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Littoral Combat Ships

Relating Performance to Mission Package Inventories, Homeports, and Installation Sites

Brien Alkire • John Birkler • Lisa Dolan • James Dryden
Bryce Mason • Gordon T. Lee • John F. Schank • Michael Hayes

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United States Navy

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Preface

The Littoral Combat Ship (LCS) is a relatively small surface combatant vessel intended to perform littoral or coastal missions where high-speed maneuverability, agility, and sprint speed are required. In early 2005, the U.S. Navy commissioned the RAND Corporation to evaluate the operational, logistical, and cost implications of modules being developed and put into service aboard the LCS, a new platform that, through modular design, can be rapidly reconfigured to suit changing tactical situations. The ships will complement America's fleets of existing Aegis ships and new-generation DDG-1000 destroyers and CG(X) cruisers.[1]

RAND's evaluation took place during the months immediately before and after the keel for the first LCS, the *USS Freedom*, was being prepared and laid.[2] The *Freedom* is the first of two LCS seaframes under production. Able to achieve speeds of 40 to 50 knots and to maneuver in waters less than 20 feet deep, these LCS seaframes will operate in environments where employing larger, multimission ships would be infeasible or ill-advised.

Plans call for the *Freedom* and each subsequent LCS to consist of two elements: a core seaframe that includes the ship platform and inherent combatant capabilities and a set of interchangeable modular "plug-and-fight" mission packages that will allow the ship to be reconfigured for antisubmarine warfare, mine warfare, or surface warfare missions, as needed.

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1 The DDG-1000 was formerly named DD(X). See Fein, 2006.

2 The *Freedom*'s keel was laid and authenticated on June 2, 2005 ("Keel Laid," 2005).

Each seaframe will be able to perform a set of primary functions—including self-defense; navigation; command, control, communications, computers, intelligence, surveillance, and reconnaissance; and launching and retrieving unmanned vehicles—common to all missions. The interchangeable mission packages will provide the LCS with additional war-fighting capabilities and allow it to perform specialized missions. A mission package may consist of a combination of mission modules, such as manned and unmanned vehicles, deployable sensors, and mission manning detachments. The components of a mission module predominantly fit inside several standard-size 20-foot cargo containers. The mission modules will integrate into the seaframe, and any LCS can hold any mission package. An LCS can be reconfigured with a new mission package in a few days while laying pier side.

This modular approach raises several questions:

- Where are the optimum locations for LCS homeports and mission package installation sites?
- How many mission packages of each type should be procured and when?
- How many mission packages of each type should be stored on available seaframes, at homeports, and at mission package installation sites?
- What are the costs of acquiring mission packages and facilities for homeports and installation sites?
- What cost and performance trade-offs and sensitivities occur with various combinations of the number of and the types of mission packages?

RAND analyzed these questions between January and November 2005, employing both qualitative and quantitative methodologies. This monograph describes the analytical procedures that the RAND team followed and summarizes its findings and recommendations.

This research was sponsored by the Naval Sea System Command's Surface Warfare Development Group and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and develop-

ment center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community. For more information on RAND's Acquisition and Technology Policy Center, contact the Director, Philip Antón. He can be reached by email at atpc-director@rand.org; by phone at 310-393-0411; or by mail at the RAND Corporation, 1776 Main Street, Santa Monica, California 90407-2138. More information about RAND is available at www.rand.org.

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Summary

In June 2005, workers at the Marinette Marine shipyard in Marinette, Wisconsin, laid the keel for the *USS Freedom*, the Navy's first Littoral Combat Ship.[1] The LCS constitutes a new class of fast, agile, and networked warships designed to overcome threats in shallow waters posed by mines, diesel-electric submarines, fast-attack craft, and fast inshore attack craft.

LCSs will be key components in a proposed family of next-generation surface combatants that also includes the much larger DDG-1000 destroyer and a future CG(X) cruiser.[2] LCSs will be able to deploy independently to overseas littoral regions; remain on station for extended periods of time, either with a carrier strike group or an expeditionary strike group or through a forward-basing arrangement; operate independently and/or with other LCS units; and be replenished while under way.

LCSs: Transformational Capabilities and Modular Mission Packages

LCSs will bring an array of transformational capabilities to the Navy. Able to achieve speeds of 40 to 50 knots and maneuver in waters less than 20 feet deep, LCSs will operate in environments where employ-

1 The *Freedom*'s keel was laid and authenticated on June 2, 2005 ("Keel Laid," 2005).

2 The DDG-1000 was formerly named DD(X). See Fein, 2006. In addition, there is also considerable interest in LCS modules for future U.S. Coast Guard applications as part of the service's Integrated Deepwater System.

ing larger, multimission ships would be infeasible or ill-advised. They will be networked into the fleet, operating as part of a distributed force; sharing tactical information with other Navy aircraft, ships, submarines, and joint units; and launching manned and unmanned vehicles to execute missions. They will incorporate advanced technologies, employing cost optimized advanced weapons; sensors; data fusion; command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems; hull forms; propulsion systems; manning concepts; smart control systems; and self-defense systems (U.S. Navy Littoral Combat Ship Web site, not dated).

But perhaps the most transformational features of LCSs will be their modular capabilities. Plans call for *Freedom* and each subsequent LCS to consist of two elements:

- a core seaframe that includes the ship platform and inherent combatant capabilities. Each seaframe will be able to perform a set of primary functions—including self-defense, navigation, C4I, and launching and retrieving unmanned vehicles—that will be common to all missions.
- a set of interchangeable modular "plug-and-fight" mission packages that will allow the ship to be reconfigured, as needed, for antisubmarine warfare (ASW), mine warfare (MIW), or surface warfare (SUW) missions. A mission package may consist of a combination of mission modules, such as manned and unmanned vehicles, deployable sensors, and mission manning detachments. The components of a mission module predominantly fit inside several standard-size 20-foot cargo containers.[3] The mission modules will integrate into the seaframe, and any LCS can hold any mission package.[4] An LCS can be reconfigured with a new mission package in a few days while laying pier side.

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[3] Standard 20-foot cargo containers measure 20 feet in length, 8 feet in width, and 8.5 feet in height. A standardized form factor is designed to allow them to be loaded on ships, trucks, and railroad cars.

[4] Our study assumed that all seaframes could operate with all mission packages, which was consistent with U.S. Navy planning at the time of the study. However, it is probable that

At the time of the study, Navy plans included acquisition of one seaframe in fiscal year (FY) 2005, an additional seaframe in FY 2006, two seaframes in FY 2007, and three in FY 2008, after which the Navy would begin acquiring five a year.[5] At that pace, the short-term inventory of seaframes could reach 36 by FY 2014, the middle-term inventory of seaframes could reach 60 by FY 2019, and the long-term inventory of seaframes could reach 84 by FY 2024.

Issues We Addressed

In early 2005, RAND was commissioned by the LCS Program Office[6] to help it think through the cost and logistics implications of modular mission packages planned for the LCSs. In particular, the LCS Program Office was interested in gaining a clearer understanding of operational, logistics, and cost trade-offs between three interdependent elements of the program: the number of LCSs in the fleet, the number of mission packages[7] that those LCSs would require to perform a range of missions, and the number of and the locations of LCS homeports and mission package installation sites.

Methods and Data We Used

RAND analyzed these issues between January and November 2005, employing both qualitative and quantitative methodologies to examine

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there will be upgrades and modernization efforts that may pose challenges for maintaining compatibility.

5 After the conclusion of the study, the Quadrennial Defense Review recommended an increase in the Navy's annual procurement of LCSs. Francis, 2006, indicates up to six ships per year from 2009 through 2011, for a total of 55 through 2029. See also Cava, 2006.

6 The official name of our sponsor is PMS 501, LCS Program Office.

7 Aviation assets were assumed to be collocated with other mission package components for the purposes of this analysis. The scope of this project did not allow for evaluation of the number of aviation assets separately from mission packages.

the LCS fleet at three discrete points in the future: the short term (by 2014), middle term (by 2019), and long term (by 2024).

Qualitative Analyses: Scenarios and LCS Employment Options

To gain an understanding of what the LCS fleet might encounter over the short, middle, and long term, we examined the LCS concept of operations (LCS CONOPS) (U.S. Navy, 2004) in conjunction with the strategic environment laid out in the 2005 National Defense Strategy and amplified in various U.S. Navy documents (U.S. Navy, 2003 and 2005).[8] This research led to various scenarios in which the ships might be expected to play a part through 2024. Every scenario that we evaluated involved a simultaneous operation from each of the following four categories:

- *Major Combat Operations (MCOs)*—for example, responding to a crisis in the Western Pacific, Southwest Asia, or Northeast Asia.
- *Global War on Terrorism Operations*—for example, responding to a chemical weapons attack on UN forces, clearing mines laid by terrorists in sea lanes, or eliminating terrorist training camps.
- *Stability Operations*—for example, providing humanitarian assistance and disaster relief, supporting a friendly government against insurgents, providing maritime security for oil platforms, providing forward presence and maritime interdiction operations in the vicinity of shipping lanes, or participating in ASW exercises/submarine tracking.
- *Homeland Defense Operations*—for example, providing security and humanitarian assistance/disaster relief following terrorist attacks on U.S. seaports, providing security and humanitarian assistance/disaster relief following a natural disaster along the U.S. seaboard, or providing humanitarian assistance following a refugee crisis in the Caribbean.

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8 Our specific terms mirror "The Evolving Strategic Environment" as shown in Figure 1 of U.S. Navy, 2005.

We also examined how the Navy plans to use LCSs. The LCS CONOPS describes plans for the Navy to embed LCSs in carrier strike groups or expeditionary strike groups, to deploy them independently, or to operate them as forward deployed units. Using these deployment concepts and potential threat characteristics, we evaluated ways in which the Navy might employ LCSs in the context of each scenario. This allowed us to develop baseline LCS requirements, including expected modes of employment, operating locations, and mission tasking.

Quantitative Analyses: Transit, Logistics, and Cost Modeling

Once we had analyzed the scenarios that LCS might encounter and the ways that the Navy plans to use the vessels, we turned to our quantitative analyses. As a first step, we derived measures of effectiveness for the LCS. Because a key capability of the LCS is its ability to respond quickly to a crisis, we used the time required for all LCSs to close on the theaters of operation as our principal measure of effectiveness—we term this metric "total closure time."[9] We also derived other metrics—the number of LCS days spent in the littoral region of an area of operation in advance of a strike group, the time it takes for each LCS to arrive on station, the time it takes for each strike group to arrive on station, the number of mission package reconfigurations by type and geographic location, and the number of refueling-at-sea operations required by each LCS to reach theaters of operation.

Once we had derived metrics, we developed a series of analytical tools to evaluate them. These tools allowed us to make trade-offs among different numbers of mission packages for the proposed number of LCSs and the locations of LCS homeports and mission package installation sites.[10]

The main analytical tool that we developed was a model that we called the LCS Transshipment Model (LCSTSM). Derived from a

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[9] Our analytical framework allows prioritization of closure time for LCSs in different operations; we treated them all with equal priority for this study rather than making assumptions on the future priorities of government decisionmakers.

[10] We assume that homeports include a mission package installation site.

well-known class of transshipment models, the LCSTSM enabled us to depict how the LCS would perform under a variety of assumptions. Other models that we developed allowed us to estimate the costs of procuring seaframes and mission packages and of constructing LCS homeports and installation site facilities.

Using the LCSTSM, we varied operational and logistics elements of the LCS, including

- the number of seaframes
- the number of mission packages
- the locations of homeports
- the locations of installation sites.

We then ran multiple computer simulations with randomly selected scenarios, locations from which LCSs would start their missions, and differing availability of assets. These simulations yielded the metrics. We examined how the average values of those metrics were affected by varying the operational and logistical elements. This information allowed us to identify the optimal locations for homeports and installation sites and the optimal sizes for mission package inventories. We then used our cost models to estimate annual and total costs to procure those mission package inventories and construct homeports and installation sites.

Preferred Homeports and Installation Sites

We analyzed 15 locations around the world as potential LCS homeports or installation sites.[11] Using the LCSTSM, we tested those locations across a range of scenarios and mission package inventories to determine the sites that LCSs would most frequently visit to install or swap mission packages in the short, middle, and long term.

[11] Bahrain; Darwin and Fremantle, Australia; Diego Garcia; Guam; Japan; Mayport, Norfolk, Pascagoula, San Diego, and Hawaii in the United States; the western and eastern Mediterranean; Puerto Rico; and Singapore. We assume that an LCS homeport includes a mission package installation site.

We found that 3 of the 15 locations were best supported as homeports by our analysis in all three time frames—Norfolk, San Diego, and Japan—and two as mission package installation sites—Singapore and Bahrain.[12]

Preferred LCS Mission Package Inventories

We used the three preferred locations for LCS homeports and the two preferred locations for installation sites to help calculate the best LCS mission package inventories in the short, medium, and long term. We employed a three-step process to make this calculation. For each time frame, we

- evaluated the average proportion of each LCS mission package type that the Navy would need to meet scenario demands
- estimated the minimum number of each LCS mission package type that the Navy needs to optimize total closure time
- determined the quantities of each LCS mission package type that the Navy will need at each preferred location.

The results of this mission package inventory analysis are summarized in Table S.1, which shows the number of ASW, MIW, and SUW missions package inventories identified by our analysis for each time period.

Summing the mission package quantities listed in Table S.1 by type, we see that our analysis suggests the Navy will need a total of 89 mission packages in the short term, 104 in the middle term, and 126 in the long term to meet scenario needs with minimal closure time across the LCS fleet.

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[12] The political sensitivities and space limitations for an installation site in Bahrain may be more significant than anticipated during the course of our study. A reexamination of this prospect was outside the scope of our charter. However, we would hypothesize that a location in the eastern or central Mediterranean might provide a suitable alternative. This hypothesis is supported by excursions discussed in this monograph, but it should be examined more carefully.

Table S.1
Mission Package Inventories in the Short Term, Middle Term, and Long Term

Time Period	ASW	MIW	SUW
Short term (by 2014)	20	27	42
Middle term (by 2019)	23	31	50
Long term (by 2024)	28	38	60

NOTES: Inventory levels depend on the operational availability, which is defined as the fraction of time that mission packages are available for mission use. Operational availability estimates for mission packages were not available at the time of this study. The inventory levels in this table assume that the operational availability of mission packages is 0.9. The numbers will need to be adjusted for different estimates of operational availability. For instance, if the operational availability is estimated to be *x*, then each number in the table should be multiplied by 0.9/*x*.

Preferred LCS Mission Package Storage Locations

Our analysis also identified the number of mission packages in inventory to be stored on available seaframes, at each homeport, and at each installation site in each time period. Table S.2 lists the inventories by location for the short term, Table S.3 for the middle term, and Table S.4 for the long term.

Total Procurement Cost for LCS Seaframes, Mission Packages, and Facility Construction

We estimated the total procurement costs for seaframes, vertical takeoff unmanned aerial vehicles (VTUAVs), mission packages, and the costs of constructing homeports and installation site facilities. To make these estimations, we took a look at the significant costs involved in trading the alternatives under study rather than taking a complete lifecycle cost or total-ownership cost approach.

Table S.2
Number of Mission Packages, by Type, Stored on Available Seaframes, at Homeports, and at Installation Sites in the Short Term (by 2014)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	5	8	12
San Diego	3	2	3
Norfolk	2	4	12
Bahrain	2	2	6
Singapore	4	7	6
Japan	4	4	3
Total	20	27	42

Table S.3
Number of Mission Packages, by Type, Stored on Available Seaframes, at Homeports, and at Installation Sites in the Middle Term (by 2019)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	9	12	21
San Diego	2	4	10
Norfolk	1	5	5
Bahrain	3	4	1
Singapore	4	3	5
Japan	4	3	8
Total	23	31	50

The results of our simplified cost estimates for the short term, middle term, and long term are shown in Table S.5. Procurement and construction costs would be \$13.8 billion in the short term, \$20.7 billion the middle term, and \$27.3 billion in the long term, expressed in FY 2004 dollars.

Table S.4
Number of Mission Packages, by Type, Stored on Available Seaframes, at Homeports, and at Installation Sites in the Long Term (by 2024)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	13	18	29
San Diego	2	2	13
Norfolk	0[a]	5	4
Bahrain	4	5	2
Singapore	4	4	4
Japan	5	4	8
Total	28	38	60

[a] Observe that our results suggest that no ASW mission packages are stored ashore in Norfolk. Care should be taken in interpreting this result. It does not imply that no ASW mission packages are available to LCSs in Norfolk, since they may be stored aboard available seaframes. Other considerations, such as training needs, should be taken into account when determining if a small number of ASW mission packages should be stored ashore in Norfolk.

LCS Performance With Our Recommended Inventories and Locations

How well would the LCS perform with the recommended inventories of mission packages in the short, middle, and long term, assuming the preferred locations for homeports and installation sites? The results are shown in Figure S.1.

Using the performance metrics that we described above, the figure shows that the average total closure time would be 43 days in the short term, 26 days in the middle term, and 23 days in the long term. The number of LCS days in the littoral would increase from about nine in the short term, to 17 in the middle term, to 23 in the long term.[13] The

[13] The number of LCS days in the littoral is defined as the sum of the days spent by each LCS in the littoral region of the area of operation in advance of the arrival of a carrier or expeditionary strike group.

Table S.5
Estimated Cumulative Procurement and Facilities Construction Costs for the Short Term, Middle Term, and Long Term

	Cost (billions of 2004 dollars)		
Item	**Short Term**	**Middle Term**	**Long Term**
Seaframes	$8.00	$13.2	$18.3
Mission packages	$4.56	$5.50[a]	$6.34
VTUAVs	$1.07	$1.75	$2.42
Construction of facilities (includes Singapore security personnel)	$0.183	$0.199[b]	$0.210
Total	$13.81	$20.65	$27.27

NOTE: Totals may not sum because of rounding.

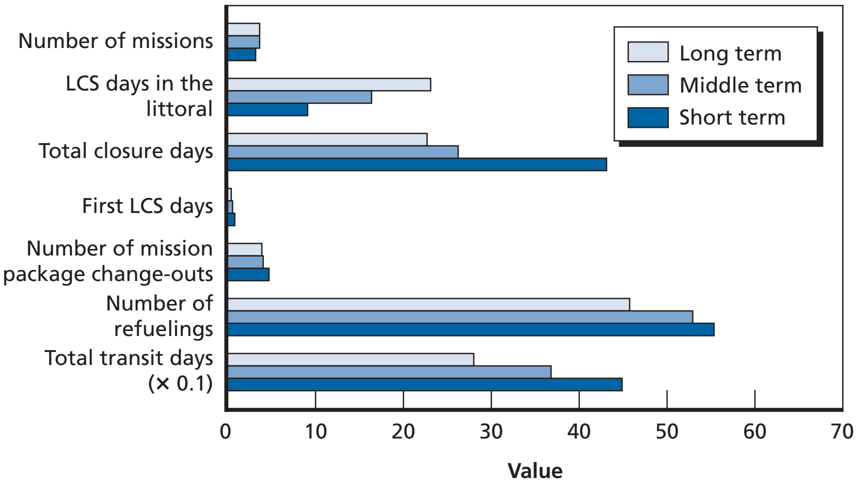
[a] More mission packages than required are purchased to maintain the production base along the way to the long-term case. The estimate for only those mission packages indicated by the transportation model is $5.2 billion in FY 2004 dollars.

[b] This is the short-term cost incremented to reflect additional mission package storage requirements. Some sites (such as Norfolk) will have excess capacity.

figure also shows that the number of underway refueling operations would decrease in transitioning from the short to middle to long term, as does the total number of transit days.

We note from Figure S.1 that the marginal improvement in total closure days is significant between the short and middle term, but less significant between the middle and long term. That is, there are diminishing returns on the improvement in total closure days as the number of LCSs in the fleet increases. On the other hand, the marginal improvement in LCS days in the littoral is fairly linear between the short, middle, and long term. We also note from Figure S.1 the very high number of refuelings required by LCSs while under way. Although it was beyond the charter of our study to determine means of refueling LCSs, our results highlight the refueling issue and the need to align fleet logistics with LCS CONOPS.

Figure S.1
Performance Metrics for Short-, Middle-, and Long-Term Solutions



NOTES: The metric values for the middle term and long term assume scenarios involving one MCO simultaneously occurring with three non-MCOs. There is an insufficient number of LCSs in the short term to satisfy scenarios involving one MCO simultaneously occurring with three non-MCOs. The metric values for the short term assume scenarios involving one MCO simultaneously occurring with an average of 2.4 non-MCOs.

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Of course the authors alone are responsible for any errors.

Abbreviations

ASW	antisubmarine warfare
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CDD	Capabilities Development Document
CONUS	continental United States
CSG	carrier strike group
CVN	Carrier Vessel Nuclear
DLM	Dynamic Lift Model
ESG	expeditionary strike group
FRP	Fleet Response Plan
FY	fiscal year
GWOT	Global War on Terrorism
ISR	intelligence, surveillance, and reconnaissance
JFAST	Joint Flow and Analysis System for Transportation
LCS	Littoral Combat Ship
LCS CONOPS	Littoral Combat Ship concept of operations
LCSTSM	Littoral Combat Ship Transshipment Model
MCO	major combat operation

MIO	maritime interdiction operation
MIW	mine warfare
MPFF	mission package forward facility
NAVFAC	Naval Facilities Engineering Command
NAVSEA	Naval Sea Systems Command
NEA	Northeast Asia
OCONUS	outside the continental United States
PEO	Program Executive Office
SAG	surface action group
SOF	Special Operations Forces
SUW	surface warfare
SWA	Southwest Asia
T-AOE	Fast Combat Support Ship
TEU	Twenty-Foot Equivalent Unit (container)
UAV	unmanned aerial vehicle
UNREP	underway replenishment
VTUAV	vertical takeoff unmanned aerial vehicle
WP	Western Pacific

CHAPTER ONE

Introduction

In June 2005, workers at the Marinette Marine shipyard in Marinette, Wisconsin, laid the keel for the *USS Freedom*, the Navy's first Littoral Combat Ship (LCS). The LCSs constitute a new class of fast, agile, and networked warships designed to overcome threats in shallow waters posed by mines, diesel-electric submarines, fast-attack craft, and fast inshore attack craft.

Announced by the Navy four years earlier, the LCS is part of a proposed family of next-generation surface combatants that also includes the much larger DDG-1000 destroyer and a future CG(X) cruiser. LCSs will have the capability to deploy independently to overseas littoral regions; remain on station for extended periods of time, either with a carrier strike group, expeditionary strike group, or through a forward-basing arrangement; and will be capable of underway replenishment.

As exemplified by the 378-foot *Freedom*, LCSs bring an array of transformational capabilities to the Navy (U.S. Navy Littoral Combat Ship Web site, not dated). The ships will be able to achieve speeds of 40 to 50 knots and operate in waters less than 20 feet deep. They will be networked into the fleet, operating as part of a netted, distributed force, sharing tactical information with other Navy aircraft, ships, submarines, and joint units and launching manned and unmanned vehicles to execute missions. They will incorporate advanced technologies, employing cost optimized advanced weapons; sensors; data fusion; command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems; hull forms; propulsion systems; manning concepts; smart control systems; and self-defense systems.

But perhaps the most radical feature of the LCS is that it will possess modular capabilities that have never been built into warships. The ships will be able to accept interchangeable mission packages—containing different weapons, communications systems, sensors, and other capabilities—allowing the vessels to be reconfigured for antisubmarine warfare (ASW), mine warfare (MIW), or surface warfare (SUW) missions, as needed. Swapping out these mission packages will take only a few days while an LCS is pier side.

"LCS represents the cutting edge of a new Navy, the likes of which we have never seen before," said then–Chief of Naval Operations ADM Vern Clark in remarks at *Freedom's* keel laying ceremony. "This idea, this ship, revolutionizes the capability of our nation and our Navy" ("Keel Laid," 2005).

At the time of this study, Navy plans included acquisition of one seaframe in fiscal year (FY) 2005, an additional seaframe in FY 2006, two seaframes in FY 2007, and three in FY 2008, after which the Navy planned to procure up to five seaframes per year. The total number of seaframes could have exceeded 80 in the next 20 years.[1] Because it wants to incorporate endurance, speed, payload capacity, sea keeping, shallow draft, and mission adaptability into a relatively inexpensive, small ship, the Navy remains open about the LCS final design and configuration. The Navy is evaluating two designs for the vessel—the *Freedom's* design, which is being produced by a team led by Lockheed Martin Corp., and another being produced by a General Dynamics Corp.-Bath Iron Works collaboration for the second seaframe, named the *Independence*. The Navy's contracts with the teams allow for up to

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[1] After conclusion of this study, the Quadrennial Defense Review recommended an increase in the Navy's annual procurement of littoral combat ships. Francis, 2006, indicates up to six ships per year from 2009 through 2011, for a total of 55 through 2029. See also Cava, 2006.

two of each design to be constructed prior to a decision on how many of each will be ordered.[2]

Figure 1.1 shows the latest Lockheed Martin design, and Figure 1.2 shows the latest General Dynamics design. The Lockheed Martin design features a monohull, whereas the General Dynamics ship is built on an aluminum-hulled trimaran design.

