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Recapitalization of Amphibious Operation and Lift

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CAPSTONE PROJECT REPORT

RECAPITALIZATION OF AMPHIBIOUS OPERATIONS AND LIFT

by

Systems Engineering and Analysis Cohort 18A and Temasek Defense Systems Institute

June 2012

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The aging Whidbey Island and Harpers Ferry class ships, LSD-41 and 49 respectively, comprise just over one third of the amphibious navy. However, a solution to the capability gap created by the loss of these ships is needed to maintain the effectiveness of the amphibious fleet across a broad spectrum of mission areas. This research effort considers future ship designs and fleet architectures to meet the capability gaps left by the decommissioning of the LSD-41 and 49 class ships. With respect to lift capacity, performance capability, cost, and a risk assessment, the analysis showed the LPD-17 or a LSD(X) approximately 30% larger than the existing classes to be acceptable replacement classes. The analysis also supports further research to determine the most robust fleet architecture apart from the current eleven LHA or LHD, eleven LPD, and eleven LSD paradigm.

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ABSTRACT

The aging Whidbey Island and Harpers Ferry class ships, LSD-41 and 49 respectively, comprise just over one third of the amphibious navy. However, a solution to the capability gap created by the loss of these ships is needed to maintain the effectiveness of the amphibious fleet across a broad spectrum of mission areas. This research effort considers future ship designs and fleet architectures to meet the capability gaps left by the decommissioning of the LSD-41 and 49 class ships. With respect to lift capacity, performance capability, cost, and a risk assessment, the analysis showed the LPD-17 or a LSD(X) approximately 30% larger than the existing classes to be acceptable replacement classes. The analysis also supports further research to determine the most robust fleet architecture apart from the current eleven LHA or LHD, eleven LPD, and eleven LSD paradigm.

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LIST OF ACRONYMS AND ABBREVIATIONS

A_o	Operational Availability
ACE	Aviation Combat Element
AE	Assault Echelon
AoA	Analysis of Alternatives
ARG	Amphibious Ready Group
ATF	Amphibious Task Force
CBA	Capabilities Based Assessment
COCOM	Combatant Commander
CONOPS	Concept of Operations
EDL	Equipment Density List
GCE	Ground Combat Element
HA/DR	Humanitarian Assistance/Disaster Relief
JCIDS	Joint Capabilities Integration and Development System
JHSV	Joint High Speed Vessel
LCAC	Landing Craft Air Cushion
LHA	Amphibious Assault Ship (General Purpose)
LHA(R)	LHA Replacement
LHD	Amphibious Assault Ship (Multi-Purpose)
LPD	Amphibious Transport Dock
LSD	Landing Ship Dock
MAGTF	Marine Air-Ground Task Force
MCO	Marine Corps Order
MEB	Marine Expeditionary Brigade

MEU	Marine Expeditionary Unit
MOE	Measure of Effectiveness
MPF	Maritime Prepositioning Force
MSC	Military Sealift Command
NEO	Noncombatant Evaluation Operations
NSE	Navy Support Element
NSFS	Naval Ship Fire Support
RDT&E	Research, Development Test and Evaluation
ROMO	Range of Military Operations
SAM	Surface to Air Missile
SOC	Special Operations Capable
SSC	Ship to Shore Connector
SSSP	Steady State Security Posture
SSM	Surface to Surface Missile
TLAM	Tomahawk Land Attack Missile
TSC	Theater Security Cooperation
VBSS	Visit, Board, Search, and Seizure

EXECUTIVE SUMMARY

U.S. Naval and Marine Corps planners desire to maintain an amphibious fleet of 33 ships to sustain a 2.0 Marine Expeditionary Brigade (MEB) lift capability and to support Combatant Commander (COCOM) tasking. To support this effort, the Systems Engineering Analysis Cohort 18A was tasked with a recapitalization and analysis of alternatives for the Whidbey Island (LSD-41) class and Harpers Ferry (LSD-49) class ships for its Capstone Project Report. The team was comprised of ten US Navy students, one US Army Intelligence Officer, and 21 civilian and military personnel from the Singaporean Temasek Defense Systems Institute. The team utilized a systems engineering process to investigate the problem space, identify requirements, develop alternative solutions, and compare these alternatives with respect to performance, cost, and risk.

Following the initial research, stakeholder analysis, and functional analysis the team developed six alternative solutions to analyze and compare. The six alternatives posited the replacement of the 12 decommissioning LSD-41 and 49 class ships with:

1. Eleven LPD-17 class ships to take advantage of the existing construction line and learning curves.
2. Eleven LSD(X) clean sheet design ships comparable in size to the existing Whidbey Island class ships.
3. Eleven LSD(XB) clean sheet design ships roughly 30% larger than the existing Whidbey Island class ships.
4. Eleven LPD-17 Flt(X) ships based on the existing San Antonio class hull and modified to increase vehicle capacity and decrease cargo capacity.
5. 4 LHA-8 class ships in addition to the six planned for procurement. This alternative considered an Amphibious Ready Group (ARG) composed of two big-deck ships to evaluate alternative ARG architectures.
6. 19 LPD-17 class ships. This alternative considered an ARG composed of five small-deck ships to evaluate alternative ARG architectures.

These six alternatives varied the ship size, the fleet size, and vehicle capacity against cargo capacity to investigate identified trade spaces.

The alternatives were compared with respect to performance by evaluating lift capability and modeling throughput delivery rates. The six alternatives included seventeen different ARG architectures which were compared against a standard for Marine

Expeditionary Unit (MEU) lift capability. The amphibious fleet as a whole was analyzed for its ability to lift 2.0 MEBs over a thirty year span. Two amphibious missions were modeled to compare throughput performance of the alternatives. A Humanitarian Assistance and Disaster Relief (HA/DR) simulation measured cargo transfer rate and an assault scenario measured troop transfer rate. All options, with the exception of the LSD(X), improved upon the current standard with a significant improvement noted in the all big-deck alternative.

A life-cycle cost estimate (LCCE) was developed for each alternative. A five parameter regression model was developed to determine lead-ship cost for clean sheet designs. The model was validated by comparing predicted costs to actual costs for five previous amphibious class ships. The regressors used were ship beam, crew size, troop capacity, cargo capacity, and landing craft air cushion (LCAC) capacity. Learning curves was applied for follow-on ships and operating and support (O&S) costs added to develop a LCCE. The costs of the six alternatives fell into four tiers with the LSD(X) being the least expensive option and the 19 LPD-17 being the most expensive.

The risk analysis sought to evaluate for threats to ARG and fleet performance, procurement cost, and procurement schedule of the six alternatives. Eighteen risk factors distributed across these three areas were identified and examined. A quantitative value was determined for comparison by assigning subjective likelihood probabilities and consequence factors. Risk mitigation strategies were identified and a best path risk mitigation strategy proposed. The LSD(X) was deemed the riskiest option as it was the least capable ship and represented an unproven, untested design. Alternative 6, the 19 LPD-17 option, was deemed the least risky largely because it increased the size of the amphibious fleet.

By comparing the options with respect to performance, cost, and risk, the team determined the LPD-17 and LSD(XB) to present the most robust alternatives as replacement class ships. However, the analysis also supported the implementation of alternative ARG architectures, and subsequent fleet architecture, apart from the current standard. There is no immediate threat to the 2.0 MEB lift capability or to fleet inventory for COCOM tasking. Further study is recommended to determine the most robust amphibious fleet architecture to support the full amphibious mission set.

I. INTRODUCTION

The American amphibious force has a long and proud history from the Continental Marines' raid of Nassau in the Bahamas in 1776, through the island hopping campaigns of World War II, up to the nation's most recent conflicts in the War on Terror. The vast majority of the world's population lives within 200 miles of the sea and the amphibious force has continuously assured access to these critical coastal areas to support the nation's interests. Though the last large scale amphibious assault occurred during the Korean War, examples of the full range of amphibious missions can be found much more recently. The following cases represent a small sample of the over 100 amphibious operations in the last 20 years:[1]

- The amphibious assault of November 25, 2001, where Task Force 58 composed of two Amphibious Ready Groups / Marine Expeditionary Units (ARG/MEUs) inserted Marines from amphibious ships over 400 miles into southern Afghanistan.
- The amphibious raid of September 9, 2010, by the USS PELELIU ARG/15th MEU which rescued the crew of the MV Magellan Star from armed pirates.
- The amphibious demonstration prior to ground operations in Operation DESERT STORM in which two Marine Expeditionary Brigades (MEBs) were staged off the Kuwaiti coast to distract and deceive Iraqi Forces of the potential for an amphibious assault.
- The amphibious withdrawal in May 1995 of 6,200 United Nations troops from Somalia conducted by a USMC led Task Force.
- The Humanitarian Assistance / Disaster Relief (HA/DR) mission to provide assistance and relief to the Haitian earthquake victims which was conducted in 2010.

While a large-scale forcible entry amphibious assault has a low likelihood of occurrence in the foreseeable future, the amphibious ship force and its missions remain relevant today as demonstrated by their consistent use in the Navy's taskings.

The amphibious fleet is currently comprised of 29 ships divided among seven ship classes. Various criteria have established a target inventory of 33 ships for the force nominally composed of eleven dock landing ships (LSDs), eleven amphibious assault ships

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[1] (Honorable Sean J Stackley, 2011)

(general purpose (LHA) and multi-purpose (LHD)), and eleven amphibious transport docks (LPD). The thirty-year plan for the force prepared by the Congressional Budget Office is displayed in Figure 1.

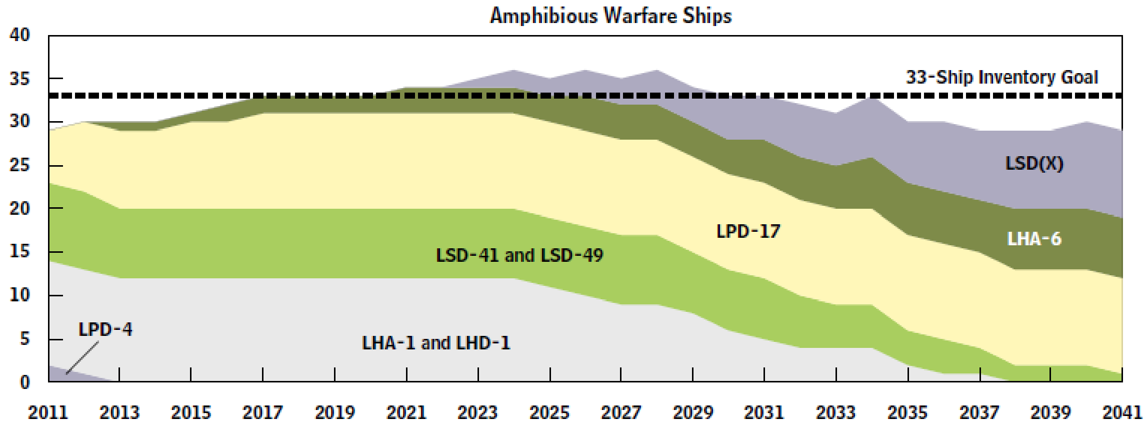

Figure 1. Amphibious Force Inventory (From [2])

The eleventh and final LPD-17 San Antonio Class ship will be completed this year (FY2012) to replace the retiring LPD-4 Austin Class ships. LHA(R) ships are scheduled for procurement beginning in FY2015 with LHA-8. The first of the LSD-41 Whidbey Island class ships is scheduled to leave the service in FY2022 and all Whidbey Island Class and LSD-49 Harpers Ferry Class ships will be retired by FY2039. A replacement class ship, commonly referred to as the LSD(X), is being considered to maintain the desired 33 amphibious ship inventory, however the characteristics of that ship are yet to be determined. This study investigates solutions to the problems posed by the retiring LSD-41 and 49 class ships.

A. TASKING

The tasking statement defined a broad analysis through which to approach the problem. The fundamental assignment is to, "Conduct a recapitalization analysis, including an analysis of alternatives (AoA), for the follow-on ships to LSD-41/49." To this end the following additional tasks were assigned:

- Develop and challenge assumptions concerning amphibious fleet architecture.
- Develop a system-of-systems approach to provide for all amphibious lift missions commensurate with current and reasonably anticipated future needs of the US Navy.

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[2] (Congress, 2011) p.35

- Develop concepts of operations for the examined range of missions.
- Develop alternative fleet architecture for ships, manning, command and control, communications, logistics, and operational procedures.
- Enumerate and evaluate the anticipated technology gaps.
- Produce a coherent vision of amphibious lift missions.
- Identify requirements for support and collaboration with coalition forces and meeting multiple missions.
- Provide a feasible roadmap to improve the effectiveness of amphibious lift ships.

B. APPROACH

The project team rooted the analysis in systems engineering tools and methods. The course of the study was guided by the following questions:

- What are the required capabilities of the amphibious fleet?
- What alternatives provide the needed capabilities?
- Are the alternatives operationally effective and suitable?
- Can the alternatives be supported?
- What are the risks associated with each alternative?
- What are the life-cycle costs for each alternative?
- How do the alternatives compare to one another?

To accomplish the required tasks, the project was organized into three teams. The bulk of the initial effort was dedicated to a Systems Engineering (SE) Team, which performed the requisite work to produce materiel and non-materiel solutions to the problem. A Cost Team and Performance and Effectiveness Team developed models and simulations to be used for the comparison of the alternatives produced by the SE Team. Finally, each team contributed to a composite risk analysis. The final recommendation is the product of a comparison of the team outputs.

C. PROBLEM DEFINITION

The problem space was formed through an extensive review of pertinent literature as well as stakeholder interviews. Research included Navy and Marine Corps doctrinal publications, official guidance, and previous governmental studies and reports. Stakeholder analysis was accomplished through correspondence and participation in various professional conferences.

An important aspect of problem formulation comes from the realization that the LSD class ships are approaching the end of their service life and that this fact presents a substantial threat to amphibious capability. This threat is of significant consequence as demonstrated before the Subcommittee on Seapower and Projection of Forces of the House Armed Services Committee:

> Failure to maintain adequate amphibious capability and capacity presents a grave risk to our national security. Without it the United States: loses credibility among both friends and foes; forfeits opportunities to establish and maintain influence; relinquishes the ability to operate in austere environments or overcome damaged infrastructure; divests itself of a critical means of responding to crises and protecting our citizens and interests; and ultimately surrenders its only sustainable entry capability, becoming reliant on the willingness of others to grant overseas access.[3]

Based on an initial view of the problem space, the project tasking was refined into an initial problem statement: Amphibious operations capability gaps will be created by the decommissioning of the Whidbey Island class and Harpers Ferry class ships. This problem statement reflects the real deficiency that will exist and leads to some specific need to respond to that deficiency. Further review of this problem statement through the implementation of an iterative systems engineering method of needs analysis resulted in this revised problem statement:

Potential alternative solutions must be analyzed and compared with respect to their cost, performance, and risk in order to support future amphibious force requirements.

This problem statement represents the crux of the need communicated by the stakeholders and opens the study to the comprehensive analysis defined in the SEA-18A Capstone.

D. BACKGROUND

Pertinent to the investigation of the problem space described above is an understanding of this amphibious force, the ships of which it is comprised, the missions to which it is tasked, and the Marine Corps force which it carries. A brief discussion follows on these areas.

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[3] (Honorable Sean J Stackley, 2011) p.3

1. Amphibious Ships

Amphibious ships make up just over 10% of the Navy's planned 313-ship battle force inventory base-lined in the Force Structure Analysis of 2005.[4] The Navy desires to maintain a force of approximately 33 ships for two purposes. Foremost is to satisfy the high demand for traditional ARG operations; and second is to satisfy the increasing demand for deployments on independent operations to conduct presence, irregular warfare, maritime security, humanitarian assistance, and partnership building missions.[5]

At the end of FY2011, the Navy's amphibious force included 31 ships. They are divided by class as follows:

- 8 Wasp (LHD-1) class ships
- 2 Tarawa (LHA-1) class ships
- 5 San Antonio (LPD-17) class ships
- 4 Austin (LPD-4) class ships
- 12 Whidbey Island/Harpers Ferry (LSD-41/49) class ships

These amphibious landing ships can be more generally divided into two groups. "Big deck" amphibious ships include the LHD and LHA classes and look akin to small aircraft carriers. The "small deck" amphibious ships include the LPD and LSD classes, which do not have the same capacity for flight operations as the larger ships. LSDs have larger well decks and can carry more landing crafts air cushion (LCACs) than other types of amphibious ships, but they cannot house helicopters. The Whidbey Island class (LSD-41) can carry four LCACs while the Harpers Ferry class (LSD-49) can carry only two but has ten times the cargo capacity of the LSD-41.The Harpers Ferry class is commonly referred to as the cargo variant LSD. The ships and their homeports are identified in Table 1.

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[4] (Director, Warefare Integration (OPNAV N8F), 2010) p.3

[5] (Director, Warefare Integration (OPNAV N8F), 2010) p.3

Hull Number	**Ship's Name**	**Home Port**	**Hull Number**	**Ship's Name**	**Home Port**
LSD-41	*USS Whidbey Island*	Little Creek, VA	LSD-49	*USS Harpers Ferry*	San Diego, CA
LSD-42	*USS Germantown*	Sasebo, Japan	LSD-50	*USS Carter Hall*	Little Creek, VA
LSD-43	*USS Fort McHenry*	Little Creek, VA	LSD-51	*USS Oak Hill*	Little Creek, VA
LSD-44	*USS Gunston Hall*	Little Creek, VA	LSD-52	*USS Pearl Harbor*	San Diego, CA
LSD-45	*USS Comstock*	San Diego, CA			
LSD-46	*USS Tortuga*	Sasebo, Japan			
LSD-47	*USS Rushmore*	San Diego, CA			
LSD-48	*USS Ashland*	Little Creek, VA			

Table 1. LSD Hulls and Homeports (Follows [6])

The mission of the LSD is to "…transport and launch loaded amphibious craft and vehicles with their crews and embarked personnel in amphibious assaults by landing craft and amphibious vehicles."[7]

The ships are typically forward deployed as part of an ARG consisting of one LHA or LHD, one LPD, and one LSD. These three ships are capable of lifting a MEU consisting of around 2,200 Marines, their combat equipment, aircraft and vehicles, and 15 days of supplies. An example ARG configuration is shown in Figure 2.

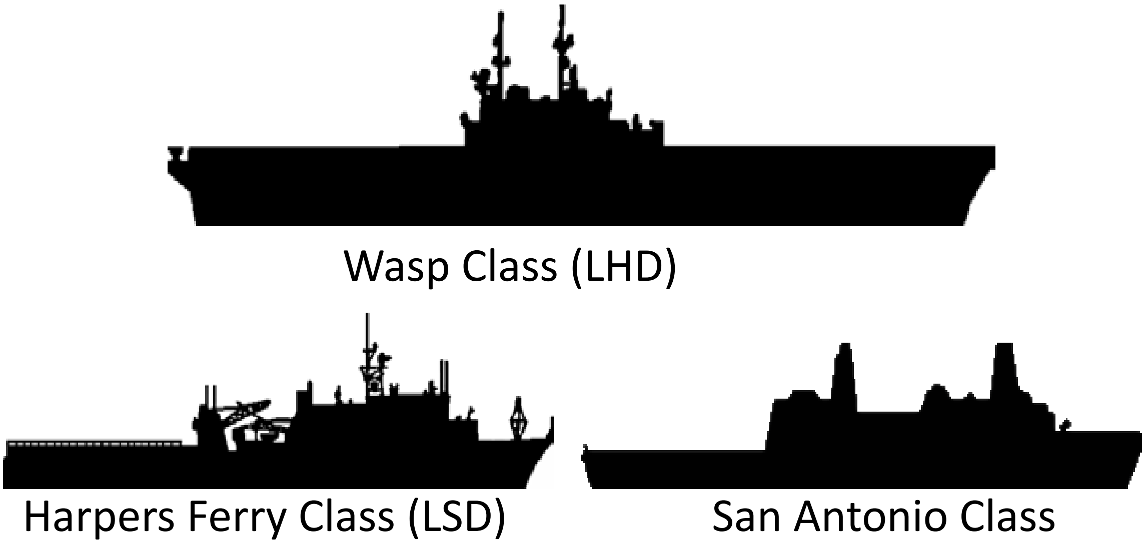

Figure 2. Example ARG Formation (Follows [8])

The driving force behind the naval amphibious force is the military's need to provide sufficient lift capacity to deliver two Marine Expeditionary Brigade Assault Echelons (MEB

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[6] (Towns, 2011)

[7] (U.S. Marine Corps, 2001) p.18

[8] (Congress, 2004)

AEs) for forcible entry operations.[9] Navy and USMC leadership have agreed that a 38 ship amphibious force is necessary to provide this capability but have accepted the operational risks of a fiscally constrained lift capability of 33 amphibious ships. A 33-ship force comprised of 11 LHA/D amphibious assault ships and a mix of 11 LPD-17 amphibious transport docks and 11 LSD dock landing ships would be sufficient to support forcible entry operations with acceptable risk in the speed of arrival of combat support elements of the MEB.[10] This plan would allow for 15 ships allocated to each MEB with as many as three ships in an overhaul status at any one time. The Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels for FY2011 shows the strength of the planned amphibious fleet as shown in Table 2.

FY	Ships	FY	Ships
2011	29	2026	36
2012	30	2027	35
2013	30	2028	36
2014	30	2029	34
2015	31	2030	33
2016	33	2031	33
2017	33	2032	32
2018	33	2033	31
2019	33	2034	33
2020	33	2035	30
2021	34	2036	30
2022	34	2037	29
2023	35	2038	29
2024	36	2039	29
2025	35	2040	30

Table 2. Projections of Amphibious Ships (Follows [11])

This force structure is not only a factor of the MEB lift requirement for major combat, but also of other objectives including presence and contingency operations in support of the Combatant Commander (COCOM) operational plans and their daily demands.[12] Due to the

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[9] (Director, Warefare Integration (OPNAV N8F), 2010) p.15

[10] (Director, Warefare Integration (OPNAV N8F), 2010) p.15

[11] (Congress, 2011)

[12] (Director, Warefare Integration (OPNAV N8F), 2010) p.15

flexibility of amphibious ships, their demand continues to increase. ARG/MEUs are typically forward deployed for Theater Security Cooperation and Irregular Warfare operations and then sent as first responders to crises events.[13]

2. Amphibious Missions

Their impressive capacity for lift of personnel and equipment make amphibious ships useful across a range of operations. Navy amphibious operations are defined in five mission areas:[14]

1. Amphibious Assault - The principal type of amphibious operation that involves establishing a force on a hostile or potentially hostile shore.
2. Amphibious Raid - A type of amphibious operation involving swift incursion into or temporary occupation of an objective followed by a planned withdrawal.
3. Amphibious Demonstration - A type of amphibious operation conducted for the purpose of deceiving the enemy by a show of force with the expectation of deluding the enemy into a course of action unfavorable to him.
4. Amphibious Withdrawal - A type of amphibious operation involving the extraction of forces by sea in ships or craft from a hostile or potentially hostile shore.
5. Amphibious Support - A type of amphibious operation which contributes to conflict prevention or crisis mitigation.

Each of these mission areas is critical to the wide range of national interests. Amphibious Demonstration offers a significant example in that the mere capability of these forces helps shape world events. In time of crisis, the positioning of an amphibious force in proximity to some particular area allows the nation’s decision makers to indicate US concerns without prematurely deploying forces ashore.[15]

These five mission areas of the Navy differ slightly from those of the USMC. The USMC defines four Amphibious Operations:[16]

1. Conduct Amphibious Assault: The principle type of amphibious operation that involves establishing a force on a hostile or potentially hostile shore.
2. Conduct Amphibious Raid: A short-duration, small-scale deliberate attack, from the sea, involving a swift penetration of hostile or denied battlespace.

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[13] (Whitney, Bradley & Brown, Inc, 2010) p.9

[14] (Joint Chiefs of Staff, 2009)

[15] (Honorable Sean J Stackley, 2011) p.1

[16] (U.S. Marine Corps, 2009) p.5

Amphibious raids are conducted in order to secure information, to confuse the enemy, or to seize, destroy, neutralize, capture, exploit, recover, or damage designated sea-based or shore-based targets. Amphibious raids end with a planned withdrawal upon completion of the assigned mission.

3. Conduct Maritime Interception Operations (MIO): Operations contained in this task include Visit, Board, Search and Seizure (VBSS), seizure of a static maritime platform and selected maritime security missions. These operations may be conducted in order to counter piracy, enforce international agreements, enforce international resolutions or sanctions, confiscate contraband, or as directed in accordance with current execution orders.

4. Conduct Advance Force Operations: To shape the battlespace in preparation for the main assault or other operations of an amphibious or Joint force by providing battlespace awareness and conducting such operations as reconnaissance, seizure of supporting positions, preliminary bombardment, and air support.

The Navy's fifth mission area of 'Amphibious Support' is closely related to the USMC 'Expeditionary Support to Other Operations / Crisis Response and Limited Contingency Operations.'[17] These include:

1. Noncombatant Evacuation Operations (NEO)
2. Humanitarian Assistance (HA)
3. Stability Operations (SO)
4. Tactical Recovery of Aircraft and Personnel (TRAP)
5. Joint and Combined Operations
6. Aviation Operations from expeditionary shore-based sites
7. Theater Security Cooperation (TSC) Activities
8. Airfield/Port Seizure

The "other operations" discussed by the Navy and USMC highlight the flexibility of these ships, which allows for their implementation in nation-building operations, maritime security operations (such as anti-piracy operations), and counter-terrorism operations.[18] The Navy's 30 Year Shipbuilding Plan further captures this sentiment stating:

> Amphibious ships are proving to be one of the most flexible battle force platforms, as indicated by the high demand for both traditional Amphibious Readiness Group operations and deployments of independent amphibious

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[17] (U.S. Marine Corps, 2009) p.5

[18] (O'Rouke, 2011) p.6

ships for a variety of presence, irregular warfare, maritime security, humanitarian assistance, disaster relief, and partnership building missions.[19]

3. USMC Organization

The Marine Air-Ground Task Force (MAGTF) is the principle organization of the force across the spectrum of conflict for conduct of every mission or operation. MAGTFs are balanced, combined-arms forces with organic ground, aviation, and sustainment elements.[20] Each MAGTF, regardless of size or mission, is composed of a command element (CE), ground combat element (GCE), aviation combat element (ACE), and combat service support element (CSSE). These MAGTFs provide a scalable capability as shown in Figure 3.

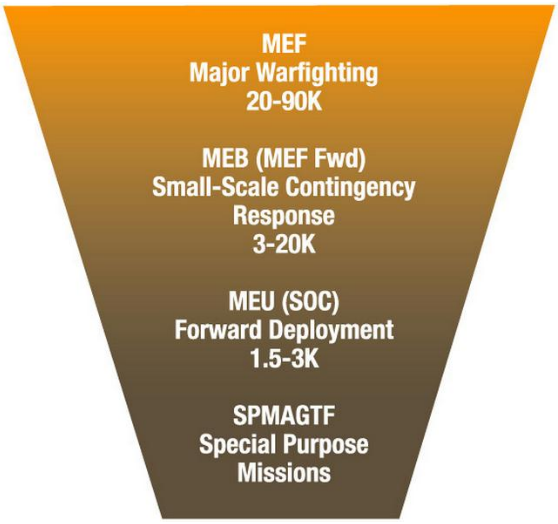

Figure 3. MAGTF Scalability (From [21])

The principal war-fighting organization is the Marine Expeditionary Force (MEF).[22] There are three permanent MEFs: I MEF based in Southern California and Arizona, II MEF based in North and South Carolina, and III MEF based in Hawaii and Japan.

Operationally, the Marines are no longer needed to storm beaches against hardened targets, and have shifted focus to 21st Century Marine doctrine such as “Operational Maneuver From The Sea” (OMFTS) and “Ship to Objective Maneuver” (STOM). A Marine Expeditionary Brigade (MEB) supports this doctrine. A MEB is a MAGTF constructed

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[19] (Director, Warefare Integration (OPNAV N8F), 2010) p.3

[20] (U.S. Marine Corps, 1998) p.2-1

[21] (U.S. Marine Corps, 2009) p.35

[22] (U.S. Marine Corps, 1998) p.2-2

around a reinforced infantry regiment, a composite Marine aircraft group, and a brigade service support group.[23] The 33-ship amphibious force is designed to fulfill the lift capability required to deliver two MEB Assault Echelons.

The principal forward-deployed organization is the Marine Expeditionary Unit, or if they are deployed with the added capability, a Marine Expeditionary Unit Special Operations Capable (MEU(SOC)). There are seven permanent MEU(SOC) commands: I MEF holds the 11th, 13th, and 15th MEUs(SOC), II MEF holds 22nd, 24th, and 26th MEUs(SOC), and III MEF holds the 31st MEU(SOC). The mission of the MEU is to:

> Provide a forward-deployed, flexible sea-based Marine Air Ground Task Force (MAGTF) capable of conducting Amphibious Operations, crisis response and limited contingency operations, to include enabling the introduction of follow on forces, and, designate special operations, in order to support the theater requirements of Geographic Combatant Commanders (GCC).[24]

An ARG must be capable of deploying with a MEU, its vehicles, aircraft, and equipment. This lift requirement is why current operating procedure defines an ARG as one big deck (either LHA or LHD), one LPD and one LSD, vice smaller combinations.

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[23] (Jacob, 2003) p15

[24] (Corps, 2009) p.4

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II. SYSTEMS ENGINEERING ANALYSIS

An iterative systems engineering process was used with the ultimate goal of ensuring proposed solutions truly satisfied the source requirements. The process was modeled after that presented in the second edition of Decision Making in System Engineering and Management and shown in Figure 4.

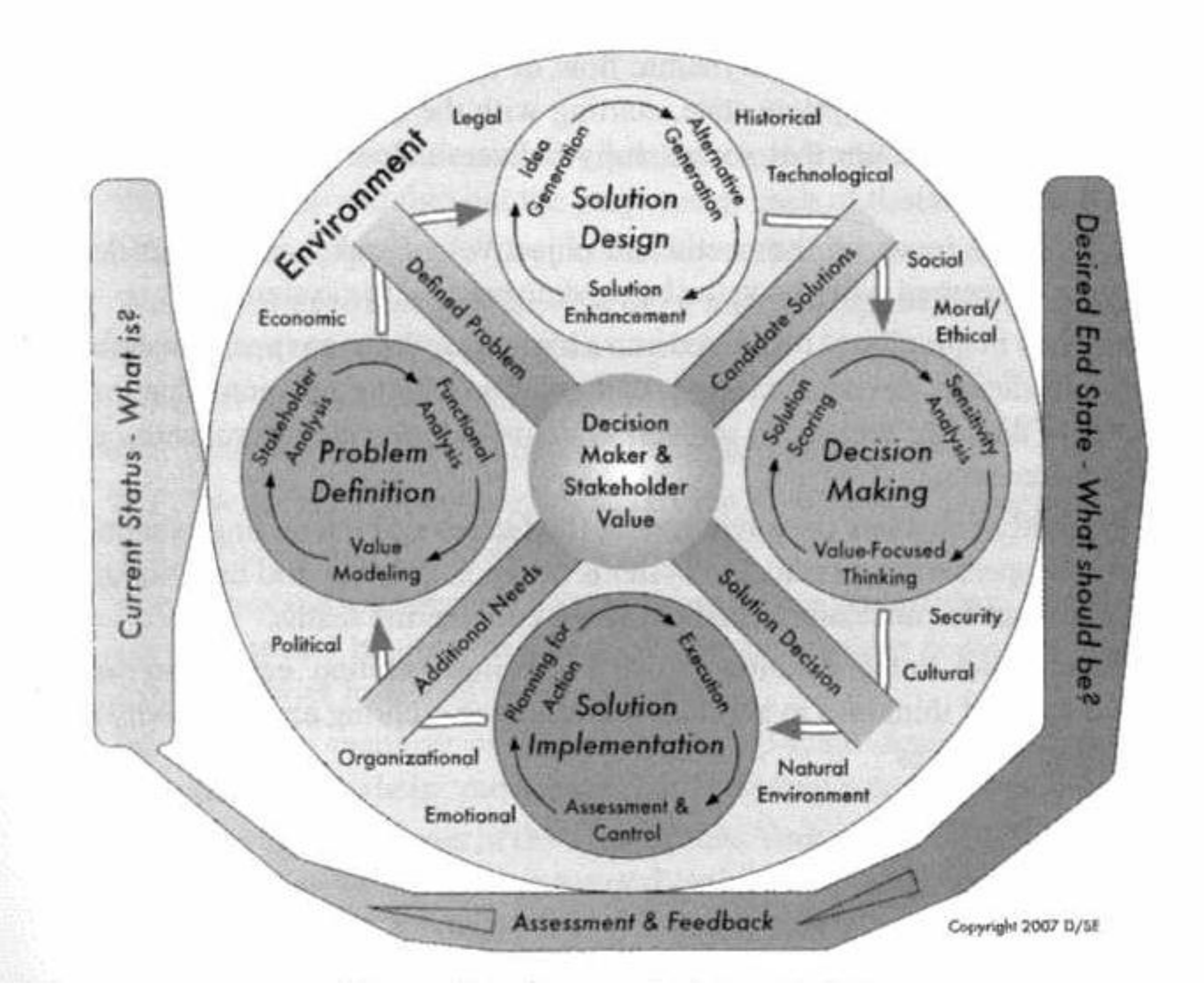

Figure 4. Systems Design Process (From [25])

It describes four steps: Problem Definition, Solution Design, Decision Analysis and Solution Implementation.[26] This research effort completed the first three phases of the process. The fourth phase is beyond the scope of this project and would be completed subsequently by the US Navy, DoD and Congressional decision makers.

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[25] (Parnell, 2011) p.17

[26] (Buede, 2009) p.49

The tailored systems engineering plan developed by the team is displayed in Figure 5.

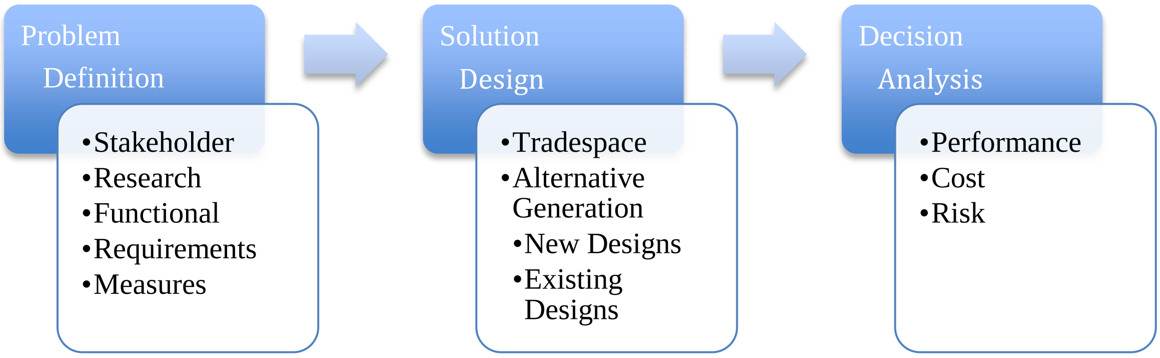

Figure 5. Systems Engineering Process

The following sections detail the method, tools, and analysis utilized by the project team, focusing first on problem space with stakeholder interviews, research and literature reviews, and functional analysis. This effort produced a list of requirements which were associated with measures of effectiveness and performance. Solution space analyzed various trade-spaces to develop alternatives. The alternatives were then compared to each other according to performance, cost and risk.

III. PROBLEM DEFINITION

A. STAKEHOLDER ANALYSIS

The systems engineering process began with the proper identification and ranking of stakeholders. Stakeholders include all interested parties in the project and its recommended solution, from the project sponsor to the future user. The stakeholder analysis conducted sought first to identify as many stakeholders as possible and then to identify those that would be most critical to the project. Criticality was determined by a need for communication, be it requirement solicitation or a request for assistance in a particular area.

The list of critical stakeholders is shown below:

- Office of the Chief of Naval Operations
    - OPNAV N8F (Warfare Integration) – Project Tasking Originator
    - OPNAV N85 – Performed the LSD(X) CBA.
    - OPNAV N81(Assessment)
- USMC Planners
- USMC Users
- Navy Users, from the COCOMs to the wardrooms and crews of the amphibious class ships
- Navy Cost Estimators
- Shipyards (Huntington Ingalls and NASSCO)

Throughout the project, N8F (as of April 2012, renamed N9I) remained the primary stakeholder and helped to guide the direction and scope of the analysis.

B. PROBLEM SPACE

The strength of the systems engineering method is the up-front effort placed on understanding the problem in all its facets and dimensions. The investigation of the problem space involved a thorough review of pertinent literature to include Joint Publications, Navy and Marine Corps Doctrine, and other related official future planning documents. Additionally, interviews with Navy and Marine Corps stakeholders were conducted with respect to current and future operations. Of particular value were the stakeholder inputs received at National Defense and Industry Association’s annual conference held in Panama City, Florida, and the Surface Navy National Symposium held in Washington, D.C.

With the initial understanding of the amphibious picture as a whole, and a focus on the specific tasking of the project, the problem space was further defined with three compulsory tools: assumptions, constraints, and scope. These three tools established the overarching rules to govern the analysis of the project team.

1. Assumptions

Assumptions describe the conditions presupposed for the analysis. Numerous assumptions were made throughout the project and documented according to their associated area. Each was deemed necessary and reasonable by the team. The following list represents the assumptions considered crucial to the study and encompassing all areas of analysis:

- Platforms in development will remain unchanged, specifically designs for the America Class (LHA-8) ships.
- The Marine Corps force structure is defined by MCO 3120.9C and will not be presupposed in any manner.[27]
- Only the LSD is a candidate for redesign if a material solution is warranted. This includes an LSD(X) based on the LPD-17 hull form.
- The need for amphibious missions described above will continue.
- Doctrine describing ARG composition, which is currently 1 LHD/LHA, 1 San Antonio class LPD and 1 LSD-41/49 class ship, can be changed if necessary. Alternatives will be compared to this baseline.
- An ARG will be complemented with a Surface Action Group (SAG) if deployed to a hostile environment, one in which a credible anti-ship weapon system threat exists with a reasonable expectation that the enemy will employ it.
- A SAG consists of at least 3 Cruiser/Destroyer ships.
- The risk associated with current lift capability shortfalls represents an acceptable level. Current ARG architectures, one LHA/D, one LPD, and one LSD, are unable to lift the entire MEU Equipment Density List (EDL). However, a recent report for OPNAV N81 based on post deployment briefs determined no adverse impacts on the MEU operations as a result of these gaps.[28]

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[27] (Commandant of the Marine Corps, 2009)

[28] (Whitney, Bradley & Brown, Inc, 2010) p. ii

- Funding for future construction will not increase beyond current projections, but funding will not decrease below a point that would prevent new ships from reaching their expected service life.

2. Constraints

Constraints are limitations or restrictions imposed upon the project team. Typically defined by the stakeholder, constraints may be physical, as the LSD(X) may not exceed some number of tons, or programmatic, as the first LSD(X) unit cost may not exceed some value. The following list includes examples of the constraints the analysis operated within:

- The alternatives must address the Navy's desire to maintain a 33-ship amphibious force.
- Cost estimating regressions limit proposed solutions with respect to size between the LSD class and LHA/D classes. This avoids extrapolating outside the bounds of the model.
- MEU and MEB lift requirements are defined by USMC.

3. Scope

The intent of this project was the generation of materiel solutions and mitigating strategies to address the capability gaps and requirements of the amphibious force. Requisite capabilities and system recommendations are defined and justified but not included in any blueprint of a ship design.

Of the five mission areas that comprise amphibious operations only Amphibious Assault and Support Operations, specifically Humanitarian Assistance and Disaster Relief (HA/DR), are analyzed in this study. These two missions are representative of the full range of missions. The forcible entry by the USMC upon a hostile shore is the primary reason for the existence of the amphibious force and drives the most stringent requirements. HA/DR represents the flexibility of the amphibious platforms for unconventional and independent operations. Furthermore, if the capability exists for assault, it follows the lesser requirements to support Demonstration, Raid, and Withdrawal are satisfied. Finally, HA/DR offers clear throughput modeling opportunities for independent ships as well as ARG/MEU operations, while Amphibious Assault allows for modeling of the amphibious force as a whole.

The decision to focus on these two mission areas is also supported by MEU(SOC) Mission Rankings prepared for OPNAV N81 in 2010. The review prioritized probable MEU missions based on the MEU(SOC) order, historical MEU utilization, and the Steady State

Security Posture (SSSP) scenarios.[29] As shown in Table 3, an amphibious assault represents the least likely but most stressing task compared to Humanitarian Assistance which represents and highly likely but low stressing task.

Most Likely	MEU Mission Essential Task	Most Stressing
1	Conduct/Support Theater Security Cooperation Activities (MCT 5.5.5)	14
2	Conduct Humanitarian Assistance (HA) (MCT 1.6.6.7)	13
3	Conduct Noncombatant Evacuation Operations (MCT 1.6.6.6)	8
4	Conduct Joint and Combined Operations (MCT5.5)	4
5	Conduct Tactical Recovery of Aircraft and Personnel (TRAP) (MCT6.2.1)	9
6	Conduct Stability Operations (SSTRO) (MCT1.6.6.9)	5
7	Conduct Visit, Board, Search and Seizure (VBSS) Operations (MCT1.3.2.9)	11
8	Conduct Aviation Operations from expeditionary shore-based sites (MCT1.3.3.3.2)	12
9	Conduct Special Reconnaissance (JP1-02)	10
10	Conduct Advance Force Operations (MCT1.6.10)	6
11	Conduct Airfield/Port Seizure (MCT1.6.5.6)	3
12	Conduct Amphibious Raid (MCT1.3.2.2)	2
13	Conduct Direct Action Operations (JP 1-02)	7
14	Conduct Amphibious Assault (MCT1.3.2.3)	1

Table 3. MEU Task Ranking (From [30])

A more complete understanding of the lift capability gaps of the force could only be achieved through extensive analysis, through war-games and simulations, of Marine Corps battles on the beaches and shores of the enemy. This project has bound the problem at the delivery of men and equipment to the beach but not their utilization thereafter. Any lift capability that can deliver more troops and equipment faster is assumed to increase combat effectiveness on the shores and vice versa.

Notably absent from the above discussion is the force structure definitions for the various amphibious force compositions. This requirement, though present in previous analyses of the problem, is specifically challenged. For example, what architectures are possible other than the Navy standard below?[31]

- A MEU is supported with an ARG comprised of 3 amphibious ships (1 Big Deck, 1 LPD, and 1 LSD or 1/1/1).

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[29] (Whitney, Bradley & Brown, Inc, 2010) p 6

[30] (Whitney, Bradley & Brown, Inc, 2010) p 6

[31] (Command, 2010)

- MEB AE lift is supported with 15 amphibious ships (5/5/5).
- 2.0 MEB AE lift requirement is supported with 30 amphibious ships (10/10/10).

C. CONCEPT OF OPERATIONS (CONOPS)

1. Operational View (OV-1)

The picture below displays the various means by which the LSD and future LSD(X) may be employed. It is taken from the LSD Initial Capabilities Document (ICD) Gate 1 Review delivered by OPNAV N85 in March 2011. Specifically it presents the three distinct formations in which the ship can expect to be deployed. These three formations depict one LSD in a three-ship ARG, as five of the ships of a fifteen-ship Amphibious Task Force (ATF), or as a lone ship conducting independent operations. In any of the three formations, the ship can expect to be deployed with Marines, their equipment and vehicles, and can expect to debark these Marines, their equipment and vehicles via LCAC and rotary aircraft. The emphasis of the project is a cost-performance analysis of these three formations circled in Figure 6.

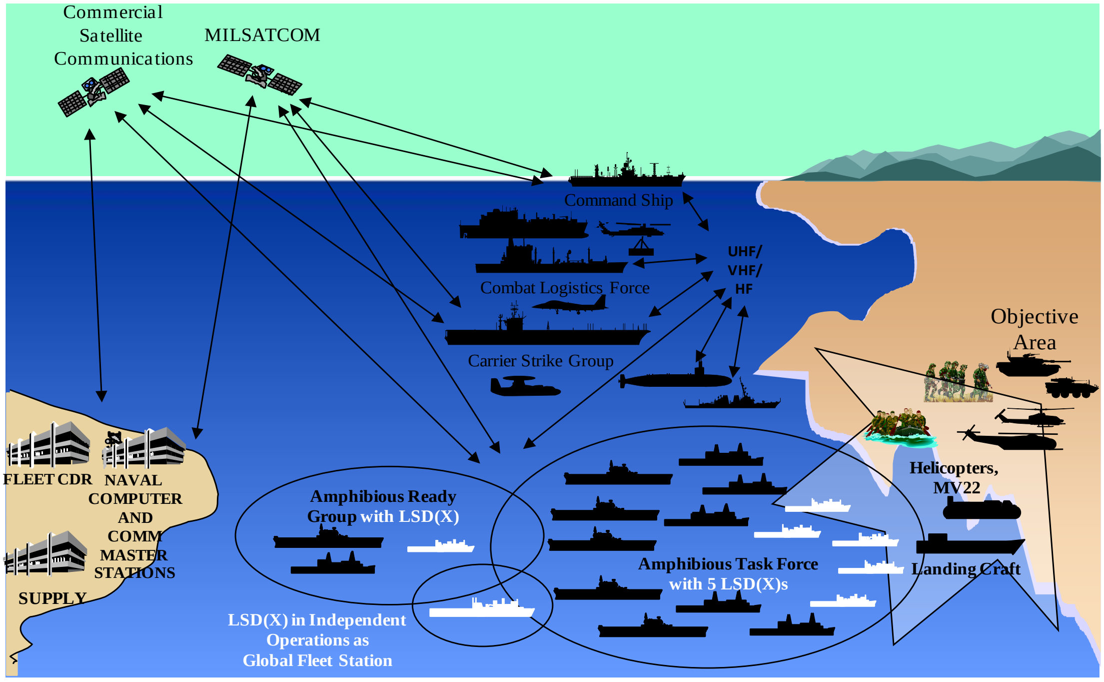

Figure 6. Operational View (OV-1) (From [32])

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[32] (Towns, 2011)

2. Mission Description for HA/DR and Assault

Two scenarios were developed for analysis, simulation, and alternative evaluation. The following are Concepts of Operations (CONOPS) for the amphibious missions of HA/DR and Amphibious Assault. These CONOPS give the necessary background for a more complete understanding of the modeling efforts described later in the report.

a. Amphibious Assault CONOPS

Current Situation: A hostile nation has invaded and currently occupies the island of Natuna Besar with a brigade-sized force and has begun setting up Surface to Air Missiles (SAM), Surface to Surface Missiles (SSM) and Dong Feng-21 sites. Additionally, they have stationed two squadrons of SU-33 at Ranai Airport and 6 Beagle MMA. They announced that all traffic through the South China Sea would henceforth be subject to inspection and control by their forces. Indonesia, Vietnam, and the Philippines have requested U.N. support, specifically calling on the United States and Japan to act. In response, the hostile nation has warned Japan and the United States that any interference in their policy enforcement will lead to war.

Mission: Using forces assigned to an Amphibious Expeditionary Strike Group (ESG) conduct an amphibious assault on the hostile nation's forces located on Natuna Basar. Gain air and sea superiority first and then take the island by conducting an amphibious assault on landing areas deemed appropriate.

Operational Tasks:[33]

1) ESG arrives in OPAREA
2) Preparation of the landing area by supporting arms: Naval Surface Fire Support Ships (NSFS) and Tomahawk Land Attack Missile (TLAM) Ships
3) Ship to shore movement of landing force
4) Air/surface assault landings
5) Link up to operations between surface and air landed forces
6) Provision of supporting arms and logistics and/or combat service support
7) Landing of remaining force elements
8) Conduct land missions to take over hostile nation forces

The LSD: The *USS Tortuga* (LSD-46), located in its homeport of Sasebo, Japan, is tasked to join the assembling Amphibious Task Force. The ship will deploy to the hostile area and conduct its mission. The ships will be escorted by a SAG consisting of

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[33] (Joint Chiefs of Staff, 2009)

surface combatants capable of defending the ATF from surface, subsurface, and air threats while conducting the assault. Once on station, the *USS Tortuga* is capable of conducting amphibious operations consisting of the following: communication, coordination, surveillance, command and control, limited self-defense, defense of delivery vehicles, Special Operations Forces (SOF) insertion, delivery of troops and equipment, extraction of troops and equipment. The primary effort will be the transfer of troops and equipment from the ship to the shore while on station. Transfer of troops and equipment will be conducted by sea via LCACs and air via rotary aircraft. Replenishment of fuel, cargo, supplies will be provided as necessary in order to allow the ship to remain on station as long as required. Once the mission is complete, the ship will redeploy as necessary for follow-on tasking.

b. HA/DR CONOPS

Current Situation: An earthquake measuring 7.0 on the moment magnitude scale (Mw) occurred with an epicenter near the town of Leogane just 16 miles west of Haiti's capital Port-au-Prince. The effects were felt across the entire country with massive damage to industrial, commercial, and residential structures. Millions of Haitians were affected by the quake and it is feared the death toll will reach into the hundreds of thousands. Air, land, and sea transport facilities, electrical and communications infrastructure, and hospitals and government buildings were all severely damaged or out of commission. The government of Haiti has asked for international assistance.

Mission: A ship is to be sent from Little Creek to respond within 72 hours. The purpose of the HA/DR mission is to relieve or reduce the impacts of the earthquake. COMPACFLT and COMTHIRDFLT have tasked the ARG with the following objectives:

- Understand the situation.
- Determine where the supplies need to be delivered.
- Provide logistical support.
    - Sealift
    - Airlift
    - "Ship to shore" maneuver
- Conduct / Maintain Situational Awareness.
    - Provide situational updates to Higher Headquarters.
    - Deploy security teams to assess the ground situation and provide security.

    - Coordinate with external agencies (Host Nation government, military, other aid organizations, etc.).
    - Utilize communication means to develop and share awareness of the situation with other services.
- Provide command and control decision support.

Operational Tasks:

1. Plan for all required resources including manpower, supplies and equipment necessary for a successful mission, perform a risk analysis of the situation in the affected region to include the ingress routes, and develop deployment and contingency plans for any unforeseen circumstances.
2. Liaise with other organizations to consolidate the overall effort.
3. Transport all required manpower, supplies and equipment to the affected region as quickly as possible to include the end-to-end transportation from Little Creek to the disaster region.
4. Aid and equipment are to be delivered to affected parties in the region, including the rebuilding of necessary infrastructure to return the affected region to normal operation.
5. Recover and return from the affected region.

