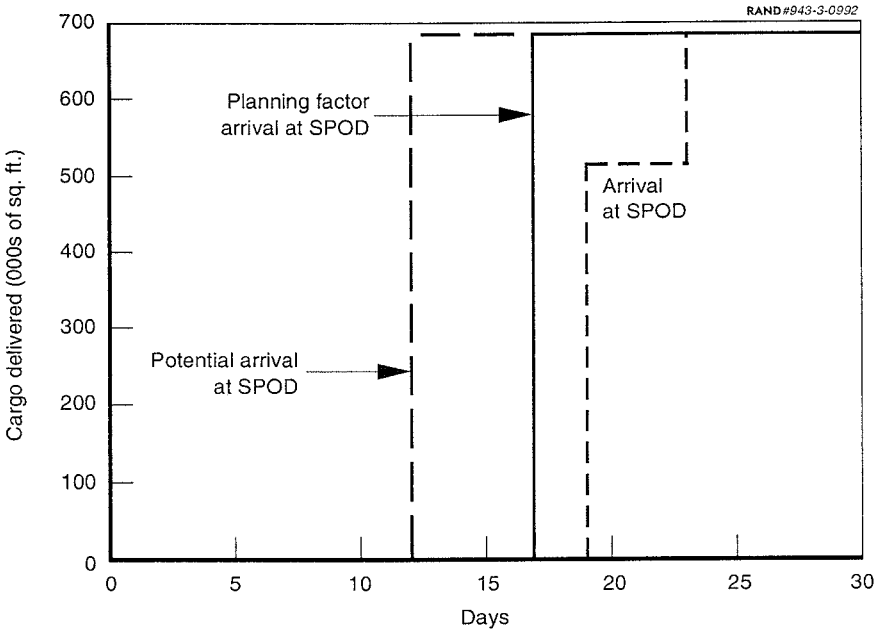

Figure 3—Potential and Actual Performance of the Guam MPS Squadron

Fast Sealift Ship Performance in ODS

On the basis of planning-factor expectations, one would anticipate the arrival of FSSs at seaports of embarkation (SPOEs) in four to six days to commence loading operations. As Figure 4 shows, actual arrivals at SPOEs were close to that of planning factor expectations. Experience with FSS peacetime operations since 1986 indicates that, on the average, one ship is in overhaul.[10] At the start of ODS, the *Denebola* was in overhaul. It took several extra days to make her ready for deployment: as a result, she did not deliver cargo until day 31.

Six of the FSSs closed before day 30, or nearly as anticipated, given the departure schedule from CONUS. One of the FSSs, the *Antares*, experienced a series of engineering plant casualties in the Atlantic

[10]Rolph Marshall, *Fast Sealift Ship Performance in Operation Desert Shield 90: Preliminary Assessment and Recommended Planning Factors for Surge Deployment Analysis,* Deputy Chief of Naval Operations (Logistics), Strategic Sealift Division, December 11, 1990.

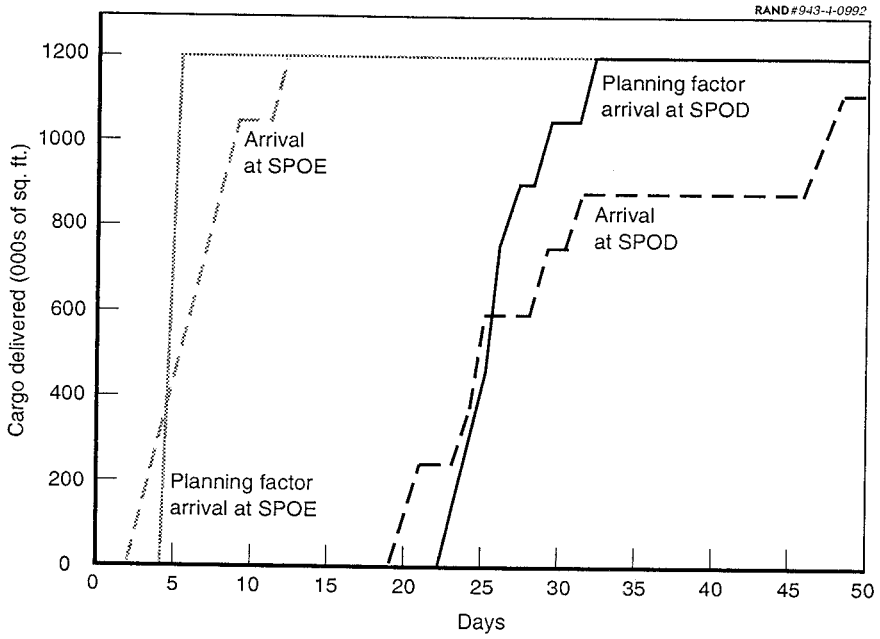

Figure 4—Initial Cycle Performance of FSSs

and had to put into Rota, Spain. Her cargo was picked up by another FSS, the *Altair,* after she completed her initial delivery to Saudi Arabia. As a result, the initial delivery of the FSS force was not completed until day 47. After the breakdown, the *Antares* did not participate in any other operations. This suggests the need for improved maintenance of FSSs during peacetime. The remaining seven FSSs continued to make other deliveries, with four completing three deliveries in 104 days.

Prior to ODS, the *Antares* had a fire that affected her boiler combustion and control systems. Also, she was scheduled for periodic maintenance about the time that ODS began. Because of the need for early delivery of heavy unit equipment, a decision was made to defer her maintenance.

The *Antares'* requirement for maintenance and her subsequent breakdown highlight the fact that it is unrealistic to base planning assumptions on availability of the full ship fleet for deployment operations. A certain percentage of ships at any given time is likely to be unavailable to support deployments. ODS experience suggests that about a 90-percent ship availability is reasonable for planning future

deployments. This assumes close coordination of FSS maintenance and participation in peacetime training operations.

RRF Contribution in the First 90 Days of ODS

During the first 90 days of ODS, only 43 of 83 dry-cargo ships of the RRF were activated. This decision made available only 2.8 million sq. ft. out of about 4.4 million sq. ft. of RRF shipping to support Desert Shield deployment. Moreover, ship activation orders were spread over 45 days. The first 18 ships, including all 17 Ro/Ro's, were ordered for activation on day 3. An additional five were ordered for activation on day 8. A third group (15 ships) was ordered for activation on days 11 through 12. The fourth group (three ships) was ordered for activation on days 22 through 23, and the remaining three ships on day 45 (Figure 5).

Taking into account the time-phasing of activation orders, the readiness status of ships, and their cargo capacities, we estimate that roughly 2.3 million sq. ft. of sealift could have arrived at SPOE's by day 20. Because of activation delays, 2.3 million sq. ft. of shipping did

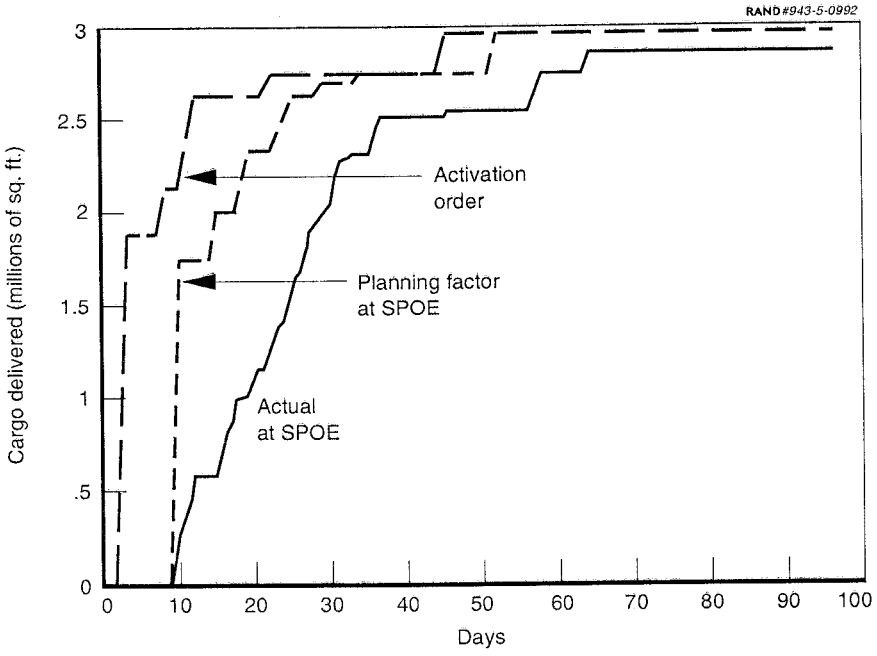

Figure 5—RRF Planning Factor Availability Not Met in ODS

not arrive at SPOEs until day 30. These delays stretched out the first deliveries of the RRF and precluded all the RRF ships from completing a second trip to Saudi Arabia in the first 90 days.

We do not have sufficient data to provide a definitive explanation for the decision(s) to phase RRF ship activation, or to establish the exact reasons for the delays in ship activations, once the orders were issued. The phased activations of the RRF may have been caused primarily by uncertainties about requirements and by budgetary considerations. At the beginning of ODS, requirements fluctuated widely, and decisionmakers may have been reluctant to allocate resources to activate RRF ships without fully validated requirements. For future deployments, this suggests a strategy of activating more RRF ships than required in the first few days of a deployment as a hedge against a rapid growth in lift requirement.

Delays in RRF ship activation, once orders were issued, appear to have been caused primarily by the less-than-satisfactory material condition of ships. This suggests that the material readiness of RRF ships needs to be improved.

Growing Contributions of Charters

Over the 240 days of Operations Desert Shield and Desert Storm, sealift delivered roughly 30 million sq. ft. of u/e and cs/css to Saudi Arabia. Commercial charters delivered roughly 45 percent of that total (Figure 6), as compared to only 30 percent of the amount delivered in the first 90 days of the deployment. The bulk of the deliveries was made by foreign charters.

Forty nine commercial ships were chartered for Phase I of ODS (roughly the first 90 days of the deployment). An additional 142 commercial ships were chartered to carry u/e and related support in Phase II. We did not have sufficient data to determine why more charter ships were not used in the first 90 days of ODS. One possible hypothesis is that additional commercial ships may not have been available early on or, if available, were not chartered while cargo requirements fluctuated. A second hypothesis is that, in the first phase of the deployment, policymakers decided to rely primarily on U.S. shipping and did not begin to charter large numbers of foreign ships aggressively until the true magnitude of the deployment became apparent.

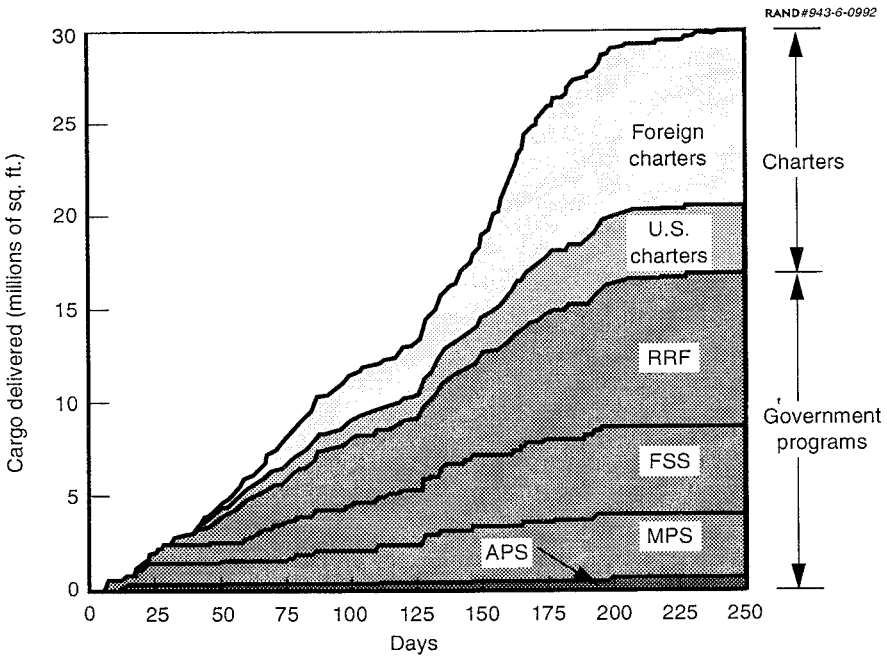

Figure 6—Substantial Growth in the Contribution of Foreign Charters over Time

In the past, sealift planners were reluctant to include foreign charter ships in force deployment planning because of uncertainties about their availability. ODS experience suggests that foreign charters should be considered as an option for deploying late cs/css in no-warning operations or u/e in operations with substantial warning.

IMPLICATIONS OF ODS FOR FUTURE SEALIFT PLANNING

In the first 90 days of ODS, the bulk of sealift cargo was delivered by government-controlled programs. Commercial shipping carried roughly 30 percent of the cargo during this period. Moreover, only ships from enhanced government-controlled programs—MPS, APS, and FSS—delivered cargo to Saudi Arabia in the first 30 days of the operation. This experience suggests that **enhanced government-controlled sealift programs are essential for early sealift deliveries.**

ODS experience raises some questions about how fast MPSs will deliver their initial cargo. Fully manned and forward positioned, they can be ordered to sail to an area in the vicinity of potential conflict, on

intelligence and warning, before hostilities commence. However, policymakers may be reluctant to send them, as appears to be the case in ODS. Moreover, unless properly positioned when ordered to sail, they may not close before FSSs from CONUS do. This suggests that decisions to procure additional prepositioning ships should be accompanied by management protocols that maximize their capabilities.

Not all ships in the RRF were called upon to support ODS in the first 90 days. Roughly 64 percent of RRF shipping capacity was activated during the first 90 days, and the activations were time phased. Moreover, RRF activations did not meet advertised standards. As a result, the RRF did not deliver significant quantities of cargo until after the first 30 days of the operation, and a large number of RRF ships did not complete a second delivery to Southwest Asia in the first 90 days. The performance of the RRF in ODS suggests that, in future deployments, RRF ships should be considered as an option for carrying cargo required after the first 30 days of the deployment.