Figure 1.3 depicts the number of LCS seaframes that we assumed would be in the Navy's fleet inventory between FYs 2006 and 2024. During that period, 15 seaframes would be acquired by 2010, and 5 more annually thereafter, making a total LCS fleet of 84 in 2024.[3]

Three Primary Missions for the LCS

The Navy plans to use the LCS primarily in contested littoral waters to counter enemy mines, submarines, and fast-attack craft. While more fully explored later in this monograph, these three missions can be briefly described as follows:

- *MIW*—LCSs will provide the joint force commanders with a full array of organic mine warfare capabilities, ranging from first-response mine detection to neutralization, avoidance, and sweeping.
- *ASW*—LCSs will provide ASW capabilities while operating in shallow or deep littoral waters. Leveraging multiple distributed sensors netted together, the ships will exploit real-time undersea data continuously, using maneuver to enhance detection, localization, classification, identification, tracking, and destruction of enemy submarines.

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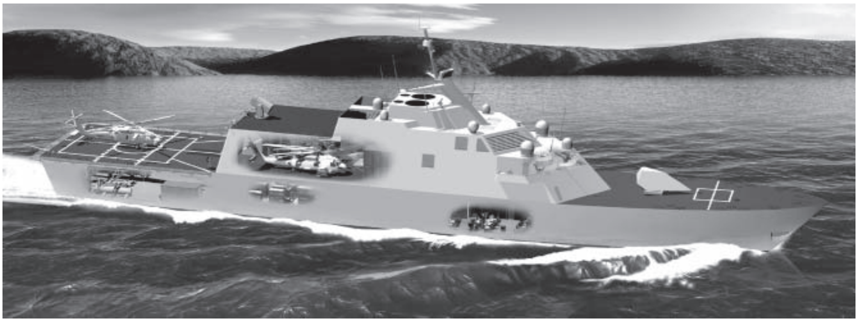
[2] In May 2004, the Navy awarded both Lockheed Martin and General Dynamics-Bath Iron Works, Bath, Maine, separate contract options for final system design with options for detailed design and construction of up to two LCSs.

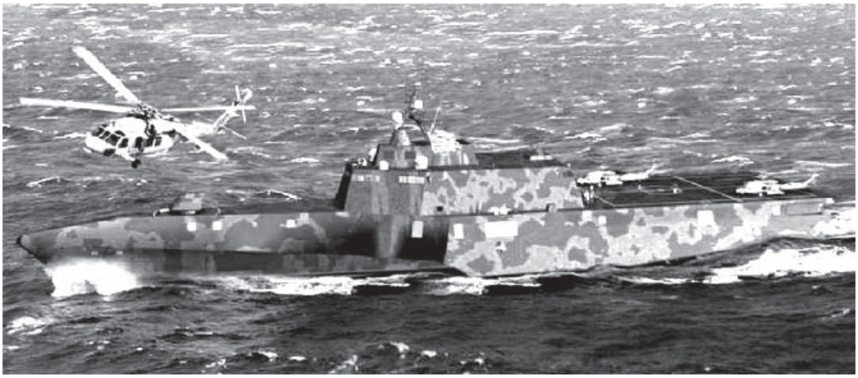
[3] See note above about the Quadrennial Defense Review's recommended increase for LCSs.

Figure 1.1
Lockheed Martin Team LCS Design



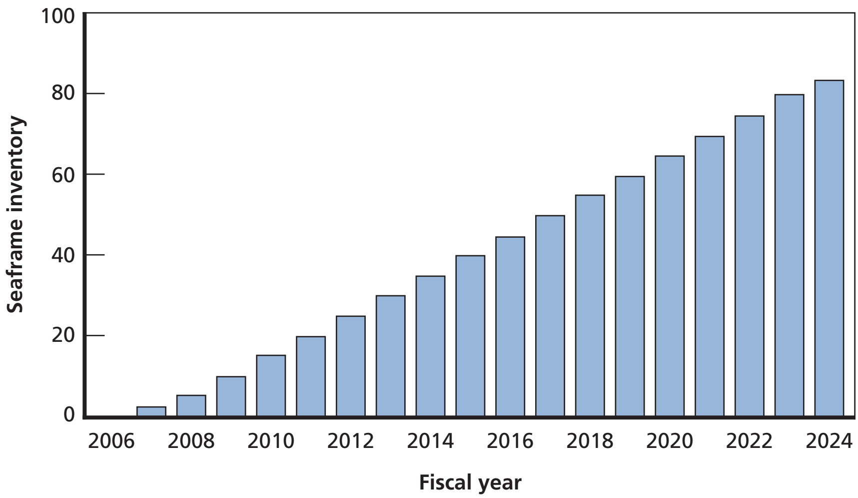
SOURCE: Program Executive Office Ships, 2007b.
RAND *MG528-1.1*

Figure 1.2
General Dynamics-Bath Iron Works LCS Design



SOURCE: Program Executive Office Ships, 2007a.
RAND *MG528-1.2*

Figure 1.3
LCS Fleet Size, FYs 2006–2024



RAND *MG528-1.3*

- *SUW*—LCSs will provide a flexible capability to detect, track, and destroy small-boat threats rapidly, giving the joint force commander the ability to protect the "seabase"[4] and move a force quickly though a chokepoint or other strategic waterway.

Inherent LCS missions, which also are expected to occur in littoral waters, include intelligence, surveillance, and reconnaissance (ISR); homeland defense; maritime interdiction operations (MIOs); Special Operations Forces (SOF) support; and logistics support for movement of personnel and supplies.

[4] Bases at sea will be motivated by "seabasing"—one of several joint integrating concepts spelling out how joint force commanders will integrate capabilities in 10 to 20 years—which envisions that U.S. forces will stage major combat and noncombat operations at sea, thereby avoiding the need to establish large headquarters or supply footprints ashore. See U.S. Department of Defense, 2005a; Fitzgerald and Hanlon, 2004, p. 1.

Modular Capabilities

Modularity is at the heart of the LCS concept. Plans call for each LCS to consist of two elements: a core seaframe, which includes the ship platform and inherent combatant capabilities, and a set of interchangeable modular "plug-and-fight" mission packages, which will allow the ship to be reconfigured for ASW, MIW, or SUW missions, as needed.

Each seaframe will be able to perform a set of inherent functions—including self-defense; navigation; C4I; and launching and retrieving unmanned vehicles—that will be common to all missions.

The interchangeable mission packages will provide LCSs with additional war-fighting capabilities and allow them to perform specialized missions. A mission package may consist of a combination of mission modules, such as manned and unmanned vehicles, deployable sensors, and mission manning detachments. Most mission modules will fit inside several standard-size 20-foot cargo containers. The mission modules will be able to be integrated into the ship so that any seaframe can hold any mission package. An LCS can be reconfigured with a new mission package in a few days while laying pier side.

RAND's Analysis

In early 2005, RAND was commissioned by the LCS Program Office[5] to help it think through the cost and logistics implications of modular mission packages planned for the LCS. In particular, the program office was interested in gaining a clearer understanding of operational, logistics, and cost trade-offs between three interdependent elements of the program: the number of LCSs in the fleet, the number of mission packages[6] that those LCSs would require in order to perform a range of missions, and the number and locations of LCS homeports and mis-

5 The official name of our sponsor is PMS 501, LCS Program Office.

6 Aviation assets were assumed to be collocated with other mission package components for the purpose of this analysis. The scope of this project did not allow for evaluation of the number of aviation assets separately from the number of mission packages.

sion package installation sites.[7] We pursued this analysis between January and November 2005.

In addition, this analysis also might help inform the cost and feasibility issues raised by the U.S. Senate Appropriations Committee and help the Navy respond to the committee's request for a report on the development status of the LCS mission packages, although that was not its original intent.

As described in greater detail later, we worked closely with the Navy to identify scenarios that define the use and deployment of LCSs. Using these scenarios and a range of LCS fleet sizes, we established baseline considerations connected with developing and deploying a modular LCS. We then developed a series of analytical tools to address the following issues:

- Where are the optimum locations for LCS homeports and mission package installation sites?
- How many mission packages of each type should be procured and when?
- How many mission packages of each type should be stored on available seaframes, at homeports, and at mission package installation sites?
- What are the costs of acquiring mission packages and facilities for homeports and installation sites?
- What cost and performance trade-offs and sensitivities occur with various combinations of the number of and the types of mission packages?

Scenario and LCS Employment Option Analyses

We pursued these questions from multiple perspectives. To gain an understanding of what the LCS fleet might encounter over the next few decades, we examined the LCS concept of operations (LCS CONOPS) (U.S. Navy, 2004) in conjunction with the strategic environment laid out in the 2005 National Defense Strategy and amplified in various

[7] We assume that homeports include a mission package installation site.

U.S. Navy documents (U.S. Navy 2003 and 2005).[8] This research led to various scenarios in which the ships might be expected to play a part in the next two decades. The scenarios, which are described in Chapter Two, involve the United States in major combat operations (MCOs), the Global War on Terrorism (GWOT), stability operations, and homeland defense. Taking place over the 2008–2024 time frame, the scenarios are speculative but represent the range of missions that LCSs might confront. The scenarios include operations from the following four categories:

- MCO
  - Crisis in the Western Pacific
  - Crisis in Southwest Asia
  - Crisis in Northeast Asia.

- GWOT operations
  - Responding to a chemical weapons attack on UN forces
  - Clearing mines laid by terrorists in sea lanes
  - Eliminating terrorist training camps.

- Stability operations
  - Providing humanitarian assistance and disaster relief
  - Supporting a friendly government against insurgents
  - Providing maritime security for oil platforms
  - Providing forward presence and MIOs in the vicinity of shipping lanes
  - Participating in ASW exercises/submarine tracking.

- Homeland defense operations
  - Providing security and humanitarian assistance/disaster relief following terrorist attacks on U.S. seaports
  - Providing security and humanitarian assistance/disaster relief following a natural disaster along the U.S. seaboard

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[8] Our specific terms mirror "The Evolving Strategic Environment" as shown in Figure 1 of U.S. Navy, 2005.

– Providing humanitarian assistance following a refugee crisis in the Caribbean.

LCS CONOPS describes plans to embed LCSs in carrier strike groups (CSGs) or expeditionary strike groups (ESGs), to deploy them independently or as part of a surface action group (SAG) to provide specific capabilities, or to operate them as forward deployed units. Using these deployment concepts and potential threat characteristics, the research team evaluated ways in which the Navy might employ LCSs in the context of each scenario. The team, thus, developed baseline LCS requirements, including expected modes of employment, operating locations, and mission sets.

Transit, Logistics, and Cost Analyses

Informed by the scenario and employment option analyses, RAND then turned to its quantitative tasks. These tasks are more fully described in Chapter Three. Briefly, we did the following:

- *Derived measures of effectiveness for the LCS.* A key capability of the LCS is its ability to respond quickly to a crisis. For this reason, our principal measure of effectiveness is the time required for all LCSs to close on the theaters of operation. Additional measures include such metrics as the number of LCS days spent in the littoral in advance of a strike group, the time it takes for each LCS to arrive on station, the time it takes for each strike group to arrive on station, the number of mission package reconfigurations by type and geographic location, and the number of underway replenishments required by each LCS in order for it to reach the theaters of operation.
- *Examined and compared the operational implications of the number of mission packages procured for the LCS fleet and the number and location of LCS homeports and installation sites.*[9] We developed a series of analytical tools to evaluate the various measures of effectiveness. We used these tools to make trade-offs among different

[9] Operational implications will be expressed in terms of presence, e.g., time on station.

numbers of mission packages for the proposed number of LCSs and the locations of LCS homeports and mission package installation sites.

- *Explored cost and schedule implications of the number of mission packages procured for the LCS fleet and the number and location of LCS homeports and installation sites.* We developed mission package acquisition schedules for the various alternatives identified in the tasks above. We then developed estimates of annual and total procurement costs for mission packages and the costs associated with construction of facilities for homeports and installation sites.

Organization of the Monograph

The tasks outlined above are addressed in separate chapters. Chapter Two states how LCSs will be employed, the scenarios they will encounter, and our assumptions on initial locations and readiness of LCSs and associated assets. Chapter Three discusses the analytical and modeling methodologies we used. Chapter Four addresses the preferred LCS homeports and mission package installation sites for the near term, the middle term, and the long term. Chapter Five addresses seaframe and mission package inventories, while Chapter Six examines projected LCS costs and performance. Chapter Seven touches upon additional considerations that arose in the course of our research. Chapter Eight provides our policy recommendations.

The monograph also includes several appendixes. Appendix A contains mathematical details of our models, Appendix B provides an overview of the LCS investment cost analysis, and Appendix C lists the assumptions we used on LCS performance. Appendix D provides a Navy SOF perspective on LCS; this perspective was provided by Navy SEAL LCDR Mike Hayes while he was on assignment at RAND.

CHAPTER TWO

Employing the LCS: Scenarios and Concepts of Operation

This chapter discusses how LCSs will be employed. It explores how the ships will relate to CSGs, ESGs, and SAGs, and it describes scenarios in which the new ships might be used. It concludes with a discussion of initial locations and readiness for LCSs and related assets.

How LCSs Will Be Employed

In accordance with the LCS CONOPS, LCSs will be employed across the range of military operations, from before hostilities begin, engagement, presence, and through combat operations to after hostilities, security, and presence (U.S. Navy, 2004). Its modular, focused mission capabilities—including MIW, ASW, and SUW—may be leveraged to "kick in the door" for a developing crisis, adding a persistent presence, surveillance capability, and situational awareness when first on the scene. As strike group assets arrive, the role of the LCS enlarges to enabling the Sea Shield.[1] In addition, all LCS seaframes have inherent capabilities for ISR/information operations, SOF support,[2] MIO, and mobility, which can be augmented in the form of personnel and carry-on equipment.

[1] "Sea Shield describes the capabilities that extend precise and persistent naval defensive capabilities, not only throughout large maritime areas but also deep over land, to protect joint forces and allies ashore" (U.S. Marine Corps, 2005).

[2] See Appendix D for a discussion of LCS operations involving SOF.

Scenarios That LCSs Will Encounter

A scenario consists of operations, and an operation consists of missions. The scenarios we have studied had LCSs responding to four simultaneous operations, consisting of one MCO and three non-MCOs.[3] One non-MCO was chosen from each of three categories: stability operations, operations related to GWOT, and homeland defense operations. This setup is based on the Department of Defense force planning construct (U.S. Department of Defense, 2005b) and the Department of Navy strategic environment construct (U.S. Navy, 2005). It integrates the capabilities of the LCS with the spectrum of operations, environments, and potential locations of future conflicts. In addition, concurrent missions with geographical diversity were chosen to align with the National Defense Strategy mandate to assure our allies and deter aggressors in four regions simultaneously.[4]

We relied on data from existing Navy and RAND studies and on interviews with Navy officials to identify the geographic locations of each scenario operation and the number of assets required for all the missions of each operation (Ryan, 2005; Pirnie and Francisco, 1998; Nichiporuk, 2005; Gordon et al., 2006; Systems Planning and Analysis, Inc., 2004). We compiled, averaged, and extrapolated those numbers to determine specific asset counts for each scenario. For example, we calculated that a specific stability operation in South America might require an expeditionary strike group and six LCS seaframes, with 50 percent of the seaframes configured with SUW and 50 percent with MIW mission packages.

In the pages that follow, we provide a sufficiently detailed overview of the operations to describe our analysis and support our results. More detailed information on each operation, including specific countries and the number and type of assets involved, is sensitive and, therefore, is not included in this monograph.

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[3] An exception to this is our analysis of the short term, during which there will be insufficient numbers of seaframes to support four simultaneous operations. We describe this case in greater detail later in the monograph.

[4] However, the geographic locations of the four simultaneous operations are randomly selected and do not always conform to those identified in the National Security Strategy.

Major Combat Operations

The MCOs we used include state-versus-state conventional campaigns in Southwest Asia, the Western Pacific, and Northeast Asia.

The Southwest Asia MCO employs LCSs configured with ASW, SUW, and MIW mission packages arriving in theater in advance of strike groups to conduct on-scene threat awareness and preparation of the battle space. ASW LCSs contribute to the ASW mission with manned and unmanned aviation assets as well as unmanned underwater vehicles capable of reducing the time for the detect, track, and engage sequence. MIW LCSs gather bottom mapping data and use unmanned aerial vehicles (UAVs) to search for possible mine-laying activity. They also employ helicopters and unmanned underwater vehicles to clear the antiship minefields blocking chokepoints in the littoral. A SAG of SUW-configured LCSs conducts ISR and protects against swarming.[5] Additionally, an independently operating LCS is augmented with SOF. In higher-threat environments, aviation and surface combatant assets provide air defense protection for LCSs as they clear operating areas, provide protected passage, and contribute to the Sea Shield.[6] The scenario involves the use of CSGs and ESGs.

In the Northeast Asia MCO, an SUW-configured LCS SAG is sent to the region to provide ISR and conduct MIO. That group establishes a networked Sea Shield for arriving strike group assets by helping detect, track, and engage surface threats.[7] The networked force expands to include aviation and surface combatant assets that strengthen the Sea Shield. ASW- and MIW-configured LCSs surge ahead of an ESG and CSG to evaluate and prepare the battle space and conduct on-scene threat awareness. ASW LCSs will deploy manned and unmanned systems and sensors to detect, localize, classify, identify, track, and engage submarines. MIW LCSs gather bottom mapping data and use UAVs to

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5 Swarming refers to attacks by large numbers of fast inshore attack craft, typically from multiple directions and with little coordination.

6 As described in a note above, Sea Shield refers to the U.S. Navy's overarching concept describing how 21st-century naval forces will project defense over water and over land.

7 A group of assets is *networked* in the sense that they can share information, including communications, ISR, and targeting information.

search for possible mine-laying activity. After they clear transit routes and operating areas for an expeditionary strike force,[8] they work with other surface combatants and aviation assets to provide protected passage and maritime force protection. All ships provide ISR capabilities for, and contribute to, the networked force. The scenario involves the use of CSGs and ESGs.

In the Western Pacific MCO scenario, ASW-configured LCSs are deployed to the region to assist in the preparation of sea lanes for follow-on strike force operations. They conduct ISR, develop maritime domain awareness, and prepare the battle space. They are provided with air defense protection by aviation and surface combatant assets. MIW LCSs gather bottom mapping data and use UAVs to search the area around approaches to harbors and ports for possible mine-laying activity. An SAG of SUW-configured LCSs arrives to conduct ISR and protect follow-on assets against fast-attack craft. After operating areas are cleared for strike force assets, LCSs provide protected passage and contribute to the maritime shield and networked force. The scenario involves CSGs and ESGs.

Stability Operations

We considered stability operations that may occur in three geographic regions: West Africa, South America, and Southeast Asia. These missions include performing counterinsurgency operations, maintaining security of oil platforms, providing "presence with a purpose" (to promote stability after attacks on shipping have occurred), and tracking submarines. The organic ISR and MIO capabilities of LCS seaframes are utilized in these operations, and operations typically involve SUW- and MIW-configured LCSs. Some utilize an ESG to perform noncombatant evacuation operations; others do not involve strike groups.

We also considered several potential humanitarian and disaster relief efforts involving LCSs. LCSs would typically be used in these efforts as joint littoral mobility assets, which provide helicopters and surface craft in the affected areas in order to conduct search and rescue and transport people, food, and medicine. Examples include respond-

[8] An expeditionary strike force consists of a CSG and an ESG.

ing in the aftermath of a hurricane in the Caribbean, providing relief following an earthquake or tsunami disaster in South Asia and Southeast Asia, providing aid following landslides in South America, and responding to similar disasters in Southeast Asia or North Africa.

Global War on Terrorism

Our analysis encompassed a variety of potential GWOT operations involving LCSs. These operations include responding to mining of sea lanes by terrorists, a chemical attack on UN forces, and the discovery of terrorist training camps, all occurring in Southwest Asia and Southeast Asia. In these operations, MIW LCSs conduct countermine operations and clear sea lanes, while SUW LCSs escort shipping and protect against fast-attack craft. Additionally, LCSs—augmented with additional boarding forces; SOF support; and chemical, biological, and radioactive teams—conduct MIO, execute raids, and contain contamination. Some missions potentially involve strike group assets and others do not.

Homeland Defense

Among the potential homeland defense operations involving LCSs that we considered was an attack on a liquid natural gas facility in a major port in the eastern United States. SUW-configured LCSs would be utilized to assist the U.S. Coast Guard with MIOs and port security following the attack. No strike groups would be needed in this operation.

A second terrorist attack that was considered was use of a weapon of mass destruction at a major port in the western United States. SUW-configured LCSs would be augmented with equipment for detecting weapons of mass destruction, perform MIOs, and provide maritime domain awareness. No strike groups would be used in this operation.

Separately, we considered using LCSs to respond to a refugee crisis in the Caribbean. The ships would assist U.S. Coast Guard assets in intercepting refugees and providing humanitarian assistance. An ESG would be utilized to provide temporary shelter and medical care.

In addition, we explored the use of LCSs in response to a natural disaster along the U.S. seaboard. LCSs could perform search and rescue using helicopters and surface assets, while UAVs could be used to provide damage assessment. LCSs would also conduct mobility operations. An ESG and a CSG would provide additional assets to aid in search and rescue and provide shelter and medical facilities.

Initial Locations and Readiness of LCSs and Related Assets

LCS deployment concepts were used to determine location and readiness of assets. Specifically, if deployed as part of a strike group, LCS start locations would be adjacent to the strike group. The operating base determined the start location for LCSs deploying as part of a SAG or operating as a forward deployed unit. We specify those locations later in the monograph.

Because of a lack of available, formally defined LCS readiness data, we assumed that LCSs embedded in a strike group have the same level of readiness as the strike group. We developed a historical database of the location and readiness of strike group assets for 96 time periods spanning two years. These data served as a basis for our assumptions. We used two sources to build this time series of strike group locations and readiness:

- The GlobalSecurity.org Web site data (not dated) describing the general location and sort of operation each carrier or amphibious group was performing. We broke each month from August 2003 through July 2005 into four periods of days (1–7, 8–14, 15–21, 22–end of the month). During each of these time periods, we recorded the most likely location of each group using the data available. Location information was occasionally determined by extrapolating between two known positions—for example, if a carrier was located in Australia in one time period and next reported in the Arabian Sea, we extrapolated that it was in the Indian Ocean during the time periods in between—while about 10 percent of the data sets for readiness were imputed, largely for

ships spending extended time in a port, presumably doing maintenance or training.
- *The Navy Times* weekly snapshot of the general location of some strike groups. There was a perfect correlation of *The Navy Times* data with the GlobalSecurity.org data of locations for each of the weeks we checked. Locations were generally estimated to the nearest sea or port, but some infrequent locations were combined with more common ones (e.g., the east coast of Australia was considered to be the Coral Sea and the west coast was considered to be Fremantle). The readiness levels of the strike group assets from this database were also found to be in close accordance with the readiness levels that follow from the Fleet Response Plan (FRP) (Boraz, 2004).

We allowed LCSs to sprint ahead of their strike group or to depart a strike group to operate in other deployment modes, as needed.

For LCSs not embedded in strike groups, we derived availability from statistics of the 27-month FRP. Namely, we assumed that

- 30 percent of seaframes were in a basic maintenance phase and would be available for mission use in no more than 250 days, and 125 days on average.
- 15 percent of seaframes were emergency-surge ready and would be available for mission use in no more than 90 days, and 45 days on average.
- 33 percent of seaframes were surge ready and would be available for mission use in no more than 30 days, and 15 days on average.
- 22 percent of seaframes were deployed and immediately available for mission use (we assume a one-day delay if the asset was located in port).

We assumed that every seaframe not undergoing maintenance would be configured with a mission package and that seaframes and mission packages would have the same state of readiness. We were unable to determine the number of mission packages undergoing maintenance, since no estimates of the operational availability of mission packages existed at the time that we conducted the study. For this reason, we report results on the inventories of mission packages for a range of operational-availability values.

CHAPTER THREE

Methodology and Analytical Framework

This chapter discusses the analytical models that we used and the reasons we chose to use them. It also describes the analyses performed and the data those analyses produced, and it explains how we used the data that our analyses produced.