The LSD: The *USS Ashland* located in its homeport of Little Creek will be tasked to respond to a humanitarian assistance and disaster relief effort. The ship will deploy to the affected area in order to provide support. The ship may be independently tasked, or deployed/re-deployed as a component of an ARG. The ship will transit to its assigned area of responsibility and establish the requisite command and control organization necessary to conduct its mission. Operations could consist of one or more of the following; communication, evacuation, delivery of goods, receipt of goods, regional support, surveillance, medical assistance, coordination, search and rescue, security, or liaison operations. The primary effort of response will be command and control and the transfer of cargo and personnel to and from the ship while on station. Transfer of personnel, equipment, and supplies will be conducted by LCACs and rotary aircraft. Replenishment of fuel, cargo, supplies will be provided as necessary in order to allow sustainment of ships stationing as long as required. Once the mission is complete, the ship will be re-deployed as necessary for follow-on tasking.

D. FUNCTIONAL ANALYSIS

The functional analysis began with a decomposition of “Amphibious Operations.” This facilitated a clearer understanding of the problem space by focusing on discrete actions necessary to complete the objective requirements. The analysis asked *what* needs to be done to complete the amphibious missions not *how* it is to be done.

The top-level functions requisite to the accomplishment of the amphibious operations are the verb phrases “lift, command, and employ forces.” Each of these top-level functions is then further divided into the necessary lower level functions. The top-level functional decomposition diagram is displayed in Figure 7.

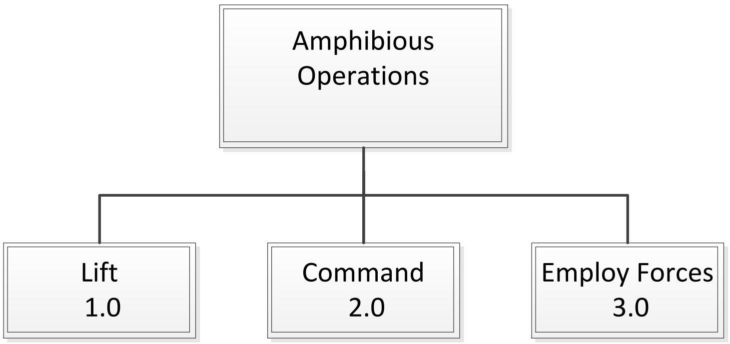

Figure 7. Amphibious Operations High Level Functions

This decomposition is dependent upon specific definitions to avoid ambiguity or confusion. The intended meaning of each function is defined below. Amphibious vessels referred to are the LHA, LHD, LPD, and LSD class ships.

1. Lift: This function refers to the capability to hold and transport personnel and equipment over the sea.
2. Command: This function describes the ability to command and control the operations, and assets with respect to the amphibious mission.
3. Employment of Forces: This function requires the utilization of those forces and equipment deployed on or assigned to the amphibious fleet. This includes, but is not limited to, USMC and naval personnel, SOF forces, and the crews who operate LCACs, small boats, rotary and fixed-wing aircraft utilized in the accomplishment of the amphibious mission set.

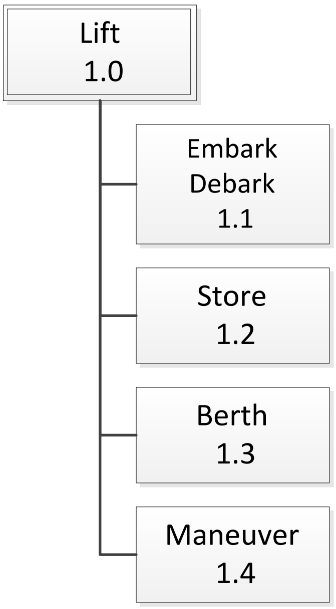

Figure 8. Functions of Lift

The function Lift, shown in Figure 8, includes the ability to perform the following sub-functions:

1.1 Embark/Debark: This function describes the loading of personnel and equipment aboard a vessel and their subsequent unloading or launching.

1.2 Store: This function describes the securing and containment of embarked equipment.

1.3 Berth: This function describes the housing of embarked personnel.

1.4 Maneuver: This function describes the movement of amphibious vessels over the sea.

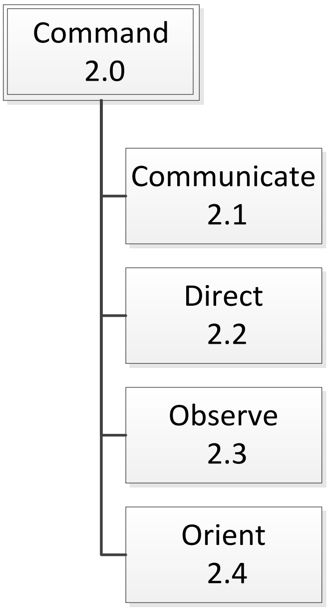

Figure 9. Functions of Command

The function Command, shown in Figure 9, includes four sub-functions:

2.1 Communicate: This function describes the ability to convey and receive information internally and externally both organically and non-organically.

2.2 Direct: This function describes the ability to manage, exert control, or dictate actions internally and externally both organically and non-organically.

2.3 Observe: This function describes the ability to receive information with sensors or personnel.

2.4 Orient: This function describes the ability to process observed information.

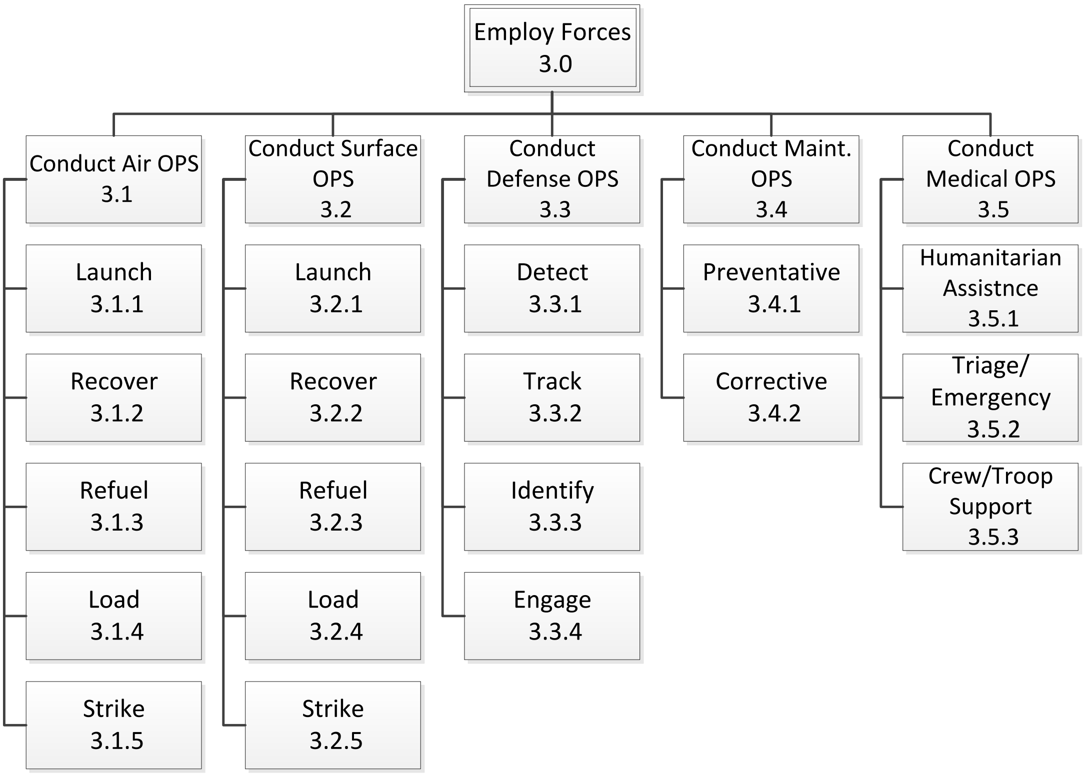

Figure 10. Functions of Employ Forces

The function Employment of Forces, shown in Figure 10, was divided into five lower-level functions with sub-functions below them.

3.1. Air Operations include all aircraft operations on the flight decks of amphibious ships.

3.1.1. Launch – Ability to have aircraft take-off from the ship.

3.1.2. Recover – Ability to have aircraft land on the ship.

3.1.3. Refuel – Ability to provide additional fuel to aircraft.

3.1.4. Load – Ability to transfer personnel and equipment onto and off of vessels and surface craft.

3.1.5. Strike – Ability to employ weapons from an aircraft.

3.2. Surface Operations refers to all amphibious vessel actions necessary for the completion of amphibious missions. This includes the maneuvers of amphibious vessels as well as the small boats and LCACs launched from those vessels.

3.2.1. Launch – Ability to have surface craft debark from the ship.

3.2.2. Recover – Ability to have surface craft embark on the ship.

3.2.3. Refuel – Ability to transfer fuel.

3.2.4. Load – Ability to transfer personnel and equipment onto and off of vessels and surface craft.

3.3. Medical Operations include all efforts to aid, treat, and attend to the medical and dental needs of embarked personnel or personnel of interest in a given area of operation.

3.4. Maintenance Operations refer those efforts to repair or prevent damage to the equipment embarked on an amphibious ship necessary for the employment of forces. This includes maintenance of LCACs, aircraft, and embarked vehicles and equipment, but does not refer to the maintenance of the amphibious vessel itself.

3.5. Defensive Operations refers to amphibious force protection and surface craft deployed in operations.

If a specific ship, for example an LSD(X), was to perform the functions necessary for amphibious operations, it would result in a new and distinct list of functions. A HA/DR mission does not require the maintenance of ships systems however, given the context of an LSD performing a HA/DR mission over some period of time, the need to maintain ships equipment becomes a functional necessity. A functional decomposition for the LSD(X) is contained in Appendix A and would lend insight during the design of a future ship.

E. REQUIREMENTS GENERATION

The previous sections were for the purpose of determining what it is precisely that needs to be accomplished. The literature review, stakeholder elicitation and the generation of constraints and assumptions led to an initial description of the problem space. CONOPS analysis and functional decompositions lead to an approach of the problem statement from distinctive angles. The product of the analysis thus far was the requirements generation. These requirements were divided into two general categories. The first requirements are clearly defined for the Navy and Marine Corps in doctrinal publications. These requirements include Marine Corps lift requirements and mirror the amphibious mission set of the Navy. Listed second are requirements taken from Navy leaders and planners that describe more general operational needs for amphibious ships and their procurement.

1. Doctrinal Requirements

1. The amphibious force must be able to lift two Marine Expeditionary Brigades (MEBs) as defined in Table 4.
2. An Amphibious Readiness Group must be able to lift a Marine Expeditionary Unit (MEU) as defined in Table 4.

Footprint	MEU	2.0 MEB
LCACs (Spots)	6	54
Troops (Bunks)	2,578	24,342
Vehicle (Sq. Ft Total)	88,640	930,488
Cargo (Cu. Ft Total)	227,048	1,861,636
Aviation (MH60 Equivalent)	104.22	922.78
JP-5 (Gal)	1,592,344	16,690,930

Table 4. MEU/MEB Footprints (Follows [34])

An important note to this MEU lift requirement is that MEU Commanders are not required to deploy with the complete Equipment Density List (EDL) as defined in Marine Corps Order 3120.9C Policy for Marine Expeditionary Units. Instead, the EDL serves the Commanders in developing their mission set based on mission analysis and the capacity of the assigned ARG.[35]

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[34] (Command, 2010)

[35] (Whitney, Bradley & Brown, Inc, 2010) p.11

3. The amphibious force must be able to perform an amphibious demonstration, defined as a type of amphibious operation conducted for the purpose of deceiving the enemy by a show of force with the expectation of deluding the enemy into a course of action unfavorable to him.[36]

4. The amphibious force must be able to perform an amphibious raid defined as a type of amphibious operation involving swift incursion into or temporary occupation of an objective followed by a planned withdrawal.[37]

5. The amphibious force must be able to perform an amphibious assault defined as the principal type of amphibious operation that involves establishing a force on a hostile or potentially hostile shore.[38]

6. The amphibious force must be able to perform an amphibious withdrawal defined as a type of amphibious operation involving the extraction of forces by sea in ships or craft from a hostile or potentially hostile shore. [39]

7. The amphibious force must be able to provide amphibious support to other operations defined as a type of amphibious operation which contributes to conflict prevention or crisis mitigation. Amphibious support to other operations includes such operations as foreign humanitarian assistance, noncombatant evacuation operations or disaster relief.[40]

2. Stakeholder Requirements

8. The amphibious force must be flexible, which is defined as the ability to independently perform the range of maritime operations (ROMO) in addition to the amphibious mission set.

9. Amphibious ships must be capable of independent operations defined as the ability to perform operations alone without the direct support of other naval ships excluding replenishment ships.

10. Fiscal restraints require that the alternatives be consistent with expected future defense budgets, the Department of the Navy’s annual shipbuilding

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[36] (Joint Chiefs of Staff, 2009)

[37] (Joint Chiefs of Staff, 2009)

[38] (Joint Chiefs of Staff, 2009)

[39] (Joint Chiefs of Staff, 2009)

[40] (Joint Chiefs of Staff, 2009)

construction (SCN) budget must average no more than \$15.9B per year FY10\$ throughout the period of this report.[41]

F. MOE/MOP GENERATION

Measure of effectiveness (MOE) generation was rooted in the ten doctrinal and stakeholder requirements and addressed the functional analysis in that each MOE can be traced to at least one function, with the exception of the fiscal MOE which traces directly to a requirement. Each MOE is associated with at least one MOP, typically a rate or quantity. This list of MOEs and MOPs is representative, but not all-inclusive, of the list that should drive the design of any materiel solution. Those measures in italics were analyzed for in this project's simulations.

1. MOE and MOP List

- Troop Support
  - MOE: Ability to lift troops
    - MOP: *Troop capacity*
    - MOP: *Troop Transfer Rate*
- Vehicle Capacity
  - MOE: Ability to lift various USMC vehicles
    - MOP: Vehicle square footage
- Cargo capacity
  - MOE: Ability to carry cargo
    - MOP: *Cargo cubic footage*
    - MOP: *Cargo Transfer Rate*
- LCAC Capacity
  - MOE: Ability to carry LCACs
    - MOP: *LCAC spots*
  - MOE: Ability to sustain LCACs
    - MOP: LCAC maintenance capacity
    - MOP: JP-5 capacity
- Aircraft Capacity
  - MOE: Ability to carry aircraft
    - MOP: *Flight deck spots*

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[41] (Director, Warefare Integration (OPNAV N8F), 2010)

        MOP: Hangar spots
        MOP: Storage capacity
    MOE: Ability to sustain aircraft
        MOP: Aircraft maintenance capacity
        MOP: JP-5 capacity
Medical Facilities
    MOE: Ability to provide medical/dental care
        MOP: Number of beds
        MOP: Number of operating rooms
Command and Control
    MOE: C2 sufficient to perform the ROMO independently, as part of a larger task force including coalition forces
        MOP: Number of available C2 paths
        MOP: Percentage of interoperability with current systems.
        Self-Defense
    MOE: Probability of Survival against selected threats
        MOP: Probability of kill (P_K) of self-defense systems against air and surface threats
Flexibility
    MOE: Ability to perform ROMO
        MOP: Number of missions able to perform
        MOE: Mobility and endurance to operate and sustain operations etc.
        MOP: Speed sufficient to operate and sustain operations as part of an ARG or ATF.
        MOP: Unrefueled range sufficient to operate and sustain operations as part of an ARG or ATF.
Fiscal Constraint
    MOE: Ability to procure ships at a cost not to exceed Navy planned budget.
        MOP: Price per ship
        MOP: Prospective O&S cost

The project created models and simulations to analyze performance and focused on system throughput. *Throughput* was defined as either of the MOPs *troop transfer rate* or *cargo transfer rate*.

2. Traceability and Mapping

The systems engineering process used was iterative and the functional definitions, requirements, and measures of effectiveness and performance evolved as the project progressed. A traceability matrix was developed to show the relationships between these fundamental products of the analysis. The matrix shown in Figure 11 illustrates the direct relationship the functional decomposition of amphibious operations has with the ten requirements. Every requirement relates to at least one function. The fiscal requirement is an exception as the total cost is the result of every decision made concerning a materiel solution. The end result of this phase of the project was the MOEs and MOPs that fed into the models and simulations used to compare alternatives.

Requirements										Functional Decomposition of Amphibious Operations	MOEs/MOPs																									
Force Lift 2 MEBs	ARG Lift 1 MEU	Conduct Demonstration	Conduct Raid	Conduct Assault	Conduct Withdrawal	Conduct Other Support	Flexible	Independent Ops.	Fiscal Constraints*		Ability to Lift Troops	Troop Capacity	Troop Transfer Rate	Ability to Lift Vehicles	Vehicle Square Footage	Ability to Lift Cargo	Cargo Cubic Footage	Cargo Transfer Rate	Ability to Lift LCACs	LCAC Spots	Ability to Sustain LCACs	Ability to Lift Aircraft	Flight Deck Spots	Hanger Spots	Storage Capacity	Ability to Sustain Aircraft	Ability to Prov. Med. Care	Number of ORs	Number of Beds	Ability to Perform ROMO	Missions Capable	Mobility	Endurance	Unrefueled Range	Ability to Defend	Ps vs. Selected Threats
X	X								X	1.0 Lift	X	X		X	X	X	X		X	X		X	X	X	X					X	X	X				
X	X								X	1.1 Embark/Debark	X	X	X	X	X	X	X	X	X	X		X	X	X	X					X	X	X				
X	X								X	1.2 Store			X	X		X	X		X			X	X	X	X											
X	X								X	1.3 Berth	X	X																								
X	X								X	1.4 Maneuver																						X	X	X		
		X	X	X	X	X	X	X	X	2.0 Command																				X	X					
		X	X	X	X	X	X	X	X	3.0 Employ Forces																				X	X					
		X	X	X	X	X	X	X	X	3.1 Conduct Air Ops			X					X				X	X	X	X	X				X	X					
		X	X	X	X	X	X	X	X	3.2 Conduct Surface Ops			X					X		X	X									X	X					
			X				X		X	3.3 Conduct Defensive Ops																				X	X				X	X
							X	X	X	3.4 Conduct Maintenance Ops			X					X			X			X		X				X	X					
						X			X	3.5 Conduct Medical Ops																	X	X	X	X	X					

Figure 11. Traceability Matrix

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IV. SOLUTION DESIGN

A. TRADE-SPACE

Trade-space describes the realities wherein all requirements cannot be met because they are to some degree mutually exclusive. Either one requirement may preclude another or one requirement dictates another through some correlation. The measures against which the various alternatives were evaluated were determined in the previous section. The next step was to decide to what extent design parameters could be synthesized into a feasible solution. This required a deeper analysis of the need. The introduction to this report discussed the Navy's desire to maintain an amphibious fleet of 33 ships. This number is partially based on the need to lift 2.0 MEBs utilizing equal numbers of the three types of ships (10 big decks, 10 LPDs, 10 LSDs, and up to 3 unavailable). The following gap analysis examined the 2.0 MEB lift requirement with respect to the six lift footprints in order to determine where the greatest need existed.

1. Gap Analysis

The specific lift elements of a MEB can be defined in 6 footprints:

- Troop berthing spots
- Vehicle storage space square feet
- Cargo storage cubic feet
- JP-5 gallons
- VTOL aircraft operating spots expressed in CH-46 equivalents
- LCAC operating spots

Each of these categories is more specifically defined in the Amphibious Ship Recapitalization Capabilities Based Assessment dated June 21, 2010. *Troops* include the total number of personnel, Marines and Naval Support Element (NSE) that require berthing. *Vehicle* square footage includes the footprint of vehicles, equipment, and cargo intended to be stowed in vehicles stowage areas. *Cargo* cubic footage includes the actual volume of the unit equipment, excluding equipment stowed with the vehicles, and sustainment and maintenance supplies associated with the units. *Aircraft* spots include the aircraft footprint on the flight deck/hangar bay and aviation logistics space required for aircraft maintenance and stowage. Aviation spots were measured in CH-46E equivalents. *LCAC* spots include the well deck spots for LCACs. Its replacement ship-to-shore connector (SSC) has the same footprint. *JP-5* includes the fuel necessary for the MAGTF and NSE operations for a 5-day assault and 10 days of sustained operations; it includes the LCAC, aircraft, and ground vehicle consumption. The amphibious classes of ship have the capacities for these footprints as displayed in Table 5.

Classes	**LHA 1**	**LHD 1**	**LHD 5**	**LHD 8**	**LHA 6**
LCAC (Spots)	1	3	3	3	0
Troops (Bunks)	1,895	1,697	1,697	1,697	1,687
Vehicle (Sq. Feet)	23,227	17,674	17,674	17,674	10,328
Cargo (Cu. Feet)	105,900	125,000	125,000	125,000	160,000
Aviation (MH60 Eq.)	68.41	81.15	81.15	81.15	87.15
JP-5 (Gallons)	407,970	478,872	478,872	478,872	1,300,000

Classes	**LHA (R)**	**LPD 4**	**LPD 17**	**LSD 41**	**LSD 49**
LCAC (Spots)	2	1	2	4	2
Troops (Bunks)	1,462	659	698	403	406
Vehicle (Sq. Feet)	16,000	11,074	20,880	17,266	17,599
Cargo (Cu. Feet)	130,000	38,300	34,000	5,100	50,700
Aviation (MH60 Eq.)	97.08	5.2	8.91	0	0
JP-5 (Gallons)	585,000	299,997	318,308	52,160	53,230

Table 5. Class Capacities (Follows [42])

The following charts are the result of the combination of the Navy's 30-year shipbuilding plan and the lift footprint capacities of the various classes shown above. The total lift capacity of the amphibious fleet was determined by summing individual ship

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[42] (Command, 2010) p.22

capacities for the number of ships defined by the Navy's 30-year shipbuilding plan. The charts illustrate the *lift capability gap* that occurs over time. To show the lift gap that will exist as a result of the LSD-41 and 49 class decommissioning, the analysis ignored a replacement class ship. Changes in the total lift capability are the result of all classes decommissioning per the schedule and the procurement of the LPD-17 San Antonio Class and LHA-8 America Class ships. For reference, three horizontal lines are illustrated to represent the lift requirement associated with 1.0, 1.5, and 2.0 Marine Expeditionary Brigades.

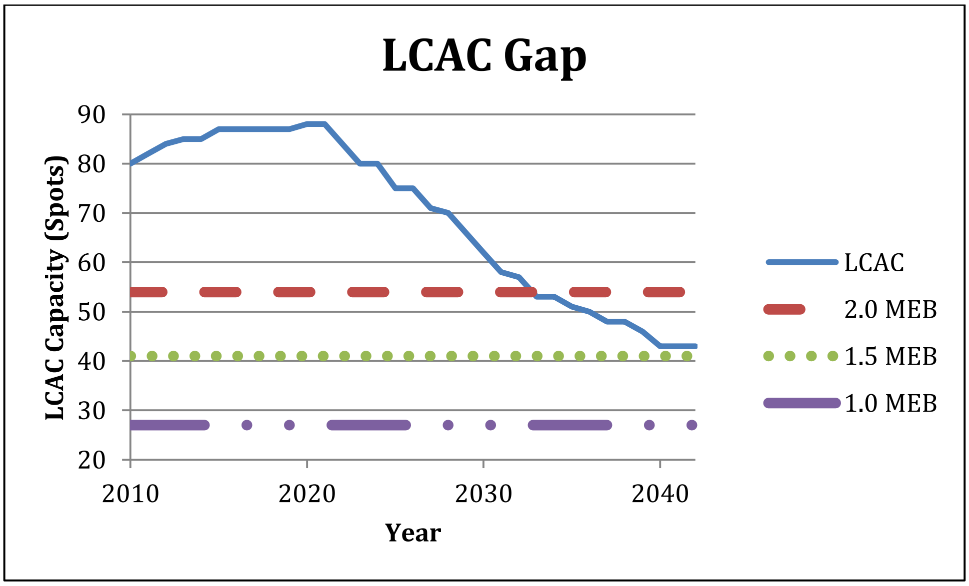

Figure 12. LCAC Lift Gap with LSD Phase-out

The LCAC lift capacity of the amphibious fleet is well above the requirement into the 2030s. LCACs are a vital component of amphibious ship effectiveness, as demonstrated in the recent failures and subsequent redesign of LHA-6. Figure 12 shows the design of the Harpers Ferry Class with well-deck space for two LCACs may be preferred to the Whidbey Island capacity for four.

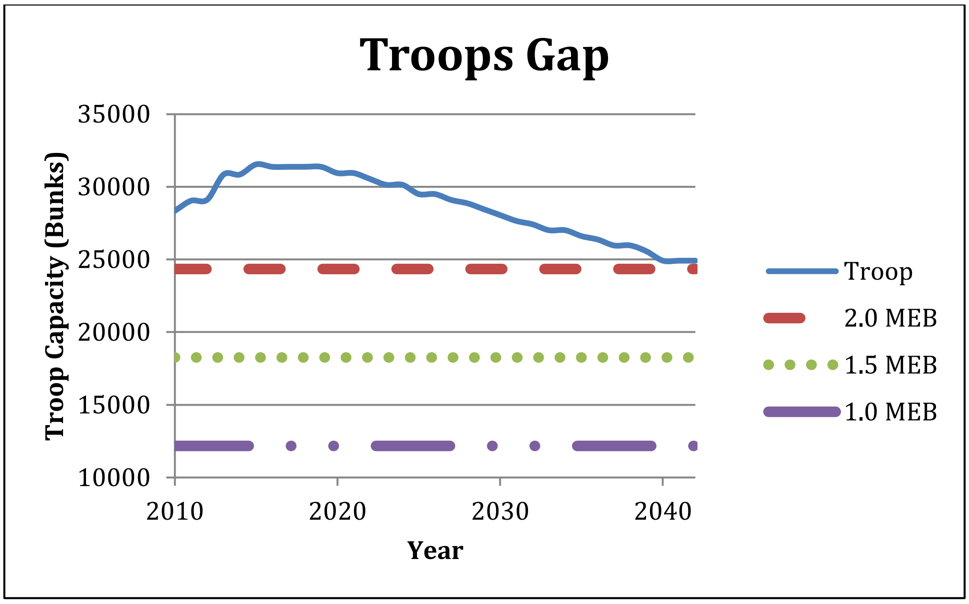

Figure 13. Troop Lift Gap with LSD Phase-out

The Troop lift capacity of the amphibious fleet is well above the requirement until 2040. The amphibious fleet exists primarily to deliver Marines onto hostile shores, but Figure 13 shows no great need exists to improve upon the current troop lift capabilities.

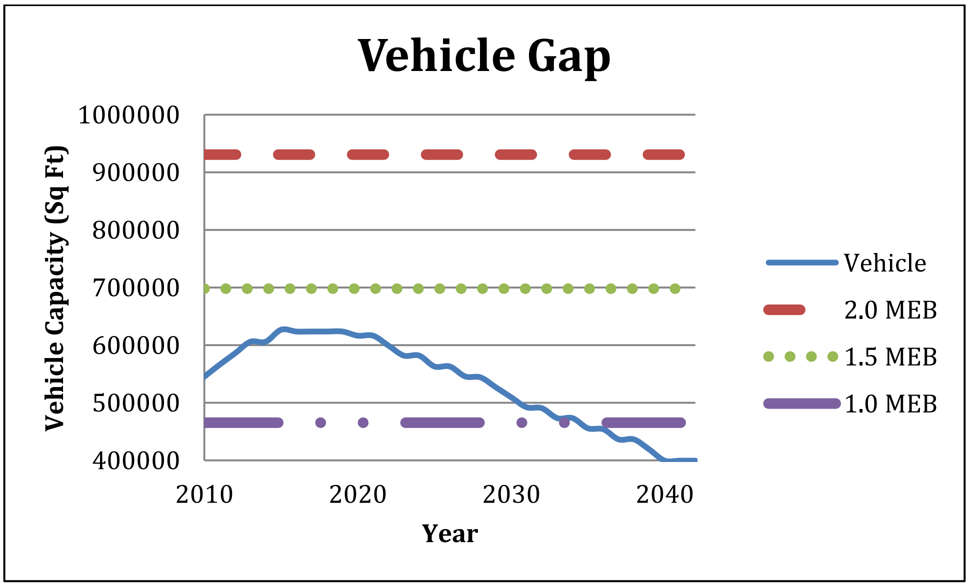

Figure 14. Vehicle Lift Gap with LSD Phase-out

The Vehicle lift capacity of the amphibious fleet never meets the threshold to lift even 1.5 MEBs as shown in Figure 14. Any new-construction materiel solution should address this lift footprint with care.

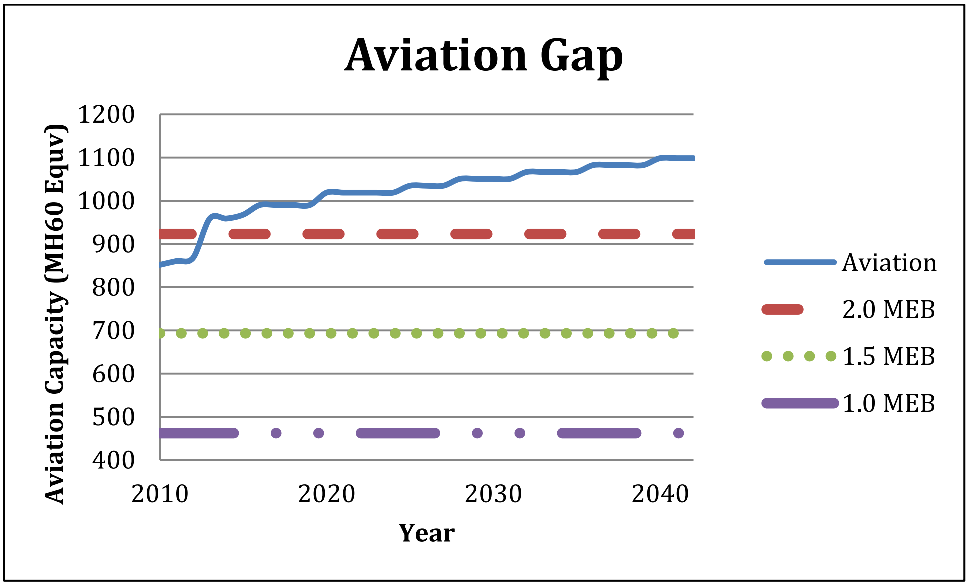

Figure 15. Aviation Lift Gap with LSD Phase-out

The Aviation lift capacity of the amphibious fleet is currently just beginning to meet the requirement. Figure 15 shows that even with the retirement of the LSD-41 and 49 class ships, this lost lift capacity is more than made up for with the planned procurement of six LHA-8 class ships.

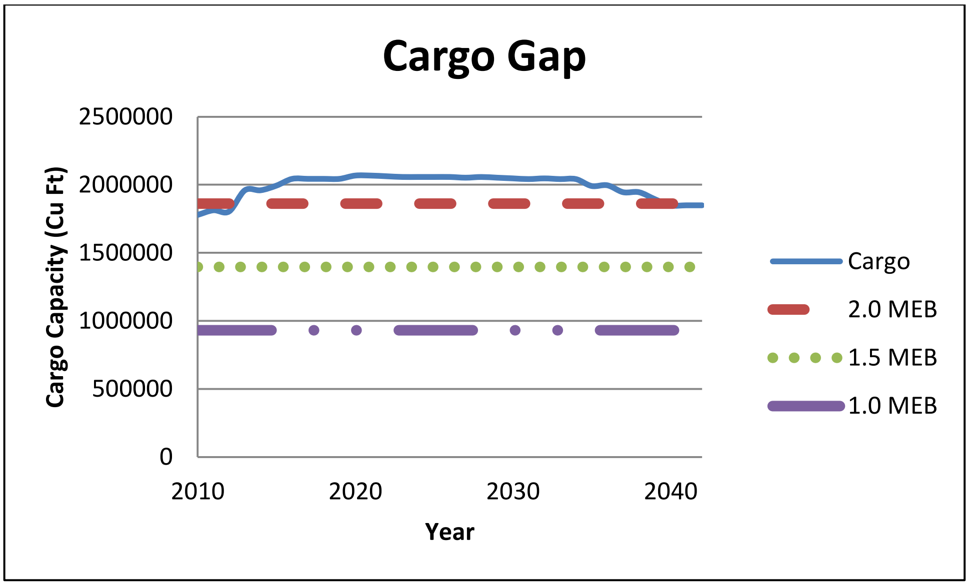

Figure 16. Cargo Lift Gap with LSD Phase-out

Similar to the Aviation lift capacity, the Cargo lift capacity of the amphibious fleet continues to meet the requirement without an LSD replacement class ship as shown in Figure 16.

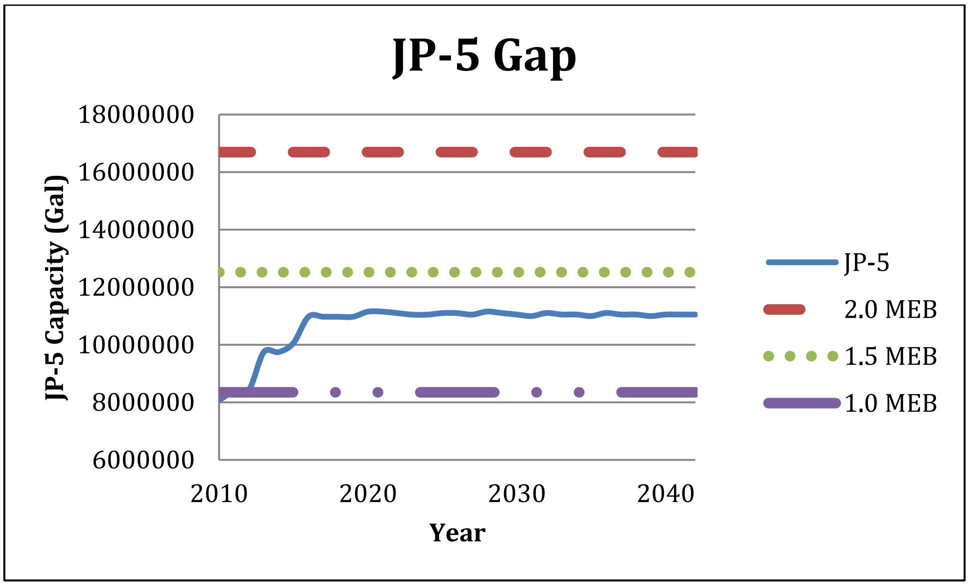

Figure 17. JP-5 Lift Gap with LSD Phase-out

The JP-5 lift capacity of the amphibious fleet shown in Figure 17 never meets the threshold to lift 1.5 MEBs. This is mitigated by the existence of at-sea refueling assets, but becomes of increasing importance when considering independent operations of any future ship.

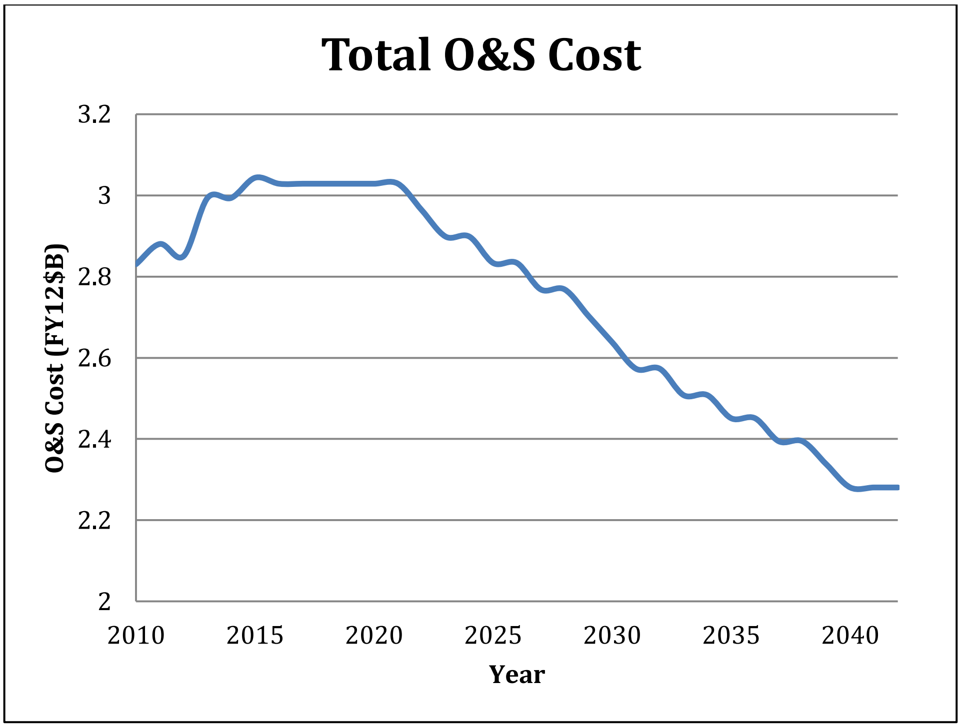

Figure 18. O&S Decrease with LSD Phase-out

Operating and Support (O&S) costs are not one of the six amphibious lift footprints but were analyzed for general comparison purposes of proposed alternatives. Figure 18 shows that over the next ten years, the annual O&S costs of the amphibious fleet are expected to hover around $3 billion.

2. Identified Trade Spaces

The following two major trade-spaces were identified investigating design parameters for potential alternatives:

- Lift Capability vs. Size of Ship vs. Cost of Ship
- Cargo Capacity vs. Vehicle Capacity

The first is larger ships typically cost more money. Fulfilling the entirety of the defined lift requirements, particularly for vehicle square footage, would require either a ship of proportions closer to LHAs and LHDs or a greater number of small ships. To address this tradeoff, new construction solutions of various sizes were considered. The second major trade-space involved the utilization of interior ship space, looking specifically at what percentage of the ship should be dedicated to cargo cubic footage and what percentage to vehicle square footage. It is also important to note that vehicle square footage may be used for cargo in some instances, but the reverse is not always true.

B. ALTERNATIVE GENERATION

In determining alternatives, the project team sought to satisfy many criteria to include using creative thinking to address this very complex problem. These criteria include but were not limited to:

- Is the alternative feasible, meaning does it meet the primary requirements of the amphibious fleet?
- Is the alternative clearly distinct from the other alternatives?
- Does the alternative appear to address all the functions?
- Do the alternatives investigate the trade-spaces?

The following six alternatives, or options, were evaluated:

- *Option 1- LPD-17*: This alternative would maintain an open San-Antonio class production line open and replace the decommissioning LSD class ships with 11 LPDs.
- *Option 2 - LSD(X) clean sheet design*: This alternative would be comparable in size to the current Whidbey Island (LSD-49) class and would replace the decommissioning class with 11 new LSD(X) ships.
- *Option 3 - LSD(XB) clean sheet design*: A new ship larger than the current classes, but smaller than an LPD would mitigate lift capability gaps to a greater extent than the LSD(X). It would replace the retiring class with 11 LSD(XB) ships.
- *Option 4 – LPD(17) Flt X*: This alternative would take advantage of the construction line for LPD-17s but would redesign the LPD utilizing the same hull while investigating the trade-space between cargo and vehicle capacity. It would replace the decommissioning class with 11 LPD(17) Flt X ships.

Each of these four alternatives would maintain a 33 ship amphibious fleet. Two other options were analyzed to challenge the notions of current fleet architectures. A “Big Deck Solution” and “All LPD-17 Solution” analyze the feasibility of ARG or ATF architectures drastically different from today’s model.

- *Option 5- LHA-8*: This alternative would procure 4 America class ships, in addition to the 6 planned for procurement. It posits the possibility of an ARG composed of two big decks. More LHDs could also be procured in the future.

- *Option 6 – All LPD-17*: This alternative supposes a procurement of 19 LPDs. It supposes turning away from the procurement of future big deck ships to analyze the performance of a fleet composed of only small deck ships.

The chosen specifications for the new design alternatives, Options 2, 3, and 4, are defined in Table 6:

Footprints	LSD(X)	LSD(XB)	LPD(17) Flt X
LCAC	2	2	2
Troops	200	530	400
Vehicle	20,000	23,000	28,000
Cargo	5,100	66,000	15,000
Aviation	4.91	6.91	8.91
JP-5	100,000	150,000	318,308

Table 6. Alternative Specs

Defining the lift capacities of the proposed LSD(X), LSD(XB), and LPD(17) Flt X displayed in Table 6 was completed as follows:

1. The LSD(X) design was based on a ship similar in size to the LSD-49 with added aviation capability. It explored the trade-space between cargo and vehicle capacity.
   LSD(X) = (Beam/Length/Displacement)(90 ft. / 602 ft. / 17,500 tons)
   a. LCAC Spots - Nominal modeling solution.
   b. Troops – Decreased to eliminate excess troop capacity shown in gap analysis.
   c. Vehicle – Same as LSD-41 class; deemed acceptable due to current gap.
   d. Cargo – In between LSD-41 and 49 classes in attempt to close expected gap.
   e. Aviation – Increased from 0 of current LSD-41 and 49 classes; necessary to support independent operations.
   f. JP-5 – Increase of 46,770 gal from LSD-49 to support increase in Aviation capacity and decrease current JP-5 gap.
2. The LSD(XB) design was based on a 30% increase similar to that observed between the LDP-4 and LPD-17 classes.
   LSD(XB) = (Beam/Length/Displacement)(94 ft. / 678 ft. / 21,600 tons)

    a. LCAC Spots - Nominal modeling solution.
    b. Troops – Increase based on 30% historic ship size increase.
    c. Vehicle – Increase based on 30% historic ship size increase.
    d. Cargo – Increase based on 30% historic ship size increase.
    e. Aviation – Increase to 6.9 from 0 of current LSD-41 and 49 classes; necessary to support independent operations and larger platform.
    f. JP-5 – Increase of 50,000 gal from LSD(X) to support increase in Aviation capacity and decrease current JP-5 gap.

3. The LPD(17) Flt X design was based on the hull design and measurements of the current San Antonio class and explored the trade-space between cargo and vehicle capacity

   LPD(17) Flt X = (Beam/Length/Displacement)(105 ft. / 684 ft. / 25,000 tons)

    a. LCAC Spots - Nominal modeling solution.
    b. Troops – Decreased to eliminate excess troop capacity shown in gap analysis.
    c. Vehicle - Increase from LPD-17 class to support closing Vehicle capacity gap.
    d. Cargo – Decrease from current LPD-17 class to support increase in Vehicle capacity.
    e. Aviation – Same as LPD-17 Aviation capacity.
    f. JP-5 – Equal to current LPD-17 JP-5 storage capacity.

The six options also defined seventeen alternative ARG architectures that were analyzed separately where appropriate or collectively within their respective options. Each option contains multiple ARG architecture possibilities based on the current and future amphibious ship classes. Three ship combinations were selected for Options 1 through 4 to match current practice. Possible ARG architectures for Options 5 and 6 were limited to those with annual Operating and Support costs equivalent to or cheaper than current costs. This resulted in two-ship combinations for Option 5. Only a five-ship combination for Option 6 was analyzed. Each of the seventeen ARG architectures is listed below.

1. LSD phase out
    - Replace LSDs by building more LPD-17s (**Option #1**)
        - LHD, LPD-17, LPD-17
        - LHA (R), LPD-17, LPD-17
        - LHA-1, LPD-17, LPD-17

2. LSD (X)
    - Build a clean sheet LSD (X) (**Option #2**)
        - LHD, LPD-17, LSD (X)
        - LHA (R), LPD-17, LSD (X)
        - LHA-1, LPD-17, LSD (X)
3. LSD (XB)
    - Build a clean sheet LSD (XB) (**Option #3**)
        - LHD, LPD-17, LSD (XB)
        - LHA (R), LPD-17, LSD (XB)
        - LHA-1, LPD-17, LSD (XB)
4. LPD(17) Flt X
    - Build a modified LPD-17, to replace current LSDs (**Option #4**)
        - LHD, LPD-17, LPD(17) Flt X
        - LHA (R), LPD-17, LPD(17) Flt X
        - LHA-1, LPD-17, LPD(17) Flt X
5. All Big Deck
    - Build more LHA (**Option #5**)
        - LHD, LHD
        - LHD, LHA-1
        - LHD, LHA (R)
        - LHA (R), LHA-1
6. All Small Deck Option
    - LPD-17s only (**Option #6**)
        - LPD-17, LPD-17, LPD-17, LPD-17, LPD-17

Noticeably absent are the first two America Class ships LHA-6 and 7, which were designed and built without a well deck. Despite the tremendous lift capacity of these two ships, the project team did not analyze them for inclusion in future ARG architectures. LPD-4 class ships are retired before these six options come into effect and were thus disregarded in the analysis.

The six options and seventeen ARG architectures are the product of the systems engineering process. They were compared and evaluated against each other with respect to lift capability and performance in accordance with the defined MOEs and MOPs, and then later compared with respect to cost and risk.

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V. PERFORMANCE DECISION ANALYSIS

A. ARG AND MEU ANALYSIS

To allow for comparison, the capability gaps of each of the alternatives were measured against a standard. This standard was a mix of the MEU requirement and current best lift capabilities of the baseline architecture. The lift requirements for LCACs and Troops remained at the USMC lift requirement to avoid any biasing or reward for exceeding the MEU lift requirement. The Vehicle, Cargo, Aviation and JP-5 standards were all set below the MEU lift requirement at the current capability of today's best baseline architecture. The standard for comparison is highlighted and shown in Table 7.

	LCAC (Spots)	**Troop (Bunks)**	**Vehicle (Sq Ft)**	**Cargo (Cu Ft)**	**Aviation (MH 60 Eq)**	**JP-5 (Gal)**
MEU Requirement	6	2578	88640	227048	104.22	1592344
LHD, LPD 17, LSD 49	7	2801	56153	209700	90	850410

Table 7. ARG/MEU Comparison Chart

The footprint lift capacities for the seventeen alternate ARG architectures according to the six developed options were compiled and are displayed in Table 8.

	ARG Configurations	LCAC	Troops	Vehicles	Cargo	Aviation	JP-5
	Requirement	6	2578	56153	209700	90.06	850410
Option #1	LHD, LPD-17, LPD-17	7	3093	59434	193000	98.97	1115488
	LHA(R), LPD-17, LPD-17	6	2858	57760	198000	114.9	1221616
	LHA-1, LPD-17, LPD-17	5	3291	64987	173900	86.23	1044586
Option #2	LHA-1, LPD-17, LSD(X)	5	2793	64107	145000	82.23	826278
	LHA(R), LPD-17, LSD(X)	6	2360	56880	169100	110.9	1003308
	LHD, LPD-17, LSD(X)	7	2595	58554	164100	94.97	897180
Option 3#	LHA-1, LPD-17, LSD(XB)	5	3123	67107	205900	84.23	876278
	LHA(R), LPD-17, LSD(XB)	6	2690	59880	230000	112.9	1053308
	LHD, LPD-17, LSD(XB)	7	2925	61554	225000	96.97	947180
Option #4	LHA-1, LPD-17, LPD(17) Flt X	5	2993	72107	154900	86.23	1044586
	LHA(R), LPD-17, LPD(17) Flt X	6	2560	64880	179000	114.9	1221616
	LHD, LPD-17, LPD(17) Flt X	7	2795	66554	174000	98.97	1115488
Option #5	LHD, LHD	6	3394	35348	250000	162.3	957744
	LHD, LHA-1	4	3592	40901	230900	149.56	886842
	LHD, LHA(R)	5	3159	33674	255000	178.23	1063872
	LHA(R), LHA-1	3	3357	39227	235900	165.49	992970
#6	LPD-17 x 5	10	3490	104400	170000	44.55	1591540

Table 8. MEU Lift Comparison

The comparison of each ARG architecture to the developed standard is shown in Table 9. Negative numbers highlighted in red show a deficiency with respect to LCACs and Troops or a decrease in capacity from the standard for the other four footprints.

	ARG Configurations	LCAC	Troops	Vehicles	Cargo	Aviation	JP-5
	Requirement	6	2578	56153	209700	90.06	850410
Option #1	**LHD, LPD-17, LPD-17**	17%	20%	6%	-8%	10%	31%
	LHA(R), LPD-17, LPD-17	0%	11%	3%	-6%	28%	44%
	LHA-1, LPD-17, LPD-17	-17%	28%	16%	-17%	-4%	23%
Option #2	**LHA-1, LPD-17, LSD(X)**	-17%	8%	14%	-31%	-9%	-3%
	LHA(R), LPD-17, LSD(X)	0%	-8%	1%	-19%	23%	18%
	LHD, LPD-17, LSD(X)	17%	1%	4%	-22%	5%	5%
Option 3#	**LHA-1, LPD-17, LSD(XB)**	-17%	21%	20%	-2%	-6%	3%
	LHA(R), LPD-17, LSD(XB)	0%	4%	7%	10%	25%	24%
	LHD, LPD-17, LSD(XB)	17%	13%	10%	7%	8%	11%
Option #4	**LHA-1, LPD-17, LPD(17 FLX)**	-17%	16%	28%	-26%	-4%	23%
	LHA(R), LPD-17, LPD(17 FLX)	0%	-1%	16%	-15%	28%	44%
	LHD, LPD-17, LPD(17 FLX)	17%	8%	19%	-17%	10%	31%
Option #5	**LHD, LHD**	0%	32%	-37%	19%	80%	13%
	LHD, LHA-1	-33%	39%	-27%	10%	66%	4%
	LHD, LHA(R)	-17%	23%	-40%	22%	98%	25%
	LHA(R), LHA-1	-50%	30%	-30%	12%	84%	17%
#6	**LPD-17 x 5**	67%	35%	86%	-19%	-51%	87%

Table 9. MEU Lift Comparison by Percentage

These percentage comparisons were then compiled into rankings according to each footprint. For example, each of the seventeen ARG architectures has capacity of 3, 4, 5, 6, 7, or 10 LCACs. The architecture with ten was assigned a ranking of 1 and those with four all tied for 2nd. JP-5 was not considered a significant factor for this portion of the analysis and was removed from consideration. Rankings across the footprints were added to give a rank sum category for each ARG architecture. The lowest score identified the architecture with the most lift. The results are shown in Table 10.