The delays in RRF ship activations probably should have been anticipated. Prior to ODS, the funding for the RRF averaged about $1 million per year per ship, or about 20 percent of that for the FSS. Yet the bulk of RRF ships were advertised to be in five-day readiness, only one day later than the FSSs. Recognizing the need for improving RRF readiness, the Navy projects an increase in funding to $3.5 million per ship per year.[11] If the increased funding materializes, existing RRF ships should be able to support force deployments into the late 1990s.

Two additional potential problem areas should be addressed to ensure the viability of the RRF in the future: (1) ship manning and (2) ship repair facilities. In ODS, no major ship manning or repair problems were reported. However, the continuing decline of the number of ships in the U.S.-flag commercial fleet may reduce the pool of qualified seamen to a level that will not support the rapid activation of the RRF. Similarly, the ongoing contraction of ship repair facilities may preclude the timely activation of RRF ships in the future.

Commercial Shipping

Policymakers did not activate the SRP to support Desert Shield and Desert Storm deployments. They chose to use chartering procedures, which introduced delays in obtaining ships from the U.S.-flag com-

[11]Deputy Chief of Naval Operations (Logistics), Strategic Sealift Division, *Navy Strategic Sealift Implementation Plan (Draft)*, Washington, D.C., August 26, 1991.

mercial fleet to support military lift operations. This decision suggests that policymakers may have been reluctant to disrupt normal commercial trade to support military operations and were willing to accept the risks of those delays.

If the number of ships in the U.S.-flag fleet continues to decline, those that remain are likely to be heavily employed in commercial trade operations. Under such conditions, policymakers may again be reluctant to call commercial ships in such programs as the SRP to support future deployments. These observations suggest that early availability of commercial ships in future deployments is unlikely.

Over time, the contribution of commercial shipping grew from 30 percent of the total in 90 days to roughly 45 percent, with the bulk carried by foreign charters. Because foreign charters are a no-cost option to DoD in peacetime, they should be considered in future mobility planning for the deployment of late cargo.

3. STRATEGIC AIRLIFT CAPABILITIES

As in the case of sealift, airlift assets can be grouped into two broad categories: government-controlled and commercial. Government-controlled airlift includes active airlifters operated by the Air Mobility Command (AMC) (formerly the Military Airlift Command [MAC]), military aircraft of the Air Force Reserve Component, and those in the Air National Guard. Aircraft in the Civil Reserve Air Fleet (CRAF) constitute the bulk of commercial assets that can be called-up to support military operations. If required, DoD can also charter commercial aircraft.

The military strategic airlift force that may be used to support deployments includes 265 C-141s, 126 C-5s, and 57 KC-10s, which also serve as aerial refuelers. As of 1 July 1990, there were 202 cargo aircraft of various sizes in the CRAF program. Using MAC (AMC) scaling factors, this translates into 149 Boeing 747 (B-747) equivalents.[1]

CRAF aircraft are in one of three call-up categories or stages (Table 3). Stage I aircraft can be activated by the Commander-in-Chief, AMC. Stage II can be activated by the Secretary of Defense (SECDEF) in emergencies that fall short of full mobilization or a declaration of a national emergency. Stage III is also activated by SECDEF, but only in wartime or in a national emergency. Thus, the bulk of CRAF cargo aircraft is likely to be available only in national emergencies.

Representative characteristics of existing assets are shown in Table 4. The payload characteristics are for a notional critical-leg distance of

Table 3

CRAF Cargo Aircraft

CRAF Stage	Number (B-747 equiv.)	Activation Authority
I	17	CINC AMC
II	46	SECDEF
III	149	SECDEF

[1]Mary Chenoweth, *The Civil Reserve Air Fleet: An Example of the Use of Commercial Assets to Expand Military Capabilities During Contingencies*, RAND, N-2838-AF, June 1990, p. 38.

Table 4

Representative Characteristics of Existing Airlift Assets

Aircraft	C-141	C-5	KC-10	CRAF (B-747 equiv.)
Cargo				
Type[a]	b/o	b/o/ou	b	b/o/ou[b]
Capacity (stons)	20	65.1	62.1	66.7
Block speed (kts) (3500 n mi range)	418	432	465	460
Parking area (sq. ft./aircraft)	94,000	193,000	105,000	159,000
Load/unload (hrs)	2.25/2.25	3.75/3.25	5/3	5/5
Utilization (hrs/day)	12.5	11.5	12.5	10

[a]b = bulk, o = oversize, ou = outsize.

[b]Only the B-747 can carry some outsize cargo.

3500 n mi and an average payload of oversize cargo, for all aircraft except KC-10s.[2] All aircraft can carry bulk cargo. The C-5 can carry most outsize cargo, and the B-747 can carry some outsize cargo. Because of their large size, C-5s use more than twice the parking space of a C-141. This may present a problem in operations to airfields with limited apron space for unloading operations. The large CRAF aircraft will also experience the same problem. Moreover, because CRAF aircraft were not designed for rapid loading and unloading, they take up more space for a longer period of time. Finally, the utilization rates of all aircraft—the number of hours per day that aircraft are available for lift operations—vary. Those of military aircraft reflect planning-factor surge rates. Those of CRAF aircraft are based on contract limits.

AIRLIFT CARGO DELIVERIES IN ODS

In the 240 days of Operations Desert Shield and Desert Storm, airlift assets delivered approximately 550,000 stons of cargo, with roughly

[2]The terms outsize, oversize, and bulk are used to describe cargo in relation to dimensions important to airlifters. Outsize is a single air-transportable item that exceeds 83.3 feet in length, 9.75 feet in width, and 8.75 feet in height. Oversize cargo cannot be more than 90.8 feet long, 9.75 feet wide, and 8.75 feet high. Oversize cargo must meet dimensional requirements of the C-141's cargo door and cargo compartment. Cargo smaller than oversize is typically defined as bulk. Source: Department of the Air Force, *Military Airlift: Airlift Planning Factors*, AFP 76–2, (C-1), Headquarters U.S. Air Force, Washington, D.C., May 29, 1987, p. 25.

180,000 stons delivered in the first 90 days (Figure 7).[3] Military aircraft made the bulk of those deliveries. These are impressive statistics, but do they reflect the full capacity of existing assets? This section explores this question.

As illustrated in Figure 8, airlift performance depends on numerous factors besides the technical characteristics of aircraft. First, the availability of commercial assets in CRAF II and CRAF III is based on National Command Authorities' (NCA) decisions, which take into consideration not only the military threat but also the political implications of disrupting on-going commercial operations. After CRAF activation, AMC integrates those assets with organic military airlifters

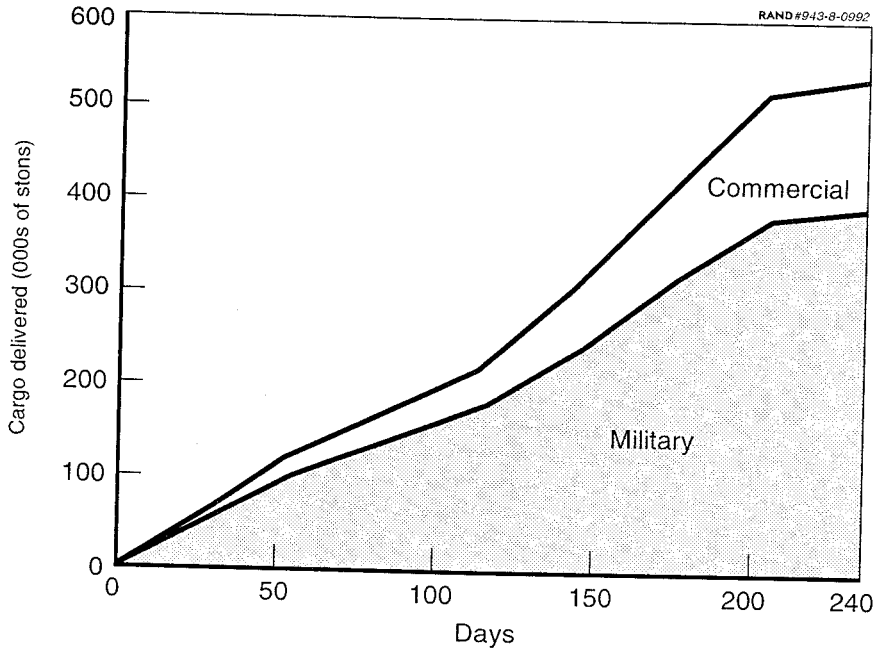

Figure 7—Airlift Cargo Deliveries in ODS

[3]In Operations Desert Shield and Desert Storm, airlift also delivered about 500,000 passengers. Because existing airlift assets did not encounter serious difficulties in meeting ODS passenger deliveries and because of the projected continued growth of passenger aircraft fleets, we believe that future force deployments will not be constrained by a shortage of passenger aircraft. For these reasons, we focus the airlift analysis on cargo operations.

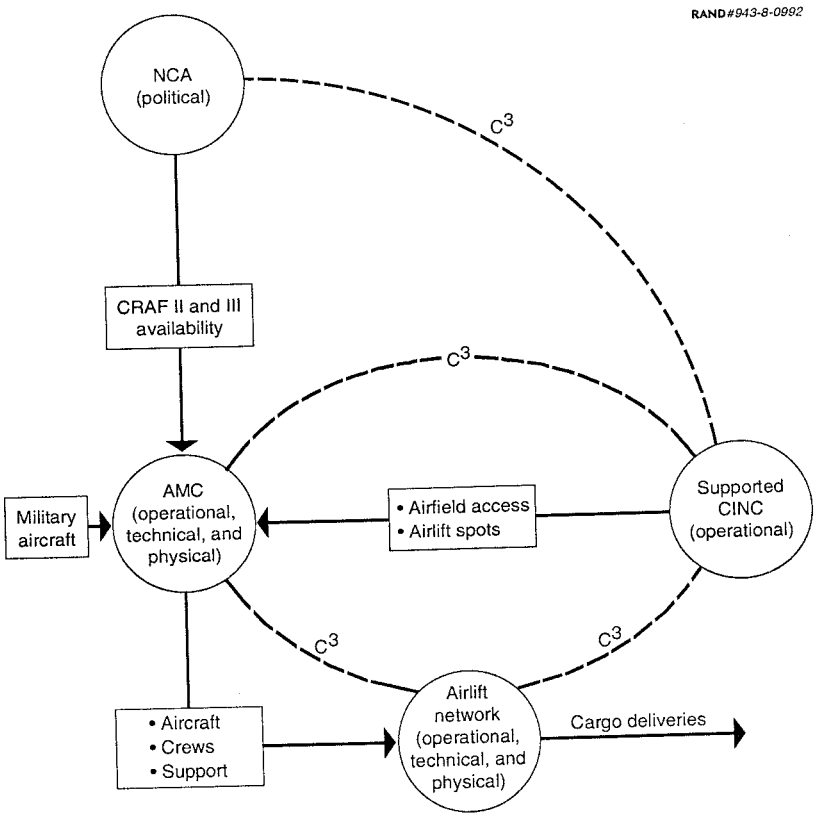

Figure 8—Factors Affecting Airlift Deliveries

and any chartered aircraft and begins projecting potential capabilities. In projecting potential capabilities, AMC planners take into consideration the technical characteristics of aircraft, their understanding of operational requirements, and the physical characteristics of the airlift network over which they anticipate conducting airlift operations.

The supported CINC, taking into account operational plans, with or without full consultation with airlift planners, stipulates where the cargo should be delivered and how much access airlifters are likely to have. With this guidance, and information on aircraft maintenance, handling, and refueling facilities at APODs, AMC planners determine the maximum number of cargo airlifters that can be handled on the

ground simultaneously (working maximum on ground [MOG]).[4] In determining the working MOG for cargo aircraft, AMC planners also take into consideration the projected flow of passenger aircraft into the theater.

Authorities responsible for different activities in the airlift network try to support the operation as planned. These authorities include those responsible for making cargo available. Thus, the amount of cargo that a given set of airlift assets can deliver directly depends on all these functions, many of which are not under the control of AMC.

ODS experience highlighted the effects of some of the preceding factors. Based on planning-factor capabilities, the theoretical maximum cargo that strategic airlift could have delivered to Southwest Asia is on the order of 6000 stons per day.[5] Early in the deployment, AMC projected airlift cargo delivery capabilities of about 2800 stons per day. This lower projection appears to reflect the activation of only CRAF I,[6] a reduction of the Air Reserve Component contribution, and an increase in working MOG constraints.

The actual deliveries over the first 54 days averaged roughly 2300 stons per day, probably because of additional MOG constraints, smaller-than-planned payloads, and lower-than-planned aircraft utilization rates. A review of aircraft availability reports indicates that additional military aircraft were available, but were not used.

Monthly deliveries peaked in January, with an average daily rate of about 3500 stons. By this time, more access and support for airlifters increased the working MOG; additional civil and military aircraft were used;[7] and a substantial fraction of cargo was moved the shorter distance from Europe to Saudi Arabia. All these factors combined to increase cargo delivery rates.

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[4]Working MOG is a function primarily of airfield physical configuration and support infrastructure and of the technical characteristics of airlifters. It varies with (1) the size and shape of the parking areas allocated to airlifters; (2) the number, type, and location of refueling facilities; (3) the amount and type of aircraft ground-handling and unloading equipment; (4) the aircraft maintenance and support facilities; and (5) the mix of aircraft. Consequently, it is difficult to accurately predict the working MOG for future operations.

[5]This estimate was calculated by dividing 80 percent of the theoretical capabilities of existing airlift programs, 52.5 million ton miles per day, by the one-way distance from the southeastern United States to Dhahran.

[6]CRAF I was activated on August 18, 1991. The activation provided DoD 23 commercial long-range cargo aircraft to support ODS deployments.

[7]The activation of CRAF II on January 17, 1991, provided 17 additional long-range cargo aircraft.

