2006-06

Maritime threat response

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NPS-97-06-004

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Maritime Threat Response

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June 2006

Prepared for: Office of the Assistant Secretary of Defense for Homeland Defense, 2600 Defense Pentagon, Rm. 5D414, Washington, D.C. 20301-2600

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This report was prepared for the Office of the Assistant Secretary of Defense for Homeland Defense, 2600 Defense Pentagon, Rm. 5D414, Washington, D.C. 20301-2600.

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2006	**3. REPORT TYPE AND DATES COVERED** Thesis Technical Report	
4. TITLE AND SUBTITLE Maritime Threat Response			**5. FUNDING NUMBERS**
6. AUTHOR(S) LCDR Andrew Kessler, MAJ Michael Shewfelt, Ms. Jennifer Davis, LT Brian Connett, LT Jared Chiu-Rourman, LT Joseph Oravec, ENS Shaunnah Wark; TDSI: Ling Siew Ng, Seng Chuan Lim, Cheng Lock Chua, Eng Choon Yeo, Kok Long Lee, Heng Hui Chew, Kwang Yong Lim, Ee Shen Tean, Sze Tek Ho, Koh Choon Chung			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER** NPS-97-06-004
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of the Assistant Secretary of Defense for Homeland Defense, 2600 Defense Pentagon, Rm. 5D414, Washington, D.C. 20301-2600			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT *(maximum 200 words)*

In the twenty-first century, the threat of asymmetric warfare in the form of terrorism is one of the most likely direct threats to the United States homeland. It has been recognized that perhaps the key element in protecting the continental United States from terrorist threats is obtaining intelligence of impending attacks in advance. Enormous amounts of resources are currently allocated to obtaining and parsing such intelligence. However, it remains a difficult problem to deal with such attacks once intelligence is obtained. In this context, the *Maritime Threat Response Project* has applied Systems Engineering processes to propose different cost-effective System of Systems (SoS) architecture solutions to surface-based terrorist threats emanating from the maritime domain. The project applied a five-year time horizon to provide near-term solutions to the prospective decision makers and take maximum advantage of commercial off-the-shelf (COTS) solutions and emphasize new Concepts of Operations (CONOPS) for existing systems. Results provided insight into requirements for interagency interactions in support of Maritime Security and demonstrated the criticality of timely and accurate intelligence in support of counterterror operations.

14. SUBJECT TERMS Homeland Security, Maritime Terrorist Threats, Maritime Security, Homeland Defense			**15. NUMBER OF PAGES** 403
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

ABOT	Al Basrah Oil Terminal
ACL	Access-Control List
AFB	Air Force Base
AI	Artificial Intelligence
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
Ao	Operational Availability
AO	Fleet Oiler
AOE	Fast Combat Support Ship
AOO	Area Objective Oriented
AOR	Area of Regard
APS	Area Problem Solving
BAC	Blood Alcohol Content
BAS	Basic Allowance for Subsistence
BTCP	Boarding Team Communications Pack
BUCE	Bottom-Up Cost-Effective
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CA	Certificate Authority
CAC	Common Access Card
CASREP	Casualty Report
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosive
CG	Guided Missile Cruiser
CIC	Combat Information Center
CIP	Common Intelligence Picture
cm	Centimeter
CMS	Corrective Maintenance Services
CONOPS	Concept of Operations
CONUS	Continental United States
COP	Common Operating Picture
COTS	Commercial Off The Shelf
CPS	Counts per Second
CQB	Close Quarter Battle
CRUDES	Cruiser-Destroyer
CT	Counter-Terror
DDG	Guided Missile Destroyer
DHS	Department of Homeland Security
DMZ	Demilitarized Zone
DoD	Department of Defense
DoE	Department of Energy
DoJ	Department of Justice

DoN	Department of the Navy
DoT	Department of Transportation
DRM	Design Reference Mission
DSCA	Defense Support to Civil Authorities
F/F	Find and Fix
FAST	Fatigue Avoidance Scheduling Tool
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Activity
FFG	Guided Missile Frigate
FIN	Finish
FM	Fission Meter
FRC	Fast Response Cutter
FSS	Fast Supply Ship
FTE	Full Time Equivalent
FY2006$M	Fiscal Year 2006 millions of dollars
GCCS	Global Command and Control System
GHz	Gigahertz
GL	Grenade Launcher
HA	Higher Authority
HARM	Helicopter Availability and Reliability Model
He	Helium
HE	High Explosive
HEU	Highly Enriched Uranium
HMS	Her Majesty's Ship
HPGe	High Purity Germanium
HSAS	Homeland Security Advisory System
HSPD	Homeland Security Presidential Directive
HVU	High Value Unit
IA	Identification and Authentication
IAEA	International Atomic Energy
IBU	Navy Inshore Boat Unit
ID	Identify
IDS	Intrusion Detection System
INCONUS	Inside the Continental United States
IOC	initial operating capability
IPSec	Internet Protocol Security
ISLMM	Improved Submarine Launched Mobile Mine
IT	Information Technology
JCATS	Joint Conflict and Tactical Simulation
JIATF	Joint Inter-Agency Task Force
JTF-N	Joint Task Force-North
JTLS	Joint Theater-level Simulation
JTO	Joint Technical Operations Team

KAAOT	Khawr Al Amaya Oil Terminal
keV	Kilo-Electron Volt
kg	Kilogram
kts	nautical miles per hour
LAN	Local Area Network
LANTAREA	Atlantic Area (Coast Guard)
LCS	Littoral Combat Ship
LLNL	Lawrence Livermore National Laboratory
LMG	Light Machine Gun
LOO	Local Objective-Oriented
LPS	Local Problem Solving
LRI	Long Range Interceptor
LRM	Linear Radiation Monitor
m	Meter
M&S	Modeling and Simulation
M/V	Merchant Vessel
MARSEC	Maritime Security
Mbps	Mega bits per second
MC	Mission Capable
MCG	Medium Caliber Gun
MDA	Maritime Domain Awareness
meV	micro-Electron Volt
MHLD	Maritime Homeland Defense
MMA	Major Metropolitan Area
MMG	Medium Machine Gun
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOTR	Maritime Operational Threat Response Plan
MPG	Miles Per Gallon
MSC	Military Sealift Command
MSD	Mobile Security Detachment
MSST	Maritime Safety and Security Team
MTR	Maritime Threat Response
NaI	Sodium Iodide Detector
NAVAIR	Naval Air Systems Command
NAVPERS	Naval Personnel Command
NCA	National Command Authority
NIDS	Network Intrusion Detection System
NIMS	National Incident Management System
NLW	Non-Lethal Weapons
NM	Nautical Mile
NMC	Non-Mission Capable
NMT	No more than
NORM	Naturally Occurring Radioactive Material
NORTHCOM	United States Northern Command

NPS	Naval Postgraduate School
NRP	National Response Plan
NSW	Naval Special Warfare
O&S	Operating and Support
OAE	Orthogonal Array Experiment
OEM	Original Equipment Manufacturer
OO	Objective Oriented
OODA	Observe, Orient, Decide, Act
OPNAV N51	Office of the Chief of Naval Operations Plans, Policy, and Operations – Strategy and Policy
OPORDS	Operations Orders
OS	Operating System
OSD	Office of the Secretary of Defense
P(hit)	Probability of Hit
P(kill)	Probability of Kill
PACAREA	Pacific Area (Coast Guard)
PAV	Potential Attack Vessel
PBS	Prepare the Battlespace
PC	Patrol Coastal
$\mathbf{P_d}$	Probability of Detection
PDA	personal digital assistant
$\mathbf{P_{fa}}$	Probability of False Alarm
PKI	Public Key Infrastructure
PMP	Project Management Plan
PMS	Preventative Maintenance Services
POR	Program of Record
$\mathbf{P_s}$	Probability of Success
PS	Problem Solving
PSTN	Public Switched Telephone Network
PSU	Port Security Unit
Pu	Plutonium
RDD	Radiological Dispersal Device
RDT&E	Research, Development, Test, and Evaluation
rem	Roentgen Equivalent Man
RGPu	Reactor Grade Plutonium
RGU	Reactor Grade Uranium
RHIB	Rigid Hull Inflatable Boat
RID	Radioisotope Identifier
ROE	Rules of Engagement
ROF	Rate of Fire
S	Secret
SA	Situational Awareness
SAR	Search and Rescue
SARM	Small Boat Availability and Reliability Model
SAW	Ship As a Weapon

SBA	Small Boat Attack
SEA	Systems Engineering and Analysis
SEAL	Sea, Air and Land
SELP	Systems Engineering Lifecycle Process
SEMP	Systems Engineering Management Plan
SF	San Francisco
ShiFCOM	Ship Fuel Consumption Model
SJFHQ-N	Standing Joint Force Headquarters - North
SME	Subject Matter Expert
SNM	special nuclear material
SOF	Special Operations Forces
SOP	Standard Operating Procedures
SORTS	Status of Resources and Training System
SoS	System of Systems
SSL	Secured Socket Layer
STSAM	Search Team Sleep Analysis Module
Sv	Severt
TDCE	Top-Down Cost-Effective
TDSI	Temasek Defense Science Institute
TEU	Twenty foot Equivalent Unit
ThI	Thallium Iodide
TNT MIO	Tactical Network Topology Maritime Interdiction Operations
TOTE	Totem Ocean Trailer Express, Inc.
TS	Top Secret
TSSE	Total Ship Systems Engineering
TTP	Tactics, Techniques, and Procedures
U	Uranium
UC	Unclassified
UNREP	underway replenishment
USAF	United States Air Force
USAV	U.S. Army Vessel
USCG	United States Coast Guard
USN	United States Navy
USS	United States Ship
USV	Unmanned Surface Vehicle
UWB	Ultra Wide Band
VA	Vital Area
VAMOSC	Visibility and Management of Operating and Support Costs
VBSS	Visit, Board, Search, and Seizure
VLCC	Very Large Crude Carrier
VOI	Vessel of Interest
VOX	Voice Operated
VPN	Virtual Private Network
WA	Wide Area
WAP	wide area paging

WaTSAM	Watch Team Sleep Analysis Model
WBS	Work Breakdown Structure
WGPu	Weapons Grade Plutonium
WGU	Weapons Grade Uranium
WHEC	U.S. Coast Guard High Endurance Cutter
WMAN	Wireless Metropolitan Area Network
WMD	Weapon of Mass Destruction
WMSL	Maritime Security Cutter
WPB-110	U.S. Coast Guard Patrol Boat, 110-ft class
WWI	World War One
WWII	World War Two
yd	Yard

EXECUTIVE SUMMARY

Background

The 2006 Naval Postgraduate School (NPS) Cross-Campus Integrated Study, titled "Maritime Threat Response" involved the combined effort of 7 NPS Systems Engineering students, 7 Singaporean Temasek Defense Systems Institute (TDSI) students, 12 students from the Total Ship Systems Engineering (TSSE) curriculum, and numerous NPS faculty members from different NPS departments. After receiving tasking provided by the Wayne E. Meyer Institute of Systems Engineering at NPS in support of the Office of the Assistant Secretary of Defense for Homeland Defense, the study examined ways to validate intelligence and respond to maritime terrorist attacks against United States coastal harbors and ports. Through assessment of likely harbors and waterways to base the study upon, the San Francisco Bay was selected as a representative test-bed for the integrated study. The NPS Systems Engineering and Analysis Cohort 9 (SEA-9) Maritime Threat Response (MTR) team, in conjunction with the TDSI students, used the Systems Engineering Lifecycle Process (SELP) shown in Figure ES-1 as a systems engineering framework to conduct the multi-disciplinary study. While not actually fabricating any hardware, such a process was well-suited for tailoring to the team's research efforts and project focus.

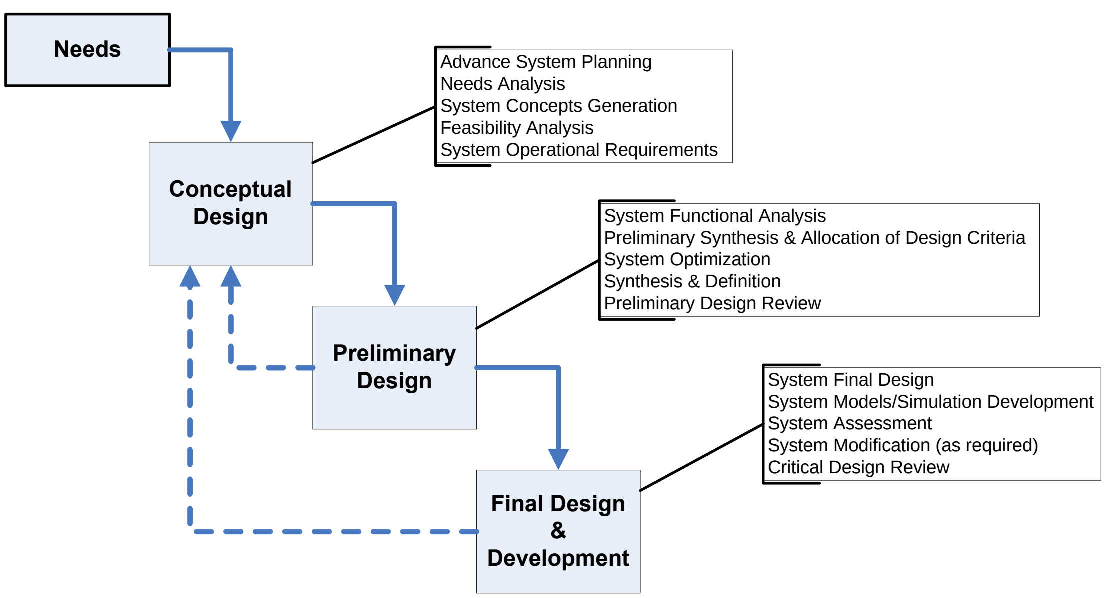

Figure ES-1: Systems Engineering Lifecycle Process (SELP)

The SELP was an iterative process used to bound and scope the MTR problem, determine needs, requirements, functions, and to design architecture alternatives to satisfy stakeholder needs and desires.

The SoS approach taken, shown in Figure ES-2, enabled the team to apply a systematic approach to problem definition, needs analysis, requirements, analysis, functional analysis, and then architecture development and assessment.

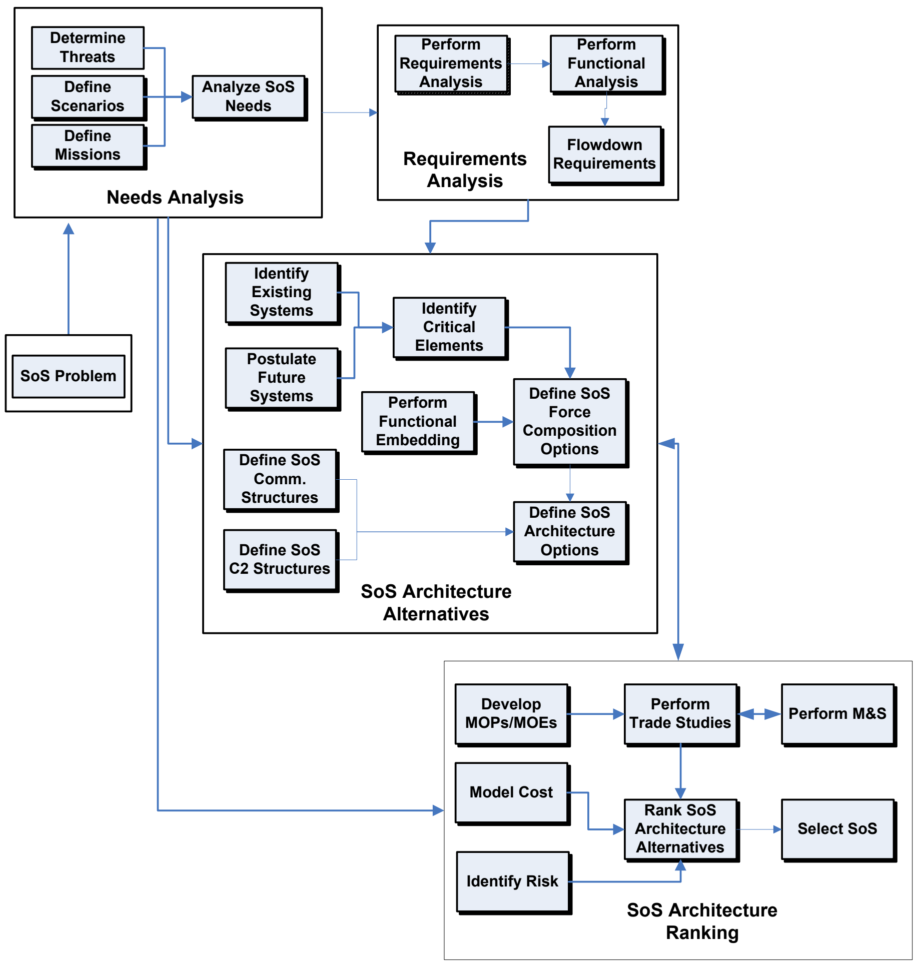

Figure ES-2: System of Systems (SoS) Architecture Alternatives Approach

Problem Definition

The volume of global maritime commerce has risen dramatically during the later half of the twentieth and into the twenty-first century. The aftermath of the 9/11 attacks on the United States has heightened concerns about the prospects of transnational terrorist groups using the global maritime commercial system as a vehicle to inflict high levels of destruction upon the United States homeland. While there have not been any documented transnational terrorist attacks on the United States homeland from the maritime domain to date, the attack on the USS Cole and other acts of maritime terror overseas, along with the 9/11 attacks, have caused great attention to be paid to the susceptibility of the United States to maritime terrorism. The size of the U.S. coastline and the amount of shipping traffic entering and exiting numerous ports make preventing such acts of terror a challenging problem. The difficulty in maintaining awareness of the global maritime domain makes the problem even more complicated.

The Report of the 9/11 commission highlighted the criticality of information-sharing and effective intelligence-gathering in preventing acts of terrorism. Knowing an attack is going to take place is a necessary but not sufficient step, however. The forces must be ready to act on such intelligence to prevent or stop the attack. The SEA-9 MTR team made the assumption that the obtaining of such intelligence was a given from the Maritime Domain Awareness (MDA) system. The team then assessed how the United States might be best organized, equipped, and trained to respond to such maritime threats as they became known.

Project Team Approach

The SEA-9 MTR team used stakeholder inputs and a “Red Cell” approach to develop representative scenarios for maritime terrorist attack upon San Francisco and its environs. With tasking to examine both externally and internally generated threats, three different scenarios were developed. In the first scenario, a weapon of mass destruction (WMD) is smuggled onboard 1 of 20 possible innocent, unknowing container ships coming from Southeast Asia heading for San Francisco. In the second scenario, a terrorist team has stowed away aboard 1 of 20 possible large merchant vessels coming from Southeast Asia heading for San Francisco. The terrorists intend to seize control of the vessel and use the ship as a weapon (SAW) in a suicide attack against another vessel or point of critical infrastructure such as the Golden Gate Bridge. In simplest terms, the tactics of the 9/11 attacks are applied to ships. In the last scenario, a terrorist sleeper cell that is already established inside the United States obtains explosives and a small boat located somewhere in San Francisco Bay to attack either a large merchant vessel or other point of critical infrastructure within the Bay (SBA).

The MTR team, using the SELP as the process guide, defined the system of systems (SoS) problem, developed an effective need statement, performed an analysis of operational and system requirements, decomposed and allocated required functions in support of operational requirements, developed architecture alternatives, and evaluated and ranked the different alternatives based on their effectiveness and cost in responding to the different scenarios. With policy guidance received from *The National Strategy for Maritime Security* (September 2005), the team constrained potential solutions such that they must absolutely minimize adverse impact on commerce due to delay and/or damage to shipping. In addition, based on stakeholder inputs as well as policy guidance, emphasis was placed on developing and integrating existing systems and Program of Record (POR) systems, but used with new Concepts of Operations (CONOPS) as part of a nationally integrated, interagency response force.