ARG Configurations	LCAC	Troops	Vehicles	Cargo	Aviation	Rank Sum
LHD, LHD	3	3	16	2	3	27
LHD, LHA-1	5	1	14	4	4	28
LHD, LHA(R)	4	6	17	1	1	29
LHA(R), LHA-1	6	4	15	3	2	30
LPD-17 x 5	1	2	1	13	15	32
LHD, LPD-17, LSD(XB)	2	10	7	5	9	33
LHA-1, LPD-17, LSD(XB)	4	7	3	7	13	34
LHA(R), LPD-17, LSD(XB)	3	14	8	4	6	35
LHD, LPD-17, LPD-17	2	8	9	9	8	36
LHA(R), LPD-17, LPD-17	3	11	11	8	5	38
LHD, LPD-17, LPD(17), FLT X	2	13	4	11	8	38
LHA-1, LPD-17, LPD-17	4	5	5	12	12	38
LHA(R), LPD-17, LPD(17) FLT X	3	16	5	10	5	39
LHA-1, LPD-17, LPD(17) FLT X	4	9	2	15	12	42
LHD, LPD-17, LSD-49	2	12	13	6	11	44
LHD, LPD-17, LSD(X)	2	15	10	14	10	51
LHA(R), LPD-17, LSD(X)	3	17	12	13	7	52
LHA-1, LPD-17, LSD(X)	4	13	6	16	14	53

Table 10. Un-weighted MEU Lift Rank

The average sum rank for each option was calculated for the final MEU lift comparison. The two top performers were Option 5: the all Big Deck alternative, and Option 6: the all Small Deck LPD-17 alternative. These ARG architectures do not currently deploy in the fleet. The entire rankings are shown in Table 11:

Alternative	#	Rank
Big Deck	5	28.50
Small Deck	6	32.00
LSD (XB)	3	34.00
LPD-17	1	37.33
LPD (17) Flt X	4	39.67
Baseline		44.00
LSD (X)	2	52.00

Table 11. MEU Lift Un-weighted Ranks

As all lift footprints are not perfectly equal to one another, a weighting factor developed by the project team was assigned to each. LCACs were deemed the most important as they represent the fundamental method of amphibious delivery. The other weighting factors are shown in Table 12.

Footprint	LCAC	Troops	Vehicles	Cargo	Aviation
Weighting	1.00	0.85	0.75	0.90	0.60

Table 12. Footprint Weights

These weighting factors were applied to the original percentage differences as compared to the standard thereby placing greater emphasis on meeting the LCAC requirement than the vehicle requirement and so forth. The weighted rankings are shown in Table 13.

ARG Configurations	LCAC	Troops	Vehicles	Cargo	Aviation	Sum
LHD, LPD-17, LPD-17	2	8	9	8	8	35
LHA(R), LPD-17, LPD-17	3	11	11	7	5	37
LHA-1, LPD-17, LPD-17	4	5	5	10	11	35
LHA-1, LPD-17, LSD(X)	4	12	6	14	13	49
LHA(R), LPD-17, LSD(X)	3	16	12	11	7	49
LHD, LPD-17, LSD(X)	3	14	10	12	10	49
LHA-1, LPD-17, LSD(XB)	4	7	3	6	12	32
LHA(R), LPD-17, LSD(XB)	3	13	8	4	6	34
LHD, LPD-17, LSD(XB)	2	10	7	5	9	33
LHA-1, LPD-17, LPD(17) FLT X	4	9	2	13	11	39
LHA(R), LPD-17, LPD(17) FLT X	3	15	5	9	5	37
LHD, LPD-17, LPD(17) FLT X	2	12	4	10	8	36
LHD, LHD	3	3	15	2	3	26
LHD, LHA-1	5	1	13	4	4	27
LHD, LHA(R)	4	6	16	1	1	28
LHA(R), LHA-1	6	4	14	3	2	29
LPD-17 x 5	1	2	1	11	14	29

Table 13. Weighted MEU Lift Rank

Applying the weighting factors to the analysis did not affect the ranked order of the alternatives, but did increase the margin by which Options 5 and 6 stood out as shown in Table 14:

Alternative	#	Rank
Big Deck	5	27.50
Small Deck	6	29.00
LSD (XB)	3	33.00
LPD-17	1	35.67
LPD (17) Flt X	4	37.33
LSD (X)	2	49.00

Table 14. MEU Lift Weighted Ranks

Figure 19 gives a visual representation of the change in lift capability compared to the standard for each option. Each option can lift more of a MEU than the standard with the exception of the LSD(X).

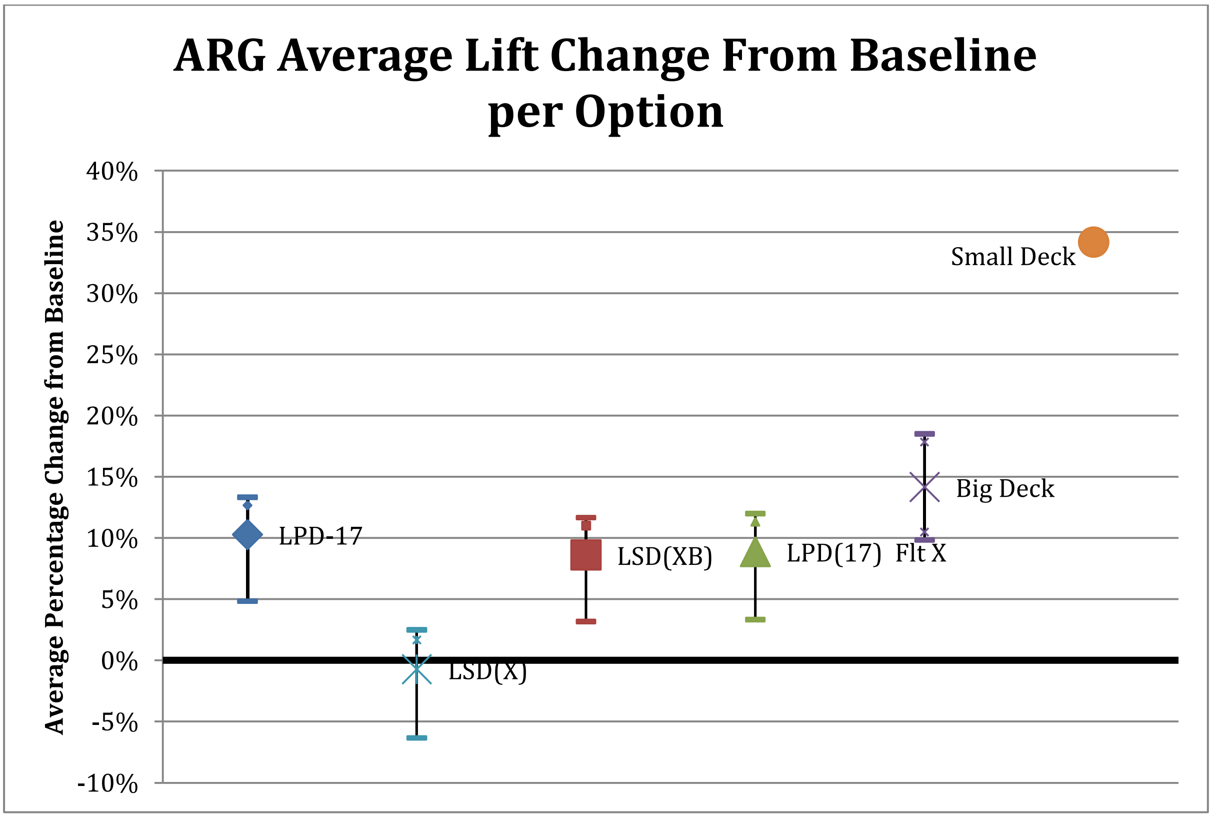

Figure 19. ARG Lift Comparison

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B. ATF AND MEB ANALYSIS

In the same manner as the gap analysis was performed, each of the six options was analyzed for overall MEB lift capability. The MEU and MEB lift requirements represent a roughly scalable problem, so the methodology of the analysis was conducted in a different manner from the MEU analysis. Because the 2.0 MEB lift requirement applies to the entirety of the amphibious fleet, not individual ARG architectures, the MEB lift analysis was instead illustrated over decades. Each of the six options assumed a procurement schedule detailed in the cost portion of the report (Section III). Using this procurement schedule and the defined lift footprints, analysis of MEB lift capacity was conducted.

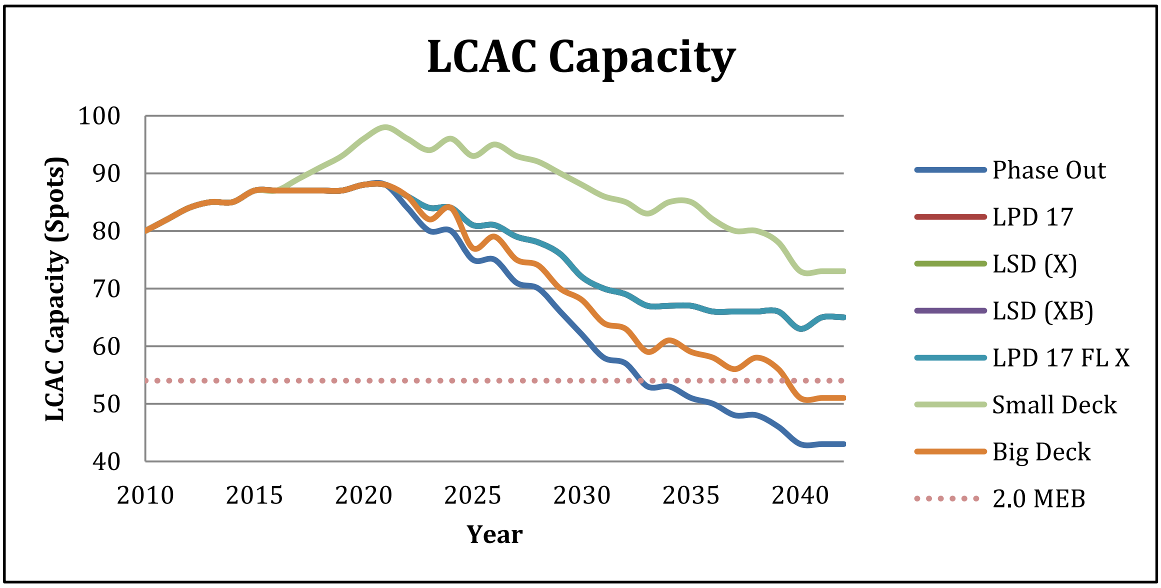

Figure 20. Alternatives Comparison – LCAC

Figure 20 depicts the difference in LCAC carrying capacity that develops when the alternative solutions come on line in the 2020s. All options are equal with the exception of Option 5: the all Big Deck alternative, which would drop below the requirement in the late 2030s and Option 6: the Small Deck Option, which has the greatest capacity.

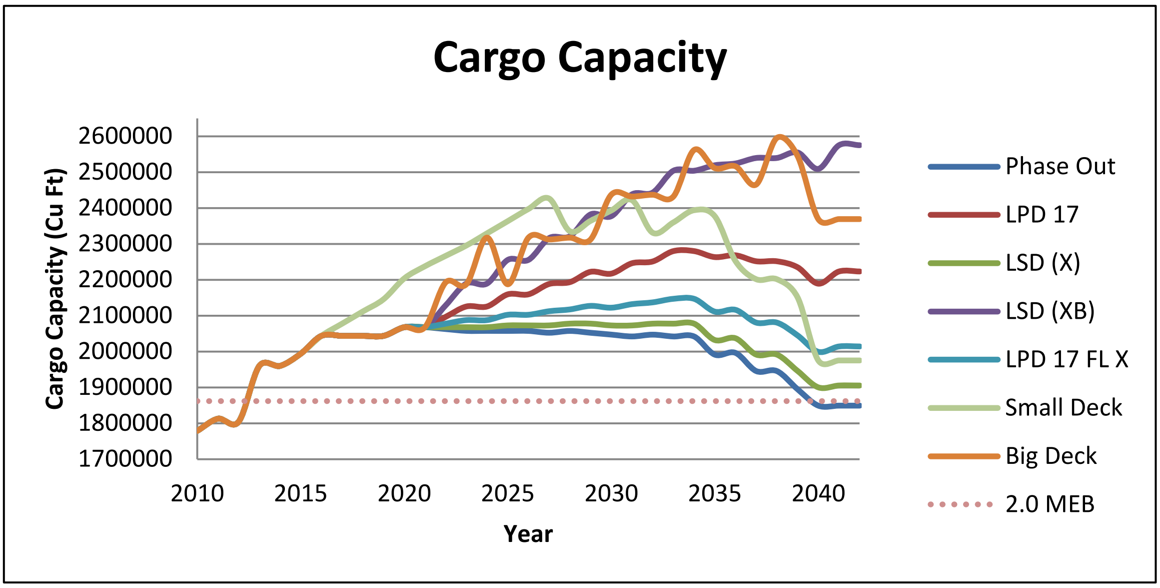

Figure 21. Alternative Comparison – Cargo

Figure 21 depicts a difference of cargo carrying capacity for each option with a difference occurring after 2022 and the LSD (XB) and all Big Deck Options performing the best.

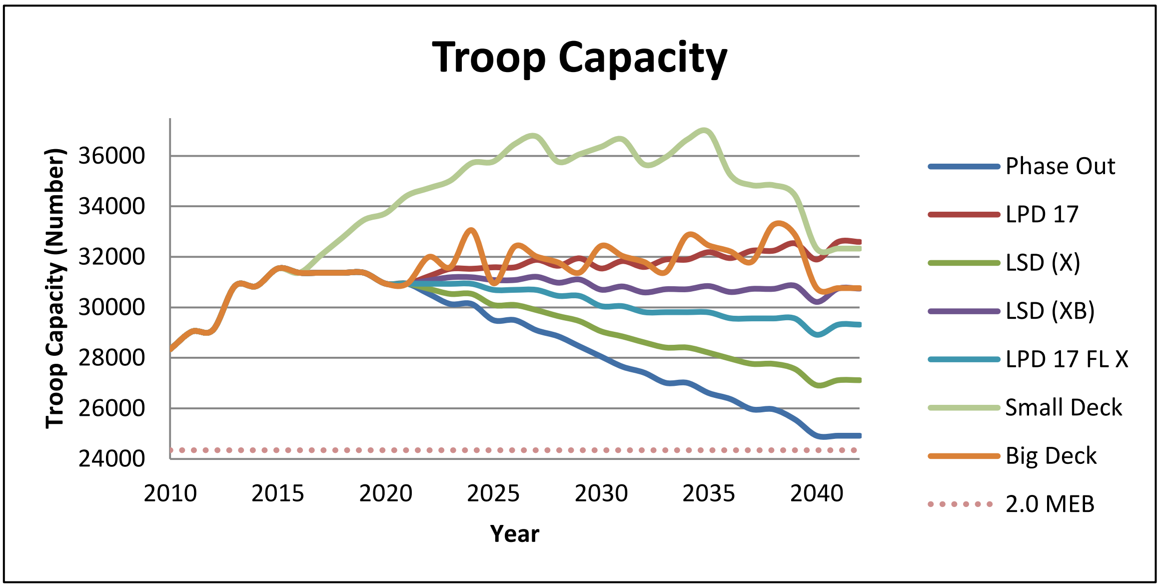

Figure 22. Alternative Comparison – Troop

Figure 22 depicts a difference of troop carrying capacity for each option with Option 1: the LPD-17, being the best choice.

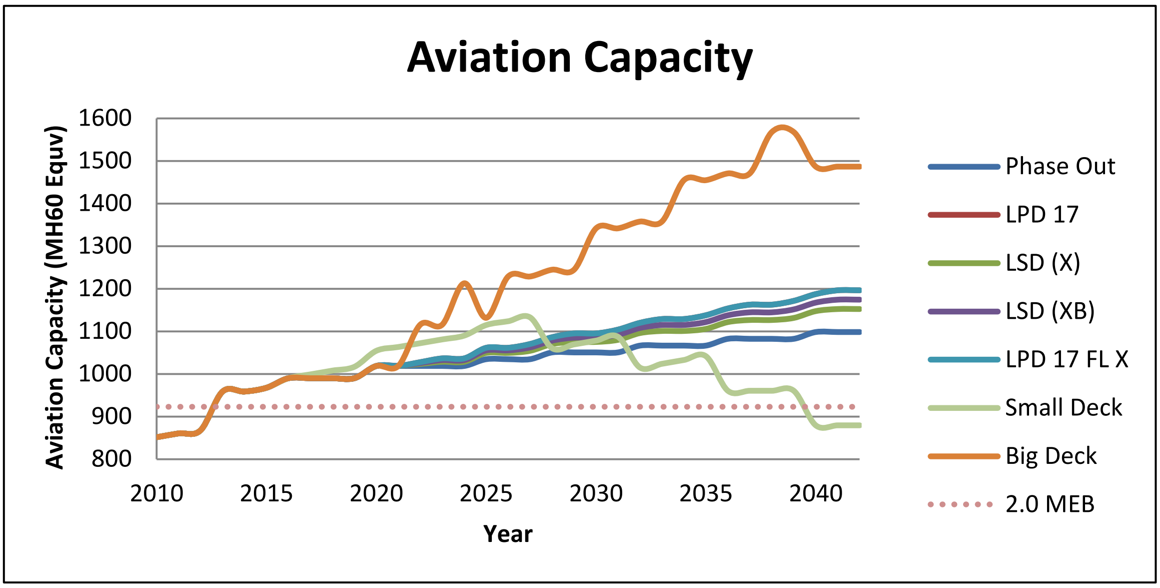

Figure 23. Alternative Comparison – Aviation

Figure 23 depicts a difference of aviation carrying capacity for each option with Option 5: the Big Deck alternative, significantly outperforming all other options.

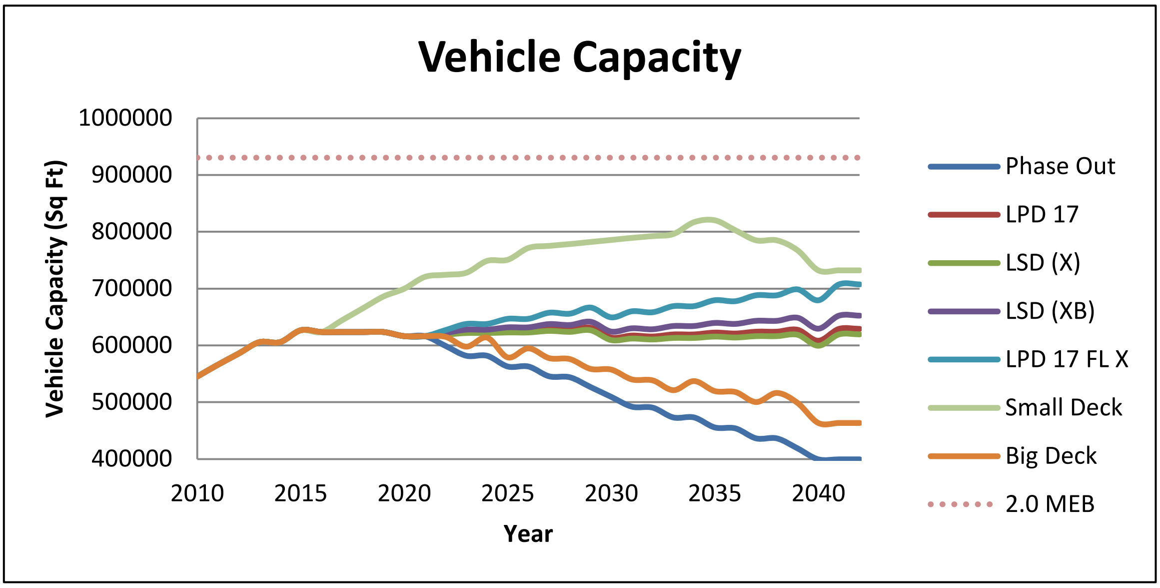

Figure 24. Alternative Comparison – Vehicle

Figure 24 shows that no option analyzed will meet the required 2.0 MEB lift requirement for vehicle carrying capacity. The Big Deck alternative (Option 5) performs the worst and the Small Deck alternative (Option 6) lifts the most.

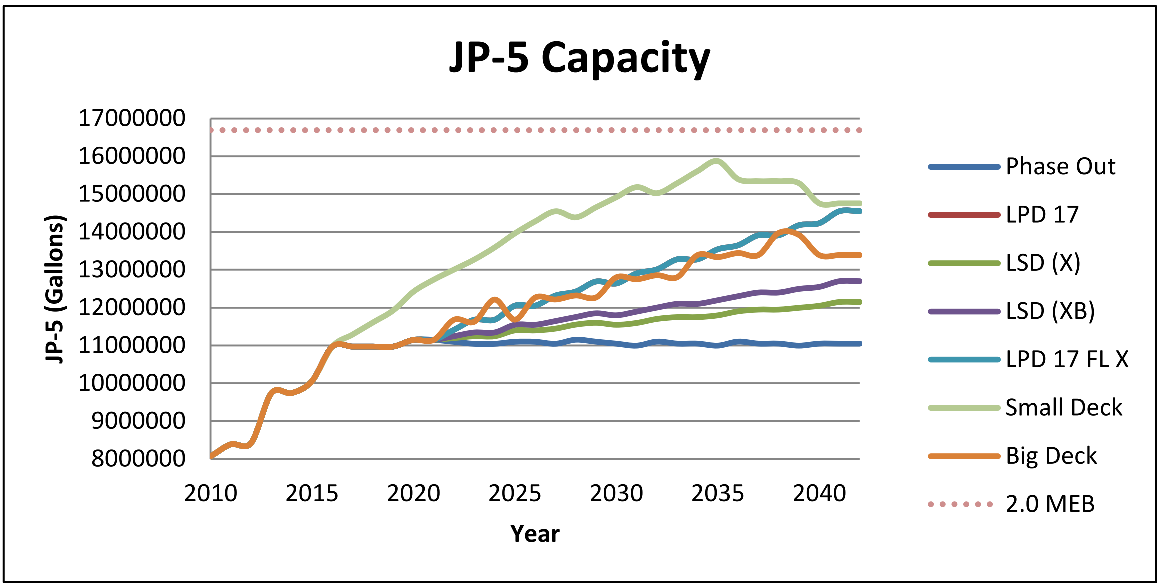

Figure 25. Alternative Comparison - JP-5

The graph depicts a difference of JP-5 carrying capacity for each option. All options increase the capacity over current levels.

To combine the comparisons of alternatives across the footprint categories, the MEB analysis used the same weighting order as the MEU analysis. The order of footprint importance was stated as LCAC capacity, cargo capacity, troop capacity, aviation capacity, vehicle capacity and finally JP-5 capacity. The six options were ranked from best to worst in each category based on lift capacity in year 2042. The remaining options were then ranked in each category and summed as shown in Table 15. The final result was that LPD-17 option was deemed best, LPD(17) Flt X second, LSD (XB) third, LSD (X) fourth, and Big deck last.

	LPD-17	LSD(X)	LSD(XB)	LPD(17) FLT X	Big Deck	Small Deck
LCAC	2	2	2	2	3	1
Cargo	3	6	1	4	2	5
Troops	1	5	3	4	3	2
Aviation	2	4	3	2	1	5
Vehicle	4	5	3	2	6	1
JP-5	2	5	4	3	2	1
SUM	14	27	16	17	17	15

Table 15. MEB Lift Ranks

C. SIMULATION DESIGN

1. Purpose

The goal of simulation was to gain insight regarding the operational effects caused by adding or removing lift capability from an ARG and/or a platform within an ARG such as the LSD. This enabled decisions to be made regarding how much lift capacity a prospective follow-on ship to the current LSD classes would need in order to maintain or exceed current operational capability.

The simulation was constructed to model the high level aspects of amphibious operations only. Namely, throughput was the measure the model was designed to examine. As discussed in the MOE Generation Section, throughput was the number of troops and cargo an ARG was able to transfer between the ships and beach per unit time. Therefore, the Measures of Performance (MOP) extracted from the simulation were the number of troops transported per hour (MOP_t) and the cargo square footage transported per hour (MOP_c). These two MOPs were used to evaluate the effectiveness of each configuration under the assault and HADR scenarios.

2. Parameters

The simulation was built using ExtenSim8 software. Its features were leveraged to produce a discrete event queuing model that simulated the interactions between the ships and connecters to shore that occur during an amphibious operation. The model was created such that the user could manipulate the following variables influencing throughput:

- Number of LCACs
- Number of A/C (CH-53 equivalency)
- Number of A/C spots
- Transit time (A/C and LCAC)
- Total Troop Capacity
- Total Cargo Capacity (sq. ft.)[43]
- Total JP-5 Capacity (gallons)
- Transit time for either platform (triangular distributions)

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[43] Information gathered for amphibious ships' cargo capacity and vehicle capacity were typically given in two different units from various sources: cubic ft. and square ft. respectively. Therefore, the decision was made to assume that cargo storage spaces were 10 ft. high in order to convert cubic ft. to square ft.

The remaining variables were hard-programmed into the simulation. Although the following variables were adjustable if necessary, the Design of Experiment (DOE) was not constructed in a manner that would investigate a range of values for these factors:

- LCAC A_o = .85
- A/C A_o = .5
- LCAC JP-5 consumption rate = 1250 gallons /hr.
- A/C JP-5 consumption rate = 441.75 gallons /hr.
- LCAC load time = triangular distribution
    - Most Frequent =43 min
    - Min = 33 min
    - Max = 180 min
- LCAC unload time = triangular distribution
    - Most Frequent = 19 min
    - Min = 12 min
    - Max = 30 min
- LCAC refueling time = triangular distribution
    - Most Frequent = 15 min
    - Min = 10 min
    - Max = 30 min
- A/C load time = triangular distribution
    - Most Frequent = 5 min
    - Min = 2 min
    - Max = 15 min
- A/C unload time = triangular distribution
    - Most Frequent = 3 min
    - Min = 2 min
    - Max = 5 min
- A/C Refueling time = triangular distribution
    - Most Frequent = 15 min
    - Min = 10 min
    - Max = 30 min
- Repair times for either platform = 120 min

All of the values for these parameters were gathered from unclassified sources such as UNCLAS DOD publications, NATOPs manuals and Subject Matter Experts' (SME) operational experience. Brief sensitivity analysis was conducted upon the completion of model construction to assess the potential bias that inaccurate parameters would inflict on the results. The differences found by changing the parameters by 50% in either direction had negligible effects. Changing the parameter values altered the magnitude of the results, however, the same trends in the data were observed. Since the purpose of this simulation was to examine points of diminishing return by adding or subtracting lift capabilities from an ARG, the end time value recorded was not significant in itself. Rather, the point where added capability did not yield a higher observed rate of transfer was meaningful.

3. Process

For the purposes of the experiment, ExtendSim8 *items* were used to represent LCACs and CH-53s transiting between the ARG ships and shore. The fundamental sequence was simple: (1) LCACs and CH-53s, used as connectors, started at the ship and loaded cargo, (2) transited to the beach once all of the cargo was loaded, (3) unloaded the cargo, and (4) returned to the ship. While returning to the ship there was a chance the connector would need repairs in accordance with the platform's operational availability (A_o). If it needed repairs, it would experience a two-hour delay before rejoining the other connectors transporting goods. If the connector needed fuel, it would experience a refueling delay in accordance with the platform type before reloading and transiting again. Before each connector loaded, it checked the amount of cargo or troops left to carry to the beach. If nothing was left to transport the connector was stowed. Figure 26 is a process model that represents the simulation's algorithm.

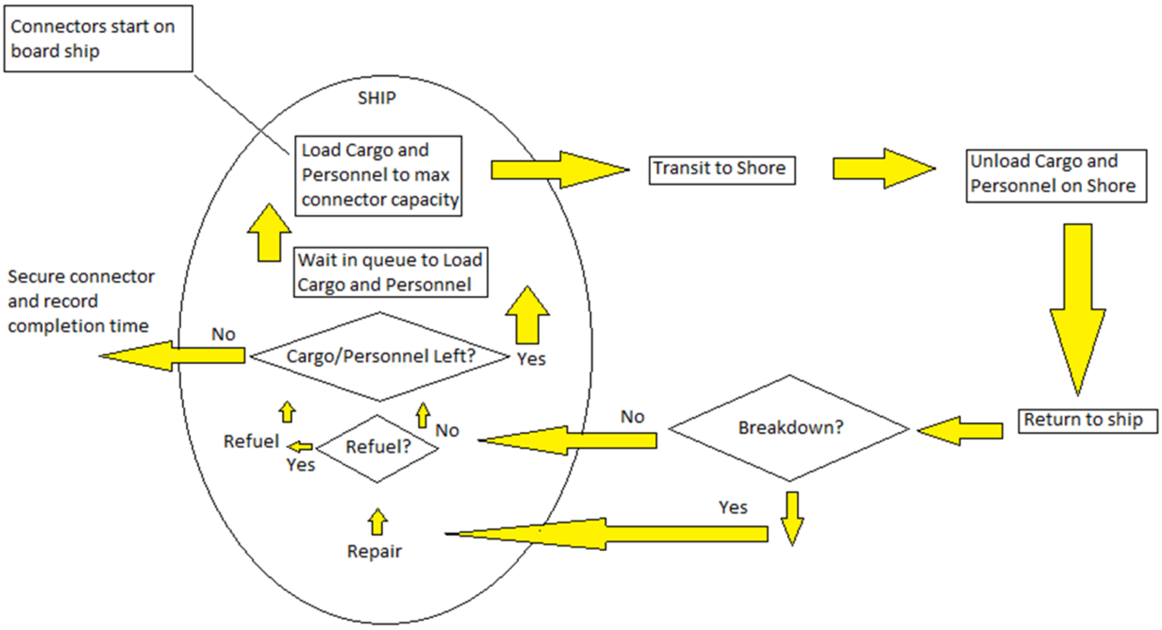
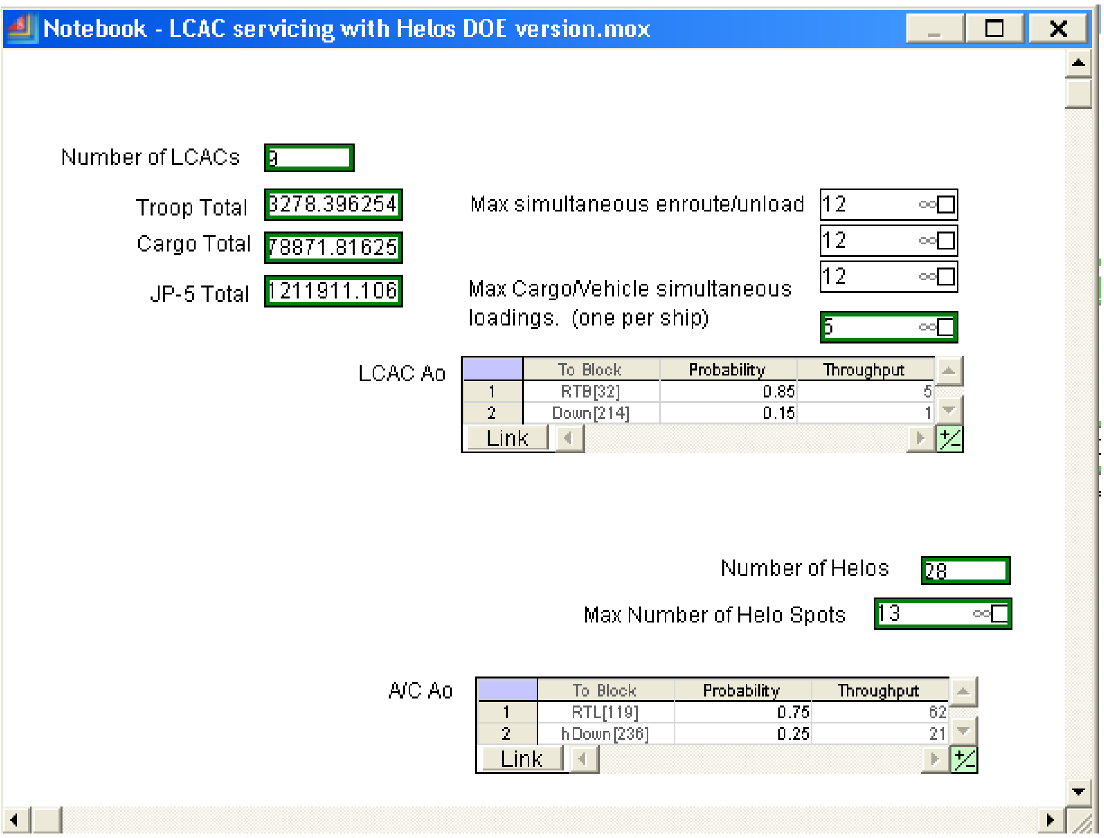


Figure 26. Simulation Process Model

a. *Data Input*

As previously noted, the simulation was constructed in a manner that allowed a user to manipulate the parameters as necessary to gain insights on amphibious operations. There were two ways in which parameter data could be entered into the simulation. Method 1 involved manually changing the simulation blocks' parameters to fit the needs of a user. All of the parameters that were deemed dynamic to any degree were gathered into a Notebook. The Notebook is a feature in the software that allowed a user quick access to the fields for various blocks that manipulate parameters as shown in Figure 27.



Number of LCACs: 9

Troop Total: 3278.396254

Cargo Total: 78871.81625

JP-5 Total: 1211911.106

Max simultaneous enroute/unload: 12 ☐

12 ☐

12 ☐

Max Cargo/Vehicle simultaneous loadings. (one per ship): 5 ☐

LCAC Ao

	To Block	Probability	Throughput
1	RTB[32]	0.85	5
2	Down[214]	0.15	1

Number of Helos: 28

Max Number of Helo Spots: 13 ☐

A/C Ao

	To Block	Probability	Throughput
1	RTL[119]	0.75	62
2	hDown[236]	0.25	21

Figure 27. Example of Parameter Entry Point via Notebook Feature

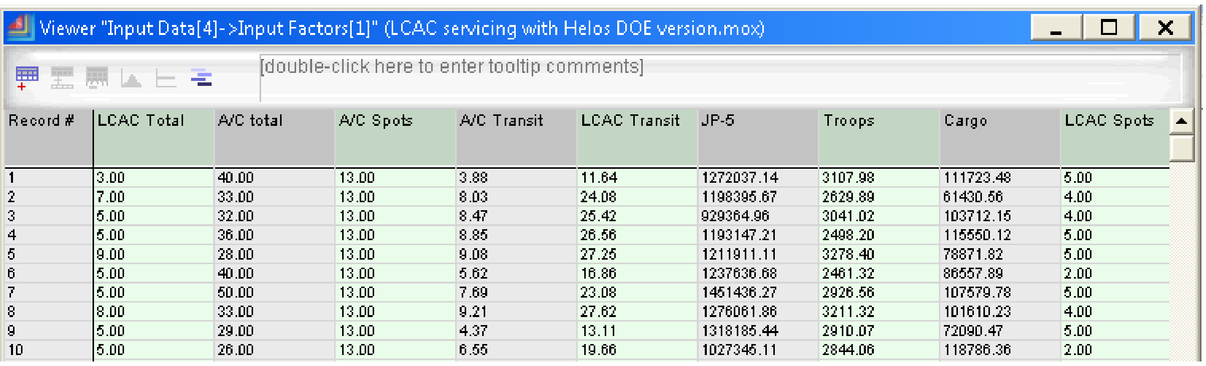
Method 2 differed in the sense that the parameters were assigned values from an "input database." The advantage of this method will be discussed below.

b. *Data Output*

The results of each simulation run total time to completion were written to an output database. If the simulation ran 50 times, then 50 rows of completion times were stored in the output database. These figures were based on the design inputs Method 1 or 2 and saved for further analysis in the following section (Chapter V Section D).

4. Execution

There were two versions of the model. The only difference between the two versions was in the data input. Version 1 supported Method 1 of data input. This result of initial model development allowed a user to input any values that represented a given ARG Architecture. This version was used to investigate the points of inflection in order to determine design parameters for the chosen alternatives. Version 2 used Method 2 of data input. This method allowed a user to feed mass quantities of parameters from a database into the simulation. Each row of the database shown in Figure 28 represented inputs associated with the given architecture that was examined.



Record #	LCAC Total	A/C total	A/C Spots	A/C Transit	LCAC Transit	JP-5	Troops	Cargo	LCAC Spots
1	3.00	40.00	13.00	3.88	11.64	1272037.14	3107.98	111723.48	5.00
2	7.00	33.00	13.00	8.03	24.08	1198395.67	2629.89	61430.56	4.00
3	5.00	32.00	13.00	8.47	25.42	929364.96	3041.02	103712.15	4.00
4	5.00	36.00	13.00	8.85	26.56	1193147.21	2498.20	115550.12	5.00
5	9.00	28.00	13.00	9.08	27.25	1211911.11	3278.40	78871.82	5.00
6	5.00	40.00	13.00	5.62	16.86	1237636.68	2461.32	86557.89	2.00
7	5.00	50.00	13.00	7.69	23.08	1451436.27	2926.56	107579.78	5.00
8	8.00	33.00	13.00	9.21	27.62	1276061.86	3211.32	101610.23	4.00
9	5.00	29.00	13.00	4.37	13.11	1318185.44	2910.07	72090.47	5.00
10	5.00	26.00	13.00	6.55	19.66	1027345.11	2844.06	118786.36	2.00

Figure 28. Database of Alternate ARG Architecture Parameters

This method of input facilitated the use of a Design of Experiments (DOE) that allowed for the examination of ranges for each of the variables that are discussed in the analysis of Section L. This method also allowed for many specific ARG architectures to be examined without having to manually input the data each time the need arose to investigate a new ARG.

Two create blocks worked in parallel and had their own sequence of blocks that followed the process flow described above. Each create block injected a predetermined number of items that represented either LCACs or CH-53's based on data input parameters. After item initialization, the items loaded cargo or troops by taking resources from resource pools that contained the total amount of troops or cargo present in a given ARG architecture. This was the first point in which items experience queuing behavior. The maximum number of items that could be loaded at a time was constrained by the maximum number of loading spots for the platform type in a given ARG architecture. Therefore, if all of the loading spots were full, additional empty connectors waited to load in a queue. The loading process for either platform was altogether simulated by attaching a resource queue to an activity block.

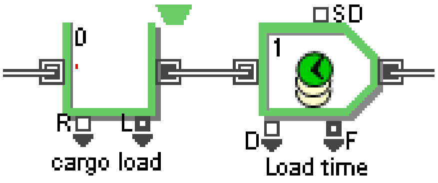


Figure 29. Cargo Load and Delay Method

This combination simulated what fundamentally happens when LCACs or aircraft load. Cargo is being taken, which the resource queue block on the left of Figure 29 represents, and time transpires while the loading takes place, which is represented by the activity block on the right. Each item took the maximum amount of troops or cargo the platform it represented could carry until either resource had dropped below the max load. At this point the simulation was designed to inform the next item due to load only to carry what remained. This was done via an equation block that allowed code to be programmed into the simulation. Any item still looking to load cargo would see that resources were depleted and would exit the simulation.

The round trip of the connectors between ships and shore was represented by activity blocks that delayed the item from moving for a set period of time. Transit times were an input variable. The user could manipulate the transit times according to a desired distance from land, either directly at the activity blocks or through database input for Version 2. Platforms would pass through the repair loop in accordance with the set A_o of each platform. The A_o values were set in decision blocks directly following the off-load activity block. The A_o was used to represent the probability that a connector would be able to transport cargo to and from the ship. A random number generator embedded in the software directed the item to either proceed on the normal path or to proceed to a repair path as shown in Figure 30.

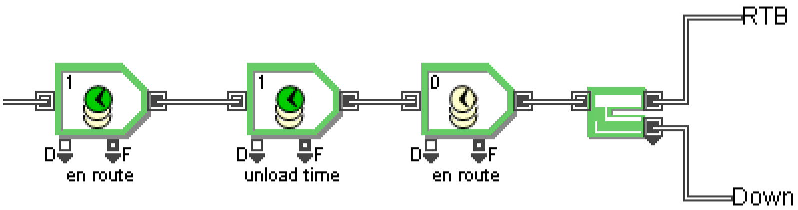


Figure 30. Failure Decision

There was no maximum number of platforms that could be repaired simultaneously. Each time a craft passed through this loop, the refuel time was reset as the team assumed a craft would take advantage of this staging time to refuel as well as repair as shown in Figure 31.

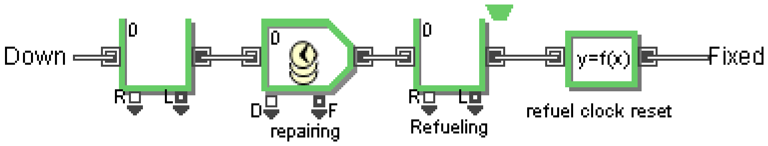


Figure 31. Repair Loop

Platforms' fuel levels were tracked by tracking the time that had elapsed since a particular platform had refueled. All items were initialized at the beginning of the simulation as having zero minutes since last refueling. The time for each item was tracked in an attribute set to each item. Once the time reached a platform's max time to refuel, the platform went through the refueling loop of the simulation, shown in Figure 32, before rejoining the off-load effort.

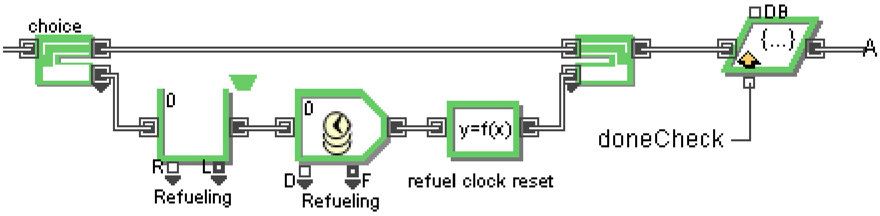


Figure 32. Refueling Loop

The method that accounted for crafts' refueling and the time delay associated with refueling was constructed in the same manner as the load delay. Each platform that refueled received fuel from a JP-5 resource pool. The amount of JP-5 in the pool was consistent with the amount carried by the ARG architecture being analyzed. The maximum amount of connectors that could refuel simultaneously was equal to the amount of launch spots there were in the simulation. However, a connector did not use a launch spot in this simulation when refueling. In essence, this implied that one connector could refuel while another loaded and launched simultaneously for every launch spot in the ARG.

Items that returned to the blocks representing the ship passed through a "stuff left" check to ensure there were items remaining to transport. If there were not, the item exited the simulation. When the last item exited the simulation the final stowage time was recorded. This represented the total time the simulation took to empty all of the contents of the vessel ashore and transit back to the ship. The completion time was written to a database. Each row in the database represented a time associated with a given simulation run number.

5. Assumptions

There were many assumptions that must be noted in order to provide the strengths and limitations of this model. The assumptions may have led to shorter overall completion times, but this should not have significantly influenced the relationships between the sets of factors examined.

Operational Availability: System failures were not taken into account until the connector was returning to its ship. The simulation assumed that any malfunction en route to or from the shore would be tolerable until the ship is reached.

Maintenance: The model assumed that each time a vessel needed repair it would be refueled in the process. Therefore, each time an item broke down and went through the repair loop it also received JP-5 from the resource pool and had its refueling clock reset.

Aircraft: All aircraft contributing to lift were converted to CH-53 equivalent aircraft. This conversion served two purposes. In most cases, the publications used to determine the lift capacities of the ship provided aircraft capacities in a specific platform equivalency. Therefore, the CH-53 equivalencies provided by the 2010 Amphibious Ship Recapitalization CBA conducted by OPNAV N8F in conjunction from information acquired from Jane's Fighting Ships and the Federation of American Scientists were used in the simulation and other facets of the project where aircraft lift capability was examined. The aircraft equivalencies provided by the sources indicated how many spots one aircraft may use when compared to a base aircraft. With that, the assumption was made that the lift capacity equivalencies were equal to the spot equivalencies.

D. SIMULATION ANALYSIS

1. Introduction

The purpose of the Performance and Effectiveness Analysis was to examine the data provided by the simulation in order to answer the following major questions:

1. Which of the seventeen derived ARG Architecture performed the best in a given scenario?
2. Which design trade-space factors influenced the results the most?
3. Which lift capability combination was associated with the most robust, theoretical ARG Architecture the Navy could achieve?

An initial set of data was extracted using Version 1 of the simulation discussed above. This first data set was used to examine the effects of adding lift capability to an ARG. Points of diminishing returns point to an optimum number that maximizes capability. Subsequently, lift capability design considerations were scoped for both the potential new construction designs (Options 2, 3, and 4) and proposed ARG configurations using these results. Simulation results were used to aid in the design of the new construction alternatives as well as aid in comparing all the alternatives in common scenarios. To aid in alternative design, the point examined was the point of diminishing returns in the mean total completion time, in hours, which referred to the mean time elapsed for a number of simulation runs with specific input settings. The quantity for design factors were adjusted one at a time while holding other design factors constant in order to extrapolate the effects caused by changing a given factor. Table 16 shows the effects of adding LCACs to an ARG:

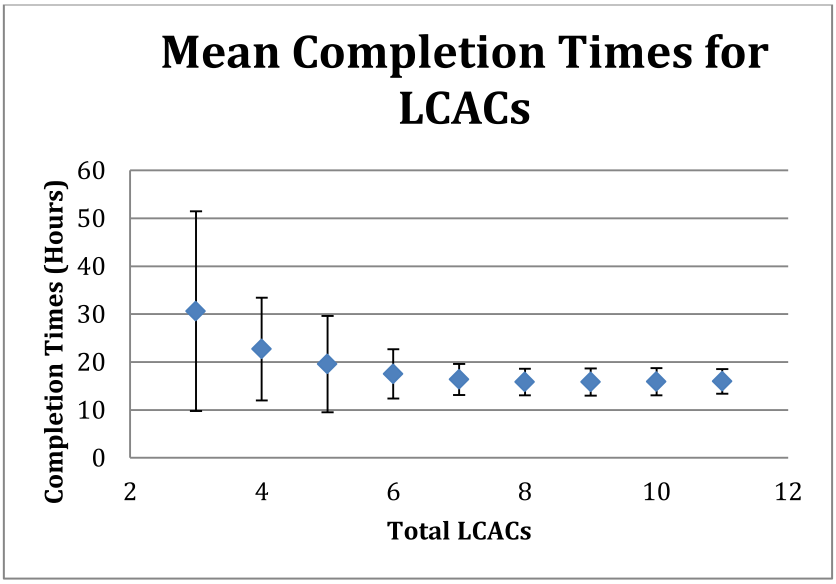


Figure 33. Mean Completion Times for LCACs

Figure 33 shows a clear point of diminishing capability returns at around six LCACs in a three ship ARG carrying the requisite amount of Marines and their equipment making a MEU. For this reason, the six alternatives proposed each came with well-decks designed for two LCACs.

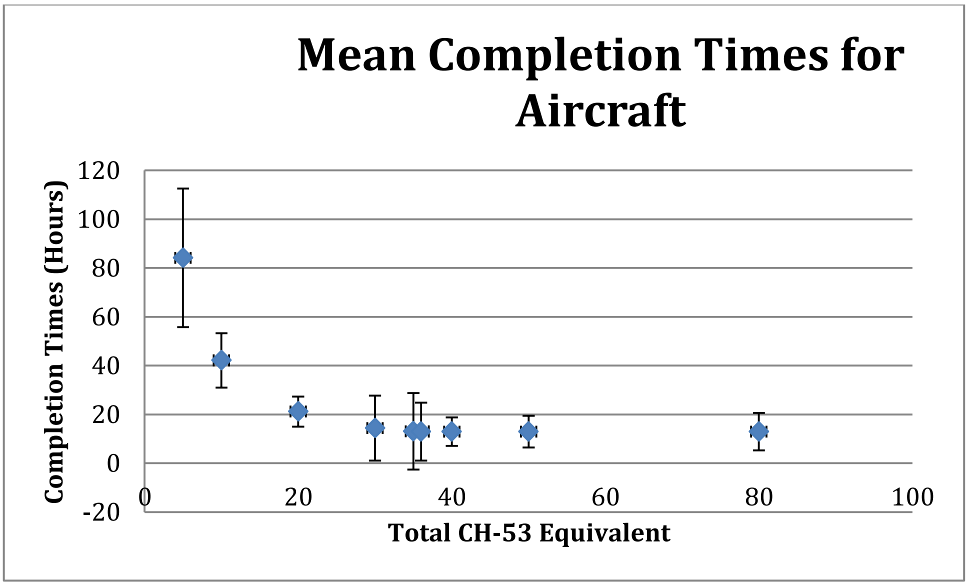


Figure 34. Mean Completion Time for Aircraft

Figure 34 shows a clear point of diminishing returns as aircraft are added to an ARG at around 27 CH-53 equivalent aircraft. It is important to note that these results represent aircraft directly contributing to offloading troops and cargo. Harriers, Cobras and Join Strike Fighters were disregarded.

As a result, there is little to no utility in adding 7 or more LCACs or 28 or more CH-53 equivalent aircrafts to improve an ARG's lift capability. This effort assisted the team in constructing 17 different ARG architectures bounded by these constraints that were analyzed as potential solutions to the problem statement. When the four current ARG architectures are included, 21 architectures are compared.

For each design point, a total of three hundred simulation runs were made for two different simulated ARG distances from shore: near and far. An ARG's distance was simulated by adjusting the transit times associated with both LCACs and Aircraft. The transit times chosen reflect reasonable minimum and maximum distances, 3 and 10 miles, between an operating ARG and the shore. This step was implemented in order to account for possible performance effects caused by changing transit time.

The key data collected from each run was the time it took to unload all troops and cargo associated with an ARG configuration. With three hundred observations collected for each ARG configuration, the mean time to unload all troops and cargo was a reasonably accurate, unbiased estimator of the true mean. Table 16 summarizes the design points for the various ARG combinations.