Implications of ODS for Future Airlift Planning

ODS highlighted the difficulties in accurately predicting airlift deliveries. Prior to ODS, airlift planners did not anticipate that working MOG constraints would limit the throughput capacity of airlift to Saudi Arabia. The large, modern airfields in Saudi Arabia were assumed to be capable of handling the flow of the existing strategic airlift fleet without constraints. However, operational and political considerations precluded the use of all available facilities. In the early days of the operation, Dhahran was the primary aerial port of debarkation. At the same time, large numbers of tactical aircraft were deployed to Dhahran. As a result, strategic airlifters had to compete for space and support with tactical aircraft.

The preceding observations suggest that working MOG constraints, even in theaters with well-developed infrastructures, may limit early airlift operations. One approach to deal with this potential problem is to open additional APODs to airlifters in the early phases of the operation. The benefits of this approach are increased numbers of runways, aprons, and fueling stations, as well as distributed operations in case of hostilities. Obviously, this assumes that additional airfields are available and requires efficient coordination between the supported operational commander and the airlift planners to ensure the proper assignment of cargo and passengers to APODs.

Another approach is to expand the working MOG of already-open APODs by airlifting in several loads of material handling and fueling equipment. The benefit of this approach is that it expands the working MOG, while maintaining the integrity of the APOD and simplifying the arrival planning process. The costs are delays in the shipment of some combat equipment while the airport equipment is being deployed and the increased vulnerability of aircraft to enemy actions because of increased aircraft density.

A third approach is the procurement of flexible aircraft that make more efficient use of constrained ground resources, such as ramp space, material handling equipment, and aircraft tractors. This analysis examines this approach. A detailed examination of the other two approaches should be conducted.

4. ANALYTICAL FRAMEWORK AND DEFINITIONS OF FUTURE TRANSPORT OPTIONS

The preceding sections of this report provide insights into the operations and capabilities of existing programs based on the recent force deployment to Southwest Asia. These insights helped structure the approach used in examining alternative transportation programs for the future. Because of uncertainties about future deployments, we defined a representative range of deployment requirements against which we measured alternative combinations of transports. This section first characterizes that range of requirements, then describes the analytical framework used in selecting attractive combinations of transports to meet them. As part of the framework discussion, we define the alternative transport options considered in the analysis.

UNCERTAINTIES ABOUT FUTURE DEPLOYMENTS

The disintegration of the former Soviet Union and the dissolution of the Warsaw Pact have reduced the threat to U.S. national interests. These revolutionary events removed the threat from which existing transportation requirements were derived. These events and economic considerations are causing a reexamination of the existing force posture. Therefore, the readiness, size, and composition of deploying forces are uncertain.

Moreover, the intelligence community has not yet fully analyzed the future threat to national interests. Consequently, there are uncertainties about future enemies and about how we might fight future wars. This in turn creates uncertainties about warning time and required delivery timelines. Finally, the destinations of future force deployments are uncertain.

For this analysis, we postulated two hypothetical deployment forces: (1) a major regional contingency force (MRCF) and (2) a low-intensity conflict force (LICF). The Army units in the notional MRCF are similar to the power-projection force discussed in the Army's Strategic Mobility Vision briefings of 1991 (Table 5). The MRCF consists of four Army divisions, a separate armored brigade, an armored cavalry regiment, an aviation brigade, an air defense unit, and a special forces airborne unit. It also includes two MEBs, 16 Air Force tactical fighter squadrons, and 8 support squadrons. One Marine Expe-

Table 5

Composition of the Notional Major Regional Contingency Force

Units	Combat u/e (stons)	cs/css/support (stons)
Army divisions		
Airborne	21,950	
Air assault	32,500	
Mechanized infantry	95,000	
Armored	96,600	
Other Army units		
Separate armored brigade	25,400	
Armored cavalry regiment	30,800	
Aviation brigade	10,000	
Air defense	2,000	
Special Forces	1,000	
Army Total	315,250	441,350
Marine Corps		
2 MEBs	60,000	40,000
1 MEF	—	—
Air Force		
16 Tactical Fighter Squadrons	9,600	10,000
8 Support Squadrons	3,200	
Navy		
3 CV BGs	—	25,000
Total	388,050	516,350

SOURCES: For Army unit weights, U.S. Army, Military Traffic Management Command Transportation Engineering Agency, *Deployment Planning Guide*, August 1991. Army Liaison Office, HQ MAC, *Airlift Planning Guide*, Scott AFB, Illinois, November 1986.

ditionary Force (MEF), and three Navy carrier battle groups (CV BG) complete the force. Assuming that most MEF and CV BG combat equipment and support cargo is carried on organic lift assets (Navy amphibious and logistic ships), these forces do not add significant cargo requirements to common-user lift assets.

In addition to u/e, common-user lift assets have to deliver cargo for support forces, primarily cs/css for the Army, sustainment cargo, and ammunition. Because we believe that most sustainment cargo and ammunition will, in the future, be carried primarily by container ships, which are not used in deploying u/e and cs/css, we do not include sustainment cargo and ammunition in the requirements of the MRCF.

Currently, there is substantial debate as to how much Army cs/css will be deployed to support various operations. Typically, the amount of cs/css to be deployed is expressed as a ratio to u/e. We initially measure the performance of transport options using a 1 to 1.4 ratio of u/e to cs/css. This ratio reflects roughly the experience of Operations Desert Shield and Desert Storm. To arrive at the total u/e and support that has to be deployed, we add 40,000 stons of support for the Marines, 25,000 stons for the Navy, and 10,000 stons for the Air Force. This translates into a total requirement of about 900,000 stons.

To include a broader representation of deployment requirements and to examine the sensitivity of transport choices to response time, we define four force closure options. The first option calls for the closure of (1) the u/e of the early units—the airborne division, 2 MEBs, 12 Air Force tactical squadrons, the air defense, and the Special Forces unit—in 21 days; (2) the u/e of two heavy divisions and a corps slice of cs/css in 70 days; and (3) the remaining u/e and cs/css in 90 days (Figure 9). The second option stipulates the closure of (1) the u/e of the early units in 21 days, (2) the u/e of two heavy divisions and a corps slice of cs/css in 50 days, and (3) the remaining u/e and cs/css in

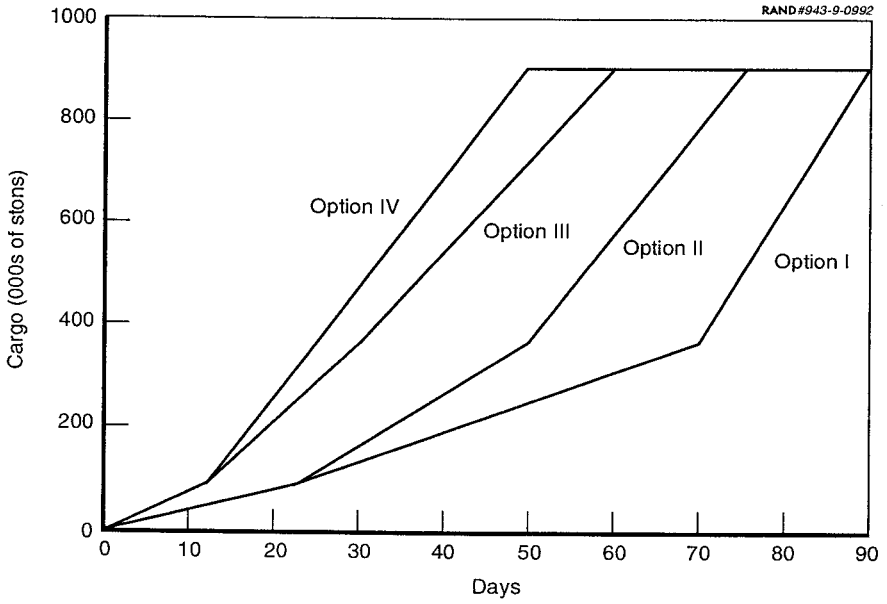

Figure 9—Cargo Delivery Requirements for the MRCF (u/e to cs/css ratio 1:1.4)

75 days. The third option calls for the closure of (1) the u/e of the early units in 12 days, (2) the u/e of two heavy divisions and the corps slice of cs/css in 30 days, and (3) the closure of the remaining u/e and cs/css in 60 days. The most demanding option calls for the closure of (1) the u/e of the early units in 12 days, (2) the u/e of two heavy divisions with the corps cs/css slice in 25 days, and (3) the remaining u/e and cs/css in 50 days.

To examine the effect of increased cs/css on transport alternatives, we also use the higher deployment requirements shown in Figure 10. These reflect a u/e to cs/css ratio of 1 to 1.7.

Low-Intensity Conflict Force

If recent deployment patterns continue into the future, the vast majority of future deployments is likely to be for small-scale conflicts.[1] Thus, it is important to ensure that mobility programs, which are sized for large-scale conflicts, are adequate for smaller conflicts. For this purpose, we define a notional LICF consisting of the 82nd Airborne Division, two brigades of a light infantry division, six Air Force tactical fighter squadrons, a Special Forces unit, an amphibious Marine brigade, and one Navy CV BG. The postulated LICF cargo requirement assumes a closure of (1) 5,000 stons of u/e of the first brigade of the 82nd Airborne division, and 3,600 stons of Air Force cargo in seven days, and (2) 51,400 stons of additional cargo in 30 days.

ANALYTICAL FRAMEWORK

To examine alternative combinations of transport assets, in conjunction with the RAND Study of DoD Future Distribution Systems, we constructed a linear optimization model that determines a cost-effective mix of transports given constraints on resources. The model consists of four interdependent input parameter sections: (1) cargo section, (2) transport section, (3) transport network, and (4) transport cost section. First, we describe each of these, and then provide a brief description of the model.

[1]In Operation Just Cause, the ground forces deployed to Panama included one brigade of the 82nd Airborne Division, two brigades of the 7th Light Infantry Division, one brigade of Military Police, one regiment of Rangers, and some Special Forces units. These diverse units add up to about 1.5 light division equivalents. However, because these units deployed with minimum cs/css, the cargo requirement for this force was less than that of one notional light division.

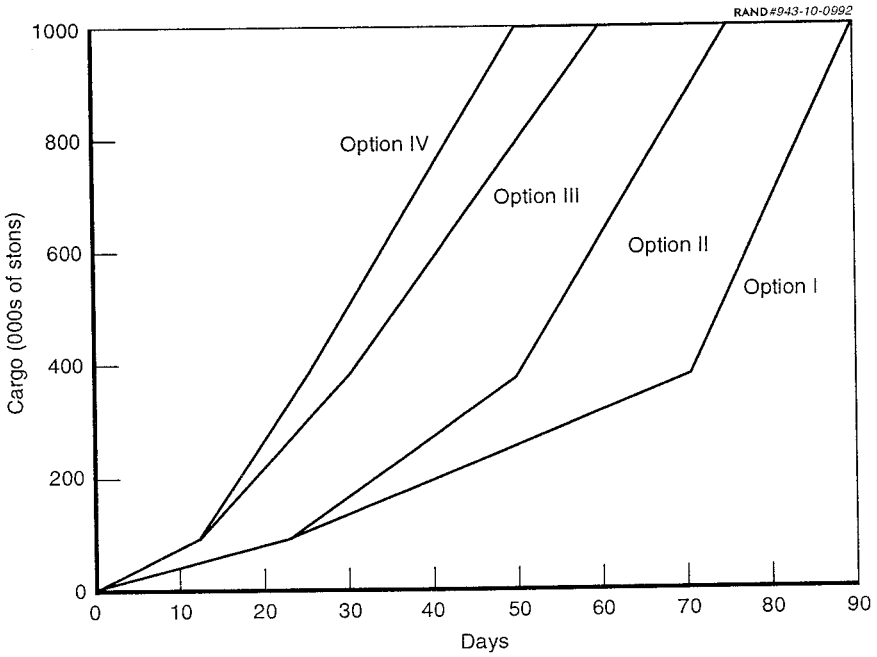

Figure 10—Cargo Delivery Requirements for the MRCF (u/e to cs/css ratio 1:1.7)

Cargo Section

The cargo section lists cargo delivery requirements, location, and availability. Cargo delivery requirements are expressed as the number of short tons to be delivered by a specific day. For this analysis, cargo is postulated to be available when transports arrive at ports of embarkation. Cargo is assumed to be at one CONUS node.

Transport Section

Baseline and alternative transport options are defined in the transport section in terms of number, initial availability, cargo capacity in short tons, speed, loading and unloading times, and utilization rates. For each run of the model, the number of baseline transports is fixed, while that of options is expressed as less than a specific number or left open. The transport options are the independent variable. In the subsequent sections, we first define baseline assets, then characterize alternative transport options examined in the analysis.

Baseline Sealift Ships. The baseline FY 1999 sealift assets included in the analysis of each scenario are shown in Table 6.

Government-controlled sealift includes the existing FSSs, two MPS squadrons, the APS, and the dry-cargo ships currently in the RRF. This assumes that existing APSs and RRF ships are provided with proper maintenance to ensure their viability over the next ten years. Because APSs are loaded, for the most part, with ammunition, material handling, and port operating equipment, their first cycle is not counted toward total u/e and cs/css lift requirements. In the baseline, we did not include 21 additional ships that have been programmed for the RRF. Because these ships represent an additional investment in future mobility assets, we treat them as an option.

The third MPS squadron is kept in reserve for other contingencies. The U.S.-flag commercial ships included in the baseline reflect ODS Phase I experience—the remainder are assumed to be in commercial trade. Container ships, typically used in sustainment operations but not in the deployment of u/e and cs/css, are not included in the baseline. Also, foreign-flag ships are not in the baseline, but are examined as an option for follow-force deployments. We assume that U.S.- and foreign-flag container ships are used to meet ammunition lift requirements.