Three architecture alternatives were developed and evaluated during the study. The first was developed using an objective, fractional design of experiments focused on maximizing effectiveness in defeating terrorist threats independent of any cost considerations. The second was developed in a subjective manner with each of the functional leads working on the project providing their best estimate as to the lowest cost system concept that was expected to meet top-level requirements. All of the system concepts selected were then integrated into an overall architecture that should be cost-effective. The third was developed using an objective, fractional design of experiments that sought to balance cost and effectiveness equally. The costs associated with each architecture included any procurement costs required, operations and support costs associated with the forces while they were performing MTR missions, and any delay and damage costs that are imposed on maritime commerce in the course of executing the MTR mission.

The performance of each architecture was measured through use of modular, discrete event simulations in terms of the likelihood of the architecture successfully stopping each of the three terrorist attacks as well as the delay and impact on commerce.

The modular approach enabled the use of a number of different modeling and simulation tools, to include Java software, Imagine That, Inc. EXTEND™ simulation software, Microsoft Excel™ spreadsheet software, and Livermore National Laboratory's Joint Conflict and Tactical Simulation (JCATS) interactive desktop war game.

Results, Recommendations, and Conclusions

The key findings of the study include:

Overall MTR

- Adequate intelligence is a necessary, but not sufficient, component of a successful homeland security posture. Knowledge of an impending attack must be complemented by robust forces and their concept of operations in order to effectively stop an attack once it is determined with some confidence that it is underway. With such forces in place and with established concepts of operation and rules of engagement, a variety of terrorist attacks can be successful repulsed without significant damage or impact on the homeland or the economy.
- Responding to maritime terrorist threats requires an integrated, interagency response taking advantage of the specific capabilities and authorities resident in different organizations within the U.S. national security apparatus. Historically, interagency missions and task forces have been far more successful when there have been preexisting command relationships and interagency representation established. Natural, human barriers to effective communication and information sharing can be overcome through the establishment of personal relationships between members of different agencies at a Joint Inter-agency Task Force.

The key findings of the study for each of the three scenarios include:

Weapon of Mass Destruction Scenario

- The majority of research effort in the field of radiation detection is centered on conducting a search as rapidly as possible; while a truck is driving through a border crossing, while a container is being off-loaded from a ship to a truck bed, and the like. Given reasonable intelligence latency of less than 160 hours, it was found that search teams could be placed onboard container ships with an opportunity to search the ship for over a week prior to entering United States territorial waters. Such search time enables minutes to be spent on individual container searches and multiple hours spent on individual cargo holds. Use of the Littoral Combat Ship's high speed sprint capability (45+ knots) along with a small fuel capacity addition in its mission module spaces enabled the greatest time to search among all potential Navy and Coast Guard search and escort vessels (over 200 hours to search with 72 hours of intelligence latency).

- Given search times ranging from 100-200 hours per ship, nuclear devices can be detected with high confidence even with slightly vague intelligence.

Commandeered Ship as a Weapon Scenario

- The threat of a commandeered ship can be effectively countered through the employment of ten man "Sea Marshall" teams that are placed onboard threatened vessels with the Harbor Pilot approximately 12 miles beyond the Golden Gate Bridge. These teams serve to secure critical control spaces of the vessel in question until the vessel is safely docked within the port. This approach needs to be complemented by a "shore battery" of some kind that can non-lethally disable the vessel, typically by fouling of its propellers and rudders, if it is found that the terrorists are in control of the vessel when the Harbor Pilot and Sea Marshalls attempt to board. There are a variety of weapons technologies that can perform this function. Such a concept of operations precludes any opportunity to recapture the vessel in question once it is determined to be under terrorist control. In addition, timing is absolutely critical and there is no room for delay in decision making.

- A different concept of operations can be employed that consists of surging Navy and Coast Guard vessels forward to intercept potentially threatened vessels as they come across the Pacific. These vessels can then be boarded and searched to determine the crew's status and use biometrics to attempt to identify any terrorists that are covertly onboard. If terrorists are in control of the vessel in question in this case, there is adequate time to attempt to recapture the vessel from the terrorists, and if such a recapture attempt is not successful, then the ship can be disabled prior to becoming a threat to the United States. This particular approach, while highly effective, places more U.S. personnel in mortal danger and is more costly in resource utilization than the Sea Marshall option.

- Little data exists that the SEA-9 MTR team could access with regard to the difficulty and challenges of attempting recapture of a commandeered, large merchant vessel at sea. As such, it is difficult to predict the prospects for success of such action and the amount of damage that such a ship might suffer during an ensuing firefight between U.S. forces and the terrorists onboard, as well as what potential exists for the terrorists in question to facilitate the sinking of the vessel if their plans were interrupted by U.S. MTR force action.

Small Boat Attack Scenario

- Even in the fairly narrow water-space areas of San Francisco Bay, attached, close escort of merchant vessels and passenger ferries proved to be more effective than the establishment of random, barrier patrols within the Bay. Further, separate escort vessels (typically four in number per defended asset) proved to be more effective than the emplacement of escort teams onboard the defended merchant vessels and ferries themselves.

- Effective countering of the SBA was much more likely if recreational boat traffic within the Bay was prohibited by local authorities and traffic within the Bay was limited to essential commercial traffic. Such a prohibition requires the effective coordination of numerous local law enforcement agencies.

- “Red Cell” analysis of potential terrorist responses to MTR operations suggested that static points of critical infrastructure needed to be defended as well as vessels to prevent small boat attack against refueling piers and the like. The analysis also suggested that passenger ferries and oil tankers were more likely terrorist targets than container ships and other dry cargo-carrying vessels.

- While the increased numbers of crew-served weapon stations onboard mid-sized escort ships (100+ feet in length) and the longer-range visual detection capability associated with the same was found to increase the likelihood by approximately 11% of stopping a SBA, it was an extraordinarily costly approach when compared to just using small escort boats, helicopters, and unmanned surface vehicles.

- The use of unmanned surface vehicles (USV) was a cost-effective option to counter terrorist SBAs when used as a complement to traditional escort forces. The USVs increase total time available to engage a threat because they reduce the amount of time required to warn off as yet unidentified incoming boats.

Caveats and Limitations

The threat scenarios and target location of San Francisco were intended to serve as representative examples that could be adjusted. The scenarios were picked as a result of Red Cell analysis of potential terrorist choices after extensive discussions with different stakeholders and reference to previous threat assessments conducted by agencies within the Department of Defense as well as agencies within the Department of Homeland Security. San Francisco was picked as representative of a variety of different homeland security problems and was modeled in such fashion that the inputs could be changed to represent other potential target locations with different vulnerabilities. The intent of the approach was to provide an example of the issues confronting homeland defense and security planners and enable adaptation to other scenarios and locales.

The SEA-9 Maritime Threat Response Cross-Campus Integrated Study was an academic exercise for purpose of validating and completing the education that the students received during their time at NPS. It was not endorsed by any branch of the United States armed forces or any agency within the United States government. The scope of the problem of maritime terrorism is daunting and could not be looked at in its entirety with the amount of personnel and time available for the study. Simplifying assumptions were made and representative examples were picked in order to facilitate completion of the study during the allotted time. While the problem could not be examined in its entirety and complexity, it was evaluated such that insights could be drawn from the study that will be useful to decision makers involved and highlighted areas for further study by future student teams.

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ACKNOWLEDGEMENT

The integrated project of SEA-9, Maritime Threat Response, would like to express our thanks and sincere gratitude for the time, dedication, expertise, and guidance of the following individuals.

The Honorable Peter Verga, Principal Deputy Assistant Secretary of Defense for Homeland Defense
VADM Roger Bacon, USN (Ret.)
RADM Wayne E. Meyer, USN (Ret.)
Dr. Frank Shoup
RADM Richard Williams, USN (Ret.)
Dr. Tom Huynh
Dr. Arden Duggan
Dr. Craig Smith
Dr. Robert Harney
Mr. Sean Kittrell
Mr. Albert Miller
CAPT Charles Dixon, USN
CAPT Wayne Hughes, USN (Ret.)
CAPT Jeff Kline, USN (Ret.)
CAPT Starr King, USN
CDR Tom Breske, USN
CDR Glenn Lintz, USN
LTC Alejandro Hernandez, USA
LTC Gregory Mislick, USMC (Ret.)
LCDR Joseph Cahill, USN
LCDR Brad Keiserman, USCG
Mr. A.J. Gipson
Mr. Alice Cooper
Mr. Daniel Nagel
Mr. Ed Nath
Professor Patrick Parker
Professor Mark Stevens
Professor Mitch Brown
Professor Matthew Boensel
Professor Doyle Daughtry
Professor Bard Mansager
Professor William Solitario
Professor Paul Sanchez
Professor Dave Netzer
Professor Alex Bordetzky
Professor John Osmundson
Professor Michael McCauley

Dr. Bill Dunlop
Mrs. Sharon King
S.S. Lurline, Master and 1st Mate

Additionally, we would like to thank the remaining faculty and staff of the Wayne Meyer Institute for Systems Engineering who provided support to our project. Lastly, we would like to extend our warmest thanks to our families for their unwavering support and patience during the eight months of our project.

1.0 INTRODUCTION

The Maritime Threat Response (MTR) System of Systems (SoS) is designed to address the resources and actions necessary to thwart a planned attack by terrorists within the maritime domain. MTR is the next logical step after successful acquisition of information through the employment of Maritime Domain Awareness assets. The MTR SoS is designed around three basic missions: a container ship carrying a Weapon of Mass Destruction (WMD), a large commercial Ship used As a Weapon (SAW), and a Small Boat Attack (SBA) conducted in a confined area such as a bay, harbor, strait, etc.

Due to events like 9/11 and the USS Cole attack, great efforts have been made to correct weaknesses in Maritime Defense and Maritime Protection. Over the past few years, numerous DoD and DHS documents and instructions have been issued to ensure a unified sharing of information and response to potential terrorist threats to the United States maritime domain. Exercises to test and refine existing maritime domain systems are ongoing (reference "Operation Seahawk," Charleston, South Carolina).

The purpose and significance of this project is defined in the following problem statement:

"Define and select a cost-effective system-of-systems (SoS) architecture and its concept of operations that will enable responses to national security threats to the U.S. homeland that emanate from the maritime domain. Consider, at a minimum, the threat being a WMD device smuggled onboard a ship and the threat being a vessel employed as a weapon itself. The responses could be validation of a suspected threat and/or the negation of an identified threat. Intelligence regarding a threat to the homeland is assumed to be available to the appropriate agencies for use by the SoS. The SoS will consist of systems that are currently in service, in development, or could be developed within the next five years."

The scenarios around which the missions are developed will be viewed as two possibilities. First, for the WMD and SAW scenarios, intelligence information alerts the NCA to a potential attack directed toward San Francisco, nuclear/radiological and collision respectively. Both the WMD and SAW scenarios will originate in Southeast Asia and terminate in one of the San Francisco Bay port facilities. The WMD will be a containerized nuclear or radiological device. The SAW will be a ship with immense destructive energy enclosed within a container, cargo, or tanker ship. The attack may be conducted from one or more of a set of 20 potential attack vessels. Second, for the SBA scenario, intelligence information alerts the NCA to a potential small boat attack to be conducted in the San Francisco Bay Area. This attack may be directed toward transiting commercial ships or critical infrastructure (port facilities, ferries, bridges, and cultural centers) within or adjacent to the bay. This is all the information that is available and the SoS must be developed to fulfill the missions.

We use a systems engineering approach to assign responsibilities and conduct our work. A timeline is established to mark goals and milestones, deliverables were identified, and progress is tracked and maintained (see Gantt Chart, Appendix C).

Once the template for the project is established, the work may begin. First is to make the realistic assumptions necessary to bound the problem. These assumptions are based on research of available intelligence, equipment, capabilities and personnel, as well as likely actions of the potential participants in the postulated scenarios. Next is the need to establish measures of effectiveness and performance by which the system concepts will be evaluated.

Numerous system concepts are then evaluated to determine cost, applicability and utility within the MTR SoS. Also, concepts of operations are developed for employment of the various systems concepts. Once completed, the selected system concepts are modeled within the various concepts of operations and simulations conducted to determine individual and overall SoS effectiveness. The missions within the MTR SoS are not necessarily congruent but all contribute to the overall SoS. This incorporation of multiple system concepts for evaluation in various missions is possible through the use of orthogonal arrays, which will be discussed in Section 7.1.2.

The alternative system concepts are based on three SoS architecture possibilities; Maximum Performance, Top-Down Cost-Effective and Bottom-Up Cost-Effective. Maximum Performance means the best possible SoS Architecture regardless of cost. The Top-Down Cost-Effective is objectively derived through the use of an orthogonal array which equally weights high capability and low costs. The Bottom-Up Cost-Effective Architecture is based on the subjective assessment of the MTR Team with cost as a consideration. Once these three SoS architectures are developed, each one is compared to the other to asses the SoS cost versus effectiveness.

Lastly, considering the academic nature of the SEA 9 MTR Project, recommendations and suggestions for further investigation are provided that may refine or expand upon the work done by the MTR Team, and possibly enhance the overall effectiveness of U.S. maritime security.

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2.0 PROJECT MANAGEMENT

The team approached the project from the standpoint of an actual research and development project focused on the future development of a system for responding to maritime threats. Without a true "customer," the team consistently strove to develop a virtual representation of the kinds of information, needs, and desires that such a customer would normally convey. The following sections outline and discuss the team's specific approach and methodology for accomplishing these tasks during the course of the project.

2.1 PROBLEM DEFINITION

Late in 2005, Naval Postgraduate School (NPS) SEA-9 students at the Wayne E. Meyer Institute for Systems Engineering (WEMISE) addressed the growing challenge of responding to terrorist threats to the United States that emanate from the maritime domain. The threats could be a nuclear WMD in a shipping container on its way to the United States, a merchant ship commandeered by terrorists used in an attack on infrastructures or high-value targets, and a suicide small boat carrying explosives aimed at a high value target (such as an oil tanker or passenger ferry).

Through the Meyer Institute for Systems Engineering at the Naval Postgraduate School, the SEA-9 students were tasked by the Office of the Assistant Secretary of Defense for Homeland Defense (OASD HD) to develop a conceptual, near-term, joint and interagency SoS in the 5-year timeframe to respond to terrorist threats to the United States that emanate from the Maritime Domain by (1) generating SoS architecture alternatives using existing systems, programs of record, and commercial off the shelf (COTS) technologies and developing concepts of operations; and (2) recommending a cost-effective SoS that must minimize impact on commerce.

An examination of the strategy documents as well as the team members' own operational experiences focused attention on the fact that simple knowledge of an impending event is often not a sufficient condition to prevent the event. Forces, tactics, techniques, and procedures (TTP) need to be in place to respond effectively once intelligence is obtained. *The Maritime Operational Threat Response Plan for The National Strategy for Maritime Security* (October 2005) deals principally with assignment of roles and responsibilities to the different executive agencies of the U.S. government. It discusses protocols for determining assignment of lead agency and supporting agency roles. It does not cover specific TTP or address specific scenarios. It was determined that a study in this particular area would be valuable to decision makers throughout the government and provide an appropriate venue as an academic exercise for the SEA students to validate their curriculum by applying a systems engineering approach to the problem.[1]

The problem was thus defined as follows:

> Define and select a cost-effective system-of-systems (SoS) architecture and its concept of operations that will enable responses to national security threats to the United States homeland that emanate from the maritime domain. Consider, at a minimum, the threat being a WMD device smuggled onboard a ship and the threat being a vessel employed as a weapon itself. The responses could be validation of a suspected threat and/or the negation of an identified threat. Intelligence regarding a threat to the homeland is assumed to be available to the appropriate agencies for use by the system of systems. The SoS will consist of systems that are currently in service, in development, or could be developed within the next five years.

Upon completion of the problem definition, the team used a "Red Cell" approach to identify perceived vulnerabilities and likely avenues of terrorist attack in the maritime domain. Team members were tasked to individually develop a list of potential threat scenarios based on previous consultation with stakeholders and research in the public

[1] At the outset of the project, the focus was initially on developing systems of systems for accomplishing Maritime Domain Awareness (MDA). Based upon discussions with the Director of the Meyer Institute and other key decision-makers in the project process, it was determined that there were several critical issues regarding MDA that made it an ill-suited subject for this particular project. The first had to do with the general classification of information and systems involved in the tasks supporting MDA. Most of such systems and information are classified at least SECRET/US ONLY or higher by the Department of Defense and other Cabinet-level agencies. Since the bulk of this project would be conducted at the UNCLASSIFIED level because of the extensive involvement of foreign nationals from Singapore, it was determined that it would be very difficult to conduct a thorough and valuable study of MDA. Even the appropriately cleared U.S. officers working on the project would have to be careful to limit their exposure to such classified material to prevent unintentionally incorporating some of its elements in an unclassified study. The second issue pertained to the amount of effort currently ongoing in the area of MDA. Numerous organizations in several Cabinet-level departments are currently conducting extensive research on MDA, and there are several research projects on it at the Naval Postgraduate School as well. As such, it was felt that there was already extensive attention on the subject of MDA, which is just one subcomponent of the overall strategy for maritime security. It was thus decided and agreed that the SEA-9 team would concentrate on another subcomponent of the overall maritime security strategy. Given the decision to move away from MDA, the team examined the other aspects of maritime security.

domain. This began an iterative process that the team used to develop missions to be considered to evaluate system performance and provide insight into the problems of achieving maritime security.

2.2 PROJECT TASKING

Once the problem statement was defined, the team began a comprehensive research effort as well as an orchestrated attempt to contact all applicable stakeholders in the maritime security realm. This involved discussions with subject matter experts at NPS as well as field trips to meet with stakeholders around the country. The intention was to further narrow and bound the scope of the project as well as to ensure that the areas of focus were considered invaluable to the stakeholders.

2.3 STAKEHOLDER ANALYSIS

The conversations and meetings with different stakeholders and subject matter experts helped shape the problem for the team and allowed the team to further refine its focus of effort. The interactions with stakeholders served to accomplish several purposes. First, appropriate design reference missions that the system of systems must accomplish were defined. Given the limited time available for the project, the team proceeded with the intention of capturing several representative missions rather than attempting to evaluate all possible missions that the system would have to perform. Second, key issues were determined that would be of value in exploring during the course of the project. These consisted of new, potential concepts of operations, new applications of existing technology, and other issues found to be noteworthy by stakeholders.

Stakeholder interest with respect to the missions varied to a certain extent but had many points of commonality. The scenario that receives the most attention in both the press as well as within threat planning conferences remains the WMD scenario. The almost incalculable amounts of potential damage from such attacks make it important to almost all concerned. With respect to the WMD scenario within the context of maritime security, the notion of a nuclear device smuggled into the country on one of the thousands of container ships that enter the country every year remains one of principal concern.

Given the stakeholder interest as well as the defined problem statement, it was decided early on that the WMD scenario would be one of the DRM considered for the study.

Some stakeholders raised the issue regarding the possibility of a WMD device being smuggled into the country on one of the thousands of small, ocean-going pleasure craft that move up and down the coasts of the western hemisphere in the Atlantic and Caribbean as well as the Pacific. This type of smuggling approach has been noted by many in evaluations of maritime security.[2] It was decided, however, that such a threat presented more of an issue relating to maintaining awareness of the traffic and obtaining the intelligence of such an impending attack rather than stopping it once one became aware of it. For this reason, the WMD scenario focused on what was considered the more difficult problem once intelligence was obtained, that being the container ship (or ships) that have up to 10,000 containers onboard.

The concept of a ship as a weapon also resounded as a significant threat among various stakeholders interviewed. Several stakeholders discussed the "trial run" hijacking of a merchant ship off of Sumatra in March 2003. In that case, the pirates or hijackers took control of the ship and practiced driving it for some period of time, then abandoned the ship without taking any cargo.[3] The parallels between this instance and the Al Qaeda flight students prior to the 9/11 attacks are easy to see and are a cause for concern. Such a scenario has two potential subsequent branches. In one case, the ship would maintain all normal track and schedule and would not deviate to become a weapon until the last possible moment. In the other case, it is postulated that the ship would be hijacked at sea and then the hijackers would change its course to attack a different destination, a so-called "Rogue Ship" scenario. Based on stakeholder feedback, it was assessed that the first case was the more difficult to detect and to counter, and it was therefore selected for investigation by the team.