	ARG Configurations	**LCAC**	**Troops**	**Cargo**	**Aviation**	**JP-5**	**Spots**
		6	**2578**	**111344**	**50**	**1592344**	**n/a**
1.	**LHD, LPD-17, LSD-49**	7	2801	77123	43.21	850410	13
2.	**LHD, LPD-17, LSD-41**	9	2798	72230	43.21	849340	13
3.	**LHA, LPD-17, LSD-49**	5	2999	80766	37.09	779508	13
4.	**LHA, LPD-17, LSD-41**	7	2996	75873	37.09	778438	13
5.	**LHD, LPD-17, LPD-17**	7	3093	78734	47.48	1115488	13
6.	**LHA(R), LPD-17, LPD-17**	6	2858	77560	55.12	1221616	13
7.	**LHA-1, LPD-17, LPD-17**	5	3291	82377	41.37	1044586	13
8.	**LHA-1, LPD-17, LSD(X)**	5	2793	78607	39.45	826278	13
9.	**LHA(R), LPD-17, LSD(X)**	6	2360	73790	53.20	1003308	13
10.	**LHD, LPD-17, LSD(X)**	7	2595	74964	45.56	897180	13
11.	**LHA-1, LPD-17, LSD(XB)**	5	3123	87697	40.41	876278	13
12.	**LHA(R), LPD-17, LSD(XB)**	6	2690	82880	54.16	1053308	13
13.	**LHD, LPD-17, LSD(XB)**	7	2925	84054	46.52	947180	13
14.	**LHA-1, LPD-17, LPD(17) FLT X**	5	2993	87597	41.37	1044586	13
15.	**LHA(R), LPD-17, LPD(17) FLT X**	6	2560	82780	55.12	1221616	13
16.	**LHD, LPD-17, LPD(17) FLT X**	7	2795	83954	47.48	1115488	13
17.	**LHD, LHD**	6	3394	60348	77.86	957744	18
18.	**LHD, LHA-1**	4	3592	63991	71.75	886842	18
19.	**LHD, LHA(R)**	5	3159	59174	85.51	1063872	18
20.	**LHA(R), LHA-1**	3	3357	62817	79.39	992970	18
21.	**LPD-17 x 5**	10	3490	121400	21.37	1591540	10

Table 16. ARG Configuration Specifications

2. Simulation

As discussed in the scoping portion of the introduction and described in the CONOPs section of the report, the project team focused on two distinct scenarios and MOPs for alternative evaluation and comparison.

a. Assault Scenario

In an assault scenario, the measure of effectiveness was assumed to be the time it took to unload all troops on the shore. Therefore, a troop-unloading rate was calculated utilizing the following formula:

$$\text{Troop Rate} = \frac{\text{Troops Carried}}{\text{Mean Time in hours}}$$

A higher troop rate was preferred to a lower troop rate.

b. Humanitarian Assistance and Disaster Relief Scenario

In a HA/DR scenario, the key performance indicator was assumed to be the time it took to unload all cargo on shore. Therefore, a cargo-unloading rate was calculated via the following formula:

$$\text{Cargo Rate} = \frac{\text{Cargo Carried}}{\text{Mean Time in hours}}$$

A higher cargo rate was preferred to a lower cargo rate.

3. Methodology

To ascertain the performance for each ARG configuration under the different scenarios, a ranking and selection procedure outlined by Rinott was performed.[44] A confidence level of 0.95 was used to rank the ARG combinations under the various scenarios. This procedure fell under the category of indifference-zone (IZ) ranking and selection procedures as it utilized an indifference zone δ to define the smallest absolute difference in the expected performance that was considered important to detect. The experimenter determined this parameter δ. The procedure also guaranteed, with a confidence level at least $1-\alpha$, that the configuration selected as the best had the largest true mean when the true mean is at least δ greater than the second best. To determine the top three configurations for each scenario, the best performer for each execution of the procedure was omitted for the

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[44] (Rinott, 1978) p.799-811

subsequent iteration. The ranking and selection procedure were then performed again, this time using a smaller subset of ARG configurations.

The aim was to determine which of the six input variables were important in predicting the performance of an ARG. To do this, a two-pronged approach was taken.

a. Principal Component Analysis

Principal Component Analysis was used to identify linear dependence among the variables, if any. This provided a deeper understanding of how the variables correlated.

b. Partition Trees

Recursive partitioning is a statistical method for multivariable analysis. Recursive partitioning creates a decision tree that strives to correctly classify members of the population based on several dichotomous dependent variables. The partition tree recursively partitions data according to optimal splitting relationships created between dependent and predictor variables. It creates simple tree-based rules for predicting the dependent variable.

Partition trees were performed fitting six of the seven input variables against the mean MOEs. This was done a total of seven times, with one variable being left out during the creation of each tree. The results of each tree were compared against the tree built with all variables included. If a tree with a variable omitted changed the Root Mean Square Error (RMSE), the omitted variable was considered important in the presence of the rest. Similarly, if a tree with a variable omitted did not change the RMSE, the omitted variable could be considered of lesser importance in the presence of the rest.

4. Performance Comparison

a. HA/DR Scenario

Near Distance: The results for the near HA/DR scenario for the various ARG configurations are shown in Table 17 and Figure 35.

Option	**Combination**	**Mean Rate**	**Standard Deviation**	**Standard Error**
Current	1. LHD, LPD-17, LSD-49	12977	1664	96
	2. LHD, LPD-17, LSD-41	12332	1637	94
	3. LHA, LPD-17, LSD-49	13498	1521	87
	4. LHA, LPD-17, LSD-41	12432	1620	93
Option 1	5. LHD, LPD-17, LPD-17	13894	1494	86
	6. LHA(R), LPD-17, LPD-17	13881	1601	92
	7. LHA-1, LPD-17, LPD-17	13674	1466	84
Option 2	8. LHA-1, LPD-17, LSD(X)	13666	1570	90
	9. LHA(R), LPD-17, LSD(X)	13830	2173	125
	10. LHD, LPD-17, LSD(X)	12850	1567	90
Option 3	11. LHA-1, LPD-17, LSD(XB)	13932	1731	99
	12. LHA(R), LPD-17,LSD(XB)	14798	2085	120
	13. LHD, LPD-17, LSD(XB)	14028	1664	96
Option 4	14. LHA-1, LPD-17, LPD(17) FLT X	14210	1708	98
	15. LHA(R), LPD-17, LPD(17) FLT X	11114	1317	76
	16. LHD, LPD-17, LPD(17) FLT X	14208	1708	98
Option 5	17. LHD, LHD	12869	2259	130
	18. LHD, LHA-1	11743	1721	99
	19. LHD, LHA(R)	12195	2230	128
	20. LHA(R), LHA-1	12777	2075	119
Option 6	21. LPD-17 x 5	18328	1869	107

Table 17. HA/DR Near Results

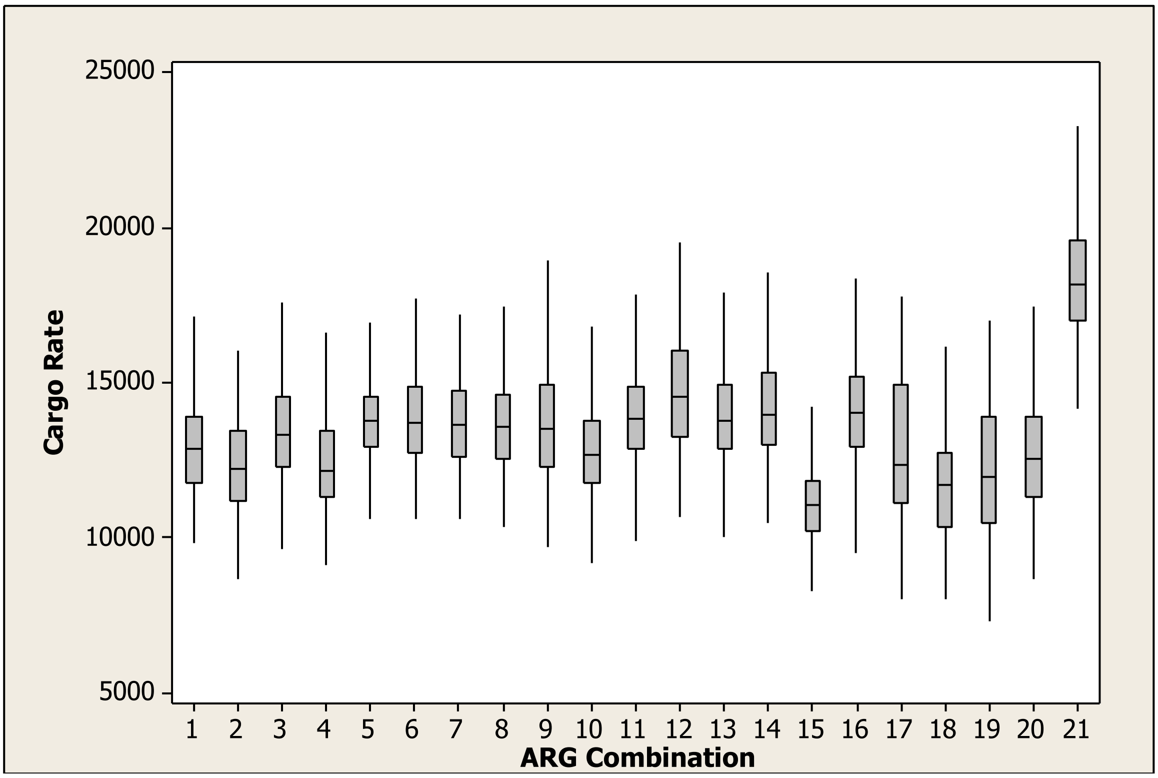

Figure 35. HA/DR Near Graph

Far Distance: The results for the far HA/DR scenario for the various ARG configurations are shown in Table 18 and Figure 36.

Option	**Combination**	**Mean Rate**	**Standard Deviation**	**Standard Error**
Current	1. LHD, LPD-17, LSD-49	11223	1144	66
	2. LHD, LPD-17, LSD-41	10107	1366	78
	3. LHA, LPD-17, LSD-49	10643	1297	74
	4. LHA, LPD-17, LSD-41	10891	1107	63
Option 1	5. LHD, LPD-17, LPD-17	11847	1062	61
	6. LHA(R), LPD-17, LPD-17	11795	1423	82
	7. LHA-1, LPD-17, LPD-17	10849	1239	71
Option 2	8. LHA-1, LPD-17, LSD(X)	10625	1153	66
	9. LHA(R), LPD-17, LSD(X)	11501	1327	76
	10. LHD, LPD-17, LSD(X)	11227	1503	86
Option 3	11. LHA-1, LPD-17, LSD(XB)	11139	1242	71
	12. LHA(R), LPD-17,LSD(XB)	12023	1211	69
	13. LHD, LPD-17, LSD(XB)	11766	1339	77
Option 4	14. LHA-1, LPD-17, LPD(17) FLT X	11246	1265	73
	15. LHA(R), LPD-17, LPD(17) FLT X	9106	1078	62
	16. LHD, LPD-17, LPD(17) FLT X	11738	1281	73
Option 5	17. LHD, LHD	10647	1563	90
	18. LHD, LHA-1	9594	1151	66
	19. LHD, LHA(R)	9711	1260	72
	20. LHA(R), LHA-1	9591	1078	62
Option 6	21. LPD-17 x 5	16125	1477	85

Table 18. HA/DR Far Results

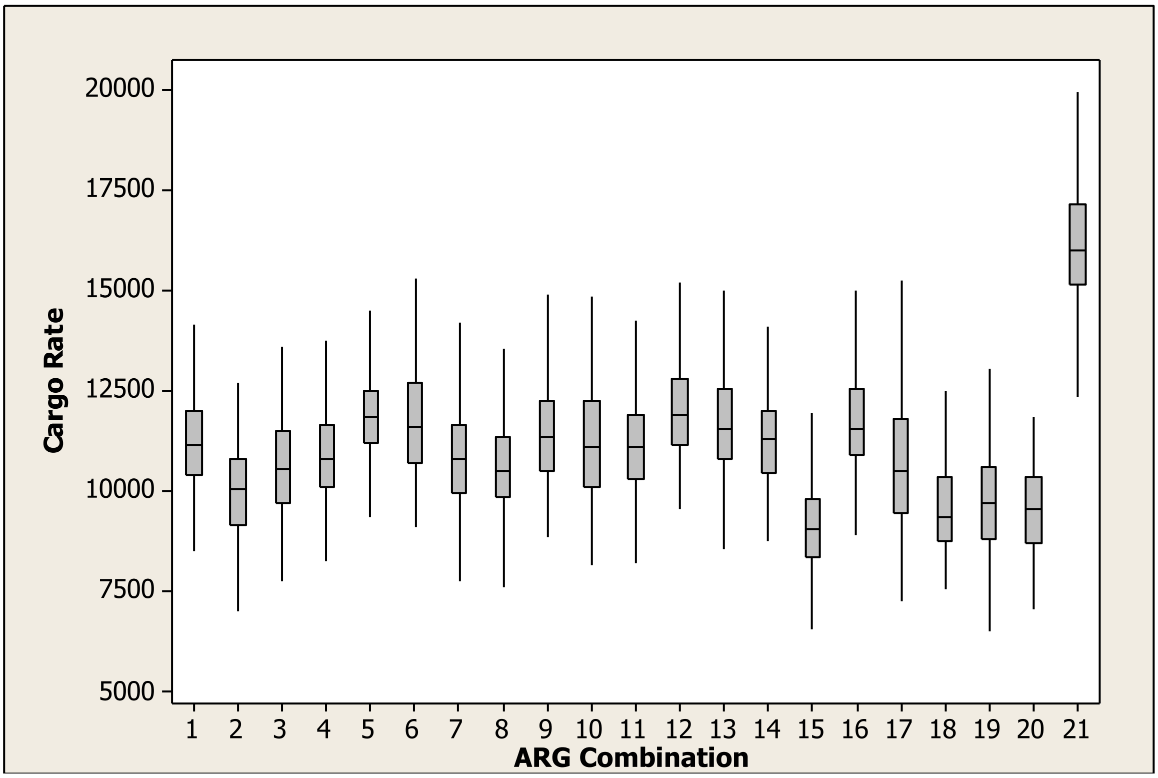

Figure 36. HA/DR Far Graph

Analysis: When the mean Cargo Rates were plotted for each ARG configuration, it became obvious that the ARG configuration corresponding to 5 x LPD-17s dominated the other configurations in both the near and far scenarios.

This result was echoed in the Rinott's ranking and selection procedure mentioned above under "Methodology." The results, obtained via sequential deletion of the best performer using a large δ as the indifference zone, are detailed in the Table 19.

Ranking	Near Scenario	Far Scenario
1.	LPD-17 x 5 (Combo 21)	LPD-17 x 5 (Combo 21)
2.	LHA(R), LPD-17, LSD(X) (Combo 12)	LHA(R), LPD-17, LSD(X) (Combo 12)
3.	LHA-1, LPD-17, LPD(17) Flt X (Combo 14)	LHA(R), LPD-17, LPD-17 (Combo 6)

Table 19. HA/DR Combined Results

a. *Assault SCENARIO*

Near Distance: The results for the near Assault scenario for the various ARG configurations are shown in Table 20 and Figure 37.

Option	Combination	Mean Rate	Standard Deviation	Standard Error
Current	LHD, LPD-17, LSD-49	471	60	3.4
	LHD, LPD-17, LSD-41	477	63	3.6
	LHA, LPD-17, LSD-49	501	56	3.2
	LHA, LPD-17, LSD-41	490	63	3.6
Option 1	LHD, LPD-17, LPD-17	545	58	3.3
	LHA(R), LPD-17, LPD-17	511	59	3.4
	LHA-1, LPD-17, LPD-17	546	58	3.3
Option 2	LHA-1, LPD-17, LSD(X)	485	55	3.2
	LHA(R), LPD-17, LSD(X)	442	69	4
	LHD, LPD-17, LSD(X)	444	54	3.1
Option 3	LHA-1, LPD-17, LSD(XB)	496	61	3.5
	LHA(R), LPD-17,LSD(XB)	480	67	3.9
	LHD, LPD-17, LSD(XB)	488	57	3.3
Option 4	LHA-1, LPD-17, LPD(17) FLT X	485	58	3.3
	LHA(R), LPD-17, LPD(17) FLT X	343	40	2.3
	LHD, LPD-17, LPD(17) FLT X	473	56	3.2
Option 5	LHD, LHD	723	127	7.3
	LHD, LHA-1	659	96	5.5
	LHD, LHA(R)	651	119	6.8
	LHA(R), LHA-1	682	110	6.4
Option 6	LPD-17 x 5	526	53	3.1

Table 20. Assault Near Results

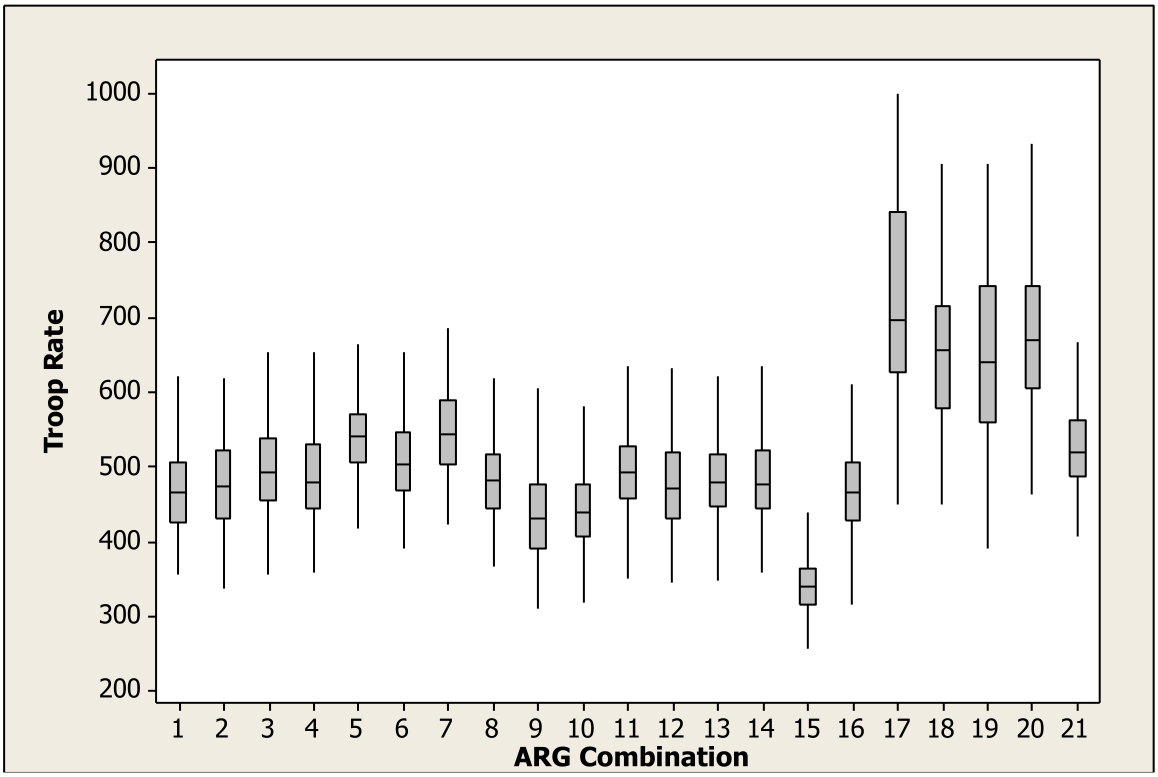

Figure 37. Assault Near Graph

Far Distance: The results for the far Assault scenario for the various ARG configurations are shown in Table 21 and Figure 38.

Option	Combination	Mean Rate	Standard Deviation	Standard Error
Current	LHD, LPD-17, LSD-49	407	41	2.3
	LHD, LPD-17, LSD-41	391	52	3
	LHA, LPD-17, LSD-49	395	48	2.7
	LHA, LPD-17, LSD-41	430	43	2.5
Option 1	LHD, LPD-17, LPD-17	465	41	2.4
	LHA(R), LPD-17, LPD-17	434	52	3
	LHA-1, LPD-17, LPD-17	433	49	2.8
Option 2	LHA-1, LPD-17, LSD(X)	377	40	2.3
	LHA(R), LPD-17, LSD(X)	367	42	2.4
	LHD, LPD-17, LSD(X)	388	52	3
Option 3	LHA-1, LPD-17, LSD(XB)	396	44	2.5
	LHA(R), LPD-17,LSD(XB)	390	39	2.2
	LHD, LPD-17, LSD(XB)	409	46	2.6
Option 4	LHA-1, LPD-17, LPD(17) FLT X	384	43	2.4
	LHA(R), LPD-17, LPD(17) FLT X	281	33	1.9
	LHD, LPD-17, LPD(17) FLT X	390	42	2.4
Option 5	LHD, LHD	598	87	5
	LHD, LHA-1	538	64	3.7
	LHD, LHA(R)	518	67	3.8
	LHA(R), LHA-1	512	57	3.3
Option 6	LPD-17 x 5	463	42	2.4

Table 21. Assault Far Results

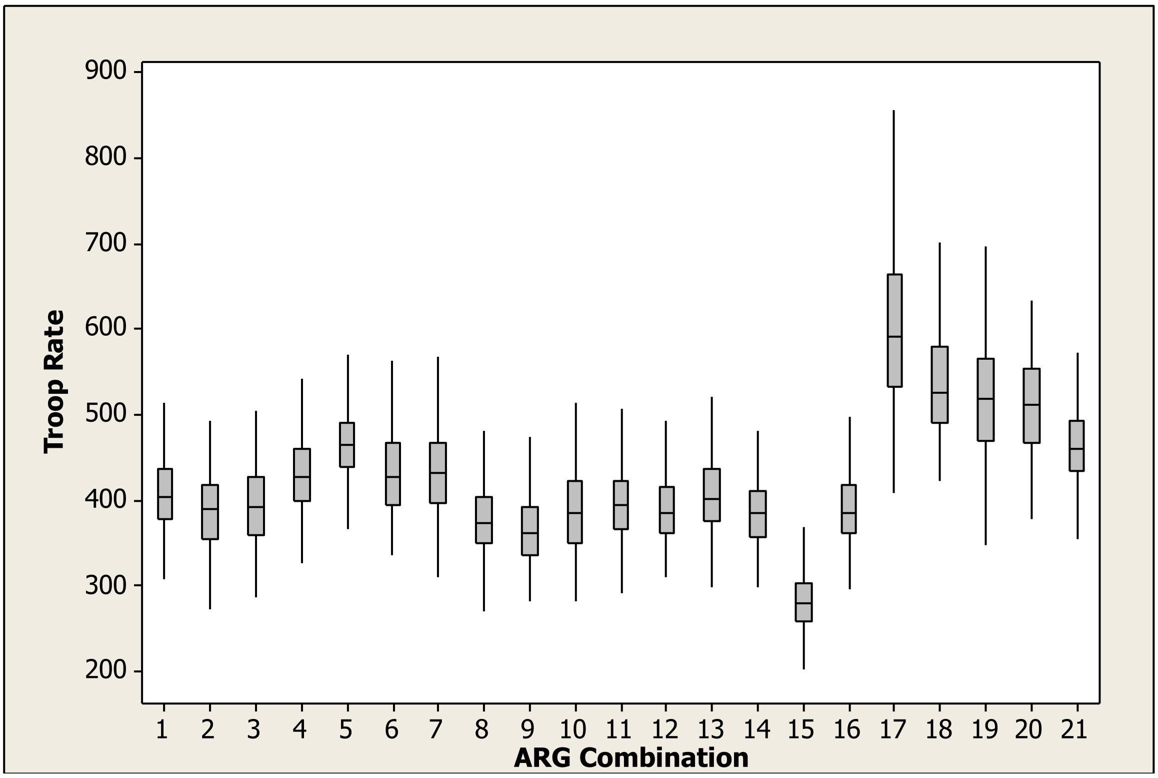

Figure 38. Assault Far Graph

Analysis: When the Troop Rates were plotted for the various ARG configurations, it is clear that in both near and far scenarios, the 2 x LHD ARG configuration outperformed all other configurations.

Again, this result is echoed in the Rinott ranking and selection procedure. The results are detailed in Table 22:

Ranking	Near Scenario	Far Scenario
1.	LHD, LHD (Combo 17)	LHD, LHD (Combo 17)
2.	LHA(R), LHA-1 (Combo 20)	LHD, LHA-1 (Combo 18)
3.	LHD, LHA-1 (Combo 18)	LHD, LHA(R) (Combo 19)

Table 22. Assault Combined Results

5. Performance Comparison

Principal component analysis found *m* orthogonal linear combinations of original *k* regressors, where $m \leq k$. In essence, this transformation was used to remove any multi-colinearity detected in the original input variables. Using a Variance Inflation Factor,[45] it was revealed that multi-colinearity existed for Cargo, Aviation and Aviation Spots.

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[45] A common guideline is that multicolinearity exists whenever $\text{VIF}_i \geq 10$.

	LCAC	**Troops**	**Cargo**	**Aviation**	**JP5**	**Aviation Spots**	**LCAC Spots**
VIF	2.05524	7.63143	15.485	58.8382	9.79275	70.6859	5.59702

Table 23. Test of Multi-Colinearity

A basic understanding of the process of moving troops and cargo to shore is proof enough that multiple colinearities exist. An LCAC would only load with troops or cargo when it was occupying an LCAC spot in the well deck in the simulation. The same held true for the aircraft in the simulation. LCACs or aircraft that arrived back to their respective ships that did not have a free spot for loading had to wait until a spot became free. Therefore, the amount of LCACs or aircraft that can load at a time is directly related to the total number of each and how many spots are available for each to load.

Instead of performing an orthogonal transformation on just these three variables, the transformation was conducted on all variables to determine the dimensionality in which the MOEs actually exist. Table 24 details the loadings for each Principal Component (PC), where each loading states the coefficient of the variable in the Principal Component.

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
LCAC	-0.36311	-0.00869	0.316885	-0.8625	0.114236	-0.10297	0.009789
Troops	0.115714	0.706915	-0.56884	-0.27414	0.088183	0.195327	0.20547
Cargo	-0.44762	0.214529	-0.13947	0.265042	0.293134	-0.75656	0.074899
Aviation	0.430399	0.208081	0.43542	-0.01251	-0.25943	-0.31713	0.6433
JP.5	-0.23835	0.584546	0.592829	0.2875	0.12459	0.325226	-0.2147
Spots	0.457382	0.23971	0.043019	-0.16411	-0.20052	-0.41519	-0.7014
LCAC Spots	-0.45072	0.10826	-0.11688	0.030723	-0.87762	-0.01169	-0.01345

Table 24. Principal Component Loading Coefficients

For example:

$$\begin{aligned} PC1 &= -0.36311\times LCAC + 0.115714\times Troops - 0.44762\times Cargo \\ &+0.430399\times Aviation - 0.23835\times JP.5 + 0.457382\times Spots \\ &-0.45072\times LCAC\ Spots \end{aligned}$$

The importance of each Principal Component is listed in Table 25.

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
Standard Deviation	2.065	1.1598	0.8449	0.69941	0.37449	0.2032	0.08629
Proportion of Variance	0.609	0.1922	0.102	0.06988	0.02003	0.0059	0.00106
Cumulative Variance	0.609	0.8012	0.9031	0.973	0.99304	0.9989	1

Table 25. Principal Component Importance

As a rule of thumb, each linear combination is kept in the model if its proportion of variance exceeds 0.1. Therefore, PC1, PC2 and PC3 were kept in the model.

Principal Component 1: The larger loadings in Principal Component 1 involved LCACs, Cargo, Aviation and Spots. This seemed intuitive given the simulation approach and parameters.

Principal Component 2: The heavier loadings in Principal Component 2 involved Troops and JP-5. At first glance this was an interesting finding, as Troops do not seem related to JP-5 consumption. However, aircraft and LCACs both carried troops in this simulation; both platforms also use JP-5. Therefore, this was a valid connection between JP-5 and Troops.

Principal Component 3: The heavier loadings in Principal Component 3 involved Troops, Aviation and JP-5. To expand on the ideas supporting PC2, aircraft carried more troops than LCACs did in the simulation. Therefore, it was logical that PC3 mathematically identified these variables as significant in this model.

Analysis: Going by the manner in which all variables were spread across the three most important Principal Components, and also that there was no Principal Component that was heavily loaded with only one variable, it appeared that there was no one variable that was significant by itself. Each variable was significant only in the presence of other variables.

6. Partition Trees

This procedure was conducted in JMP, a statistical analysis software package, and the results are shown in Table 26.

	HADR Near		HADR Far		Assault Near		Assault Far	
	RMSE	**R^2**	**RMSE**	**R^2**	**RMSE**	**R^2**	**RMSE**	**R^2**
All 6 Variables	1023.4	0.47	1044.0	0.43	44.3	0.74	32.9	0.76
No LCAC	1023.4447	0.47	1044.0015	0.433	44.3517	0.745	32.7758	0.769
No Troops	1023.4447	0.47	1044.0015	0.433	44.3517	0.745	36.7843	0.708
No Cargo	1052.7143	0.44	1090.8536	0.381	44.3517	0.745	32.9097	0.767
No Aviation	1008.6354	0.486	1044.0015	0.433	44.3517	0.745	32.9097	0.767
No JP-5	1023.4447	0.47	1044.0015	0.433	44.3517	0.745	32.9097	0.767
No Spot	1023.4447	0.47	1044.0015	0.433	47.2712	0.710	36.8686	0.707

Table 26. Partition Tree Results

Within the HA/DR mission set for both Near and Far scenarios, it was observed that omitting Cargo as an input parameter had the most effect on RMSE and R-square. This was intuitive given the MOE used for the HA/DR missions was Cargo Rate. It was also observed that within the HA/DR Near scenario, RMSE decreased when Aviation was left out of the model. Aviation was the last variable to be branched upon in the tree. While it appeared, from the decrease in RMSE, that leaving out Aviation actually improved the model, this decrease was due wholly to the "Minimum Size Split" setting.[46] Given Aviation was the second variable to be split; aviation can be considered an important variable in the HA/DR model. The partition tree for the HA/DR Near scenario with all seven variables included is displayed in Figure 39.

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[46] A node will not be branched upon if either of its children nodes has less than 5 observations in it.

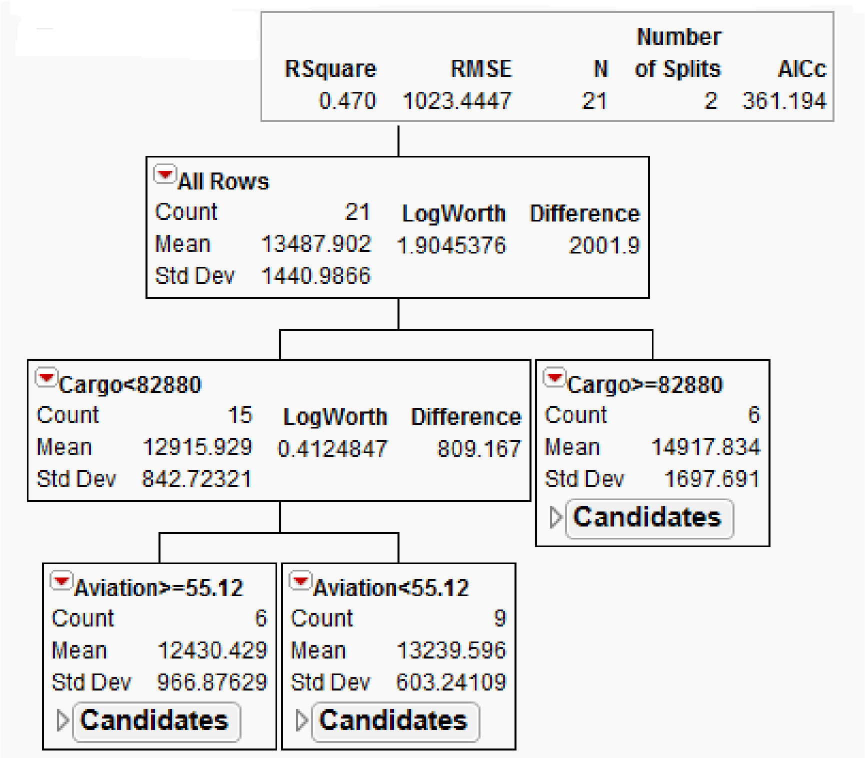


Figure 39. HA/DR Near Scenario With All Seven Variables

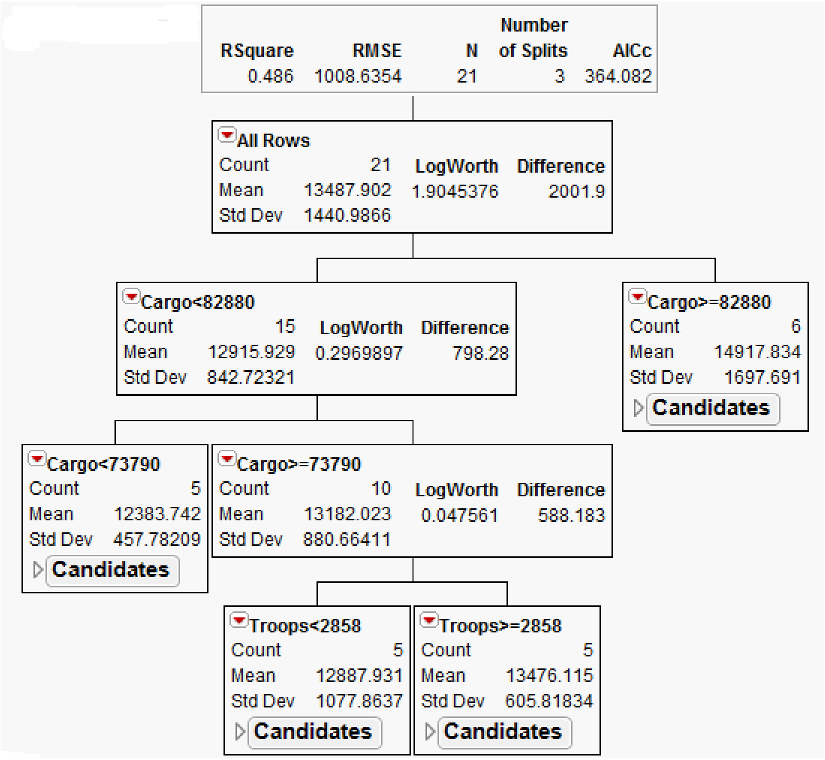
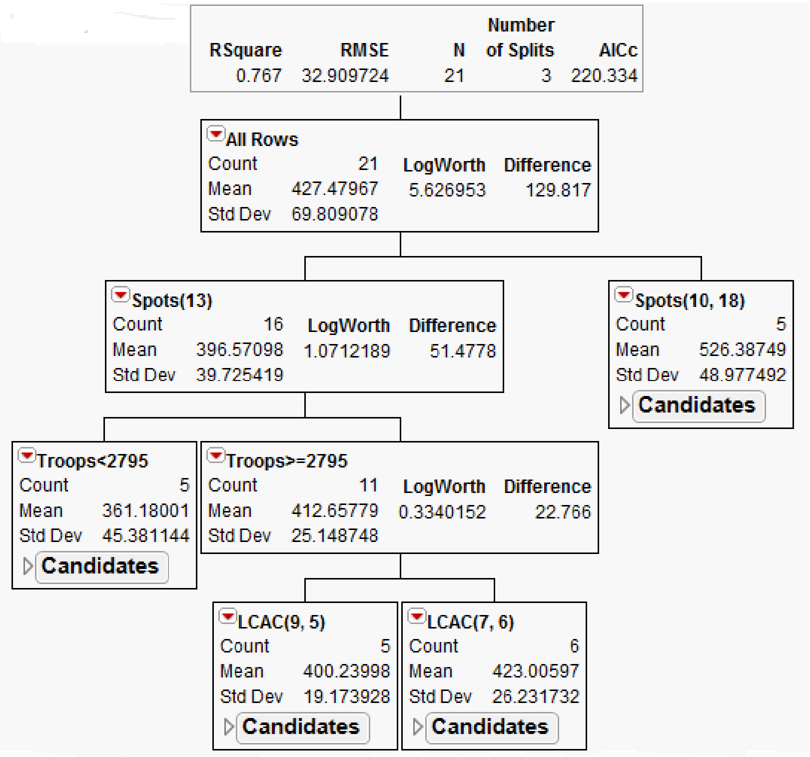


Figure 40. HA/DR Near Scenario With Aviation Omitted

Under the Assault mission set for both Near and Far scenarios, it was observed that omitting Troops had the most effect on RMSE and R-square. Again this was intuitive given the MOE for the assault mission was the Troop Rate. As with the HA/DR Near scenario, the Assault Far scenario had RMSE decrease when LCACs were omitted. The reasoning for this was similar to that presented for Aviation under the HA/DR Near scenario. The partition tree for the Assault Far Scenario with all seven variables included is shown in Figure 41.



RSquare	RMSE	N	Number of Splits	AICc
0.767	32.909724	21	3	220.334

Figure 41. Assault Far Scenario With All Seven Variables

The partition tree for the Assault Far scenario with LCACs omitted is shown in the Figure 42.

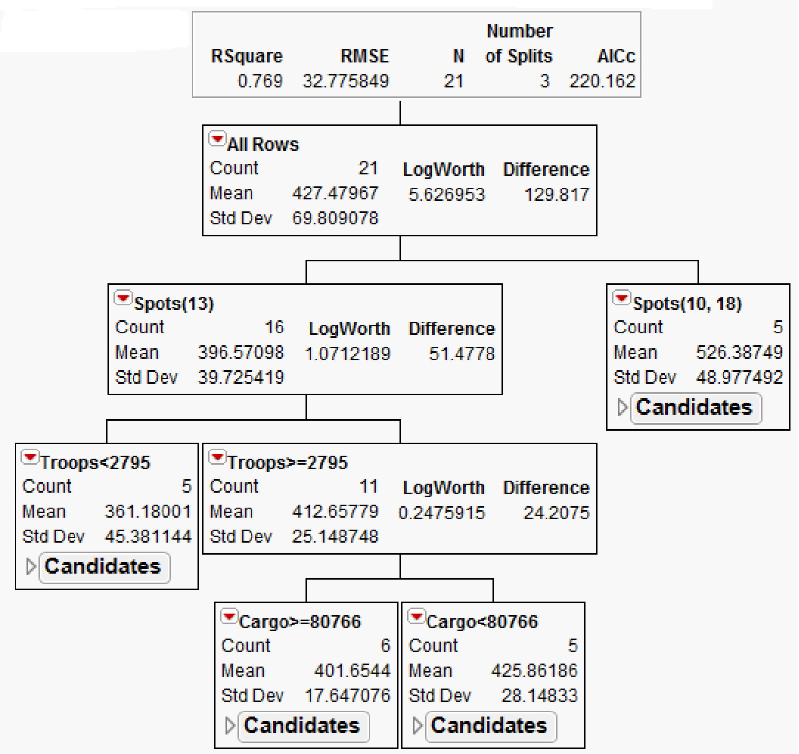


Figure 42. Assault Far Scenario With LCACs Omitted

7. Summary of PC Analysis

A classical IZ ranking and selection procedure allowed for the identification of which ARG configuration performed best under the different mission sets. Ideally, there would be one ARG configuration that performs best in each scenario, but the results showed otherwise, with LPD-17 x 5 (Architecture 21) performing best in the HA/DR mission set, and LHD x 2 (Architecture 17) performing best in the Assault mission set.

The Principal Component Analysis and partition tree approaches allowed for a deeper understanding of how the input variables correlated with each other, and which ones were more significant in the two mission sets. A possible improvement would be to extract from the simulation the time taken to unload only troops, and the time taken to unload only cargo.[47] This would perhaps be a more accurate representation of the MOEs.

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[47] Currently, the output from the simulation is derived as follows: output = max{troops unloading time, cargo unloading time}.

8. Design of Experiments Analysis

The design of experiment (DOE) analysis aimed to identify the most robust architecture with respect to the most significant factors influencing the output. Based on the simulation output for each of the derived architectures, the data was analyzed to determine which architecture performed the best in terms of completion time, and which of the factors (Number of LCAC spots, Aircraft spots, LCACs, Aircrafts, JP-5, Troops and Cargo unloading) influenced the completion time the most.

The experiment was designed using Nearly Orthogonal Latin Hypercubes.[48] This method was designed to examine multivariate multilevel space where a simple multifactor two level design is not sufficient. This method allowed an analyst to be confident that the distribution of values represented in the experimental design has sufficiently covered factor space such that a highly robust combination of levels could be identified. In this case, three hundred configurations were generated and input into version 2 of the simulation. Each configuration was run thirty times. Based on the means of the outputs, the significant factors were determined through partition tree analysis. The generated design has varied the factors between their high and low values as listed in Table 27.

Factor Name	**LCAC Spots**	**A/C Spots**	**LCAC Total**	**A/C Total**	**Transit Time**	**JP-5**	**Troops**	**Cargo**	**A/C Transit**
Type	Disc.	Disc.	Disc	Disc.	Cont.	Cont.	Cont.	Cont.	Cont.
Number Levels	4	7	8	26	300	300	300	300	300
Model Form	MQI	MQI	MQI	MQI	MQI	MQI	MQI	MQI	MQI
Low Level	2	12	3	25	10	778438	2360	48174	5
High Level	5	18	10	50	30	1591540	3592	129900	15
Round					6	6	6	6	

Table 27. DOE Factor Table

The partition tree analysis was performed on the 9 factors against the mean outputs of the simulation data to determine the significant factors. The results of each tree were compared against the tree built containing all variables. As previously noted, if a tree with a variable omitted changed the Root Mean Square Error (RMSE) the omitted variable was considered significant. Similarly, if a tree with a variable omitted did not change the RMSE, the omitted

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[48] (MacCalman, 2012)

variable was considered insignificant with respect to influencing the results. Figure 43 and 44 below show the Partition Tree Analysis for Troop and Cargo Unloading rate respectively.

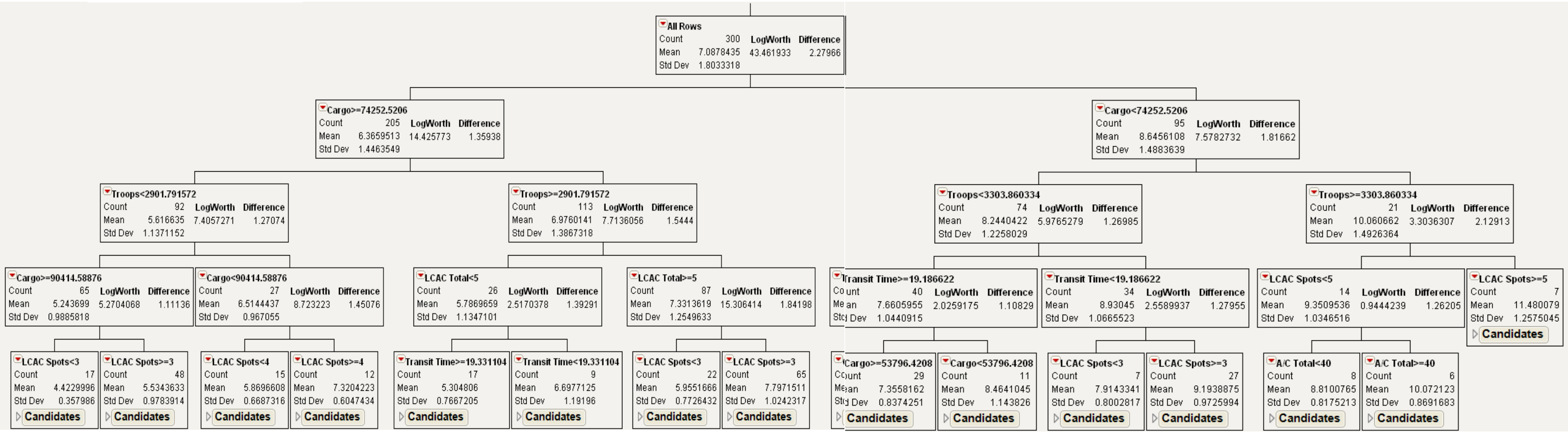

Figure 43. Partition Tree Analysis for Troop Unloading Rate

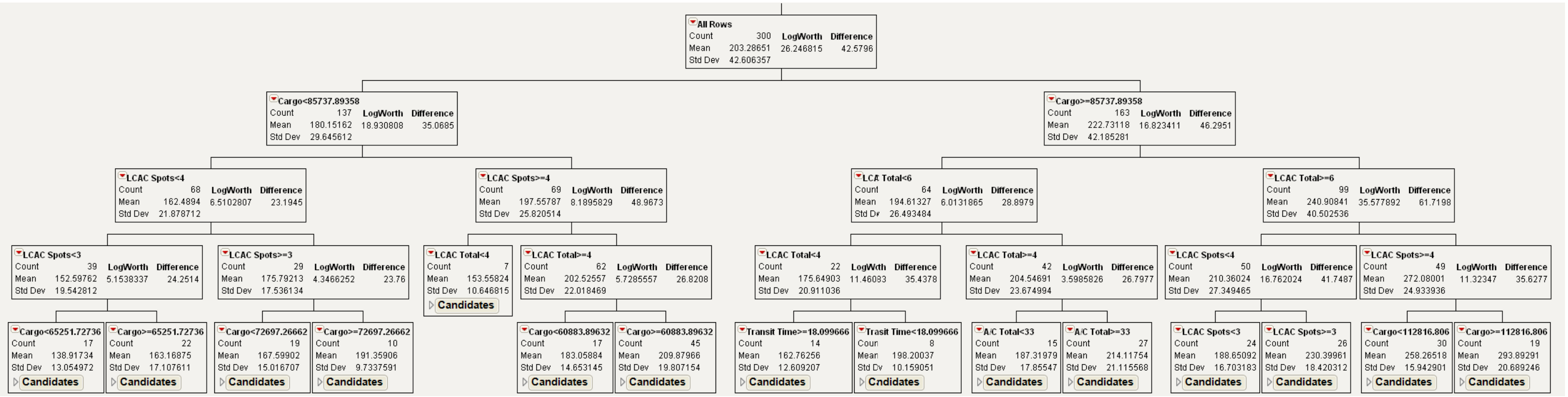

Figure 44. Partition Tree Analysis for Cargo Unloading Rate

By splitting the partition tree down to the fourth level, the team was able to identify the branches that had the highest means (unloading rates), and then traced the tree upwards to identify the significant factors that contributed to that particular mean unloading rate value. For the HADR scenario, it seemed that the significant factors were LCAC Spots, Total Number of LCACs and Aircrafts, Transit Time and Cargo Space. For the Assault scenario, the significant factors were LCAC Spots, Total Number of LCACs and Aircrafts, Transit Time, Cargo Space and Troop Space. It seemed that the other factors such as Aircraft Spots, Aircraft Transit Time and JP-5 were not significant factors that contributed to the unloading rates.

Based on the results of the partition tree analysis, Table 28 lists the various design possibilities based on the desired cargo-unloading rate for the HADR scenario. For each of the designs, the limits for the significant factors are shown. For example, for Design 1 with the highest cargo-unloading rate, one can have more than 6 LCACs with more than 4 LCAC spots and more than 85737.89 square feet of cargo space.

Design	Cargo Unloading Rate	LCAC Spots	LCAC Total	A/C Total	Transit Time	Cargo
1	293.89	>=4	>=6			>=85737.89
2	258.27	>=4	>=6			85737.89< x <112816.81
3	230.4	3<= x <4	>=6			>=85737.89
4	214.12		4<= x <6	>=33		>=85737.89
5	209.87	>=4	>=4			60883.90 <= x <85737.89
6	198.2		<4		<18.10	>=85737.89
7	191.36	3<= x <4				72697.27<= x <85737.89
8	187.32		4<= x <6	>=33		>=85737.89

Table 28. Design Parameters for HA/DR Scenario

Similarly, Table 29 lists the various design possibilities based on the desired troop-unloading rate for the Assault scenario. For Design 1 with the highest troop-unloading rate, we can have more than 40 Aircrafts, with less than 5 LCAC spots and carry more than 3303 troops.

Design	Troop Unloading Rate	LCAC Spots	LCAC Total	A/C Total	Transit Time	Cargo	Troops
1	10.07	<5		>= 40		<74252.52	>=3303.86
2	9.19	>= 3			<19.186	<74252.52	<3303.86
3	8.81	<5		<40		<74252.52	>=3303.86
4	8.46				>=19.186	53796.42 < x <74252.52	<3303.86
5	7.91	<3			<19.186	<74252.52	<3303.86
6	7.79	>=3	>=5			>=74252.52	>=2901.79
7	7.35				>=19.186	53796.42 < x <74252.52	<3303.86
8	7.32	>=4				74252.52 < x <90414.59	<2901.79

Table 29. Design Parameters for Assault Scenario

Comparing both tables for the HA/DR and Assault scenarios, Design 5 would have the highest troop and cargo unloading rates with non-conflicting design parameters. Design 5 allows for more than 4 LCACs, but there must be less than 3 LCAC spots, with a transit time of less than 19.18 minutes, and must carry between 60883 and 85737 square feet of cargo and less than 3303 troops.

Design	Desired Troop Rate	Desired Cargo Rate	LCAC Spots	LCAC Total	A/C Total	Transit Time	Cargo	Troops
1	10.07	293.89	4<= x <5	>=6	>= 40		Conflict	>=3303.86
2	9.19	258.27	>= 3	>=6		<19.186	Conflict	<3303.86
3	8.81	230.4	3<= x <4	>=6	<40		Conflict	>=3303.86
4	8.46	214.12		4<= x <6	>=33	>=19.186	Conflict	<3303.86
5	7.91	209.87	<3	>=4		<19.186	60883.90 <= x <85737.89	<3303.86
6	7.79	198.2	>=3	Conflict		<18.10	>=74252.52	>=2901.79
7	7.35	191.36	3<= x <4			>=19.186	72697.27< x <74252.52	<3303.86
8	7.32	187.32	>=4	4<= x <6	>=33		85737.89< x <90414.59	<2901.79

Table 30. Design Parameters for HA/DR and Assault Scenarios

The results showed the most robust derived ARG architecture consisted of 6 or more LCACs with 4 LCAC spots and 40 or more CH-53 equivalent aircraft. Partition tree analysis showed that this combination provided a relatively high rate for both MOPs analyzed and made transit time an insignificant factor. The Cargo amount calculated conflicted with an amount actually analyzed. However, an amphibious operation planner would aspire to load as much cargo and as many troops as necessary to successfully conduct a given amphibious operation. Furthermore, any proposed ARG architecture or new ship design presented in this report allows the set Cargo, Vehicle and Troop *requirements* to influence design. Since these requirements are seen as set values, these factors are not seen as values that can be manipulated to influence performance. Their inclusion in the simulation was necessary since the main trade space factors (LCACs, LCAC spots, aircraft, aircraft spots and transit time) were contributing to moving these quantities to shore at certain rates. Therefore, as long as there were not conflicts with these main trade space factors within the results, that combination was deemed valid (i.e. design 6 listed on Table 30 was invalid).