The cargo capacities of ships, in terms of short tons, reflect a conversion factor of 25 sq. ft. per ston. This factor is higher than planning factors for u/e but takes into account that cs/css is less dense. We derived this conversion factor using a u/e density factor of 16 sq. ft. per ston, and a cs/css density factor of 31 sq. ft. per ston, assuming a u/e to cs/css ratio of 1 to 1.4. In actual operations, the square footage–to–short ton conversion factors may vary substantially. For example,

Table 6

Sealift Baseline

Ship Category	Existing Ships	Baseline Ships	u/e & cs/css (stons/ship)	Activation Days	Speed (kts.)	Loading Days
Government						
FSS	8	8	6600	4	30	2
MPS	13	8	5000	1	18	2
APS	8	8	3300	1	17	4
RRF less Ro/Ro[a]	66	66	1900	10	17	4
RRF Ro/Ro	17	17	4400	10	20	2
Commercial U.S.						
Breakbulk	31	8	1600	10/20/35	17	4
Ro/Ro	20	10	3000	10/20/35	20	2
Container	95	0	—	—	—	—

[a]Includes breakbulks, barge and lighter-carrying ships, and T-ACS.

tracked and wheeled vehicles may be loaded with ammunition, resupplies, and sustainment cargo. If this were the case, the conversion factor would be less than our estimate. However, it would not affect the amount of square feet required to carry a short ton of the notional u/e and cs/css mix, provided that loads are not stacked on top of each other.

The initial availability of sealift assets is a function of their peacetime operating regime. FSSs are maintained in ROS, ready to sail in four days. MPSs and APSs are active ships ready to sail within a day. RRF ships are maintained in one of three advertised readiness conditions—5, 10, and 20 days—with the vast majority in the 5-day category. ODS experience showed that a 5-day readiness for the majority of RRF ships was overly optimistic; consequently, in our analysis, we place the RRF ships in 10-day readiness. Charter ships' availability is phased, with 40 percent of charter ships available in 10 days, another 40 percent on day 20, and the remaining 20 percent on day 35.

The maximum speed of baseline ships ranges from 17 to 30 knots, with the FSS being the fastest. To account for reduced speeds in entering and leaving port, course and speed changes to avoid shipping, and potential adverse weather, we use 90 percent of maximum ship speed in transit time calculations. All ships' loading and unloading times, except for the breakbulk and APS, are estimated at two days.

Baseline Airlift Aircraft. The projected FY 1999 airlift force considered in the analysis consists of 318 primary aircraft authorization (PAA) military airlifters, and 149 CRAF aircraft (Table 7). The model baseline numbers reflect our estimates of aircraft withholds for other operations. KC-10s, because of their dual capabilities as aerial refuelers and cargo carriers, are not included as part of the baseline.

Table 7

Airlift Baseline

Aircraft	Projected FY 1999 Assets	Model Baseline
C-141	152	122
C-5	109	98
KC-10	57	—
CRAF I	17	17
CRAF II	29	29
CRAF III	103	—

During the early stages of major deployments, when airlift is generally most needed, they are likely to be used as aerial refuelers to support (1) tactical Air Force deployments, (2) long-range bombing operations, and (3) airlift operations for which en route bases for refueling are unavailable. For these reasons, we withheld them from early deployment operations and assume that they are used in sustainment operations. Also, 20 percent of the C-141s and 10 percent of the C-5s are reserved for resupply operations or withheld for other contingencies. CRAF III is not activated because of the severe disruption that it imposes on commercial cargo operations. We chose not to include C-17s in the baseline, but to treat them as an option for improving future mobility capabilities. This allows us to examine the added value of the planned C-17 program.

Baseline military aircraft begin cargo loading 24 hours after the operation is ordered. This delay reflects the start-up time for getting cargo ready for airlift operations. CRAF I and II aircraft are assumed to be available on day 4.

Cargo capacities of aircraft vary as a function of critical leg[2] and the type of cargo carried. A matrix of payloads over specific distances is included in the transport section of the model. The payloads are AMC's oversize cargo planning factor payloads.[3] The C-17 payloads reflect our estimates based on aircraft design characteristics.

Sealift Options. In the analysis, we considered the eight ships listed in Table 8. The ships are defined in terms of speed, cargo capacity, loading and unloading times, activation time, and rough order of magnitude procurement cost and projected annual operations and support (O&S) cost. All but two, the build and charter (B/C) and foreign charter candidates, are government-controlled ships.

The fastest candidate is the 30-knot, new-construction SL-7 (NSL-7), with a cargo capacity of 6600 stons of u/e and cs/css and the capability of loading or unloading cargo within two days. As the existing FSS, the NSL-7 is maintained in reduced operating status (ROS), in readiness to sail within four days of call-up. The procurement and O&S costs for the NSL-7 and the costs of other candidates, except as noted,

[2]The mission route segment with the largest fuel requirement. The larger the fuel requirement, the lower the payload.

[3]Department of the Air Force, *Military Airlift Planning Factors*, AFP 76-2, Headquarters U.S. Air Force, Washington, D.C., May 29, 1987.

Table 8

Sealift Ship Candidates

	Government Controlled						Build and Charter	Foreign Charter
	New SL-7	SSS	950-ft. Ro/Ro	700-ft. Ro/Ro	Used Ro/Ro	Prepo Ro/Ro	700 ft. B/C	Used Ro/Ro
Speed (kts.)	30	25	24	24	18	24	24	20
Capacity (000s of sq. ft.)	220	200	380	296	75	300	296	75
Stons (u/e and cs/css)[a]	6,600	6,000	11,400	8,800	3,000	9,000	8,800	3,000
Operating regime	ROS	ROS	ROS	ROS	RRF	Active	Civil	Civil
Availability (day)	4	4	4	4	10	1	10/20/35	10/20/35
Cost FY91 ($ million)								
Unit procurement	255	240	260	250	30	275	250	0
Unit annual O&S	5	5	5	5	3.5	12	0	0

[a]The cargo capacities in short tons (u/e and cs/css) of all ship candidates, except those of the used Ro/Ro and foreign charter, reflect a 0.75 cargo stowage factor and a 25 sq. ft. per ston conversion factor. Those of the used Ro/Ro and foreign charter are based on the average square feet of cargo carried in ODS and a 25 sq. ft. per ston conversion factor.

were extracted from the Navy Strategic Sealift Implementation Plan (Draft).[4]

The strategic sealift ship (SSS) is patterned on the Saudi Abha, a large foreign Ro/Ro used in ODS that proved to be efficient in carrying military equipment. It is slower than the NSL-7 and carries approximately 10 percent less cargo. Recently, the Navy awarded contracts for the preliminary designs of the next two candidates, the 950-ft. Ro/Ro and the 700-ft. Ro/Ro. The 950-ft. Ro/Ro is roughly the same length as the NSL-7 but, because it is equipped with several more decks, can carry roughly 73-percent more cargo than the NSL-7. The 700-ft. Ro/Ro is of similar design but shorter and carries 23-percent less cargo than the 950-ft. Ro/Ro candidate.

The Ro/Ro we used is patterned on the average commercial Ro/Ro used in ODS that might be available on the world market for purchase by DoD and put into the RRF. It is the smallest of all the government candidates and the least costly.

The prepositioning ship candidate (Prepo) is of the same construction as the 950-ft. Ro/Ro, but is equipped with additional air-conditioning units and environmental controls to support long-term storage of equipment. Prepo ships are fully manned and capable of sailing within one day. Properly positioned and loaded, they provide the earliest sealift response in no-warning scenarios. The penalty for improved response is increased O&S cost: $12 million per ship per year, or roughly 2.4 times that of ROS candidates.

The B/C candidate has the same physical characteristics as the 700-ft. Ro/Ro. The B/C has been proposed as a way of increasing sealift capacity while minimizing the cost to DoD. The B/C is built with DoD funds, and during peacetime it is chartered to commercial shipping firms. If successful, this approach would shift O&S cost to the civil sector and perhaps result in DoD recouping some fraction of the procurement cost. The major drawback of this option is uncertainty in ship availability. The phased availability dates listed for this candi-

[4]Deputy Chief of Naval Operations (Logistics), Strategic Sealift Division, *Navy Strategic Sealift Implementation Plan (Draft)*, Washington, D.C., August 26, 1991. Over the past decade, no large sealift ships have been built in U.S. shipyards. As a result, there is no recent empirical data on which to base sealift ship costs. Consequently, we consider the listed procurement costs as only adequate for initial comparison of alternative ships.

date reflect reasonable delays that DoD might encounter in calling up B/Cs in emergencies.[5]

The B/C has removable decks for converting the ship into a large car carrier. The viability of this option is primarily a function of the market demand for new car carriers. In 1990, there were only five car carriers in the U.S.-flag commercial fleet. Thus, the B/C option assumes a substantial expansion in this category of ship. The currently decreasing demand for U.S.-built cars overseas calls into question the viability of this option. To reflect this uncertainty, we assume that DoD does not recoup the procurement cost of the B/C, but does save annual O&S cost.

The foreign charter, bought and operated by commercial firms, is a no-cost option to DoD in peacetime. However, because its availability to DoD in time of emergencies is likely to vary, we assume that it is time phased.

Airlift Candidates. The three airlift candidates considered in this analysis are drawn from the RAND Future DoD Distribution System Study. These are (1) the C-17, (2) a newly constructed C-5, and (3) a used B-747 (Table 9). The C-17 is the new military airlifter, which is in the early stages of testing; its capabilities have not yet been operationally proven. It is designed to operate as both an intertheater and an intratheater lifter. Over a nominal range of 3500 n mi, it carries less cargo than the other two candidates. However, it can land on much shorter runways and has much better ground-handling capabilities than the other candidates. Its smaller size, better ground maneuverability, and upward engine thrust deflectors allow for better ground-space utilization. The block speed of the C-17, over a nominal range of 3500 n mi, is roughly 10 percent less than that of the used B-747 candidate. Our estimates of C-17 procurement and O&S costs are based on costs reported in Selected Acquisition Reports (SAR),[6] updated to 1991 dollars. The C-17 procurement cost, shown in Table 9, reflects the average unit cost listed in the SAR for the 110 C-17s remaining in the program buy after 1991. The total program

[5]The Navy Strategic Sealift Implementation Plan (Draft) assumes that 40 percent of the B/Cs would be available by day 10, an additional 40 percent by day 20, and the remaining 20 percent by day 35. We use these assumptions to define the availability of B/Cs and commercial charter ships in subsequent analysis.

[6]U.S. Air Force, Aeronautical Systems Division, Wright-Patterson AFB, C-17 Systems Program Office, *Selected Acquisition Report (RCS: DD-COMP (O&A) 823) Program: C-17*, Dayton, Ohio, December 31, 1991.

Table 9

Airlift Candidates

Aircraft	C-17	C-5 (new)	B-747 (used)
Cargo			
Type[a]	b/o/ou	b/o/ou	b/o/ou
Capacity (stons)	41	65.9	66.7
Block speed (kts)	432	432	460
Runway length (ft) for landing	3000–5000	5000–7000	5000–7000
Parking area (sq. ft.)	99,000	193,000	159,000
Load/unload (hrs)	3/2.75	3.75/3.25	5/5
Utilization (hrs)	15.6	11.5	12.5
Cost FY91 ($ million)			
Procurement (unit)	180	162	84
Annual O&S (unit)	12.0	7.6	8.7

[a]b = bulk, o = oversize, ou = outsize.

buy shown in the SAR is 120. Because there is no analog with which to compare our SAR-derived C-17 O&S cost estimates, we test the sensitivity of varying the O&S cost by increments of $1 million per year per aircraft.

Both the C-5 and B-747 were used extensively in ODS. The C-5 can carry all categories of military cargo, over a nominal distance of 3500 n mi; it can carry roughly 60 percent more cargo than the C-17. However, because of its large size and limited ground maneuverability, the C-5 typically flies into major airfields, with long runways and large parking areas. The estimated procurement cost of the new C-5 is based on C-5B acquisition costs, updated to 1991 dollars, with an added cost for reopening the production line. The O&S costs reflect reported C-5 experience.[7]

A used B-747 can carry roughly 63 percent more oversize cargo than the C-17. It also can carry some outsize cargo. However, because it is designed to operate at large commercial airfields, it requires ground support and material-handling equipment. The estimated procure-

[7]C-5 annual O&S costs are lower than those of the C-17 because they are based on a planning flying-hour rate of 640 hours per year, while those of the C-17 are based on planning rate of 1432 hours per year. Thus, even though the C-5 has a higher rate of maintenance hours per flight hour than the C-17, the expected total O&S cost per year for the C-17 is higher. The planned peacetime employment of the C-17 includes replacement of C-141s in peacetime cargo deliveries; use as a training aircraft for AMC pilots, including those flying the C-5 and special training requirements for combat cargo deliveries in low altitude parachute extraction system operations; and short-field operations. The larger number of flying hours for the C-17 increases crew and maintenance requirements and the use of consumables.

ment cost for the used/modified B-747 is based on discussions with used-aircraft dealers and includes the added cost to cover refurbishment and conversion for military cargo operations. Its O&S cost reflects reported costs of KC-10s, cargo/tanker derivatives of the DC-10.

The above discussion points out that a direct trade-off among the three candidates is difficult and cannot be made solely on the basis of technical characteristics and cost. It requires careful consideration of the existing capabilities and projected airlift shortfalls in potential future deployments. For example, there are a large number of B-747 equivalents in CRAF III that can be requisitioned to support future large deployments to well-developed theaters. Therefore, it is arguable whether DoD should consider investing in additional B-747s. On the other hand, if the additional capacity of the B-747 equivalents in CRAF III is deemed essential, DoD should examine alternatives, including additional monetary incentives, to improve the availability of this capacity for military deployments.

Transportation Network Section

The transportation network section includes the locations of nodes, distances between nodes, the size of nodes (seaports and airports), and en route delays that might be encountered. For example, to reflect the time required for ships to reach SPOEs, after initial activation, a two-day delay factor is added. Similarly, a one-day delay is added to transits of the Suez or the Panama canals. Aircraft are assumed to begin cargo loading 24 hours after the operation is ordered. The one-day delay reflects the start-up time for getting cargo ready for airlift operations.