Analytical Models That We Used

Littoral Combat Ship Transshipment Model (LCSTSM)

The LCS CONOPS describes the ship as "kicking in the door" for a developing crisis. LCSs function as a persistent presence and add surveillance capability and situational awareness when they are first on the scene (U.S. Navy, 2004). For this reason we sought an analytical model that would allow us to change operational and logistical elements, such as mission package inventories and locations of homeports and installation sites, and to measure the impact of those changes on the LCSs' ability to respond rapidly and be the first on the scene in a developing crisis. These criteria meant that the model needed to provide metrics that conveyed time needed for LCSs and strike groups to transit from their start locations to demand sites, accounting for stops at installation sites for mission package reconfigurations, as needed. It also needed to provide details on how many reconfigurations would be needed and where they would occur.

Such features would allow us to vary operational and logistical elements and to measure the resulting impact on the ability of the LCSs to respond rapidly and be the first on the scene in a developing crisis. A well-known class of models, called *transshipment models,* offers this capability and is widely used to solve transportation problems with commercial and military applications (Bertsimas and Tsitsiklis, 1997, p. 266; Luenberger, 1989, pp. 161–162; Glover and Klingman, 1975; Glaser, 1991; Staniec, 1987; Derbes, 1997).

Transshipment models determine the routes that assets take from start locations to destinations, with a stop at an intermediate site along the way, as needed. The models ensure that supply meets demand, and the routes are typically chosen so that the sum of the time required for each asset to reach its destination is minimized. Optimization methods based on linear programming are used to solve transshipment problems.

The modeling needs for our study were similar. The start location in our case was the initial position of an LCS at the start of a conflict. A destination would be a theater of operations from a scenario. Installation sites served as intermediate sites if mission package reconfigurations were required. But there were some differences between typical transshipment models and the modeling needs for our study.

Transshipment models typically minimize the sum of the time required for each asset to reach its destination, but with LCSs we were interested in a *total-closure-time* metric: the time required for all LCSs to reach their destination. Another significant difference is that we also were interested in the total time that LCSs spend in the littoral prior to arrival of a strike group. This metric is called the *LCS days in the littoral*. The total-closure-time and LCS-days-in-the-littoral metrics measure the LCSs' ability to be the first on the scene and prepare the battle space in advance of other assets. Because of these differences, the RAND team developed a unique model, the LCSTSM.

Rather than minimizing the sum of the time required for each asset to reach its destination, the LCSTSM was designed to minimize *total closure time.* Also, the LCSTSM determined the routes and transportation time required for CSGs and ESGs to reach their destinations, as well as for LCSs. The LCSTSM also drew upon concepts utilized in a tool called the Dynamic Lift Model (DLM), developed at RAND for a study of joint "forcible-entry" operations (Button et al., 2005). DLM was used in that study to estimate the force closure performance of Marine expeditionary brigades and related assets. However, DLM is suitable only for single and not multiple simultaneous mission demands, and it is not suitable for estimating closure on assets that require intermediate stops, such as LCSs' stops to reconfigure mission packages. We modified concepts from DLM for use in the optimization framework of a transshipment problem that includes intermediate stops and for scenarios involving multiple simultaneous demands (see Button et al., 2005).

However, the LCSTSM is more than a modified transshipment model.[1] It also incorporates utilities to

- aid the user in specifying operational and logistical elements, including locations of homeports and installation sites and mission package inventories.
- randomly select scenarios. The user can specify the MCO, and the tool randomly generates the non-MCO missions automatically.
- randomly select the start locations and availability of LCSs, CSGs, and ESGs. Our random selection was drawn from the database of strike group locations and levels of readiness discussed in Chapter Two.
- randomly distribute mission packages among available seaframes, homeports, and installation sites. Mission packages can also be distributed manually. Both methods of distributing mission packages were used in the course of our study.

After the operational and logistical elements were specified, the scenarios randomly selected, the start locations and availability of assets randomly selected, and mission packages distributed, the LCSTSM

[1] The LCSTSM has two components, a *setup* component and a *solver* component. The setup component provides a user interface, provides most of the utilities and features for varying the operational and logistical elements, and interfaces with the solver component for determining routes. The setup component is implemented in Microsoft Excel™. The solver component reads a text file created by the setup component and solves the modified transshipment problem using optimization methods based on linear programming. The solver component is implemented in GNU Linear Programming Kit (GLPK) (Makhorin, 2003). The LCSTSM can be used on PCs running variants of Microsoft Windows™ and on Apple Macintosh™ computers running OS X™.

determined the routes that LCSs, CSGs, and ESGs will take to meet scenario demands with minimum total closure time.

Mathematical details of the LCSTSM and of our mathematical formulation of total closure time are provided in Appendix A. Total closure time depends on

- asset availability (ships in maintenance and ships that are emergency-surge ready, surge ready, or deployed)
- sailing distance and average speed of advance
- status of canals and major waterways
- time required for underway refueling operations
- time required to reconfigure mission packages.

The sailing distances between potential start locations, installation sites, and the sites associated with scenarios were entered directly into the LCSTSM. The source of that information was the Joint Flow and Analysis System for Transportation (JFAST) (Meyer-Campbell, 2003). JFAST provided the sailing distances between locations and allowed us to specify whether certain waterways, such as canals, could be utilized. For instance, we ensured that sailing distances for CSGs took into account that aircraft carriers do not traverse the Panama Canal. We also compared the sailing distances predicted by JFAST with those specified by N81[2] in our study of joint forcible-entry operations mentioned above (Button et al., 2005), and we generally found them to be in agreement. We assumed that LCSs could sprint for short distances but average speed of advance would decline steadily toward economical speed with increased sailing distance. Our model for average speed of advance is described in detail in Appendix C. We assumed that the fuel remaining would not drop below 20 percent and that underway replenishment (UNREP) takes place whenever the LCSs undergo refueling at sea. Hence, UNREP and refueling at sea are synonymous in this study. We also assumed that UNREP would require four hours on average, that the LCSs would not make significant progress toward

[2] N81 refers to an organizational group in the Office of the Chief of Naval Operations. Specifically, it refers to the Assessment group under the Deputy Chiefs of Naval Operations.

their destination during UNREP, and that refueling assets would be immediately available, as needed by the LCSs.[3]

As discussed above, key attributes of the LCS are its ability to respond quickly to an emerging crisis and to be the first on the scene. We chose total closure time as our primary metric of performance, since it conveys the capability of the LCS to rapidly respond to emerging crises. We also used the number of LCS days-in-the-littoral metric, which shows the capability of the LCS to be the first on the scene.

The model provided several additional metrics. Some were by-products of total closure time or LCS days in the littoral, and some were of interest for other reasons. These additional metrics include the following:

- *Total Number of Mission Package Reconfigurations, by Type and Location*. This metric allowed us to evaluate the demands on homeports and installation sites, which aided us in determining their locations.
- *First LCS Closure Days*. This is the time in days for the first LCS to arrive on station for any operation of a given scenario.
- *Closure Days for the First and Last CSG*. Closure days for the first CSG is a by-product of evaluating LCS days in the littoral. It was also convenient for evaluating the closure days of the last CSG.
- *Closure Days for the First and Last ESG*. Closure days for the first ESG is a by-product of evaluating LCS days in the littoral. It was also convenient for evaluating the closure days of the last ESG.
- *Total LCS Fleet Transit Days*. This is the sum of the number of transit days for the entire LCS fleet. A secondary objective of the LCSTSM is to minimize this metric.
- *Number of Underway Refueling Operations for the LCS Fleet*. While we do not optimize for this metric, the metric is an important indicator of the demands for refueling vessels.

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[3] We will show later that our model predicts that a large number of UNREPs will be required for LCSs. As a result, the assumption that refueling assets are immediately available is optimistic. While it was beyond our charter to address ways of refueling LCSs under way, we hope our results will highlight the need to investigate this important issue.

Cost Models

We used the LCSTSM to determine the mission package inventories and locations of homeports and installation sites that best optimized total closure time. We also developed cost models that allowed us to estimate procurement costs for seaframes, for mission packages, and for constructing facilities for homeports and installation sites. These cost models were implemented in Microsoft Excel™.

We worked closely with the Naval Sea Systems Command (NAVSEA) to derive cost factors to populate our cost models.

Appendix B provides a detailed discussion of our cost model. The discussion includes the data we used, the sources for those data, and detailed formulas for our cost estimates.

Analyses That We Performed

We varied the following operational and logistical elements:

- the number of seaframes
- the number of mission packages
- the locations of homeports
- the locations of installation sites.

We then ran multiple simulations with randomly selected scenarios, start locations, and availability of assets using the LCSTSM. The simulations yielded evaluation metrics. Average values of these metrics allowed us to determine the effects of varying the operational and logistical elements on operational performance. We used this information to determine optimal locations of homeports and installation sites and optimal sizes of mission package inventories. We then used our cost models to associate acquisition and facility cost estimates with these results.

CHAPTER FOUR

Preferred LCS Homeports and Mission Package Installation Sites

In this chapter, we discuss our analysis of and recommendations for preferred locations of LCS homeports and mission package installation sites in the short, middle, and long terms.

The chapter describes how we determined the list of more than a dozen sites that we examined as possible LCS homeports and mission package installation locations, how we analyzed and narrowed that list, and how we identified preferred locations.

The Navy's Expected LCS fleet

Determining an optimum size of the LCS seaframe fleet at various points in time was not the focus of this study. While we assumed in this and subsequent chapters that the Navy's inventory of LCS seaframes will grow over the next several decades, our analysis relied on taking snapshots of the fleet at three points in time—the short term, middle term, and long term.

To obtain the snapshots, we assumed that LCS seaframes would be produced at a rate of about five a year. At that pace, the short-term inventory of seaframes could reach 36 by FY 2014, the middle-term inventory of seaframes could reach 60 by FY 2019, and the long-term inventory of seaframes could reach 84 by FY 2024.

For this analysis, we assumed that, in the short term, one seaframe will be assigned to each of 12 CSGs and another seaframe will be assigned to each of 12 ESGs.[1] In the middle term, we assumed that two seaframes will be assigned to each of those strike groups; in the long term, three seaframes are assumed to be assigned to them. Additionally, we assumed that in all three time frames another 12 seaframes will be operating in stand-alone LCS squadrons.

Criteria for Choosing Suitable Homeports and Installation Sites

The LCSTSM allowed us to associate quantitative performance metrics with the selection of homeports and installation sites, but it did not take into account qualitative criteria, such as the political ramifications associated with having a homeport in a particular country. Therefore, we applied the following quantitative and qualitative criteria to the selection of locations for homeports and installation sites:

- Locations that resulted in good performance, as determined by model metrics.
- Locations with existing facilities: preferred for cost reasons.
- Locations where the United States currently operates: preferred for political reasons.
- Title 10, U.S. Code, Subsection 7310 considerations: This subsection restricts maintenance (other than voyage repairs) from being performed in foreign ports. This restriction could limit the selection of homeports. It is not likely to limit the selection of installation sites because of the low level of maintenance that would be performed there (U.S. Code, 2006).

[1] Note that in the short term, there is an insufficient number of seaframes to satisfy scenarios involving one MCO simultaneously occurring with three non-MCOs. Hence, in the short term, we used scenarios involving one MCO simultaneously occurring with one non-MCO to determine the best locations for homeports and installation sites. The non-MCO was chosen randomly, with equal probability of occurrence, from the categories of stability operations, Global War on Terrorism operations, and homeland defense operations.

- Dock and storage space requirements: We took these into account in determining the total number of homeports and installation sites.

Selecting Preferred Homeports and Installation Sites

Initial Analysis of 15 Sites

For all three time frames, we determined the performance associated with having a vast number of homeports, installation sites, and mission packages as a first step in the process of selecting suitable locations. For this purpose, we began with the following 15 locations:

1. Bahrain
2. Darwin, Australia
3. Diego Garcia
4. Fremantle, Australia
5. Guam
6. Japan
7. Mayport, Florida, United States
8. Western Mediterranean
9. Norfolk, Virginia, United States
10. Pascagoula, Mississippi, United States
11. Hawaii, United States
12. Puerto Rico
13. San Diego, California, United States
14. Singapore
15. Eastern Mediterranean.

Initial Analysis of Preferred Sites for the Short Term, Middle Term, and Long Term: 15 Sites

For all three time frames, we configured the LCSTSM for an unlimited number of each mission package type at all of these 15 locations. We then randomly generated scenarios, each with equal probability of occurrence, and exercised the model to determine performance metrics. Our goal was to determine if specific locations would be frequently visited and others would not, which would allow us to narrow the list of potential locations for homeports and installation sites. The results of this experiment for the short term are shown in Figure 4.1, for the middle term in Figure 4.2, and for the long term in Figure 4.3. In these figures, we used blue bars to indicate the sites visited most often and black bars for the remaining sites.

Figures 4.1, 4.2, and 4.3 show that for all the time frames, the vast majority of mission package change-outs would occur in Japan, Norfolk, San Diego, and Singapore.

Second-Order Analysis of Preferred Sites for the Short Term, Middle Term, and Long Term: Eight Sites

To narrow the field of possible sites, we retained the four sites that bubbled up in the above analysis since they meet both the quantitative

Figure 4.1
Percentage of Mission Package Change-Outs, by Location, in the Short Term for the 15 Potential Sites

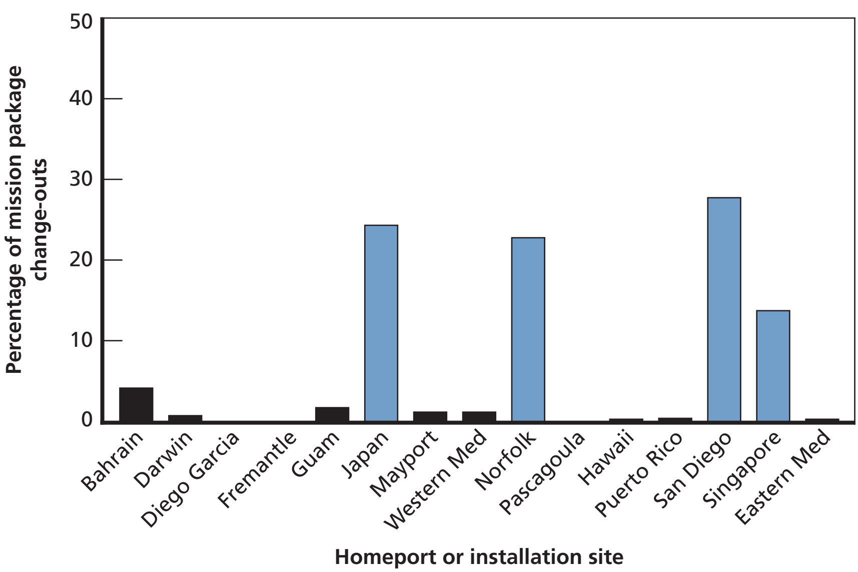

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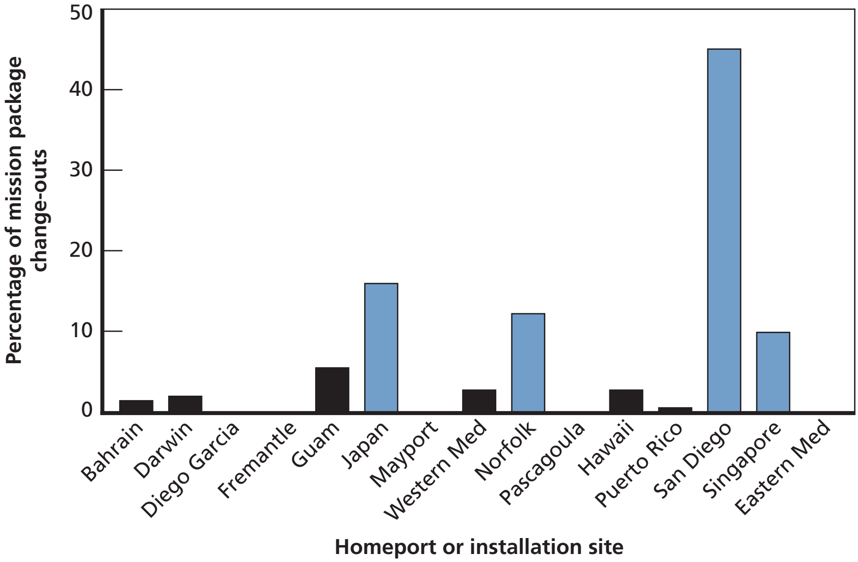
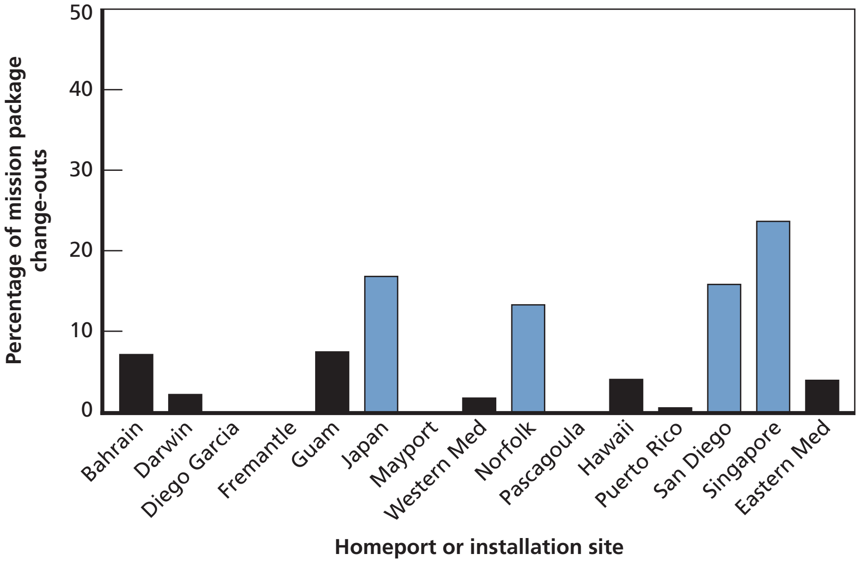
Figure 4.2
Percentage of Mission Package Change-Outs, by Location, in the Middle Term for the 15 Potential Sites



RAND *MG528-4.2*

and qualitative criteria. We also retained Bahrain, Guam, the Western Mediterranean, and Hawaii since they meet the criteria of having existing facilities where the United States operates and because most of them lack political or Title 10 restrictions (U.S. Code, 2006). Pascagoula, Fremantle, and Diego Garcia were removed from consideration because no mission package change-outs occurred at those locations. The Eastern Mediterranean was removed from consideration because (1) few mission package change-outs would occur there and (2) the Western Mediterranean and Bahrain were retained and could serve as locations for mission package change-outs that might otherwise occur in the Eastern Mediterranean. There were a few mission package change-outs in Darwin, because the start location of some LCSs and strike groups was in the vicinity of Darwin for some simulations. Relatively few mission package change-outs would occur there, and LCSs starting from that vicinity would have other options, such as Singapore

Figure 4.3
Percentage of Mission Package Change-Outs, by Location, in the Long Term for the 15 Potential Sites



RAND *MG528-4.3*

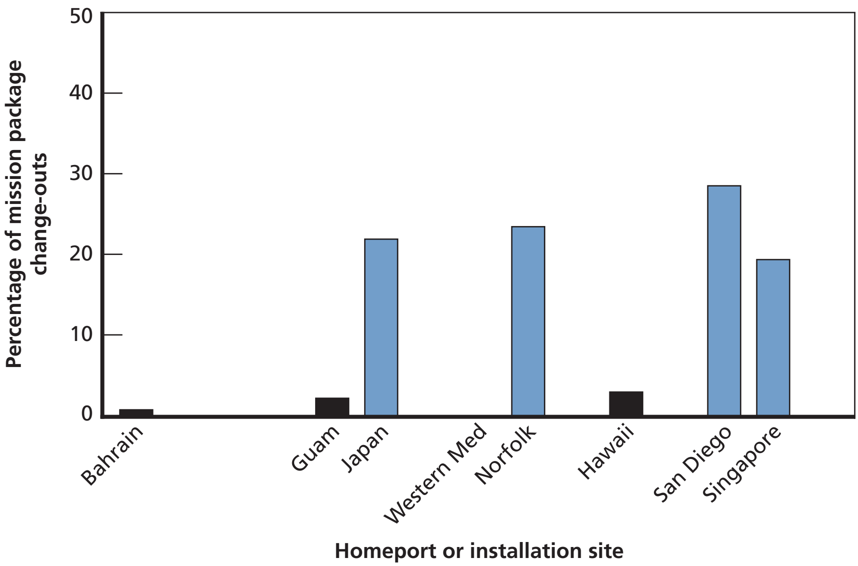
or Bahrain for mission package change-outs en route to MCOs and non-MCOs. For this reason, we removed Darwin from consideration. Puerto Rico was removed from consideration since very few mission package change-outs would occur there. Therefore, we narrowed the list of potential sites from fifteen to the following eight most likely sites:

1. Bahrain
2. Guam
3. Japan
4. Western Mediterranean
5. Norfolk, Virginia, United States
6. Hawaii, United States
7. San Diego, California, United States
8. Singapore

We reran the model using these eight sites with unlimited numbers of mission packages at each location. The average total closure time did not change in reducing the list of potential sites from fifteen to eight. The percentage of mission package change-outs by location for these eight potential sites is shown in Figure 4.4 for the short term, Figure 4.5 for the middle term, and Figure 4.6 for the long term.

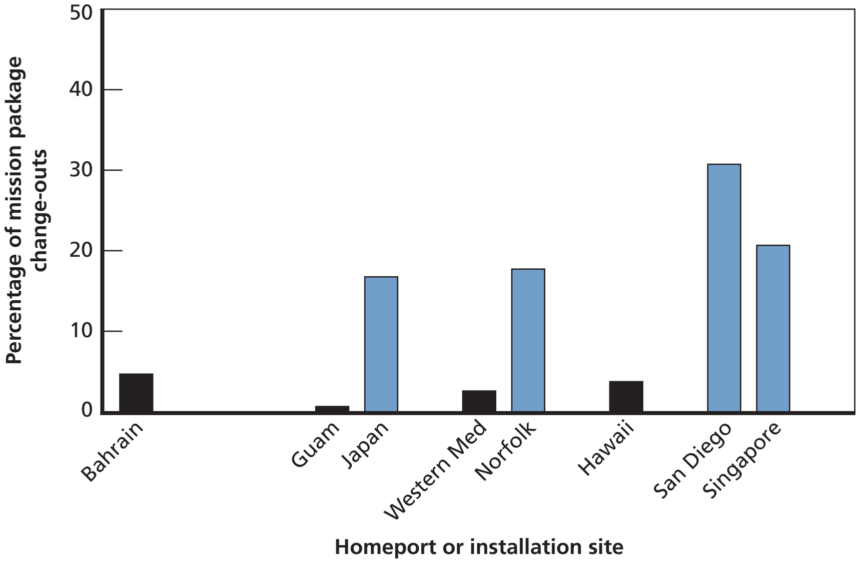
Figures 4.4, 4.5, and 4.6 show that for all the time frames the vast majority of mission package change-outs would occur in Japan, Norfolk, San Diego, and Singapore. Bahrain, Guam, Hawaii, and the Western Mediterranean would account for less change-out activity.