On-campus faculty consultants at NPS were also concerned with examination of terrorist threats that were not necessarily external in origin. It was felt that the study

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[2] Siobhan Gorman and Sydney J. Freedburg, "Efforts to Combat Nuclear Terrorism Hindered by Porous Borders," [http://www.govexec.com/dailyfed/0605/061705nj1.htm], June 17, 2005, Accessed on March 17, 2006.

[3] Simon Elegant and Kuala Sepetang, "Dire Straits. Ships That Pass Through Some of the Busiest Waterways in Asia are Often the Target of Pirates. Is a Terrorist Attack Next?" *Time Asia*, [http://www.time.com/], Accessed on March 19, 2006.

ought to consider instances where the terrorists were already established in the United States prior to mounting their attack, again following the modus operandi of the 9/11 attacks. Additional stakeholders assessed that the difficulty in locating small boat traffic inter-mixed with more sizable merchant traffic made SBA a worthwhile scenario to consider. Based upon the combined input of stakeholders both on- and off-campus, it was decided that the SBA would become the third scenario for the study. The problem statement is refined as follows:

> Develop a conceptual, near-term, joint and interagency system of systems (SoS) in the 5-year timeframe to respond to terrorist threats to the United States that emanate from the Maritime Domain by (1) generating SoS architecture alternatives using existing systems, programs of record, and commercial off the shelf (COTS) technologies and developing concepts of operations and (2) recommending a cost-effective SoS that must minimize impact on commerce. The SoS would be deployed in three missions: prevention of a nuclear WMD attack, prevention or defeat of an attack using a merchant ship (SAW), and defeat of a suicide small boat attack (SBA) on a high value target (such as an oil tanker or passenger ferry).

2.4 ORGANIZATION STRUCTURE

Following interviews with stakeholders and an initial analysis of their needs, the system of systems (in its primitive form) began to take shape by decomposing the problem into functions necessary to accomplish the stakeholder needs. Section 5 contains a complete system of systems functional decomposition. The team was organized according to the five core functions the system of systems must perform:

1) Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)
2) Prepare the Battle Space (PBS)
3) Find/Fix
4) Finish
5) Sustain

Various student curricula including SEA, TDSI, TSSE, and NPS Homeland Security, as well as NPS faculty subject matter experts and professors dedicated to the project were then organized to support the execution of the project. As shown in Figure 2-1, the organizational structure delineates interfaces among the various groups participating in the project. Tasking and guidance flowed periodically from the clients, depicted on the right side of the diagram, to the SEA9 project management team. SEA9, shown in the middle of the diagram, provided requirements to and obtained input from technical teams and defense contractors located on the left side of the diagram. In meeting mission requirements, specific group tasking was organized according to group technical specialization contributing to the overall project success.

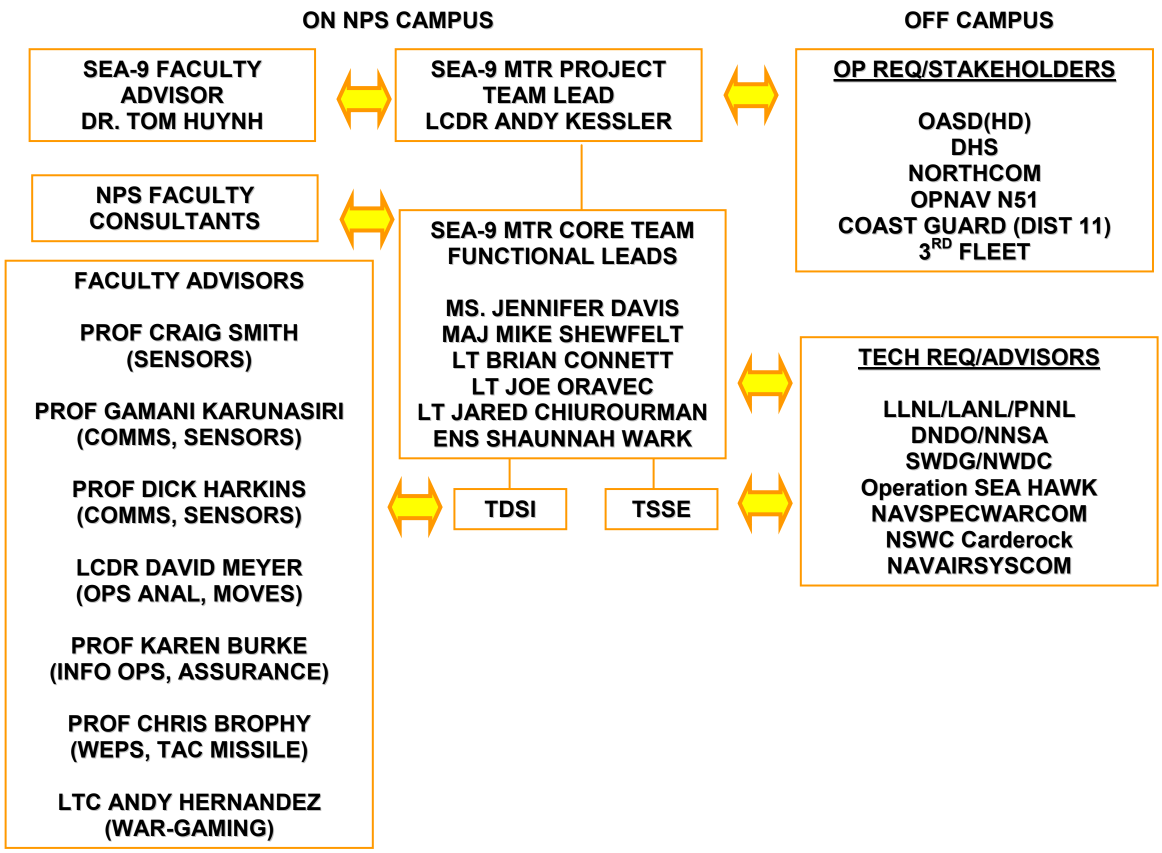

Figure 2-1: Overall MTR Project Organization

2.4.1 MTR Core Team

The SEA-9 MTR core team consists of seven students. Outside of the MTR core team, individuals and organizations providing supporting work to the MTR project are considered subcontractors. The MTR core team is responsible for the designing the SoS, the final report and the final presentation. Subcontractors, in the form of TDSI and TSSE students, are responsible for subsystem-level and component-level designs in support of the overall system architecture. The organizational structure and relationships between MTR core team and supporting organizations is depicted in Figure 2-2.

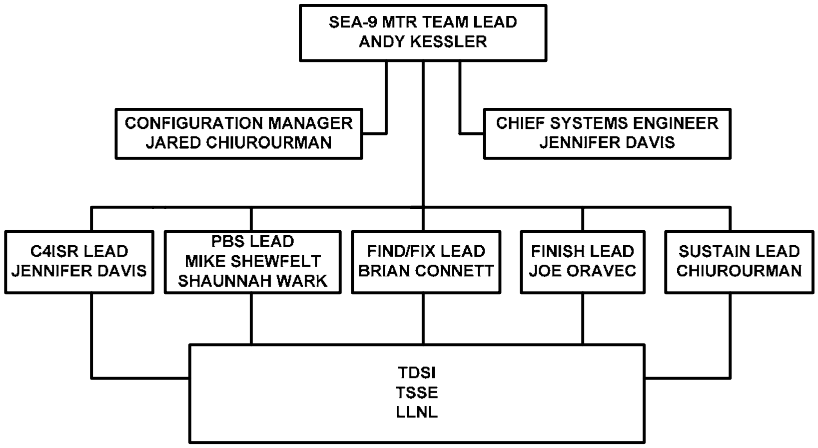

Figure 2-2: MTR Internal Organizational Chart

2.4.2 Internal Interfaces

The following internal customers interact directly with the MTR core team:

- NPS Meyer Institute — Dr. Frank Shoup
- SEA-9 MTR Faculty Advisor — Dr. Tom Huynh
- LLNL Visiting Professor/MTR Nuclear Advisor — Dr. Craig Smith
- TDSI Faculty Advisors
  - Communications and Sensors — Dr. Gamani Karunasiri
  - Communications and Sensors — Prof. Dick Harkins
  - Operations Analysis and MOVES — LCDR David Meyer
  - Information Operations/Assurance — Prof. Karen Burke
  - Weapons and Tactical Missiles — Dr. Chris Brophy

2.4.3 External Interfaces

SEA-9 interfaces with numerous external sources to ensure a solid perspective on each entity's contribution and limitation within the realm of MTR. Such interfaces include, but are not limited to, USCG, Customs, DoD, DoN, FBI, Local Maritime Patrol Agencies, Local Police, and FEMA. The primary external customers are NORTHCOM, Office of the Secretary of Defense for Homeland Defense, OPNAV N51, and Department of Homeland Security.

The following external agencies were identified:

- Project SEAHAWK, Charleston, SC

- COMTHIRDFLEET, San Diego, CA
- USCG District 11, San Francisco, CA
- NAVAL WARFARE DEVELOPMENT COMMAND, Newport, RI
- NAVAL SURFACE WARFARE CENTER CARDEROCK DIVISION, Detachment Norfolk, VA
- MARITIME FORCE PROTECTION COMMAND
- COMMANDER FLEET FORCES COMMAND, Norfolk, VA
- NAVAL AIR SYSTEMS COMMAND, Pawtuxet River, MD
- DOMESTIC NUCLEAR DETECTION OFFICE, Washington, D.C.
- NATIONAL NUCLEAR SECURITY ADMINISTRATION, Washington, D.C.
- SURFACE WARFARE DEVELOPMENT GROUP, Little Creek, VA

Dialogue with these organizations continues throughout the project such that stakeholder input, feedback, and buy-in are appropriately incorporated into the MTR SoS architecture.

2.5 MANAGEMENT APPROACH

The SEA-9 MTR team applied the project management methodology espoused by Mooz and Forzberg.[4] In this methodology, ten elements work in combination to help successfully orchestrate the project team and develop a quality product. First, the core team focused on the "project requirements" and "project planning" elements. For the initial step, the core team researched and attempted to fully understand customer needs and wants. The team established contacts with and regularly consulted various on-campus subject matter experts and advisors, as well as appropriate personnel within the DoD. These conversations helped both to bound the MTR problem statement and guide the team's work, as well as establish proper expectations within the most likely final briefing audience. Next, the team quantified the desired end state of the project by reviewing past SEA project reports and presentations, especially looking for any lessons learned by former project advisors and team members that could help identify and

[4] Kevin Forsberg, Hal Mooz, and Howard Cotterman, *Visualizing Project Management: Models and Frameworks for Mastering Complex Systems*, 3rd Edition, 2005, John Wiley & Sons, Inc., Hoboken, NJ.

mitigate project risks. The desired end state was captured as a list of elements to be covered in the final deliverable presentation and report, and from here, the list of work tasks that need to be completed to reach the desired end state was developed. The work task list included all program management and system engineering tasks required to complete the conceptual design of an SoS architecture. This became the initial Work Breakdown Structure and helped identify areas that could be tasked out to TDSI, as well as other interested cross-campus participants, any risks to project completion, and a realistic project schedule. All of the preceding activities contributed to the writing of the final PMP and SEMP.

As MTR project planning documents were developed, the core team also considered and incorporated the remainder of Mooz and Forsberg's ten elements of project management: organization options, project team, opportunities and risks, project control, project visibility, project status, and corrective action. In organizing the project team, the goal is to best structure the project for success. In the MTR project team, each SEA core team member was assigned certain main managerial-type roles, as well as one or more collateral duties. One student served as the project manager, one, the chief systems engineer, one, the project planner, one, the configuration manager, and so on. During scenario development for the DRM analysis, the overall team lead assigned a lead to each scenario, as well as supporting personnel. Following top-level functional analysis, team members were assigned to each top-level function. For the project team element, although the core SEA project team and TDSI support were already defined, the MTR team recruited participation from critical specialty students, such as TSSE and operations research, across campus. The team worked to identify any new technologies that could be applicable to the conceptual architecture. Any schedule risks previously identified, plus the risks inherent in cross-campus or off-campus participant product delivery, were mitigated through scheduled triggers and fall-back plans. The completed master schedule was given a prominent position in the team meeting room to increase project visibility for all involved. All team documents were posted to the MTR SharePoint Website, which facilitates version control and history-keeping. Minutes are recorded during all team meetings, which will occur weekly, and the master schedule, the

PMP, and the SEMP are used to track actual performance against the plan. Corrective actions are developed and implemented at the early stages of variance from plan.

The final critical project management element is leadership. The MTR core team subscribed to Theory Y leadership, believing that all teammates want to put in a reasonable level of effort to make the project a success. The team capitalized on members' strengths when making roles and task assignments, as well as respecting personal interests and striving to place team members in the additional roles that most intrigued them. With the project sufficiently bounded by plans, schedule, and a statusing method that are in keeping with the Mooz and Forsberg's ten elements of project management, the team was encouraged to take ownership and be creative within the pre-established boundaries.

2.5.1 Project Life-Cycle

An overview of the project life cycle (based on Mooz, p. 92-95) is depicted in Table 2-1. It is important to note that the MTR SoS design is conceptual in nature and does not result in the manufacture of any actual system.

Planned Start Date	Planned End Date	Key Activities
November 2005	December 2005	Advanced Planning/Research Phase
January 5, 2006	January 23, 2006	Finalize SEMP/TEMP/WBS; Needs Analysis; Feasibility Analysis
January 12	January 12	MTR Internal Team Kickoff Meeting
January 24	February 15	Requirements Development and Analysis
January 31	February 7	Functional Analysis
February 16	February 16	Initial Project Review
February 16	March 22	Analysis of Alternatives
March 16	March 16	Preliminary Design Review
March 23	April 24	Architecture Evaluation and Ranking
April 27	April 27	Critical Design Review
April 15	June 16	Final Deliverables editing
May 24	May 24	Final Project Review

Table 2-1: Project Deliverables Schedule

2.5.2 Staffing

The director of the Meyer Institute is responsible for assigning an Academic Advisor for the project and for formally assigning the students to the project. The students assigned are responsible for electing a lead who acts as the Project Manager for the group. TDSI Academic Advisors are responsible for assigning TDSI students to the project. Student project component staffing is conducted by the Project Manager, with the

Chief Systems Engineer approval. Academic Advisor comments on staffing as required, but the Project Manager has final say.

2.5.3 Communication

Open communication is authorized and encouraged by all members of the team and sub-contractors. The Project Manager is informed and provides authorization for communication involving assignment of responsibility outside of the SEA-9 MTR core team. All external communications are made available to the entire team to ensure continuity and focus of effort.

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3.0 SYSTEMS ENGINEERING APPROACH

3.1 INTRODUCTION/OVERVIEW OF SYSTEMS ENGINEERING APPROACH

The desired final products of the MTR project are an SoS architecture and an associated concept of operations (CONOPS) for responding to maritime threats. In order to develop this architecture, a systems engineering approach is employed, which provides structure, thoroughness, and unity to the design effort.

As depicted in Figure 3-1, the MTR design effort is divided into three main phases, each culminating in a design review. The three phases are called Conceptual Design, Preliminary Design, and Final Design. It is important to understand that the particular names selected for the different MTR phases should not be used, in and of themselves, to infer anything about the detail of the design and the particular type of products produced during that phase. The Design Activity Boxes depicted on the right-hand side of Figure 3-1 list the pertinent design activities for each phase. The three design reviews are the Interim Progress Review, Preliminary Design Review, and Critical Design Review. Review feedback is incorporated into the design and used to refine the design products of all preceding phases. The first step in any design process is to investigate and discover the critical mission needs. These needs initiate the design process by defining the nature of the problem to be solved, as well as the criteria by which all final architectures are judged.

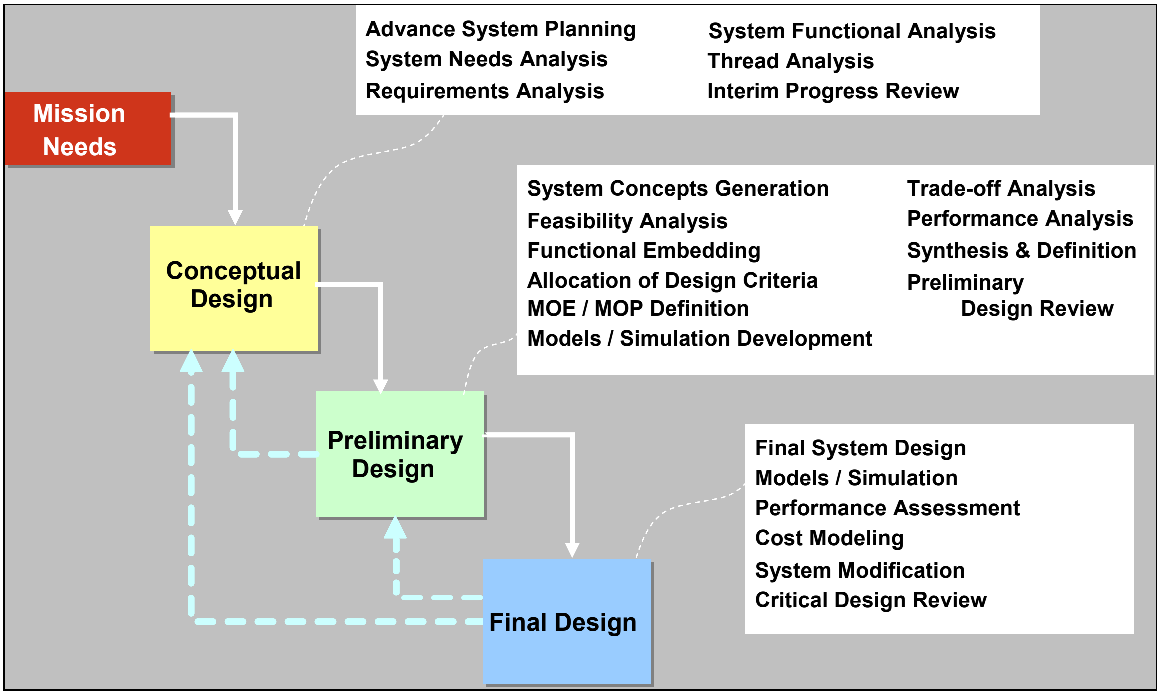

Figure 3-1: MTR Systems Engineering Approach

3.2 CONCEPTUAL DESIGN

The MTR SoS design effort begins with the Conceptual Design phase. This phase is preceded by a preliminary planning phase, meaning that a project planning revision and updating effort called Advance System Planning is necessary once the System Needs Analysis is completed. The plans developed include a project management and systems engineering management plan, as well as the project schedule and personnel tasking.

Problem definition goes hand in hand with System Needs analysis. In this project, the needs of the stakeholders are identified with the aid of national strategy documents.[5, 6] The problem statement, including terrorist threats that the MTR SoS would neutralize, is formulated and then refined and validated with information obtained from face-to-face interviews of stakeholders.

Also through stakeholder interviews, the design reference mission scenarios are developed, followed by Requirements Analysis. From the stakeholder needs and design reference mission, the operational requirements are derived and then used in the

[5] White House, The National Security Strategy of the United States, (2006).
[6] White House, The National Strategy for Maritime Security, (2005).

development of functional requirements, which state the functions that the system must do, as well as quantitative performance requirements, which establish how well the system must be able to perform these functions. During the MTR conceptual design phase, the top-level requirements and second level functional requirements are derived. A thread analysis is performed to establish the interfaces among the functions themselves and with the outside environment. As described in Chapter 6.0, the thread analysis is the evaluation of the system functions with respect to a given scenario or mission, which ensures that the system meets the functional requirements set by the user. The thread analysis also aids in the understanding and establishment of system boundaries, at times precipitating modification or reorganization of system functions, and in the modeling of the SoS.

3.3 PRELIMINARY DESIGN

Functional decomposition continues in the Preliminary Design phase. All top-level functions are decomposed to the lowest level possible to facilitate the assignment of appropriate resources. In order to determine the utility of a particular resource assignment, the Measures of Effectiveness and Measures of Performance established as part of Operational Requirements definition are finalized and allocated in the form of quantitative performance requirements to the lower levels of functional decomposition.