Cost Section

This section is a simple matrix listing the rough order of magnitude unit procurement and O&S cost for each of the transports considered in the analysis (Table 10).

General Description of the Model

The data described thus far—cargo delivery requirements and cargo availability, transport characteristics, transport network, and cost of transports—are inputs to the model. The model is a linear optimization program that determines a cost-effective mix of transports, given constraints on resources. The model is programmed within a com-

Table 10

Transport Candidate Cost (FY91 $million)

Candidates	Unit Procurement	Unit Annual O&S
Ship		
NSL-7	255	5.0
SSS	240	5.0
950-ft. Ro/Ro	260	5.0
700-ft. Ro/Ro	250	5.0
Used Ro/Ro	30	3.5
Prepo ship	275	12.0
B/C	250	0
Foreign charter	0	0
Aircraft		
C-17	180	12.0
C-5 (new)	162	7.6
B-747 (used)	84	8.7

mercial software package, the General Algebraic Modeling System. This system allows the user to store all constraint parameters in organized tables rather than as unique coefficients within each equation. This simplifies the task of programming and sensitivity analysis, as well as makes the model more transparent to users. The model uses a commercial software package, the MINOS 5 solver, to solve the linear program. A Sun Sparcstation, equipped with 16 megabytes of memory linked to a small computer system interface disk, provides the necessary computational and data-storage capacity. The model and all associated hardware and software are housed and run through RAND's Military Operations Simulation Facility.

Using the system of linear equations, the model calculates both the time each transport would take on each route and the capacity, or payload, each transport would carry on each route. At the same time the model calculates the cost of transports to achieve various capacities and the physical space both at en route nodes and destination nodes that transports use.

Then, the model compares the two sets of information and begins to try to meet specified cargo delivery requirements. The model does this iteratively, beginning with the use of the baseline forces and adding alternative mixes of optional transports, as necessary. Through each iteration, the model compares the total quantity carried with the total budget and space available. If limits on space, budget, or both preclude the attainment of cargo delivery requirements, the

model determines the mix of transports that minimizes delivery shortfalls.

If an iteration results in the transports carrying an amount equal to or more than the quantity required, and if both the cost and space utilization are less than specified limits, the model would normally stop and provide a solution to the user. However, this solution may not be the most cost-efficient in meeting requirements. To handle this issue, the model has a secondary objective—to limit the cost spent per short ton delivered. By setting this to a high value, the model does not solve for this objective until the main objective of meeting the delivery schedule has been met. Then the model begins looking for the most cost-efficient mix of transports that meet cargo delivery requirements.

5. ANALYSIS OF ALTERNATIVE TRANSPORT OPTIONS

The performance of alternative transport options is examined in cargo deliveries to three destinations: Southwest Asia, Korea, and Zaire. The notional deployments to Southwest Asia and Korea serve to assess transport options for the MRCF and LICF. The notional Zaire deployment is used to assess transport options for the LICF.

In the Southwest Asian and Korean cases, the performance of alternative transports is assessed in four deployment options for the MRCF, with closure times ranging from 50 to 90 days. As a point of departure, we examine transport options in unconstrained sealift and airlift operations. Then, we focus the analysis on transport options in unconstrained sealift, but working-MOG–constrained airlift operations. Under these conditions, we examine the sensitivity of the results to: (1) cargo growth, (2) MOG constraints, and (3) airlifter (O&S) cost estimates. We also assess the utility of commercial charter ships in carrying the added cargo.

ANALYSIS OF ALTERNATIVE TRANSPORT OPTIONS TO SOUTHWEST ASIA WITH SUEZ

From the East Coast of the United States, sealift ships can travel to Saudi Arabian ports in the Persian Gulf through the Suez Canal, a distance of roughly 8700 n mi (Figure 11). Prior to entering the Suez Canal, ships at both the south and north entrances are formed into convoys. Because of navigation constraints in the Canal, the convoys have to pass each other at designated locations. These operations typically impose a one-day delay on ship transits.

Saudi Arabia has several large, well-equipped ports. Damman and Jubail alone can accommodate more than 30 large sealift ships simultaneously.[1] Should these berths be unavailable, sealift ships might be able to use the large port facilities of the United Arab Emirates for unloading operations. Because of the large port facilities, we assess sealift operations to Southwest Asia to be unconstrained.

[1] *Lloyd's Ports of the World*, Lloyd's of London Press, Essex, United Kingdom, 1989.

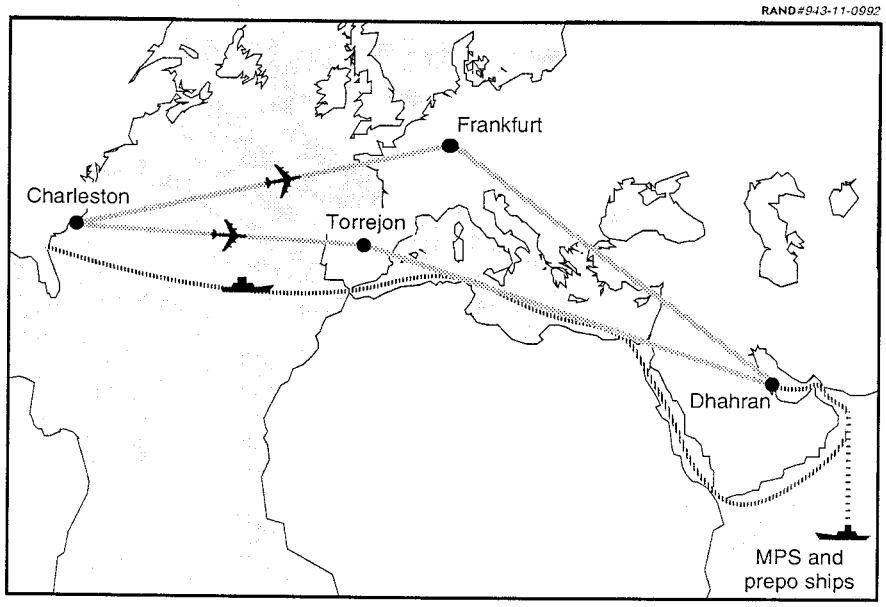

Figure 11—Sealift and Airlift Operations to Southwest Asia

In ODS, airlifters departing from the southeastern United States made en route stops in Germany or Spain traveling to and from Southwest Asia. The round trip distance from Charleston, South Carolina, to Dhahran via Germany is roughly 7000 n mi. Saudi Arabia has several airfields capable of handling large numbers of aircraft. Prior to ODS, most planners projected airlift operations to Saudi Arabia as unconstrained. However, in the early days of ODS, working MOG constraints limited airlift operations. MAC reported that three principal Saudi Arabian APODs—Dhahran, Jubail, and King Fahd—could only handle eight C-5 equivalents simultaneously. Because similar constraints may arise in future deployments, the emphasis of the analysis is on unconstrained sealift, but constrained airlift operations.

Transport Options in Unconstrained Operations to Southwest Asia

Using the hypothetical cargo requirements of the smaller MRCF, we first determine the preferred combinations of new transportation assets that have to be added to the airlift and sealift baselines to meet closure requirements of alternative deployment options. The pre-

ferred combinations of new assets to close 900,000 stons of u/e and cs/css to Southwest Asia in unconstrained operations are shown in Table 11. The first column lists the deployment options for the MRCF, with required closure dates for (1) u/e of early light forces, (2) u/e of two heavy Army divisions and a corps slice of cs/css, and (3) the remaining u/e and cs/css. In the case of deployment Option I, these dates are (1) 21 days for the u/e of early light forces, (2) 70 days for the u/e of two heavy Army divisions and a corps slice of cs/css, and (3) 90 days for the remaining u/e and cs/css.

In unconstrained operations, the airlift baseline met the hypothetical air cargo closure requirements for all options (40,000 stons in 21 or 12 days). Therefore, no new airlift assets are listed in any of the four deployment options. To establish which of the new airlift candidates would be preferred in unconstrained cases, we increased the early air requirements for Option IV to 50,000 stons in 12 days. Under these conditions, the used B-747 would be the candidate of choice to augment the airlift baseline.

The sealift baseline met the cargo delivery requirements of Option I. Five 950-ft. Ro/Ro's, costing $1.3 billion, have to be added to the baseline to close the MRCF in 75 days (Option II). Because all costs in this analysis are rough order of magnitude estimates, the costs presented in Table 11 and all other subsequent tables are rounded to the nearest tenth of a billion.

The more demanding Option III requires the addition of 17 NSL-7s and three 950-ft. Ro/Ro's to close the u/e and cs/css of the two heavy

Table 11

Transport Options to Southwest Asia in Unconstrained Operations

Deployment Options	New Assets	Investment Costs ($ billion)	30-Year Life-Cycle Costs ($ billion)
I 21/70/90	none	none	none
II 21/50/75	5 950-ft. Ro/Ro	1.3	2.0
III 12/30/60	17 NSL-7 3 950-ft Ro/Ro	5.1	8.1
IV 12/25/50	10 Prepo 13 NSL-7 9 950-ft Ro/Ro	8.4	15.3

divisions in 30 days, and the remaining cargo in 60 days. The most demanding option, IV, requires the addition of ten Prepo ships, 13 NSL-7s, and nine 950-ft. Ro/Ro's. Prepo ships, based in Diego Garcia, are the only sealift assets capable of making two deliveries to Southwest Asia, with the use of the Suez Canal, in 50 days. For this reason, Prepo ships are the most cost-efficient sealift candidates for deployment Option IV and, unconstrained by other considerations, would be the only sealift candidates selected.[2]

Two important factors have to be considered in determining a reasonable number of Prepo ships that should be procured. The first is risk of malpositioning. To provide the quickest sealift response, Prepo ships have to be appropriately prepositioned, i.e., Diego Garcia for Middle East, Indian Ocean, and Southwest Asia deployments. However, NSL-7s, which are based on the East Coast of the United States, would be first to deliver sealift cargo to locations on the northwest coast of Africa, the coasts of Central America, and most of South America.

The second factor is risk of mismatching prepositioned u/e and cs/css cargo to contingency requirements. Deployments to different theaters may require different Army units. For example, a light Army unit may be required to support a specific contingency. MPS ships, preloaded with the u/e and cs/css of a heavy Army unit, would have to return to appropriate U.S. ports and exchange cargo. Under these conditions, the Prepo ships lose their quick-response advantage over other sealift ships.

Because of these factors and the high O&S cost of Prepo ships, the Army argues for limiting the amount of prepositioned u/e and cs/css cargo to about 2 million sq. ft. Allowing one Prepo ship to be off station for periodic maintenance, ten Prepo ships are required to carry that amount of cargo. Because we consider the Army position reasonable, we limit the number of Prepo ships to ten.

The investment costs for the additional transports to meet Options III and IV are $5.1 and $8.4 billion, respectively. The 30-year life-cycle costs for these two options are roughly $8.1 and $15.3 billion, respectively.

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[2]As evidenced in Operation Desert Shield, Prepo ships are also the only sealift candidates that can deliver cargo to Southwest Asia in the first 10 days of a deployment. This requirement is not specifically called for in the postulated notional deployments of this analysis. If such a capability is deemed necessary, the Prepo ships would also be selected. For additional discussion of Prepo ship capabilities see: M. Hura and R. Robinson, *Fast Sealift and Maritime Prepositioning Options for Improving Sealift Capabilities*, RAND, N-3321-P&L/DAG/JS, 1991.

Transport Options to Southwest Asia in Constrained Operations

If airlift operations are constrained by working MOG limits, similar to those encountered during the early days of ODS (roughly 60 C-5 equivalents per day), the airlift baseline assets cannot close 40,000 stons of air cargo in 12 days, as required by Option III or IV. Under these conditions, the new C-17 airlifter, with its advertised austere-field operating capabilities, is required. The addition of either new C-5s or used B-747s airlift candidates will not support cargo closure. Roughly 65 (PAA) C-17s[3] have to be added to meet this requirement (Table 12). The choice of sealift ships is not affected by MOG constraints; however, more ships are needed to compensate for the decrease in cargo deliveries by airlift. One 950-ft. Ro/Ro, costing roughly $0.3 billion, has to be added to baseline assets to meet Deployment Option I. An additional investment (beyond that shown in Table 11) of $1.3 billion in five more 950-ft. Ro/Ro's is required to

Table 12

Transport Options to Southwest Asia in Constrained Operations

Deployment Options	New Assets	Investment Costs ($ billion)	30-Year Life-Cycle Costs ($ billion)
I 21/70/90	1 950-ft. Ro/Ro	0.3	0.4
II 21/50/75	10 950-ft. Ro/Ro	2.6	4.1
III 12/30/60	65 C-17 21 NSL-7 3 950-ft. Ro/Ro	20.4	47.4
IV 12/25/50	65 C-17 10 Prepo 16 NSL-7 11 950-ft. Ro/Ro	24.0	55.0

[3]A new airlift procurement program may include additional aircraft for a training squadron or as spares. The number of additional aircraft may vary substantially, as a function of budgetary constraints, maintenance, and training policy. Moreover, if necessary, aircraft assigned to training may also be used to support deployments. Because of these uncertainties, the analysis focuses on PAA aircraft, those actually assigned to airlift missions. Neither the potential lift capabilities nor the cost of the additional aircraft are included in the analysis.

meet Deployment Option II. Four additional NSL-7s are required to meet Deployment Option III, and three more NSL-7s and two more 950-ft. Ro/Ro's are needed to meet Option IV. The added investment costs for these ships are roughly $1 billion and $1.3 billion, respectively.

Under constrained airlift operations, investment costs increase dramatically to $20.4 and $24 billion for Options III and IV, respectively, with the new airlifters accounting for more than half of the total.[4] The primary factors driving the requirement for aircraft are early cargo delivery requirements and the postulated working MOG.