Figure 4.4
Percentage of Mission Package Change-Outs, by Location, in the Short Term for Eight Potential Sites



RAND *MG528-4.4*

Figure 4.5
Percentage of Mission Package Change-Outs, by Location, in the Middle Term for Eight Potential Sites



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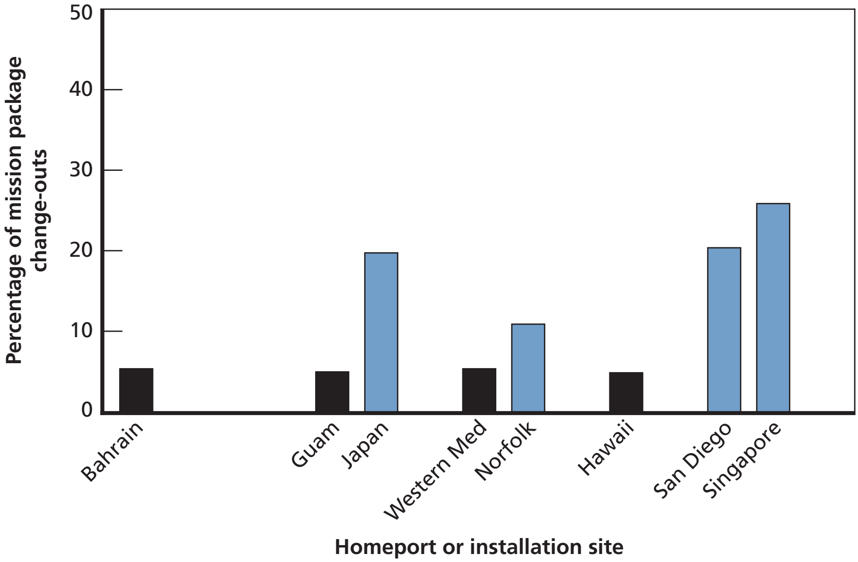
Testing the Sensitivity of Performance of Second-Order Sites to Removal or Retention of Japan in the Short Term, Middle Term, and Long Term

In the above second-order analysis of eight sites, we noted that homeports in Norfolk and San Diego are already in planning and are highly likely. Hence, we wanted to test the sensitivity of site performance to Japan and Singapore. First, we removed Japan from the list of eight potential sites and reran the model. Several performance metrics, with and without Japan, are shown in Figures 4.7, 4.8, and 4.9 (short, middle, and long term, respectively). We can see from these figures that there would be negligible difference in performance, with or without Japan.[2]

[2] We note approximately 45 UNREPs are required for the LCS fleet. This number corresponds to about 20 required LCSs, needing an average of about 2.3 UNREPs each. While it

Figure 4.6
Percentage of Mission Package Change-Outs, by Location, in the Long Term for Eight Potential Sites



RAND *MG528-4.6*

The percentage of mission package change-outs, with and without Japan, is shown in Figures 4.10, 4.11, and 4.12. Figure 4.10 shows that there would be an increase in the percentage of mission package change-outs in Guam, Norfolk, and San Diego if Japan were removed from consideration.[3] With Japan removed, that increase of activity in Guam becomes even more pronounced in the middle and long term (Figures 4.11 and 4.12). This increase implies a potential trade-off

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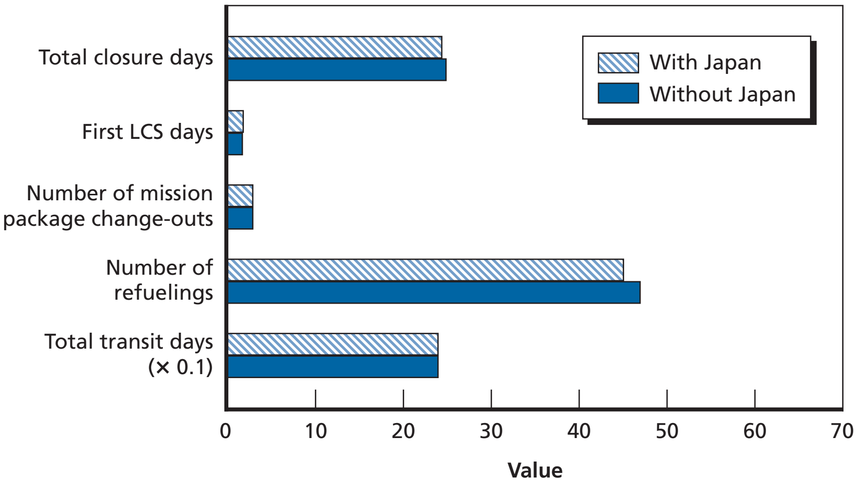
was beyond our charter to address ways of refueling the LCS fleet, we note that these requirements are high.

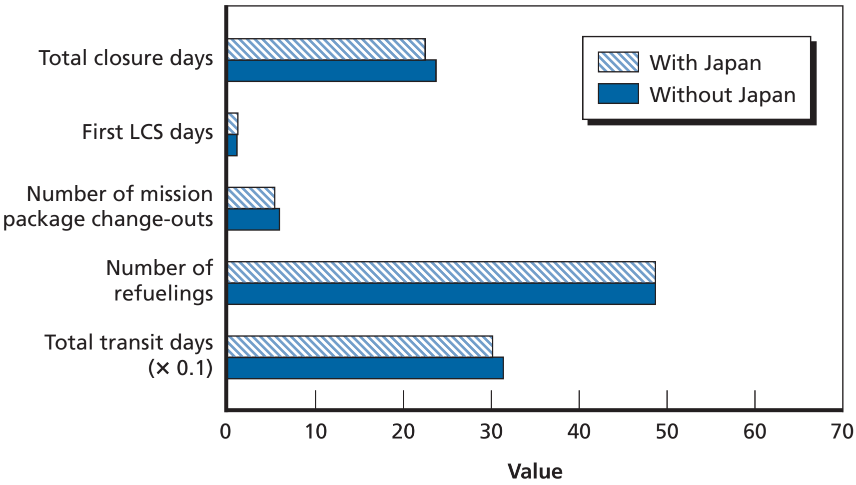
[3] We also note an increase in activity in Norfolk when Japan is removed from consideration. In this case, operations in Southwest Asia are satisfied in some cases by LCSs from the Atlantic rather than the Pacific Rim, in the absence of a homeport or installation site in Japan. Also, if Japan is removed from consideration, then there is a greater reliance on San Diego and Guam. LCSs bound from San Diego tend to reconfigure mission packages, as needed, in Guam, slightly reducing the activity in Hawaii.

Figure 4.7
Performance Metrics in the Short Term, With and Without Japan



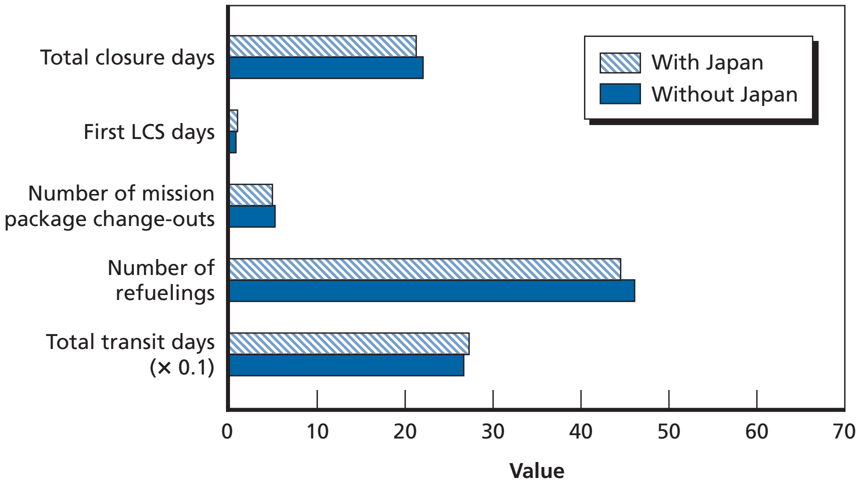
RAND *MG528-4.7*

Figure 4.8
Performance Metrics in the Middle Term, With and Without Japan



RAND *MG528-4.8*

Figure 4.9
Performance Metrics in the Long Term, With and Without Japan



RAND *MG528-4.9*

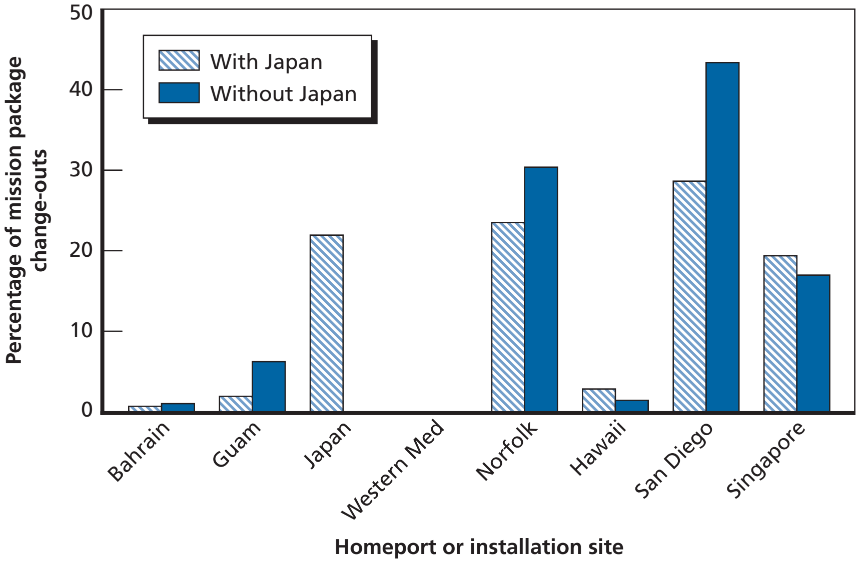
between Japan and Guam: If Japan were removed, there would be an increasing reliance on Guam for mission package change-outs as we move from the short term to the middle term and the long term.

Choosing Between Guam and Japan: Cost Comparison

As pointed out in the discussion above, there is a potential trade-off between Guam and Japan. Guam is an unincorporated U.S. territory, and the U.S. military currently operates in Japan. Title 10, Subsection 7310 restrictions do not apply to either location (U.S. Code, 2006). Both have existing facilities.

We determined that there would be a negligible cost difference between constructing a mission package installation site in Japan and constructing one in Guam. However, it appears that a larger facility investment would be required for a homeport in Guam than in Japan. Table 4.1 summarizes our estimates of the investments that would be required for Guam that would not be required for Japan. It shows that about 200 million FY 2004 dollars would be required for a homeport

Figure 4.10
Percentage of Mission Package Change-Outs in the Short Term, With and Without Japan



RAND *MG528-4.10*

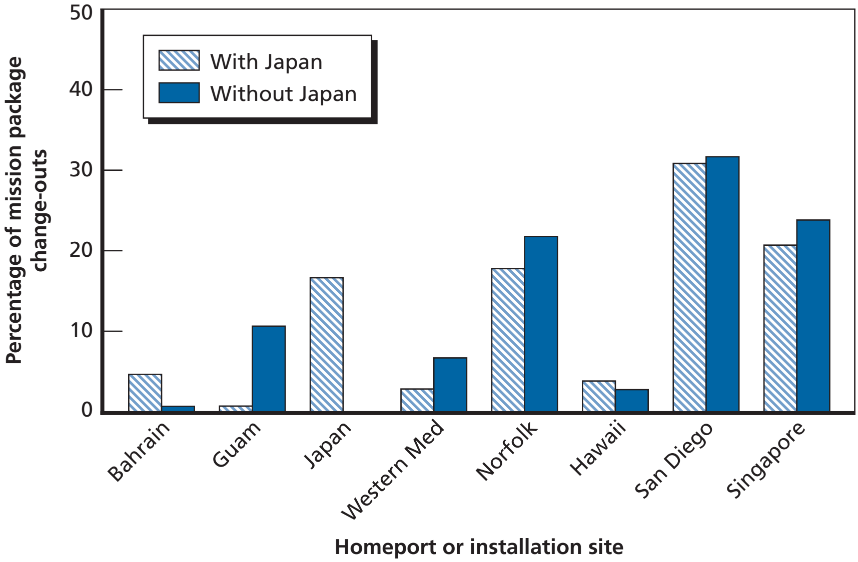
in Guam that would not be required for Japan. Hence, for cost reasons, Japan appears to be the preferred location.

Testing the Sensitivity of Performance of Second-Order Sites to Removal or Retention of Singapore in the Short Term, Middle Term, and Long Term

We performed the identical analysis with respect to removing or retaining Singapore.[4] Our results for the short-term, middle-term, and long-term performance of the potential sites, with and without Singapore, measured by the same metrics as above, are depicted in Figures 4.13, 4.14, and 4.15. The figures show that while there would be no significant change in total closure time if Singapore were removed from

4 Since there is no U.S. base at Singapore, we estimate the following extra costs for security: $5 million in investment costs, 60 million FY 2004 dollars, net present value for 20 years of manning.

Figure 4.11
Percentage of Mission Package Change-Outs in the Middle Term, With and Without Japan

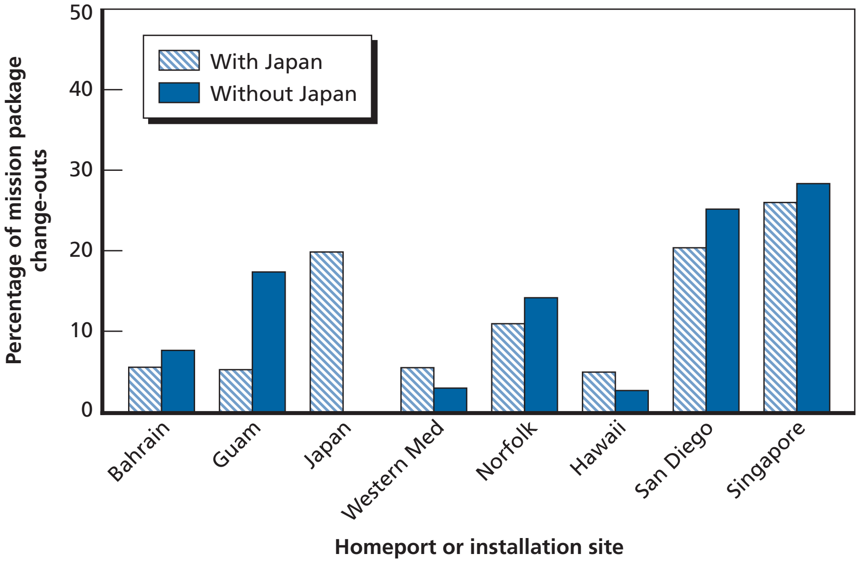


RAND *MG528-4.11*

consideration, in the middle term the total transit days may increase and therefore the number of underway refueling operations may also increase. This increase would not occur in the short term because there are fewer mission demands. This increase would not occur in the long term since the fleet size would be larger, and, therefore, there would be more options for satisfying mission demands.

The percentage of mission package change-outs, with and without Singapore, in the short, middle, and long term are depicted in Figures 4.16, 4.17, and 4.18. These figures show that there would be an increase in the percentage of mission package change-outs in Bahrain, Japan, Norfolk, and San Diego if Singapore were removed from consideration. The most significant change would be in the activity in Bahrain. This conclusion is not surprising. LCSs bound from the West Coast of the United States to Southwest Asia could reconfigure their

Figure 4.12
Percentage of Mission Package Change-Outs in the Long Term, With and Without Japan



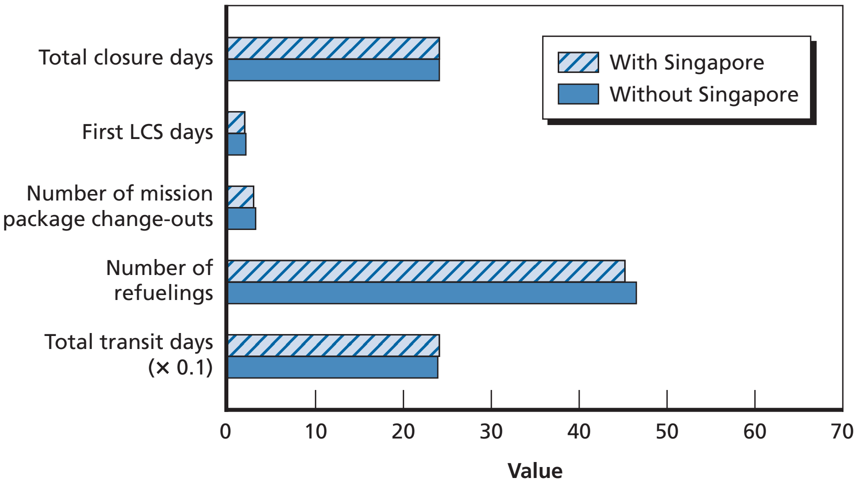
RAND *MG528-4.12*

Table 4.1
Comparison of Homeport Upgrade Costs for Japan and Guam (millions of FY 2004 dollars)

	Guam	Japan
Pier	$100	$0
Bachelor enlisted quarters	$50	$0
Operations center	$10	$0
Maintenance shops	$20	$0
Margin	$20	$0
Total	$200	$0

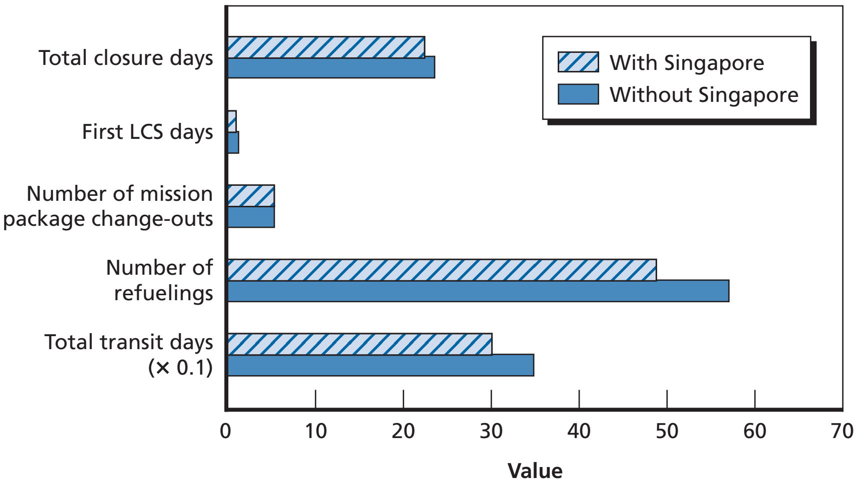
NOTES: These estimates of marginal costs assume an Area Construction Cost Index of 2.02. RAND developed analogies for building facilities in the United States from the FY 2005 Military Construction Budget. Current facilities are assumed to be occupied or obsolete, requiring construction to support six LCSs at an existing base. See Appendix B.

Figure 4.13
Performance Metrics in the Short Term, With and Without Singapore



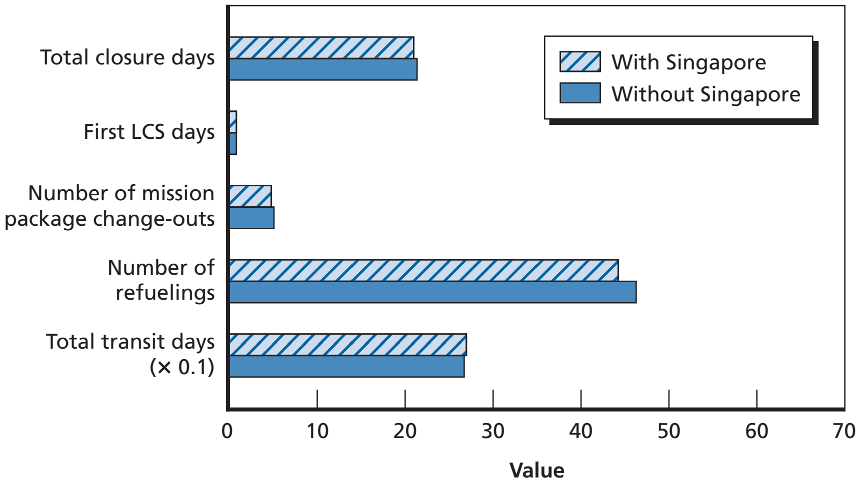
RAND *MG528-4.13*

Figure 4.14
Performance Metrics in the Middle Term, With and Without Singapore



RAND *MG528-4.14*

Figure 4.15
Performance Metrics in the Long Term, With and Without Singapore



RAND *MG528-4.15*

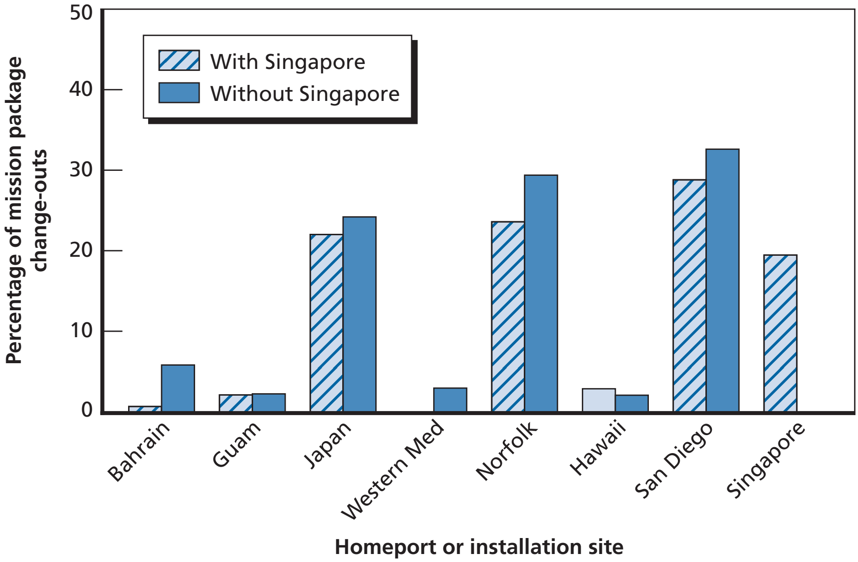
mission package in either Singapore or Bahrain, with no significant difference in closure time.

Conclusion: The Same Five Sites Are Preferred for Each Time Frame for Homeports and Mission Package Installation Sites

Our second-order analysis of the eight potential sites led us to the following considerations for all time frames:

- Retain Japan, Norfolk, and San Diego as homeports and Singapore as a mission package installation site because of the large number of mission package change-outs that would occur there.
- Drop Hawaii and the Western Mediterranean since few mission package change-outs would occur there.

Figure 4.16
Percentage of Mission Package Change-Outs in the Short Term, With and Without Singapore



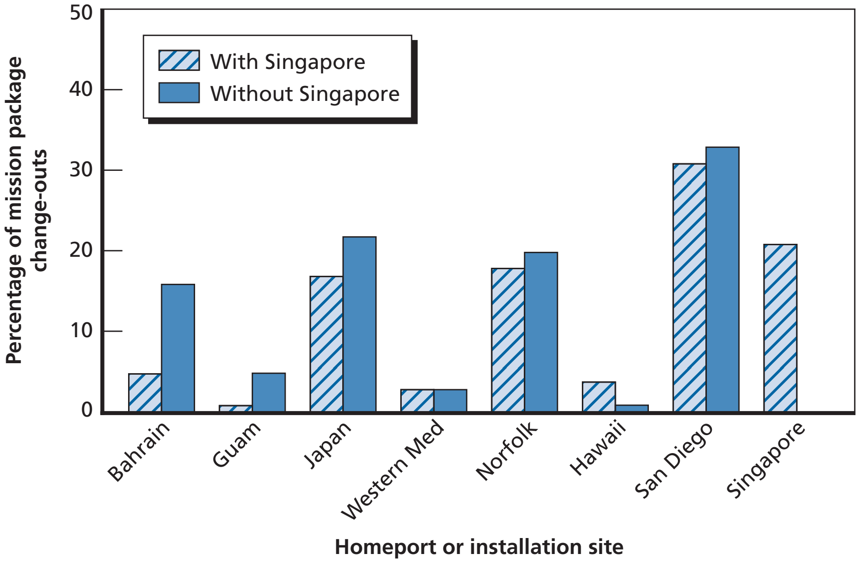
RAND *MG528-4.16*

- Remove Guam from consideration based on our trade-off analysis between Guam and Japan.
- Retain Bahrain as a potential mission package installation site since there is some amount of mission package change-out activity predicted there, it meets other criteria as home of the Fifth Fleet, it provides geographic balance to the list of sites, it provides an alternative to Norfolk for ships deploying from the Atlantic, and it provides an alternative for Singapore for ships transiting from the Pacific.[5]

These considerations drove us to conclude that the same five geographic locations are suitable sites in the short, middle, and long term:

[5] It should be noted that there are no large surface combatants homeported in Bahrain.

Figure 4.17
Percentage of Mission Package Change-Outs in the Middle Term, With and Without Singapore

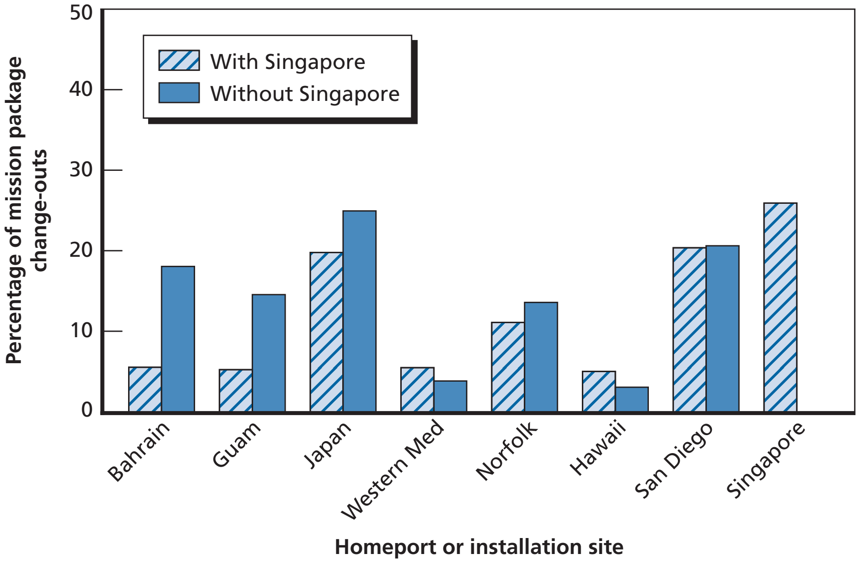


RAND *MG528-4.17*

- Homeports: Norfolk, San Diego, and Japan
- Installation sites: Bahrain and Singapore. Both are suitable as installation sites only because of political sensitivities and Title 10, Subsection 7310 restrictions (U.S. Code, 2006).