This robust solution provided implications as to where a decision maker should expend resources in order to maximize ARG performance. For instance, identification of transit time as an insignificant factor might imply that there is no need to fund improving an LCAC's or connecting aircraft's speed. Conversely, the results showed that improving LCAC and aircraft totals improve performance. Combining this information with the sensitivity analysis previously shown can further refine this observation. This partition tree analysis places no upper bound on LCAC and air craft totals but does provide minimums. Sensitivity analysis showed points of diminishing return for adding capability in both areas. Since it has already been shown that more is not necessarily better one can assume these minimums are associated with points in which no further performance increase will be achieved when exceeding these quantities. In summary, four ships (LCAC spots), six LCACs and 40 aircraft is the most robust solution the team was able to derive.

E. OTHER DESIGN CONSIDERATIONS

Self-Defense – A significant probability of survivability (P_S) analysis was completed to determine what capability a new design ship should incorporate. This analysis is contained in Appendix B and concluded that the presence of an escort group made a significant difference in the survivability of lesser-equipped ships. Two courses of action were developed to address the appropriate balance between weapon systems cost and P_S. (1) Have Escort Groups with the platforms whenever the expected threat level is high. (2) Have a new construction ship design that is modular in nature (similar to LCS concept), allowing the addition of added NSSM modules whenever the threat level is high but otherwise operating with just the RAM as a basic defense (similar to LPD-17) when low threats are expected.

Hangar – The current LSD does not have an aircraft hangar on board. Therefore, its air operations are restricted to non-organic operations. This hinders the current LSD from embarking on independent operations as it is missing a key element of the nation’s current method of conducting maritime operations. A follow-on ship developed to replace the current LSD should be designed with an aircraft hangar capable of embarking modern and anticipated aircraft, such as the MV-22 or Unmanned Aerial Vehicles (UAVs), to adequately support independent operations.

C2 Suite – The current LSD is limited in its capability to share C2 intelligence with platforms in a group due it a relatively weak C2 suite. The LSD does not have many of the links and frequencies necessary to effectively contribute to the Common Operational Picture (COP). It specifically lacks the modern Tactical Data Information Link (TADIL) capability, Cooperative Engagement Capability (CEC), modern Self-Defense Integration capability and many other communication frequencies shared by platforms with more modern C2 capabilities. A follow-on ship should be designed with a C2 suite that facilitates communication with modern systems. It should also be designed such that it is adaptable to technological advances. This modular or “plug-and-play” idea mitigates the threat of the LSD returning to a state in which it is not capable of contributing to the COP.

Unmanned Vehicles (UV) – With the push toward unmanned systems rapidly increasing in the Navy, a follow-on platform should not be designed in a manner that would hinder UV operations. Additionally, the size and type of UVs deployable to a follow-on ship must be determined. This will influence any additional design considerations pertinent to UV implementation. The main design factors include launching, recovery, and storage space. These factors will also influence other design considerations such as C2 needs and potential stability issues.

Propulsion Plant – Any new ship design should implement a hybrid or even all electrical plant or other alternative to diesel, if possible, propulsion system. This effort would serve two main purposes. The first would be to decrease the Navy’s dependency on foreign oil. It is well known the US aspires to reduce dependency on foreign oil. With that, the Navy can assist the government in achieving this goal by taking steps to reduce dependency within the organization. The more dependent our platforms are on foreign resources, the more our platforms operate at the mercy of those providing the resources. Furthermore, the more foreign entities realize the gravity of the US’s dependency on their material, the more likely they are to inflate the price. This leads to an increased risk of high costs and lower availability for desired resources. The second purpose is alternative fuel sources contribute to a cleaner environment by reducing harmful emissions.

VI. COST DECISION ANALYSIS

A. INTRODUCTION

The objective of this cost estimating process was to provide a realistic life cycle cost estimate (LCCE) for the different design alternatives and fleet architectures. These estimates were anchored in historical data from analogous systems, and created using quantitative models to predict the costs of each alternative. LCCEs were the tool used to evaluate and rank the six alternatives with respect to cost, and combined with the performance and evaluation results, form the foundation for the comparison of alternatives. The cost estimating results were used to make recommendations on which alternative is most cost effective.

LCCEs cover all the time phases of each alternative's life cycle, namely Research and Development (R&D), Production, and Operation and Support (O&S) Costs. This section outlines the research, analysis, and modeling techniques that underlie the cost estimates that were developed for the proposed alternatives.

1. Assumptions

The following assumptions were utilized to allow for the most similar cost comparisons between the alternatives. All cost calculation predictions are in Fiscal Year 2012 (FY12) dollars.

- Adjustments for costs were made for both quantity and quality of the systems being compared using Base Year 2012 dollars.
- A 30-year life cycle was used for all ships for the total life cycle cost estimate.
- Recommended new ship constructions were assumed to be relative in size to current ships to allow for the parametric cost model approximation.
- The new construction cost model will be a single variable regression, either linear, logarithmic, power or exponential, of the historical data broken down to the 1-digit Ship Work Breakdown Structure (SWBS) level (100, 200, …900).
- All ships built will be accepted. There are no spares or test equipment.
- Historical ship construction data is complete, accurate and sufficient for cost estimation analysis.
- Learning curves are assumed to be 99% for material and 95% for labor in the new design models.

- Learning curves for current production ships, LPD-17 and LHA-8, are assumed to be 99% for material and labor.
- A point estimate was developed for lead ship costs. Monte Carlo simulation was used to develop an estimate of the 80th percentile of the LCCE cumulative distribution function.

2. Terms and Definitions[49]

Life Cycle Cost Estimate (LCCE): The LCCE is the sum of the acquisition and ownership costs of a ship class over its expected life cycle. This cost includes the cost of R&D, Production and Manufacturing (P&M), and O&S for each of the ships throughout their operational years. The cost of disposal was not utilized for this calculation. LCCE is given by Equation 1.

$$LCCE_{Amphib.Class} = \sum_{year(j)=1}^{30} \sum_{ships(i)=1}^{\#ships.in.year(j)} [(R\&D)_i + (P\&M)_i + (O\&S)_i]_j$$

Equation 1: Life Cycle Cost Estimate[50]

Research & Development Costs (R&D): Estimated cost of all program specific research and development.

Production & Manufacturing Costs (P&M): Estimated cost of the investment phase, including total cost of procuring the prime equipment, related support equipment, training, initial and war reserve spares, preplanned product improvements and military construction.

Operations & Support Costs (O&S): Estimated cost of operating and supporting the fielded system, including all direct and indirect costs incurred in using the system, e.g., personnel, maintenance (unit and depot), and sustaining investment (replenishment spares). The bulk of lifecycle costs occur in this category.

Ship Work Breakdown Structure (SWBS): This is the work break down structure (WBS) of ship construction. MIL-STD-881C (3 OCT 2011) defines the WBS as a product-oriented family tree composed of hardware, software, services, data, and facilities. The family tree results from systems engineering efforts during the acquisition of a defense materiel item. A WBS displays and defines the product, or products, to be developed and/or produced. It relates the elements of work to be accomplished to each other and to the end product. In other

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[49] (AACE International. 2011)

[50] (AACE International. 2011)

words, the WBS is an organized method to breakdown a product into sub-products at lower levels of detail. For the cost analysis the 1-digit SWBS was utilized, as displayed and defined in Table 31.

SWBS 100 Level Breakdown Chart		
Level	**Title**	**Components**
100	Hull Structure	Shell plating, decks, bulkheads, framing, superstructure, pressure hulls & foundations.
200	Propulsion Plant	Boilers, reactors, turbines, gears, shafting, propellers, steam piping & lube oil piping.
300	Electric Plant	Ship service power generation equipment, power cable, lighting systems & emergency electrical power systems.
400	Command & Surveillance	Navigation systems, interior communication systems, fire control systems, radars, sonars, radios, telephones & command and control systems.
500	Auxiliary Systems	Air conditioning, ventilation, refrigeration, replenishment at sea systems, anchor handling, elevators, fire extinguishing systems, distilling plants, steering systems & aircraft launch and recovery systems.
600	Outfit and Furnishing	Hull fittings, painting, insulation, berthing, sanitary spaces, offices, medical spaces, ladders, storerooms, laundry & workshops.
700	Armament	Guns, missile launchers, ammunition handling and stowage, torpedo tubes, depth charges, mine handling and stowage & small arms.
800	Integration & Engineering	Recurring Engineering.
900	Ship Assembly & Support Services	Staging, scaffolding, launching, trials, temporary utilities and services, material handling and removal services & cleaning services.

Table 31. 1-digit SWBS Titles and Definitions (From [51])

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[51] (Department of Defense, 2011)

Analogy Estimation: A cost estimation technique that is based on analogous relations found within a similar type of system. These relationships are based on actual, subject matter expert or estimated relations between two or more components of a WBS as a ratio to a base quantity. This technique is utilized when limited historical information is available for comparison.

Parametric Estimation: A cost estimation technique that is based on functional relationships. These relationships are generally based on similar systems that were of similar technical, performance and schedule standards. This technique is utilized when enough historical cost data is available for comparison.

$$\text{Cost} = f\left(\text{technical, performance, schedule}\right)$$

Equation 2: Cost Equation

3. Cost Estimating Process Methodology

Each of the alternatives that were examined may have elements that are either currently in existence, so-called legacy components, or need to be developed, new construction. The cost of these alternatives can then be estimated using different design parameters that were developed by the systems engineering team.

Life Cycle Cost Estimates were completed for the following six options:

- New construction of the LSD(X)
- New construction of the LSD(XB)
- Additional procurement of 11 LPD-17s
- Additional Procurement of 19 LPD-17s
- Follow-on to the LPD-17 designated as LPD(17) Flt X
- Additional procurement of LHA-8s.

A LCCE was developed for each of these options. These LCCEs were used in the project decision process to compare the alternatives. The detailed description of these options is contained in the previous section of the report subtitled *Alternative Generation*.

B. NEW CONSTRUCTION COST MODEL DEFINITIONS AND DOCUMENTATION

1. Objective and Summary

The objective of this cost estimating model was to develop the LCCE for producing a new class of LSDs designated the LSD(X). The procurement cost of the lead ship was modeled using regression analysis, with the independent variables being the LSD(X)'s desired attributes and capabilities. The regression model was derived from data of five lead ships of existing similar classes (LSD-41, LSD-49, LPD-17, LHA-6, LHD-1). Follow-on ship construction costs were estimated using the estimated cost of the lead ship and learning curve theory. Operation and Support (O&S) costs are estimated by analogy to the O&S costs of existing ships and then applied over the life-cycle. The sum of all these costs was the LCCE.

2. Overview

An overview of the cost estimating model is shown in Figure 45, and the paragraphs below describe the blocks of the model.

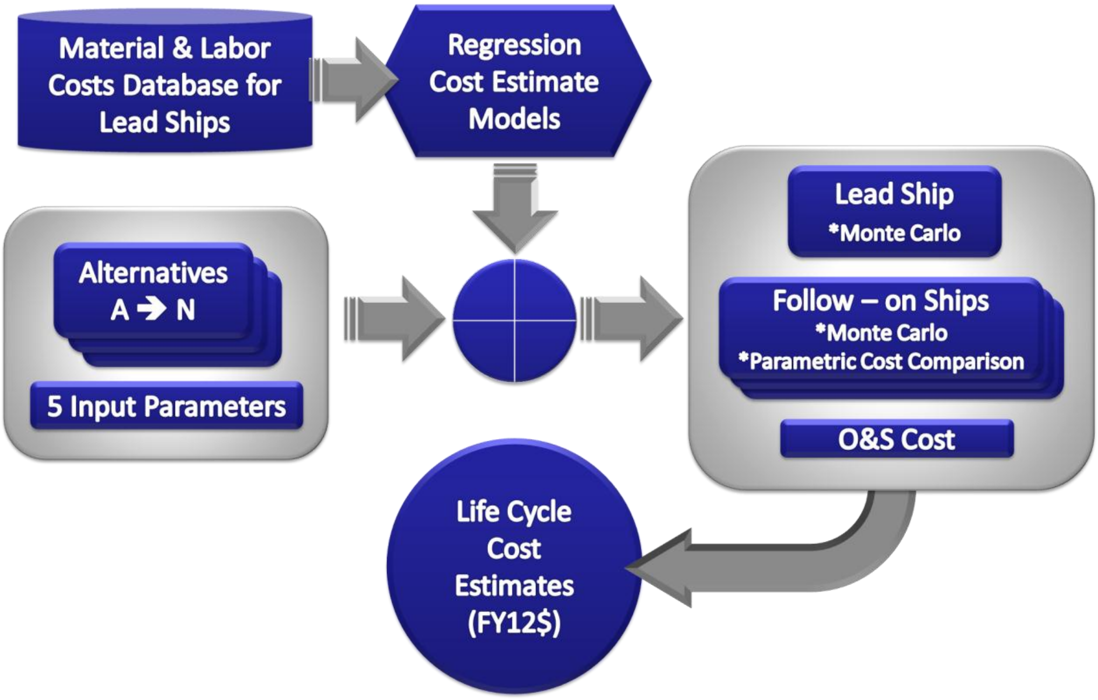

Figure 45. Overview of Cost Estimating Model

“Material & Labor Costs Database for Lead Ships” refers to historical industry data from previous amphibious ship classes.

“Regression Cost Estimate Models” refers to the models compiled and analyzed by LT Allison Hills, USN as part of her thesis *Life Cycle Cost of LSD(X).*[52] Her models estimated total costs of the lead ship at the 1-digit SWBS level. These models formed the foundation from which the new ship construction model was built. In her thesis LT Hills used single and multivariate regression to examine the relationships in the cost of historic ships construction as a function of the 1-digit SWBS level. Results from her analysis concluded that no multivariate regression fit was an acceptable estimation to the costs of

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[52] (Hills, 2012)

construction of the amphibious ship class. She concluded that some single variable regressions modeled the construction with fair estimation to a ships construction cost on most SWBS levels through several different regression techniques. These specific techniques were integrated and validated in this project's new construction model.

“Alternatives” refers to the scenarios and developments by the systems engineering team that resulted in the six options for analysis. These alternatives are described by size and mission and by five input parameters: cargo capacity in cubic feet, troop size in bunks, number of LCACs, crew size, and beam of the ship in feet. These parameters are the independent variables that drove the lead ship cost estimates.

“Lead Ship” includes the design cost, material, labor, and non-recurring costs for the Lead ship.

“Follow-on Ship” accounts for the use of lead ship estimates and learning curve theory to estimate the cost of procurement for additional ships.

“O&S Cost” encompasses all the Operating and Support data and O&S cost estimates. The total personnel and material O&S costs of the five current amphibious ship classes was extracted from Navy’s Visibility and Management of Operating and Support Costs (VAMOSC) management information system and categorized. Operational and Support cost data, which includes personnel cost data, was obtained through the Ships Data Universe of VAMOSC. As described in the VAMOSC website at https://www.vamosc.navy.mil, the VAMOSC system is used by the Navy to estimate future life cycle costs (LCC) of legacy and future programs as well as determine opportunity areas to reduce LCC.[53] The VAMOSC system processes historical data taken from over 160 data sources. The detailed cost element format provides a system level that can be broken down further to subsystem and component levels.

VAMOSC presents data in the O&S categories required by the Cost Analysis Improvement Group (CAIG) Office of the Secretary of Defense (OSD). This allowed the team to estimate annual costs specifically for operations, support, and personnel of specific ship classes that best related to each of the six alternatives.

For each CAIG O&S cost element, the team used VAMOSC class average data from the following similar classes of ships: LSD-41, LSD-49, LPD-4, and LPD-17. In reporting the CAIG structure, VAMOSC reported average cost values from ships that were in

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[53] (Naval VAMOSC, 2012)

commissioned service of the active fleet during the entire fiscal year.[54] The average cost values were reported in FY2012 dollars. In order to forecast future O&S costs for a new ship, seven-year averages in manpower O&S costs were taken from the LSD-41, LSD-49 and LPD-4 class of ships. A five-year average in the same categories was determined for the LPD-17 class of ships due to the limited period of service for that class. These values were then averaged to estimate annual operations, maintenance, and personnel costs for the base year 2012, and this average was used to estimate future year (O&S) costs, as part of the LCCE for the different alternatives. Each O&S cost estimate was adjusted to be an estimate based on the alternative ship's input parameters.

Other factors within the model included inflation and labor rate. As ship construction is sequential over many years and the O&S stretches decades before decommission, inflation can be an important factor to consider within the model. This cost model has the functionality to utilize the inflation factors generated using the Joint Inflation Calculator, FY2012 version 1c, available at www.ncca.navy.mil. The inflation figures were generated based on the selections listed in Appendix C, and the inflation rates for FY 2013-2042 are shown in Appendix D. All cost estimates in this model are in FY12$ for consistency. The labor rate used in the model is $67.02/hr. (FY12$). This rate was determined using a mean base rate for Ship and Boat Building labor of $22.34 from the Bureau of Labor Statistics (BLS).[55] From discussions with subject matter experts in the shipbuilding field, it was determined based on historical experience that a 200% load was appropriate, yielding a fully loaded or wrapped rate of $67.02/hr.

"Life Cycle Cost Estimate" is the final product of the modeling effort. It is a summation of all costs associated with each new construction alternative.

3. Methodology

a. Regression Cost Estimate Model

Regression analysis was performed on each of the nine levels of the Ship Work Breakdown Structures (SWBS) for the currently existing five classes of ships: LSD-41, LSD-49, LPD-17, LHA-6, LHD-1. This analysis was completed and compiled by LT Allison Hills, USN, as part of her NPS thesis. The capability figures defined within the model's input parameters, number of LCACs, number of troops, crew size, cargo size and ship beam,

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[54] (IBM, 2012) p.78

[55] (Labor, 2012)

were input into the alternatives costing model to create a material and labor cost estimate model for the construction of a ship in accordance with required capabilities. Different regression models, linear, exponential, etc., were developed to determine the best-fit regressors. The regression models that yielded the top three best fits were then considered for adoption into the new construction model for each SWBS. Of the top three best fits, the cost estimation team chose the regressors that would be most responsive to the five input parameters of the model. For SWBS 200, 400, 500, and 700 where historical data on the labor cost does not exhibit any strong relationship for the creation of the model, defined as a low R-squared value, less than .65, within the regression, the mean cost value of the five ships was used instead.

The selected input parameters for material and labor of each SWBS are shown in Table 32. Table 32 also shows which model was chosen to estimate the cost of each SWBS. "In regression, a transformation to achieve linearity is a unique kind of nonlinear transformation that portrays the non-linear relationship between two variables. Transformations are often applied when the data ranges over several orders of magnitude."[56] For the purpose of this project, the Exponential, Logarithmic and Power models were used in addition to the simple linear regression model.

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[56] (Bohdan, 2011) p.4

SWBS Level	Material Variables	Regression Model	Labor Variables	Regression Model
100	Beam	Linear	Troops	Power
200	Cargo	Linear	Mean	-
300	Crew	Power	Beam	Logarithmic
400	Troops	Exponential	Mean	-
500	Crew	Logarithmic	Mean	-
600	Cargo	Linear	Troops	Power
700	LCAC	Linear	Mean	-
800	Beam	Linear	Crew	Logarithmic
900	Beam	Linear	Troops	Logarithmic

Table 32. Input Parameters for Estimating Material and Labor

The transformations of the variables are provided in Table 33.[57]

Method	**Transformation(s)**	**Regression Equation**	**Predicted Value ($\hat{y}$)**
Linear Model	None	$y = b_0 + b_1x$	$\hat{y} = b_0 + b_1x$
Exponential model	Dependent variable = log(y)	$\log(y) = b_0 + b_1x$	$\hat{y} = 10^{b_0 + b_1 x}$
Logarithmic model	Independent variable = log(x)	$y = b_0 + b_1\log(x)$	$\hat{y} = b_0 + b_1\log(x)$
Power model	Dependent variable = log(y) Independent variable = log(x)	$\log(y) = b_0 + b_1\log(x)$	$\hat{y} = 10^{b_0 + b_1 \log(x)}$

Table 33. Transformations to Achieve Linearity

b. *Model Verification*

In order to ensure that the model was credibly estimating the cost of new ship construction, the cost estimation team ran the Navy's five current amphibious ships through

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[57] (Hills, 2012) p.41

the model to validate results. Table 34 shows the Input Parameters that were used and the resulting estimated costs. The model costs were then compared to the historical costs to determine if the model was producing credible estimates of the known ships.

	Whidbey Island	**Harpers Ferry**	**San Antonio**	**America**	**Wasp**
Input Parameters	LSD-41	LSD-49	LPD-17	LHA-6	LHD-1
Number of LCACs	4	2	2	0	3
Cargo (cubic ft.)	5000	50700	34000	160000	125000
Crew	434	434	388	1124	1188
Troops	402	402	720	1687	1687
Beam (ft.)	84	84	105	194	140
Model Output cost	1.0025	1.1149	0.6834	0.9839	1.1850
Total Cost Historical	1.0000	1.0000	1.0000	1.0000	1.0000
Total Cost Difference	0.26%	11.49%	-31.66%	-1.61%	18.50%

Table 34. Model Comparisons with Historical Data

The final line in Table 34 “Total Cost Difference” shows the percent difference between the model cost estimate and the historical cost. A positive number indicates the model is overestimating by that percentage and a negative number indicates the model is underestimating by that percentage. Note that the costs are normalized, with historical costs set to 1.0. The model is close (less than 2%) on the LSD-41 and LHA-6 and not unreasonable (less than 20%) on all of the other ships except the LPD-17 (-32%). This shows that the model would expect the LPD-17 to cost 32% less than it actually did. Historically, the LPD-17 was over budget and behind schedule from its very beginning:

> The LPD-17 program has experienced considerable cost growth, schedule delays, and construction problems, particularly on the earlier ships in the program. The first ship in the program experienced cost growth of about 70%, and later ships in the program were substantially more expensive to build than originally estimated.[58]

The model was validated by estimating the costs of amphibious ships within an acceptable margin, with the one outlier as explained. This gave the cost estimation team

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[58] (O'Rourke, 2011) p.4

the confidence to use the model to estimate the cost of new ship construction and acquisition. The team then used this model to estimate the cost of the lead ship for the two new construction options LSD(X) and LSD(XB).

c. Calculating Lead Ship Cost

Material and labor costs were modeled for each SWBS according to the regressor selection and the transformation equations, these estimates were summed to develop the point estimate for the lead ship. This lead ship cost includes capital costs, which are acquisition and construction costs, including acquisition of materials and systems to build a ship, labor costs during construction, and services rendered.

For the LSD(X) and LSD(XB) alternatives, the input parameters are summarized in Table 35. These are the design parameters developed by the systems engineering team. Using these parameters the cost estimation team estimated the cost of the lead ship of both variants.

	LSD(X)	**LSD(XB)**
Beam	90	94
LCACs	2	2
Troops	400	530
Cargo	20000	66000
Crew	350	380

Table 35. New Construction Parameter Inputs

This lead ship cost point estimate was then additionally modeled using a Monte Carlo simulation to account for variations in costs and to adjust the estimates to use the 80th percentile of the Cumulative Distribution Function (CDF), which is in compliance with the Weapons Systems Acquisition Reform Act of 2009, requiring a 80% confidence level when calculating a cost estimate for a major defense acquisition program.[59] For more information concerning the Monte Carlo Simulations used, see Appendix F.

Methodology: A Monte Carlo simulation was run for each cost component, i.e. material costs and labor costs. The steps are detailed below.

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[59] (Congress, 2009)

a. Identifying Probability Distribution: The first step involves identifying the parameters of a suitable probability distribution. Given the limited data points in creating the regression model for each SWBS level, it was decided that using a triangular distribution would be appropriate.[60]

b. Deriving Parameters: As mentioned previously, each SWBS level had a regression model built, to estimate either material costs or labor hours, as a function of only one regressor; let this model be termed *f(x)*. The range of this regressor was obtained from the data set and three values in this range were passed through the regression model to obtain the parameters for the triangular distribution, namely, the lowest value over the range *a* to obtain parameter *f(a)*, the highest value over the range *c* to obtain parameter *f(c)* and the most likely value *b* to obtain parameter *f(b)*. Figure 46 illustrates this process.

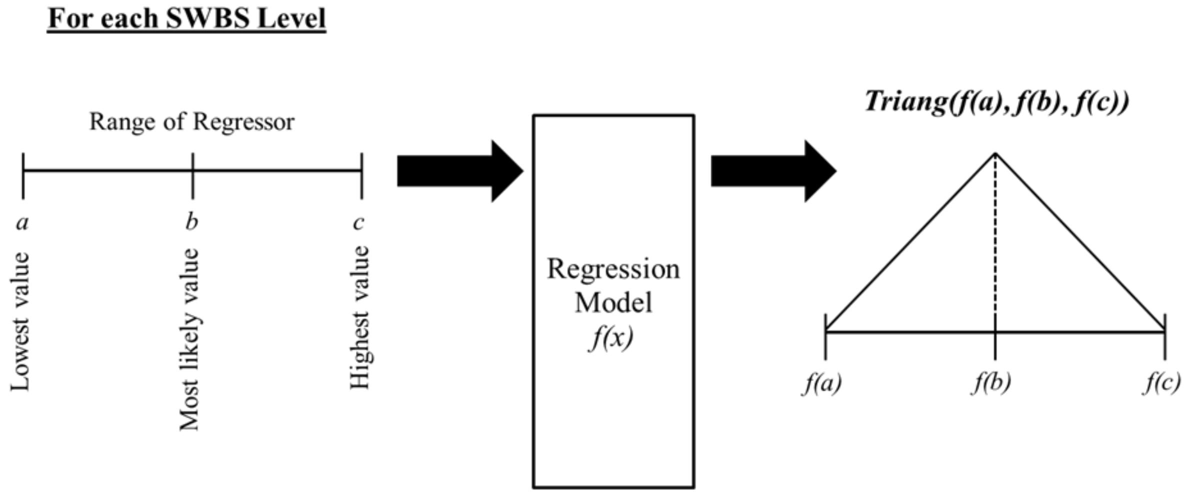

Figure 46. Procedure for Derivation of Parameters

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[60] *Tri (a, b, c)* where *a* corresponds with the lowest value, *c* corresponds with the highest value and *b* corresponds with the most likely value.

C. LSD(X) AND LSD(XB) ALTERNATIVES

1. LSD(X) Lead Ship Model

The following methodology applied to estimates for alternatives that involve utilizing a newly designed ship hull form for the project. These alternatives are the LSD(X) and LSD(XB). The ranges of the regressors used as input parameters to estimate the cost of the LSD(X) are shown in Table 36.

Regressor	Lowest Value	Most Likely Value	Highest Value
Beam (Ft)	81	90	99
LCACs (Spots)	1	2	3
Troops (Bunks)	340	400	460
Cargo (Cu Ft)	17000	20000	23000
Crew (Number)	298	350	403

Table 36. Range of Values for Regressors – LSD(X)

The final probability distributions for material costs and labor hours are shown in Tables 37 and 38.

SWBS Level	Regressor	*f(a)*	*f(b)*	*f(c)*
100	Beam	5763380	11332421	16901463
200	Cargo	25585255	27484003	29382750
300	Crew	7295348	9869447	12863317
400	Troops	14359267	15702126	17170568
500	Crew	1976422	22281333	40082053
600	Cargo	17396813	18436561	19476310
700	LCAC	3374304	2367834	1361364
800	Beam	25347691	30090861	34834031
900	Beam	538299	5698065	10857831

Table 37. Probability Distributions for Material Costs – LSD(X)

SWBS Level	**Regressor**	***f(a)***	***f(b)***	***f(c)***
100	Troops	1217227	1355175	1486245
200	Mean	307295	307295	307295
300	Beam	322356	525375	709028
400	Mean	453541	453541	453541
500	Mean	2243576	2243576	2243576
600	Troops	482747	579471	678013
700	Mean	50235	50235	50235
800	Crew	-236374	446661	1045457
900	Troops	1063360	1407275	1703032

Table 38. Probability Distributions for Labor Hours – LSD(X)

Simulation Results: 100,000 simulations were run for each cost component with the following results:

a. Material Costs: The simulations resulted in a mean of $142.6M with a standard deviation of $8.7M. This resulted in a range from $133.8M to $151.3M based on one standard deviation. The results of the Monte Carlo simulation are shown in Figure 47. The corresponding 80% CDF level is approximately $150M.

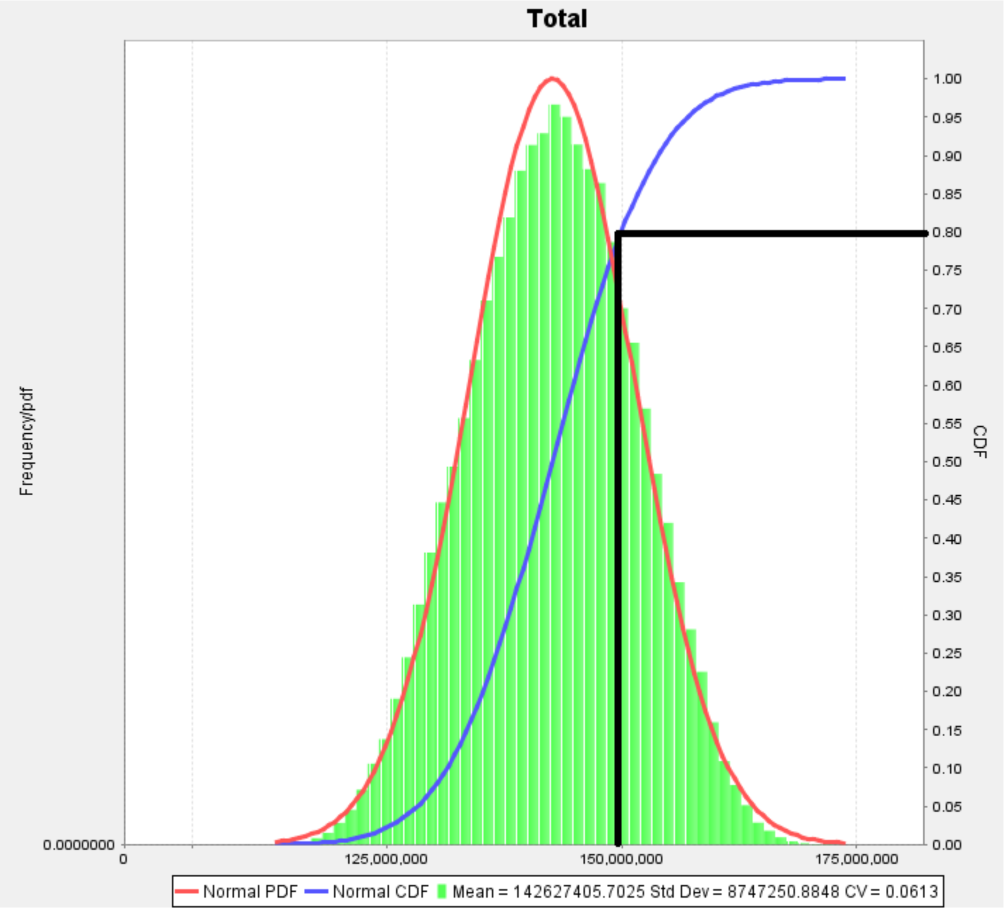

Figure 47. Results of Monte Carlo Simulation for Material Costs – LSD(X)

b. Labor Hours: The simulations resulted in a mean 7.3M hours, with a standard deviation of 310,118 hours. After factoring in the recommended labor rate of $67.02 per hour, the range for the total cost of labor was from $469.6M to $511.1M based on one standard deviation. The results of the Monte Carlo simulation are shown in Figure 48. The corresponding 80% CDF level is approximately 7.6M hours, or $510.0M after factoring in labor rates.

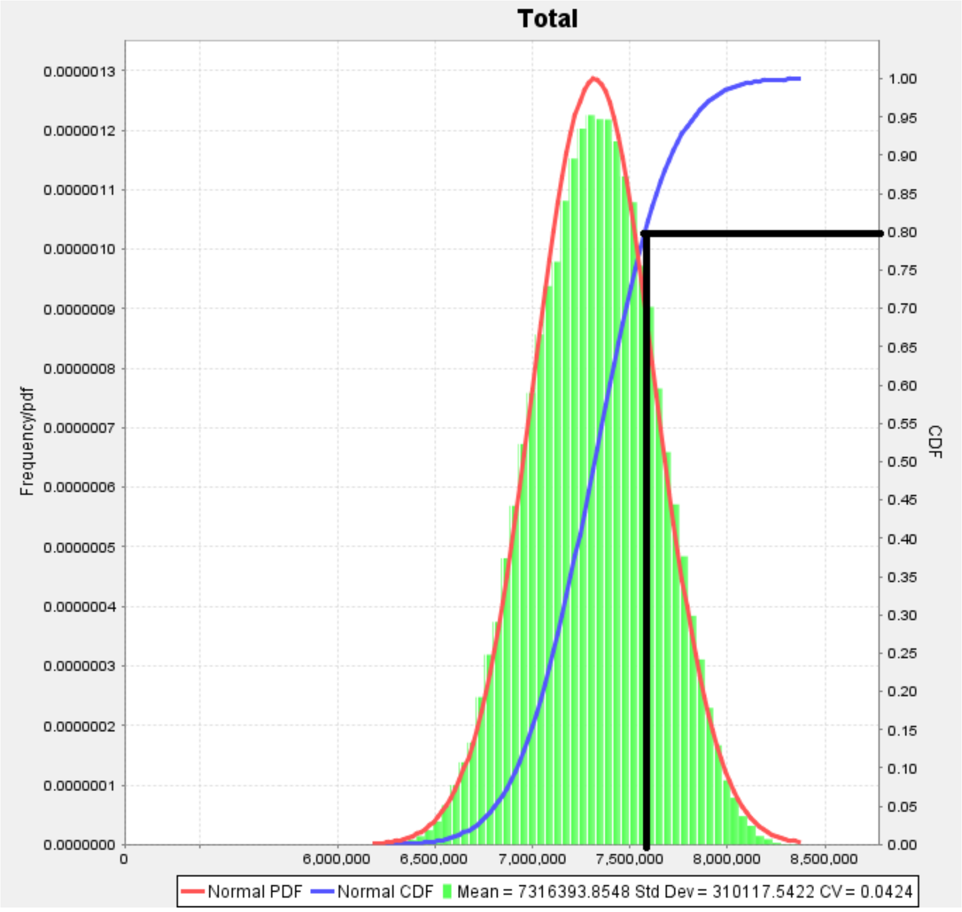

Figure 48. Results of Monte Carlo Simulation for Labor Hours – LSD(X)

Monte Carlo simulation yielded a total cost range was from \$603.4M to \$662.5M based on one standard deviation for the LSD(X). The 80% CDF level is \$660M.

2. LSD(XB) Lead Ship Model

The ranges of the regressors used as input parameters to estimate the cost of the LSD(XB) alternative are shown in Table 39.

Regressor	Lowest Value	Most Likely Value	Highest Value
Beam (Ft)	84.6	94	103.4
LCACs (Spots)	1	2	3
Troops (Bunks)	451	530	610
Cargo (Cu Ft)	56100	66000	75900
Crew (Number)	323	380	437

Table 39. Range of Values for Regressors – LSD(XB)

The final probability distributions for material costs and labor hours are shown in Tables 40 and 41.

SWBS Level	**Regressor**	***f(a)***	***f(b)***	***f(c)***
100	Beam	7990996	13807551	19624106
200	Cargo	50332263	56598130	62863996
300	Crew	8487560	11518606	14977766
400	Troops	16941846	19058201	21470896
500	Crew	12146426	32663333	50307325
600	Cargo	30948204	34379375	37810545
700	LCAC	3374304	2367834	1361364
800	Beam	27244959	32198937	37152915
900	Beam	2602205	7991294	13380383

Table 40. Probability Distributions for Material Costs – LSD(XB)

SWBS Level	**Regressor**	***f(a)***	***f(b)***	***f(c)***
100	Troops	1466972	1632027	1790843
200	Mean	307295	307295	307295
300	Beam	406148	609166	792819
400	Mean	453541	453541	453541
500	Mean	2243576	2243576	2243576
600	Troops	663124	794998	931048
700	Mean	50235	50235	50235
800	Crew	105733	795900	1389424
900	Troops	1661219	2002786	2300279

Table 41. Probability Distributions for Labor Hours – LSD(XB)

<u>Simulation Results</u>: 100,000 simulations were run for each cost component with the following results:

a. <u>Material Costs</u>: The simulations resulted in a mean of $209.8M with a standard deviation of $9.3M. This resulted in a range from $200.5M to $219.1M based on one standard deviation. The results of the Monte Carlo simulation are shown in Figure 49. The corresponding 80% CDF level is approximately $218M.

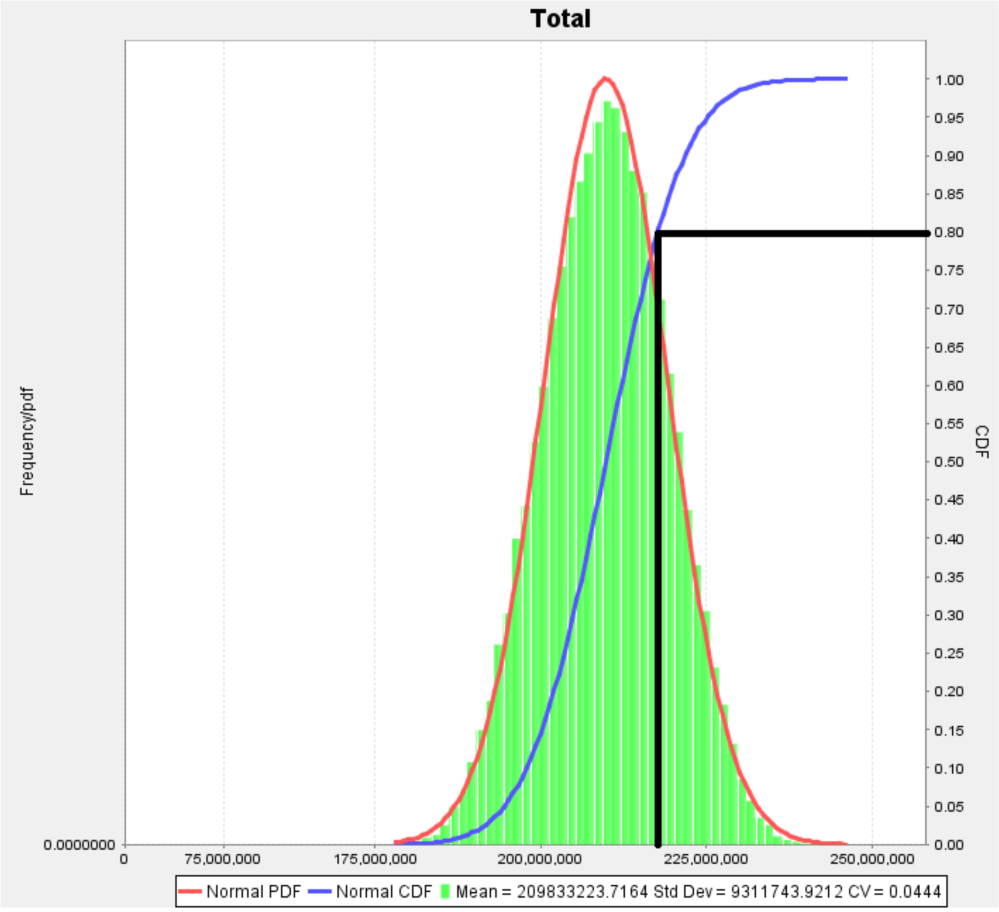

Figure 49. Results of Monte Carlo Simulation for Material Costs – LSD(XB)

b. <u>Labor Hours</u>: The simulations resulted in a mean 8.8M hours, with a standard deviation of 315,740 hours. After factoring in the recommended labor rate of $67.02 per hour, the range for the total cost of labor was from $571.1M to $613.4M based on one standard deviation. The results of the Monte Carlo simulation are shown in Figure 50. The corresponding 80% CDF level is approximately 9.1M hours, or $609.9M after factoring in labor rates.

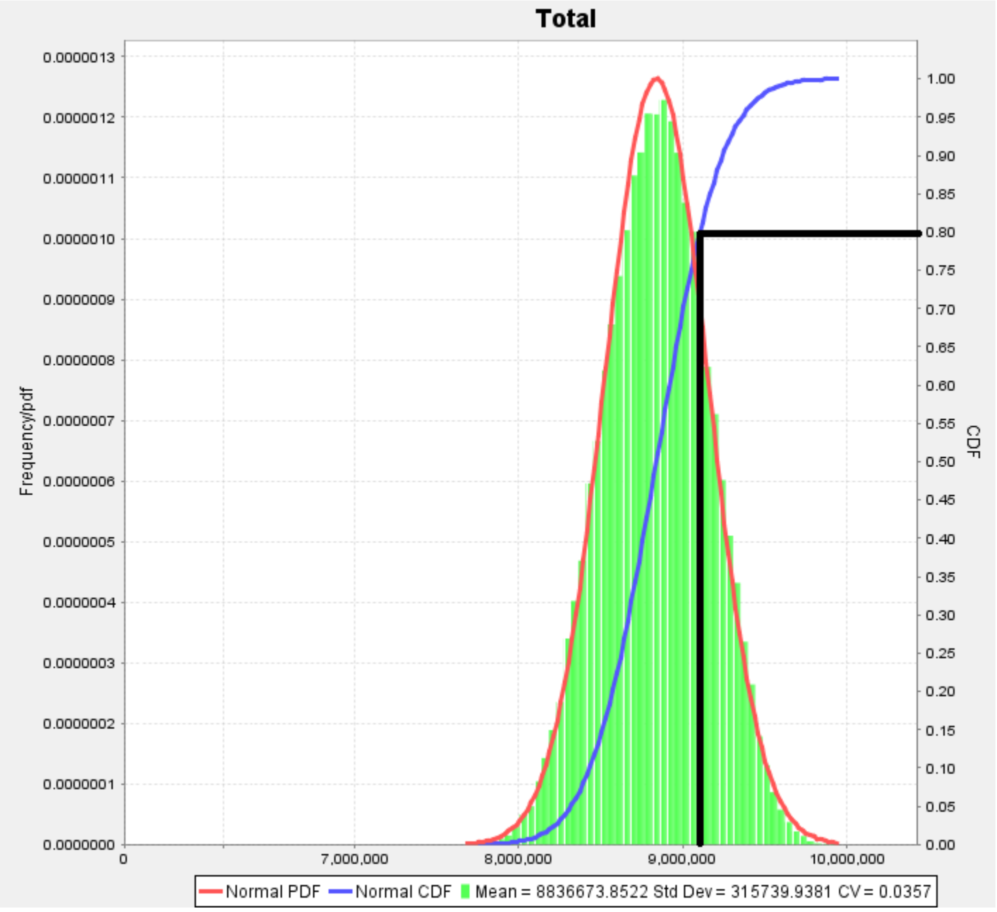

Figure 50. Results of Monte Carlo Simulation for Labor Hours – LSD(XB)

Monte Carlo simulation yielded a total cost range from $771.6M to $832.5M based on one standard deviation for the LSD(XB) variant. The 80% CDF level is $827.9M.

3. Follow Ship Costs and Other Costs

The output cost ranges based on one standard deviation for the two simulated alternatives, and their respective 80% CDF levels are summarized in Table 42. All estimates are in FY12$M.

Alternatives	Lower Limit	Upper Limit	80% CDF
LSD(X)	$603.4M	$662.5M	$660.0M
LSD(XB)	$771.6M	$832.5M	$827.9M

Table 42. Summary of Monte Carlo Results

From a purely lead ship procurement perspective, the LSD(X) alternative appeared to be the cheaper alternative, assuming both alternatives are equally able to meet the desired performance levels. However, other elements of the Life Cycle Costs, namely acquisition and O&S, still need to be considered, and they represent a larger portion of the LCCE than does the lead ship. The results from this section help form the basis from which a substantial portion of the remaining Life Cycle Costs portions were estimated.

Design Costs: With each of the new ship construction designs there is an associated design cost which is attached to the lead ship cost. This cost accounts for the preliminary design as well as any design changes and modifications that need to be made during construction of the first ship. Discussion with industry experts led to an estimated design cost for an amphibious ship of this size to be $350M (FY12$). This cost was be added to each of the lead ship for all new construction alternatives.

Follow Ship Costs: (2nd – nth ships) Utilizes learning curve theory to model efficiency gains made for material and labor aspects as the construction proceeds. The model also made provisions for customizations of the learning curve within the class as the hull number progresses. This customization of ship components for ‘n’ ships is also built into the model to allow flexibility in cost estimation.

Base case learning curve parameters for the labor learning curve was set at 95% while the material learning curve was set at 99%, based on discussions with subject matter experts. The learning curve formula is shown below:[61]

$$y_x = Tx^b$$

Where b= $\frac{\ln of\ slope}{\ln of\ 2}$
x = hull number
y = unit cost for hull number x
T = Lead ship cost

Life Cycle Operational and Support (O&S) Costs: Annual O&S costs are required to maintain and sustain the operation of the ship. This includes the material and personnel costs. As additional ships are procured there is an annual O&S cost for each new ship.

Table 43 shows the averages of the current annual O&S costs of amphibious ships in the US Navy. This data was obtained from the VAMOSC database. These are the base line values that were used for computation in the models. These numbers represent the average cost to operate one ship for one year in FY12$.

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[61] (Nussbaum, 2012)

Historical O&S Data Averages (FY12$M)				
	Total O&S	**Manpower**	**Operations**	**Support**
LHA-1	$157.8M	$89.4M	$30.8M	$37.6M
LHD-1	$157.8M	$86.8M	$28.6M	$42.3M
LSD-41	$65.1M	$23.5M	$8.0M	$33.6M
LSD-49	$56.9M	$23.7M	$9.6M	$23.6M
LPD-4	$64.3M	$29.3M	$14.9M	$20.1M
LPD-17	$49.6M	$28.2M	$6.5M	$14.9M

Table 43. VAMOSC Historical O&S data (Follows [62])

Table 43 shows the actual, historical, and O&S values derived from the VAMOSC historical database, and used to estimate O&S costs for LSD(X). LSD(X) O&S was estimated as the average of the two current LSD variants, where the LSD(XB) value is the LSD(X) value increased by 10% to account for the larger ship size and increase in crew size. The LPD-17 and LHA-8 values are the current O&S averages over the past seven years.

Alternative	FY12$M
LSD(X)	60.0
LSD(XB)	67.1
LPD-17	49.6
LPD(17) Flt X	49.6
LHA-8	157.8

Table 44. Alternatives O&S

Additional O&S considerations: There was some consideration for adding helicopter and LCAC O&S. The LSD(X) and LSD(XB) new construction designs are based on CH-53 equivalent aircraft at an annual O&S cost of $6.3M, based on the VAMOSC historical data from the past five years. Both of these options include two helicopter assets associated with their ship design. They also both include two LCACs with an annual O&S cost of $1.8M, based on the average O&S of the 81 LCACs in the fleet over the past three years. Since both designs include the same number of aircraft and LCACs and the O&S costs are relatively small in comparison to the ships' O&S, the decision was made to exclude the external assets' O&S from the calculations. This would also allow the cost team to compare and contrast, more fairly, the LCCE alternatives of different ship classes.

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[62] (Naval VAMOSC, 2012)

4. New Construction LSD(X) and LSD(XB) Results

The results from the modeling, lead ship procurement and follow on ship procurement, described above produced the final procurement cost estimates shown in Table 45. These results are estimates for the procurement of the eleven new construction ships for both designs provided by the systems engineering team. The lead ship of both classes also accounts for the design cost of a new construction ship.

New Construction (FY12$M)		
Hull #	**LSD(X)**	**LSD(XB)**
1	1010.0	1177.9
2	633.0	795.2
3	617.8	776.8
4	607.3	764.1
5	599.3	754.4
6	592.8	746.6
7	587.4	740.0
8	582.8	734.4
9	578.8	729.5
10	575.2M	725.2M
11	572.0M	721.3M

Table 45. New Construction Procurement Cost

The LCCEs are based on the model results for Procurement Cost as well as the Operating and Support Cost and cover a 30-year period which begins with the procurement of the first ship and ends with the completion of the 30 year life of the lead ship, therefore, operational life will be left on the remaining 10 ships. These options include buying 11 new construction LSD(X)s or LSD(XB)s at an interval of one ship every other year during a 22 year period. The O&S costs are incurred annually for each. An example of how the LCCE is calculated can be seen in Table 46. The table shows that each time a new procurement occurs there is an O&S cost associated with it, which is then continued for each year of the LCCE. The LCCE covers years 1-30, so there is some usable life left in hulls 2-11. The LCCE for the LSD(X) is $20.37 Billion and $23.42 Billion for LSD(XB). The entire analysis can be seen in Appendix G.

Year	1	2	3	4	5	6	7
LSD(X)	1		2		3		4
Procurement Cost	1010.00		633.00		617.80		607.30
	61.00	61.00	61.00 61.00	61.00 61.00	61.00 61.00 61.00	61.00 61.00 61.00	61.00 61.00 61.00 61.00
Cost per Year	1071.00	61.00	755.00	122.00	800.80	183.00	851.30
Cumulative LCCE	1071.00	1132.00	1887.00	2009.00	2809.80	2992.80	3844.10

Table 46. Example of LCCE Calculation

D. LPD-17 ALTERNATIVES

There were three options for LPD-17 procurement that were examined by the cost estimation team. The first two options continue procuring LPD-17s at the completion of the current order. This would allow for the use of already established best building practices and avoid the cost of new design and plans. The third alternative would be to use a portion of the current LPD-17 and redesign and reapportion the interior of the ship to better fill the requirement capability gaps. This option was considered an LPD(17) Flt X. The following analysis examines these options.

1. Continuation of the Current LPD-17

To estimate the cost of continuing the current LPD-17 line the team examined the data for ships currently being procured. Procurement data, taken from the Selected Acquisition Report LPD-17 dated December 31, 2011, for the first 11 LPD-17s allowed for an estimate of the current learning curve. Figure 51 shows the cost of the first 11 LPD-17s (T_1-T_{11}). Using this data and an exponential best-fit curve yields a learning curve equation of:

$$y = 1756.6e^{-0.011x}$$

Equation 3: Learning Curve Calculation

The learning curve value is $2^{-0.011}$, which equals 0.9924. This is a 99.24% learning curve.