To test the sensitivity of these factors, (1) we varied early delivery requirements by 5, 10, and 20 percent, while maintaining MOG constant, and (2) varied MOG constraints by the same increments, while maintaining requirements constant. A 10-percent increase in cargo requirement increases the number of C-17s required to 99, or by roughly 50 percent. This suggests that very-high-resolution analyses of early delivery requirements are essential to size the C-17 buy. A 10-percent decrease in MOG capacity raises the number of C-17s required to 91, or by roughly 40 percent. This suggests that alternatives other than the procurement of new airlifters be examined to reduce the effect of MOG constraints.

Life-cycle costs also increase dramatically, to $47.4 and $55 billion, respectively, with the new aircraft accounting for more than 50 percent of the life-cycle costs. These costs are based on a yearly O&S of $12 million per C-17. Because C-17 O&S costs are uncertain, we reran the model increasing the C-17 O&S cost by $1 million and $2 million. Because of MOG constraints, the same number of C-17s was required for Deployment Options III and IV. However, each $1 million change per C-17 O&S cost translated to roughly a $2 billion change in the life-cycle cost for Options III or IV in constrained airlift operations.

Effect of Increased cs/css Cargo

Currently, there is substantial debate as to the amount of cs/css that will be deployed with specific combat units. In the preceding cases,

[4]To account for the smaller-than-planned C-17 program buy (65 versus 120), the C-17 unit cost is increased to $220 million. We derived this value by assuming that the current procurement plan, as shown in the SAR, remains constant and by curtailing the number of aircraft at the point where the required number are acquired. We incorporated the remaining fraction of both military construction and R&D and allocated $250 million for closing out the program.

the postulated u/e to cs/css weight ratio is 1 to 1.4, or roughly equal to the ratio deployed in ODS. To test the effect of increased cs/css cargo, we assume a u/e to cs/css ratio of 1 to 1.7 and add the weight increase to the cargo requirements. This becomes a total cargo requirement of 1 million stons, or roughly 11 percent more than in the 1 to 1.4 ratio cases.

Baseline assets cannot meet the increased cargo requirements of any of the four deployment options. To meet Option I, they have to be augmented by about five 950-ft. Ro/Ro's at an investment of $1.3 billion (Table 13). A comparison of Table 12 and Table 13 data shows that an additional two NSL-7s and seven 950-ft. Ro/Ro's are necessary to meet Option IV requirements for the larger MRCF. This is an increase of $2.3 billion in investment and a $3.7 billion increase in life-cycle costs, for moving roughly 100,000 stons of added cs/css.

Niche for Commercial Shipping

As previously discussed in the ODS section of this report, charter shipping proved effective for deploying large quantities of cargo after the first 40 days of the operation. To examine the value of this category of ships, we first introduce the B/C sealift candidate into the calculations. Then we include foreign charters.

Data in Table 14 show that if B/Cs are available, they displace 950-ft. Ro/Ro's as the preferred option for carrying late cargo in Options I and IV. However, because they are smaller and less available than 950-ft. Ro/Ro's, more B/Cs have to be bought to carry an equal amount of cargo. As a result, the investment costs for B/Cs are higher, but their life-cycle costs are lower.

In Option II, 950-ft. Ro/Ro's continue to be preferred, because they complete two cargo deliveries to Southwest Asia, while B/Cs, because of their later availability, do not. In Option III, B/Cs are a preferred substitute for a small number of NSL-7s.

The cost advantage of B/Cs over other candidates is only in their 30-year life-cycle cost (comparison of Tables 13 and 14). Moreover, to realize these savings, a long-term stable market for B/Cs has to exist. The availability of B/Cs is also uncertain. Because of these factors, we do not carry B/Cs further in the analysis.

In ODS, foreign charters were used extensively to deploy midterm and late cargo. Because they may prove equally useful in future deployments, we add 50 foreign-charter ships over 35 days and assess

Table 13

Effect of Increased cs/css Cargo on Transport Choices to Southwest Asia in Constrained Operations

Deployment Options	New Assets	Investment Costs ($ billion)	30-Year Life-Cycle Costs ($ billion)
I 21/70/90	5 950-ft. Ro/Ro	1.3	2.0
II 21/50/75	15 950-ft. Ro/Ro	3.9	6.2
III 12/30/60	65 C-17 31 NSL-7	22.2	50.2
IV 12/25/50	65 C-17 10 Prepo 18 NSL-7 18 950-ft. Ro/Ro	26.3	58.7

Table 14

B/C Option for Increased cs/css Cargo (in Constrained Operations)

Deployment Options	New Assets B/C Option	Investment Costs ($ billion)	30-Year Life-Cycle Costs ($ billion)
I 21/70/90	7 B/C	1.6	1.6
II 21/50/75	15 950-ft. Ro/Ro	3.9	6.2
III 12/30/60	65 C-17 28 NSL-7 4 B/C	22.3	50.0
IV 12/25/50	65 C-17 10 Prepo 18 NSL-7 30 B/C	28.4	58.1

their utility in carrying the added cargo of the larger MRCF. The addition of foreign charters allows the sealift baseline to meet Option I (Table 15). Moreover, the use of foreign charters reduces the number of new ships and associated investment and life-cycle costs for meeting the remaining three options (comparison of Table 13 and 15). For

Table 15

Foreign Charters for Increased cs/css Cargo (in Constrained Operations)

Deployment Options	New Assets with Foreign Charter Option	Investment Costs ($ billion)	30-Year Life-Cycle Costs ($ billion)
I 21/70/90	none	none	none
II 21/50/75	8 950-ft. Ro/Ro	2.1	3.3
III 12/30/60	65 C-17 9 NSL-7 11 950-ft. Ro/Ro	18.9	45.9
IV 12/25/50	65 C-17 10 Prepo 18 NSL-7 8 950-ft. Ro/Ro	23.7	54.6

example, the use of foreign charters in Deployment Options III and IV saves $3.3 and $2.6 billion in investment costs, respectively. These savings are on the order of the investments in new assets required to carry the added cs/css of the larger MRCF. Foreign charters also decrease life-cycle costs.

Reliance on foreign charters poses some risks to DoD because of uncertainties in ships' availability. However, with an effective database on foreign shipping, and in-place protocols to facilitate the chartering of ships in emergencies, the foreign charters appear acceptable for carrying added cs/css cargo.

Summary of Transport Options to SWA with Suez

No dominant sealift candidate emerges from the analysis (Table 16). Because of its slower speed and postulated smaller size (average size of the commercial Ro/Ro's used in ODS), the used Ro/Ro candidate is dominated by other ship options. The 950-ft. Ro/Ro is preferred in the two less demanding deployment options. The two more demanding deployment options require a combination of sealift candidates and C-17s. Baseline airlift and sealift assets augmented with one 950-ft. Ro/Ro can close 900,000 stons of MRCF u/e and cs/css cargo to Southwest Asia, with access to the Suez, in 90 days.

If MRCF cargo increases to 1 million stons, baseline assets have to be augmented with five 950-ft. Ro/Ro's at an estimated cost of $1.3 billion, or $1 billion more than for the smaller MRCF. The life-cycle cost

Table 16

Transport Options to Southwest Asia with Suez in Constrained Operations

Deployment Option	New Assets		Investment and Life-Cycle Costs ($ billion)	
	900,000 stons	1,000,000 stons	900,000 stons	1,000,000 stons
I 21/70/90	1 950-ft. Ro/Ro	5 950-ft. Ro/Ro	0.3/0.4	1.3/2.0
II 21/50/75	10 950-ft. Ro/Ro	15 950-ft. Ro/Ro	2.6/4.1	3.9/6.2
III 12/30/60	65 C-17 21 NSL-7 3 950-ft. Ro/Ro	65 C-17 31 NSL-7	20.4/47.4	22.2/50.2
IV 12/25/50	65 C-17 10 Prepo 16 NSL-7 11 950-ft. Ro/Ro	65 C-17 10 Prepo 18 NSL-7 18 950-ft. Ro/Ro	24.0/55.0	26.3/58.7

increases by $1.6 billion. Meeting the closure requirements of the 900,000 ston MRCF in the most demanding case requires the procurement of 65 C-17s, 10 Prepo ships, 16 NSL-7s and 11 Ro/Ro's, at an estimated cost of $24 billion, with C-17s accounting for more than half of the total. If the cargo increases to 1 million stons, an additional two NSL-7s and seven 950-ft. Ro/Ro's, at an estimated investment cost of $2.3 billion, would be required. The life-cycle cost increases by $3.7 billion. This increase in cost could be offset by the use of foreign charters.

ANALYSIS OF ALTERNATIVE TRANSPORT OPTIONS TO SOUTHWEST ASIA WITHOUT SUEZ

In ODS, U.S. sealift ships had access to the Suez Canal; however, in future deployments, the canal may not be available. Access to the Canal for sealift operations in support of unilateral U.S. policy decisions may be denied for political reasons. Alternatively, such actions as mining may close or severely restrict ship passage through the canal. To test the effect of losing access to the canal on the performance of alternative transports, the analysis also examines deployments to Southwest Asia without the use of the Suez Canal. Without access to the canal, sealift ships from southeastern U.S. ports have to travel around the southern tip of Africa to reach Persian Gulf ports, a distance of roughly 12,000 n mi. This distance is 38 percent longer than that via the Suez Canal.

Using the same approach as in the case using the Suez Canal to reach Southwest Asia, we first determine the preferred mix of transports to meet alternative force deployment options in unconstrained operations. Next, we focus the analysis on unconstrained sealift, but constrained airlift operations. Then we examine the effect of cargo growth on transport options and assess the utility of foreign charters for deploying the added cargo.

Transport Options in Deployments to Southwest Asia Without Suez

An additional seven 950-ft. Ro/Ro's have to be bought to close the cargo of the smaller MRCF in 90 days (Table 17). Twelve new 950-ft. Ro/Ro's are necessary to close the larger MRCF in the same time, without the use of foreign charters. The 30-knot NSL-7s, because they can complete two deliveries in 75 days, prove to be the most cost-effective in Option II. The more demanding Option III requires C-17s, NSL-7s, and 950-ft. Ro/Ro's. Because Prepo ships are the only sealift candidates capable of delivering the early sealift cargo to Southwest Asia, without access to the Suez Canal, in less than 25 days, they are required in Deployment Option IV. However, to meet this requirement, they have to be preloaded with the u/e of two heavy Army divisions and a corps slice of cs/css. This amount of u/e and cs/css is well in excess of what the Army considers reasonable for afloat prepositioning. For this reason, we strike Option IV from fur-

Table 17

Transport Options to Southwest Asia Without Suez

Deployment Option	Unconstrained New Assets 900,000 stons	Constrained Airlift Operations		
		New Assets 900,000 stons	New Assets 1,000,000 stons	New Assets +F Charters 1,000,000 stons
I 21/70/90	1 950-ft. Ro/Ro	7 950-ft. Ro/Ro	12 950-ft. Ro/Ro	5 950-ft. Ro/Ro
II 21/50/75	10 NSL-7	18 NSL-7	26 NSL-7	17 NSL-7
III 12/30/60	22 NSL-7 15 950-ft. Ro/Ro	65 C-17 26 NSL-7 17 950-ft. Ro/Ro	65 C-17 28 NSL-7 24 950-ft. Ro/Ro	65 C-17 28 NSL-7 13 950-ft. Ro/Ro
IV 12/25/50	25 Prepo 13 950-ft. Ro/Ro	65 C-17 27 Prepo 15 950-ft. Ro/Ro	65 NSL-7 29 Prepo 22 950-ft. Ro/Ro	65 C-17 29 Prepo 17 950-ft. Ro/Ro

ther consideration in deployments to Southwest Asia without use of the Suez.

Because the lack of access to the Suez Canal does not affect airlift routes, the number of C-17s required does not change from the Southwest Asia-with-Suez cases. As in the Southwest Asia-with-Suez deployments, foreign charters are effective in reducing the number of government-controlled ships required to carry the increased cs/css of the larger MRCF.

The investment and life-cycle costs to meet deployment requirements to Saudi Arabia without the Suez Canal are shown in Table 18. Excluding deployment Option IV as unreasonable, the investment costs for developing the capability to deploy the smaller MRCF to Southwest Asia without the Suez Canal in 60 days is on the order of $25.4 billion, or $5 billion more than required to deploy the same force in 60 days to Southwest Asia with access to the Suez Canal. An investment of $27.7 billion would be required to move the cargo of the larger MRCF. The use of charter ships reduces this investment by $2.9 billion. Assuming constrained airlift operations, the life-cycle cost of transport options to close the smaller MRCF to Southwest Asia in 60 days, without access to the Suez, is $55.2 billion. This total increases by $3.7 billion for moving the larger MRCF.

Table 18

Investment and Life-Cycle Costs of Transport Options to Southwest Asia Without the Suez ($ billion)

Deployment Option	Unconstrained New Assets 900,000 stons[a]	Constrained Airlift Operations		
		New Assets 900,000 stons[a]	New Assets 1,000,000 stons[a]	New Assets +F Charters 1,000,000 stons[a]
I 21/70/90	0.3/0.4	1.8/2.9	3.1/4.9	2.0/1.3
II 21/50/75	2.6/4.0	4.6/7.3	6.6/10.5	4.3/6.9
III 12/30/60	9.5/15.1	25.4/55.2	27.7/58.9	24.8/54.4
IV 12/25/50	NA	NA	NA	NA

[a]Investment cost/life-cycle cost.

Deployment of a Notional Low-Intensity Conflict Force to Southwest Asia

Not all military operations to Southwest Asia are likely to require the deployment of the notional MRCF along the timelines examined in the preceding section. Potentially, a force comparable to the notional LICF may be more appropriate. Because the delivery schedule of the LICF is less demanding than that of the early force package of the MRCF, baseline transports are sufficient to deliver the LICF to Saudi Arabia, as required.