These five sites provide the same level of performance in terms of model metrics as the original list of fifteen. Adding an additional site does not improve the model metrics. Removing one of these sites begins to degrade performance.

Figure 4.18
Percentage of Mission Package Change-Outs in the Long Term, With and Without Singapore



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CHAPTER FIVE

Preferred LCS Mission Package Inventories

In this chapter, we provide results of our analysis of preferred LCS mission package inventories in the short, middle, and long term. We discuss how we determined the preferred inventories of mission packages for those time frames and the specific number of mission packages the Navy should store aboard available seaframes, at homeports, and at mission package installation sites.

Assumed LCS Seaframe Inventories in the Short Term, Middle Term, and Long Term

As described in Chapter Four, we assumed that inventories of LCS seaframes would grow over the next several decades, with fleet sizes of 36 in the short term, 60 in the middle term, and 84 in the long term.

In this chapter, we make several additional assumptions. We assumed that a squadron of four stand-alone seaframes will be assigned to each of the three homeports that we identified in Chapter Four—San Diego, Norfolk, and Japan—in all time frames. We assumed that the LCSs in those stand-alone squadrons would be located near their homeports. And, for all time frames, we assumed that one seaframe in each squadron would be in maintenance and not available for 125 days, another would be emergency-surge ready and unavailable for 45 days, a third would be surge ready and unavailable for 15 days, and the remaining seaframe would be deployed or immediately ready for deployment. This level of availability roughly corresponds with the FRP.

LCS Mission Package Inventories in the Short Term, Middle Term, and Long Term

To determine the best LCS mission package inventories in the short, middle, and long term, we used a three-step process. For each time frame:

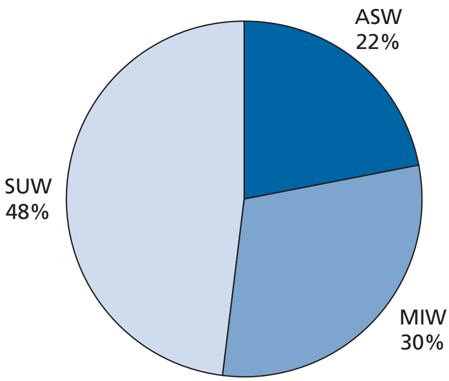
1. We evaluated the average proportion of LCS mission packages by type needed to meet the demands of the scenarios described in Chapter Two.
2. We calculated the minimum number of each LCS mission package type that the Navy will need to optimize total closure time as defined in Chapter Three.
3. We determined the quantities of LCS mission packages by type that the Navy will need at each installation site to optimize total LCS closure time.

The Proportion of Mission Package Types Needed in the Short Term, Middle Term, and Long Term

To gauge the size of future LCS mission package inventories, we first needed to establish the demand by proportion for each type of mission package that the range of military operations might require from the LCS fleet. To accomplish this, we used the numbers of each type of mission package that we identified as being required for each scenario in Chapter Two. We translated those numbers into proportions and averaged those proportions over all scenarios, treating each scenario as equally likely.[1] The result is shown in Figure 5.1, which depicts the proportion of ASW, MIW and SUW mission packages needed, on average, to meet scenario demands.

[1] We assumed the proportions would be the same for the short-, middle-, and long-term cases. While there was an insufficient number of seaframes to always satisfy one MCO simultaneously occurring with three non-MCOs in the short term, on average it was possible to satisfy one MCO simultaneously occurring with 2.4 non-MCOs in the short term. For this reason, we did not alter the number of non-MCO missions in evaluating the proportion of mission packages by type for the short-term case.

Figure 5.1
Proportion of Mission Packages Needed, by Type, to Meet Average Scenario Demands



RAND *MG528-5.1*

Figure 5.1 shows that, on average, the Navy should plan that 48 percent of its total inventory of LCS mission packages should be SUW, 30 percent should be MIW, and 22 percent ASW.

Minimum Number of Each Mission Package Type Needed in the Short Term, Middle Term, and Long Term

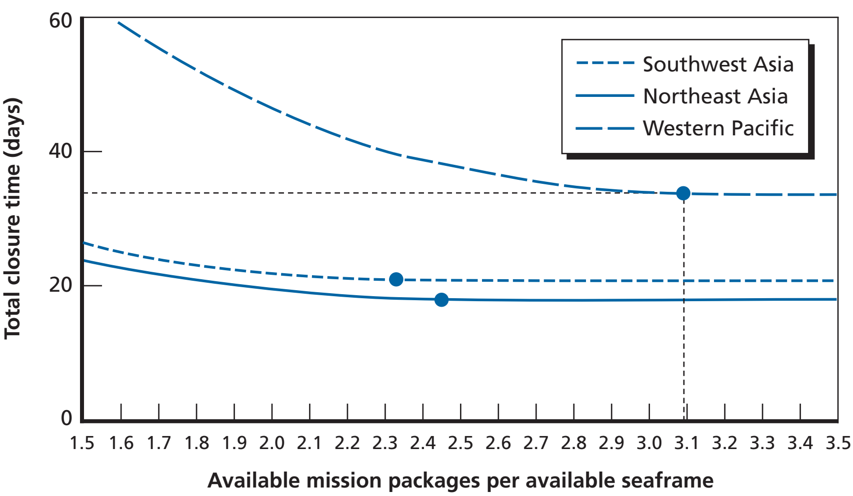
Our second step in determining optimal LCS mission package inventories in the short, middle, and long term involved calculating the minimum total number of LCS mission packages that the Navy will need to optimize total closure time. This step was a departure from our earlier analysis, which focused on an unlimited number of each mission package type at each homeport or installation site.

This step involved estimating the smallest total number of mission packages so that adding additional mission packages does not improve performance as measured by model metrics but so that reducing the total number of mission packages causes performance to diminish rapidly. This estimate is the optimal number of mission packages.

We began this analysis by examining a large ratio of available mission packages to available seaframes; we then reduced this ratio until the total-closure-time metric began to increase. We did this separately for each of the three MCOs: Southwest Asia (SWA), the Western

Pacific (WP), and Northeast Asia (NEA). This way, we chose the minimum number of mission packages so that performance for any scenario is not significantly affected. Figure 5.2 shows the results of this experiment for the short term. Figures 5.3 and 5.4 show corresponding middle-term and long-term results.[2] Figure 5.2 shows that the total closure time for the WP scenario in the short term would begin to rise appreciably if the ratio of available mission packages to available seaframes were reduced below 3.1. Figures 5.3 and 5.4 show corresponding closure time rises when the ratio falls below 2.2 (middle term) or 1.9 (long term), respectively. In all time frames, adding additional mission packages would not significantly improve the average total closure

Figure 5.2
Closure Time Versus Ratio of Available Mission Packages to Available Seaframes in the Short Term



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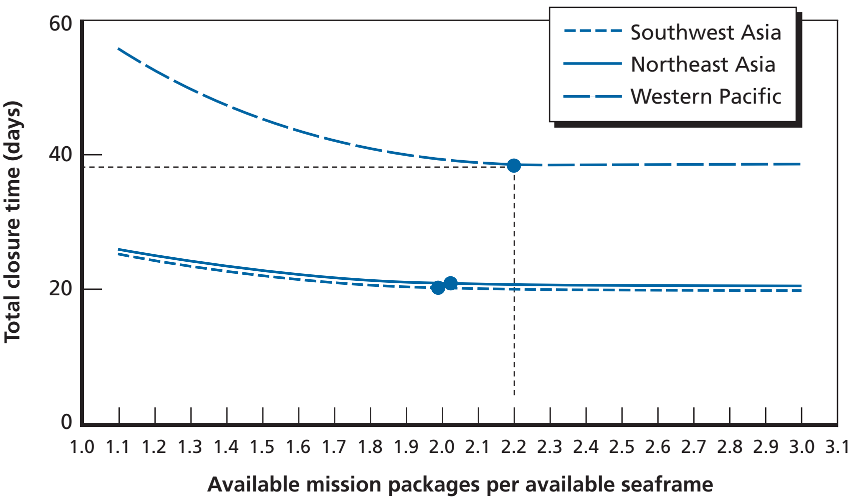
2 Figures 5.2, 5.3, and 5.4 show curves fit to the data. The total-closure-time values for the short-term case that are depicted in Figure 5.2 are smaller than the values for the middle-term case that are depicted in Figure 5.3 since the short-term case assumes one MCO simultaneously occurring with one non-MCO, whereas the middle-term case assumes one MCO simultaneously occurring with three non-MCOs.

Figure 5.3
Closure Time Versus Ratio of Available Mission Packages to Available Seaframes in the Middle Term



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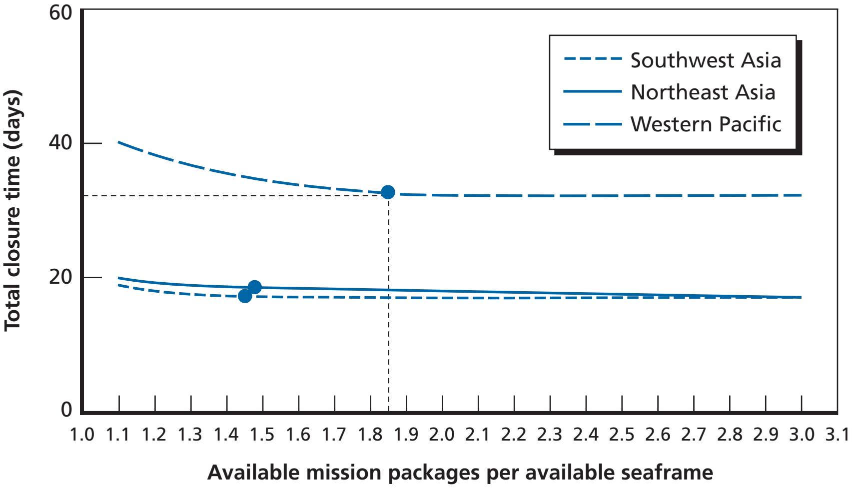
time. It is not surprising that the largest ratio value for which total closure time begins to increase for any scenario is determined by scenarios involving the WP MCO, since it requires the largest number of LCSs and other assets of all three MCOs.

Quantities of LCS Mission Packages, by Type, That the Navy Will Need in the Short Term, Middle Term, and Long Term

To determine the quantities of LCS mission packages, by type, that the Navy will need, we first multiplied the ratio of available mission packages to available seaframes by the number of available seaframes for the short, middle, and long term.[3] The result was the total number of available mission packages for each time period. We then multiplied the total number of available mission packages for each time period by the proportions shown in Figure 5.1. This total produced the number of available mission packages of each type. Since no estimates of mission

[3] We assumed that the average operational availability of seaframes is 0.7. This average is consistent with the availability of surface assets as determined by the FRP.

Figure 5.4
Closure Time Versus Ratio of Available Mission Packages to Available Seaframes in the Long Term

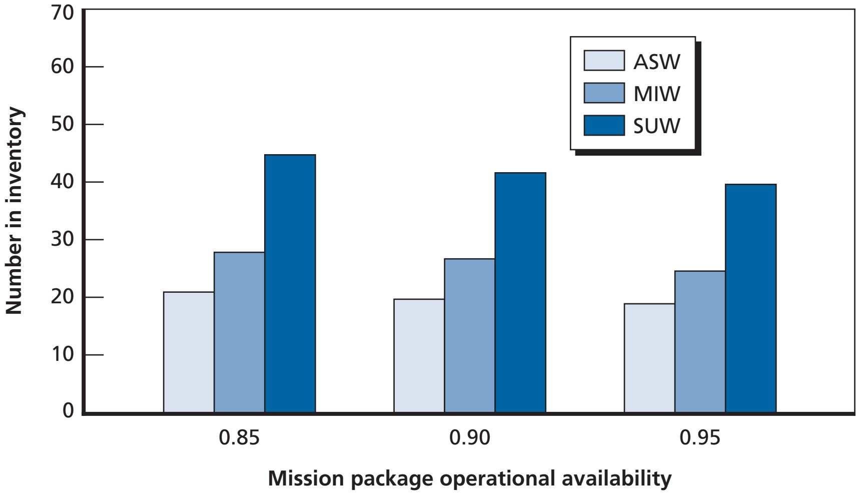


RAND *MG528-5.4*

package availability existed at the time of this study, we evaluated the inventory of mission packages by type for a range of availability values. Figure 5.5 shows the short-term inventory of mission packages of each type as a function of the operational availability of mission packages. Figures 5.6 and 5.7 show the corresponding middle-term and long-term results.

These figures show that, with an operational availability of 0.9, the Navy likely would need an inventory of 20 ASW, 27 MIW, and 42 SUW mission packages in the short term. These totals correspond to a ratio of total mission packages per total seaframes of 2.5. With that same operational availability in the middle term, the Navy would need 23 ASW, 31 MIW, and 50 SUW mission (with a corresponding ratio of 1.7). In the long term, it would require 28 ASW, 38 MIW, and 60 SUW mission packages (with a corresponding ratio of 1.5).

Figure 5.5
Inventory of Mission Packages in the Short Term as a Function of Operational Availability



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Locations Where LCS Mission Packages Change-Outs Will Occur

To determine the optimal storage locations for the numbers of mission packages we identified above, we programmed the LCSTSM with the best locations for homeports and installation sites, the proportion of each type as determined by our analysis, and for a ratio of 3.1 for available mission packages per available seaframe in the short term. We then replicated that modeling program for the middle term and long term, using ratios of 2.2 and 1.9, respectively. In all the efforts, we let the model distribute the available mission packages to available seaframes, homeports, and installation sites, assuming a uniform probability distribution. We then exercised the model and determined the percentage of mission package change-outs by type for each installation site. The results are shown in Figures 5.8, 5.9, and 5.10.

Figure 5.6
Inventory of Mission Packages in the Middle Term as a Function of Operational Availability

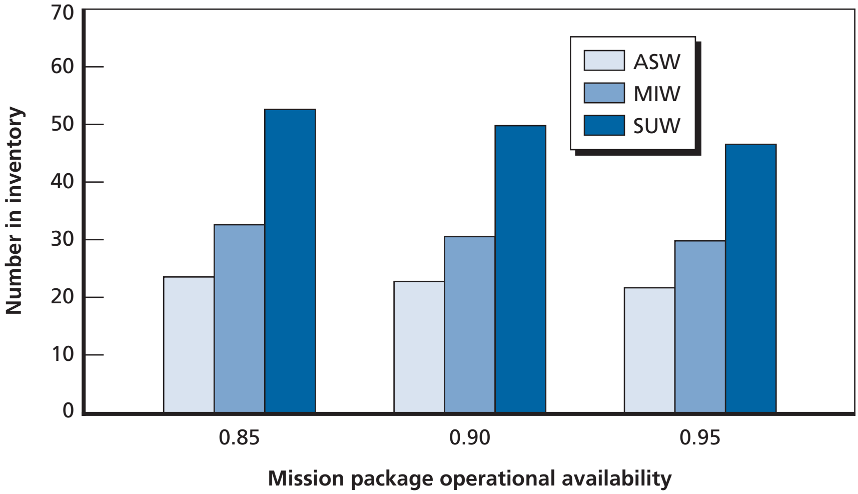

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Figure 5.8 displays the distribution of change-outs in the short term by mission package type and location. It shows that in the short term, 15 percent of ASW change-outs would be performed in Bahrain, 27 percent in Japan, 12 percent in Norfolk, 19 percent in San Diego, and 27 percent in Singapore—for a total of 100 percent. During the same time frame, 10 percent of MIW mission package change-outs would occur in Bahrain, 21 percent in Japan, 20 percent in Norfolk, 11 percent in San Diego, and 38 percent in Singapore. And 20 percent of SUW mission package change-outs would occur in Bahrain, 10 percent in Japan, 40 percent in Norfolk, 10 percent in San Diego, and 20 percent in Singapore.[4]

Figures 5.9 and 5.10 display similar data for the distributions of change-outs in the middle term and long term, respectively.

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4 Note that these percentages differ from those of Figures 4.4, 4.5, and 4.6, which considered eight potential locations for homeports and installation sites rather than five, but there is a negligible difference in performance metrics.

Figure 5.7
Inventory of Mission Packages in the Long Term as a Function of Operational Availability

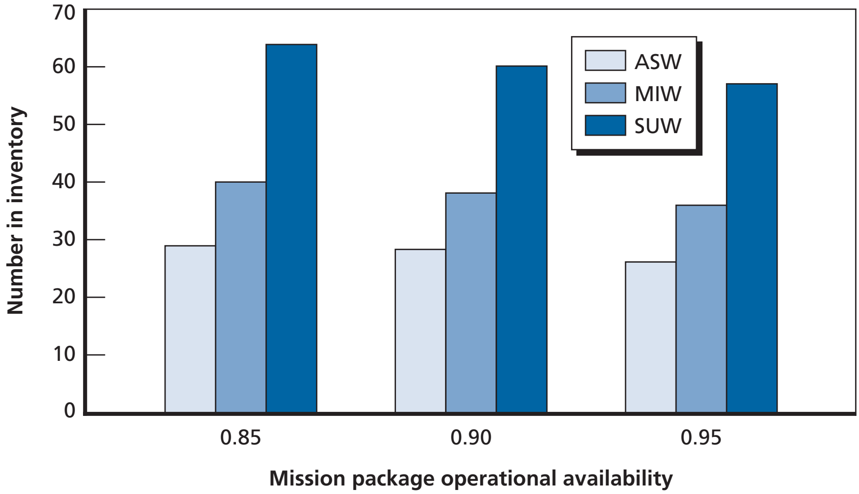

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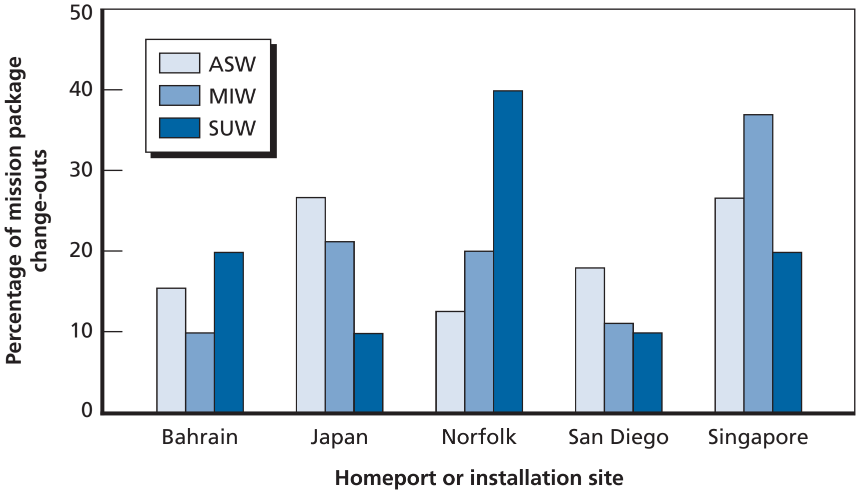
Figure 5.8
Percentage Distribution of Mission Package Change-Outs, by Type, for Each Homeport or Installation Site in the Short Term



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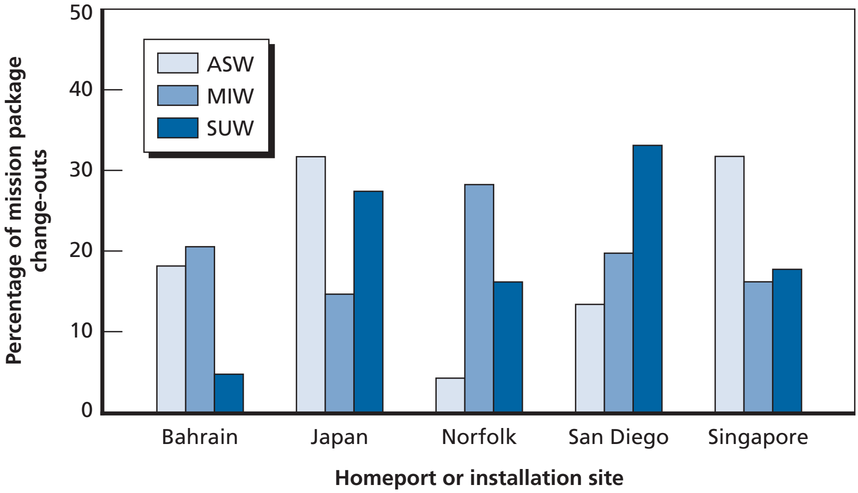
Conclusion: The Number of Mission Packages the Navy Will Need and Where They Should Be Kept

We determined the total number of mission packages installed on each available seaframe or stored in a homeport or at an installation site through the following calculation: Multiply the percentages in Figures 5.9, 5.8, and 5.10 by the number of mission packages by type in inventory. In these calculations, we assumed an operational availability for mission packages of 0.9.

The results provided our recommendations for mission package inventories, which are displayed in the following tables. Our recommendations for short-term inventories are shown in Table 5.1, for middle-term inventories in Table 5.2, and for long-term inventories in Table 5.3.

Figure 5.9
Percentage Distribution of Mission Package Change-Outs, by Type, for Each Homeport or Installation Site in the Middle Term



RAND *MG528-5.9*

In summary, we recommend the inventory levels of mission packages for the short, middle, and long term as summarized in Table 5.4.

Figure 5.10
Percentage Distribution of Mission Package Change-Outs, by Type, for Each Homeport or Installation Site in the Long Term

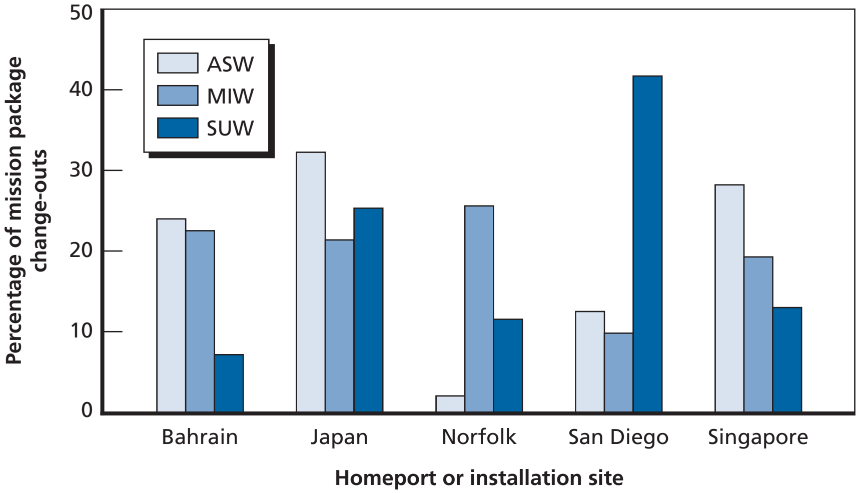


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Table 5.1
Number of Mission Packages, by Type, Stored on Available Seaframes, at Homeports, and at Installation Sites in the Short Term (by 2014)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	5	8	12
San Diego	3	2	3
Norfolk	2	4	12
Bahrain	2	2	6
Singapore	4	7	6
Japan	4	4	3
Total	20	27	42

Table 5.2
Number of Mission Packages, by Type, Stored on Available Seaframes or Stored at Homeports and Installation Sites in the Middle Term (by 2019)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	9	12	21
San Diego	2	4	10
Norfolk	1	5	5
Bahrain	3	4	1
Singapore	4	3	5
Japan	4	3	8
Total	23	31	50

Table 5.3
Number of Mission Packages, by Type, Stored on Available Seaframes or Stored at Homeports and Installation Sites in the Long Term (by 2024)

Location	ASW Mission Packages	MIW Mission Packages	SUW Mission Packages
Available seaframes	13	18	29
San Diego	2	2	13
Norfolk	0[a]	5	4
Bahrain	4	5	2
Singapore	4	4	4
Japan	5	4	8
Total	28	38	60

[a] Observe that our results suggest that no ASW mission packages are stored ashore in Norfolk. Care should be taken in interpreting this result. It does not imply that no ASW mission packages are available to LCSs in Norfolk, since they may be stored aboard available seaframes. Other considerations, such as training needs, should be taken into account when determining if a small number of ASW mission packages should be stored ashore in Norfolk.

Table 5.4
Mission Package Inventories in the Short Term, Middle Term, and Long Term

Time Period	ASW	MIW	SUW
Short term (by 2014)	20	27	42
Middle term (by 2019)	23	31	50
Long term (by 2024)	28	38	60

NOTES: Inventory levels depend on the operational availability, which is defined as the fraction of time that mission packages are available for mission use. Operational availability estimates for mission packages were not available at the time of this study. The inventory levels in this table assume that the operational availability of mission packages is 0.9. The numbers will need to be adjusted for different estimates of operational availability. For instance, if the operational availability is estimated to be *x,* then each number in the table should be multiplied by 0.9/*x.*

CHAPTER SIX

Projected LCS and Mission Package Costs and Performance

In this chapter, we provide the results of our analysis of projected LCS and mission package costs and performance in the short, middle, and long term.