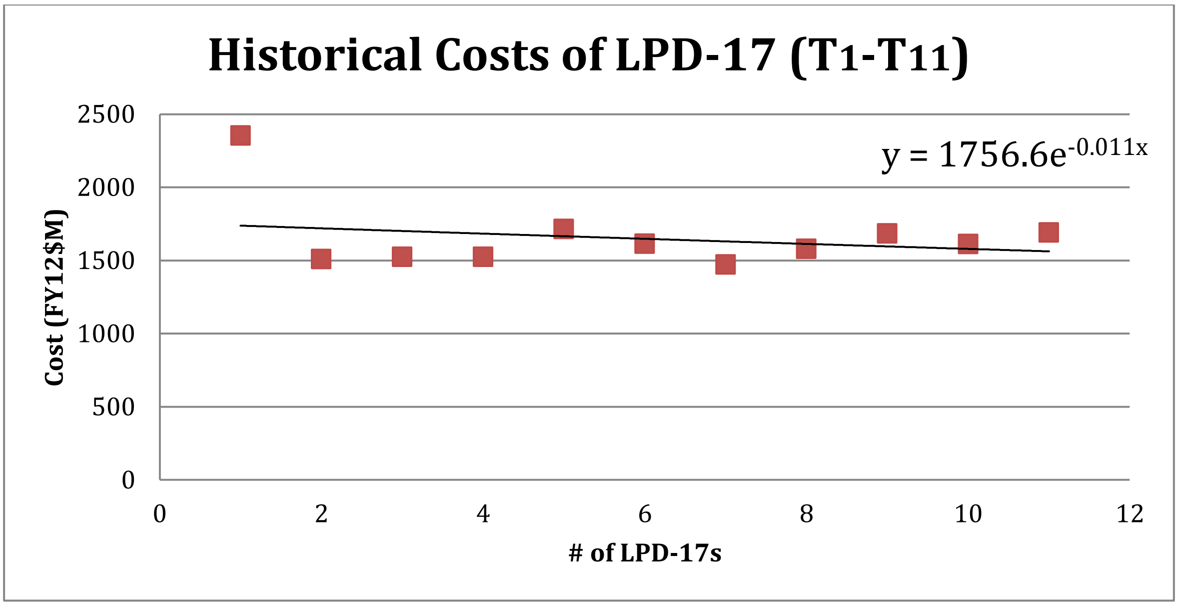

Figure 51. Estimated LPD-17 Learning Curve (Follows [63])

A major assumption for this alternative was that the continued construction of LPD-17s would take advantage of the current learning curve. In accordance with the FY 2011 shipbuilding plan this would lead to a construction gap of three years between construction of ship 11 and 12. This assumption stipulates that no learning would be lost and this alternative would recommend that current ship construction be slowed to maintain the industrial base until additional funding would be available to continue construction.

The equation of $y = 1756.6e^{-0.011x}$ where y is the cost in FY12$ and x is the consecutive number of LPD-17, allowed for a model that can predict the next 10 follow-on ships. For example, hull 12 is estimated to cost $1539M. This can be seen in Figure 52.

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[63] (DAMIR, 2010)

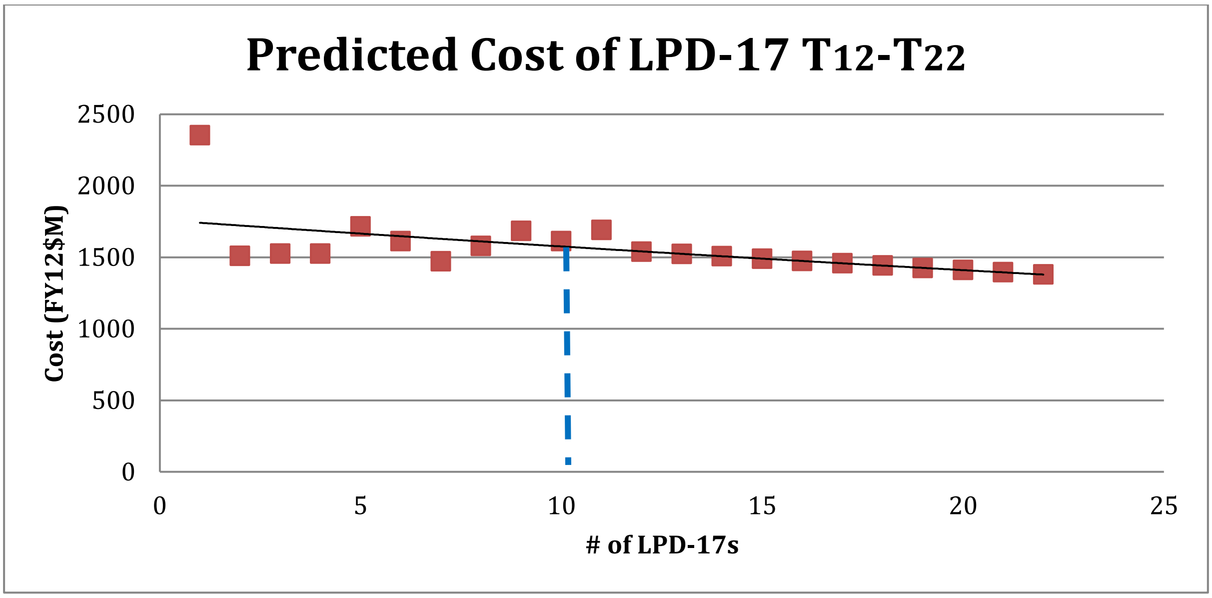

Figure 52. Prediction of constructing additional LPD-17s (Follows [64])

The historical LPD-17 cost as well as the predicted procurement of the next 11 LPD-17s can be seen in Table 47. These estimates are shown in FY12$ Millions and represent buying one ship every other year for 22 years.

Historical (FY12$M)		**11 LPD-17s (FY12$M)**		**19 LPD-17s (FY12$M)**	
Hull #	Procurement	Hull #	Procurement	Hull #	Procurement
1	2353	12	1539	23	1364
2	1509	13	1523	24	1349
3	1524	14	1506	25	1334
4	1524	15	1489	26	1320
5	1714	16	1473	27	1305
6	1613	17	1457	28	1291
7	1471	18	1441	29	1277
8	1579	19	1425	30	1263
9	1685	20	1410		
10	1611	21	1394		
11	1691	22	1379		

Table 47. Historical and Predicted Procurement Costs of LPD-17s

The additional LPD-17s LCCEs were based on the model prediction of Procurement Cost and the Operating and Support Cost for a 30-year period beginning with the

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[64] (DAMIR, 2010)

procurement of the first ship. The first alternative included buying 11 additional LPD-17s at an interval of one ship every other year during a 22-year period. The O&S costs are cumulative for each additional ship resulting in 11 ships' O&S for the final 8 years in the life cycle cost of the first ship before they begin decommissioning. The second alternative included buying 19 additional LPD-17s at an interval of one ship every year over a 19-year period. The O&S costs are cumulative for each additional ship resulting in 19 ships' O&S for the final 11 years of the life cycle. There was no design costs associated with these alternatives because the construction line for the current LPD-17 would be continued. The LCCE is $26.94 Billion (FY12$) for 11 LPD-17s and $46.32 Billion (FY12$) for 19 LPD-17s. The price of the 19 LPD-17s is much higher than any other options in this analysis, but this alternative would not require the procurement of the LHA-8 class ship, which would decrease the total ship procurement budget of the Navy. The entire analysis can be seen in Appendix J.

2. LPD(17) Flt X

The cost estimate for the LPD(17) Flt X was also based on the current 11 LPD-17s and used learning curve theory to predict the cost of the next 11 ships. To estimate the cost for the LPD(17) Flt X, an estimate was needed concerning how much of the ship would remain the same as the previous ships and how much the systems engineering team expected it to change compared to previous ships.

In order to estimate the cost of LPD(17) Flt X, the cost and system engineering teams analyzed the ship at the 1-digit SWBS level to determine which levels would be changed in order to accommodate the new design. It was determined that the ship would be 70% legacy and 30% new design and construction. The team used the original LPD-17 learning curve equation to estimate the cost of T_{12}-T_{22}. Knowing that the ship would be 70% legacy allowed the team to multiply these values by 0.7 and sum them with the values of T_1-T_{11} multiplied by 0.3 to get a price for each LPD(17) Flt X ship. The new construction portion began with T_1 for LPD-17. The equation below demonstrates how the cost of T_{12} was calculated.

$$\text{LPD(17) Flt X} \quad T_{12}=(T_{12}*.70)+(T_1*.30)$$

Equation 4: T12 Calculation

	Ship #	FY12$M	70% Legacy	30% New	LPD(17) Flt X FY12$M
Historical Data	1	2353		706	
	2	1509		453	
	3	1524		457	
	4	1524		457	
	5	1714		514	
	6	1613		484	
	7	1471		441	
	8	1579		474	
	9	1685		505	
	10	1611		483	
	11	1691		507	
Predicted Procurement Cost	12	1539	1078		1783
	13	1523	1066		1518
	14	1506	1054		1511
	15	1489	1043		1500
	16	1473	1031		1545
	17	1457	1020		1504
	18	1441	1009		1450
	19	1425	998		1471
	20	1410	987		1492
	21	1394	976		1459
	22	1379	965		1472

Table 48. LPD-17 procurement Cost Estimates

This LCCE for the LPD(17) Flt X is based on the model prediction of Procurement Cost and the Operating and Support Cost for a 30-year period beginning with the procurement of the first ship. This alternative includes buying 11 additional LPD(17) Flt Xs at an interval of one ship every other year during a 22-year period. The O&S costs are cumulative for each additional ship resulting in 11 ships O&S for the final 8 years in the life cycle cost of the first ship before they begin decommissioning. The cost of this option was slightly higher because of the design costs and the inability to use the lessons learned for the 30% of the ship that is new. The LCCE for the LPD(17) Flt X is $27.86 Billion (FY12$). The entire analysis can be seen in Appendix I.

E. LHA-8 ALTERNATIVE

The final alternative would procure four LHA-8s in addition to the six that are already being designed and procured, for a total of 10 new LHA-8s in the fleet. With six LHA-8s as part of the current Navy shipbuilding plan, the challenge was determining how to compare procuring an additional four and determining the LCCE of just these four, so it could be compared to the LCCE of the other alternatives.

A major assumption was the LHA-8 will be analogous to LHA-6 and that T_1 for LHA-6 could be used as the T_1 for the learning curve associated with the LHA-8 class. The team also assumed that the Navy was going to procure and operate the LHA-8 class as described in the current Navy Ship Building plan dated February of 2010.[65]

Development of the LCCE for the LHA-8 alternative was done in a similar manner as the LPD-17 options. LHA-6 was used for analogy to estimate the T_1 for the new class of ships. Costs to follow-on ships were modeled using a 99% learning curve for material and labor. This allowed the team to estimate the entire cost of procuring and operating the six LHA-8s that are scheduled to be built as part of the current ship building plan, and to model the procurement of 10 LHA-8s, buying one every other year, over the course of 20 years. Using these two procurement plans and adding the O&S costs of the ships as they were completed allowed the team to build two LCCEs.

The Navy shipbuilding plan calls for the procurement of LHAs in 2020, 2025, 2028, 2032, 2036, and 2040. The team planned for procuring 10 ships over the course of 20 years. The two plans did not line up neatly to allow for some of the 10 ships (and their associated O&S) to be called additional costs over the original planned procurement. To account for the variance in the two plans the cost team estimated the cost of the original plan and the cost of the team's alternative. With this information the difference was taken between the 10 LHA-8s plan and the original six LHA-8s plan to determine the LCCE of just the additional four LHA-8s for comparison to the other alternatives LCCEs.

The procurement costs of the LHA-8s can be seen in Table 49. These procurement costs and their associated O&S costs were used to develop LCCEs for both the six and ten LHA plans which led to the final LCCE for this alternative of $23.045B in FY12$. The entire analysis including O&S and the difference between the two LHA-8 plans that make up this LCCE can be found in Appendix J.

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[65] (Command, 2010) p.12

Hull #	FY12$M
LHA-8	2210
LHA-9	2201
LHA-10	2194
LHA-11	2189
LHA-12	2184
LHA-13	2180
LHA-14	2177
LHA-15	2173
LHA-16	2170
LHA-17	2168

Table 49. Procurement cost of LHA-8s

F. SUMMARY OF COST ESTIMATES AND CONCLUSIONS

The results of the Total Life Cycle Cost for the six alternatives can be seen be seen in Figure 53.

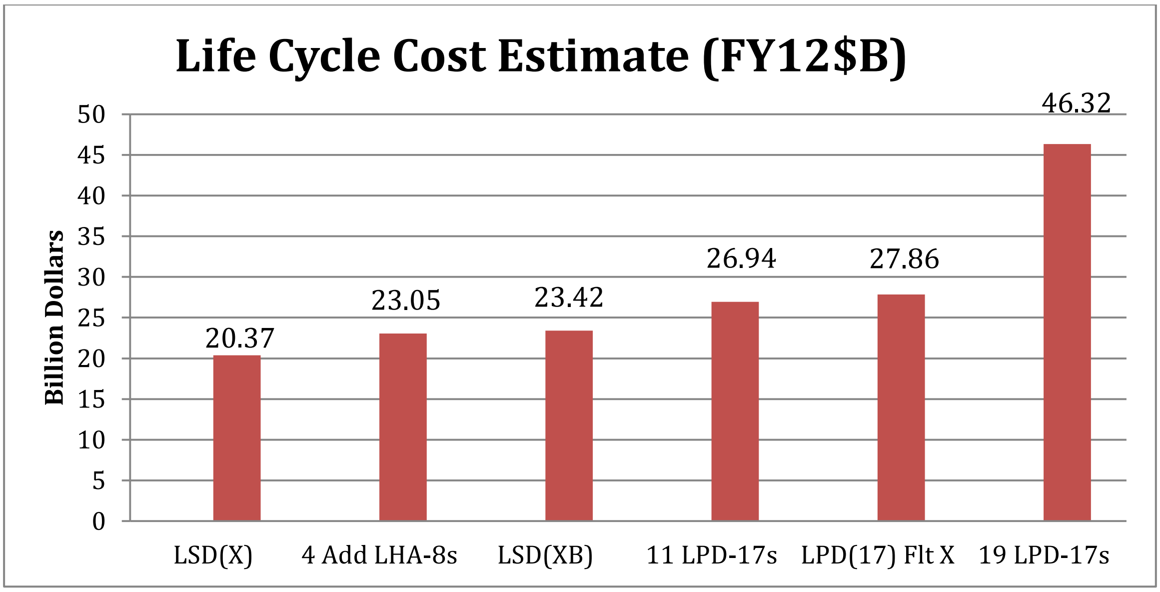

Figure 53. LCCE Summary

Additionally, Figure 54 shows Cumulative LCCE on a yearly basis over the 30-year life cycle for the six alternatives. It shows that all six options retain their relative position to each other throughout the life cycle. The only exception is the LSD(XB) which overtakes the LHA-8s around year 26 of the life cycle. This is because it is more costly to operate 11 LSD(XB)s than 4 LHA-8s.

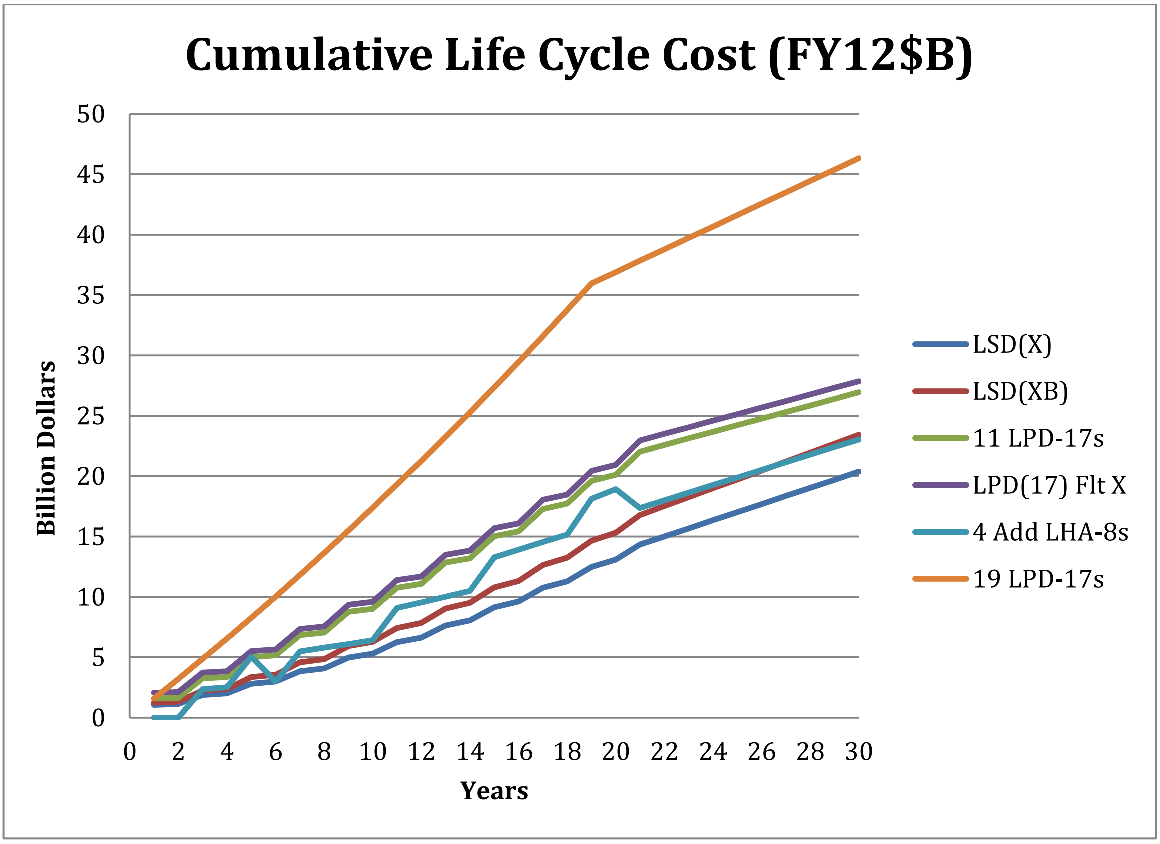

Figure 54. Cumulative LCCE (Yearly Basis)[66]

Looking at the results there are effectively four different cost points. The LSD(X) option is the least expensive option, the LSD(XB) and 4 additional LHAs are the second least expensive, the 11 LPD-17s and LPD(17) Flt X are the third least expensive, and the 19 LPD-17s is the most expensive option.

The LSD(X) is the smallest ship and therefore would be expected to cost the least. This is a new construction alternative but has relatively small size requirements, which helps keep the costs down.

The LSD(XB) is a larger ship, but still smaller than an LPD-17 and starts the second cost tier. This ship has an added capability, but this comes with the higher price. The reason the LHA option is so cost competitive is because it requires the procurement and O&S of only four new ships, as opposed to the other options, which all require 11 ships. Additionally, the team made the assumption that with six LHA-8s already in the procurement process there would be no additional design or startup costs for this option.

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[66] The negative slope of the LHA-8 alternative at year five can be explained by the fact that the team subtracted the LCCE of 6 ships from the LCCE of 10 ships. At year four the team plan calls for a procurement which causes the large positive slope but then in year 5 the original plan calls for a procurement without a procurement in the team plan causing the negative slope.

The third price tier of LPD-17 and LPD(17) Flt X is expected. The LPD-17 has been a historically expensive ship class and has shown very little decrease in cost over the first ten built. This analysis showed that continued procurement of the LPD-17 would continue to be a very expensive alternative.

The final, and highest, price tier is the 19 LPD-17 alternative. This is a very expensive option due to the expense of the ships and also that it requires 19 instead of the 11 required by most of the other options. If this option is chosen there are several other cost considerations that should be measured. This option would not require the LHA-8 class to be built with some mitigating considerations. The current LHA-8 class of six ships was estimated to cost approximately $31.9 Billion over the 30-year life cycle. If it is decided that this money can be reappropriated to the 19 LPD-17 alternative, it would then be an additional $14.4 Billion and make this option the least expensive option over the course of its 30 year life cycle. However, as it currently stands it is the most expensive option at double the cost of the bottom two tiers.

The LCCEs of all six alternatives were used as part of the cost-versus-risk-versus-performance analysis to determine which alternative is the best solution to identified problem.

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VII. RISK DECISION ANALYSIS

A. INTRODUCTION

The following risk analysis aimed to identify the areas throughout the lifecycle of the ship that should be considered prior to selecting an alternative. The goal was to give decision makers a rudimentary understanding of areas that, if left unaddressed, could lead to serious issues during the acquisition or operations of an LSD replacement ship. The assessment that follows was founded in the principles of the DOD's Risk Management Guide for Acquisition 6th Edition, and the majority of risk for the project focused on the areas of performance, schedule and cost.[67] The analysis defined risk as it relates to the proposed alternatives, evaluates risk within the three basic areas, and attempted to give operationally based consideration to guide alternative comparison. The risk of each option was subjectively quantified according to techniques described by Mierzwick & Brown solely for the sake of comparing the six options.[68] The emphasis of this section was the identification of risk factors and correlating mitigating strategies as they relate to the alternatives. At the conclusion of this chapter a list of mitigation techniques is provided.

1. Terms and Definitions[69]

Risk: A measure of future uncertainties in achieving program performance goals within defined cost and schedule constraints. It has three components: a future root cause, a likelihood assessed at the present time of that future root cause occurring, and the consequence of that future occurrence.

Consequence: The outcome of a future occurrence expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain.

Future Root Cause: The reason, which, if eliminated or corrected, would prevent a potential consequence from occurring. It is the most basic reason for the presence of a risk.

2. Risk Management Process

Risk Management is an overarching process that encompasses identification, analysis, mitigation planning, mitigation implementation, and tracking of future causes and their

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[67] (Department of Defense, 2006)

[68] (Mierzwick & Brown, 2004)

[69] (Department of Defense, 2006) p.33

consequences. The risk management process model included the following key activities, performed on a continuous basis as shown in the Figure 55.[70]

- Risk Identification
- Risk Analysis
- Risk Mitigation Planning
- Risk Mitigation Plan Implementation
- Risk Tracking

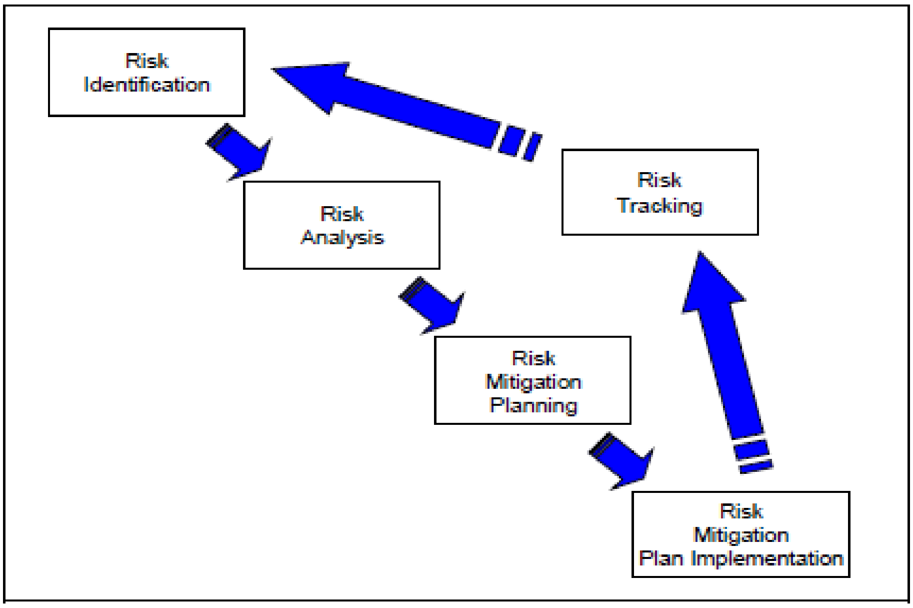

Figure 55. DoD Risk Management Process (From[71])

Risk Identification: The activity that examines each element of the program to identify associated future root causes, begin their documentation, and set the stage for their successful management. Risk identification begins as early as possible in successful programs and continues throughout the life of the program.

Risk Analysis: The activity of examining each identified risk to refine the description of the risk, isolate the cause, determine the effects, and aid in setting risk mitigation priorities. It refines each risk in terms of its likelihood, its consequence, and its relationship to other risk areas or processes.

Risk Mitigation Plan Implementation**:** The activity of executing the risk mitigation plan to ensure successful risk mitigation occurs. It determines what planning, budget, and

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[70] (Department of Defense, August 2006) p.4

[71] (Department of Defense, August 2006) p.4

requirements and contractual changes are needed, provides a coordination vehicle with management and other stakeholders, directs the teams to execute the defined and approved risk mitigation plans, outlines the risk reporting requirements for on-going monitoring, and documents the change history.

Risk Mitigation Planning: The activity that identifies, evaluates, and selects options to set risk at acceptable levels given program constraints and objectives. It includes the specifics of what should be done, when it should be accomplished, who is responsible, and the funding required to implement the risk mitigation plan.

Risk Tracking: The activity of systematically tracking and evaluating the performance of risk mitigation actions against established metrics throughout the acquisition process and develops further risk mitigation options or executes risk mitigation plans, as appropriate. It feeds information back into the other risk management activities of identification, analysis, mitigation planning, and mitigation plan implementation.

This analysis focused on the first three steps; Risk Mitigation Plan Implementation and Risk Tracking would be performed during the conduct of the acquisition process.

3. Risk Identification

The first objective in the risk management process was risk identification. Risk identification includes the screening of all requirements and the identification of those likely not to be met. The intent of risk identification was to answer the question, “What can go wrong?” by:

- Looking at current and proposed staffing, process, design, supplier, operational employment, resources, dependencies, etc.
- Reviewing potential shortfalls against expectations.

Risk identification begins as early as possible and continues throughout the program with regular reviews and analyses, paying particular attention to schedule, resource data, and life-cycle costs.[72]

4. Types of Risk

a. Performance (P) Considerations

Performance considerations focused on the effective impact that technical performance could have on the scope of the project. These impacts are associated with how

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[72] (Department of Defense, August 2006) p.7

well a solution does what it was designed to do in the environment for which it was designed. These considerations are generally defined within the analysis of stakeholder requirements and during the initial design. They should be traced through the functional and physical decompositions and the scenarios in which the designs will be utilized. The overall question examined in this section was, “What can go wrong from an operational perspective and what are the consequences of it happening?”

b. Performance Risk Factors

(P1) Risk of Not Meeting Lift Requirements – This factor included the risks associated with the probability of the given architecture not being able to meet the mission requirements due to inadequate lift capability. The lift capability was inclusive of the the analysis performed in Section V of this report for both the MEU and MEB lift requirements.

(P2) Number of Ships (Failure, Maintenance) – This factor focused on the risks associated with the impact of ship failures, due to maintenance or equipment failure, in certain sized amphibious fleets as well as the implications of a design flaw impacting multiple ships.

(P3) Risk of Failing to Conduct a Diverse Mission Set – This factor focused on the ability of the various alternatives to conduct the range of military operations.

(P4) Mission Accomplishment (Split-Ops Impacts) – This factor focused on the impact the number of ships might have on the Combatant Commander’s ability to conduct multiple, simultaneous operations effectively.

(P5) Risk of Mission / Force Projection Delays Due to Enemy Actions – This factor addressed the risk of mission accomplishment and force projection delays due to enemy actions.

(P6) Risk Associated with Logistical Support – This factor considered the size of the ship and the requisite replenishment needs as well as the impact of ship size with respect to ports and shipyards.

c. Schedule (S) Considerations

Schedule considerations focused on the impact the building schedule could have on the ability to meet requirements. The primary measure for dealing with schedule impacts is effect on the critical path construction process. Certain impacts may be positive in isolation but can have a negative effect to the overall schedule. The overall question to be examined in this section was, “What can go wrong from the perspective of the building schedule that can impact the fielding of the solution?”

d. *Schedule Risk Factors*

(S1) Number of Ships Being Built or Timeline Required – This factor primarily examined the ship construction schedule. It examined those areas in the schedule most likely to slip the potential effects if they did.

(S2) Risk of Delay – This factor examined the components of the architecture as they apply to the risk associated with the construction schedule. It examined those components with sufficient complexity to threaten the schedule.

(S3) Risk of Insufficient Testing of Systems – This factor addressed the threat of flawed or inadequate testing on requirement achievement.

(S4) Ship Design / Building Issues – This factor examined issues related to the maturity of design, technology needed for the architecture, and adequacy of the facilities and workers available to meet the building requirements.

(S5) Construction Availability – This factor examined the impact of the architecture in relation to the current FY 2011 shipbuilding plan with respect to budget, shipbuilding plan, and annual construction limits.

(S6) Risk of Exceeding Approved Annual Ship Construction Budget – This factor examined budgetary constraints of the US Navy's annual construction plan.

e. *Cost (C) Considerations*

Cost considerations focused on the likelihood for cost changes and the impact those changes could have on the procurement of a replacement ship. The overall question examined in this section was: "What issues during the construction and operation of a replacement ship could most impact cost."

f. *Cost Risk Factors*

(C1) Cost Overrun – This factor examined the probability that is associated with the risk of the project going over budget. Are there any historical trends that need to be mitigated from any similar projects?

(C2) Production Process Not Proven – This section examined the probability that production processes could impact the cost of the ships. Are there any production processes that are being recommended in the alternatives that are not proven?

(C3) Sufficient Facilities are Not Available for Construction – This section examined the likelihood of current construction not being able to handle the required size, amount or complexity of the recommended alternatives.

(C4) Sensitivity to Fuel, Maintenance, Personnel Cost Flux – This section addressed the overall confidence level of the cost estimate by examining the underlying assumptions.

(C5) Infrastructure Changes Required for Port Facilities – This section examined the possibility that current Navy facilities would require modification to handle the size or number of ships being serviced or stationed in the fleet.

B. RISK MITIGATION STRATEGY

According to the DOD's Risk Management Guide for DOD Acquisition, the intent of risk mitigation planning is to answer the question "What is the program approach for addressing this potential unfavorable consequence?" There are four general means by which to mitigate risk. One of more may be applied for each identified risk. They are:[73]

1. Avoid the risk by eliminating the root cause and/or the consequence,
2. Control the cause or consequence,
3. Transfer the risk
4. Assume the level of risk and continuing on the current program plan.

The risk mitigation strategy for this project was to provide several overall mitigations that should be considered during the design phase. Those identified issues associated with each of the alternatives will lend insight during the decision-making phase.

C. RISK ANALYSIS METHODOLOGY

For each of the developed alternatives several factors were identified as key to the risk comparison. These key factors were: (1) Lift Capability (MEU and MEB Level); (2) Modeled Unload Times; and (3) Cost.

The greater part of the analysis of these three key factors was considered to be associated with performance and cost risks. The following analysis sought to identify and quantify possible risks areas, as well as provide an initial framework for the areas that should be examined for risk mitigation throughout the life cycle. This analysis began with an examination of each of the alternatives from the perspective of these key factors.

The analysis of lift capability was conducted in Section V of this report. It focused on the comparable metrics of the six footprints at both the MEU and MEB level. The alternative ARG configurations were then modeled through simulation to see the estimated expected unload times of the ship's cargo by both LCACs and aircraft. Within the cost chapter of this

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[73] (Department of Defense, August 2006) p.18

report, Section VI, each of the alternatives was examined to determine the estimated expected cost of each configuration over the 30-year life cycle of the alternative. These analyses ranked each of the developed alternatives, lowest numerical rank being best, to determine which alternative most met the desired requirements. A summary of the findings is shown in Table 50.

Summary of Rankings								
		Lift		**Performance**		**Cost**	**Overall Rank**	
		MEU	**MEB**	**HA/DR**	**Assault**	**LCCE**	**Sum**	**Place**
Option 1	LPD-17	1	1	3	2	4	11	1
Option 2	LSD (X)	2	6	4	5	1	18	3
Option 3	LSD (XB)	3	3	2	4	3	15	2
Option 4	LPD(17) FLT X	4	4	5	6	5	24	4
Option 5	Big Deck	5	4	6	1	2	18	3
Option 6	Small Deck	6	2	1	3	6	18	3

Table 50. Ranking Summary

After conducting the alternative analysis utilizing the three key factors of Lift Capability (MEU and MEB Level), Modeled Unload Times, and Cost, the team determined that alternatives 5 and 6 would require additional and more thorough analysis beyond just these three key factors as they each significantly alter the composition of the amphibious fleet.

D. RISK ANALYSIS OF ALTERNATIVES

The following analysis of the alternatives was conducted in the three areas of risk: performance, schedule and cost. The basic premise of this analysis was to quantify risk using a systematic examination of probabilities and consequences that are inherent to each of the identified risk factors. The analysis follows the procedures described by Mierzwick, et al, to define the values associated with the probabilities and consequences within the analysis and then calculate an overall risk value.[74] Table 51 shows the probability likelihoods that were assigned for each risk factor.

Probability / Likelihood Level Criteria, PLi	
Likelihood Level	**Description**
0.1	Remote
0.3	Unlikely
0.5	Likely
0.7	Highly Likely
0.9	Near Certain

Table 51. Probability/Likelihood of Risk Factor (From [75])

The team formed working groups to discuss each of the key areas of analysis. The groups discussed the likelihood of each of the risk factors and assigned them a likelihood of occurrence (probability) level. The groups then discussed the consequences that might be associated with each risk factor and determined a consequence level. The definition for these consequence levels is shown in Table 52 for each of the three areas of analysis.

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[74] (Mierzwick & Brown 2004) p.8

[75] (Mierzwick & Brown 2004)

Consequence Level Criteria			
Level	**Performance, CFi**	**Schedule, CFk**	**Cost, CFj**
0.1	Minimal or no impact	Minimal or no impact on total ship design or production schedule	Minimal or no impact on total objective cost
0.3	Acceptable with some reduction in margin	Additional resources required; able to meet need dates	< 5% increase
0.5	Acceptable with significant reduction in margin	Minor slip in key milestones; not able to meet need date	5 - 7% increase
0.7	Acceptable; no remaining margin	Major slip in key milestone or critical path impacted	7-10% increase
0.9	Unacceptable	Can't achieve key team or major program milestone	>10% increase

Table 52. Consequence Level Criteria (Follows [76])

The value of risk to each of the alternatives was given by the following equations:

$$R_p = \sum_{perf} w_i PL_i CF_i$$

$$R_c = \sum_{cost} w_j PL_j CF_j$$

$$R_s = \sum_{schedule} w_k PL_k CF_k$$

Equation 5 (From [77])

$$Overall\ Risk = w_p R_p + w_c R_c + w_s R_s$$

Equation 6 (From [78])

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[76] (Mierzwick & Brown 2004))

[77] (Mierzwick & Brown 2004) P. 3

[78] (Mierzwick & Brown 2004) P. 3

Term / Symbol	Definition
$R_{p,c,s}$	Risk Level
$PL_{i,j,k}$	Probability Level
$CF_{i,j,k}$	Consequence Factor
w_p	Weight Factor (Performance)
R_p	Risk Level (Performance)
w_s	Weight Factor (Schedule)
R_s	Risk Level (Schedule)
w_c	Weight Factor (Cost)
R_c	Risk Level (Cost)

Table 53. Risk Equations Term and Definitions

There were six, seven, and five risk factors identified for performance, schedule and cost, respectively. Within performance, each of these six risk factors was determined to present an equal threat, and thus, each w_i equaled 1/6. Similarly for schedule and cost, each w_j was set to 1/7, and each w_k to 1/5. This normalized the risk value for performance, schedule, and cost according to the number of risk factors identified.

Overall risk was calculated using Equation 6 and assigned weighting factors in line with overall stakeholder requirements for performance, schedule, and cost risk. It was determined that several risk factors for each of the alternatives needed to be examined in order to derive an explanation as to the root cause for the overall risk score given to each alternative. These key risk factors were determined by examining those individual risk factors that had high consequence scores, all those greater than 0.25, and led to the selection of three to five factors per alternative that required further explanation. The intent was to identify any underlying root causes for risks that were common throughout all proposed alternatives. These root causes were then examined in the determination of mitigation strategies. A complete risk card for the analysis is shown in Appendix K.

E. HIGH RISK FACTORS LEADING TO ROOT CAUSE

1. Alternatives That Add LPD-17s

The alternatives replacing the Whidbey Island and Harpers Ferry classes with the San Antonio Class, option 1 with 11 LPDs and the Small Deck option 6 with 19 LPDs, would be suitable on the basis of continuation of a current hull design; but historically there have always been changes to the design based on a desire to upgrade the existing system. The LPD-17 hull design has had significant challenges due to budget overruns of around 30%. This inherent risk to the cost of the project may be unacceptable to decision makers without significant mitigation measures in place.

2. Alternatives That Utilize A New Hull Design

The alternatives based on replacing the Whidbey Island and Harpers Ferry classes with a newly designed hull form, the LSD(X), LSD(XB) and LPD(17) Flt X, offer the most flexibility to address new or different requirements. One risk identified was the development of new ship designs has historically been problematic. Cost overruns and delays associated with the acquisition of recent systems such as the LPD-17 and LCS have been significant.

3. Alternatives That Reduce Or Increase The Number Of Ships

Alternatives that increase or decrease the number of ships within the amphibious fleet, the Big Deck option 5 and Small Deck option 6, also have associated risks. With the implementation of option 5, the projected fleet size would decrease in the number of ships and would eventually rely solely on the capabilities of the larger LHA and LHD classes. The risk associated with the loss of one of these ships due to construction, enemy action or maintenance delays pose a significant threat to the amphibious fleet’s ability to meet mission requirements. Likewise, the ability of the amphibious fleet to meet the COCOM’s desire to conduct multiple missions would likely be constrained due to the risk of losing such a valuable asset. This is despite the greatly increased lift capacity associated with alternative 5.

The analysis of alternative 6, the Small Deck option, identified significant risks in the limited ability to support fixed wing aircraft operations. This capability loss will have to be analyzed to determine if the projected cost savings in the operations and support of the fleet is enough to justify the loss of this capability.

4. Overall Weighted Risk Card

Table 54 shows the results of the weighted risk analysis of each of the proposed alternatives. A weighting was assigned to the factors of performance, cost and schedule risk at 0.9, 0.5, and 0.3 respectively. These weighting factors were based on stakeholder analysis to place emphasis on threats to ship and fleet performance over threats to cost, and both over threats to procurement schedule. The result is a unit-less risk measure that allowed for a general comparison of the six options. According to this analysis, Option 6, the Small Deck Option, presents the least risk while Option 2, the LSD(X), presents the most risk. The risk cards shown in Appendix K display the probability likelihoods and consequence factors assigned to each risk factor as well as the overall risk value for performance, schedule, and cost for each alternative. The results are displayed in Table 54.

Overall Risk Assessment for Alternative Architecture	
Alternative	**Overall Weighted Risk**
Option 1: LPD-17	0.30
Option 2: LSD(X)	0.45
Option 3: LSD(XB)	0.38
Option 4: LPD(17) FLT X	0.34
Option 5: Big Deck Option	0.41
Option 6: Small Deck Option	0.25

Table 54. Overall Risk Assessment

The results of the analysis show options that focused on the production of the LPD-17 to replace the LSD demonstrate the lowest risk in achieving a satisfactory impact to the cost, performance and schedule of the amphibious fleet. This is intuitive, as a known design should present less risk than any new and untested design.

F. RISK MITIGATION PLANNING

Risk mitigation planning is the activity that identifies, evaluates, and selects options to set risk at acceptable levels given program constraints and objectives.[79] Below are the recommended mitigating strategies in the three major risk consideration areas of performance, schedule and cost. The strategy will first deal with considerations that need to be addressed within each of the alternatives of this analysis and then any that were found to be specific to a particular alternative.

1. Mitigation to Risks to Mission Performance (P):

- *Adding an Additional Ship to the Traditional ARG Configuration*: Adding an additional ship to the ARG would eliminate the risk of not having the required lift capabilities to meet mission objectives.
- *Improving Maintenance Scheduling to Reduce Time in Maintenance*: The risk of losing one ship to maintenance would present significant problems to meeting mission objectives. Improving the maintenance schedule would reduce the loss of a ship due to unscheduled maintenance.

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[79] (Department of Defense, 2006) p.18

- *Preposition Equipment*: Prepositioning equipment would mitigate the risk of not being able to conduct multiple or diverse missions. Prepositioned equipment would enable a ship to leave more quickly, with less equipment and give it a wider range of capabilities by effectively expanding its cargo capacity.
- *Change Doctrine to Allow for More Follow-on Shipping*: Follow-on shipping would enable a ship or ARG to mitigate the risk of not meeting lift requirements. This would enable the ship to carry only what is needed in the short term of an amphibious mission. Follow-on shipping would augment supplies to meet longer-term requirements.
- *Change Doctrine to Change Fixed Wing Operation (CVN Only)*: Using an all small deck ARG composition eliminates a fixed wing aviation capability. Fixed wing aircraft will most likely be needed only during an assault operation. In the case of an assault, the amphibious force will be accompanied by a CSG where the CVN could fulfill the fixed wing aircraft requirements.

The potential risk reduction for the successful implementation of each of these was calculated and is displayed in Table 55.

Performance Risk Mitigation Table			
Strategy	**Likelihood of Implementation**	**Likelihood of Success**	**Possible Reduction Range**
Add Additional Ship	.1	.9	2-5%
Optimize Maintenance Schedule	.8	.8	5-7%
Preposition Equipment	.3	.6	3-5%
Follow-on Shipping	.5	.8	2-4%
Fixed Wing CVN Only	.7	.8	4-6%

Table 55. Performance Risk Mitigations

2. Mitigation to Risks to Project Schedule (S):

Using Earned Value Management Procedures: Earned Value Management (EVM) is a method for integrating scope, schedule, and resources for measuring project time. It compares the amount of work or effort that was planned with what was actually earned and spent to determine if cost and schedule are tracking as planned. By comparing planned value (the ideal progress of the project) to the earned value (the value of the project to date based on work or effort expended), a project manager can detect early if the project is going awry. This will help to mitigate schedule delays early in the SEP.

Using Mature Technology: Technology Readiness Level (TRL) is a measure used by the DoD and many of the world's major companies to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem. When a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem. Current policy requires technology to have met TRL6 before it is used in a new or existing system. Technology Readiness Level 6 demonstrates technology maturity at the subcomponent level, not the integrated system.[80] If the technology used meets the minimum requirement of TRL 6 then it is clear that schedule risk will be reduced due to time not being wasted in experimentation and testing.

Using Well Known Facilities: Working closely with known industry leadership in shipbuilding helps to mitigate schedule risk since factors impacting its shipbuilding plans are known and seen before. This closer working relationship may require the DoD to supply industry with more information regarding long-range plans, future budgets, and procurement options. However, it should also reduce risk in shipbuilding programs by providing the government with greater understanding and certainty regarding industrial capacity as well as better progress indicators. This mitigation factor also will allow for the use of complementary skills, skill synergies (such as design resources), and give DoD procurement options, which result in greater industrial efficiencies.

The potential risk reduction for the successful implementation of each of these strategies was calculated and is displayed in Table 56.

Schedule Risk Mitigation Table			
Strategy	**Likelihood of Implementation**	**Likelihood of Success**	**Possible Reduction Range**
Using EVM	.9	.9	2-5%
Mature Technology	.9	.8	5-8%
Using Known Facilities	.7	.6	3-5%

Table 56. Schedule Risk Mitigations

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[80] (Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), 2011)

3. Mitigation to Risks to Project Cost (C)

Open Ship to Foreign Military Sales: By opening the ship to foreign military sales, it is possible for the US to conduct joint collaboration with purchasing nations. The increase in production of ships would reduce the overall individual ship cost associated with each ship.

Incentivize Lower Cost: Contracts could be written in order to incentivize lower cost of the ship construction. This option would focus on the desires of the company to reduce costs in order to achieve a company level bonus.

Increase Automation: Automation (robotics, streamlined supply chain) can be implemented on the shipbuilding process to improve productivity, thus reducing the manpower requirements and costs accordingly.

Optimize Internal Sensors: More internal sensors can be installed within the ships to perform damage detection and limited damage control functions, thus reducing the manpower requirements and costs on board each ship.

Increased Specialized Training: A core group of selected personnel can be groomed to develop deep expertise in their specialized fields (engine specialist, radar specialist) and serve as permanent party to the ship for longer periods of time, providing two key benefits. The first is the deeper knowledge base made available onboard, and the second is the possible faster training of newer personnel to manage the systems, as this core of experts can provide more in-depth and effective training to the inexperienced crews.

Expand Life-Cycle: In-service upgrading or life extension programs should be scheduled within the life cycle of the ship, reducing the probability of more severe malfunctions or damages within the ships that may result in more costly repairs.

Improve Maintenance Programs: Frequent Preventive Maintenance (PM) should be scheduled throughout the life cycle of the ships to rectify minor problems before they can develop into more severe malfunctions and cause higher maintenance costs. Increased scheduling efficiency can be developed in order to provide for expected high cost repairs to be done at locations that have reduced labor rates.

Reduce Building Standards: The introduction of civilian ship building standards at certain points in the ship construction could reduce the overall cost of the construction of the ship.

Minimize Class Upgrades (Use Standard Technology): The ship should integrate largely established and stable systems that have proven performance records with other countries or platforms. This can reduce the probability of integration issues, and hence the development and construction costs. This option would also look to push for standard modularization of higher cost systems.

Pre-Warehouse Spares: Further studies should be conducted in order to predict the spares requirements throughout the life cycle of the ships, which can then allow for advanced planning and budgeting for parts and components. This reduces the probability of overstocking spares, and the subsequent warehousing costs. Alternatively, accurate prediction can allow for the just-in-time order and delivery of spares to minimize any equipment downtime, or minimize the increased cost of ad-hoc orders.

Continue Research for New Fuel Technology: Research into new and alternative fuels can result in the development of cheaper and more efficient fuels. These new alternatives fuels can reduce the per-knot / per-hour cost of operation of the ships.

Out-Source Labor: Outsourcing labor to countries with lower labor costs can reduce the overall construction costs of the ships. This can also be accomplished by working with companies to expand foreign worker visas to supplement current labor. This strategy may reduce the estimated 70% ship construction cost that is due to labor costs.

The potential risk reduction for the successful implementation of each of these strategies was calculated and is displayed in Table 57.

Cost Risk Mitigation Table			
Strategy	**Likelihood of Implementation**	**Likelihood of Success**	**Possible Reduction Range**
Open Ship to Foreign Military Sales	.9	.7	5-9%
Incentivize Lower Cost	.8	.7	3-5%
Increase Automation	.8	.8	2-4%
Optimize Internal Sensors	.8	.8	1-3%
Increased Specialized Training	.8	.9	2-5%
Expand Life-cycle	.9	.9	4-6%
Optimize Maintenance Programs	.9	.9	5-7%
Reduce Building Standards	.7	.8	4-6%
Minimize Class Upgrades (Use Standard Technology)	.7	.7	3-5%
Pre-Warehouse Spares	.9	.9	3-5%
Continue Research for New Fuel Technology	.7	.7	1-2%
Out-Source Labor	.5	.9	5-7%

Table 57. Cost Risk Mitigations

G. MITIGATION STRATEGY ANALYSIS

The risk mitigation strategy analysis was based on the analysis of factors that would most likely impact decisions being made for the adoption of an overall strategy. The primary factors that were chosen represent a combination of the probability that decision makers would adopt the strategy, the probability that the strategy would be successful and the anticipated range of cost savings that could be expected for that strategy on the overall cost of the program. The product values for each of these three factors (including the average expected savings) were calculated to determine the overall value of the strategy. The top five strategies are shown in Table 58.

Risk Mitigation Strategy Table				
Strategy	**Mitigation Strategy Category**	**Assessed Implementation**	**Assessed $P_{SUCCESS}$**	**Possible Reduction Range**
Optimize Maintenance Schedule	Performance	0.8	0.8	5-7%
Using Mature Technology	Schedule	0.9	0.8	5-8%
Open Ship to Foreign Military Sales	Cost	0.9	0.5	5-9%
Expand Life Cycle	Cost	0.9	0.9	4-6%
Pre-Warehouse Spares	Cost	0.9	0.9	3-5%

Table 58. Risk Mitigation Strategy

The use of these individual strategies in a combined overall cost savings strategy was determined to be the most cost effective methodology that should be incorporated in the decision of the next ship class.

H. CONCLUSIONS

This assessment proposed a two-tiered approach to objective risk management of the problem. First, by utilizing a simplified risk event approach for concept exploration and requirement definitions; and second, by identifying the proposed mitigation strategies described above. Utilizing concept exploration, risk was evaluated using subjectively determined occurrence probabilities and scaled consequence values; an overall risk assessment score was assigned that identified the high-risk events associated with each alternative. Through the use of these scores the analysis identified the most and least risky alternatives. Analyzing risk through this process was simple, direct, and consistent with the DoD 5000 risk management approach.

Our analysis identified alternative 6, the Small Deck Options, as the least risky option and alternative 2, the LSD(X) Option, w_i as the most risky option for the LSD replacement. Furthermore, our analysis demonstrated that through the utilization of the two-tiered approach mentioned above that the overall risk level for each alternative could be reduced, thus allowing for more options in the design and development of the LSD replacement.

VIII. SUMMARY AND RECOMMENDATIONS

The Whidbey Island and Harpers Ferry classes of LSD ships begin decommissioning in 2022 with the last ship leaving active service in 2039. A replacement ship class must be procured if the Navy wishes to maintain a 33 ship amphibious fleet in order to meet the 2.0 MEB lift capability as well as operational tasking from various COCOMs. However, neither of these two requirements is threatened in the near term. With the arrivals of the last San Antonio class ship and the planned procurement of new LHA class ships, the amphibious fleet maintains a level of at least 33 ships until that first Whidbey Island decommissioning a decade from now. And the 2.0 MEB lift capability maintains or exceeds current levels in all footprint categories except Vehicle capacity into the 2030s. The Navy's current plan has the first LSD replacement ship reach the fleet in 2022 but could push this date back. Given the changing fiscal environment and strategic environment, both internal to US force structure and external with respect to current threats and areas of emphasis, time should be taken to make an informed decision regarding this national security issue.

This project analyzed four options which provide a one-to-one replacement for the LSD class ships. It also chose to analyze the possibility of an amphibious fleet composed of all Big Decks or all Small Decks, Options 5 and 6, simply for the sake of comparison and to validate the need for a robust and diverse set of capabilities. But when analyzed for MEU and MEB lift capability, modeled for throughput performance in the given scenarios, and estimated for cost given an assumed procurement schedule, these two options appear to be reasonable considerations. While the project has four viable alternatives to recommend as replacement ships for the LSD-41 and 49 class ships, it is the opinion of the project team that the best course of action would be to further study the degree of viability for Options 5 and 6.