ANALYSIS OF ALTERNATIVE TRANSPORT OPTIONS TO KOREA

The analysis of alternative transport options to Korea parallels that for Saudi Arabia, with the major differences being transit routes and distances. Because the bulk of Army combat units of the notional MRCF are located in the southeastern and Gulf areas of the United States, the analysis assumes that ships deploy from southeastern or Gulf of Mexico ports (Figure 12). The distance from these ports to Korea, through the Panama Canal is roughly 10,000 n mi, or 2000 n mi less than deployments to Saudi Arabia without the Suez Canal, and about 1300 n mi longer than to Southwest Asia with the Suez Canal.[5]

Korea has several seaports that can accommodate roughly 25 large sealift ships, with Pusan, the largest port, capable of handling ten or more ships simultaneously. Thus, sealift operations to Korea are also assessed as unconstrained.

Using Charleston, South Carolina, as a conservative notional central point for deploying air cargo and Elmendorf, Alaska, and Yokota, Japan, as en route stops, the total distance from Charleston to Korea is about 7100 n mi. To minimize congestion at Elmendorf, airlifters on return trips can fly directly from Japan to California for refueling before returning to South Carolina. If this is the case, the return distance is about 7800 n mi.

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[5]Arguments can be made for examining an alternative notional Korean deployment scenario, one in which the u/e and early cs/css cargo are deployed from the southeast of the United States, but the late cs/css cargo is moved from the West Coast of the United States. We did not select this scenario because its distance and transit time factors are, on the average, very close to those of the Southwest Asia with access to the Suez Canal case.

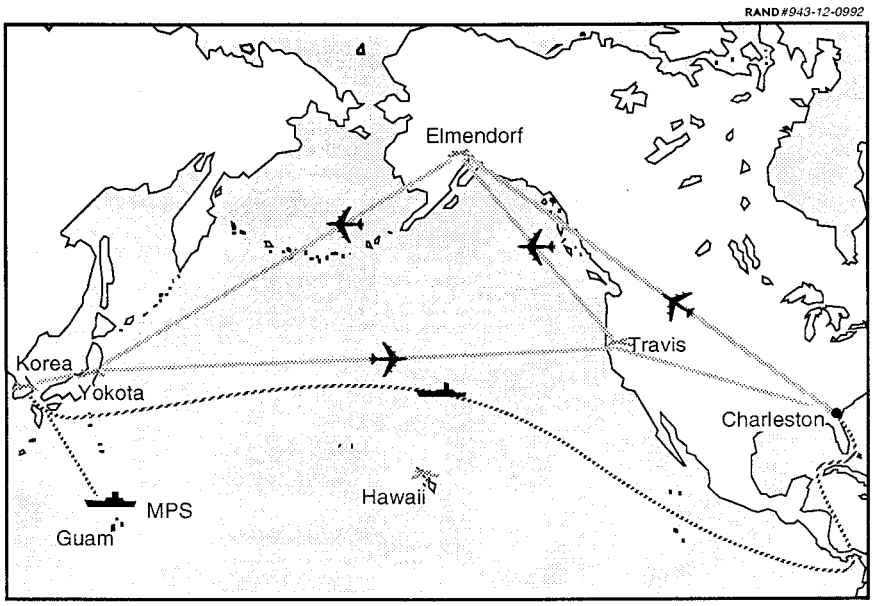


Figure 12—Sealift and Airlift Operations to Korea

Several Korean airfields, including Chinhae, Kunsan, Taegu, Osan, Sachon, Pohang, and Yechon, may support C-5s, the largest military airlifters. As ODS experience showed, it is difficult to predict the working MOG for airlift operations. Passenger and tactical aircraft are also likely to deploy to these airfields and use parking space and support. Consequently, we first examine airlift operations to Korea as unconstrained, and then assume a working MOG of eight C-5 equivalents.

Alternative Transport Options to Korea

As in the Southwest Asia cases, no dominant sealift candidate emerges in the Korean deployment options. The 950-ft. Ro/Ro is the preferred sealift candidate for the less demanding deployment options. Baseline airlift and sealift assets, augmented with 11 950-ft. Ro/Ro's, meet all deployment cases of Option I. The use of foreign charters reduces this number to two. Combinations of candidates are required in all Option III and IV constrained-airlift cases. Because the postulated airlift routes to Korea are slightly longer than those to Southwest Asia, about 15 more C-17s are required (Table 19).

Table 19

Alternative Transport Options to Korea

Deployment Option	Unconstrained New Assets 900,000 stons	Constrained Airlift Operations		
		New Assets 900,000 stons	New Assets 1,000,000 stons	New Assets +F Charters 1,000,000 stons
I 21/70/90	2 950-ft. Ro/Ro	7 950-ft. Ro/Ro	11 950-ft. Ro/Ro	2 950-ft. Ro/Ro
II 21/50/75	7 950-ft. Ro/Ro	11 950-ft. Ro/Ro	23 950-ft. Ro/Ro	16 950-ft. Ro/Ro
III 12/30/60	27 950-ft. Ro/Ro	80 C-17 30 950-ft. Ro/Ro	80 C-17 38 950-ft. Ro/Ro	80 C-17 25 950-ft. Ro/Ro
IV 12/25/50	10 Prepo 13 NSL-7 18 950-ft. Ro/Ro	80 C-17 10 Prepo 15 NSL-7 19 950-ft. Ro/Ro	80 C-17 10 Prepo 18 NSL-7 26 950-ft. Ro/Ro	80 C-17 10 Prepo 18 NSL-7 17 950-ft. Ro/Ro

As in the Southwest Asia cases, in constrained-airlift operations to Korea, the number of C-17s required is a function of early cargo-closure requirements and postulated MOG constraints. A 10-percent growth in early cargo requirement to Korea increases the number of C-17s required by 60 percent. A similar decrease in MOG capacity increases the number of C-17s required by 50 percent.

The most demanding option for deploying the smaller MRCF to Korea requires about 80 C-17s, 10 Prepo, 15 NSL-7s, and 19 950-ft. Ro/Ro's. An additional three NSL-7s and seven 950-ft. Ro/Ro's are necessary to close the larger MRCF. As in the Southwest Asia cases, foreign charters are an attractive option for reducing the number of 950-ft. Ro/Ro's required to carry added cs/css cargo.

The development of the capability to deploy the smaller notional MRCF to Korea in 90 days, with the early force package closing in about three weeks, requires a modest investment in sealift of about $1.8 billion (Table 20). This investment grows by more than 60 percent for the larger MRCF. The most demanding closure option for the smaller MRCF requires a $27.9 billion investment, or $2.6 billion less than for the larger MRCF. The use of foreign charters would reduce the investment cost for moving the larger MRCF by $2.3 billion.

The life-cycle costs of the transport options for Korea in the most demanding cases are the highest in all cases examined. This is primar-

Table 20

Investment and Life-Cycle Costs of Transport Options to Korea ($ billion)

Deployment Option	Unconstrained New Assets 900,000 stons[a]	Constrained Airlift Operations		
		New Assets 900,000 stons[a]	New Assets 1,000,000 stons[a]	New Assets +F Charters 1,000,000 stons[a]
I 21/70/90	0.5/0.8	1.8/2.9	2.9/4.5	0.5/0.8
II 21/50/75	1.8/2.9	2.9/4.5	6.0/9.4	4.2/6.6
III 12/30/60	7.0/11.1	24.2/57.5	26.3/60.8	22.9/55.4
IV 12/25/50	10.7/19.0	27.9/65.4	30.5/69.5	28.2/65.8

[a]Investment cost/life-cycle cost.

ily due to the increased number of aircraft needed to meet early delivery requirements.[6]

Deployment of the LICF to Korea

Future military operations to Korea may not require the deployment of the notional MRCF. The postulated LICF may be sufficient. If that were the case, baseline airlift and sealift assets would be sufficient. No investments in new transportation assets for deploying the LICF to Korea appear warranted.

ANALYSIS OF TRANSPORT OPTIONS TO ZAIRE

To test the performance of transport options in potential deployments to future low intensity conflicts, we examined the deployment of the postulated LICF to Zaire. In this notional deployment, the u/e and cs/css of the LICF have to be delivered to the Shaba province, located in the southeastern corner of Zaire, about 800 n mi from its capital of

[6]To account for the smaller-than-planned C-17 program buy (80 versus 120), the C-17 unit cost is increased to $205 million. We derived this value by assuming that the current procurement plan, as shown in the SAR, remains constant and by curtailing the number of aircraft at the point where the required number is acquired. We incorporated the remaining fraction of both military construction and R&D and allocated $250 million for closing out the program.

Kinshasa. This mineral-rich province of Zaire has been the focus of past military conflicts with Angola and may be again in the future.

Transport operations to Zaire face a very austere reception and support infrastructure. Zaire has only three small ports, Banana, Boma, and Matadi, none of which are likely to accommodate large sealift ships. Its major port, Matadi, is located 80 n mi up the Congo river. Because of shifting sand banks and strong currents, navigation of the Congo River is limited to ships smaller than baseline and proposed sealift ship options. Consequently, only airlift assets are used to deploy the LICF to Zaire.

Airlift operations from the East Coast of the United States to this area may take several routes: (1) Charleston–Puerto Rico–Ascension Island–Kinshasa–APODs, (2) Charleston–Azores–Dakar–Kinshasa–APODs, and (3) Charleston–Ascension Island–Kinshasa–APODs (Figure 13). Obviously, return trips can be made along the same routes, selecting those that would minimize congestion.

Kinshasa, the major airfield in Zaire, has roughly 1.1 million sq. ft. of parking space. It has significant fuel storage and is supplied by a major fuel pipeline from Matadi. Assuming that ground support and fueling equipment are available, we estimated that Kinshasa can support four C-5 equivalents simultaneously. In the Shaba province, there are airfields that may support a similar number of large airlifters. Therefore, we postulated a total working MOG of four C-5 equivalents for the deployment of the hypothetical LICF to Zaire.

Because of MOG constraints at Kinshasa and the APODs, the baseline airlift force cannot deliver the early air cargo of the LICF in 30 days. Roughly 60 C-17s have to be added to the airlift baseline to complete deliveries. This means an investment of roughly $13.5 billion and a life-cycle cost of $33.8 billion.

COMPARISON OF PREFERRED TRANSPORT OPTIONS ACROSS DEPLOYMENT LOCATIONS

No dominant sealift candidate emerged from the analysis (Table 21). Assuming that early airlift operations are constrained by working MOG, the analysis of notional deployments to Southwest Asia and Korea shows that existing baseline airlift and sealift assets with seven 950-ft. Ro/Ro's have the potential to deploy 900,000 stons of MRCF u/e and cs/css cargo in 90 days. The investment cost for the added ships is on the order of $1.8 billion, or about 15 percent less than the $2.1 billion set aside by Congress for the construction of sealift ships (Table 22). Developing the capability to close the MRCF

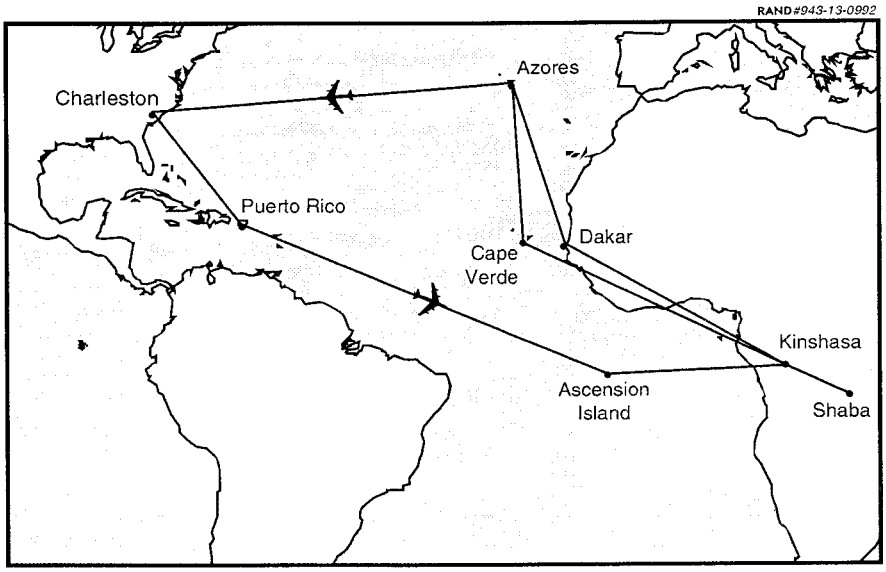


Figure 13—Airlift Operations to Zaire

Table 21

Preferred Transport Options for Deploying the MRCF (900,000 stons; constrained airlift operations)

Deployment Option	Southwest Asia (w/Suez)	Southwest Asia (wo/Suez)	Korea
I 21/70/90	1 950-ft. Ro/Ro	7 950-ft. Ro/Ro	7 950-ft. Ro/Ro
II 21/50/75	10 950-ft. Ro/Ro	18 NSL-7	11 950-ft. Ro/Ro
III 12/30/60	65 C-17 21 NSL-7 3 950-ft. Ro/Ro	65 C-17 26 NSL-7 17 950-ft. Ro/Ro	80 C-17 30 950-ft. Ro/Ro
IV 12/25/50	65 C-17 10 Prepo 16 NSL-7 11 950-ft. Ro/Ro	NA	80 C-17 10 Prepo 15 NSL-7 19 950-ft. Ro/Ro

Table 22

Investment and Life-Cycle Costs of Preferred Transport Options for the MRCF ($ billion) (900,000 stons; constrained airlift operations)

Deployment Option	Southwest Asia (w/Suez)[a]	Southwest Asia (wo/Suez)[a]	Korea[a]
I 21/70/90	0.3/0.4	1.8/2.9	1.8/2.9
II 21/50/75	2.6/4.1	4.6/7.3	2.9/4.5
III 12/30/60	20.4/47.4	25.4/55.2	24.2/57.5
IV 12/25/50	24.0/55.0	NA	27.9/65.4

[a]Investment cost/life-cycle cost.

two weeks earlier across the scenarios examined requires the procurement of about 18 NSL-7s at an estimated cost of $4.6 billion. For both Options I and II, baseline airlift assets are sufficient to meet the 21-day closure of the u/e of early units.