Cumulative Procurement Costs for LCS Seaframes, Mission Packages, and Facilities Construction

We estimated the total procurement costs for seaframes, vertical take-off unmanned aerial vehicles (VTUAVs), and mission packages, and the costs of construction for facilities of homeports and installation sites that we identified in Chapters Four and Five. The cost factors and cost estimating relationships that we used are described in detail in Appendix B.

To make these estimations, we chose not to take a complete life-cycle cost or total ownership cost approach. Rather, we took an ad hoc look at the significant costs involved in trading the alternatives under study. For the most part, we developed this information with the support of NAVSEA. However, the final result is a RAND product. Costs are put into FY 2004 dollars, consistent with the LCS Selected Acquisition Report (Babcock, 2004) baseline year.

The results of our cost estimates for the short term, middle term, and long term are shown in Table 6.1.

Table 6.1
Estimated Cumulative Procurement and Facility Construction Costs for the Short Term, Middle Term, and Long Term

	Cost (billions of FY 2004 dollars)		
Item	**Short Term**	**Middle Term**	**Long Term**
Seaframes	\$8.00	\$13.2	\$18.3
Mission packages	\$4.56	\$5.50[a]	\$6.34
VTUAVs	\$1.07	\$1.75	\$2.42
Facility construction costs (includes Singapore security personnel)	\$0.183	\$0.199[b]	\$0.210
Total	\$13.81	\$20.65	\$27.27

NOTES: VTUAV costs assume one set of three VTUAVs per seaframe. Mission package costs assume a mission-package operational availability of 0.9. Totals may not sum because of rounding.

[a] More mission packages than required are purchased to maintain the production base for the time period leading to the long-term case. The estimate for only those mission packages indicated by the LCSTSM is \$5.2 billion in FY 2004 dollars.

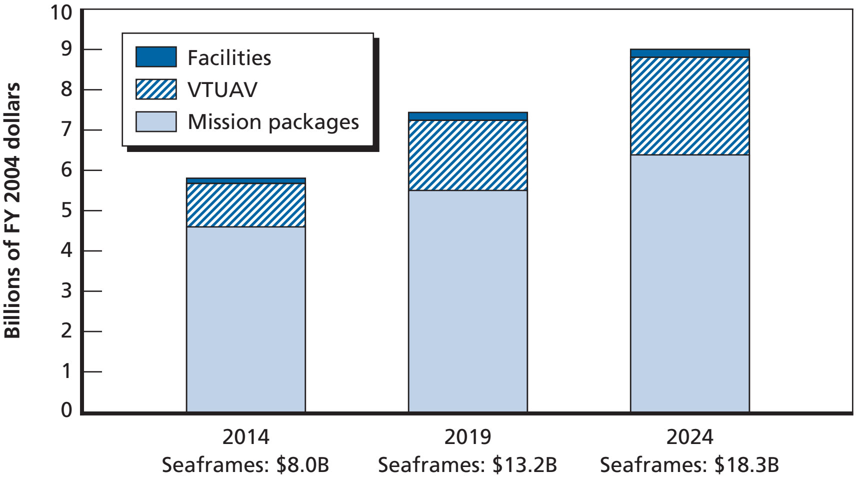
[b] This is the short-term cost incremented to reflect additional mission package storage requirements. Some sites (such as Norfolk) will have excess capacity.

Figure 6.1 graphically displays these estimated total procurement costs for seaframes, VTUAVs, and mission packages, and costs of facility construction of homeports and installation sites for the short, middle, and long term.

Performance of LCS With Our Recommended Inventories and Locations

How well do the recommended inventories of mission packages that we identified in Chapter Five perform in the short, middle, and long term, assuming the locations of homeports and installation sites that we identified in Chapter Four? The results are shown in Figure 6.2.

Figure 6.1
Estimated Cumulative Procurement and Facility Construction Costs for the Short Term, Middle Term, and Long Term



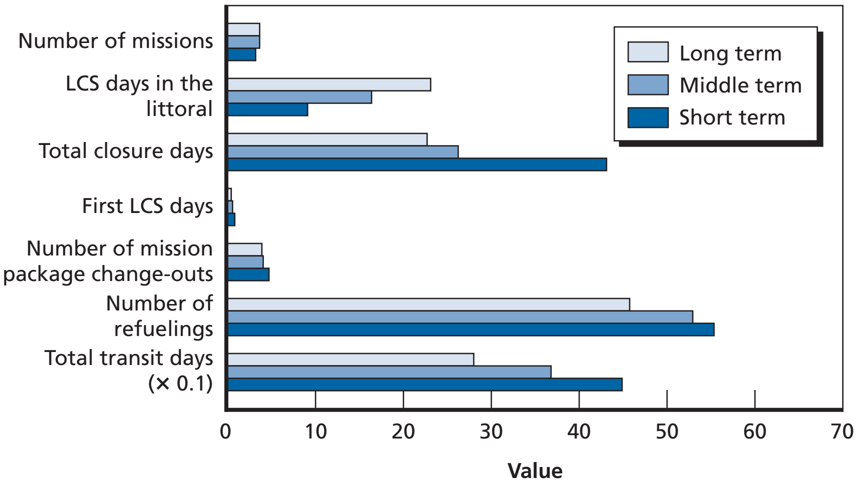
NOTES: Inventory levels depend on the operational availability, which is defined as the fraction of time that mission packages are available for mission use. Operational availability estimates for mission packages were not available at the time of this study. The inventory levels in this figure assume that the operational availability of mission packages is 0.9. The numbers will need to be adjusted for different estimates of operational availability. For instance, if the operational availability is estimated to be *x*, then each number in the table should be multiplied by 0.9/*x*.

RAND *MG528-6.1*

Using the performance measure that we described in Chapters Three and Four, the figure shows that the average total closure time would be 43 days in the short term, 26 days in the middle term, and 23 days in the long term. The figure also shows that the number of underway refueling operations would decrease in transitioning from the short to middle to long term, as does the total number of transit days. The LCS days in the littoral would increase from about nine in the short term, to 17 in the middle term, to 23 in the long term.

Table 6.2 combines the costs with the primary performance variables of total closure days and LCS time in the littoral. The marginal costs indicate that it is difficult to reduce closure days, but increasing time in the littoral increases at a fairly constant cost per day.

Figure 6.2
Performance Metrics for Short-, Middle-, and Long-Term Solutions



NOTES: The metric values for the middle term and long term assume scenarios involving one MCO simultaneously occurring with three non-MCOs. There is an insufficient number of LCSs in the short term to satisfy scenarios involving one MCO simultaneously occurring with three non-MCOs. The metric values for the short term assume scenarios involving one MCO simultaneously occurring with an average of 2.4 non-MCOs.
RAND *MG528-6.2*

Table 6.2
Combined Cost and Performance Results

	Short Term	Middle Term	Long Term
Incremental cost	$13.8B	$6.8B	$6.6B
Total closure days	43.2	26.5	22.8
Days reduced	—	16.7	3.7
Cost per day	—	$0.4B	$1.8B
LCS days in the littoral	9.4	16.6	23.3
Days increased	—	7.2	6.7
Cost per day	—	$0.9B	$1.0B

NOTES: Dollars are in billions of FY 2004 dollars.

CHAPTER SEVEN

Additional Considerations

In this chapter, we examine three additional issues connected with the challenges of a modular LCS.

First, we examine a few of the risks and benefits involved with storing and installing mission packages at different sites. Second, we look at whether the same level of performance may be obtained with fewer mission packages by adding additional installation sites. Third, we contrast how the proportion of mission packages by type and the locations of homeports and installation sites suited for scenarios involving MCOs would differ from those that are suited for scenarios with non-MCOs.

Risks and Benefits Involved With Storing and Installing Mission Packages at Different Sites

Up to this point, our analysis is consistent with storing and installing mission packages at the same site. Colocating storage and installation sites is consistent with current NAVFAC (Naval Facilities Engineering Command) planning. But separating storage from installation sites may have potential benefits:

- Cost benefits: storage can be at low-cost facilities not necessarily adjacent to ports.
- Operational benefits: installation sites would not be limited to locations with adequate storage space.

There are also other benefits from separating storage and installation sites. For example, consolidation of training facilities at a few storage sites could yield efficiencies, providing additional cost and operational benefits. However, separating storage from installation sites poses transportation risks:

1. *Transportation resources:* assets will be needed to transport mission packages if storage and installation sites are separated.
2. *Transportation time:* the time required to transport mission packages from storage to installation sites could delay reconfiguration unless needs are anticipated well in advance.
3. *Transportation costs:* there will be costs associated with transporting mission packages from storage to installation sites.

A comprehensive examination of these three risks was beyond the scope of our study. However, we made a cursory examination of the risks that are associated with transportation resources and time if mission packages are stored in either Norfolk or San Diego and transported to overseas installation sites via sealift or airlift.

Our analysis considered the transportation needs of all mission package components with the exception of personnel, helicopters, VTUAVs, and other vehicles. We assumed that the remaining equipment could be stored in containers compatible in form-fit with Twenty-Foot Equivalent Unit containers (TEUs). Per information received from PMS[1] 420, we assumed that the remaining equipment could be stored in 9.5 to 11 TEUs, depending on the mission package type (Carson-Jelley, 2006). We assumed that the weight of this equipment could be evenly distributed across the TEUs. This assumption results in a conservative estimate of the number of assets required for transporting mission package TEUs.

Sealift

Many resources will be available to transport mission packages from storage to installation sites via sealift. They include military and com-

[1] PMS is the NAVSEA code for a program management organization.

mercial varieties of container ships, roll-on/roll-off ships, fast-sealift ships, and the newly proposed Joint High Speed Vehicle.[2] Few cargo space limitations exist for sealift.

We used JFAST to determine the port-to-port transit time in days for sealift (Meyer-Campbell, 2003). We assumed an average speed of advance of 15 knots for this evaluation. The results are shown in Table 7.1.

From Table 7.1 we see that the transit time risk for sealift would range from one week to approximately one month. This is a substantial amount of time compared with the mission package reconfiguration time of a few days for an LCS, suggesting that mission package configuration needs must be anticipated well in advance when employing sealift to avoid delaying mission package change-out.

Airlift

We examined the resource and time risks associated with airlift of mission packages using variants of C-17 and C-130 aircraft. We evaluated pallet and aircraft dimensions and capacities for these aircraft (U.S.

Table 7.1
Port-to-Port Transit Time, in Days, for Sealift of Mission Packages

Installation Site	Norfolk	San Diego
Singapore	29	22
Japan	27	14
Bahrain	24	33
Guam	28	16
Hawaii	19	7
Naples	13	24

NOTES: The numbers assume an average speed of advance of 15 knots. The days are rounded up.

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2 Transporting mission packages via Joint High Speed Vehicle was considered in recent unpublished RAND research by Schank et al., 2006. See also U.S. Navy's Military Sealift Command Web site, not dated.

Army Transportation School, 2004; Peltz, Halliday, and Bower, 2003). For a conservative estimate, we assumed that mission package equipment could be perfectly palletized with no bulk issues and that the maximum weight per pallet could be used subject to the aircraft takeoff mass constraints. We also evaluated refueling requirements for these aircraft (U.S. Air Force, 1999). We used JFAST to determine flight times between sites (Meyer-Campbell, 2003).

The number of sorties needed to transport the equipment for a single mission package using C-17 or C-130 aircraft and the payload weight of that equipment are shown in Table 7.2.

Consider that our simulation results suggest that five seaframes, on average, would require a mission package change-out for a given scenario. From Table 7.2 we see that 10 C-130 sorties would be required per mission package. This implies that 50 C-130 sorties would be required to airlift five mission packages from storage to installation sites. In contrast, only two C-17 sorties would be required per mission package. This implies that 10 C-17 sorties would be required to airlift five mission packages from storage to installation sites.

Table 7.3 shows the transit time per sortie for airlift of mission packages and the required number of refueling operations.

From Table 7.3 we see that the requirements for C-17 and C-130 aircraft would be similar, with both requiring between one-half and one day, and one to two refueling operations per sortie. This estimate

Table 7.2
Number of C-17 or C-130 Sorties Required for Airlift of One Mission Package, Including Mission Package Payload Weights

Mission Package Type	Payload (metric tons)	C-17 Sorties	C-130 Sorties
ASW	71	2	10
MIW	91	2	10
SUW	61	2	10

NOTES: The totals do not take into account the transport of mission package personnel, helicopters, VTUAVs, or other vehicles. The sortie requirements were determined by the weight requirements and assume that the payload weight can be evenly distributed among the pallets.

Table 7.3
Transit Time per Sortie, in Days, and Number of Refueling Operations for Airlift of Mission Packages with C-17 or C-130 Aircraft

Installation Site	Norfolk: Flight Time (hours) C-17	Norfolk: Flight Time (hours) C-130	Norfolk: Number of Refuelings	San Diego: Flight Time (hours) C-17	San Diego: Flight Time (hours) C-130	San Diego: Number of Refuelings
Singapore	21	29.8	2	20.3	29.5	1–2
Japan	16	23.5	1–2	13.5	20.3	1
Bahrain	13.5	18.5	1	17.4	24.4	1–2
Guam	18.7	27.4	1–2	14.6	21.6	1
Hawaii	12	17.7	1	6.2	9.4	0
Naples	9	12	1	12.9	17.7	1

does not include the time required to move mission packages from the storage site to an airfield, the time required to load and unload equipment, or the time to move mission packages from the airfield to the installation site. If five mission packages need to be transported from storage to installation sites and enough assets are available to airlift the equipment with one sortie per aircraft, the time required would be on the order of one to one and one-half days, optimistically.

Our view is that the transportation asset risk for airlift is high, especially if C-130 variants are to be used. The risk is much lower if C-17 aircraft are available. The time risk associated with airlift is much improved over that of sealift, and it may or may not delay mission package reconfiguration, depending on the number of aircraft available and how much in advance mission package needs can be anticipated.

Another airlift option is the C-5. This option should be looked at in depth because, while it is significantly more expensive to use than the C-17, it may have the capacity to move TEUs, VTUAVs, vehicles, and even helicopters in one or two sorties per mission package.

Maintaining Performance With Fewer Mission Packages and More Installation Sites

In determining the best locations for homeports and installation sites and the number of mission packages, we began with a large number of potential sites and an unlimited number of mission packages at each. We then determined the minimum number of installation sites that could be used without adversely affecting performance. We also determined the minimum number of mission packages required so that performance would not be adversely affected.

What if this process were reversed? What if we first minimized the number of mission packages and then reduced the number of installation sites. Would fewer mission packages be required at the expense of more installation sites? This would be attractive, considering that the cost of procuring a mission package is substantial in comparison with the cost of constructing facilities for an installation site.

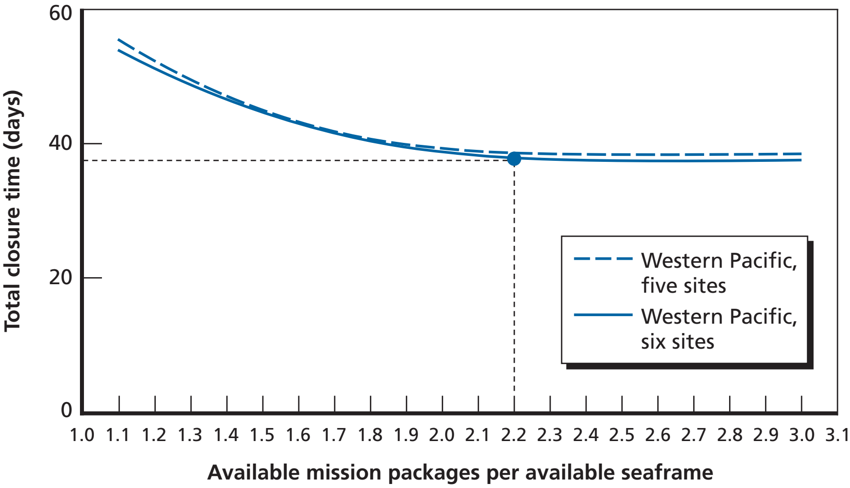
We decided to test this theory by performing a sensitivity experiment as follows:

- Add a sixth mission package installation site at Naples, Italy.
- Determine the minimum number of mission packages so that performance is not adversely affected.

We conducted this experiment for the middle-term case only, which considers 60 seaframes that the Navy could acquire by FY 2019. We evaluated performance for scenarios with one MCO simultaneously occurring with three non-MCOs, and we repeated this experiment for all three candidate MCOs: SWA, WP, and NEA. Once again, we found that the scenarios involving an MCO in the WP determined the minimum number of mission packages required without adversely affecting closure time performance. The result for this case, with five and six installation sites, is shown in Figure 7.1.

Figure 7.1 shows that at least 2.2 available mission packages per available seaframe would be needed, regardless of whether there were five or six installation sites. That is, adding an installation site would not reduce the required number of mission packages.

Figure 7.1
Closure Time Versus Ratio of Available Mission Packages to Available Seaframes for the Scenario With the WP MCO, With Five and Six Installation Sites



NOTE: The plot shows curves that are fit to the data.
RAND *MG528-7.1*

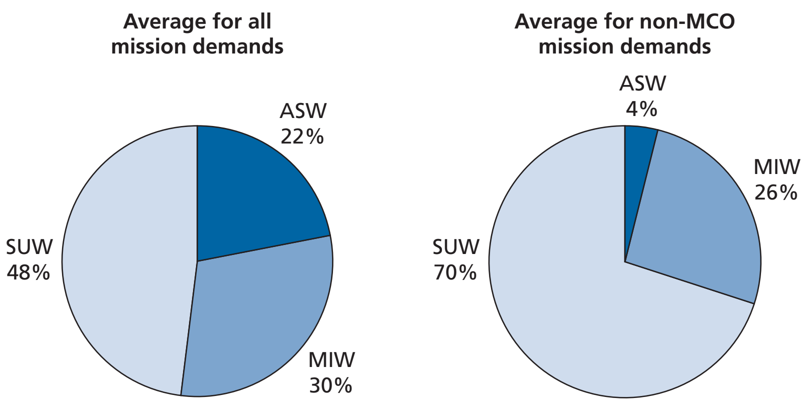
Homeport Locations and Mission Package Proportions for Scenarios Involving MCOs Versus Scenarios Not Involving MCOs

We assumed that the scenarios involved an MCO simultaneously occurring with non-MCOs in our determination of the best locations for homeports and installation sites and the proportions of mission packages by type required. We felt that it was important to characterize the influence of MCO needs on our results. In this section, we make those determinations assuming scenarios involving non-MCOs only. We evaluated those determinations for the middle-term case of 60 seaframes, which the Navy could acquire by FY 2019. We emphasize that the purpose of this excursion is to demonstrate the sensitivity of the results to the MCO needs; we are not suggesting that LCS mission package configurations be optimized for non-MCO scenarios.

Figure 7.2 shows the proportion of mission packages by type that would be required to meet all mission demands and the proportion to meet non-MCO demands only.

From Figure 7.2, we see that 48 percent of mission packages should be the SUW type in order to meet all mission demands, whereas the number increases to 70 percent for non-MCO mission demands. This difference is not surprising, since many missions common in stability operations, GWOT operations, and homeland defense operations require SUW mission packages. For example, the SUW mission package is best suited to extended MIO and counterinsurgency missions. The figure also shows that 22 percent of mission packages should be the ASW type in order to meet all mission demands, whereas the number decreases to 4 percent for non-MCO mission demands. This difference is not surprising, since non-MCO mission demands for ASW mission packages consist of ASW exercises and peacetime tracking operations only. The proportion of MIW mission packages is 30 percent to meet all mission demands, and it decreases to 26 percent for non-MCO demands.

Figure 7.2
Proportion of Mission Packages, by Type, for All Mission Demands and for Non-MCO Mission Demands

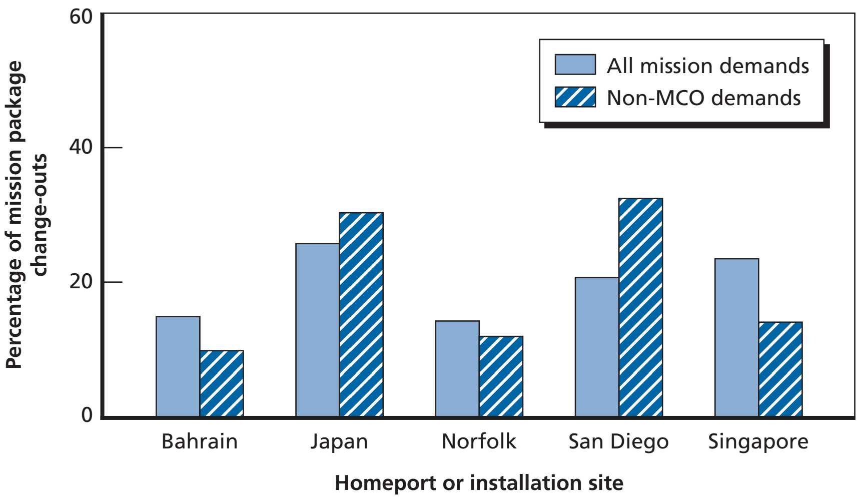


RAND *MG528-7.2*

Our analysis identified the same five locations for homeports and installation sites to meet non-MCO demands as were identified to meet all mission demands. Figure 7.3 shows the percentage of mission package change-outs for homeports and installation sites that would be required to meet all mission demands and to meet non-MCO mission demands.

From Figure 7.3, we see that a lower percentage of mission package change-outs would occur in Bahrain, Norfolk, and Singapore to meet non-MCO demands than are required to meet all mission demands. The figure also shows that a higher percentage of mission package change-outs would occur in Japan and San Diego to meet non-MCO demands than are required to meet all mission demands. Figure 7.4 shows the percentage of ASW mission package change-outs for each homeport and installation site to meet all or non-MCO mission demands.

Figure 7.3
Percentage of Mission Package Change-Outs for Homeports and Installation Sites to Meet All or Non-MCO Demands



NOTE: We assumed that the mission package configuration of LCSs follows proportions identified by the demands that are shown in Figure 7.2.

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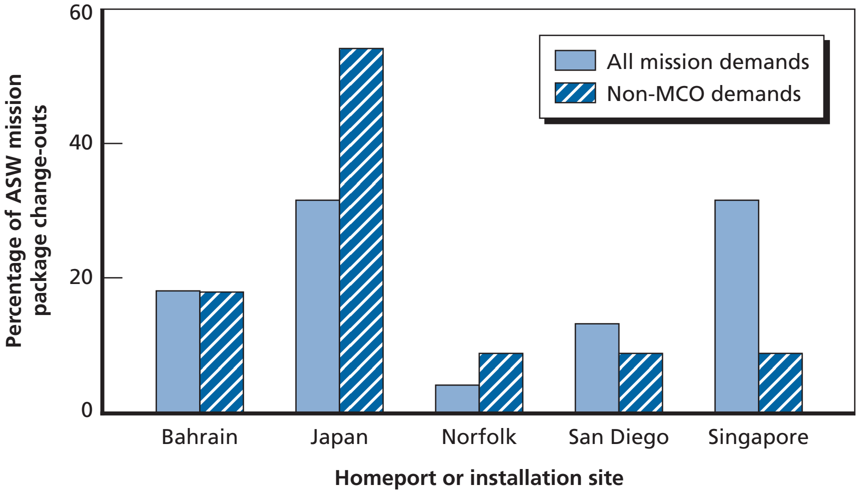
Figure 7.4
Percentage of ASW Mission Package Change-Outs for Homeports and Installation Sites to Meet All or Non-MCO Mission Demands

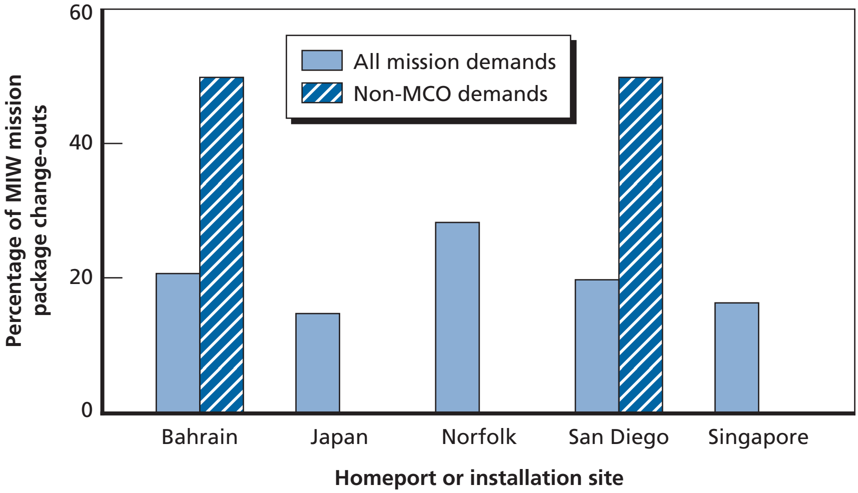


NOTE: An ASW mission package change-out means that an ASW mission package was installed on an LCS.
RAND *MG528-7.4*

From Figure 7.4, we see that there is a substantial increase in the percentage of ASW mission package change-outs anticipated for Japan, and a substantial decrease in ASW mission package change-outs anticipated for Singapore, to meet non-MCO demands, as compared with those for all mission demands. Figure 7.5 shows the percentage of MIW mission package change-outs for each homeport and installation site to meet all or non-MCO mission demands.