Both these options offer significant advantages and disadvantages to the amphibious fleet. A fleet comprised of all big decks provides a tremendous lift capability but at the cost of assets available for tasking by the Combatant Commanders. An all small deck fleet would maximize the COCOM's available assets but would require a significant shift in Marine Corps fixed-wing operations. The high cost of the small deck option would be significantly decreased by the procurement of an LSD(X) or LSD(XB) instead of the LPD-17 analyzed for. Both of these options represent extremes, but this analysis shows that an ARG composed one big deck, one LPD, and one LSD is not the ideal configuration for all scenarios. The ideal amphibious fleet structure may not be 11 big decks, 11 LPDs, and 11 LSDs. This simplified answer to the 2.0 MEB lift requirement, comes at the cost of many other considerations regarding day-to-day amphibious operations. All the analysis conducted in the previous chapters supports an amphibious fleet restructuring and further study to investigate the most appropriate balance.

As to a simple ship-for-ship replacement, three of the four options have merit. A replacement class ship called LPD(17) Flt X modeled on the hull of the San Antonio class designated Option 4, was determined to achieve few performance gains and few cost savings and is not recommended for selection. The LSD(X), Option 2, was the cheapest option with measurable gains over the current standard. If cost were the most significant factor, the LSD(X) would be the clear winner.

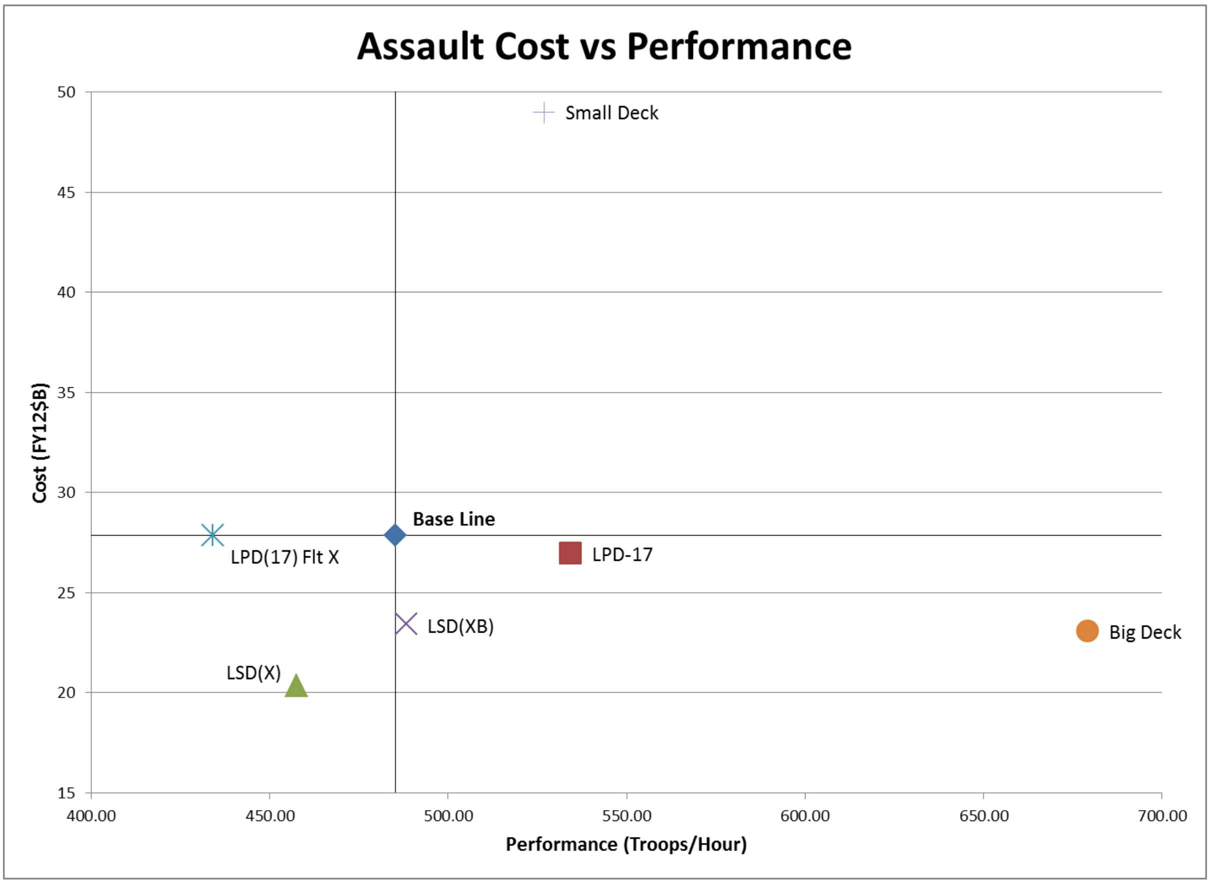

Figure 56. Performance vs. Cost (Assault)

The LPD-17 and the LSD(XB) stand out when cost and performance are considered together as shown in Figure 56. Each of these options offers bang for the buck by improving capability at a lower cost. The LPD-17 program has been plagued by cost overruns, but it is an extremely capable ship and with eleven ships already procured the savings in R&D cannot be ignored. Similarly, the LSD(XB) represents a significant improvement in capability for the fleet at a moderate cost. These two options are the best alternatives for selection.

Having considered lift capacity, throughput performance, cost and risk, the best solution to the defined problem most likely lies outside the bounds of current accepted fleet architectures. With the time available, further study should determine the appropriate fleet composition before further procurement decisions are made.

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APPENDICES

A. LSD FUNCTIONAL DECOMPOSITION

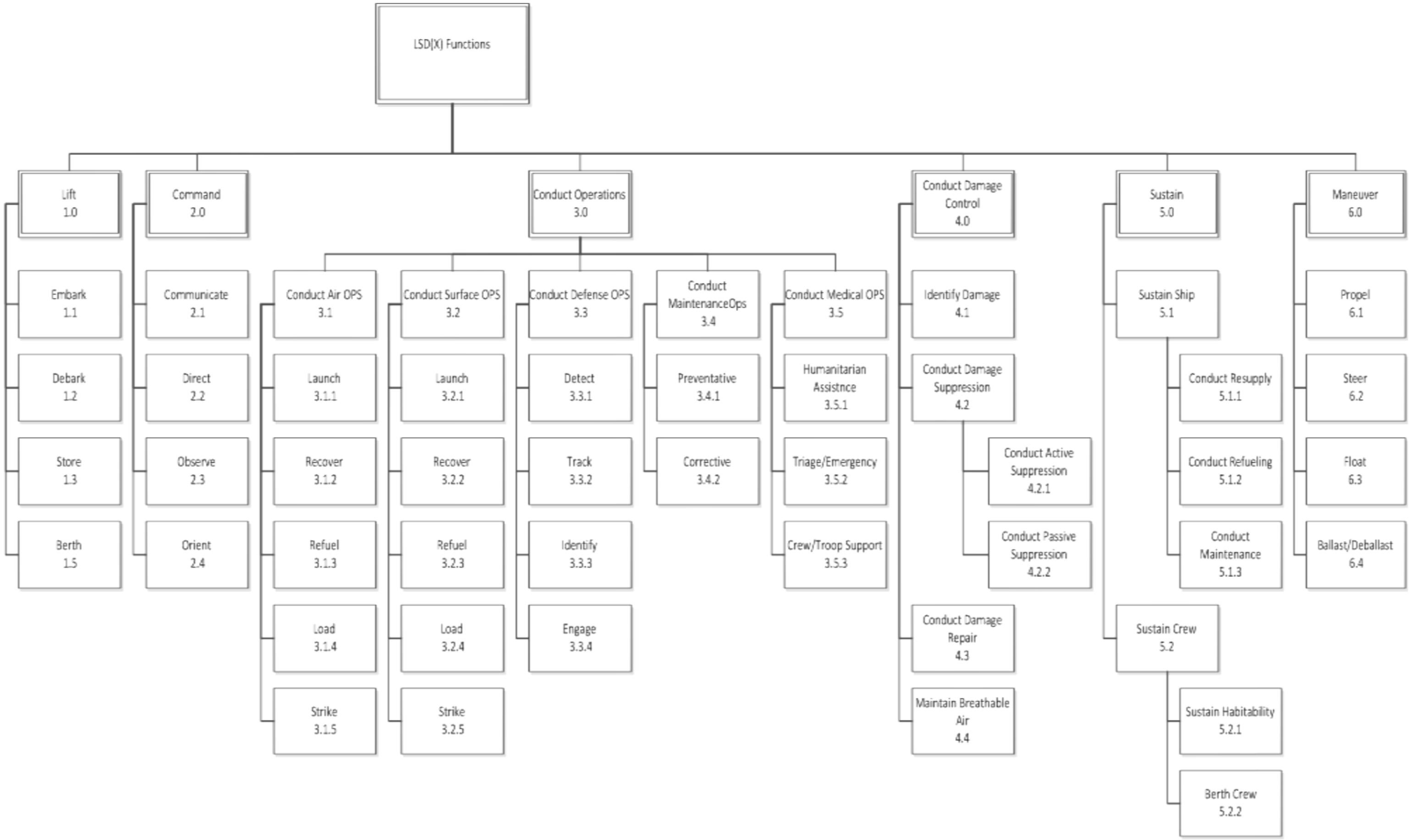

Figure 57. LSD Function Decomposition

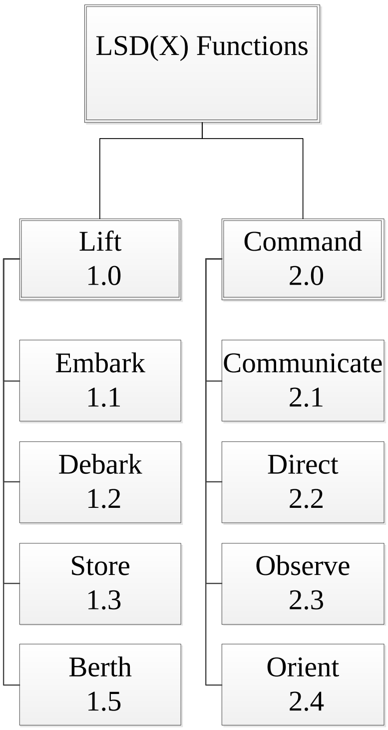

Figure 58. LSD Functional Decomposition (a)

1. Lift: This function refers to the capability to hold and transport personnel and equipment over the sea. This shall include the ability to perform the following functions:
    1.1. Embark: This function describes the loading of the personnel and equipment onboard.
    1.2. Debark: This function describes the unloading or launching of embarked personnel and equipment.
    1.3. Store: This function describes the securing and containment of embarked equipment.
    1.4. Berth: This function describes the housing of embarked personnel.
    1.5. Maneuver: This function describes the movement over the sea.
2. Command: This function describes the ability to control the functions, operations, and assets with respect to the amphibious vessel’s mission.
    2.1. Communicate: This function describes the ability to convey and receive information internally and externally both organically and non-organically.
    2.2. Direct: This function describes the ability to manage, exert control, or dictate actions internally and externally both organically and non-organically.
    2.3. Observe: This function describes the ability to receive information with sensors or personnel.
    2.4. Orient: This function describes the ability to process observed information.

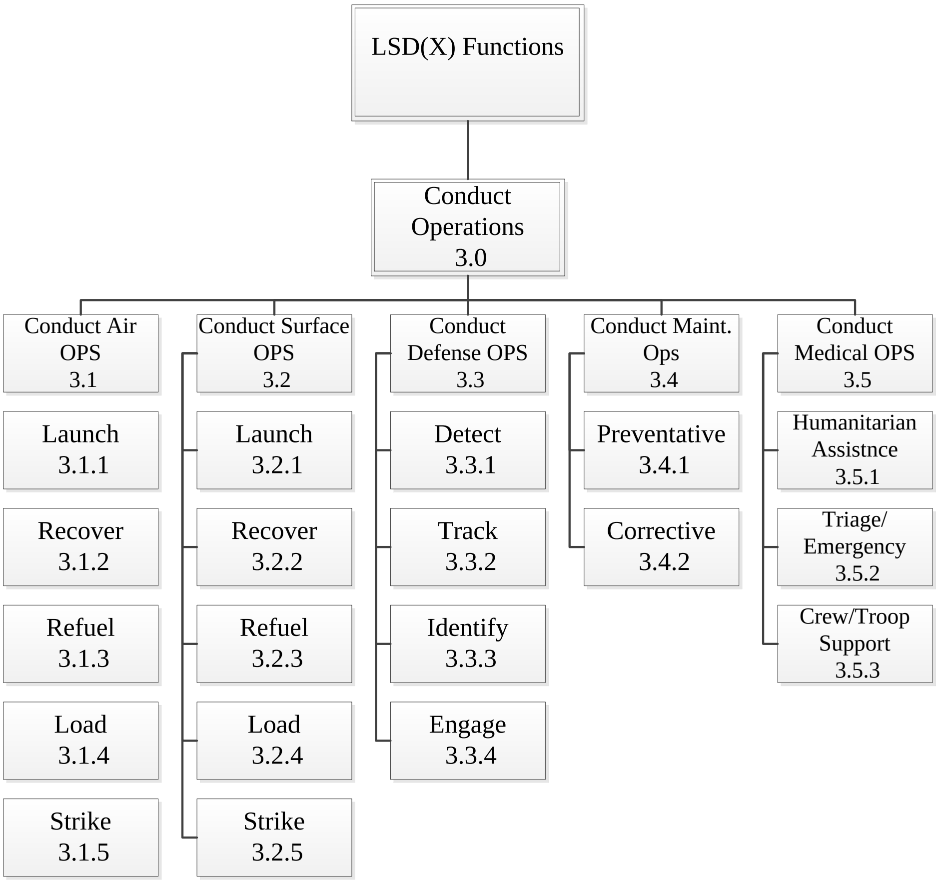

Figure 59. LSD Functional Decomposition (b)

3. Conduct Operations: Amphibious Operations functionally requires the utilization of those forces and equipment deployed on or assigned to the amphibious vessel. This includes but is not limited to USMC and naval personnel, SOF forces, and the crews who operate the LCACs, small boats, and rotary aircraft utilized in the accomplishment of the amphibious mission set.
    3.1. Air Operations include all aircraft operations on the flight deck and in the hangar of the amphibious vessel.
        3.1.1. Launch – Ability to have aircraft take-off from the ship.
        3.1.2. Recover – Ability to have aircraft land on the ship.
        3.1.3. Refuel – Ability to provide additional fuel to aircraft.
        3.1.4. Load – Ability to transfer personnel and equipment onto and off of aircraft.
        3.1.5. Transfer – Ability to move aircraft as necessary to include between the flight deck and hangar.

3.2. Surface Operations refers to all amphibious vessel actions necessary for the completion of amphibious missions. This includes the maneuvers of amphibious vessel as well as the small boats and LCACs launched from that vessel.

  3.2.1. Launch – Ability to have surface craft debark from the ship.

  3.2.2. Recover – Ability to have surface craft embark on the ship.

  3.2.3. Refuel – Ability to transfer fuel.

  3.2.4. Load – Ability to transfer personnel and equipment onto and off of the vessel and surface craft.

3.3. Medical Operations include all efforts to aid, treat, and attend to the medical and dental needs of embarked personnel or personnel of interest in a given area of operation.

3.4. Maintenance Operations refer those efforts to repair or prevent damage to the equipment embarked on the vessel necessary for the employment of forces. This includes maintenance of LCACs, aircraft, and embarked vehicles and equipment but does not refer to the maintenance of the amphibious vessel itself.

3.5. Defensive Operations refers to amphibious force protection and surface craft deployed in operations.

  3.5.1. Detect: To discover or determine the existence or presence of a potential threat in the operating area.

  3.5.2. Track: To receive updates of the threats position

  3.5.3. Identify: To discern whether the potential threat is friend, foe, or neutral.

  3.5.4. Engage: To employ weapons against the potential threat.

3.6. Conduct Medical Ops: This function describes the ability to provide for the coordination of medical care to troops onboard the ship. It includes the provision of equipment necessary for performing emergency medical functions like life support units

  3.6.1. Humanitarian Assistance (HA): This function describes the ability to provide for emergency on-site care for people affected in the disaster region. It includes provision of operating rooms, hospital facilities, and auxiliary supporting features like backup power supply and oxygen-supporting plants.

  3.6.2. Triage/Emergency: This function describes the ability to provide operating rooms, hospital facilities and auxiliary supporting features for the emergency on-site care of US combatant forces deployed in war or other operations. This includes equipment for the treatment and containment of chemical and biological threats.

3.6.3. Crew/Troop Support: This function describes the ability to provide for basic health care services for crew and troops onboard the ship. Preventive measures for personnel include health checks consisting of both physical and psychological aspects.

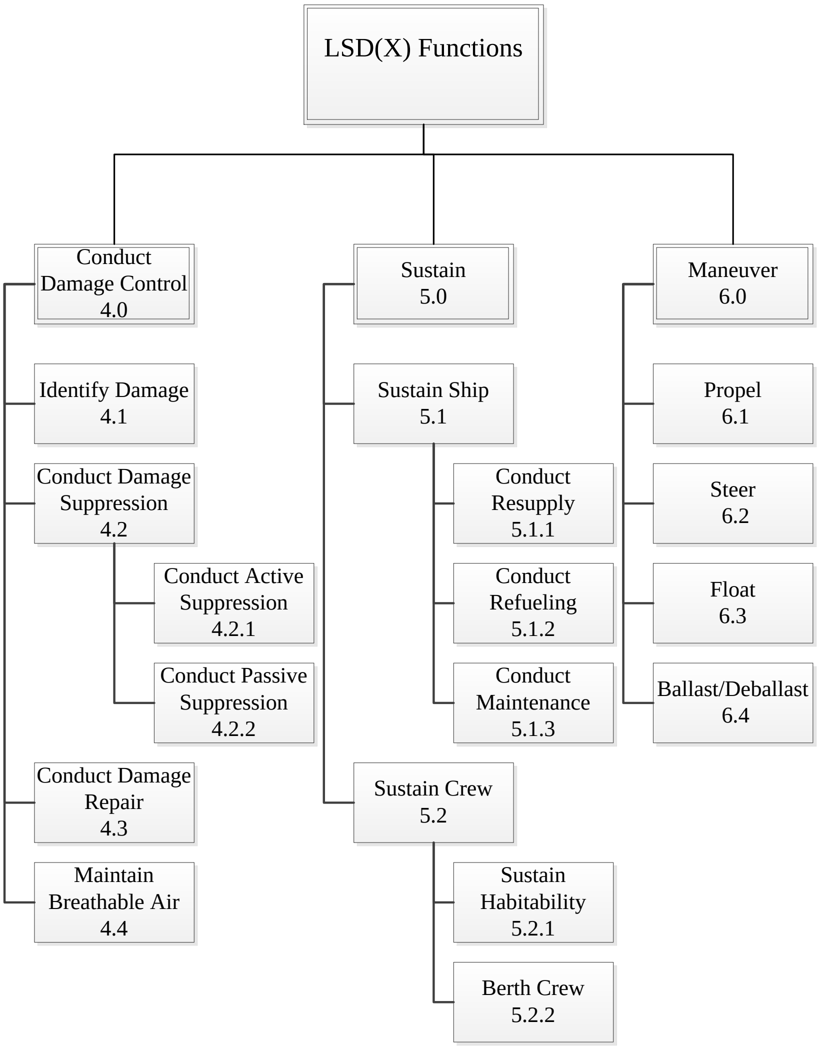

Figure 60. LSD Functional Decomposition (c)

4. Conduct Damage Control: This function describes any tasks or actions that are undertaken to control any situation that may result in the sinking of the ship. It consists of the following actions:

4.1. Identification: This function describes any action that detects the presence, extent and/or location of any damages inflicted on the ship.

  - 4.2. Damage Suppression: This function describes any action that reduces vulnerability to the ship either by containing or minimizing the damage or reducing the effects of damage to the critical components.
    - 4.2.1. Passive Damage Suppression: This function refers to damage suppression measures that do not have any damage-sensing capabilities.
    - 4.2.2. Active Damage Suppression: This function refers to damage suppression measures that utilize a sensor or other device that senses when a hit or damage process occurs and activates a function that either contains the subsequent damage or reduces the effects of the damage.
  - 4.3. Damage Repair: This function refers to any action performed on a damaged component, in order to restore it to a serviceable condition.
  - 4.4. Maintenance of Breathable Air: This function describes the provision, filtering and/or re-circulation of air that can be inhaled by the crew without detrimental effects to their health.
- 5. Sustain: This function describes the combination of providing for the needs of both the crew and vessel so that operations will be conducted efficiently.
  - 5.1. Sustain Ship: This function describes the abilities necessary for the ship to maintain an operational tempo required by the directed tasking.
    - 5.1.1. Conduct Resupply: The act of obtaining needed sustenance for both crew and embarked personnel or materials required onboard the vessel that were not already located there.
    - 5.1.2. Conduct Refueling: The process of obtaining required fuel either underway or while in port.
    - 5.1.3. Conduct Maintenance: The practice of vessel wide care for all facets aboard through corrective or preventative upkeep conducted while in port or underway.
  - 5.2. Sustain Crew: This function describes the abilities necessary for the crew to maintain an operational tempo required by the directed tasking.
    - 5.2.1. Sustain Habitability: The vessel will provide shelter from the weather, provide running water, access to a toilets and bathing facilities, heating, electricity, freedom from noxious smells, noise and garbage.
    - 5.2.2. Berth Crew: Provision of a sleeping space for crewmembers.
- 6. Maneuver
  - 6.1. Propel – The ability to generate thrust to move the ship across water
  - 6.2. Steer – The ability to direct the course of the ship.

6.3. Float – The ability to displace water, be buoyant or suspended in water. To remain suspended on the surface of the sea without sinking
6.4. Ballast – The act of adding any weight in solid or liquid form to increase draft, to change trim, or to improve the stability.
6.5. De-ballast – The act of returning the ship to its operational draft following ballasting.

B. PROBABILITY OF SURVIVABILITY ANALYSIS

Abstract: A deterministic model was implemented using MATLAB to compute the probability of survival (Ps) of various amphibious platforms against Anti-Ship Missile threats. The models implemented a layered defense approach based on equipping of each ship and allowed the possibility to add an outer defensive escort layer (e.g. SAG / CSG). Based on the results, the impact of equipping on Ps strongly depends on the expected threat. For cases of a single threat (subsonic or supersonic), all equipping combinations less the LSD-4 perform well even without the presence of an escort ship. However, as the number of threats increased, the presence of additional layers of defensive started to make a difference in the survivability of individual platforms. The presence of an Escort Group made a significant difference to the survivability of lesser-equipped ships.

In view of the results, two possible courses of actions to balance between Ps and cost of equipping is:

> (1) Have Escort Groups with the platforms whenever the expected level of threat is high.
>
> (2) Have a LSD(X) design that is modular in nature (similar to LCS concept), allowing the plug-on of added NSSM modules whenever threat level is high but operating with just the RAM as a basic defense (similar to LPD-17) when low threats are expected.

Objective: The Ps values obtained from this model are intended to be:

1. Used in a higher-level simulation that studies the amphibious group operations performance in terms of Probability of Survival when faced with a possibly hostile landing zone with anti-ship missile threats.
2. A Measure of Effectiveness (MOE) relating to the survivability of amphibious group operations during amphibious landing operations in “hot” landing zone against anti-ship missile threats.

1. Description & Assumptions:

The schematic diagram below illustrates the geometrical layout (not to scale) assumed in the computations. The implemented concept is one of layered defense, where each layer would attrite the numbers of threats as far as possible before handing-over the “leakers” to the next layer.

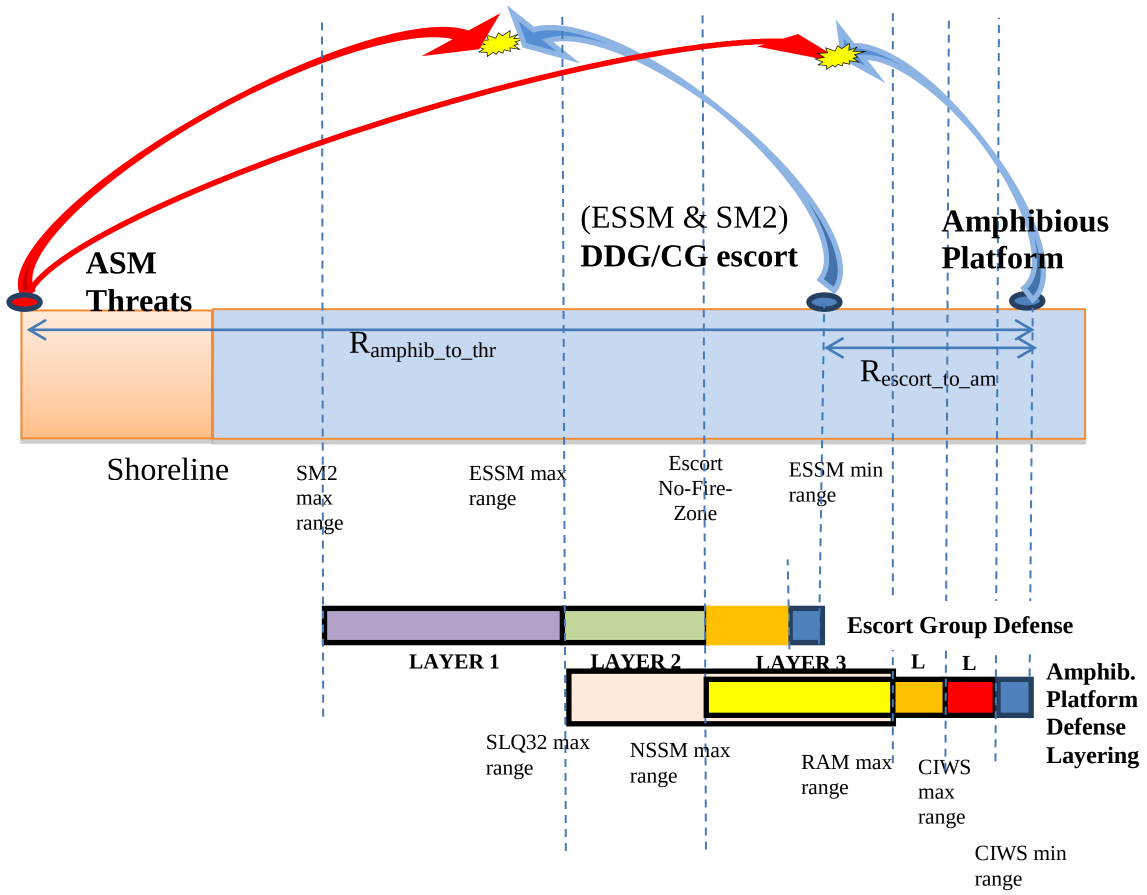

Figure 61. Engagement Geometry and Layered Defense Concept*

*(Actual layering may differ from platform to platform depending on equipping)

The baseline defensive layers assumed for the study are summarized in Table 59. It should be noted that the actual layering would vary from platform to platform depending on their equipping. When present, the Escort Group, comprising either a Surface Action Group (SAG) or Carrier Strike Group (CSG), would supplement the layers. These escort layers can be switched on or off in the model depending on need as part of the study.

	Amphib. Platform Self Defense Systems	**Escort Group Outer Layer defense**	**Assumed Layer Ranges** (WRT Amphib. Platform)
Layer 1		SM-2	15nm to 40nm
Layer 2	SLQ32 (Jammer)	ESSM	10nm to 15nm
Layer 3	NSSM (if avail) and SLQ32	Escort No Fire Zone (*)	3.5nm to 10nm
Layer 4	RAM		1.1nm to 3.5nm
Layer 5	CIWS		0.3nm to 1.5nm

Table 59. Summary of Defense Layering

(* SAG assumed to leave the leakers in this zone for the self-defense systems of the amphibious platforms)

Computation Methodology

(1) Threat scenario definitions:

In the computations performed, it was assumed that all threats were simultaneously incoming and identical. In order to compute the results where there were different kinds of threats (e.g. 2 subsonic and 1 supersonic), it was necessary to obtain independent results for these two kinds of threats and combine the probabilities obtained (i.e. $Ps = Ps_{2\ \text{subsonic}} * Ps_{1\ \text{supersonic}}$). An additional step prior to performing the independent runs was to manually adjust the resource allocation, to ensure that the launchers at each layer had sufficient rounds to engage both sets of targets. It should be noted that this way of combination represents a very coarse computation and would only be accurate if there was ample time within each layer to engage the different kinds of targets independently. This condition could be practically achieved if it is assumed that the different threat kinds have sufficient time offsets between their arrivals.

(2) Interaction between different defensive layers:

The concept of a layered defense was implemented using Bayesian analysis on a layer-by-layer basis. The computed probabilities for each previous layer acted as the conditional probability for the subsequent layer (Note: This required the layers to be independent). The final probability of survival was computed by summing the probabilities for all the cumulative outcomes with no “leakers” at the end of the last layer. This concept is illustrated in Figure 62.

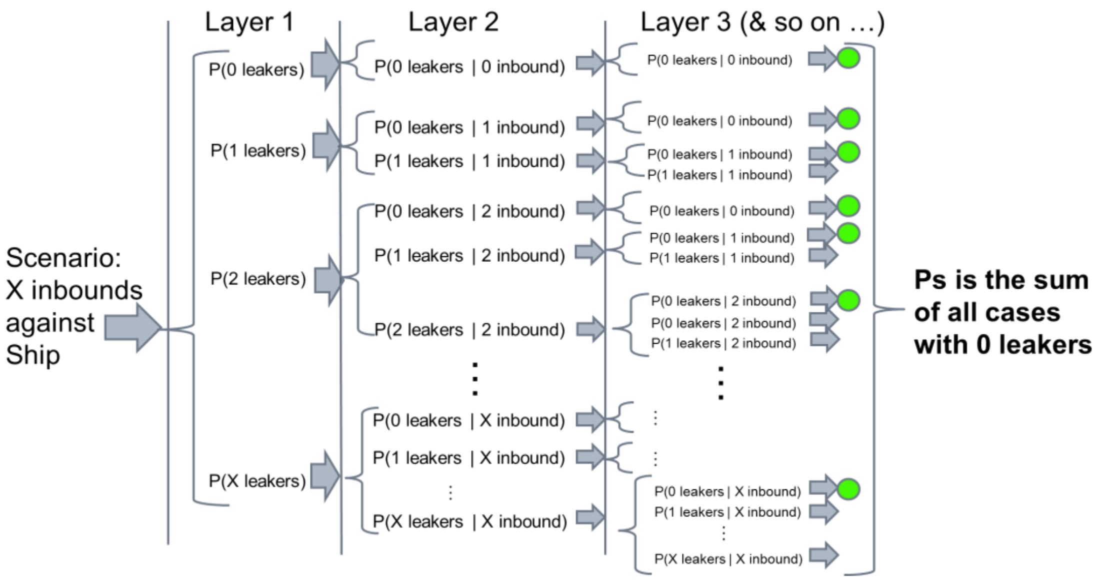

Figure 62. Bayesian Analysis for Layered Defense

(3) Computation of probabilities within each layer:

The computation of probabilities within each layer took into account each weapon's capabilities as follows:

- The "firing window" (i.e. the amount of time during which the weapon can be fired) was computed using weapons' maximum and minimum ranges, which are defined in conjunction with the start and stop ranges of each layer (i.e. these may not be the weapon's actual max and min ranges, but rather these are limited by the layer's limits). The flight time of the missile and the threat were used to determine the time window within which the weapon can be fired to intercept the threat for the layer.
- Within the firing window, the number of shots that can be fired was computed based on:
  - Firing rate (or time between launches) for the weapon
  - Time needed to slew weapon between targets (if applicable)
  - Quantity of rounds per launcher (assuming no reload during engagement)
  - Max number of rounds that could be allocated per threat. This was manually set to "simulate" a simple resource allocation function across different threats in case of multiple threats; otherwise it was assumed that all available resources for the weapon would be devoted to defeating the threat.

For missile systems, it was assumed that all the shots would be "ripple-launched," that is launched consecutively as soon as possible to ensure maximum intercept range and hence the supporting systems, fire-directors, were assumed to be able to support this mode of operation.

- To determine the kill probability for each incoming threat:
    - The round allocation for each threat was first determined. The number of rounds that could be fired in the window was divided across the number of threats, but only an integer number of rounds could be assigned to each threat. Hence, if 7 shots could be fired within the firing window and there were 4 threats, the first 3 threats were targeted with 2 rounds each and the last threat was targeted with 1 round.
    - The kill probability for each target was computed based on the number of rounds allocated as:

$$Pk_{Nrounds} = 1 - (1 - Pk_{1round})^{Nrounds}$$

Equation 6: Probability of Kill

-
    - The conditional probability for the number of leakers (i.e. not killed) was computed by considering the probabilities of all the different permutations of killed/not killed for all the threats, e.g. if there were 3 threats, then there would be 1 case when all 3 were killed, 3 cases of single kill, 3 cases of 2 kills and 1 case of all 3 not killed. This is similar to the computation of binomial distribution probabilities, except that in this case the probabilities were not uniform across each threat, as different number of rounds had been allocated for the different threats.

(4) Computation of survival probabilities for each individual amphibious platform:

As described previously, the conditional probabilities for cases with no leakers were summed at the end of the last defensive to compute the Ps for entire layered defense. For individual amphibious platforms, the team introduced the concept of "defensive sectors" to account for the fact that the turreted weapons currently equipped on the amphibious platforms (i.e. NSSM on rail launchers, RAM & Phalanx CIWS) cannot provide all-round coverage and typically pairs or multiple of pairs would be needed to provide omni-directional coverage (e.g. fore & aft or port & starboard configurations).[81] This was implemented in the simulations by

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[81] Based on IPR1, there was a comment that there is no intention to consider Vertical Launch System (VLS) type systems, which can provide omni-directional coverage with a single launcher, for a LSD(X) in this study.

dividing the number of systems for each type by two when considering the number of available rounds which was equivalent to the constraint that systems on the “other sector” of a ship cannot help to engage a threat inbound in one sector. For threats approaching within a single sector, the Ps was derived directly from the layered defense calculations. For threats approaching from two sectors, the result was obtained by combining the results from the 2 sectors independently (i.e. $Ps_{2sectors} = Ps_{sector1} * Ps_{sectors2}$) since the overall survivability was based on survival within both sectors.

(5) Computation of survival probabilities for an Amphibious Ready Group (ARG):

In the computation of the Ps for an ARG, the team would need to consider the relative geometry of the different amphibious ships as part of fleet formations in order to complete the analysis. The analysis would vary from case-to-case and would require some judgment from the analyst on how best to combine the results for the different ships for an overall result. *This was not performed in this simulation but is as part of the ExtendSim simulations at the higher level using the Ps derived from this set of simulations.*

Model Assumptions:

The assumptions used in the model are summarized as follows:

1. It was assumed that the overarching firing policy would designate “kill zones” for each platform such that the defenses could be considered to comprise mutually exclusive layers (with the exception of parallel engagements with SLQ32 from the amphibious platforms and SM-2/ESSMs from the SAG). SM-2 and ESSMs from the SAG were assumed to be unaffected by SLQ32 operations such that concurrent usage within a single layer was possible.
2. Only a one-dimensional model was used in the modeling, i.e. the effects of cross-range between the threat and own weapon were neglected. This approximation was considered reasonable since:
    a. The threat was assumed to always emanate from the shoreward direction within the confines of the beach frontal area and headed in a straight line towards the LCAC.
    b. Assumed, for such frontal landing operations, the escort ship(s) could be well positioned to be able to reach their respective defended zone independent of geometry.

3. A constant P_K was assumed for all considered weapons up to a maximum range, then a P_K of zero thereafter. This simplistic model may not be fully accurate, but was expected to be conservative in terms of results. More information about a P_K versus range would be required to implement a more accurate model.
4. For missile systems, it was assumed that all the shots would be "ripple-launched," launched consecutively as soon as possible to ensure maximum intercept range and hence the supporting systems (e.g. fire-directors) were assumed to be able to support this mode of operation.
5. Each amphibious platform was protected by a maximum of 3 SM-2 and 3 ESSM shots from the escort(s). This assumption sought to place a reasonable balance between resource (i.e. ESSM) availability versus P_S without having to model the actual number of ESSMs available across all the escorts. Implicitly built into this assumption was the underlying assumption that escorts had enough ESSMs to protect as many LCACs as could be launched, the amphibious platforms and themselves for all threats missiles that could be launched.
6. The amphibious platform and escort were assumed to be stationary in their relative locations, with only the threat and defensive weapons moving with their respective speeds (in the down range direction).
7. As explained in the model description, it was assumed that all threats were simultaneous and identical for each computation. For cases where there were different threat kinds, launcher resources were manually allocated to ensure sufficient rounds for all threats without reloading. It is also assumed that the different threat kinds arrived with sufficient time offset in order for them to be engaged independently.
8. As explained in the model description, the team simplified the model by considering only a one-dimensional model for the separation in range between the different amphibious ships relative to the threat direction taken into account. It was also assumed that the escort ships were well positioned to provide protective coverage to all the amphibious ships.

2. Results and Analysis:

Parameters for Study

The key parameters used for the study are listed below.

Threats: 2 basic threat types, namely, subsonic and supersonic anti-ship missiles were considered with the following characteristics:

Threat Type	**Subsonic**	**Supersonic**
Threat Speed	320 m/s	1200 m/s
Threat Detected (w.r.t amphib)	12 Nm from Amphib	20 Nm from Amphib
Threat P_K per round	100%	100%

Table 60. Threat Parameters

The following threat quantities (against single platform) were considered:

- 1, 2, 3 or 4 subsonic missiles inbound within 1 sector
- 2, 4, 6 or 8 subsonic missiles inbound spread equally across 2 sectors
- 1 or 2 supersonic missiles inbound within 1 sector
- 2 or 4 supersonic missiles inbound spread equally across 2 sectors
- 2 subsonic plus 1 supersonic missile inbound within 1 sector
- 4 subsonic plus 2 supersonic missile inbound spread equally across 2 sectors

Rationales for threat selection:

(1) They were more stringent than the most capable current threats for both types (i.e. has built in margin for future threats circa 2025). The current threats surveyed in making this assessment included the DongFeng-21 and SS-N-22 “Sunburn”. (See Appendix B2).

(2) A P_K of 1 for the threat was conservative, but noting the comment about using non-MIL SPEC and also the trend taken with LCS (i.e. survivability level 1), this was be a good assumption to make since survivability/threat P_K is highly dependent on ship construction.

(3) None of the current threats seemed to be stealthy, so the detection ranges assumed were conservative (i.e. may represent future stealth advancements or littoral blockages).

Amphibious Platform Equipping: As a baseline, the existing classes of ships (LHD-1, LHA-1, LSD-41/49, LPD-4, LPD-17) with their existing equipping were used as a starting point. Additional hypothetical LSD(X) equipping which differed from existing platforms, shown in Table 61, was also studied. It was assumed for the hypothetical designs that the self-defense suite may only consist of combinations of existing self-defense systems in similar quantities.

Platform Designation	**LSD-X1**	**LSD-X2**	**LSD-X3**
Assumed no. of sectors	2	2	2
NSSM launchers/ sector	1	1	1
RAM turrets / sector	0	1	0
CIWS turrets / sector	0	0	1
SLQ32 Jammer	1	1	1

Table 61. LSD(X) Self-Defense Options

(B1) Results for Single Amphibious Platform Survivability

Detailed Ps results for the following cases are presented in Appendix B3:

Case	**Case Description**	**Reference**
1	Against non-RF anti-ship missile(s) without Escort Group	Table A2-1
2	Against RF anti-ship missile(s) without Escort Group	Table A2-2
3	Against non-RF anti-ship missile(s) with Escort Group	Table A2-3
4	Against RF anti-ship missile(s) with Escort Group	Table A2-4

Table 62. Survivability Results

(B2) Analysis for Single Amphibious Platform Survivability

- Based on the results, the impact of equipping on Ps strongly depends on the expected threat. For cases of a single threat (subsonic or supersonic), all equipping combinations less the LSD-4 perform well even without the presence of an escort ship. However, as the number of threats increases, the presence of additional layers of defense starts to make a difference in the survivability of individual platforms. The presence of an Escort Group makes a significant difference to the survivability of lesser-equipped ships.
- In view of the results, two possible courses of actions to balance between Ps and cost of equipping is:
    - (1) To have Escort Groups with the platforms whenever the expected level of threat is high. With this arrangement, the LPD-17 (minimum equipping recommendation) is expected to have a Ps of at least 75% and typically closer to 85% against up to 3 inbound non-RF and RF anti-ship missile threats, respectively, within a single defensive sector.

  - (2) Have a LSD(X) design that is modular in nature (similar to LCS concept), allowing the plug-on of added NSSM modules whenever the threat level is high but operating with just the RAM as a basic defense (similar to LPD-17) when low threats are expected. With this arrangement, the NSSM equipped platform (equivalent to LSD-X2) is expected to have a Ps of at least 92.1% and 98.4% against up to 3 inbound non-RF and RF anti-ship missile threats, respectively, within a single defensive sector. This drops to 42.3% and 84.6% without NSSM equipped. However, in this unaugmented configuration (i.e. LPD-17 baseline), the P_S against a single non-RF and RF threat are 99.6% and 99.8%, respectively.

- While the CIWS by itself is not sufficient to bring the Ps to a high level, it should be considered from the viewpoint that current CIWS versions have been upgraded to be also effective against swarming boat attacks and thus it would still be a useful dual role weapon if equipped.

Appendix B1: Fixed Data Parameters assumed

1. Threat Parameters

These values were assumed for a typical subsonic and supersonic anti-ship missile. They can be adjusted in the model if required.

Threat Type	Subsonic	Supersonic
Threat Speed	320 m/s	1200 m/s
Threat Detected (w.r.t amphib)	12 Nm from Amphib	20 Nm from Amphib
Threat Pk per round	100%	100%

Table 63. Threat Parameters

2. Escort Group Weapons Parameters

These parameters are assumed as “possible values” and can be adjusted in the model if required.

Escort Range from Amphib	4 Nm (ahead)

Actual Escort Group (SAG or CSG) Weapons parameters are classified. These parameters were assumed.

Weapon Types	SM-2	ESSM
Weapon Speed	1000 m/s	1000 m/s
Weapon min range	15 Nm from SAG (*)	10 Nm from Amphib (**)
Weapon max range	40 Nm from SAG	15 Nm from SAG
Weapon Time Betw. Launches	2 sec	2 sec
Weapon Slew Interval	0 sec (VLS)	0 sec (VLS)
Weapon Pk per round	90%	90%
Weapon Max Round per Threat	3 rounds	3 rounds
Weapon Max Qty Available	Unlimited	Unlimited

Table 64. Weapons Parameters

(* to deconflict with ESSM coverage, this is set to be the same as max ESSM range)
(** This is set as the limit of the SAG No-Fire zone since it is the max range of the NSSM)

3. Amphibious Platform Self-Defense Weapons Equipping

The amphibious platform types modeled are summarized below, with their assumed equipping. These platforms are considered to be representative of the weapon mix expected even for a new amphibious platform. These can be adjusted if required.

	Existing Platforms				Hypothetical Designs		
Platform Type	**LHD-1**	**LHA-1 or LSD-41/49**	**LPD-4**	**LPD-17**	**LSD-X1**	**LSD-X2**	**LSD-X3**
Class Name	Wasp	Tawara Harper Ferry / Whidbey Island	Austin	San Antonio	LSD(X1)	LSD(X2)	LSD(X3)
Assumed no. of sectors	2	2	2	2	2	2	2
NSSM launchers/ sector	1	0	0	0	1	1	1
RAM turrets / sector	1	1	0	1	1	0	0
CIWS turrets / sector	1	1	1	0	0	1	0
SLQ32 Jammer	1	1	1	1	1	1	1

Table 65. Weapons Mix

The defense layering assumed varies from platform to platform due to differences in weapons mix. In general, the selected layering seeks to maximize usage of all weapons while minimizing gaps. Regions beyond 15nm (NSSM max range) from the platform left to the Escort Group and regions within 15nm are considered as “No-Fire-Zone” for the Escort Group in order to deconflict with potential NSSM firing since currently it is assumed that an ARG always has at least one platform equipped with NSSM.

Platform Type	LHD-1	LHA-1 or LSD-41/49	LPD-4	LPD-17	LSD-X1	LSD-X2	LSD-X3
Layer 0A (If Escorted)	15-40nm, SM-2				15-40nm, SM-2		
Layer 1A (If Escorted)	10-15nm, ESSM				10-15nm, ESSM		
Layer 1B (Outermost)	10-15nm SLQ32	10-15nm SLQ32	10-15nm SLQ32	10-15nm SLQ32	10-15nm SLQ32	10-15nm SLQ32	10-15nm SLQ32
Layer 2	3.5-10nm NSSM+ SLQ32	3.5-10nm SLQ32	3.5-10nm SLQ32	3.5-10nm SLQ32	3.5-10nm NSSM+SLQ32	3.5-10nm NSSM+SLQ32	3.5-10nm NSSM+SLQ32
Layer 3	1.1-3.5nm RAM	1.1-3.5nm RAM	1.1-3.5nm (NIL)	0.5-3.5nm RAM	0.5-3.5nm NSSM	0.5-3.5nm RAM	1.1-3.5nm (NSSM)
Layer 4 (Innermost)	0.3-1.1nm CIWS	0.3-1.1nm CIWS	0.3-1.1nm CIWS				0.3-1.1nm CIWS

Table 66. Assumed Defense Layering

4. Amphibious Platform Self-Defense Weapons Parameters

Actual Weapons parameters are classified. These parameters are assumed as possible values and could be adjusted in the model if required. Gun systems such as 25mm & 30mm cannons are not expected to be effective against incoming missiles.

Weapon Types	NSSM	RAM	Phalanx CIWS	SLQ32 Jammer
Weapon Speed	385 m/s	600 m/s	1100 m/s	$3\text{x}10^{8}$ m/s
Weapon min range	3.5 Nm	1.1 Nm	0.3 Nm	3.5 Nm (*)
Weapon max range	10 Nm	3.5 Nm	1.1 Nm	15 Nm (*)
Weapon Time Betw. Launches	2 sec	5 sec	0.02 sec	10 sec (*)
Weapon Slew Interval	3 sec	3 sec	3 sec	0 sec
Weapon Pk per round	70%	60%	0.2%	50%
Weapon Max Round per Threat	*Scenario-based*	*Scenario-based*	*Scenario-based*	1
Weapon Max Qty Available	8 rds./launcher	21 rds./launcher	1550 rds./load	Unlimited

Table 67. Weapon Parameters

(* This is expected to be the range where an RF anti-ship missile can be effectively jammed and it is expected to take a finite amount of time for this jamming)

Appendix B2: Survey of Current Anti-Ship Missile systems

As missile parameters are typically highly classified, these are based on survey of open literature and may not be fully accurate. However these represented a useful guide for consideration of threat scenario in this work.