The more demanding options, III and IV, require a substantial number of new airlift and sealift assets. Closing the early air cargo of the MRCF in 12 days requires about 65 C-17s for Southwest Asia and 80 C-17s for Korea. To meet Option III in Southwest Asia and Korea, roughly 80 C-17s, 26 NSL-7s, and 17 950-ft. Ro/Ro's, with an investment cost of roughly $27.4 billion, have to be added.

Option IV is unreasonable in the Southwest Asia (without Suez) case, because it requires afloat prepositioning of the u/e of two heavy Army divisions and a corps slice of cs/css, an alternative that is probably unacceptable to the Army. Developing the capability of closing the MRCF in 50 days to Southwest Asia (with Suez) and Korea requires the procurement of about 80 C-17s, 10 Prepo, 15 NSL-7s, and 19 950-ft. Ro/Ro's, at an estimated cost of about $27.9 billion, with C-17s accounting for over half of this total. The 30-year life-cycle cost of maintaining these capabilities is estimated as roughly $65.4 billion.

Effect of Increased CS/CSS Cargo

The growth of cargo from 900,000 to 1,000,000 stons increases the number of sealift ships needed to meet cargo closures in all cases examined. To close the u/e and cs/css of the larger MRCF in 90 days,

baseline sealift assets have to be augmented with 12 950-ft. Ro/Ro's (Table 23). This requires an investment of $3.1 billion, or $1.3 billion more than that required for the smaller MRCF (Table 24). To close the larger MRCF in 50 days to all destinations examined, 80 C-17s, 10 Prepo, 18 NSL-7s, and about 26 950-ft. Ro/Ro's have to be added, at an investment of $30.5 billion, or $2.6 billion more than for the smaller MRCF.

Table 23

Preferred Transport Options for Deploying the MRCF (1,000,000 stons of u/e and cs/css; constrained airlift operations)

Deployment Option	Southwest Asia (w/Suez)	Southwest Asia (wo/Suez)	Korea
I 21/70/90	5 950-ft. Ro/Ro	12 950-ft. Ro/Ro	11 950-ft. Ro/Ro
II 21/50/75	15 950-ft. Ro/Ro	26 NSL-7	23 950-ft. Ro/Ro
III 12/30/60	65 C-17 31 NSL-7	65 C-17 28 NSL-7 24 950-ft. Ro/Ro	80 C-17 38 950-ft. Ro/Ro
IV 12/25/50	65 C-17 10 Prepo 18 NSL-7 18 950-ft. Ro/Ro	NA	80 C-17 10 Prepo 18 NSL-7 26 950-ft. Ro/Ro

Table 24

Investment and Life-Cycle Costs of Preferred Transport Options for the MRCF ($ billion) (1,000,000 stons; constrained airlift operations)

Deployment Option	Southwest Asia (w/Suez)[a]	Southwest Asia (wo/Suez)[a]	Korea[a]
I 21/70/90	1.3/2.0	3.1/4.9	2.9/4.5
II 21/50/75	3.9/6.2	6.6/10.5	6.0/9.4
III 12/30/60	22.2/50.2	27.7/58.9	26.3/60.8
IV 12/25/50	26.3/58.7	NA	30.5/69.5

[a]Investment cost/life-cycle cost.

As expected, the growth of cs/css cargo also increases the life-cycle cost for each deployment option. For Deployment Option I, the life-cycle cost of the larger MRCF is $1.6 to $2 billion more than for the smaller MRCF. For Deployment Option IV, the differences in life-cycle cost are more substantial, $3.7 to $4.1 billion.

6. CONCLUSIONS

Because future deployment requirements are uncertain, alternative transport options were measured in postulated deployments of a notional MRCF, with 900,000 or 1,000,000 stons of u/e and cs/css, to Southwest Asia, with and without use of the Suez Canal, and to Korea. Four closure options for the MRCF, ranging from 50 to 90 days, were used in the analysis. To ensure that transport combinations designed to deploy the MRCF were also adequate to deploy a smaller force to austere locations, the analysis also examined the deployment of a notional LICF, with 60,000 stons of u/e and cs/css, to Zaire in 30 days.

PREFERRED TRANSPORT CANDIDATES

Taking into account late-1990 projected capabilities of existing mobility programs, the analysis assessed 11 alternative transport candidates. Four preferred candidates emerged from the analysis:

- The new C-17 military airlifter,
- A newly constructed 30-knot fast sealift ship (NSL-7),
- A new-design large 24-knot roll-on/roll-off ship (950-ft. Ro/Ro), and
- A new-design large 24-knot prepositioning ship (Prepo).

The Prepo candidate is of the same hull and propulsion plant design as the 950-ft. Ro/Ro, but is equipped with additional air-conditioning units and with environmental controls to support the long-term storage of military equipment. Thus, from a ship-construction perspective, only two new sealift candidates would have to be built.

Assuming that the C-17 meets design specifications to operate on austere airfields, its procurement would add flexibility to existing airlift programs. In the more demanding cases examined, the C-17 proved necessary for delivering the required cargo to constrained APODs. The choice among the preferred sealift candidates varies as a function of closure requirements and transit routes. NSL-7s and Prepo ships—the only candidates capable of delivering cargo in 30 days or less to Southwest Asia, without the use of the Suez Canal—proved necessary for meeting early cargo deliveries in the most demanding cases examined. In some of the less demanding cases, NSL-7s were also the most cost-effective in delivering late cargo. In the

majority of cases examined, the 950-ft. Ro/Ro's are the most cost-effective in meeting less time-demanding deployment options. Because of its relatively slow speed and postulated size (average size of commercial Ro/Ro's used in ODS), the used Ro/Ro is not a preferred candidate.

The distinct capabilities of the preferred candidates suggest that combinations of these candidates should be considered in planning future mobility programs. The specific combination—how many C-17s, NSL-7s, Prepo ships, and 950-ft. Ro/Ro's, respectively—depends on requirements. Of the four requirement levels considered, the two extreme cases provide the framework for defining future mobility planning strategies.

TRANSPORT OPTIONS FOR DEPLOYING THE MRCF IN 21/70/90 DAYS

The projected FY 1999 baseline mobility programs—government-controlled airlift and sealift programs, CRAF, and U.S. charter ships—with seven new 950-ft. Ro/Ro's have the potential of delivering 900,000 stons of MRCF u/e and cs/css to Southwest Asia, with and without the use of the Suez Canal, or to Korea in about 90 days. The estimated investment for seven new 950-ft. Ro/Ro's is about $1.8 billion, or roughly 15 percent less than the amount of funding set aside by Congress for sealift ship construction. The use of foreign charter ships to carry late cargo would negate the need for the new ships and the associated investment costs.

If the cargo of the MRCF grows to 1,000,000 stons, 12 950-ft. Ro/Ro's, costing $3.1 billion, have to be added to meet the 90-day closures. The use of foreign charter ships to carry the added cargo reduces the number of 950-ft. Ro/Ro's to five, and investment costs to $1.3 billion.

TRANSPORT OPTIONS FOR DEPLOYING THE MRCF IN 12/25/50 DAYS

The airlift baseline cannot close the 40,000 stons of early air cargo of the MRCF in 12 days in all cases examined. To achieve this capability, about 80 C-17s,[1] with an investment cost of about $16.4 billion, have to be added. In operations to constrained APODs, the number of C-17s is highly sensitive to early cargo-closure requirements and MOG constraints. A 10-percent growth in early cargo requirements

[1]The quantity of C-17s is in terms of PAA, which may be 10 to 15 less than the total aircraft inventory.

to Southwest Asia or Korea increases the number of C-17s by about 50 to 60 percent, respectively. These results suggest that in-depth analysis of early cargo requirements is an essential element for sizing the C-17 buy. A 10-percent decrease in MOG increases the number of C-17s by roughly 40 percent for Southwest Asia or by 50 percent for Korea. This suggests that alternatives other than the procurement of new airlifters should also be explored to reduce the effect of MOG constraints.

The baseline sealift programs cannot deliver the cargo for two heavy divisions in 25 days and close 900,000 stons of MRCF u/e and cs/css in 50 days to Southwest Asia and Korea. To meet these requirements, an investment of roughly $11.5 billion, in 10 Prepo, 15 NSL-7s, and 19 950-ft. Ro/Ro's is needed. Adding new ship costs to those of new airlifters becomes an investment of $27.9 billion and a life-cycle cost of $65.4 billion.

If the cargo of the MRCF grows to 1,000,000 stons, an additional investment of $2.6 billion in another three NSL-7s and seven 950-ft. Ro/Ro's is necessary to meet requirements. The life-cycle cost also increases by roughly $4 billion. The use of foreign charter ships to carry the added cargo almost negates these additional costs.

STRATEGIES FOR PLANNING FUTURE MOBILITY PROGRAMS

Because future deployments are uncertain, decisionmakers should consider a range of strategies in planning future mobility programs. At one extreme, they may choose to design mobility programs to meet the most demanding requirements. In the cases we examined, this means a capability of delivering the early air cargo of the MRCF in 12 days and a total of one million stons of u/e and cs/css in 60 days to Southwest Asia, without the Suez Canal, or in 50 days to Korea. This would require the procurement of 80 C-17s, 10 Prepo ships, 18 NSL-7s, and 26 950-ft. Ro/Ro's at an estimated cost of $30.5 billion, with C-17s accounting for more than half of this investment. The use of foreign charter ships would reduce the number of required 950-ft. Ro/Ro's by nine and the investment by roughly 8 percent. The number of C-17s procured for deploying the MRCF to Southwest Asia or Korea would be sufficient to close the cargo of the postulated LICF to Zaire.

At the other extreme, choosing to increase the capabilities of existing sealift programs only modestly requires an investment of about $3.1 billion in 12 new 950-ft. Ro/Ro's. The use of foreign charter ships

would decrease the number of new 950-ft. Ro/Ro's to five and the investment to roughly $1.3 billion. This strategy would allow closure of the early air cargo of the MRCF in about three weeks and of all cargo in 90 days to Southwest Asia, with and without access to the Suez Canal, or to Korea.

As an intermediate option, choosing to improve existing sealift programs only modestly and to improve airlift capabilities to deliver cargo to constrained APODs or austere locations requires an investment of about $19.5 billion in 80 C-17s and 12 new 950-ft. Ro/Ro's. This allows the closure of the early air cargo of the MRCF in 12 days and of all cargo in 90 days to Southwest Asia, with and without the Suez Canal, or Korea. The added airlift capabilities are also sufficient to close the LICF in 30 days to Zaire.

In-depth analyses of future threats and of DoD-planned responses to those threats have to be completed before a compelling rationale for selecting a specific planning strategy can be offered. Until such analyses are completed, the choice of planning strategies will rely primarily on policymakers' perceptions of future threats and judgments as to what mobility capabilities are sufficient to meet those threats. Because of these factors, **the results of this analysis suggest that an initial investment be made to improve modestly the capabilities of existing mobility programs for the future.** If rapid deployment requirements beyond the capabilities of existing programs are validated, then DoD should continue the procurement of C-17s and invest in a combination of 30-knot NSL-7s, and 24-knot 950-ft. Ro/Ro's and Prepo ships.

BIBLIOGRAPHY

Chenoweth, Mary, *The Civil Reserve Air Fleet: An Example of the Use of Commercial Assets to Expand Military Capabilities During Contingencies*, RAND, N-2838-AF, June 1990.

Commission on Merchant Marine and Defense, *Second Report of the Commission on Merchant Marine and Defense: Recommendations*, December 30, 1987.

Department of the Air Force, *Military Airlift Planning Factors*, AFP 76-2 (C-1), Headquarters U.S. Air Force, Washington, D.C., May 29, 1987.

Deputy Chief of Naval Operations (Logistics), Strategic Sealift Division, *Navy Strategic Sealift Implementation Plan (Draft)*, Washington, D.C., August 26, 1991.

Hura, M., and R. Robinson, *Fast Sealift and Maritime Prepositioning Options for Improving Sealift Capabilities*, RAND, N-3321-P&L/DAG/JS, 1991.

Lloyd's, *Lloyd's Ports of the World*, Lloyd's of London Press, Essex, United Kingdom, 1989.

Maritime Administration, *RRF Ship Inventory,* MAR-745, January 1, 1991.

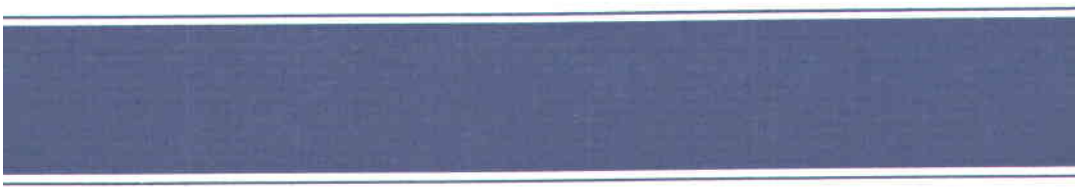
Marshall, Rolph, *Fast Sealift Ship Performance in Operation Desert Shield 90: Preliminary Assessment and Recommended Planning Factors for Surge Deployment Analysis,* Office of Deputy Chief of Naval Operations (Logistics), Strategic Sealift Division, December 11, 1990.

Naval Audit Service, *Logistics Planning for the Maritime Prepositioning Ships Program,* Falls Church, VA., February 29, 1989.

Rost, R., et al., *Sealift in Operation Desert Shield/Desert Storm: 7 August 1990 to 17 February 1991*, Center for Naval Analysis, Alexandria, Virginia, May 1991.

U.S. Air Force, Aeronautical Systems Division, Wright-Patterson AFB, C-17 Systems Program Office, *Selected Acquisition Report (RCS: DD-COMP (O&A) 823) Program: C-17*, Dayton, Ohio, December 31, 1991.

U.S. Army, Liaison Office, Headquarters MAC, *Airlift Planning Guide*, Scott AFB, Illinois, November 1986.

U.S. Army, Military Traffic Management Command Transportation Engineering Agency, *Deployment Planning Guide*, August 1991.

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