In order to develop the physical view of the SoS architecture, system concept alternatives are identified for each SoS function. This assignment of resources to perform one or several functional requirements is called Functional Embedding. Alternative concepts are then assessed for feasibility and performance via modeling and simulation. The models are both analytic and probabilistic; the simulations are event-driven.[7] Concept alternatives that are found to be acceptable (i.e., meet the requirements) are considered as part of the SoS. Thus, SoS Design Alternatives include all the possible combinations of system concept options corresponding to the SoS top-level functions. As discussed in Section 7.1.2.1, there are more than 3,000 possible combinations. In order to test a manageable number of alternatives and select the optimal architecture,

[7] Imagine That, Inc., "EXTEND™ Version 6 User's Guide," 2002, pp. E106-108.

orthogonal array experiments (OAE) are performed, followed by the so-called Taguchi data analysis.[8]

3.4 FINAL DESIGN

As detailed in Section 7.1.2, two different approaches are used to arrive at the final candidate SoS architectures: (1) objective, experiment-driven analyses to select an architecture based on a fractional experiment design, and (2) a subjective, bottom-up approach focusing on cost-effectiveness. Both function-specific as well as mission-specific models are used to determine the SoS performance for each of the OAE trials, which represent 32 SoS design alternatives. Performance of each design alternative is quantified in terms of time required, probability of success, and incurred delay and damage cost. SBA mission performance is further assessed via wargaming. The insights gleaned from the simulation efforts are used to refine and optimize the recommended force structure. Lastly, cost is calculated for each SoS alternative, as described in Section 7.4. Cost is combined with performance, and the resulting cost-effectiveness measure is the ultimate criterion used in the selection of the recommended SoS architecture.

The three final candidate architectures are the Maximum Performance architecture, the Bottom Up Cost Effective (BUCE) architecture, and the Top Down Cost Effective (TDCE) architecture. The Maximum Performance architecture disregards cost and seeks only to provide the best possible performance. The BUCE weights cost and performance equally at the system level, while the TDCE weights cost and performance equally at the system of systems level. As detailed in Section 7.5, the TDCE is the recommended MTR SoS architecture, because it provides the largest expected return (in terms of performance) on investment.

3.5 SOS ARCHITECTING METHODOLOGY

3.5.1 Purpose/Overview

The stakeholder needs reveal that the MTR design is a SoS problem. In an SoS problem, existing platforms or programs of records are used in new combinations or ways

[8] R.K. Roy, "A Primer on the Taguchi Method," New York: Van Nostand Reinhold, 1990.

in order to provide a capability that has not previously existed. National strategy documents[9, 10] indicate that the MTR SoS should be low cost, minimize delay to commerce, and maximize the use of existing DoD and DHS platforms. Figure 3-2 depicts the SoS architecting methodology[11] selected for the MTR project. This methodology provides amplification of the activities in Figure 3-1 that pertain to SoS architecting.

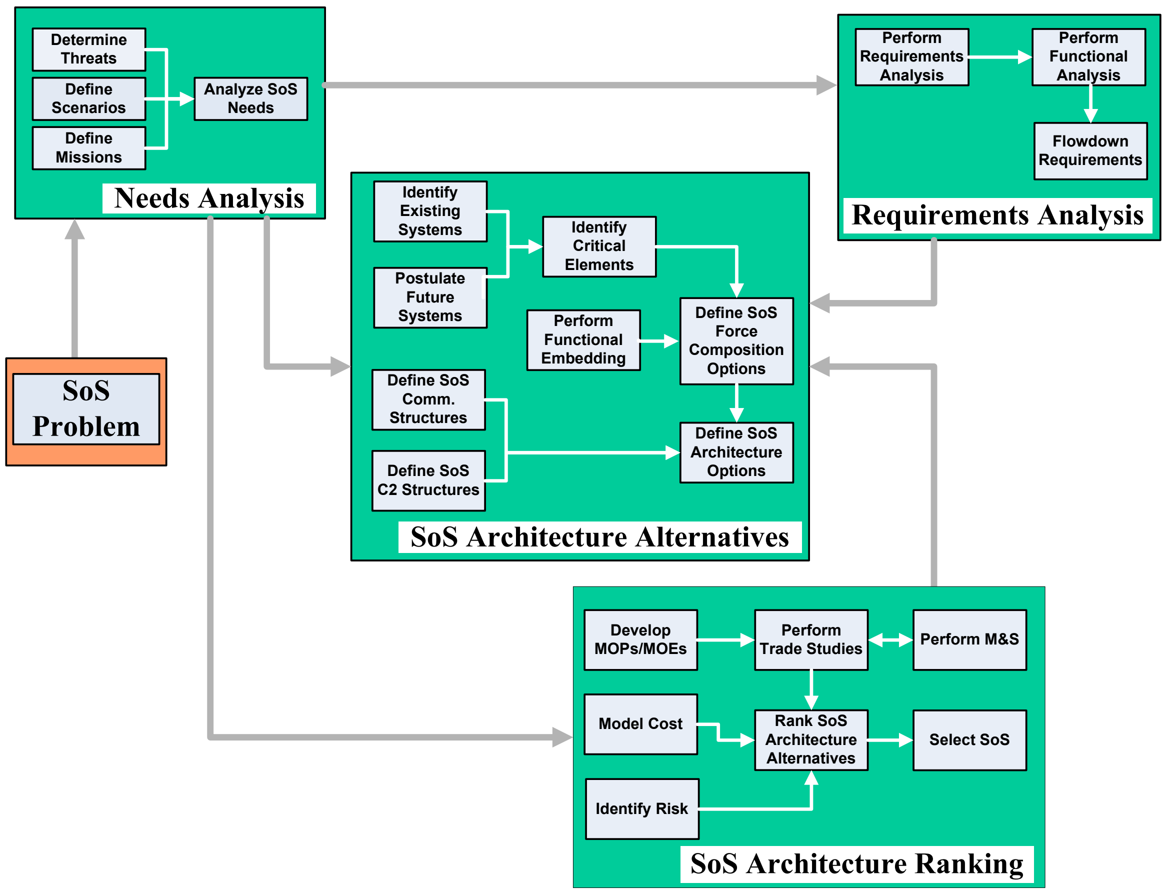

Figure 3-2: MTR SoS Architecting Methodology

The SoS architecting methodology depicts the key sub-processes and process relationships that lead to an SoS design. The key design processes are Needs Analysis, Requirements Analysis, Development of Architecture Alternatives, and Architecture Ranking. The results of Needs Analysis are input to the other three design processes:

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9 White House, "The National Security Strategy of the United States," 2006.

10 White House, "The National Strategy for Maritime Security," 2005.

11 T.V. Huynh, "Architecture Engineering Methodology," SI4001, Department of Systems Engineering, Naval Postgraduate School, Monterey, CA, 2005.

Requirements Analysis, Architecture Alternative development, and Architecture Ranking. Requirements Analysis provides input to Architecture Alternative Development, while the Architecture Alternative development process and Architecture Ranking process both provide results to, and accept inputs from, each other. Note that this diagram has no time domain; activities can happen concurrently and iteratively.

3.5.2 Problem Definition

The problem is defined by identifying and quantifying upstream design influences. In the case of MTR, these influences included strategy and policy documents, the likely terrorist threats, the need to work in concert with existing DoD and DHS assets, the tight defense budget, and the need to avoid delaying the normal flow of maritime commerce. Refer to Section 2.1 for the MTR problem statement. Because existing assets will be used to provide a new capability, developing an MTR architecture is an SoS problem, setting in motion the process depicted in Figure 3-2.

3.5.3 Needs Analysis

SoS Needs are derived from threats, scenarios, and missions. During Needs Analysis, the spectrum of potential maritime terrorist threats is researched and catalogued. Three of these threats are selected for study and a scenario is developed concerning each of them. The three representative threat scenarios for the MTR project are a WMD smuggled onboard an unsuspecting container ship, a merchant ship used as a weapon (SAW) to attack critical infrastructure on the approaches to and within San Francisco Bay, and an SBA against a high-value, commercial shipping unit within San Francisco Bay. Representative commercial ships and area of operations for each scenario are displayed in Figure 3-3. Once the scenarios are defined and vetted with stakeholders, the SoS missions are postulated to counter the terrorist threats. These three missions bound the MTR SoS design, and from them, the full scope of SoS needs is determined. Detailed information on the MTR design reference missions and their development is provided in Chapter 4.0.

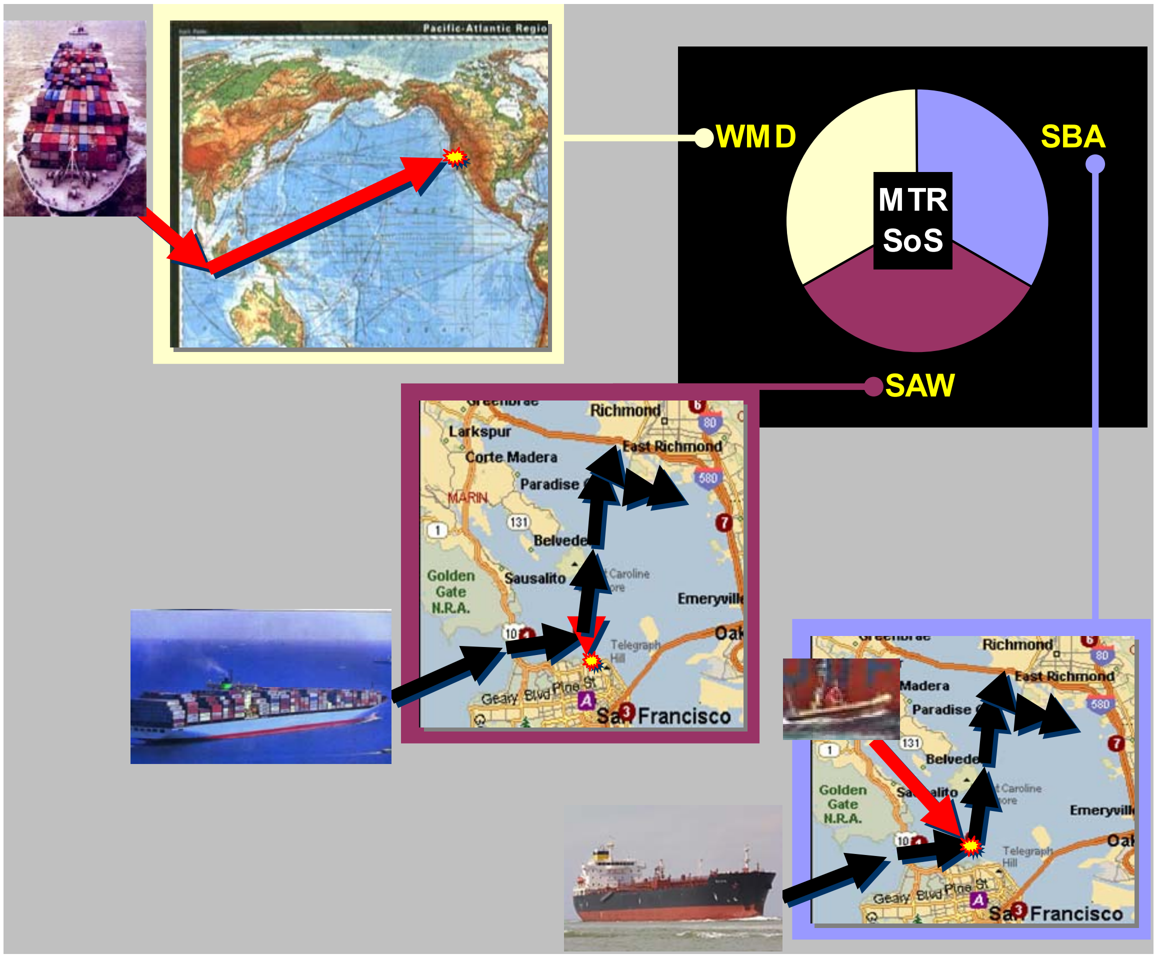

Figure 3-3: MTR Mission Scenarios

3.5.4 Requirements Analysis

The Requirements Analysis process includes defining operational, functional, and quantitative performance requirements. The operational requirements are derived directly from the SoS mission needs, while the functional requirements are derived from the operational requirements. This progression is depicted graphically in Figure 3-4, which shows the three MTR missions at left leading to operational requirements definition, and operational requirements in turn leading to the five top-level capability requirements shown at bottom right: C4ISR, Prepare the Battlespace, Find/Fix Threat, Finish Threat, and Sustain.

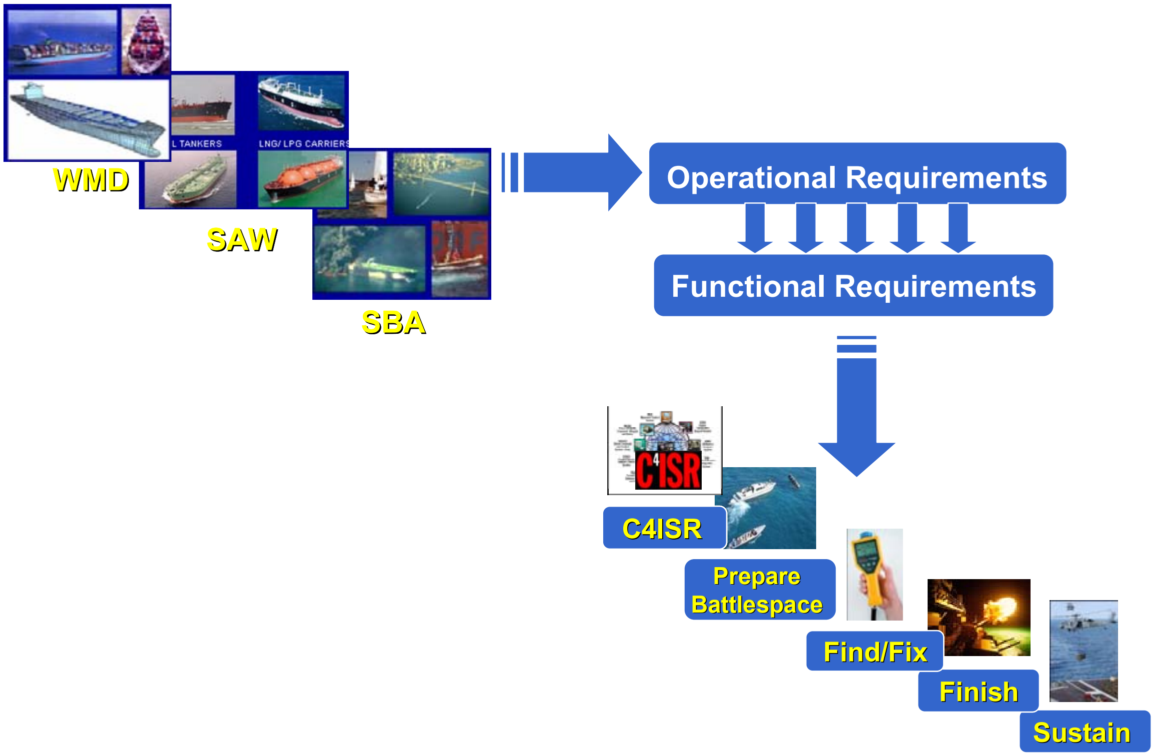

Figure 3-4: Requirements Analysis Process

The operational requirements are defined for each mission scenario and include the following categories: mission profile, operational distribution, performance parameters, utilization requirements, effectiveness requirements, life cycle horizon, and operating environment.[12] The requirements derived for the three MTR missions are displayed in Figure 3-5.

[12] B.S. Blanchard and W.J. Fabrycky, *Systems Engineering and Analysis*, 3rd Edition, Prentice Hall, New Jersey, 1981, pp. 50-52.

Scenario	WMD	SAW	SBA
Mission Profile	Neutralize WMD device outside 100 NM	Neutralize PAV by 15 NM or retake prior to impact	Prevent damage to vessels or infrastructure
Operational Distribution	Pacific Ocean 3 shipping routes 20 (6000 TEU) PAV	10 terrorists onboard Approach and within San Francisco Bay	San Francisco Bay 13 HVU (merchant & ferry) 1 attacking small boat
Performance Parameters	Time to intercept Search time Search P_D	Terrorist neutralize time Time to control ship	Time to detect Time to neutralize small boat
Utilization Requirements	1 → 20 day duration 24/7 availability	1 → 20 day duration 24/7 availability	1 → 30 day duration 24/7 availability
Effectiveness Requirements	95% P_S $$ impact on commerce System cost	90% P_S $$ impact on commerce System cost	88% P_S $$ impact on commerce System cost
Life Cycle Horizon	Average 10 years	Average 10 years	Average 10 years
Environment	Open Ocean Holding Area	Littoral and Port Poor visibility	Congested Port Poor visibility

Figure 3-5: MTR SoS Operational Requirements

The top-level functions along with their corresponding embedded subfunctions are presented in nested N^2 diagram format in Figure 3-6. N^2 diagrams are selected to represent the fact that with "N" subsystems, there are N^2 possible interfaces between these subsystems. Thus, the use of this format reinforces the required focus on interfaces necessary to successful SoS architecting. The MTR top-level functions are C4ISR, Prepare the Battlespace, Find/Fix Threat, Finish Threat, and Sustain. For each top level function, there are two or more lower-level functions that enable its accomplishment. These subfunctions are further decomposed into their component capabilities. Functional decomposition down to the fourth level is presented in Section 5.1.2, and the complete MTR functional decomposition is provided in Appendix A.

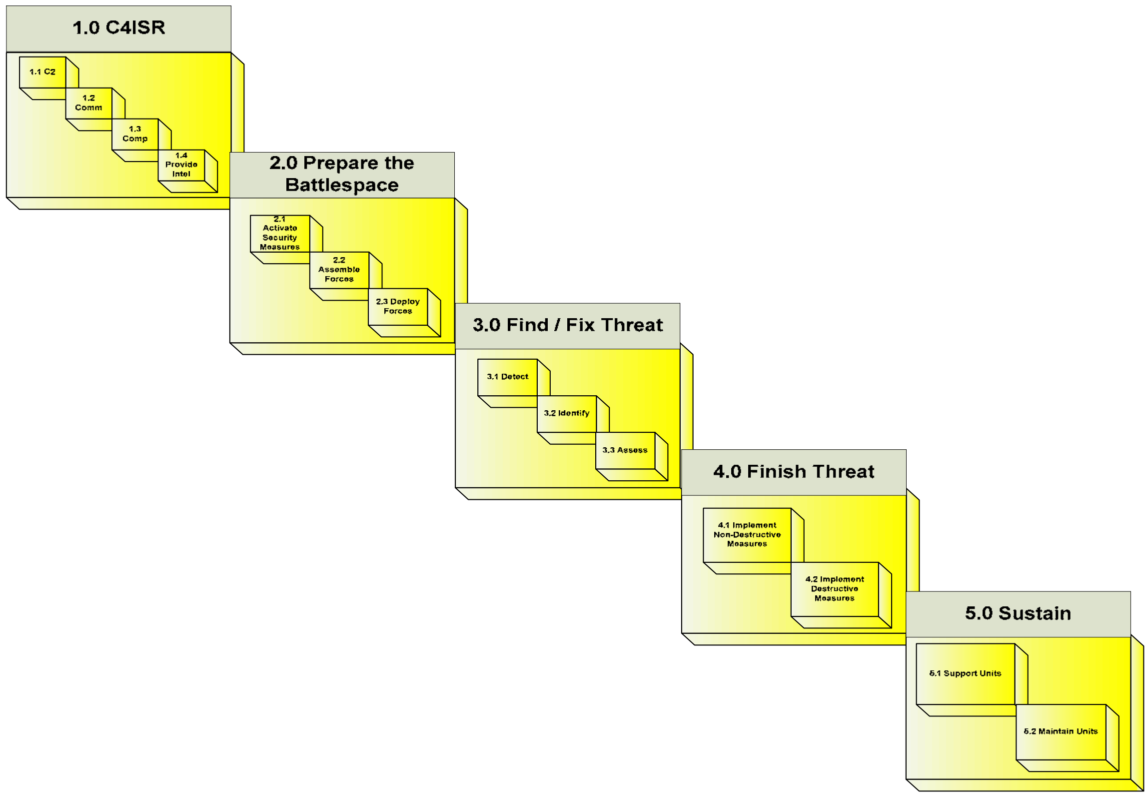

Figure 3-6: MTR Top-Level Functional Requirements

The quantitative requirements allocated each top-level function within the context of each mission are presented in Figure 3-7. The probability of success for each mission is developed for the operational effectiveness requirement, and the required contribution of each top-level function in order to achieve this effectiveness is then defined in terms of both response time and probability of success. Derivation of the overall system effectiveness requirements is detailed in Section 5.2.1, and the allocation process to lower levels of functional decomposition is described in Section 5.2.2. The complete requirements allocation for both time and probability of success is provided as Appendix B.