From Figure 7.5, we see that 50 percent of MIW mission package change-outs are anticipated for Bahrain and 50 percent for San Diego to meet non-MCO demands. The percentage of MIW change-outs for all mission demands would be spread evenly, roughly speaking, among the five locations. Figure 7.6 shows the percentage of SUW mission package change-outs for each homeport and installation site that would be required to meet all or non-MCO mission demands.

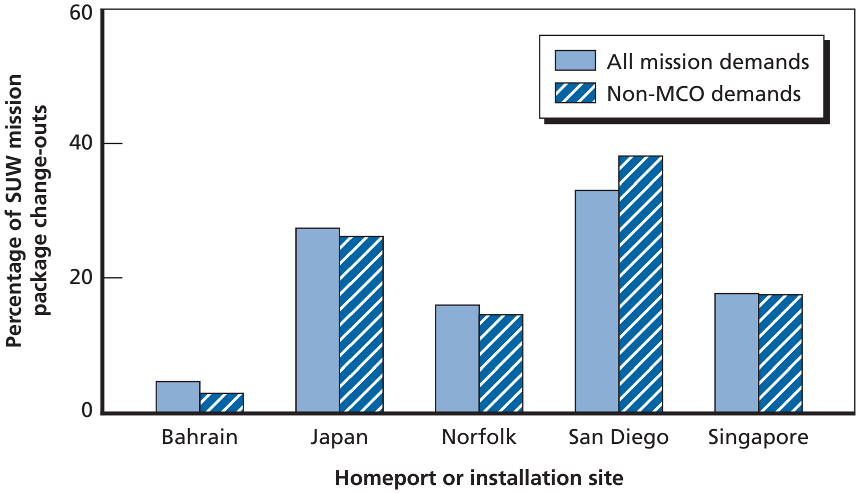
Figure 7.5
Percentage of MIW Mission Package Change-Outs for Homeports and Installation Sites to Meet All or Non-MCO Mission Demands



NOTE: An MIW mission package change-out means that an MIW mission package was installed on an LCS.
RAND *MG528-7.5*

From Figure 7.6 we see that the percentage of SUW mission package change-outs for each location is similar in order to meet all or non-MCO mission demands. The reason for this similarity is that most demands for SUW mission packages are for non-MCOs.

Figure 7.6
Percentage of SUW Mission Package Change-Outs for Homeports and Installation Sites to Meet All or Non-MCO Mission Demands



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CHAPTER EIGHT

Recommendations

Homeports and Installation Sites

Based on our analysis we recommend that the Navy consider three locations for homeports:

- Norfolk
- San Diego
- Japan.

Furthermore, we recommend that the Navy consider two locations for mission package installation sites:

- Singapore
- Bahrain.[1]

Our analysis suggests that these homeports and installation sites are suitable in the short, middle, and long term.

1 The political sensitivities and space limitations for an installation site in Bahrain may be more significant than anticipated during the course of our study. A reexamination of this prospect was outside the scope of our charter. However, we would hypothesize that a location in the eastern or central Mediterranean might provide a suitable alternative. This hypothesis is supported by excursions discussed in this monograph, but it should be examined more carefully.

Inventories of Mission Packages

We recommend inventory levels of mission packages for the short, middle, and long term as summarized in Table 8.1. We refer the reader to Table 5.1 for the specific quantities to be installed on available seaframes or stored ashore in the short term, Table 5.2 for the middle term, and Table 5.3 for the long term.

Table 8.1
Mission Package Inventories in the Short Term, Middle Term, and Long Term

Time Period	ASW	MIW	SUW
Short term (by 2014)	20	27	42
Middle term (by 2019)	23	31	50
Long term (by 2024)	28	38	60

NOTES: Inventory levels depend on the operational availability, which is defined as the fraction of time that mission packages are available for mission use. Operational availability estimates for mission packages were not available at the time of this study. The inventory levels in this table assume that the operational availability of mission packages is 0.9. The numbers will need to be adjusted for different estimates of operational availability. For instance, if the operational availability is estimated to be *x,* then each number in the table should be multiplied by 0.9/*x*.

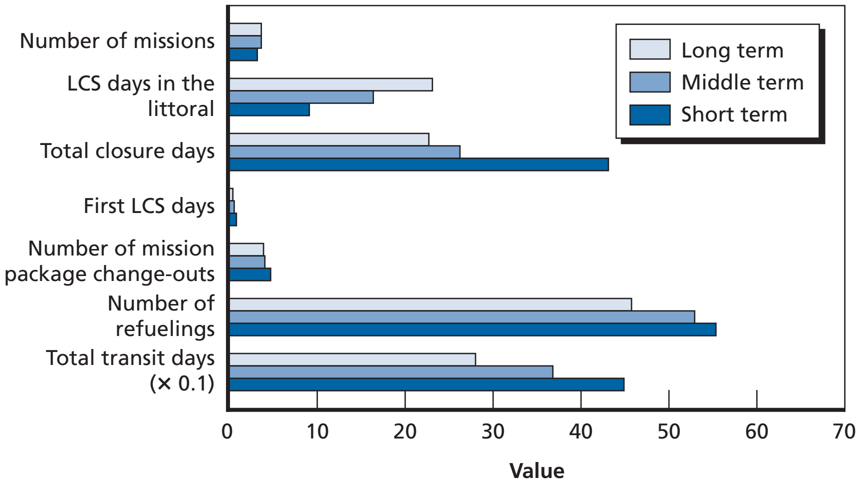
Theater Transit Times

We associated performance metrics with our suggestions for the short, middle, and long term. These metrics, including theater closure times, are shown in Figure 8.1.

Costs and Schedule of Acquisitions

The total costs of facility construction for homeports and installation sites and of procuring mission packages and VTUAVs for the short, middle, and long term are shown in Figure 8.2.

Figure 8.1
Performance Metrics for Short-, Middle-, and Long-Term Solutions



NOTES: The metric values for the middle term and long term assume scenarios involving one MCO simultaneously occurring with three non-MCOs. There is an insufficient number of LCSs in the short term to satisfy scenarios involving one MCO simultaneously occurring with three non-MCOs. The metric values for the short term assume scenarios involving one MCO simultaneously occurring with an average of 2.4 non-MCOs.

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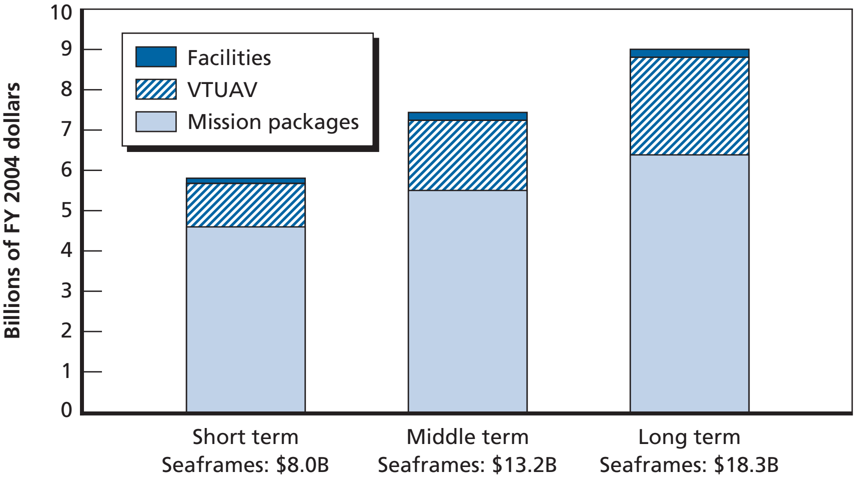
One possible schedule for acquiring the inventories of mission packages and VTUAVs identified by our analysis is shown in Figure 8.3. The figure suggests rapid acquisition of mission packages in the short term, with the rate of acquisition declining in later years. This schedule reflects that the ratio of available mission packages per available seaframe is 2.5 in the short term, declines to 2.2 in the middle term, and further declines to 1.9 in the long term. That is, many mission packages per seaframe are needed early in the program when there are few seaframes. On the other hand, few mission packages per seaframe are needed late in the program when there are many seaframes. This program acquires a slight surplus of mission packages in the middle term to maintain production rates for the long term. The reason for this surplus is to avoid having to increase the production rate when transitioning from the middle to the long term.

Figure 8.2
Estimated Cumulative Procurement and Facility Construction Costs for the Short Term, Middle Term, and Long Term



NOTES: Inventory levels depend on the operational availability, which is defined as the fraction of time that mission packages are available for mission use. Operational availability estimates for mission packages were not available at the time of this study. The inventory levels in this figure assume that the operational availability of mission packages is 0.9. The numbers will need to be adjusted for different estimates of operational availability. For instance, if the operational availability is estimated to be *x*, then each number in the table should be multiplied by 0.9/*x*.
RAND *MG528-8.2*

The annual procurement costs associated with the acquisition schedule of Figure 8.3 are shown in Figure 8.4.

An annual cost stream for the costs of constructing facilities for homeports and installation sites is shown in Figure 8.5. This cost stream frontloads construction based on the long-term mission package storage needs rather than on incremental needs that may not be cost-effective.

Figure 8.3
One Possible Acquisition Schedule for Mission Packages and VTUAVs

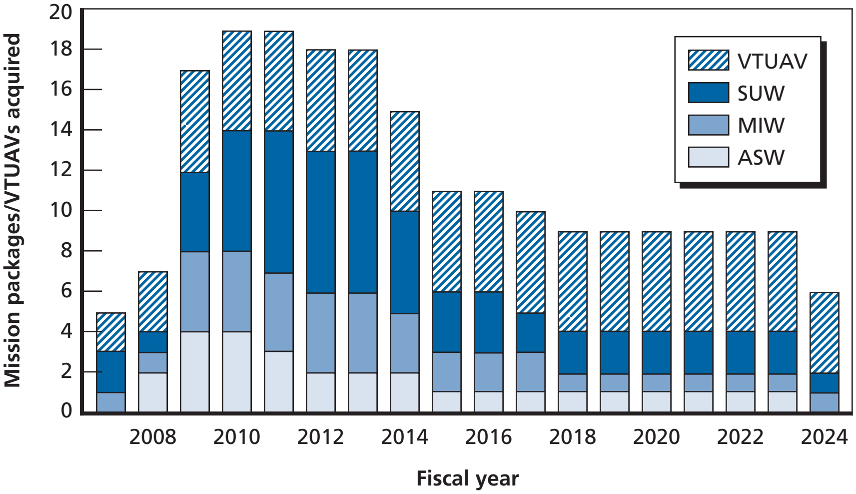


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Figure 8.4
Annual Procurement Costs for Mission Packages and VTUAVs

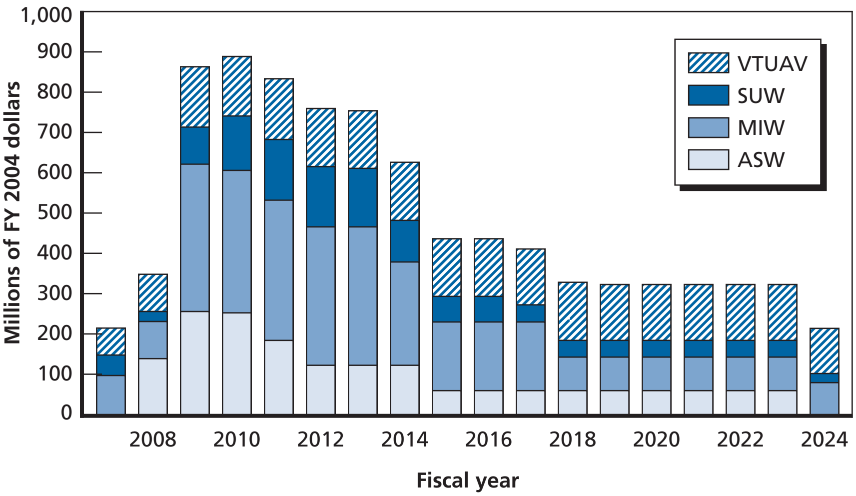

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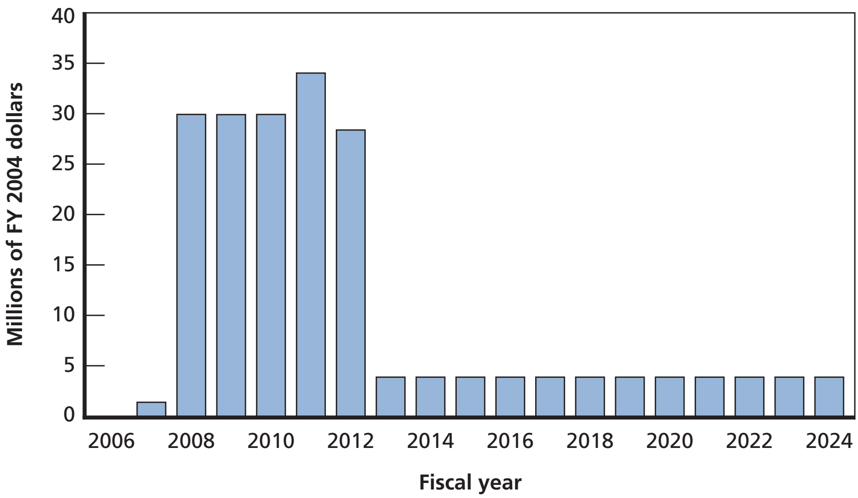
Figure 8.5
Annual Costs of Constructing Facilities for Homeports and Installation Sites



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Emerging Issues

This study provides the first quantitative evaluation of the best locations for homeports and installation sites and the inventories of mission packages by type to be stored at those locations and on available seaframes. Clearly, our results hinge on our assumptions, including our scenarios. In Chapters Four, Five, and Six, we provided some analysis of the sensitivity of the results to our assumptions. There is no doubt that assumptions will change as the LCS program evolves. It is our hope that the tools and methodologies described in this monograph provide a clear and rapid means for evaluating potential changes as the LCS program moves forward.

We did not evaluate means of refueling or replenishing LCSs at sea during our study; it was beyond our charter. However, our study highlights the large demand that the LCS fleet may place upon assets to provide refueling and replenishment and highlights the need to align fleet logistics with LCS CONOPS. We feel that this issue warrants careful consideration and hope that our work provides a quantitative basis for the demand of assets to provide refueling and replenishment of LCSs at sea.

The study was conducted while mission packages were still in development. Decisions about the exact makeup of mission packages appeared to be in flux, and the Navy was considering making some mission modules and mission package components organic to the seaframe rather than as part of a mission package. For this reason, we treated mission packages as a whole in this study and did not consider logistical and operational implications of individual mission modules. Also, we did not evaluate the personnel and helicopter components of mission packages. Modeling performance under a budget constraint was also beyond the scope of the current study, but the trade-offs between performance and budget constraints could be addressed in the future with extensions of the LCSTSM. We recommend that the operational, logistical, and cost implications of these mission modules and components be evaluated as decisions are made, and we believe that the methodologies described in this monograph might serve as a framework for those evaluations.

Our study assumed that all seaframes could operate with all mission packages, which was consistent with U.S. Navy planning at the time of the study. However, it is probable that there will be upgrades and modernization efforts that may pose challenges for maintaining compatibility. We note that the methodology developed in this study can accommodate differences in compatibility between seaframes and mission packages should this issue need to be addressed in the future.

APPENDIX A

Mathematical Details of the LCS Transshipment Model

In this appendix, we provide mathematical details of the LCSTSM. The reader will require some familiarity with linear programming. The necessary background information is available in standard textbooks on optimization (for instance, see Luenberger, 1989, or Bertsimas and Tsitsiklis, 1997).

We begin by providing a formulation of LCSTSM as a mixed-integer linear program. We then provide a formula for evaluating transit times of LCSs and strike groups.

Mixed Integer Programming Formulation of LCSTSM

Let $m^{(L)}$ denote the number of LCS supply sites, numbered 1 through $m^{(L)}$. Similarly, let $m^{(C)}$ denote the number of CSG supply sites and $m^{(E)}$ denote the number of ESG supply sites. Let there be n mission package installation sites, and p demand sites for LCSs or strike groups. Let $x_{i,j,k}^{(L)}$ denote the number of LCSs routed from LCS supply site i, to installation site j, and to demand site k for $i = 1, \ldots, m^{(L)}$; $j = 1, \ldots, n$; $k = 1, \ldots, p$. Let $x_{i,0,k}^{(L)}$ denote the number of LCSs routed directly from LCS supply site i to demand site k without stopping at an installation site, for $i = 1, \ldots, m^{(L)}$; $k = 1, \ldots, p$. Similarly, let $x_{i,k}^{(C)}$ denote the number of CSGs routed from CSG supply site i, to demand site k for $i = 1, \ldots, m^{(C)}$; $k = 1, \ldots, p$, and let $x_{i,k}^{(E)}$ denote the number of ESGs routed from ESG supply site i, to demand site k for $i = 1, \ldots, m^{(E)}$; $k = 1, \ldots, p$.

Let q denote the number of possible mission package configurations, numbered $1, \ldots, q$. Let $I(l)$ denote the set of LCS supply sites that are associated with mission package configuration l for $l = 1, \ldots, q$. Similarly, let $\overline{K}(l)$ denote the set of demand sites *not* associated with mission package configuration l for $l = 1, \ldots, q$.

Denote an upper bound on the number of mission package configurations of type l that may be performed at installation site j as $a_{j,l}$ for $j = 1, \ldots, n$ and $l = 1, \ldots, q$. Denote an upper bound on the total number of LCSs that may transit through installation site j as b_j for $j = 1, \ldots, n$.

Let $d_k^{(L)}$ denote the number of LCSs required at LCS demand site k for $k = 1, \ldots, p$. Similarly, let $d_k^{(C)}$ denote the number of CSGs required at CSG demand site k for $k = 1, \ldots, p$, and let $d_k^{(E)}$ denote the number of ESGs required at ESG demand site k for $k = 1, \ldots, p$. Without loss of generality, we assume that the supply of available LCSs equals the demand for LCSs, the supply of available CSGs meets the demand for CSGs, and the supply of available ESGs meets the demand for ESGs.[1]

Let $t_{i,j,k}^{(L)}$ denote the transit time in days for an LCS departing from LCS supply site i, transiting through installation site j for mission package reconfiguration, and arriving at LCS demand site k for $i = 1, \ldots, m^{(L)}$; $j = 1, \ldots, n$; $k = 1, \ldots, p$. Let $t_{i,0,k}^{(L)}$ denote the transit time in days for an LCS departing from LCS supply site i and steaming directly to LCS demand site k, without a stop for mission package reconfiguration, for $i = 1, \ldots, m^{(L)}$; $k = 1, \ldots, p$. Similarly, let $t_{i,k}^{(C)}$ denote the transit time in days for a CSG departing from CSG supply site i and steaming directly to CSG demand site k for $i = 1, \ldots, m^{(C)}$; $k = 1, \ldots, p$, and let $t_{i,k}^{(E)}$ denote the transit time in days for an ESG departing from ESG supply site i and steaming directly to ESG demand site k for $i = 1, \ldots, m^{(E)}$; $k = 1, \ldots, p$.

---

1 If demand exceeds supply, then the demands can be prioritized and lower-priority demands disregarded. If supply exceeds demand, then we can create a "dummy" demand site to take up the excess supply.

The LCSTSM problem is formulated as follows:

$$\text{minimize } \; ws + \sum_{k=1}^{p}\left(\sum_{i=1}^{m^{(L)}}\sum_{j=0}^{n} t_{i,j,k}^{(L)} x_{i,j,k}^{(L)} + \sum_{i=1}^{m^{(C)}} t_{i,k}^{(C)} x_{i,k}^{(C)} + \sum_{i=1}^{m^{(E)}} t_{i,k}^{(E)} x_{i,k}^{(E)}\right)$$

subject to:

$$t_{i,j,k}^{(L)} x_{i,j,k}^{(L)} \le s,\; i=1,\ldots,m^{(L)}; j=0,\ldots,n; k=1,\ldots,p$$

$$t_{i,k}^{(C)} x_{i,k}^{(C)} \le s,\; i=1,\ldots,m^{(C)}; k=1,\ldots,p$$

$$t_{i,k}^{(E)} x_{i,k}^{(E)} \le s,\; i=1,\ldots,m^{(E)}; k=1,\ldots,p$$

$$x_{i,j,k}^{(L)} \in \{0,1\},\; i=1,\ldots,m^{(L)}; j=0,\ldots,n; k=1,\ldots p$$

$$x_{i,k}^{(C)} \in \{0,1\},\; i=1,\ldots,m^{(C)}; k=1,\ldots p$$

$$x_{i,k}^{(E)} \in \{0,1\},\; i=1,\ldots,m^{(E)}; k=1,\ldots p$$

$$x_{i,0,k}^{(L)} = 0,\; i \in I(l); k \in \bar{K}(l); l=1,\ldots,q$$

$$\sum_{i=1}^{m^{(L)}} \sum_{k \in K(l)} x_{i,j,k}^{(L)} \le a_{j,l},\; j=1,\ldots,n; l=1,\ldots,q$$

$$\sum_{i=1}^{m^{(L)}} \sum_{k=1}^{p} x_{i,j,k}^{(L)} \le b_j,\; j=1,\ldots,n$$

$$\sum_{j=0}^{n} \sum_{k=1}^{p} x_{i,j,k}^{(L)} = 1,\; i=1,\ldots,m^{(L)}$$

$$\sum_{k=1}^{p} x_{i,k}^{(C)} = 1,\; i=1,\ldots,m^{(C)}$$

$$\sum_{k=1}^{p} x_{i,k}^{(E)} = 1,\; i=1,\ldots,m^{(E)}$$

$$\sum_{i=1}^{m^{(L)}} \sum_{j=0}^{n} x_{i,j,k}^{(L)} = d_k^{(L)},\; k=1,\ldots,p$$

$$\sum_{i=1}^{m^{(C)}} x_{i,k}^{(C)} = d_k^{(C)},\; k=1,\ldots,p$$

$$\sum_{i=1}^{m^{(E)}} x_{i,k}^{(E)} = d_k^{(E)},\; k=1,\ldots,p.$$

The problem variables are the quantities $x^{(L)}_{i,j,k}, x^{(C)}_{i,k}, x^{(E)}_{i,k}$ and the auxiliary variable *s*. The problem data are the objective function weight parameter *w*, the transit time parameters $t^{(L)}_{i,j,k}, t^{(C)}_{i,k}, t^{(E)}_{i,k}$, the sets $I(l)$, $\bar{K}(l)$, the upper bounds $a_{j,l}, b_j$, and the demand parameters $d^{(L)}_k, d^{(C)}_k, d^{(E)}_k$. We used an objective weight value of $w = 1{,}000$. As a result, the primary objective of the model is to minimize total closure time, which is defined as the time for all assets to reach the demand sites. The secondary objective is to minimize the sum of the transportation times.

A Formula for Evaluating Transit Times of LCSs and Strike Groups

In this section, we provide formulas for evaluating the transit time parameters $t^{(L)}_{i,j,k}, t^{(C)}_{i,k}, t^{(E)}_{i,k}$.