Missile Name	Speed (kts)	Range (Nm)	Pk
DongFeng-21	500 (to 800)	1100-1600	Unknown
C-802	500	65-270	0.98
Silkworm	400-500	45-81	0.7
FL-7	926	17	Unknown
Exocet	612	38-97	Unknown

Table 68. Subsonic Missile Parameters

Missile Name	Speed (kts)	Range (Nm)	Pk
SS-N-21 Sampson	1400	5-81	Unknown
SS-N-22 Sunburn	1985	135	Unknown
C101	1323	24	Unknown
Brahmos	1985	17	Unknown

Table 69. Supersonic Missile Parameters

Table of Results for Single Amphibious Ship

Case 1 - Against a non-RF anti-ship missile without Escort Group

The SLQ-32 Jammer will not be effective against such threats. The results for various threat quantities are summarized in Table A2-1 (in order of most equipped ships to least):

Threats Scenario	Scenario Weightage	LHD-1	LSD X1	LSD X2	LSD X3	LHA-1 or LSD41/49	LPD17	LPD4
1 - subsonic in 1 sector	1	0.999999630765869	0.999999731261440	0.999964014095427	0.999934390000000	0.994372288811262	0.995904000000000	0.450418829224756
2 - subsonic across 2 sectors	1	0.999999261531874	0.999999462522952	0.999928029485839	0.999868784304672	0.988776248755747	0.991824777216000	0.202877121720200
2 - subsonic across 1 sector	1	0.999898229780079	0.999920157483520	0.991122228619173	0.983865610000000	0.827164046253234	0.786240000000000	0.019197849907017
4 - subsonic across 2 sectors	1	0.999796469917336	0.999840321341868	0.982323272063037	0.967991538540672	0.684200359414022	0.618173337600000	0.000368557441052
3 - subsonic across 1 sector	1	0.998287561634863	0.998264691262720	0.921688599562913	0.861523390000000	0.514007582407129	0.423360000000000	0.000000000000000
6 - subsonic across 2 sectors	1	0.996578055714881	0.996532393821854	0.849509874564245	0.742222551517092	0.264203794772022	0.179233689600000	0.000000000000000
4 - subsonic across 1 sector	1	0.990169093510939	0.988698646282240	0.809022228275815	0.685749610000000	0.105583938272378	0.129600000000000	0.000000000000000
8 - subsonic across 2 sectors	1	0.980434833744275	0.977525013160334	0.654516965844366	0.470252527615152	0.011147968021105	0.016796160000000	0.000000000000000
1 - supersonic	1	0.999880117272570	0.999844480000000	0.999949424474365	0.999934390000000	0.950665544267475	0.936000000000000	0.229149129179291
2 - supersonic across 2 sectors	1	0.999760248917008	0.999688984186470	0.999898851506615	0.999868784304672	0.903764977057374	0.876096000000000	0.052509323403627
2 - supersonic across 1 sector	1	0.969113395588035	0.965104000000000	0.987547756943974	0.983865610000000	0.469991582006060	0.504000000000000	0.000000000000000
4 - supersonic across 2 sectors	1	0.939180773508171	0.931425730816000	0.975250572245074	0.967991538540672	0.220892087156559	0.254016000000000	0.000000000000000
2 sub + 1 sup in 1 sector	1	0.984206258742494	0.977102809661440	0.903139160821592	0.861523390000000	0.725144826194692	0.592704000000000	0.004399170588308
4 sub + 2 sup across 2 sectors	1	0.968661959747898	0.954729900648280	0.815660343809530	0.742222551517092	0.525835018956931	0.351298031616000	0.000019352701865
	Weighted Ps	0.987568992169735	0.984905451603509	0.920680094450854	0.876201047595716	0.584696447310428	0.546803285430857	0.068495666726151

Table 70. Against Non-RF Anti-Ship Missile Without Escort Group

Case 2 - Against RF anti-ship missile without Escort Group

It is assumed that the SLQ32 Jammer will be effective against such threats and that only the Amphibious platforms provide the jammer (i.e. not the Escort Group). The results for various threat quantities are summarized in Table A2-2 (in order of most equipped ships to least):

Threats Scenario	**Scenario Weightage**	**LHD-1**	**LSD X1**	**LSD X2**	**LSD X3**	**LHA-1 or LSD41/49**	**LPD17**	**LPD4**
1 - subsonic in 1 sector	1	0.999999815382934	0.999999865630720	0.999982007047713	0.999967195000000	0.997186144405631	0.997952000000000	0.725209414612378
2 - subsonic across 2 sectors	1	0.999999630765903	0.999999731261458	0.999964014419173	0.999934391076168	0.994380206594567	0.995908194304000	0.525928695042428
2 - subsonic across 1 sector	1	0.999974372827954	0.999979905001600	0.997762564202507	0.995933597500000	0.953977155968939	0.944512000000000	0.480008877089132
4 - subsonic across 2 sectors	1	0.999948746312660	0.999959810407009	0.995530134523961	0.991883730629292	0.910072414110586	0.892102918144000	0.230408522084369
3 - subsonic across 1 sector	1	0.999747642909089	0.999753044687200	0.986868415963339	0.976615423750000	0.872327073450077	0.846224000000000	0.301106254674415
6 - subsonic across 2 sectors	1	0.999495349502278	0.999506150361326	0.973909270425990	0.953777685906392	0.760954523073976	0.716095058176000	0.090664976604053
4 - subsonic across 1 sector	1	0.998365538159572	0.998234008968160	0.946298101112281	0.906970211875000	0.665960366891513	0.612648000000000	0.063501547368226
8 - subsonic across 2 sectors	1	0.996733747784651	0.996471136660644	0.895480096168708	0.822594965228582	0.443503210270279	0.375337571904000	0.004032446518159
1 - supersonic	1	0.999940058636285	0.999922240000000	0.999974712237183	0.999967195000000	0.975332772133737	0.968000000000000	0.614574564589645
2 - supersonic across 2 sectors	1	0.999880120865537	0.999844486046618	0.999949425113836	0.999934391076168	0.951274016398081	0.937024000000000	0.377701895440552
2 - supersonic across 1 sector	1	0.992218407533294	0.991198240000000	0.996861651473176	0.995933597500000	0.842830667635252	0.844000000000000	0.364574564589645
4 - supersonic across 2 sectors	1	0.984497368247906	0.982473950979098	0.993733152177828	0.991883730629292	0.710363534306485	0.712336000000000	0.132914613145730
2 sub + 1 sup in 1 sector	1	0.992089409286692	0.988515736007680	0.951036874386602	0.929389048750000	0.856532391938833	0.778688000000000	0.295001246636218
4 sub + 2 sup across 2 sectors	1	0.984241396018818	0.977163360334805	0.904471136443038	0.863764003936430	0.733647738440458	0.606355001344000	0.087025735516923
	Weighted Ps	0.996223686016684	0.995215833310451	0.974415825406810	0.959182083418380	0.833453015401315	0.801941624562286	0.306618096707991

Table 71. Against RF Anti-Ship Missile Without Escort Group

Case 3 - Against a non-RF anti-ship missile with Escort Group

The SLQ32 Jammer will not be effective against such threats. The results for various threat quantities are summarized in Table A2-3 (in order of most equipped ships to least):

Threats Scenario	**Scenario Weightage**	**LHD-1**	**LSD X1**	**LSD X2**	**LSD X3**	**LHA-1 or LSD41/49**	**LPD17**	**LPD4**
1 - subsonic in 1 sector	1	0.999999963076587	0.999999973126144	0.999996401409543	0.999993439000000	0.999437228881126	0.999590400000000	0.945041882922476
2 - subsonic across 2 sectors	1	0.999999926153175	0.999999946252289	0.999992802832035	0.999986878043047	0.998874774473584	0.999180967772160	0.893104160477658
2 - subsonic across 1 sector	1	0.999989490667290	0.999991773883648	0.999079835547801	0.998327512000000	0.977651464555459	0.974937600000000	0.407296731292982
4 - subsonic across 2 sectors	1	0.999978981445026	0.999983547834965	0.998160517798222	0.996657821216110	0.955802386147433	0.950503323893760	0.165890627321947
3 - subsonic across 1 sector	1	0.999737162965558	0.999754610861440	0.984178865713547	0.971631388000000	0.795848399868623	0.749952000000000	0.017278064916315
6 - subsonic across 2 sectors	1	0.999474395014422	0.999509281938710	0.968608039717205	0.944067554146807	0.633374675573448	0.562428002304000	0.000298531527252
4 - subsonic across 1 sector	1	0.997475714822471	0.997308086764672	0.910421962434204	0.843946012000000	0.473165217993654	0.393984000000000	0.000000000000000
8 - subsonic across 2 sectors	1	0.994957801660599	0.994623419926211	0.828868149682547	0.712244871170704	0.223885323518982	0.155223392256000	0.000000000000000
1 – supersonic	1	0.999999880117273	0.999999844480000	0.999999949424474	0.999999934390000	0.999950665544267	0.999936000000000	0.999229149129179
2 - supersonic across 2 sectors	1	0.999999760234560	0.999999688960024	0.999999898848951	0.999999868780004	0.999901333522424	0.999872004096000	0.998458892469424
2 - supersonic across 1 sector	1	0.999956166061026	0.999948307840000	0.999982085600175	0.999976779730000	0.994141870362893	0.992592000000000	0.915748105951363
4 - supersonic across 2 sectors	1	0.999912334043466	0.999896618352080	0.999964171521277	0.999953559999181	0.988318058408632	0.985238878464000	0.838594593553510
2 sub + 1 sup in 1 sector	1	0.997377539899535	0.995235534641926	0.983650323049710	0.970285566439000	0.903465272369943	0.826427750400000	0.406982766252982
4 sub + 2 sup across 2 sectors	1	0.994761957096050	0.990493769414001	0.967567958035799	0.941454080439851	0.816249498378495	0.682982826631205	0.165634972026930
	Weighted Ps	0.998830076661217	0.998338886019722	0.974319354401107	0.955608947525336	0.840004726399926	0.805203510415509	0.482397034131573

Table 72. Against Non-RF Anti-Ship Missile With Escort Group

Case 4 - Against RF anti-ship missile with Escort Group

It is assumed that the SLQ32 Jammer will be effective against such threats and that only the Amphibious platforms provide the jammer (i.e. not the Escort Group). The results for various threat quantities are summarized in Table A2-4 (in order of most equipped ships to least):

Threats Scenario	**Scenario Weightage**	**LHD-1**	**LSD X1**	**LSD X2**	**LSD X3**	**LHA-1 or LSD41/49**	**LPD17**	**LPD4**
1 - subsonic in 1 sector	1	0.999999982120289	0.999999986563072	0.999998253934435	0.999996719500000	0.999727484965849	0.999795200000000	0.973387203696198
2 - subsonic across 2 sectors	1	0.999999964240578	0.999999973126144	0.999996507871918	0.999993439010762	0.999455044196142	0.999590441943040	0.947482648319505
2 - subsonic across 1 sector	1	0.999997356022467	0.999997869567808	0.999767119527743	0.999563835250000	0.993072923824909	0.992608000000000	0.709451489682673
4 - subsonic across 2 sectors	1	0.999994712051924	0.999995739140154	0.999534293288800	0.999127860739689	0.986193832034154	0.985270641664000	0.503321416212963
3 - subsonic across 1 sector	1	0.999953158783809	0.999957218970160	0.996769407034171	0.994001780125000	0.947258153553714	0.934683200000000	0.471609501956051
6 - subsonic across 2 sectors	1	0.999906319761717	0.999914439770536	0.993549250799253	0.988039538891669	0.897298009473992	0.873632684362240	0.222415522335235
4 - subsonic across 1 sector	1	0.999422595182324	0.999396966832336	0.973757641945489	0.952264546187500	0.782973059374835	0.734407200000000	0.122388811154625
8 - subsonic across 2 sectors	1	0.998845523760971	0.998794297313673	0.948203945247239	0.906807765925685	0.613046811706789	0.539353935411840	0.014979021095843
1 - supersonic	1	0.999999994733336	0.999999993001600	0.999999975312512	0.999999967195000	0.999975918316674	0.999968000000000	0.999623723698031
2 - supersonic across 2 sectors	1	0.999999989466672	0.999999986003200	0.999999950625024	0.999999934390001	0.999951837213275	0.999936001024000	0.999247588979917
2 - supersonic across 1 sector	1	0.999999822429063	0.999999767625040	0.999999204763680	0.999998943820750	0.999507743870565	0.999350800000000	0.992487101590807
4 - supersonic across 2 sectors	1	0.999999644858158	0.999999535250134	0.999998409527992	0.999997887642616	0.999015730057226	0.998702021460640	0.985030646824120
2 sub + 1 sup in 1 sector	1	0.998688707481174	0.997617283663841	0.991822757778803	0.985123892429875	0.951653917214930	0.912566988800000	0.700419297358056
4 sub + 2 sup across 2 sectors	1	0.997379134450419	0.995240244664820	0.983712382847949	0.970469083436188	0.905645178150521	0.832778509047500	0.490587192111553
	Weighted Ps	0.999584778953064	0.999350950106608	0.991936364321786	0.985384656753195	0.933912545996684	0.914474544550947	0.652316511786827

Table 73. Against RF Anti-Ship Missile With Escort Group

C. INFLATION QUERY TABLE

Categories	Inputs	Remarks
Service Type	Navy	
Appropriation/Cost Element	SCN=Shipbuilding & Conversion, Navy(1611)	Capital Material
	Civ pay = Civilian Payroll for all services (OSD Cost Element)	Capital Labor
	O&MN (COMPOSITE) Operations & Maintenance, Navy (1804)	O&S
	MPN (COMPOSITE) Military Personnel, Navy (1453)	O&S
Base/Input Year	2012	
Inflation Type	Budget/Then-Year $ to Budget/Then-Year $	Budget Dollar - Funds inflated for budgeting purposes that include inflation for the years of expenditure, calculated using the outlay profile. Also called "then-year dollar" for a particular budget year.

Table 74. Inflation Query Table

D. INFLATION RATES FROM YEAR 2013 TO 2042

	Capital		O&S	
	Ship Building Mat	Ship Building Labor	O&S	
Cost Element	SCN=Shipbuilding & Conversion, Navy(1611)	Civ pay = Civilian Payroll for all services (OSD Cost Element)	O&MN (COMPOSITE) Operations & Maintenance, Navy (1804)	MPN (COMPOSITE) Military Personnel, Navy (1453)
2012	1	1	1	1
2013	1.0168	1.0173	1.0168	1.021
2014	1.0341	1.0406	1.0341	1.0479
2015	1.0517	1.0646	1.0517	1.0766
2016	1.0696	1.0891	1.0696	1.106
2017	1.0878	1.1141	1.0878	1.1362
2018	1.1063	1.1397	1.1063	1.1672
2019	1.1251	1.166	1.1251	1.199
2020	1.1442	1.1928	1.1442	1.2317
2021	1.1636	1.2202	1.1636	1.2654
2022	1.1834	1.2483	1.1834	1.2999
2023	1.2035	1.277	1.2035	1.3354
2024	1.224	1.3064	1.224	1.3718
2025	1.2448	1.3364	1.2448	1.4092
2026	1.266	1.3671	1.266	1.4477
2027	1.2876	1.3986	1.2875	1.4871
2028	1.3094	1.4307	1.3094	1.5278
2029	1.3316	1.4637	1.3316	1.5695
2030	1.3543	1.4973	1.3543	1.6123
2031	1.3773	1.5318	1.3773	1.6563
2032	1.4007	1.567	1.4007	1.7015
2033	1.4245	1.603	1.4245	1.7479
2034	1.4488	1.6399	1.4488	1.7956
2035	1.4734	1.6776	1.4734	1.8446
2036	1.4984	1.7162	1.4984	1.895
2037	1.5239	1.7557	1.5239	1.9467
2038	1.5498	1.7961	1.5498	1.9998
2039	1.5762	1.8374	1.5762	2.0544
2040	1.603	1.8796	1.603	2.1104
2041	1.6302	1.9229	1.6302	2.168
2042	1.6579	1.9671	1.6579	2.2272

Table 75. Inflation Rates From 2013 to 2032

E. O&S HISTORICAL DATA

	LHA-1				LHD-1			
	Total O&S	**Manpower**	**Operations**	**Support**	**Total O&S**	**Manpower**	**Operations**	**Support**
1984	$ 95,672,398	$ 39,341,453	$ 29,795,243	$ 26,535,702				
1985	$ 104,344,180	$ 38,747,304	$ 25,693,351	$ 39,903,525				
1986	$ 136,504,713	$ 39,125,768	$ 18,026,616	$ 79,352,329				
1987	$ 107,589,349	$ 40,237,331	$ 24,024,002	$ 43,328,016				
1988	$ 105,675,068	$ 39,901,511	$ 16,662,200	$ 49,111,357				
1989	$ 83,052,480	$ 41,231,146	$ 26,250,083	$ 15,571,251				
1990	$ 82,204,119	$ 41,967,053	$ 26,186,032	$ 14,051,034	$ 65,422,007	$ 44,093,462	$ 10,628,759	$ 10,699,786
1991	$ 120,418,830	$ 44,034,347	$ 23,399,740	$ 52,984,743	$ 101,662,719	$ 48,659,434	$ 25,111,436	$ 27,891,849
1992	$ 130,818,937	$ 44,544,902	$ 23,457,430	$ 62,816,605	$ 124,169,968	$ 51,583,385	$ 30,038,630	$ 42,547,953
1993	$ 137,074,993	$ 41,831,685	$ 21,659,229	$ 73,584,079	$ 85,704,005	$ 47,169,091	$ 18,245,265	$ 20,289,649
1994	$ 133,897,439	$ 45,210,360	$ 19,770,576	$ 68,916,503	$ 114,924,305	$ 48,973,381	$ 19,105,434	$ 46,845,490
1995	$ 133,263,936	$ 48,715,456	$ 25,526,114	$ 59,022,366	$ 107,419,218	$ 53,753,054	$ 29,595,975	$ 24,070,189
1996	$ 107,944,487	$ 50,174,710	$ 27,923,651	$ 29,846,126	$ 130,207,729	$ 51,480,130	$ 20,218,500	$ 58,509,099
1997	$ 139,354,773	$ 58,942,893	$ 22,505,815	$ 57,906,065	$ 131,725,630	$ 65,414,463	$ 29,078,907	$ 37,232,260
1998	$ 130,446,360	$ 56,863,450	$ 27,883,193	$ 45,699,717	$ 110,583,263	$ 60,475,783	$ 20,649,916	$ 29,457,564
1999	$ 156,392,842	$ 55,542,972	$ 26,151,974	$ 74,697,896	$ 106,149,905	$ 57,324,312	$ 23,317,659	$ 25,507,934
2000	$ 169,260,429	$ 61,851,973	$ 20,912,245	$ 86,496,211	$ 119,026,970	$ 64,468,854	$ 22,562,188	$ 31,995,928
2001	$ 160,878,329	$ 63,642,544	$ 18,425,713	$ 78,810,072	$ 125,864,324	$ 68,521,510	$ 25,381,760	$ 31,961,054
2002	$ 152,067,271	$ 74,216,715	$ 24,293,857	$ 53,556,699	$ 144,098,953	$ 78,005,064	$ 24,380,274	$ 41,713,615
2003	$ 163,646,528	$ 81,824,356	$ 30,591,570	$ 51,230,602	$ 166,345,317	$ 85,241,774	$ 32,404,789	$ 48,698,754
2004	$ 169,296,041	$ 87,525,877	$ 22,869,623	$ 58,900,541	$ 151,782,977	$ 88,934,491	$ 26,920,432	$ 35,928,054
2005	$ 134,167,019	$ 88,819,838	$ 26,740,127	$ 18,607,054	$ 154,938,629	$ 89,822,114	$ 32,782,719	$ 32,333,796
2006	$ 156,861,794	$ 90,549,971	$ 33,570,682	$ 32,741,141	$ 139,631,205	$ 88,926,457	$ 26,755,647	$ 23,949,101
2007	$ 154,236,510	$ 92,100,650	$ 27,441,903	$ 34,693,957	$ 165,042,045	$ 87,792,667	$ 32,717,439	$ 44,531,939
2008	$ 165,766,638	$ 89,468,356	$ 44,376,738	$ 31,921,544	$ 171,355,585	$ 87,422,983	$ 27,757,621	$ 56,174,981
2009	$ 177,195,556	$ 87,075,995	$ 15,421,350	$ 74,698,211	$ 166,958,747	$ 86,119,080	$ 31,094,804	$ 49,744,863
2010	$ 155,706,820	$ 85,714,413	$ 43,817,731	$ 26,174,676	$ 171,790,534	$ 84,042,263	$ 31,594,539	$ 56,153,732
2011	$ 160,470,488	$ 91,710,054	$ 24,447,912	$ 44,312,522	$ 134,332,394	$ 83,693,521	$ 17,484,217	$ 33,154,656

LHA-1				LHD-1			
Total O&S	Manpower	Operations	Support	Total O&S	Manpower	Operations	Support
$ 157,772,118	$ 89,348,468	$ 30,830,920	$ 37,592,729	$ 157,721,306	$ 86,831,298	$ 28,598,141	$ 42,291,867

Table 76. Big Deck Historical O&S Data

	LSD-41					**LSD-49**			
	Total O&S	**Manpower**	**Operations**	**Support**		**Total O&S**	**Manpower**	**Operations**	**Support**
1984									
1985									
1986	$ 24,184,418	$ 14,452,183	$ 7,743,400	$ 1,988,835					
1987	$ 26,030,975	$ 15,424,647	$ 7,818,496	$ 2,787,832					
1988	$ 25,220,104	$ 15,007,414	$ 5,927,086	$ 4,285,604					
1989	$ 26,916,541	$ 16,159,735	$ 7,768,452	$ 2,988,354					
1990	$ 31,390,603	$ 15,040,372	$ 6,152,251	$ 10,197,980					
1991	$ 33,971,543	$ 16,197,884	$ 8,303,841	$ 9,469,818					
1992	$ 37,243,556	$ 15,307,257	$ 10,097,666	$ 11,838,633					
1993	$ 30,501,137	$ 14,213,936	$ 6,835,524	$ 9,451,677					
1994	$ 32,802,352	$ 14,708,267	$ 7,662,705	$ 10,431,380					
1995	$ 36,349,220	$ 15,821,830	$ 6,378,042	$ 14,149,348					
1996	$ 33,877,424	$ 15,785,146	$ 7,461,671	$ 10,630,607		$ 33,455,496	$ 15,007,590	$ 5,629,872	$ 12,818,034
1997	$ 36,533,471	$ 17,754,508	$ 5,341,267	$ 13,437,696		$ 39,530,707	$ 19,479,754	$ 5,887,716	$ 14,163,237
1998	$ 38,501,242	$ 16,946,482	$ 6,876,947	$ 14,677,813		$ 35,665,296	$ 18,333,678	$ 6,412,912	$ 10,918,706
1999	$ 38,979,109	$ 16,478,326	$ 7,140,493	$ 15,360,290		$ 31,841,319	$ 17,288,550	$ 7,626,010	$ 6,926,759
2000	$ 43,491,835	$ 18,766,959	$ 5,919,902	$ 18,804,974		$ 37,775,704	$ 19,123,026	$ 6,471,744	$ 12,180,934
2001	$ 38,956,862	$ 19,413,417	$ 5,909,181	$ 13,634,264		$ 37,588,755	$ 19,985,860	$ 8,209,401	$ 9,393,494
2002	$ 51,006,995	$ 21,002,209	$ 6,961,716	$ 23,043,070		$ 44,410,332	$ 20,736,263	$ 8,250,882	$ 15,423,187
2003	$ 53,655,588	$ 22,546,674	$ 9,803,886	$ 21,305,028		$ 50,226,243	$ 22,299,754	$ 9,152,934	$ 18,773,555
2004	$ 48,819,644	$ 23,205,434	$ 6,776,256	$ 18,837,954		$ 42,649,239	$ 23,770,800	$ 5,835,642	$ 13,042,797
2005	$ 56,121,694	$ 24,379,012	$ 9,322,262	$ 22,420,420		$ 48,461,427	$ 24,639,115	$ 9,318,134	$ 14,504,178
2006	$ 51,454,544	$ 24,138,091	$ 7,839,189	$ 19,477,264		$ 53,667,182	$ 24,310,450	$ 11,961,559	$ 17,395,173
2007	$ 51,507,028	$ 24,708,889	$ 8,880,975	$ 17,917,164		$ 53,040,288	$ 24,290,300	$ 10,723,223	$ 18,026,765
2008	$ 56,337,337	$ 24,562,372	$ 8,913,438	$ 22,861,527		$ 53,171,351	$ 24,237,631	$ 11,642,127	$ 17,291,593
2009	$ 76,650,456	$ 22,492,785	$ 7,172,157	$ 46,985,514		$ 49,157,801	$ 22,734,047	$ 8,833,379	$ 17,590,375
2010	$ 87,627,136	$ 22,201,713	$ 7,835,643	$ 57,589,780		$ 61,034,182	$ 22,434,497	$ 9,908,524	$ 28,691,161
2011	$ 75,954,852	$ 22,281,270	$ 6,019,018	$ 47,654,564		$ 79,338,996	$ 22,964,710	$ 4,591,057	$ 51,783,229

	LSD-41					LSD-49			
	Total O&S	Manpower	Operations	Support		Total O&S	Manpower	Operations	Support
	$ 65,093,292	$ 23,537,733	$ 7,997,526	$ 33,558,033		$ 56,838,747	$ 23,658,679	$ 9,568,286	$ 23,611,782

Table 77. LSD Historical O&S Data

	LPD-4					**LPD-17**			
	Total O&S	**Manpower**	**Operations**	**Support**		**Total O&S**	**Manpower**	**Operations**	**Support**
1984	$ 48,787,805	$ 18,118,593	$ 11,124,431	$ 19,544,781					
1985	$ 47,540,272	$ 17,715,763	$ 11,003,299	$ 18,821,210					
1986	$ 43,049,308	$ 17,153,050	$ 9,249,604	$ 16,646,654					
1987	$ 41,150,111	$ 17,916,929	$ 10,617,748	$ 12,615,434					
1988	$ 37,946,973	$ 18,118,367	$ 11,164,566	$ 8,664,040					
1989	$ 39,636,595	$ 17,902,475	$ 10,327,105	$ 11,407,015					
1990	$ 39,396,331	$ 17,663,908	$ 10,561,609	$ 11,170,814					
1991	$ 46,233,460	$ 18,823,067	$ 12,936,682	$ 14,473,711					
1992	$ 48,847,185	$ 18,356,600	$ 10,598,725	$ 19,891,860					
1993	$ 41,690,400	$ 16,853,338	$ 11,783,535	$ 13,053,527					
1994	$ 42,155,736	$ 17,485,793	$ 11,578,676	$ 13,091,267					
1995	$ 43,179,532	$ 18,784,397	$ 11,358,705	$ 13,036,430					
1996	$ 40,347,962	$ 18,855,086	$ 11,517,312	$ 9,975,564					
1997	$ 46,323,592	$ 21,986,358	$ 10,019,186	$ 14,318,048					
1998	$ 57,250,487	$ 20,764,648	$ 12,311,628	$ 24,174,211					
1999	$ 49,225,856	$ 19,663,769	$ 11,848,722	$ 17,713,365					
2000	$ 47,783,918	$ 21,810,447	$ 9,603,445	$ 16,370,026					
2001	$ 43,810,033	$ 22,824,281	$ 10,560,654	$ 10,425,098					
2002	$ 52,853,038	$ 23,998,734	$ 12,176,051	$ 16,678,253					
2003	$ 59,167,499	$ 26,440,567	$ 13,657,680	$ 19,069,252					
2004	$ 66,174,458	$ 28,566,484	$ 9,471,144	$ 28,136,830					
2005	$ 63,523,658	$ 29,917,409	$ 12,149,050	$ 21,457,199					
2006	$ 73,485,045	$ 29,451,711	$ 12,736,677	$ 31,296,657					
2007	$ 63,408,811	$ 29,941,443	$ 15,804,726	$ 17,662,642		$ 42,461,145	$ 27,991,200	$ 4,012,976	$ 10,456,969
2008	$ 67,291,000	$ 30,215,119	$ 15,728,354	$ 21,347,527		$ 48,461,393	$ 29,219,832	$ 8,160,799	$ 11,080,762
2009	$ 64,112,260	$ 29,679,847	$ 15,108,717	$ 19,323,696		$ 47,098,863	$ 27,635,614	$ 9,977,245	$ 9,486,004
2010	$ 65,341,486	$ 28,721,256	$ 19,044,605	$ 17,575,625		$ 55,224,517	$ 28,047,942	$ 7,120,832	$ 20,055,743
2011	$ 53,097,038	$ 27,323,948	$ 14,001,250	$ 11,771,840		$ 54,652,935	$ 28,098,422	$ 3,042,693	$ 23,511,820

	LPD-4					LPD-17			
	Total O&S	Manpower	Operations	Support		Total O&S	Manpower	Operations	Support
	$ 64,322,757	$ 29,321,533	$ 14,939,054	$ 20,062,169		$ 49,579,771	$ 28,198,602	$ 6,462,909	$ 14,918,260

Table 78. LPD Historical O&S Data

F. MONTE CARLO SIMULATIONS

Monte Carlo Simulations: Monte Carlo simulation techniques were used for estimating uncertainty for the lead ship. Monte Carlo simulations are computational algorithms that rely on repeated random sampling to compute their results. These simulations were used to account for variations in the design, construction, and cost estimating processes.

Background: The American Association of Cost Engineers (AACE) defines cost engineering as "…that area of engineering practice where engineering judgment and experience are utilized in the application of scientific principles and techniques to the problems of cost estimation, cost control, and profitability."[82] Cost estimation essentially uses the plan of a project and maps it to a dollar value by applying appropriate costs to the quantities identified in the plan, and in this case, gives insight into how much a lead ship would cost. However, it must be noted that figures derived via this process are predictions at best due to the fundamentally uncertain nature of cost estimation. This uncertainty stems from the following two categories:[83]

Requirements Uncertainty: This refers to the variability in cost estimates due to changes in the configuration of the system being estimated. As an example, suppose that, at present, the analysis of system configurations for each ship suggested an optimal loading capacity of 1,000 troops. While valid under present day circumstances, this requirement may change further down the acquisition/manufacturing process, thereby rendering cost estimates incorrect. While the example cited specifications of the ship, this uncertainty may also apply to hardware characteristics and/or operational concepts.

Cost-Estimating Uncertainty: This refers to variations in cost estimates of a system even though the original configuration remains unchanged. This variation may arise from errors in the data base, errors or inappropriateness of cost estimating techniques, insufficient data for building the costing model, and the inherent uncertainty of the cost model, as identified, for example in the statistics such as Standard Error of the Estimates (SEE).

The relationship between the system cost uncertainty and its sources can be depicted as shown in Figure 63.

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[82] (AACE International, 2011)

[83] (Fisher, 1962)

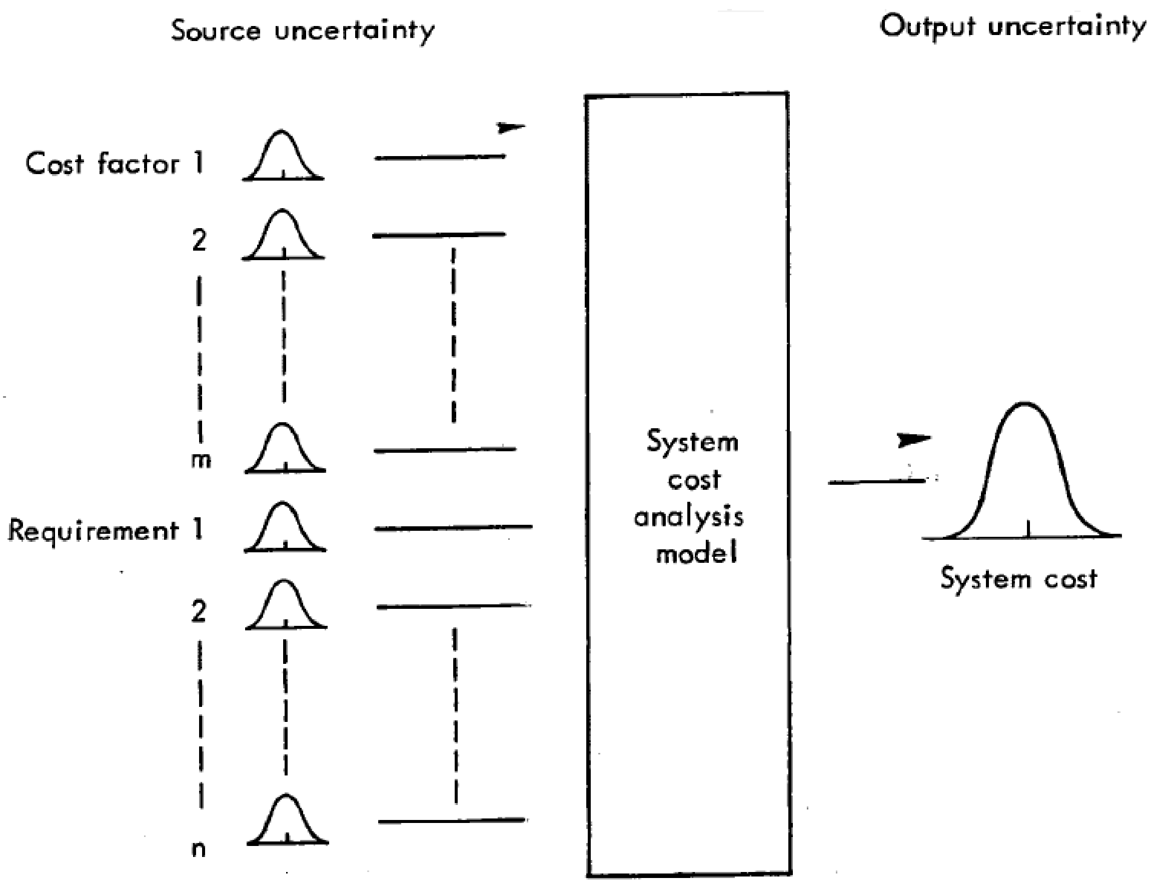

Figure 63. Relation of System Cost Uncertainty to Source Uncertainty (From [84])

Associated with each cost input is a probability distribution to reflect its uncertainty. Given that each input parameter is described with a probability distribution, the distribution is then treated as a theoretical population from which random samples are taken, and are used to develop an aggregated LCCE distribution. This is technique is referred to as Monte Carlo simulation.

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[84] (Dienemann, 1966) p. 6

G. LSD(X) AND LSD(XB) ALTERNATIVES’ COST

	LSD(X)				LSD(XB)			
Yr	O&S	Procurement	Annual Cost	Cumulative LCCE	O&S	Procurement	Annual Cost	Cumulative LCCE
1	$60,966,020	$1,010,022,200	$1,070,988,220	$1,070,988,220	$67,062,622	$1,177,882,000	$1,244,944,622	$1,244,944,622
2	$60,966,020	$0	$60,966,020	$1,131,954,240	$67,062,622	$0	$67,062,622	$1,312,007,244
3	$121,932,040	$633,021,090	$754,953,130	$1,886,907,370	$134,125,244	$795,207,900	$929,333,144	$2,241,340,388
4	$121,932,040	$0	$121,932,040	$2,008,839,410	$134,125,244	$0	$134,125,244	$2,375,465,632
5	$182,898,060	$617,828,659	$800,726,719	$2,809,566,129	$201,187,866	$776,816,685	$978,004,551	$3,353,470,183
6	$182,898,060	$0	$182,898,060	$2,992,464,189	$201,187,866	$0	$201,187,866	$3,554,658,049
7	$243,864,080	$607,310,036	$851,174,116	$3,843,638,304	$268,250,488	$764,080,305	$1,032,330,793	$4,586,988,842
8	$243,864,080	$0	$243,864,080	$4,087,502,384	$268,250,488	$0	$268,250,488	$4,855,239,330
9	$304,830,100	$599,296,812	$904,126,912	$4,991,629,296	$335,313,110	$754,375,828	$1,089,688,938	$5,944,928,268
10	$304,830,100	$0	$304,830,100	$5,296,459,396	$335,313,110	$0	$335,313,110	$6,280,241,378
11	$365,796,120	$592,842,407	$958,638,527	$6,255,097,923	$402,375,732	$746,558,047	$1,148,933,779	$7,429,175,156
12	$365,796,120	$0	$365,796,120	$6,620,894,043	$402,375,732	$0	$402,375,732	$7,831,550,888
13	$426,762,140	$587,449,564	$1,014,211,704	$7,635,105,747	$469,438,354	$740,025,276	$1,209,463,630	$9,041,014,518
14	$426,762,140	$0	$426,762,140	$8,061,867,887	$469,438,354	$0	$469,438,354	$9,510,452,872
15	$487,728,160	$582,825,134	$1,070,553,294	$9,132,421,181	$536,500,976	$734,422,762	$1,270,923,738	$10,781,376,610
16	$487,728,160	$0	$487,728,160	$9,620,149,341	$536,500,976	$0	$536,500,976	$11,317,877,586
17	$548,694,180	$578,782,005	$1,127,476,185	$10,747,625,525	$603,563,598	$729,524,049	$1,333,087,647	$12,650,965,233
18	$548,694,180	$0	$548,694,180	$11,296,319,705	$603,563,598	$0	$603,563,598	$13,254,528,831
19	$609,660,200	$575,193,575	$1,184,853,775	$12,481,173,481	$670,626,220	$725,175,901	$1,395,802,121	$14,650,330,952
20	$609,660,200	$0	$609,660,200	$13,090,833,681	$670,626,220	$0	$670,626,220	$15,320,957,172
21	$670,626,220	$571,970,268	$1,242,596,488	$14,333,430,169	$737,688,842	$721,269,889	$1,458,958,731	$16,779,915,903
22	$670,626,220	$0	$670,626,220	$15,004,056,389	$737,688,842	$0	$737,688,842	$17,517,604,745
23	$670,626,220	$0	$670,626,220	$15,674,682,609	$737,688,842	$0	$737,688,842	$18,255,293,587
24	$670,626,220	$0	$670,626,220	$16,345,308,829	$737,688,842	$0	$737,688,842	$18,992,982,429
25	$670,626,220	$0	$670,626,220	$17,015,935,049	$737,688,842	$0	$737,688,842	$19,730,671,271
26	$670,626,220	$0	$670,626,220	$17,686,561,269	$737,688,842	$0	$737,688,842	$20,468,360,113
27	$670,626,220	$0	$670,626,220	$18,357,187,489	$737,688,842	$0	$737,688,842	$21,206,048,955
28	$670,626,220	$0	$670,626,220	$19,027,813,709	$737,688,842	$0	$737,688,842	$21,943,737,797
29	$670,626,220	$0	$670,626,220	$19,698,439,929	$737,688,842	$0	$737,688,842	$22,681,426,639
30	$670,626,220	$0	$670,626,220	$20,369,066,149	$737,688,842	$0	$737,688,842	$23,419,115,481
	$13,412,524,400	$6,956,541,749	$20,369,066,149		$14,753,776,840	$8,665,338,641	$23,419,115,481	

Table 79. LSD(X) and LSD(XB) Costs

H. LPD-17 ALTERNATIVES’ COST: PROCUREMENT OF 11 AND 19 ADDITIONAL LPD-17S

Continued Procurement of 11 Additional LPD-17

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LPD Hull #	12		13		14		15		16		17		18	
Procurement Cost	1539.38		1522.54		1505.88		1489.41		1473.12		1457.00		1441.06	
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
			49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
					49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
							49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
									49.58	49.58	49.58	49.58	49.58	49.58
											49.58	49.58	49.58	49.58
													49.58	49.58
Annual Cost	1588.96	49.58	1621.70	99.16	1654.62	148.74	1687.73	198.32	1721.02	247.90	1754.48	297.48	1788.12	347.06
Cumulative LCCE	1588.96	1638.54	3260.24	3359.40	5014.02	5162.76	6850.49	7048.81	8769.83	9017.72	10772.20	11069.68	12857.80	13204.86

Table 80. LPD 17 Costs

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
19		20		21		22									
1425.30		1409.70		1394.28		1379.03									
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
		49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
				49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
						49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
1821.94	396.64	1855.92	446.22	1890.08	495.80	1924.41	545.38	545.38	545.38	545.38	545.38	545.38	545.38	545.38	545.38
15026.80	15423.43	17279.36	17725.57	19615.66	20111.45	22035.86	22581.24	23126.61	23671.99	24217.37	24762.75	25308.12	25853.50	26398.88	26944.26
															Million FY12$

Table 81. LPD 17 Costs (continued)

Continued Procurement of 19 Additional LPD-17s (Part 1)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LPD Hull #	12	13	14	15	16	17	18	18	20	21	22	23	24	25	26
Procurement Cost	1539.38	1522.54	1505.88	1489.41	1473.12	1457.00	1441.06	1425.30	1409.70	1394.28	1379.03	1363.94	1349.02	1334.26	1319.67
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
		49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
			49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
				49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
					49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
						49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
							49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
								49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
									49.58	49.58	49.58	49.58	49.58	49.58	49.58
										49.58	49.58	49.58	49.58	49.58	49.58
											49.58	49.58	49.58	49.58	49.58
												49.58	49.58	49.58	49.58
													49.58	49.58	49.58
														49.58	49.58
															49.58
Annual Cost	1588.96	1621.70	1654.62	1687.73	1721.02	1754.48	1788.12	1821.94	1855.92	1890.08	1924.41	1958.90	1993.56	2028.38	2063.36
Cumulative LCCE	1588.96	3210.66	4865.28	6553.01	8274.03	10028.51	11816.63	13638.56	15494.48	17384.57	19308.97	21267.87	23261.43	25289.81	27353.18

Table 82. LPD 17 Costs (continued)

Continued Procurement of 19 Additional LPD-17s (Part 2)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
27	28	29	30											
1305.23	1290.95	1276.83	1262.86											
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
		49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
			49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
2098.51	2133.81	2169.27	2204.88	942.02	942.02	942.02	942.02	942.02	942.02	942.02	942.02	942.02	942.02	942.02
29451.69	31585.49	33754.76	35959.64	36901.65	37843.67	38785.68	39727.70	40669.71	41611.73	42553.75	43495.76	44437.78	45379.79	46321.81
														Million FY12$

Table 83. LPD 17 Cost (continued)

I. LPD(17) FLT X ALTERNATIVE COST

Procurement of 11 Additional LPD-17 Flt (X) (70% Legacy)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LPD Hull #	12		13		14		15		16		17		18	
Procurement Cost	2028.47		1518.44		1511.41		1499.88		1545.42		1503.86		1450.04	
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
			49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
					49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
							49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
									49.58	49.58	49.58	49.58	49.58	49.58
											49.58	49.58	49.58	49.58
													49.58	49.58
	2078.05	49.58	1617.60	99.16	1660.15	148.74	1698.20	198.32	1793.32	247.90	1801.33	297.48	1797.09	347.06
Cumulative LCCE	2078.05	2127.63	3745.23	3844.39	5504.54	5653.28	7351.47	7549.79	9343.11	9591.01	11392.34	11689.82	13486.92	13833.97

Year	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
LPD Hull #	19		20		21		22									
Procurement Cost	1471.46		1492.20		1459.45		1472.47									
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
			49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
					49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
							49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
	1868.10	396.64	1938.41	446.22	1955.24	495.80	2017.85	545.38	545.38	545.38	545.38	545.38	545.38	545.38	545.38	545.38
Cumulative LCCE	15702.08	16098.71	18037.13	18483.35	20438.59	20934.39	22952.24	23497.62	24042.99	24588.37	25133.75	25679.13	26224.50	26769.88	27315.26	27860.64

Million FY12$

Table 84. LPD(17) Flt X Costs

J. LHA-8 ALTERNATIVE COST

SEA-18A Plan for 10 LHA-8s

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LPD Hull #	8		9		10		11		12		13		14	
Procurement Cost	2210.24		2201.36		2194.49		2188.90		2184.18		2180.10		2176.51	
	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
			157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
					157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
							157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
									157.77	157.77	157.77	157.77	157.77	157.77
											157.77	157.77	157.77	157.77
													157.77	157.77
Annual Cost	2368.01	157.77	2516.90	315.54	2667.81	473.32	2819.99	631.09	2973.04	788.86	3126.73	946.63	3280.91	1104.40
Cumulative LCCE	2368.01	2525.79	5042.69	5358.23	8026.04	8499.36	11319.34	11950.43	14923.47	15712.33	18839.07	19785.70	23066.61	24171.02

Current Shipbuilding Plan 6 LHA-8s

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LPD Hull #	8					9			10				11	
Procurement Cost	2210.24					2201.36			2194.49				2188.90	
	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
						157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
									157.77	157.77	157.77	157.77	157.77	157.77
													157.77	157.77
Annual Cost	2368.01	157.77	157.77	157.77	157.77	2516.90	315.54	315.54	2667.81	473.32	473.32	473.32	2819.99	631.09
Cumulative LCCE	2368.01	2525.79	2683.56	2841.33	2999.10	5516.01	5831.55	6147.09	8814.90	9288.22	9761.54	10234.85	13054.84	13685.93

Cost of LHA-8's Option

Difference between SEA-18A and Current Plan

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Annual Cost	0.000	0.000	2359.131	157.772	2510.036	-2043.586	2504.442	315.544	305.231	315.544	2653.416	473.316	460.926	473.316
Cumulative LCCE	0.000	0.000	2359.131	2516.903	5026.939	2983.353	5487.795	5803.339	6108.570	6424.114	9077.530	9550.847	10011.773	10485.089

Table 85. LHA-8 Costs

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
15		16		17											
2173.30		2170.40		2167.76											
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
		157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
				157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
3435.48	1262.18	3590.35	1419.95	3745.48	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72	1577.72
27606.49	28868.67	32459.02	33878.97	37624.45	39202.17	40779.89	42357.61	43935.33	45513.06	47090.78	48668.50	50246.22	51823.94	53401.66	54979.38

Million FY12$

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
		12				13									
		2184.18				2180.10									
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
		157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
						157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77	157.77
631.09	631.09	2973.04	788.86	788.86	788.86	3126.73	946.63	946.63	946.63	946.63	946.63	946.63	946.63	946.63	946.63
14317.02	14948.10	17921.14	18710.00	19498.86	20287.72	23414.46	24361.09	25307.72	26254.36	27200.99	28147.62	29094.25	30040.89	30987.52	31934.15

Million FY12$

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
2804.388	631.088	617.311	631.088	2956.620	788.861	-1549.011	631.088	631.088	631.088	631.088	631.088	631.088	631.088	631.088	631.088
13289.478	13920.566	14537.877	15168.966	18125.586	18914.446	17365.435	17996.523	18627.612	19258.700	19889.789	20520.877	21151.966	21783.054	22414.143	23045.231

Million FY12$

Table 86. LHA-8 Costs (continued)

K. RISK CARDS

Alternative 1: LPD-17 Option			
	PERFORMANCE		
		Weighting Factor	**0.9**
	Risk Factor	**CF**	**PL**
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.3**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.3	**0.3**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.3**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.4**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.4**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.4**
	Overall Performance Risk Value:		**0.21**
	SCHEDULE		
		Weighting Factor	**0.3**
	Risk Factor	**CF**	**PL**
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.3	**0.7**
S2	RISK OF DELAY	0.3	**0.7**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.5	**0.5**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.1**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.1**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
	Overall Schedule Risk Value:		**0.11**
	COST		
		Weighting Factor	**0.5**
	Risk Factor	**CF**	**PL**
C1	RISK OF COST OVERRUN	0.7	**0.3**
C2	PRODUCTION PROCESS NOT PROVEN	0.3	**0.3**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.3**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.3**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.5	**0.3**
	Overall Cost Risk Value:		**0.15**

Table 87. Option 1 Risk Card

Alternative 2: LSD(X) Option			
	PERFORMANCE		
	Weighting Factor		0.9
Risk Factor		CF	PL
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.7**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.3	**0.3**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.3**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.3**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.3**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.5**
Overall Performance Risk Value:			**0.26**

SCHEDULE			
	Weighting Factor		0.3
Risk Factor		CF	PL
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.5	**0.7**
S2	RISK OF DELAY	0.5	**0.7**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.5	**0.5**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.7**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.5**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
Overall Schedule Risk Value:			**0.20**

COST			
	Weighting Factor		0.5
Risk Factor		CF	PL
C1	RISK OF COST OVERRUN	0.7	**0.7**
C2	PRODUCTION PROCESS NOT PROVEN	0.7	**0.7**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.4**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.5**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.8	**0.2**
Overall Cost Risk Value:			**0.32**

Table 88. Option 2 Risk Card

Alternative 3: LSD(XB) Option			
	PERFORMANCE		
	Weighting Factor		**0.9**
Risk Factor		CF	PL
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.4**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.3	**0.3**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.3**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.3**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.3**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.2**
Overall Performance Risk Value:			**0.18**

SCHEDULE			
	Weighting Factor		**0.3**
Risk Factor		CF	PL
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.5	**0.7**
S2	RISK OF DELAY	0.5	**0.7**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.5	**0.5**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.7**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.5**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
Overall Schedule Risk Value:			**0.20**

COST			
	Weighting Factor		**0.5**
Risk Factor		CF	PL
C1	RISK OF COST OVERRUN	0.7	**0.7**
C2	PRODUCTION PROCESS NOT PROVEN	0.7	**0.7**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.4**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.5**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.8	**0.2**
Overall Cost Risk Value:			**0.32**

Table 89. Option 3 Risk Card

Alternative 4: LPD(17) FLT X Option			
	PERFORMANCE		
	Weighting Factor		0.9
Risk Factor		CF	PL
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.3**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.3	**0.3**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.3**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.3**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.3**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.3**
Overall Performance Risk Value:			**0.18**

SCHEDULE			
	Weighting Factor		0.3
Risk Factor		CF	PL
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.5	**0.7**
S2	RISK OF DELAY	0.5	**0.7**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.5	**0.5**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.7**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.5**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
Overall Schedule Risk Value:			**0.20**

COST			
	Weighting Factor		0.5
Risk Factor		CF	PL
C1	RISK OF COST OVERRUN	0.7	**0.5**
C2	PRODUCTION PROCESS NOT PROVEN	0.5	**0.5**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.4**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.5**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.8	**0.2**
Overall Cost Risk Value:			**0.24**

Table 90. Option 4 Risk Card

Alternative 5: Big Deck Option			
	PERFORMANCE		
	Weighting Factor		**0.9**
Risk Factor		**CF**	**PL**
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.5**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.9	**0.2**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.4**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.5**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.5**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.6**
Overall Performance Risk Value:			**0.29**

SCHEDULE			
	Weighting Factor		**0.3**
Risk Factor		**CF**	**PL**
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.3	**0.3**
S2	RISK OF DELAY	0.3	**0.3**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.3	**0.3**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.3**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.3**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
Overall Schedule Risk Value:			**0.07**

COST			
	Weighting Factor		**0.5**
Risk Factor		**CF**	**PL**
C1	RISK OF COST OVERRUN	0.7	**0.3**
C2	PRODUCTION PROCESS NOT PROVEN	0.3	**0.3**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.3**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.9**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.5	**0.8**
Overall Cost Risk Value:			**0.26**

Table 91. Option 5 Risk Card

	Alternative 6: Small Deck Option		
	PERFORMANCE		
	Weighting Factor		**0.9**
	Risk Factor	**CF**	**PL**
P1	RISK OF NOT HAVING THE LIFT REQUIREMENTS TO MEET THE MISSION OBJECTIVES	0.9	**0.1**
P2	RISK OF LOSING 1 SHIP TO MEET THE MISSION OBJECTIVES (BASED ON MAINTENANCE)	0.6	**0.4**
P3	RISK OF NOT BEING ABLE TO CONDUCT DIVERSE MISSION SETS	0.7	**0.5**
P4	RISK OF NOT BEING ABLE TO COMPLETE MULTIPLE MISSIONS	0.5	**0.2**
P5	RISK OF MISSION / FORCE PROJECTION DELAYS DUE TO ENEMEY ACTIONS (BASED ON # OF SHIPS)	0.5	**0.2**
P6	RISK OF NOT HAVING ADEQUATE LOGISTICAL CAPABILITY TO SUPPORT MISSION OBJECTIVES	0.7	**0.1**
	Overall Performance Risk Value:		**0.16**
	SCHEDULE		
	Weighting Factor		**0.3**
	Risk Factor	**CF**	**PL**
S1	RISK OF NOT MEETING DELIVERY SCHEDULE	0.3	**0.7**
S2	RISK OF DELAY	0.3	**0.7**
S3	INSUFFICIENT TIME TO TEST SYSTEMS THOROUGHLY	0.3	**0.5**
S4	RISKS OF NOT HAVING MATURE TECHNOLOGY	0.3	**0.3**
S5	INSUFFICIENT FACILITIES AVAILABLE	0.3	**0.3**
S6	INSUFFICIENT NUMBER OF SHIPBUILDERS	0.3	**0.1**
S7	RISK OF EXCEEDING APPROVED ANNUAL SHIP CONSTRUCTION ALLOCATION	0.3	**0.1**
	Overall Schedule Risk Value:		**0.12**
	COST		
	Weighting Factor		**0.5**
	Risk Factor	**CF**	**PL**
C1	RISK OF COST OVERRUN	0.7	**0.3**
C2	PRODUCTION PROCESS NOT PROVEN	0.3	**0.3**
C3	SUFFICIENT FACILITIES ARE NOT READILY AVAILABLE FOR COST-EFFECTIVE PRODUCTION	0.5	**0.3**
C4	RISK OF FLUX IN PERSONNEL / MAINTENANCE / FUEL COSTS	0.5	**0.3**
C5	RISK OF INFRASTRUCTURE CHANGES (I.E. PORT FACILITIES)	0.5	**0.3**
	Overall Cost Risk Value:		**0.15**

Table 92. Option 6 Risk Card

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