Function \ Scenario	WMD 0.95	SAW 0.90	SBA 0.88
C4ISR	◆ Process time NMT 24 hrs	◆ Process time NMT 30 min (depending on intelligence latency)	◆ Process time NMT 1 hr
PBS	◆ Assemble teams and deploy vessels in less than 24 hrs	◆ Assemble teams and deploy vessels in less than 24 hrs ◆ Alert team with Pilot	◆ Immediately start clearing non-essential boats ◆ Assemble crews and deploy escort vehicles in less than 1 hr
FIND/FIX	◆ Search 9400 TEU ship in less than 160 hr ◆ $P_d \geq 0.96$ $P_{FA} \leq 10^{-6}$ ◆ Dwell time ≤ 3 min per container	◆ Determine PAV status upon boarding ◆ Search PAVs with Escort teams given time	◆ Detect incoming small boats at sufficient range to allow warning, ID, and two shots prior to VA ◆ $P_S \geq 0.94$
FINISH	◆ Transfer to DoE JTO	◆ Disable PAV ≤ 21 min ◆ Sink PAV ≤ 21 min ◆ $P_S \geq 0.91$	◆ Defeat attack within 15 seconds ◆ $P_S \geq 0.94$

Figure 3-7: MTR Top-Level Function Performance Requirements

3.5.5 Architecture Alternatives Analysis

First, the existing DoD and DHS systems that can meet the requirements are identified. Both command and control (C2) and communications structures and concepts are defined within the C4ISR function. Force Composition concepts are defined to satisfy the combination of PBS, Finish, and Sustain functional requirements.

When either systems do not already exist in the DoD or DHS portfolio of platforms or the performance of existing systems does not meet the MTR requirements, future systems are postulated. This is the nature of gap analysis, which is performed for each of the top-level functions. The need for a near-term MTR SoS solution, where "near-term" is operationally defined as deployable within the next five years, dictated that gaps be filled with Program of Record or commercial off the shelf (COTS) concepts, if they exist. The gaps are identified for the C4ISR, PBS, Find/Fix, and Finish top-level functions. All postulated systems are assessed for feasibility and are described in Section 7.1.1.

3.5.6 Architecture Ranking

Critical performance parameters are identified and selected as a part of the operational requirements definition. These parameters, the Measures of Performance (MOPs), reflect the performance of the system functions and are flowed down to the lower level functions. The MTR Measure of Effectiveness (MOE) is the combination of (1) the costs associated with system procurement, operations, sustainment, and delay/damage, and (2) the probability of success in the available time window. It is a type of cost effectiveness,[13] where the figure of merit is the SoS probability of success divided by the total cost of SoS procurement, operations and support, and delay and/or damage to commercial shipping or critical infrastructure.

In order to determine the optimal SoS architecture, the different combinations of system concept alternatives are assessed against the MOPs and MOE. This assessment is performed via modeling and simulation, where modeling is both analytical and probabilistic. Since the number of possible system concept alternative combinations exceeds 3,000, and orthogonal array experiment (OAE) is utilized to reduce the number of combinations tested with no degradation in final results. Refer to Section 7.1.2 for complete details on this approach.

Performance of each OAE trial within the context of each mission scenario is estimated via modeling and simulation, as detailed in Section 7.2. Trade studies are conducted with the aid of simulative A Monte Carlo Analysis in order to compare the performance of different SoS architectures. Each OAE trial is costed as described in Section 7.4. Briefly, all system concept alternatives are assessed for procurement, operation, and support cost incurrence. Procurement is incurred for new systems or for additional copies of existing systems that are not programmed in the DoD/DHS budget. Operating and support costs are incurred for the expected time during which the assets would be involved in MTR-related activities during a one-year period. Note that technical risk is avoided by using existing hardware and software technology for MTR SoS components and is thus not a consideration in the ranking.

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[13] B.S. Blanchard and W.J. Fabrycky, *Systems Engineering and Analysis*, 3rd Edition, Prentice Hall, New Jersey, 1981, p. 360.

As previously discussed in Section 3.4, the final candidate architectures are the Maximum Performance, TDCE, and BUCE, and the final recommended architecture, which provides the highest expected return on investment, is the TDCE. Section 7.1.2 contains a complete description of the development and the contents of all three candidates, while Section 7.5 provides final selection rationale.

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4.0 DESIGN REFERENCE MISSIONS

Identification of relevant missions and creation of thorough and realistic scenarios are an integral part of the needs and requirements analysis phases of the systems engineering process.[14] SEA-9's study considers three representative missions for a conceptual MTR SoS: prevention of a nuclear WMD attack, prevention or defeat of an attack using a merchant ship as a WMD, and defeat of a suicide boat attack on a high-value target (such as an oil tanker or passenger ferry).

4.1 MISSIONS

These missions are derived directly from threats and threat scenarios that appear in the Homeland Security Council's *Planning Scenarios* document.[15] They are also based on previous terrorist attacks and commonly postulated future attacks.[16] The design reference missions are the result of significant research and stakeholder input. The three missions span a full spectrum of threats and consequences and require different forces and CONOPS. The three missions present a significant challenge to a maritime SoS.

The current *National Strategy for Maritime Security* lists three broad strategic principles to guide national effort in maritime security. They are: preserve freedom of the seas, facilitate and defend commerce, and facilitate the movement of desirable goods and people across borders while preventing the movement of undesirable goods or people. It also states that the United States will prevent terrorist acts by ". . . stopping such activities at any stage of development or deployment . . . *preferably overseas*."[17] It emphasizes five strategic actions to support the strategic principles:

1. Enhancing international cooperation
2. Maximizing domain awareness

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[14] For example, see B. Blanchard and W. Fabrycky, *Systems Engineering and Analysis* (3rd Edition); Defense Acquisition University, *Systems Engineering Fundamentals*; INCOSE and AIAA, *Systems Engineering*; or U.S. Air Force Space and Missile Systems Center, *Systems Engineering Primer and Handbook* (2nd Edition).

[15] David Howe, *Planning Scenarios*, The Homeland Security Council, July 2004.

[16] See D. Eberhart, "Container Ships: The Next Terrorist Weapon?" www.newsmax.com; "Peril on the Sea," *The Economist*, 2 October 2003; and John Fritelli et al., *Port and Maritime Security: Background and Issues*, Novinka Books, 2003.

[17] *National Strategy for Maritime Security*, pp. 8-9.

3. Embedding security into commercial practices
4. Deploying layered security
5. Assuring continuity of the marine transportation system[18]

The SoS architectures reflect an amalgamation of the eight goals above into two principles of maritime and homeland defense. The two principles are:

1. Meet and defeat threats as early as practicable
2. Operate with minimum impact on commerce

These two principles are the primary customer requirements affecting the architectures and CONOPS developed for MTR. The primary customer need is to accomplish the three missions described above.

The San Francisco/Oakland major metropolitan area (MMA) has numerous features that make it an attractive target for terrorist attacks. The Bay area has a combined population of 3.2 million.[19] It attracts over 11 million visitors and tourists each year. It is the second-largest container port in California and the fourth largest in the nation. The combined ports of San Francisco, Oakland, and Richmond receive an average of ten overseas merchant vessels daily, primarily crude oil tankers and container ships.[20] There are also numerous points of critical infrastructure on or near the Bay.

The Golden Gate Bridge, connecting San Francisco to the Marin peninsula, is one of the nation's premiere landmarks and one of the most famous bridges in the world. The San Francisco-Oakland Bay Bridge is a vital economic connection between the two cities. There are other large public transportation systems and hubs (as expected of any MMA), including two large airports, numerous ferries, rail lines, and three other bridges of significant size. Any action that would curtail or stop transportation in the Bay area would have significant economic impact estimable in billions of dollars.[21] In addition, a large explosion, fire, or chemical cloud at the Fisherman's Wharf waterfront tourist area

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[18] *National Strategy for Maritime Security*. The White House, September 2005.

[19] 2004 estimate. Source: www.demographia.com; from 2002 U.S. Census Bureau data.

[20] Randy Young, "Baseline Study of U.S. Port Merchant Ship Traffic During 2004," Office of Naval Intelligence, 31 August 2005. Unclassified/For Official Use Only.

[21] Staff, "Port Shutdown for Terrorist Incidents Could Cost Billions, Drill Shows," *CQ Homeland Security*, 5 December 2002. Bruce Arnold et al., "The Economic Costs of Disruption in Container Shipments," Congressional Budget Officer, 26 March 2006.

has the potential for mass casualties and the "cinematic" effect that Al-Qaeda and other groups pursue.[22]

The San Francisco/Oakland MMA is also relatively isolated from large military concentration areas, particularly naval assets. The two West Coast fleet concentration areas are San Diego and Seattle. The main assets for *immediate* maritime defense are therefore USCG units already in the Bay area. This is not to say that USCG assets are not capable of performing MTR missions, but rather to highlight that assistance may be several *days* in arriving. Even USCG PACAREA and District 11 assets are spread from the Oregon to Mexican borders.

4.1.1 WMD Mission

The use of a WMD to attack American citizens is the undeniable "worst case scenario" of homeland defense. The WMD threat occupies a central place in all homeland defense strategy, planning, and research literature. The *National Strategy for Maritime Security* states "**Preeminent among our national security priorities is to take all necessary steps to prevent WMD from entering the country and to avert an attack on the homeland**."[23] Eight of the 15 Department of Homeland Security *Planning Scenarios* involve WMD of some type. A nuclear detonation in a major American city may cause tens of thousands of deaths, hundreds of thousands of casualties, and hundreds of billions of dollars in damages.[24]

A WMD can be brought into the United States by many methods. One of the most commonly mentioned is by standard cargo container.[25] Millions of such containers enter the United States every year. A very small percentage are actually opened and inspected. Cargo control procedures and security methods are generally poor, particularly at certain overseas locations.[26] Inspections of containers after they have

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[22] Fisherman's Wharf hosted approximately 10 million visitors in 2004. A calculation shows that 50% of the visitors arrived on a weekend would result in an average of approximately 52,000 visitors per weekend day and 18,500 visitors per weekday. Almost all of these people would be compressed into an area of a few city blocks, and the number would be larger when local employees and commuters are added.

[23] *National Strategy for Maritime Security*, p. 7. Emphasis in original.

[24] There are many works on nuclear terrorism. SEA-9's most common reference was Graham Allison's *Nuclear Terrorism: the Ultimate Preventable Catastrophe*, Times Books, New York, NY. 2004.

[25] See Allison, Eberhart, and Fritelli, among others (op. cit.).

[26] See Fritelli (op. cit.) and Fred Evans, *Securing the Nation: Maritime and Port Security*, Chelsea House Publishers, 2004.

arrived in the United States do not meet the two principles of the MTR system. Smuggling a WMD into the United States is by no means limited to containers or container vessels; it is, however, a viable method. It also presents a challenging systems engineering problem.

The WMD scenario fills the “middle ground” that lies at the intersection of intelligence and threat response. If one postulates that information concerning a smuggled WMD becomes available, and that the information is specific to a particular ship, then capabilities exist to counter the threat. If one postulates that the intelligence system will produce no specific information concerning a smuggled WMD, then it is highly unlikely that a device could ever be found. The only option in such a case is to close all ports and borders—which will disrupt commerce on a massive scale. The scenario postulates that some specific information concerning origin and time of departure of a smuggled WMD is available, but not enough is available to allow identification of a single vessel. Instead, a group of twenty potential attacking vessels is identified.

The device is presumed to be in a legitimate container on one of the twenty ships. The insertion of the device into the container is undetected by port authorities or the originating company and the ship’s crew is oblivious to its presence. Therefore, there is no obvious “paper trail” to aid in the location of the device. No terrorist is onboard to help “shepherd” the device to its destination.

The scenario considers two types of nuclear devices. The first is a nuclear device using an IAEA-significant amount of either enriched uranium (greater than 25 kg) or Plutonium-239 (greater than 8 kg). The second device is a Radiological Dispersion Device (RDD) or “Dirty Bomb.” It is composed of a small amount of Cesium-137, Americium-141, Strontium-90, or Cobalt-60 wrapped around approximately 100 pounds of conventional explosive. Both devices are shielded in either a square lead container of 0.635 cm to 5.08 cm uniform thickness or by 128 cm of high-density nitrogen.

The nuclear device’s characteristics were used to determine a likely area of lethal effects which incorporates thermal radiation, gamma and neutron radiation, blast (overpressure), and likely fallout patterns.

The threat in this scenario can be summarized as follows. A nuclear WMD is in a container located on one of 20 container vessels. The 20 vessels have departed a common Far East port within a 24 to 48 hour period. The vessels are all bound for the United States. The ship's crews and owners are unaware of the nature of the cargo. There are no terrorists onboard the ship and the ship's crews and owners are expected to cooperate with friendly forces when approached.

4.1.2 SAW Mission

A hijacked ship used as a WMD is a commonly postulated maritime threat.[27] A small number of hijackers (less than the combined number of hijackers on September 11th) with appropriate training could control almost any modern merchant vessel. The largest modern merchant ships are equal to or larger in size than a modern aircraft carrier. Such a vessel, used as a weapon or used in combination with some dangerous cargo, is a formidable threat. Particularly vulnerable are the large suspension bridges and waterside infrastructure of the Bay area. This type of attack has been commonly characterized as "September 11th at sea."

There are several historical precedents for envisioning ships used as weapons. On 6 December 1917, the French ammunition ship *Mont Blanc* exploded in the harbor of Halifax, Nova Scotia. The resulting explosion and fire killed (approximately) 1,900 people, injured 9,000 others, and damaged or destroyed 1,600 buildings.[28] On 16 April 1947, the French ammonium nitrate carrier *S.S. Grandcamp* exploded at the pier in Texas City, Texas, after an onboard fire. This explosion, estimated to equal the yield of a two- to four-kiloton nuclear device, killed 581 and injured 5,000. The resulting fire caused the destruction of two additional merchant ships near the *Grandcamp*, and the resulting conflagration burned the city for a week. The blast threw the ship's anchor, which weighed 3,000 pounds, over two miles.[29]

On 27-28 March 1942 British forces loaded the WWI-era destroyer HMS *Campbelltown* (ex-USS *Buchanan*) with four tons of explosives and rammed her into the St. Nazaire dry dock as part of an extensive special operations mission.

[27] Eberhart, op. cit.
[28] www.cbc.ca/halifaxexplosion
[29] en.wikipedia.org; www.texas-city-tx.org

Disguised as a German gunboat, the ruse was detected as the *Campbelltown* entered the harbor. The ship was under intense fire from a number of large caliber guns, including 20 mm and 37 mm antiaircraft guns, 6 inch howitzers, and 75 mm, 150 mm, and 170 mm artillery pieces. The ship took multiple hits and suffered numerous personnel casualties. Despite the damage the ship rammed into the dry dock at 18 knots, exactly as planned.[30]

On 9 May 1980, in the midst of dense fog and thunderstorms, the bulk carrier *Summit Venture* hit one of the supports of the Sunshine Skyway Bridge, a 15-mile cantilever-truss bridge connecting St. Petersburg and Bradenton, Florida. The impact caused a 1,300-foot section of the bridge to fall into Tampa Bay, killing 35 people.[31] On 26 May 2002, a tug and barge hit a bridge portion of Interstate 40 over the Arkansas River. A 600-foot section of the bridge collapsed, killing 14.[32]

In March 2003, the chemical tanker *Dewi Madrim* was boarded and seized by unknown persons. Those persons remained onboard for roughly one hour, maneuvering the vessel repeatedly, until departing with the Captain and First Officer as hostages. The incident has been characterized as ". . . the equivalent of flight training school for terrorists."[33] In June of the same year, Greek authorities discovered 680 tons of commercial mining explosives and 8,000 detonators on the cargo vessel *Baltic Sky*. The shipment was bound for a bogus address in the Sudan.[34]

The study does not differentiate between the use of the ship as a weapon and the use of the ship's cargo. In either case, terrorists would need to seize control of the vessel for some period of time in order to commence the attack. It is this critical action which must be defeated. If brought to speed at the last moment, there is little chance of stopping the vessel in time to prevent an attack.

This analysis considers a team of terrorists onboard a merchant vessel, some of whom are onboard the ship in a legitimate capacity. Some are trained to operate and

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[30] Robert B. Smith, "British Raid on St. Nazaire: The Greatest Raid of All," *World War Two*, March 2003. Also see extensive analysis in CDR W. McRaven, "The Theory of Special Operations," Thesis, Naval Postgraduate School, Monterey, CA, June 1993.

[31] www2.sptimes.com

[32] National Transportation Safety Board, *Safety Recommendation re: U.S. towboat Robert K. Love Collision with Interstate 40 Highway Bridge near Webbers Falls*, *Oklahoma 26 May 2002*, 9 September 2004, www.odl.state.ok.us

[33] Quoted in Charles Glass, "Officials Fear Terror on High Seas," *ABCNews.com*, 10 September 2003.

[34] "Greece Traces Route of Seized Ship," www.edition.cnn.com, 24 June 2003.

navigate the vessel. They will take control of the ship at the last possible moment. There are ten terrorists, two for each of five major control stations: bridge, engineering control, after steering, and two engine rooms. The terrorists are armed to eliminate the ship's crew and defend against boarding. If the ship is boarded (or an attempt to board is made) by friendly security forces, the terrorists will offer armed resistance and will seize control of the ship if they have not already done so. Intelligence information can only narrow the list of potential attackers to one of twenty merchant ships inbound daily to the Bay area.

4.1.3 SBA Mission

Unlike the previous two scenarios, small boat attacks by terrorists have already occurred. The SBA scenario is the most likely future attack because bombing of public transportation, suicide or otherwise, is the most common form of terror attack. The number of terrorist attacks on transportation is too extensive to detail here; what follows are descriptions of the most recent maritime incidents.

On 12 October 2000, the USS *Cole* was severely damaged by the detonation of a terrorist suicide boat packed with high explosives. Seventeen sailors were killed and 39 were wounded in the attack, and the cost of repairing the ship was approximately $250 million.[35] On 6 October 2002, the French oil tanker M/V *Limburg* suffered a similar attack three nautical miles from the coast of Yemen. The attack produced an oil spill estimated at 90,000 barrels. Both hulls of the ship's double-hull design were breached by the explosion; this illustrates the vulnerability of large ships to such an attack. On 24 April 2004, three suicide boats attempted to damage or destroy the Khawr Al Amaya and Al Basrah Offshore Terminals (KAAOT and ABOT), which handle 90% of Iraqi crude oil exports, and two Very Large Crude Carriers (VLCC) tied up alongside the terminals.[36] The attack was foiled, but the damage or loss of the

[35] CRS Report RS20721, "Terrorist Attack on USS Cole: Background and Issues for Congress," March 2001.

[36] "Countering Maritime Terrorism, U.S. Thwarts Attack, Builds Up Foreign Navies," www.jinsa.org, 17 June 2004.

terminals would have an enormous impact on the Iraqi economy. Finally, two separate ferry bombings in the Philippines (one in 2004 and one in 2005) killed over 100 people.[37]

The San Francisco Bay area has many critical points of infrastructure as well as extensive commercial shipping traffic of all types and tonnages that are vulnerable to SBA. An SBA on a densely packed passenger ferry would certainly cause extensive casualties and would make emergency response and casualty treatment much more difficult than a similar attack on a land-based target. A significant oil spill from a large crude oil tanker could cause environmental damage in the large offshore marine sanctuary area and incur significant cleanup costs. The Bay area has an extensive recreational boat community and infrastructure in which terrorists could operate and launch their attack.