Let $\gamma^{(L)}$ denote the average number of hours required for underway refueling of an LCS. Let $\gamma^{(C)}$ denote the average number of hours required for underway refueling of a CSG, and let $\gamma^{(E)}$ denote the average number of hours required for underway refueling of an ESG. Let $\alpha_i^{(L)}$ denote the number of days required for the LCS to get under way from LCS supply site *i* for $i = 1, \ldots, m^{(L)}$. Let $\alpha_i^{(C)}$ denote the number of days required for the CSG to get under way from CSG supply site *i* for $i = 1, \ldots, m^{(C)}$, and let $\alpha_i^{(E)}$ denote the number of days required for the ESG to get under way from ESG supply site *i* for $i = 1, \ldots, m^{(E)}$. Let $\mu_i^{(1)}$ denote the mission package removal time (i.e., the time required to remove a mission package) in days for the LCS originating from LCS supply site *i*. Let $\mu_k^{(2)}$ denote the mission package installation time (not including the time to remove an existing mission package) in days for LCSs required at demand site *k*. Let $\delta_{i,j}^{(1)}$ denote the sailing distance in nautical miles between the LCS supply site *i* and the installation site *j*. Let $\delta_{j,k}^{(2)}$ denote the sailing distance in nautical miles between the installation site *j* and the demand site *k*. Let $\delta_{i,k}^{(L)}$ denote the sailing distance in nautical miles between the LCS supply site *i* and the LCS demand site *k*. Similarly, let $\delta_{i,k}^{(C)}$ denote the sailing distance in nautical miles between the CSG supply site *i* and the CSG demand site *k*, and let $\delta_{i,k}^{(E)}$ denote the sailing distance in nautical miles between the ESG supply site *i* and the ESG demand site *k*. Let $\sigma_{i,j,k}^{(L)}$ denote the average speed of advance in knots of an LCS originating from LCS supply site *i,* transiting through installation site *j* for mission package reconfiguration and arriving at LCS demand site *k*, for $i = 1, \ldots, m^{(L)}$; $j = 1, \ldots, n$; $k = 1, \ldots, p$. Let $\sigma_{i,0,k}^{(L)}$ denote the average speed of advance in knots of an LCS originating from supply site *i* and steaming directly to LCS demand site *k,* for $i = 1, \ldots, m^{(L)}$; $k = 1, \ldots, p$. Similarly, let $\sigma_{i,k}^{(C)}$ denote the average speed of advance in knots of a CSG originating from CSG supply site *i* and steaming directly to CSG demand site *k,* and let $\sigma_{i,k}^{(E)}$ denote the average speed of advance in knots of an ESG originating from ESG supply site *i* and steaming directly to ESG demand site *k*. Let $\rho_{i,j,k}$ denote the average range in nautical miles of an LCS originating from supply site *i,* transiting through installation site *j* for mission package reconfiguration, and arriving at LCS demand site *k* for $i = 1, \ldots, m^{(L)}$; $j = 1, \ldots, n$; $k = 1, \ldots, p$. Let $\rho_{i,0,k}^{(L)}$ denote the average range in nautical miles of an LCS originating from supply site *i* and steaming directly to LCS demand site *k,* for $i = 1, \ldots, m^{(L)}$; $k = 1, \ldots, p$. Similarly, let $\rho_{i,k}^{(C)}$ denote the average range in nautical miles of a CSG originating from CSG supply site *i* and steaming directly to CSG demand site *k,* and let $\rho_{i,k}^{(E)}$ denote the average range in nautical miles of an ESG originating from ESG supply site *i* and steaming directly to ESG demand site *k.* The transit times for LCSs are evaluated as

$$t_{i,j,k}^{(L)} = \alpha_i^{(L)} + \left(\frac{\delta^{(L)}{}_{i,k}}{\sigma_{i,j,k}^{(L)}} + \left\lfloor \frac{\delta^{(L)}{}_{i,k}}{\rho_{i,j,k}^{(L)}} \right\rfloor \gamma^{(L)} \right) \frac{1}{24}$$

for $j = 0$, and

$$t_{i,j,k}^{(L)} = \alpha_i^{(L)} + \left(\frac{\delta^{(1)}{}_{i,j} + \delta^{(2)}{}_{j,k}}{\sigma_{i,j,k}^{(L)}} + \left(\left\lfloor \frac{\delta^{(1)}{}_{i,j}}{\rho_{i,j,k}^{(L)}} \right\rfloor + \left\lfloor \frac{\delta^{(2)}{}_{j,k}}{\rho_{i,j,k}^{(L)}} \right\rfloor \right) \gamma^{(L)} \right) \frac{1}{24}$$
$$+ \mu^{(1)}{}_i + \mu^{(2)}{}_k$$

for $i = 1, \ldots, m^{(L)}$; $j = 1, \ldots, n$; and $k = 1, \ldots, p$. The transit times for CSGs are evaluated as

$$t_{i,k}^{(C)} = \alpha_i^{(C)} + \left(\frac{\delta^{(C)}{}_{i,k}}{\sigma_{i,k}^{(C)}} + \left\lfloor \frac{\delta^{(C)}{}_{i,k}}{\rho_{i,k}^{(C)}} \right\rfloor \gamma^{(C)} \right) \frac{1}{24}$$

for $i = 1, \ldots, m^{(C)}$ and $k = 1, \ldots, p$. The transit times for ESGs are evaluated as

$$t_{i,k}^{(E)} = \alpha_i^{(E)} + \left(\frac{\delta^{(E)}{}_{i,k}}{\sigma_{i,k}^{(E)}} + \left\lfloor \frac{\delta^{(E)}{}_{i,k}}{\rho_{i,k}^{(E)}} \right\rfloor \gamma^{(E)} \right) \frac{1}{24}$$

for $i = 1, \ldots, m^{(E)}$ and $k = 1, \ldots, p$.

APPENDIX B

LCS Investment Cost Analysis

Introduction

This appendix describes the cost factors and cost estimating relationships used to evaluate options in this study. We did not use a complete life-cycle cost or total ownership cost approach to analysis, but rather we took an ad hoc look at the significant costs involved in trading the alternatives under study. For the most part, this information was developed with the support of NAVSEA. However, the final product is completely our own. Costs are put into FY 2004 dollars, consistent with the LCS Selected Acquisition Report baseline year. In the following, we present the cost breakdown structure and the cost factor development for seaframes, mission packages, and facilities.

Cost Breakdown Structure

This is a *trade* study, and as such there are many elements of cost that are not affected by the variables under analysis. We have chosen the primary cost elements relevant to the study and present them in Table B.1.

Table B.1
LCS Abbreviated Cost Breakdown Structure

Level 1	Level 2
Seaframe	
Mission packages	
	Common (VTUAV)
	MIW
	ASW
	SUW
Mission package facilities	
	Homeports
	Forward sites
Homeport development	(Guam)

Seaframe Cost Factor Development

SEA O17[1] provided a nominal seaframe cost of $220 million in FY 2004 dollars for 56 units and indicated that a 95 percent learning curve on labor would be appropriate. We are assuming that this percentage is a unit learning curve relative to the first unit.[2] Labor accounted for 60 percent of seaframe construction costs, and material accounted for 40 percent of seaframe construction costs. From this information, we can estimate the cumulative seaframe production cost as

$$C_{SF} = 144 Q_{SF}^{\ 0.963} + 96 Q_{SF},$$

1 SEA O17 refers to the Cost Engineering & Industrial Analysis organization of Naval Sea Systems Command.

2 Personal communication with Virginia Lustre, NAVSEA 017, September 27, 2005.

where C_{SF} denotes the cumulative seaframe production cost in millions of FY 2004 dollars and Q_{SF} equals the cumulative quantity of seaframes produced.

Mission Package Cost Factor Development

Table B.2 shows mission package costs as provided to us in a Program Executive Officer (PEO) littoral and mine warfare briefing (Carson-Jelley, 2006). We assume that these amounts refer to the costs of the first unit.

We applied U.S. Navy inflation factors to mission package procurement costs (Naval Center for Cost Analysis, 2005). In particular, the FY 2007 OPN (other procurement Navy) inflation factors were applied to MIW and SUW mission packages, and FY 2006 research, development, test, and evaluation inflation factors were applied to ASW mission packages. However, an exception was made for common equipment, for which the value used for ASW mission packages was held equal to the value used for MIW and SUW mission packages as a whole. The inflation-factor values we used are specified in Table B.3.

Learning-curve factors were not available for mission packages. We applied a 95 percent unit learning curve to the first unit costs specified in Table B.2.

Table B.2
Costs of the First Unit for Mission Packages (in millions of FY 2004 dollars)

	MIW	ASW	SUW
Common modules	34.0	34.0	34.0
Unique modules	20.9	25.0	6.7
Unique mission systems	75.9	29.6	14.9
Other	3.3	16.1	2.9
Total	134.1	104.7	58.6

Table B.3
Inflation Factors Applied to Mission Package Procurement Costs

MIW	ASW[a]	SUW
1.0872	1.053	1.0872

SOURCE: Naval Center for Cost Analysis, 2005.

[a] This inflation factor was applied to all ASW cost elements except for common equipment. An inflation factor of 1.0872 was applied to ASW common equipment.

The common component of the mission packages is the VTUAV. It will be configured with different sensors for the various missions. However, we are assuming that the base package of three VTUAV airframes stays with the seaframe. Thus, if one of each of the mission packages is procured, then only one set of three VTUAVs would be procured.

VTUAVs will have many applications, so the calculation of learning effects is approximate at best. We conservatively assume that the VTUAVs will follow a 95 percent learning curve, with a first unit cost of $34.0 million in FY 2004 dollars. The cumulative cost of VTUAVs may then be expressed as

$$C_V = 34.0 {Q_{SF}}^{0.963},$$

where C_V denotes the cumulative cost in millions of FY 2004 dollars.

The cumulative cost of the unique mission systems and components of MIW mission packages can be expressed as

$$C_M = 100.1 {Q_M}^{0.963},$$

where C_M denotes the cumulative cost in millions of FY 2004 dollars and Q_M is the cumulative quantity of MIW mission packages procured.

The cumulative cost of the unique mission systems and components of SUW mission packages can be expressed as

$$C_S = 24.6 Q_S^{0.963},$$

where C_S denotes the cumulative cost in millions of FY 2004 dollars and Q_S is the cumulative quantity of SUW mission packages procured.

The cumulative cost of the unique mission systems and components of ASW mission packages can be expressed as

$$C_A = 70.7 Q_A^{0.963},$$

where C_A denotes the cumulative cost in millions of FY 2004 dollars and Q_A is the cumulative quantity of ASW mission packages procured.

Facility Construction Cost Factor Development

LCS facility costs were provided to us by NAVFAC in the form of a briefing provided by the commander of Naval Installations (Ludovici, 2005). We also drew upon the FY 2005 Navy Military Construction Program for the costs associated with security for some sites and for construction costs associated with a homeport in Guam.

Mission Package Storage Facilities

The NAVFAC briefing specifies four homeports and four forward installation sites by FY 2020. The homeport facility sizes specified in that briefing are shown in Table B.4.

The NAVFAC briefing specifies that the first two homeports will be Naval Station San Diego and Naval Air Base Little Creek. Existing facilities at these two locations will provide some of the above requirements. In FY 2008 "military construction" funding, $14.7 million in FY 2008 dollars has been requested for San Diego. This amount equates to $13.1 million in FY 2004 dollars. In addition, $12.08 million in FY 2008 dollars was requested for Little Creek. This amount equates to $10.8 million in FY 2004 dollars. A "work-around" of $1.5 million in FY 2006 dollars was approved in FY 2006 for unspecified "minor construction" in support of initial basing in FY 2007. This amount equates

Table B.4
LCS Homeport Facilities per NAVFAC (in square feet)

Facility	Building Size	Parking
LCS support facility	19,219	30,800
Module support facility (for 12 mission packages)	45,900	10,500
Maritime support detachment	3,688	5,250
Training facilities	TBD	TBD
Regional distance support center	TBD	TBD

NOTE: TBD = to be determined.

to $1.4 million in FY 2004 dollars. The other two homeports will most likely also have existing facilities that can be converted to LCS use.

Our basing solutions produce mission package storage requirements that are not equal to the capacity of the "module support facility" specified by NAVFAC, which has a capacity of 12 mission packages. Therefore, we have parameterized the cost estimate for mission package installation sites in the continental United States (CONUS) as

$$C_{CONUS} = 2 + MP,$$

where C_{CONUS} is the estimate in millions of FY 2004 dollars and MP is the quantity of mission packages stored there.

NAVFAC specified mission package forward facilities (MPFFs) that will serve as mission package installation sites outside the continental United States (OCONUS). They are being sized for the storage of three mission packages. Storage of double-stacked 20-foot containers will be indoors, and administrative areas for a six-man working team will be provided. The total building structure will be 11,850 square feet. Parking space at the facility will be 1,400 square feet. There will also be 15,000 square feet of uncovered operating apron. Based on building structure, this amount is less than 20 percent of the space for homeport facilities.

Our basing solutions produce mission package storage requirements at installation sites that are not equal to the planned capacity of the MPFFs, which is three mission packages. Our estimated storage requirements for OCONUS installation sites are not multiples of the planned facilities. Instead, we parameterize the facility cost and take into account the cost of overseas construction, using the fact that Guam has an area cost construction factor of 2.02. Therefore, we have parameterized the cost estimate for an MPFF as

$$C_{MPFF} = 4 + 2MP,$$

where C_{MPFF} is the estimate in millions of FY 2004 dollars.

Security Facilities

In some cases, such as Singapore, there will not be a U.S. facility available on which to erect the MPFF. In these cases, additional security investment will be required. As a basis for analogy, the FY 2005 Navy Military Construction Program has the projects shown in Table B.5.

The average cost of the projects in Table B.5 is $3.3 million in FY 2005 dollars. Our planning factor for ad hoc overseas security facilities is $5.0 million in FY 2004 dollars. The operations and support impact for the security force will be on the order of $3–$5 million per year in

Table B.5
Fiscal-Year 2005 Navy Military Construction Program Project Costs (in millions of FY 2005 dollars)

Project	Cost
Gate 5 Security at Norfolk, VA	$4.33
Post 2 Security at Oceana, VA	$2.77
Gate 5 Security at Little Creek, VA	$2.85

FY 2005 dollars. The center point of this range results in a discounted present value of $60 million in FY 2004 dollars for services through 2024.[3]

Homeport Investment

Japan and Guam are two of the homeport options we have considered that would accommodate four LCSs. For Japan, where we have a major naval presence, we are assuming that existing facilities or host country investment will support the LCSs.[4] Guam, however, only supports three submarines, a tender, and a few Military Sealift Command ships. We are assuming that other existing facilities are obsolete and will require replacement.

For the cost of bachelor enlisted quarters construction, we drew upon the data shown in Table B.6.

The average cost per room from the information in Table B.6 is $110,000 in FY 2005 dollars. We estimated that on the order of 200 rooms would be required in Guam. Applying the Area Construction Cost Index of 2.02 and converting to FY 2004 dollars, we estimated the cost of constructing bachelor enlisted quarters in Guam as approximately $50.0 million in FY 2004 dollars.

Table B.6
Bachelor Enlisted Quarters Construction Data

Location	Number of Rooms	Construction Cost[a]
Arizona	150	$18.74
North Carolina	216	$20.78
Virginia	130	$15.09

[a] In millions of FY 2005 dollars.

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3 In accordance with Office of Management and Budget Circular No. A-94, Appendix C, revised January 2005, 20-year security operations and support funding is discounted at a real rate of 2.8 percent, which is the average of the 10-year rate (2.5 percent) and the 30-year rate (3.1 percent).

4 A homeport in Japan may require increasing the U.S. footprint in Japan. This possibility and any associated political concerns will have to be carefully considered.

For the cost of pier construction in Guam, we drew upon the data shown in Table B.7.

We estimated that the pier requirements for LCSs would exceed those required for T-AOEs, but would be significantly less than those required for CVNs, and probably around $50 million in FY 2005 dollars if constructed in CONUS. Applying the Area Construction Cost Index of 2.02 and converting to FY 2004 dollars, we estimated the cost of constructing the required pier in Guam as approximately $100.0 million in FY 2004 dollars.

For the cost of constructing an operations center in Guam, we noted that the cost of an 11,000 square-foot operations center in Louisiana was $4.9 million in FY 2005 dollars. Applying the Area Construction Cost Index of 2.02 and converting to FY 2004 dollars, we estimated the cost of constructing the required operations center in Guam as approximately $10.0 million in FY 2004 dollars.

For the cost of constructing a maintenance shop in Guam, we noted that the cost of a 50,000 square-foot maintenance shop in Virginia was $9.87 million in FY 2005 dollars. Applying the Area Construction Cost Index of 2.02 and converting to FY 2004 dollars, we estimated the cost of constructing the required maintenance shop in Guam as approximately $20.0 million in FY 2004 dollars.

A summary of the construction cost of facilities for an LCS homeport in Guam, including an assumed margin of $20 million in FY 2004 dollars, is shown in Table B.8. The total construction cost is estimated to be $200.0 million in FY 2004 dollars.

Table B.7
CONUS Pier Construction Cost Data (in millions of FY 2005 dollars)

Pier Use	Construction Cost
Submarines (64 feet by 496 feet)	28.8
T-AOEs	45.0
CVNs	137.5

Table B.8
Construction Costs for Homeport in Guam (in millions of FY 2004 dollars)

Item	Construction Cost
Bachelor enlisted quarters	50.0
Piers	100.0
Operations center	10.0
Maintenance shop	20.0
Margin	20.0
Total	200.0

APPENDIX C

LCS Performance Assumptions

Our primary source of information for the performance of an LCS as it relates to our study is the Capabilities Development Document (CDD) for Flight 0 (NAVSEA Systems Command, 2004, and NAVSEA Systems Command N76 and N7, 2003). Our baseline assumption is that the LCS will meet the average of the threshold and objective-level performance specified in the CDD. This information is summarized in Table C.1.

We assumed that the fuel remaining would not drop below 20 percent. We also assumed that UNREP would take place whenever the

Table C.1
Threshold, Objective, and Average Seaframe Performance Levels as Specified in CDD for Flight 0

Category	Threshold Level	Objective Level	Average
Sprint speed at full load displacement in sea state 3	40 knots	50 knots	45 knots
Range at sprint speed	1,000 nautical miles	1,500 nautical miles	1,250 nautical miles
Economical speed at full load displacement in sea state 3	18 knots	20 knots	19 knots
Range at economical speed	3,500 nautical miles	4,300 nautical miles	3,900 nautical miles
Time for mission package change-out to full operational capability including system operational testing	4 days	1 day	2.5 days

LCS undergoes fueling at sea. Hence, UNREP and fueling at sea are synonymous in this study.

We split the 2.5 days for mission package change-out to full operational capability including system operational testing as specified in Table B.1 into two parts: 1.25 days to remove an existing mission package and 1.25 days to install a new mission package.

We assumed that the LCS can transit at sprint speed for moderate distances. We also assumed that the average transit speed would decline at longer distances because of such factors as crew fatigue, the need to periodically perform air vehicle operations, the greater chance of encountering unfavorable weather conditions, and transiting areas of considerable shipping traffic. Therefore, at longer distances, we assumed that the transit speed approaches the average of the sprint and economical speeds. Specifically, we assumed that the average transit speed declines from the sprint speed of 45 knots at a constant rate for distances up to 2 × 3,900 = 7,800 nautical miles (nm), and then levels off to (45 + 19)/2 = 32 knots. In summary, the average transit speed s in knots as a function of the distance d in nautical miles is given by the equation

$$s = \begin{cases} 45 - \dfrac{45-32}{7,800}d & 0 < d \leq 7,800 \\ 32 & d \geq 7,800 \end{cases}.$$

The average transit speed as a function of the distance is shown graphically in Figure C.1.

We used the official U.S. Navy estimates summarized in Table C.1 for range at the economical and sprint speeds, and we assumed that the range is a linear function between the economical and sprint speeds.[1] We also assumed that the range is fixed at the economical range for speeds lower than the economical speed. Specifically, we assumed that the range at a transit speed of 45 knots is 1,250 nm and the range at

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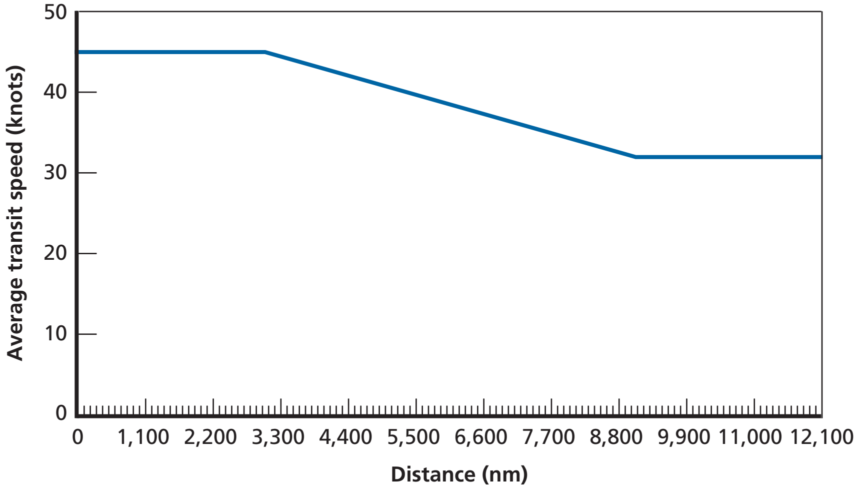
1 We recognize that range is typically not a linear function of speed. However, we had no data to base an assumption upon other than the range at two values of transit speed.

Figure C.1
Average Transit Speed as a Function of Distance



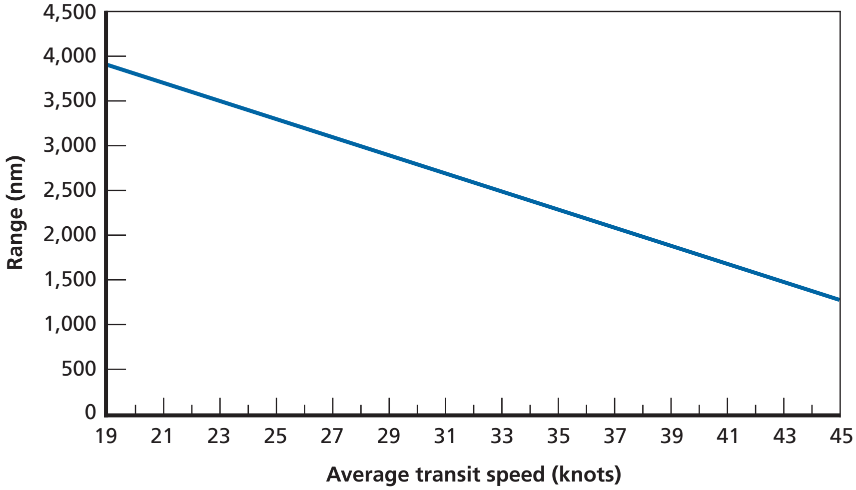
RAND *MG528-C.1*

a speed of 19 knots is 3,900 nm. These assumptions are in agreement with the values given in Table B.1. We assumed that the range declines in a linear fashion for average transit speeds between 45 and 19 knots. In summary, the range *r* in nautical miles as a function of the average transit speed *s* in knots is given by the equation

$$r = \begin{cases} 5{,}836.54 - 101.92 \times s & 19 \le s \le 45 \\ 3{,}900 & 0 < s < 19 \end{cases}.$$

The range as a function of the average transit speed is shown graphically in Figure C.2.

Figure C.2
Range as a Function of Average Transit Speed



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APPENDIX D

Navy Special Operations Forces Perspective on LCS

This appendix provides a summary of the Navy SOF perspective on LCS. It is a synopsis of a course paper for the John F. Kennedy School of Government, Harvard University, authored by Navy SEAL LCDR Mike Hayes (2005) while he was on assignment at RAND.

For Navy SOF, a surface ship provides a capability that may be used for tasks ranging from serving as a mother ship for mission planning, rest, and recovery; to supporting the insertion, extraction, and logistics for medium and small SOF boats (less than 85 feet); to serving as a central command and control station for all communications and phases of an SOF mission; to providing air support if embarked aboard the vessel.

SOF are self-contained, bring their own gear and equipment on board, and can be looked at as their own mission module. SOF will use the LCS as a surface warfare ship and will not be reliant on any antisurface, submarine, or mine modules for mission success. The baseline LCS should be able to accomplish key tasks, such as the ability to launch and recover small boats, provide gasoline for these boats, provide work spaces for SOF to plan their missions, serve as a communications base station, and provide storage space for equipment, weapons, and ammunition. None of these tasks requires a mission module plug-in, and it is not cost-effective to procure something that is not greatly needed.

Depending on the final capacity of the LCS to carry troops, it may eventually be effective to create a simple SOF module that provides more space for berthing, mission planning, and equipment storage. Whether it is effective or not will need to be determined once the baseline design and operational characteristics are finalized.

The speed of the LCS, her ability to launch smaller boats used to board noncompliant ships, and the SOF team make [noncompliant] MIOs possible. Projection of power is also clearly enhanced by adding the offensive capabilities of an SOF team to the LCS. The SOF ability to penetrate enemy lines or to strike and depart without enemy knowledge enables the LCS to project power through a means not normally possible. There is a clear niche for the SOF/LCS team across a broad spectrum of naval missions; MIO and offensive power-projection missions are just two examples in which SOF and the LCS will be able to work in conjunction supporting the missions of the Navy and the joint force commander.

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