The SBA scenario involves protection of 5 oil tankers inbound to the SF Bay area and the protection of 13 ferries operating on five different routes. The five oil tankers arrive uniformly distributed over a 24-hour period; the ferries operate 12 out of every 24 hours. The scenario also requires the constant protection of five points of critical infrastructure representing strategic targets such as oil offload terminals, pipelines, power facilities, and so forth. The attacker uses a single 30-foot civilian speedboat with a top speed of 40 knots. The craft is loaded with 1,000 pounds of conventional explosives.

Figure 4-1 shows a map of the Bay area with major bridges and representative tanker and ferry routes. These are only representations of facilities and routes, not actual installations.

[37] Marichu Villanueva, "Superferry Sinking Last February a Terrorist Act," www.newsflash.org, 12 October 2004; "Thirty Injured in Philippines Ferry Bomb Attack," www.thescotsman.scotsman.com, 29 August 2005.

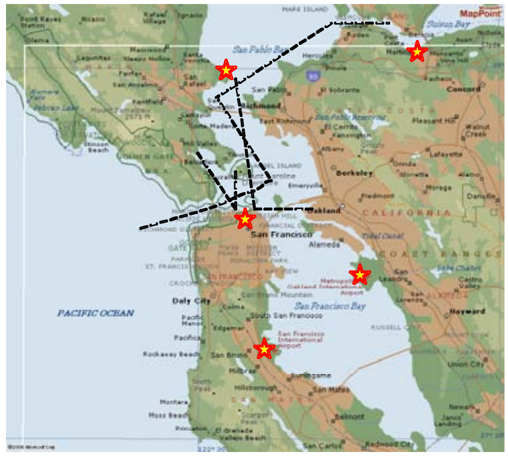

Figure 4-1: Representative critical infrastructure in San Francisco Bay

4.2 MISSION ANALYSIS

4.2.1 WMD Mission Analysis

The analysis of the WMD mission focuses on three areas: determining the minimum distance from San Francisco at which a nuclear detonation would produce minimal effects, assessing the feasibility of an at-sea radiological search on a container vessel, and determining the optimum location of ships to intercept the 20 suspect vessels. The first two are discussed in this section. The optimum allocation of ships is incorporated in the WMD EXTEND™ mission model and is discussed in Chapter 7.0.

A minimum standoff distance of 100 nautical miles is assumed for sea-level detonation of a device with an IAEA-significant amount of fissionable material. This distance, verified by stakeholders,[38] minimizes the risk of fallout given prevailing winds and weather conditions.

Radiological detection onboard a container ship underway poses significant challenges. Foremost among these is the physical difficulty of reaching all containers onboard. Containers onboard container ships are typically divided into two main groups: above decks and below decks. Lashed to the deck with cables, the above decks containers are typically stacked four or five high in paired rows. Although tightly spaced, at least one lengthwise-end of every container is accessible with climbing gear or specialized equipment.

[38] Lawrence Livermore National Laboratory.

The below decks containers are divided among the ship's cargo holds. The holds are designed to maximize the space available for cargo and minimize "dead" space; the containers are packed as tightly as possible. Modern container ships use cell guides in their cargo holds to guide the containers into position. It is common to have just one or two inches of space between containers. Metal framing for the cell guides makes the hold even more crowded. Depending on the design of the vessel, the lengthwise ends of the containers may be inaccessible. Figures 4-2 through 4-5 are photographs showing these aspects of a container vessel.

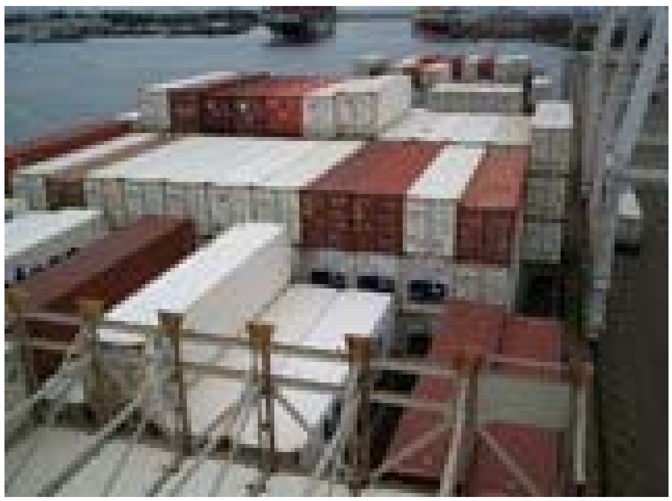

Figure 4-2: Cargo containers on deck

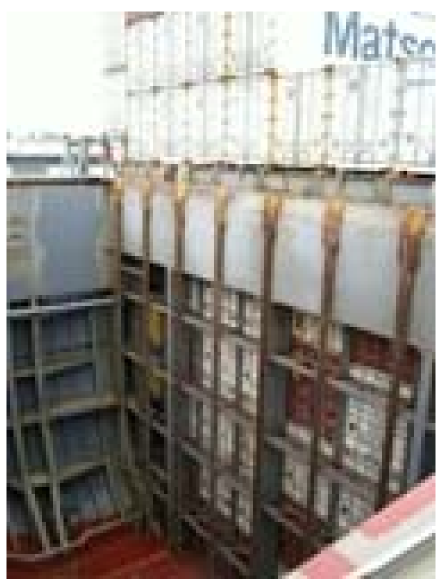

Figure 4-3: An empty cargo hold

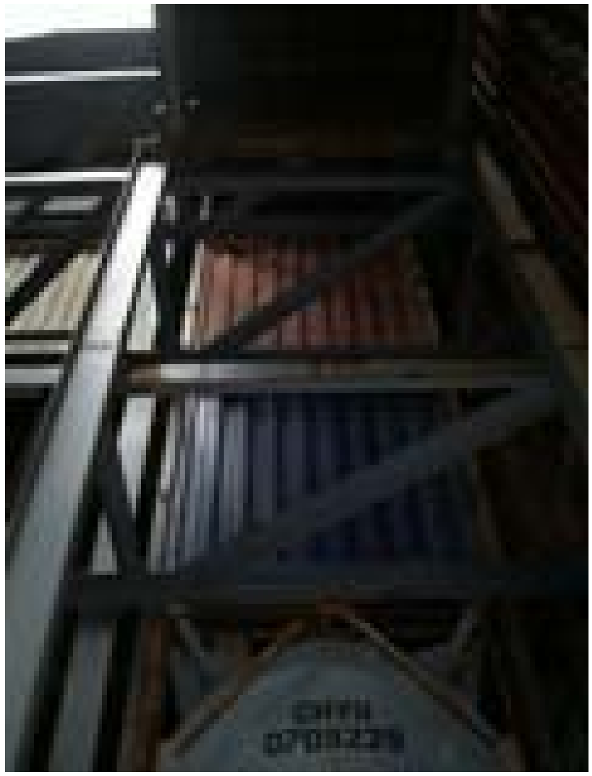

Figure 4-4: Cell guides in cargo hold

Figure 4-5: Cell guides in cargo hold, another view

The cramped shipboard environment impacts radiological search in several ways. First, the sensors used must have physical dimensions that allow them to be deployed in the most restricted spaces of the cargo holds. The cramped quarters will delay search by forcing personnel to crawl and climb through awkward spaces between cell guide framing, bulkheads, ship's equipment, and the containers. Some areas may be completely inaccessible. Personnel may face physical injury if seas are heavy or lighting is poor.

Second, because of these accessibility issues, the sensors must operate through intervening material that may include containers, the contents of the containers, bulkheads, and ship's equipment. Search methods must account for normally occurring radiological material (NORM) that may comprise some or all of the container's contents.

Third, the ocean environment affects radiological search. The absence of absorbing material (such as soil) results in more background radiation or "noise" that must be filtered by the sensor system.[39] Other factors concerning sensors and radiological detection can be found in the classified addendum to this report.

The WMD EXTEND™ mission model determines the time available for and effectiveness of MTR radiological search teams. The model is described in Section 7.

4.2.2 SAW Mission Analysis

The analysis of the SAW mission, and the conclusions that flow from the analysis, are more dependent on initial assumptions than either the WMD or SBA scenarios. Terrorists are assumed to resist any boarding attempt (see Section 4.1.2). Boarding inbound vessels thus becomes a guaranteed way to detect terrorists. Our analysis considered the Golden Gate Bridge to be the "goal line" of the SAW mission; all system functions must be complete before vessels reach the bridge.

Once a boarding attempt is made, successfully or not, the next course of action for friendly forces becomes clear: disabling or sinking the hijacked vessel. An unmolested vessel can have the boarding team remain onboard until it reaches its destination.

The sea buoy marking the approach to San Francisco is 14 nautical miles from the Golden Gate Bridge. A vessel at 25 knots will reach the bridge from the sea buoy in

[39] http://www.eml.doe.gov/Factsheets/ShipEffect.pdf

33 minutes. The mouth of the channel is nine nautical miles from the bridge; the corresponding travel time is therefore 21 minutes. In that time, it is unreasonable to expect that the ship could be recaptured. The only option available is to disable or sink the vessel before it reaches the bridge.[40]

A variety of weapons and platforms could be employed to disable a large merchant vessel. Given the time constraints described, the weapon system must be available for use within minutes. This leads to consideration of weapons that can be deployed upon receipt of initial intelligence and used immediately. The exact type, characteristics, and effectiveness of this weapon or weapon system are open to research by future cohorts of the Systems Engineering and Analysis program.

Furthermore, according to research conducted in this study and subject matter experts, a command-activated, deployable mine or series of mines can accomplish this mission and could be fielded in the five-year timeframe mandated by the study.

4.2.3 SBA Mission Analysis

Determining Force Structure

Two methods were employed to determine force structure. First, a schedule of HVUs and escorts is prepared to determine the number of forces required to escort all HVUs and impose no delay on commerce.[41] Second, an EXTEND™ model is created to calculate the delay on commerce given a number of escorts. The model is described in Appendix F. Force structure is also affected by protection technique (see below).

Determining Effectiveness

Architecture effectiveness in the SBA mission is assessed as a function of five areas: protection technique, weapon effectiveness, platform effectiveness, escort option effectiveness, and architecture effectiveness. The first two areas are described below; the other three are Section 7.

[40] The Golden Gate Bridge is not the only target, but serves as a convenient boundary marking all of the targets inside the Bay area. According to stakeholder sources, sinking or disabling a ship at this point in the channel or approaches (while undesirable) would not significantly affect ship traffic.

[41] The complete schedule and explanation can be found in Appendix E.

Protection Technique

Two techniques of HVU protection are close escort and barrier patrol. In the close escort technique, friendly forces travel alongside the HVU from beginning to end of its transit. Separation of escort and HVU generally varies from 50 to 200 yards (depending on the size of escort). The close spacing allows escorts to concentrate on potential threats in relation to their proximity to the HVU and allows the most time to respond to a threat. The proximity of escort to HVU means that an attack on the HVU is, in essence, an attack on the escorts.

The barrier patrol technique uses one or more escorts to patrol a barrier of fixed length. The patrol keeps threats from crossing into a protected area or allows the patrol to respond to an incursion of the barrier. In the SBA mission, barrier patrols could be used for critical infrastructure protection as well as patrol of the fixed shipping channels and ferry routes in the Bay. The advantage of the barrier patrol is that generally smaller numbers of forces are required.

Determining Weapon Effectiveness

The effectiveness four weapons against a single small boat attacker is assessed.[42] Primary sources of information for the statistical analysis of weapons against small boat threats are subject matter experts, previous unclassified studies, and open source weapons data.[43] The following assumptions are made for weapon analysis (in addition to those in Section 4.1.3.):

1. The attacker maintains course and speed (no evasive maneuvers) even if hit by defender fire;
2. The defender has constant probabilities of hit (based on weapon type and range) even if attacker is hit by defender fire;

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[42] The example weapons and their abbreviations are:
LMG: a .30 (7.62mm)) Light Machinegun, such as the M60
MMG: a .50 cal (12.7mm) Medium Machinegun, such as the Browning M2
MCG: a 25mm Medium Caliber Gun; such as the Navy Mk38
GL: a 40mm Grenade Launcher; such as the Mk19

[43] Previous studies included the Thesis Technical Report of Systems Engineering and Analysis Cohort Seven, "Maritime Domain Protection in the Strait of Malacca," June 2005 and R. Rigazzio, "Defense Against Small Boat Threat: Single DDG and Surface Action Group (SAG) Transits; Analysis Supporting CONOP Development," NWDC, June 2005.

3. Each "shot" by the defender is actually a burst of multiple rounds and a hit signifies that at least 75% of the rounds in the burst hit the attacker;[44]
4. The time to reload a LMG, MMG, and GL is 10 seconds (reloading the MCG cannot be completed in the scenario time);
5. Each shot is independent of other shots.

All weapons were assigned an ammunition capacity and rate of fire (ROF). Probability of hit data from an earlier study is used.[45] The probabilities of hit increase as range decreases. Three different range "bands" are used: Band 1 (500-1,000 yards), Band 2 (200-500 yards), and Band 3 (50-200 yards). Because each weapon is manually-aimed and mounted on a fixed mount or bipods/tripods, all weapons are assigned identical hit probabilities. To account for its High Explosive (HE) round, the probabilities for a grenade launcher are slightly higher than those of the other weapons.

The number of hits required to kill the target ("hits to kill") is determined in the following manner. The attacking vessel is divided into five sections. If a single burst of fire hits a vital compartment, the attacker is killed. A statistical analysis indicates that the number of bursts required to guarantee a 0.90 probability of hitting a vital compartment once is three for the MMG, MCG, and GL and five for the LMG.[46] The time for a weapon to fire one burst is obtained by dividing the burst size by the ROF. Weapon traits are summarized in Table 4-1.[47]

Weapon	Ammo Capacity	Band 1 500-1,000 yds P(hit)	Band 2 200-500 yds P(hit)	Band 3 50-200 yds P(hit)	Burst Size	# Bursts Before Reload	Hits to Kill	Time to Fire One Burst
LMG	200	0.08	0.15	0.40	20	10	5	2
MMG	200	0.08	0.15	0.40	20	10	3	3
MCG	175	0.08	0.15	0.40	6	29	3	2
GL	48	0.10	0.30	0.60	3	16	3	4

Table 4-1: Weapon Characteristics

[44] The terms "burst" and "shot" will be used interchangeably.

[45] Rigazzio, op. cit.

[46] A negative binomial cumulative distribution function, with probability of success of .40 (2/5), results in number of trials needed for 0.90 probability of one success.

[47] Although using different methodology, the number of individual rounds required to hit the target to achieve a kill (45 to 60) is comparable to the 50-100 round range used in earlier studies. See Rigazzio, op. cit.

The time the target is present in each range band ("target dwell time") is computed by dividing the length of the range band by the target's speed. Then an engagement in each range band can be modeled as a binomial distribution. The calculations are shown in Appendix D.

When the number of shots taken equals the ammunition capacity of the weapon, there is a reloading delay before another shot can be fired. For example, the LMG requires two seconds to fire a burst and can fire ten bursts before reloading. The attacker's dwell time is 22 seconds in Band 1, it is 13 seconds in Band 2, and 6 seconds in Band 3. Therefore, the LMG fires ten shots while the attacker is in Band 1. Twenty seconds elapse. It takes ten seconds to reload; the attacker continues to close the range. When reloading is complete, the attacker has 5 seconds remaining in Band 2 (22–20 = 2, 2–10 = –8, –8+13 = 5). The LMG fires two shots in Band 2 and three more shots when the attacker is in Band 3.

Finally, the probability of kill can be established for each weapon by determining the probability of gaining the required number of hits on the target across all range bands. This method allows multiple variations of the basic scenario. Nine variations ("cases") are analyzed. A variation is characterized by the target initial distance, time to fire one burst, the number of weapons firing, and the reloading policy. The nine cases are summarized in Table 4-2.

Case	Open Fire Range (yds)	Rate of Fire	Number of Weapons	Reload Policy
1	1,000	MAX	1	INDIVIDUAL
2	1,000	MAX	2 (=1)	COORDINATED
3	1,000	AIMED	1	INDIVIDUAL
4	1,000	MIX	1	INDIVIDUAL
5	1,000	MIX	4 (=2)	COORDINATED
6	500	BEST	1	N/A
7	500	BEST	2	N/A
8	200	BEST	1	N/A
9	200	BEST	2	N/A

Table 4-2: Nine variations of the basic attack scenario

The weapon analysis (See Appendix D) yields the probabilities of kill for the four weapons in each case. They are found in Table 4-3.

Case	LMG	MMG	MCG	GL
1	0.0213	0.0865	0.3198	0.2365
2	0.0599	0.2123	—	—
3	0.0048	0.0526	0.0526	0.1614
4	0.0036	0.0562	0.2392	0.2365
5	0.2536	0.4738	0.6879	0.7242
6	0.0260	0.1958	0.2392	0.2365
7	0.2932	0.6158	0.6879	0.7242
8	0.0000	0.0640	0.0640	0.0000
9	0.0409	0.4557	0.4557	0.4752

Table 4-3: Weapon performance in nine variations of the basic attack scenario

Analysis similar to that described above was conducted for a twin MMG mount and a helicopter engagement against a small boat. The main difference for the twin mount is a reduction in the hits to kill from 3 to 2 (because a burst size for a twin mount is now 30 to 40 rounds, instead of 15 to 20). The helicopter has a moderately higher P(hit) and fewer hits to kill.[48] In the helicopter case engagements are based on the total time of engagement, instead of the time derived from speed/distance. These engagements are cases 10 through 13 and are summarized in Tables 4-4 and 4-5.

Case	Open Fire Range or Time of Engagement	Rate of Fire	Number of Weapons	Reload Policy
10	500	BEST	1	—
11	200	BEST	1	—
12	25 seconds	BEST	1	—
13	15 seconds	BEST	1	—

Table 4-4: Four additional variations of the basic attack scenario

Weapon	Case 10	Case 11	Case 12	Case 13
Twin MMG	0.4361	0.3520	—	—
Helo w/LMG	—	—	0.2160	0.6826
Helo w/MMG	—	—	0.6480	0.9130

Table 4-5: Weapon performance in four additional variations of the basic attack scenario

Results of Weapon Analysis

The first result of weapon analysis is that the number of shots at close range is the key driver of weapon effectiveness. This has several implications.

First, the optimum employment of all weapons is to open fire when the target is at 500 yards or less. This increases the number of shots with the highest P(hit) and removes

[48] This is Intended to show a better chance of directing fire into a vital compartment from the overhead angle of the aircraft.

reloading from consideration (all weapons can fire through the end of engagement without reloading if holding fire until 500 yards).

Second, because the number of shots can be increased by increasing the number of weapons, two weapons of lesser effectiveness can combine to be more effective than a single weapon of higher effectiveness. This is particularly effective when combined with the "hold fire" policy. Doubling the number of weapons causes a more-than-double increase in P(kill). Also, two weapons holding fire are more effective than two weapons firing at maximum range even if the maximum range weapons coordinated their firing and reloading. This benefit of multiple weapons applies to all cases. In particular, only multiple weapons give adequate probabilities of kill against an extreme close range attacker (200 yards; cases 8 and 9).

Implications for force structure follow from these results. In the absence of other considerations, larger escorts are preferable to smaller because they carry more weapons.[49] All escorts should mount the maximum number of weapons possible, not the largest. The MMG has the best average performance in all cases considered and it should be used when available. The twin-MMG mount should also be used whenever possible.

The hold fire firing policy has benefits beyond weapon effectiveness. In any homeland defense operating environment, it is highly unlikely that an engagement with shipboard weapons would commence at ranges greater than 500 yards. First, current rules of engagement establish a protection zone of 500 yards around high-value units; vessels beyond 500 yards are free to operate as they wish.[50] Discriminating a suicide attacker from an innocent recreational boater traveling at high speed is difficult. Escorts face a challenging task of detecting and classifying high numbers of small boats. Without specific cueing to threat behavior, escorts will employ verbal and visual warnings against all boats fitting a target profile. These actions take time, which will allow targets to close rapidly.

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[49] A Navy *Cyclone*-class patrol ship simultaneously mounts two 25mm guns, two twin-.50s, two 40mm Mk19 grenade launchers, and two 7.62mm MGs. The class also has adequate deck space to station additional crew served weapons if circumstances permit.

[50] Current Coast Guard regulations require all boats to slow within 500 yards of designated high value units, and to stay 100 yards away from any high value unit. When that is impossible, as in a narrow channel, the small boat must slow to bare steerageway. Cited in Commander Coast Guard LANTAREA Letter (5800) dated 25 September 2001: "Jurisdictional limitations of selected Coast Guard authorities."

Third, the potential for collateral damage to other boats, infrastructure, and civilians on shore is a strong push to minimize the number of shots taken. Fourth, the hold fire policy increases the effectiveness of the LMG and MMG without affecting the performance of the MCG and GL. It dispenses with the need to assume "perfect" firing and reloading coordination between two different weapon teams. The LMG and MMG are the most common weapons available and the hold fire policy is an effective employment doctrine for them.

The results of the weapons analysis are used in the platform and architecture analysis which appears in Section 7. The recommendations of the analysis were reflected in the armament of all escorts in the SBA EXTEND™ mission model which is described in Section 7.

Results of Protection Technique Analysis

Comparison of the two methods reveals that barrier patrol is unsuitable for the SBA mission. The large geographic area requiring protection calls for a large number of forces in both the close escort and barrier patrol techniques. Table 4-6 displays a comparison of barrier patrol and close escort with parameters. Moreover, barrier patrol reduces the effectiveness of friendly forces below acceptable levels. See Appendix F for details.

Protection Technique	Parameters	Forces Required	Delay Imposed on Commerce
Close escort	4 per HVU 2 per critical point	124	0
Barrier patrol	2 per nautical mile	144	0

Table 4-6: Comparison of Escort Methods

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5.0 REQUIREMENTS ANALYSIS

Through extensive research and consultation with the stakeholders, SEA-9 has arrived at the MTR requirements for the SoS. There are two types of requirements: Functional and Nonfunctional. The functional requirements are derived from an abstraction of the customer's needs followed by the derivation of the objectives to be accomplished by the SoS. The functional requirements are the functions, or actions, the SoS must perform to achieve these objectives. Through functional analysis, the system level functions are derived, followed by the hierarchical decomposition of the system level functions to subsystem level functions.[51] The nonfunctional requirements are the quantitative requirements associated with each function.

5.1 FUNCTIONAL REQUIREMENTS

The system-level functions required to meet the objectives of the SoS are defined and then followed by their decomposition to arrive at the subsystem level and supporting functions.

5.1.1 System-Level Functions

In order to accomplish the SoS objectives for the WMD, SAW, SBA missions, five system-level functions are identified: C4ISR, Prepare the Battlespace, Find/Fix Threat, Finish Threat, and Sustain. The C4ISR (Command, Control, Computers, Communication, Intelligence, Surveillance, and Reconnaissance) function ensures that the SoS has the appropriate means to carry out the mission in terms of C2 and to have the appropriate lines of communication to keep the forces informed of the status of operations. The Prepare the Battlespace function ensures that the SoS has the appropriate personnel, equipment, and platforms to carry out the mission. Also, Prepare the Battlespace renders the area of operations ready for countering a potential attack. The Find/Fix Threat and Finish Threat functions are executed as MTR forces actually carry out the mission. The process of carrying out the mission includes searching and detecting

[51] B.S. Blanchard and W.J. Fabrycky, *Systems Engineering and Analysis*, 3rd Edition, Prentice Hall, 1998.

the threat and neutralizing the detected threat. The Sustain function ensures that all units and equipment are properly supported and maintained for the duration of operations.

5.1.2 Functional Decomposition

The decomposition of each of the system-level functions—C4ISR, Prepare the Battlespace, Find/Fix Threat, Finish Threat, and Sustain—is performed and represented in a tree structure (Appendix A). The following sections discuss the system-level functions and their respective functional decomposition.

5.1.2.1 C4ISR

The C4ISR function is decomposed into these four subfunctions: Command and Control (C2), Communicate, Compute, and Provide Intelligence as shown in Appendix A.

The C2 function is supported by two subfunctions: Command Forces and Interface with External C2. The Command Forces function consists of the subfunctions: Plan Operation, Direct Operation, Coordinate Operation, and Control Operation. The Interface with External C2 function enables the MTR C2 subsystem to interface with existing or planned C2 sources that are external to the MTR SoS, such as higher authority, coalition forces, the Global Command and Control System (GCCS), and the MDA system. Interfacing includes receiving orders or information, requesting permission or information, coordinating efforts, and providing status updates as required. Thus, the subfunctions supporting the Interface with External C2 function are Interface with Higher Authority, Interface with Coalition C2, Interface with GCCS, and Interface with MDA.

The Communicate function is comprised of three subfunctions: Provide Voice and Data, Network MTR Nodes, and Receive MDA Intelligence. Within the Provide Voice and Data function, the MTR Communication subsystem must be able to transmit and receive voice, data, and images. The Transmit and Receive functions comprise the Provide Voice and Data function. The MTR Communication subsystem ensures that all nodes in the MTR SoS can quickly and reliably communicate with each other. Thus, the subfunctions within the Network MTR Nodes function are

Provide Sufficient Nodes, Provide Robust Network, Minimize Downtime, Provide Redundancy, Minimize Data Corruption, Minimize Nodal Failure, and Reroute. The Receive MDA Intelligence function maintains a communications link with the MDA system and routes MDA intelligence to the Compute function for processing. The subfunctions supporting Receive MDA Intelligence are Maintain Link with MDA, Collect, Prioritize, Fuse Information, and Disseminate Information.

The Compute function contains two subfunctions—Information Assurance and Data Fusion. Information Assurance provides a security policy that guarantees that data being received and sent by the C4ISR system has not been tampered with or corrupted. Subfunctions that support Information Assurance are: Provide Confidentiality, Provide Integrity, Provide Authenticity, Provide Availability, and Network Security. Data Fusion enables rapid decision-making and situational awareness. Thus, the subfunctions within the Data Fusion are Data Association, Data Analysis, Threat Assessment Based on Scenarios, Automate Processes and Collaborative Tools, Request for Data Recollection, Collaborative Feedback, and Provide "No-MDA" Function.

The Provide Intelligence function receives fused information from the Compute function and transforms it into meaningful operational pictures that best enhance situational awareness. The overall operational picture is created for the commander, while customized pictures are created for the individual functional teams based on their orders and operational needs. Provide Intelligence is comprised of three subfunctions: Form Overall Ops Picture, Analyze Operational Needs, and Provide Customized COPs.

5.1.2.2 Prepare the Battlespace

The Prepare the Battlespace function addresses the first physical actions to be taken to prepare for an incoming threat as well as the prepositioning of forces to allow for the intercept of the potential threat. As seen in Appendix A, Prepare the Battlespace has three subfunctions: Activate Security Measures, Assemble and Prepare Teams and Platforms, and Deploy the Forces. Each of these subfunctions covers the security planning, assembling component units, placement, and deployment of the SoS.

Activate Security Measures consists of the functions Prepare Critical Infrastructure and Activate Preplanned Operation Orders. Prepare Critical Infrastructure involves heightening the Homeland Security Advisory System (HSAS)[52] and Maritime Security (MARSEC)[53] levels as well as upgrading or augmenting the existing security forces for the intended target area. By increasing the HSAS level, the Department of Homeland Security ensures that all parties, civilian and government, in the target area are aware of the threat and are preparing accordingly. The U.S. Coast Guard will set the MARSEC level to correspond with the HSAS level set by the DHS. Upgrade/Augment Existing Security Forces involves increasing security to the areas that are critical to the operation or economy of a city or port facility. Restrict Nonessential Boat Traffic applies more to the confined transit areas such as straits, bays, harbors, rivers, and inlets. Restrict Nonessential Boat Traffic includes passive and active measures. Passive measures are radio updates and "Notice to Mariners" while active measures involve boat ramp closures and patrol boats.

Assemble and Prepare Teams and Platforms consists of Activate Required Personnel, Issue Equipment, and Prepare Deployment Platforms. This subfunction can vary greatly depending on the mission to be conducted and the time available to execute the mission. For example, a container ship carrying a WMD on the open ocean may not require the same mission equipment as a threat of an SBA in a bay or harbor. Also, considering the latency of intelligence, there may not be enough time to assemble all the desired equipment and personnel at one time.

Deploy the Forces consists of Embark Deployment Platforms, Move Deployment Platforms into Position, Move Teams to Potential Attacking Vessel, and Recover Teams from Potential Attacking Vessel. Embark Deployment Platforms is when the teams and their equipment board the deployment platforms. Move Deployment Platforms into Position involves the platforms, with teams and equipment onboard, traveling out to their area of concern. Move Teams to Potential Attacking Vessel involves the gathering teams for debarkation of the deployment platforms and then providing them with a means of transportation to the potential attacking vessel. Recover

[52] http://www.dhs.gov/dhspublic/interapp/press_release/press_release_0046.xml
[53] http://www.uscg.mil/safetylevels/whatismarsec.html

Teams from Potential Attacking Vessel involves gathering teams for debarkation of the potential attacking vessel and providing them with a means of transport back to the deployment platforms.

5.1.2.3 Find/Fix Threat

The third system-level function, Find/Fix Threat, consists of three subfunctions: Detect Threat, Identify Threat, and Assess Threat.

As directed by the National Security Presidential Directive-41/Homeland Security Presidential Directive-13 (NSPD-41/HSPD-13) the MTR SoS must be capable of conducting stand-off detection for weapons of mass destruction in the maritime domain while complementing existing and emerging cargo inspection systems and hand-held detection devices.[54, 55] According to this plan, the SoS needs to examine ways to integrate parallel efforts to improve WMD portable and standoff detection capabilities. In this light, the collaboration of several stakeholders to identify such parallel efforts is paramount. Ongoing efforts undertaken by these stakeholders demonstrate the importance and urgency of placing the effective tools in place and on demand.

The Find/Fix Threat function must place search teams on any one of the vessels of interest while in transit towards the mainland United States. Once in place, the teams will use proven technologies to detect, with a high level of certainty, any material capable of being used as an ingredient in a WMD. Accurate detection of a potential threat source alone warrants actions by the SoS to push the threat out of the system to external agencies such as the Department of Energy and the Joint Technical Operations Team to be isolated and/or destroyed. When considering illicit devices that can be used against the United States it is important to consider much more than just the threat of a weapon of mass destruction. As an extension, the Find/Fix Threat function will assist in locating persons of interest, as in the case a vessel has been taken over by terrorists. Additionally, when protecting High Value Units (HVU) that enter the area of operations,

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[54] National Plan to Achieve Maritime Domain Awareness for the National Strategy for Maritime Security, October 2005.

[55] National Security Presidential Directive-41/Homeland Security Presidential Directive-13 (NSPD-41/HSPD-13) (Maritime Security Policy, December 21, 2004).

the SoS also provides capabilities to detect any attacking vessel or suspicious entity capable of inflicting damage or harm on the HVUs.

At the next level of decomposition, the Detect Threat subfunction will execute two processes, Scan Area of Interest and Process Scan Data. Scanning the area of interest is intended to provide total iterative coverage. As this scanning subfunction scrutinizes the area of interest, it is necessary to have the system process the information simultaneously, as intended in the Processing subfunction.

Once a potential threat has been detected with the level of certainty required of the overall system, the threat data is then sent to the appropriate external agencies aforementioned capable of dealing with a nuclear threat. The Find/Fix Threat function will then incorporate the Identify Threat function to operate concurrently with the Detect Threat function. By simultaneously detecting and identifying the source the system is prepared to redirect an identified threat to the appropriate agencies. Unlike the improvised nuclear source, a person of interest detected on a potential ship as a weapon must be positively identified before the system can proceed. This identification process will take place near-simultaneously with the detection function in such a manner that will provide a high level of certainty as to the identification of that person interest.

As it is not always possible to conduct identification while in the AOR, further sublevel functions necessary to complete this task would be both on-site and off-site analyses. As part of the on-site analysis subfunction the search teams use the information immediately available to identify the threat. Otherwise, if the information available is not sufficient to aid in making such a determination, then the information is sent away from the AOR via other communications and data transportation means described in the C4ISR functions to an off-site analyst, outside of the system, who can make the final determination using what has been collected.

The third subfunction of the Find/Fix function, Assess the Threat, provides means of evaluation of the potential of the threat. In the case of the WMD, this subfunction assesses the magnitude of any possible detonation. In the SAW and SBA missions, the Assess Threat function will evaluate the threat to see what type of damage this threat is capable of inflicting.

5.1.2.4 Finish Threat

The Finish Threat function includes all actions necessary to stop the threat. Finish Threat is divided into two subfunctions: Use Nonlethal Measures and Use Lethal Measures. As shown in Appendix A, Use Nonlethal Measures is composed of seven subfunctions: Guard an HVU from an Internal Threat, Guard an HVU from an External Threat, Warn, Conduct a Nonlethal Weapons Engagement, Shoulder an Attacking Vessel, Tow a Disabled Vessel, and Conduct Search and Rescue Operations.

Guard an HVU from Internal Threat is the system's main response in the SAW mission. The mission analysis (Section 4.1) concludes that friendly forces had to board suspect vessels to verify that they are still in friendly hands, and if they are, the vessel should be guarded until safely pierside. The embedded functions are Guard Control Spaces and Guard Crew. Guard an HVU from External Threat is the system's main response in the SBA mission. The embedded functions are Escort HVU and Place Forces on HVU. Warn, Conduct Nonlethal Weapons Engagement, and Shoulder Attacking Vessel are mainly associated with the SBA scenario.[56] Their logical flow should be obvious; their inclusion is vital as the SoS will be operating in CONUS and interacting with the American public daily. The Warn subfunctions are Use Visual and Use Auditory. The embedded functions for Conduct Nonlethal Weapon Engagement are Use Anti-personnel and Use Anti-vehicle; each of these has the identical embedded functions of Target, Fire weapon, and Assess engagement. Tow a Disabled Vessel and Conduct Search and Rescue Operations are consequence actions that the system must perform when other actions have been performed.

Use Lethal Measures is composed of three subfunctions: Disable, Sink/Destroy, and Recapture. Disable has the subfunctions of Target, Fire Weapon, and Assess Engagement; Sink/Destroy has the same three with the additional subfunctions of Detect/Track and Classify. Recapture is composed of Board Vessel and Secure Control Spaces. The Sink/Destroy function is expanded in the most detail because it is used in the SBA model. The Disable function, a straightforward option in the WMD and SAW

[56] Shouldering is the technique of maneuvering as escort vessel between an attacker and its target.

missions, does not require the same level of detail. The Recapture function is the second main option in the SAW mission.

5.1.2.5 Sustain

The fifth system-level function, Sustain, is decomposed into two subfunctions, Support Units and Maintain Units, as shown in Appendix A.

The Support Units function is composed of subfunctions responsible for delivering recurring-type necessities to ensure units can continue operations for the projected mission time. Four subfunctions compose the Support Units function: Deliver Consumables, Parts and Supplies to Units; Refuel Platforms; Provide Manning; and Provide Barracks.

The objective of the Deliver Consumables, Parts and Supplies to Units subfunction is self-explanatory: The delivery vehicle for the consumables will vary according to the situation and environment. The Delivery function is decomposed according to specific unit-types within the system that require consumables during a mission: Deliver to Military Ships and Deliver to Non-Military Ships. Communication of each of the various units' needs is part of the C4ISR function addressed earlier.

Deliver to Military Ships applies to the WMD, SAW and SBA missions by ensuring ships and small boats underway receive resupply of consumables and parts, when needed, in order to continue extended-duration operations without affecting unit readiness. The Deliver to Nonmilitary Ships function enables the military teams deployed to the transiting commercial ships (such as the container ships in the WMD mission or the water taxis in the SBA mission) to receive the consumables and supplies (such as food and replacement parts) necessary to conduct their mission.

The Refuel Platforms function consists of the system's ability to provide fuel (i.e., JP-5, F-44, etc.) to vehicles being used within each of the missions. This function is further decomposed by platform types within the system requiring fuel for the duration of their mission. The subfunctions composing Refuel Platforms are: Refuel Ships, Refuel Small Boats, and Refuel Aircraft.

Each of the Refuel subfunctions is concerned with conducting refueling operations that enable platforms to continue their mission with minimal impact to continuous operations. Refuel Ships applies to underway replenishment in the WMD and SAW missions; Refuel Small Boats and Aircraft applies to centralized gas station facilities for each of the respective platforms.

The Provide Manning function allows the system to provide and deliver a pool of manpower to enable operations for the duration of the mission without exhausting the forces available in the process. It ensures unit readiness is maintained at a constant or enhanced state throughout the mission. In most cases this function will be accomplished by current military manpower systems (i.e., NAVPERS), but the function ensures other methods are in place to account for unexplained current-system shortfalls. Provide Manning is further decomposed into the following subfunctions: Receive Manning Reports, Identify Deficiencies, Locate Manning Sources, and Transport Manning to Units.

Receive Manning Reports is accomplished through lower level C4I system subfunctions (i.e., standard Naval message traffic, personnel musters being faxed or emailed, etc.). It provides the method for reporting units' current and required manning. Receive Manning Reports allows the next subfunction, Identify Manning Deficiencies, to input units' manning reports and identify differences between the current and required manning. In most cases this is accomplished by the current military administrative and logistics commands (such as NAVPERS), but it also allows a centralized mission administrative and logistics support unit to verify manning levels, in order to add a level of redundancy to ensure the function is accomplished. Locate Manning Sources receives the information concerning needed manning to correct deficiencies from the unit(s) performing the Identify Manning Deficiency function. Locate Manning is self-explanatory and draws manning from current military manpower pools, such as the Naval Training Command center, available manpower within the fleet, etc. Once available manpower is located, the Transport Manning function is activated, moving the located manpower to its final destination (the unit with manning deficiency, as identified by the unit performing the associated function). The final destination of the needed manpower determines the variables associated with the transportation of the manpower, such as use of ground transportation to transfer to a shore station, aircraft to transfer to a ship at sea, etc. Transportation of manning is further decomposed by the location of the unit requiring manpower. The subfunctions composing Transport Manning are self-explanatory: Transport Manning to Military Units at Sea, Transport Manning to Military Units in Port and Transport Manning to Nonmilitary Units at Sea.

The Provide Barracks function ensures that berthing of manpower is accomplished for all units conducting the mission, including those units without pre-constructed (or preplanned) berthing locations (such as civilian agencies or units that were not originally conceived with military missions in mind). Provide Barracks is decomposed by unit-type (military or nonmilitary) and environment (at sea or import) in which the barracks are required. Provide Barracks subfunctions are: Provide Barracks for Units Onboard Military Ships at Sea; Provide Barracks for Units Onboard Nonmilitary Ships at Sea; and Provide Barracks for Units in Port.

Berthing aboard military ships is planned prior to ship construction to enable the ship's crew to conduct their missions. Missions calling for additional crew berthing beyond the preplanned, allotted facilities aboard ships may come up short-handed, affecting unit readiness during the mission. The Provide Barracks for Units Onboard Military Ships at Sea function ensures total crew (both organic and non-organic) berthing is planned for and assigned to ensure unit readiness is maintained (or enhanced). Berthing aboard nonmilitary ships such commercial cargo carriers, on the other hand, is set during ship-construction planning to maximize economic revenue. These ships have a low probability of being able to provide berthing beyond their immediate organic crew.[57] Provide Barracks for Units Onboard Nonmilitary Ships at Sea therefore ensures non-organic crew berthing is planned for and assigned in the mission. Missions conducted in or near port facilities have a much greater variety of berthing options available: aside from barracks facilities within military bases, hotels and other nonmilitary berthing is available (however, at a price). Provide Barracks for Units in Port therefore ensures that berthing facilities are planned for so as to minimize the total mission cost, while ensuring readiness is maintained or enhanced.

Maintain Units differs from the Support Units function in that Support Units is concerned with predictable consumables that apply to all units (such as food, fuel and manpower), Maintain Units requires supplies and parts specific to each

[57] Interview with M/V Lorlei Master, 24 March 2006.

platform or equipment type (such as engine-specific parts). Maintain Units is decomposed into Identify Maintenance Deficiencies, Nondepot-Level Maintenance, and Depot-Level Maintenance.

The Identify Maintenance Deficiency function enables the system to identify units conducting the missions that do not have the manpower, training, equipment or capability to conduct organic (nondepot-level) maintenance. The Identify Maintenance Deficiency function is decomposed into Receive Unit Capability Reports, Asses System Capability, and Correct System Deficiency.

The Receive Unit Capability Reports is accomplished through lower level C4I system subfunctions in the same manner as the Receive Manning Reports subfunction (i.e., standard naval message traffic, personnel musters being faxed or emailed, etc.). It provides the capability within the system for reporting units' maintenance capabilities and is accomplished through current military maintenance-type reporting systems, such as the Navy's Casualty Reporting System (CASREP). Receive Unit Capability Reports outputs information to the Asses System Capability subfunction. Asses Unit Deficiencies receives the unit capability reports, such as CASREPs, and analyzes the system of system's ability to continue the mission. For example, a unit with major system malfunctions that requires depot-level facilities to correct the problem will not be able to continue its mission. However, other units within the SoS (still mission-capable) may be able to continue the mission by assuming the non-mission capable unit's duties.

The Assess System Capabilities function outputs information to the Correct System Deficiency function to enable the system to take action allowing the system of systems to continue operating in the wake of unit casualties. Should one unit within the system become non-mission capable, upon assessment of the overall remaining system capabilities, the Correct System Deficiency function then activates a unit capable of assuming the duties to allow the SoS to continue functioning.

The Non-Depot Level Maintenance function involves unit organic maintenance and repair capabilities that allow the unit to conduct continuous mission operations, should maintenance be required or a component failure occur.

Nondepot-Level Maintenance is decomposed into the following subfunctions: Identify Components, Stock Spares, and Replace Components.

The Identify Components subfunction enables the system to analyze component reliability and operational availability levels over the duration of the mission. The information from the Identify Components function is input to the Stock Spares function; the Stock Spares function identifies spare part inventory levels to ensure continuous system operation throughout the mission. The Replace Component subfunction then utilizes the inventory of spare parts to fix broken components, allowing the system to continue (or resume) operating with minimum impact on mission effectiveness.

The Depot-Level Maintenance function allows the system to rotate units (out of operation) to conduct depot-level Preventative Maintenance Services (PMS), Corrective Maintenance Services (CMS), or Unit Stand-down (i.e., annual leave). The Depot-Level Maintenance function enables total life-cycle system management by maintaining overall unit readiness beyond the duration of the mission. Depot-Level Maintenance is decomposed into the following subfunctions: Identify Prescheduled Depot-Level Maintenance and Enable Unit Rotation.

The Identify Prescheduled Depot-Level Maintenance subfunction enables the system to analyze unit depot-level maintenance schedules (such as engine grooming, annual leave schedules, etc.). Analysis of maintenance schedules is performed by current military commands, such as Operations and Material (i.e., J3/J4) departments within unit squadrons.

Unit depot-level maintenance requirements resulting from analysis are output from the Identify Prescheduled Depot-Level Maintenance function to the Enable Unit Rotation function; the Enable Unit Rotation function enables the system to rotate units in and out of mission use without affecting the ability of the SoS to continue the mission. Enable Unit Rotation is decomposed into the following subfunctions: Identify Unit Replacements and Schedule Unit Turnover.

The Identify Unit Replacements function allows the system to identify replacements that meet mission capability and availability requirements. Information from the Identify Unit Replacements function is input to the Schedule Unit Turnover function; the Schedule Unit Turnover function then ensures unit rotation into and out of the mission is conducted by efficient, smooth, timely and complete unit turnover. This ensures that the SoS continues unfaltering operation, while allowing units to conduct their depot-level requirements, thus ensuring total life-cycle readiness is maintained or enhanced.

5.2 NONFUNCTIONAL REQUIREMENTS

The development of a method for measuring success for each of the subfunctions follows the SoS functional decomposition. The nature of the systems involved in Maritime Threat Response implies a degree of reactionary actions taken in response to a situation. Time is selected as a measure of effectiveness (MOE) for each of the system functions and subfunctions. The probability of success (P_s) in accomplishing each of the system functions is also selected as an MOE.

Values of the MOEs are then assigned for the top-level system functions and subsequently allocated to each subfunction. The development of the operational requirements is discussed in the following sections. To allocate requirements to the subfunctions, the requirement assigned to the top-level function is mathematically divided down among the subfunctions according to the structure of the functional decomposition and the execution order (parallel or sequential) of the subfunctions.

5.2.1 Top-Level System Effectiveness Requirements

Top-level system effectiveness requirements need be quantified. As stakeholders are unable to quantify effectiveness required of the Maritime Threat Response (MTR) SoS against individual threats described in the missions, the top-level system operational performance requirements are developed in this project, taking into account a number of sources, as follows.

The likely amount of damage, measured in economic cost, caused by successful terrorist attacks in each of the three scenarios, is assessed. For instance, a total amount of direct costs of $27.2 billion resulted from the attacks against the World Trade Center complex on 9/11, which account for the direct costs associated with destruction of property (two 110-story towers, five ancillary buildings, and 25 buildings surrounding the

Center) estimated at $16.2 billion and those associated with rescue and clean-up efforts estimated at $11 billion.[58]

While the size of the nuclear device and the location and altitude of its detonation can have an enormous impact on the overall amount of damage, a 10-kiloton nuclear device would cause damage to a major metropolitan city approximated at an amount of a $500 billion (FY2004).[59] This amount could fluctuate wildly dependent on the circumstances of the terrorist attack, but it is a reasonable estimate of the costs resulting from such an attack. This is less than 20 times the amount of direct damage cost estimated at the World Trade Center.

In a successful SBA, in which the target vessel sinks, the damage (the total loss of the value of the ship as well as its cargo) is roughly $1 billion (FY2004).[60] Again, the total amount of damage in a successful SBA can vary, but this estimate can be used as a reasonable figure on which to base further calculation.

The damage from the SAW attack consists of the damage similar to that from a successful SBA, assuming the ship is sunk with all of its cargo onboard, and the cost of damage to critical infrastructures under attack. The critical infrastructures could be port facilities, tourist attractions such as Fisherman's Wharf in downtown San Francisco, or bridges. The total damage is estimated at $2,500,000,000 (FY2004).[61]

Next, the relative probabilities of occurrence of the three different envisaged scenarios are assessed, based on an assessment of the technical difficulty as well as expense in conducting the different types of attacks. The nuclear weapon attack appears to be the most expensive and technically difficult scenario for a terrorist group to accomplish. The SAW scenario, much less technically difficult and less expensive to

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[58] Robert Looney, "Economic Costs to the United States Stemming from the 9/11 Attacks," *Strategic Insight,* Issue 6, Volume I, August 2002.

[59] David Howe, "The Homeland Security Council Planning Scenarios: Executive Summaries, Version 2.0," (July 2004) available online at http://www.globalsecurity.org/security/library/report/2004/hsc-planning-scenarios-jul04.htm, accessed on December 15, 2005.

[60] The estimate assumes the value of a large merchant vessel at approximately $300M and its cargo at approximately $700M. The values of the cargoes can obviously fluctuate. A 6,000 car carrier would nominally have a smaller value of approximately $120M to $180M in cargo. A 6,000 TEU container ship would nominally contain up to 360,000,000 pounds of cargo, if each TEU carried 30 tons. A large LNG tanker carries 250,000 cubic meters of LNG.

[61] The ship as a weapon estimate can be derived from the assumption that the ship and its cargo are totally destroyed ($1B), the target is the Golden Gate Bridge and the attack is successful ($1.3B for the bridge), and additional property damage ($200M).

accomplish than the nuclear weapon scenario, is similar to the Al Qaeda 9/11 attacks—simply using a commandeered ship rather than a commandeered aircraft. The small boat attack appears to be the least difficult and expensive to accomplish, and similar attacks have been staged by Al Qaeda in the form of the USS Cole attack in Yemen in 2000 and the M/V Lindberg attack off of Yemen in 2003. Given these variations, and after consulting numerous stakeholders and analysts, the SBA appears to be twice as likely as the SAW attack, and the SAW one hundred times more likely than a nuclear weapon attack.

Finally, the relative probabilities of occurrence are multiplied by the damage estimates for each of the three scenarios to provide an expected value of damage caused by the attacks when there is no defensive system in place to counter the terrorist attacks. The required probabilities of success in countering the different types of terrorist attack are then calculated, assuming that the expected value of damage from each of the attacks with a defensive system in place is equal. In other words, the top-level probability of success is adjusted for each mission so that the expected value of damage cost from each mission is equal. Table 5-1 shows the calculated damage cost and system P_s requirements.

When the system stops the terrorist attack from occurring, a success is declared. In the WMD mission, success means that the device is located and disarmed, or, if the terrorists somehow detonate it, such a detonation occurs at least 100 NM away from the United States coast. For the SAW mission, success means that the ship is either protected from seizure, recaptured if previously seized, or disabled prior to being used as a weapon. In the SBA mission, success means that the SBA is prevented from happening such that the terrorist attack boat does not significantly damage the protected merchant vessels or critical infrastructures.

During the course of the MTR SoS operating in each of the missions, commerce may suffer from costs through either delay costs associated with accomplishing the MTR mission or through damage to the vessels in question. These costs, not considered in the expected damage calculations, are factored into the costs associated with a given system option in the system cost-effectiveness analysis. In other words, MTR system architectures that increase delays on commerce or damage to merchants may be less cost-effective than those that reduce delay times and damage.

MTR Mission Type	System P_s Requirement (%)	Raw Damage Cost from Attack ($M)	Relative Probability of Occurrence	Expected Damage without MTR System ($M)	Expected Damage with MTR System ($M)
WMD	95	500,000	0.001	1,000	50
SAW	90	2,500	1.0	500	50
SBA	88	1,000	2.0	400	50

Table 5-1: Damage Cost and System P_s Requirements

5.2.2 Requirements Flow Down

The requirements flow down process begins with the information obtained from the various stake-holders and SMEs involved in the project. At the beginning of the problem definition phase the missions and scenarios are not fully developed, resulting in stakeholder needs stated in more general and abstract form. As the scenarios become more fully fleshed out, the stakeholder needs are redefined in more detail. Once the top-level system functions are identified (C4ISR, PBS, Find/Fix, Finish, and Sustain), the stakeholder system requirements are broken down by requirements within each of the system functions. For example, a stakeholder need for a system that stops WMD from being carried by commercial container ships into U.S. ports is broken into its C4ISR requirements (tracking the shipment via the MDA system), PBS (deploying teams to the container ship prior to arrival in port), Find/Fix (searching the container ship and being able to pinpoint the container holding a potential WMD), Finish (disposing of the WMD), and Sustain (enabling the search teams to conduct their mission). Top-level values are then assigned to each of the functional requirements. For example, in the WMD mission the typical container ship carrying a shipment from Singapore to a port in San Francisco would take approximately 21 days to complete its voyage across the Pacific Ocean. According to the stakeholders and SMEs, a search of the containers for a WMD on the vessel as it is transiting would take at least 7 days (see Appendix B for a complete description). Since the stakeholder requirement is to find the WMD cargo prior to entering the U.S. port, and the search would take at least 7 days to complete, the top-level time requirement for PBS is 14 days or less. All the subfunctions within PBS must therefore aggregate to no more than 14 days (though some subfunctions may take place in parallel; in this case, their time requirements do not necessarily add to 14 days).

As each of the top-level system functions is decomposed into subfunctions, the system requirements categorized by each top-level function are also allocated to the subfunctions such that the aggregate top-level requirement would reflect the subfunction requirements when combined in series or parallel (depending on how the subfunctions interacted with each other). For example, in the Sustain Function the top-level probability of success (P_s) for the function is set at 0.9999 (see Appendix B). The probability of success required for the two second-level subfunctions (Support Units and Maintain Units) is obtained by taking the square root (since the two subfunctions operated in series) of the top-level function requirement , yielding the requirement of P_s equal to 0.99995 for Support Units and Maintain Units.

Determination and assignment of values for each of the functions and subfunctions are then used as goals for the designing the system components. Additionally, these requirement goals are used as objectives when measuring the effectiveness of the systems during the modeling and simulation phase. When a system achieves the established P_s or time objectives, the system is then deemed successful in meeting the associated stakeholder requirement. For example, for an SoS architecture, if an aggregate time for all PBS subfunctions is less than 14 days, then the PBS function within that architecture is deemed a success.

5.2.2.1 C4ISR

There are two types of system-level requirements for C4ISR—timing and probability of success. The required probability of success for C4ISR is near unity (99.9%). The probability of success requirement is flowed down to a near unity probability of success for all lower-level functions as shown in Appendix B.

The maximum time for the C4ISR function to issue initial ROE and orders is 24 hours for the WMD mission, 30 minutes for the SAW mission, and 1 hour for the SBA mission. This time period functions as the C4ISR system's initial response time, and commences at time zero when the C4ISR system receives the initial tasking order from higher authority. For the WMD scenario, the C4ISR function has the additional requirement to activate all forces within 1 hour of receiving this initial tasking order. Since both must occur within 1 hour of time, the timing allocation for the SBA initial response is used for the WMD forces activation and is covered in the SBA section only. Furthermore, the SAW mission timing allocation is also used for the WMD mission's operational response time and is discussed in the SAW section only. Trade studies are performed and subject matter experts are consulted in allocating the requirements to lower-level functional requirements as shown in Appendix B. This flow down for each mission follows.

WMD Mission

To provide the capability to issue orders and ROE, C4ISR requires the execution of these four functions: C2, Communicate, Compute, and Provide Intelligence. Subtracting the initial 1-hour force activation time, these functions must therefore be completed within the remaining 23 hours. The C2 function has a total of 11 hours within which to gather and understand the available information and to prepare the final detailed orders and ROE. To do this rapidly, the C2 function employs the Communicate, Compute, and Provide Intelligence functions. The Communicate function has a total of 4 hours within which to send and receive information. The Compute function has a total of 7 hours to assure incoming information and fuse it for use by the Provide Intelligence function. The Provide Intelligence function then has no more than 1 hour within which to form both the overall and the customized operational pictures.

C2 consists of commanding forces and simultaneously interfacing with external C2. Commanding forces must take place with 6 hours, while interfacing with external C2 must be completed in less than 5 hours. In order to perform C2, information must be transmitted and received via the Communicate function. The three communication subfunctions of Providing Voice/Data, Networking MTR Nodes, and Receiving MDA Intelligence are assumed occur simultaneously within a 4-hour total period. Data received via the Communicate function flows to the Compute function where it is first assured and then fused. The Information Assurance function must take no more than 1 minute while the Data Fusion function can run for up to 7 hours in order to converge on the best solution. The fused information is simultaneously routed to both the C2 function for review and the Provide Intelligence function for transformation into an overall operational picture. Provide Intelligence has a maximum of 1 hour to perform the functions: Form Overall Operational Picture, Analyze Operational Needs, and Provide Customized COPs. Each of these subfunctions can take no longer than 20 minutes.

SAW Mission

As in the WMD mission, C4ISR requires the execution of these four functions: C2, Communicate, Compute, and Provide Intelligence. These functions must therefore be completed within the 30-minute initial response time requirement. At time zero, intelligence data begins to flow through the Communicate function into the Compute function. Communications into the system may take no more than 5 minutes. Once the information is assured, it is available to the C2 function for initial review. Information assurance must be completed in 1 minute. Simultaneous with C2 review, the Compute function fuses the data and creates or updates the COP. Data fusion occurs within 13 minutes and COP creation within 1 minute. The C2 time includes the 14 minutes allocated to the Compute function as well as an additional 5 minutes following Compute function completion for final review of orders prior to sending. The process of communicating the orders to all forces must take place within 5 minutes.

The C2 function consists of commanding forces and interfacing with external C2. Commanding forces must take place within 14 minutes, while interfacing with external C2 must be completed in less than 5 minutes, for a total of 19 minutes. In order to communicate, no more than 5 minutes can be used in receipt of information and no more than 5 minutes can be used to transmit information, for a total communication time limit of 10 minutes. The Network MTR Nodes function is assumed to occur simultaneously and therefore must occur within this 10-minute period. The Provide Intelligence function includes forming the overall and customized COPs as well as analyzing operational needs. These three subfunctions are assumed to occur nearly simultaneously within 1 minute.

SBA Mission

As in the WMD and SAW missions, C4ISR requires the execution of these four functions: C2, Communicate, Compute, and Provide Intelligence. These functions must therefore be completed within the 1-hour initial response time requirement. At time zero, intelligence data begins to flow through the Communicate function into the Compute function. Communications into the system may take no more than 5 minutes. Once the information is assured, it is available to the C2 function for initial review. Information assurance must be completed in no longer than 1 minute. Simultaneous with C2 review, the Compute function fuses the data and creates or updates the COP. Data fusion occurs within 33 minutes and COP creation within 1 minute. The C2 time includes 5 minutes of initial review time, 34 minutes allocated to the Compute function, and an additional 10 minutes following Compute function completion for final review of orders prior to sending. The process of communicating the orders to all forces must take place within 5 minutes.

The C2 function consists of commanding forces and interfacing with external C2. Commanding forces must take place within 30 minutes, while interfacing with external C2 must be completed in less than 19 minutes, for a total of 49 minutes. In order to Communicate, no more than 5 minutes can be used in receipt of information and no more than 5 minutes can be used to transmit information, for a total communication time limit of 10 minutes. The Network MTR Nodes function is assumed to occur simultaneously and therefore must occur within this 10-minute period. The Provide Intelligence function includes forming the overall and customized COPs as well as analyzing operational needs. These three subfunctions are assumed to occur nearly simultaneously within 1 minute.

5.2.2.2 Prepare the Battlespace

There are two types of system-level requirements for preparing the battlespace—timing and probability of success. The required probability of success for prepare the battlespace is near unity (99.9%). The probability of success requirement is flowed down to a near unity probability of success for all lower-level functions (Appendix B).

The maximum time to prepare the battlespace is 124 hours for the WMD mission, 36 hours for the SAW mission, and 6 hours for the SBA mission. Trade studies are performed and subject matter experts are consulted in allocating the requirements to lower-level functional requirements as shown in Appendix B. This flow down for each mission follows.

WMD Mission

Prepare the Battlespace requires the execution of these three functions: Activate Security Measures, Assemble and Prepare Teams and Platforms, and Deploy the Forces. These functions must therefore be completed within 124 hours. Both the activation of security measures and the assembly and preparation of teams and platforms must occur within 24 hours from the arrival of the intelligence. Forces must be deployed within 100 hours from the time the teams and platforms have been assembled and prepared.

Activating security measures consists of preparing the critical infrastructure and simultaneously activating preplanned operational orders (OPORDS). Preparing the critical infrastructure must take place within 12 hours, while activating preplanned OPORDS must be completed in less than 24 hours. In order to prepare the critical infrastructure, the Homeland Security Advisory System (HSAS) level must be heightened in less than 1.5 hours. The process of heightening the HSAS level accounts for the time to initiate the command to the Department of Homeland Security to heighten the level and the time to receive compliance that the level has been heightened. The 24-hour timing requirement for activating preplanned OPORDS accounts for placing specialized teams on alert within 24 hours and getting the United States Coast Guard to activate their specific Maritime Security (MARSEC) plan within 1 hour. In order to place the specialized teams on alert, the SoS must contact the specialized teams in less than 2 hours, assemble them in less than 12 hours, and activate them within the following 10 hours.

The time to assemble and prepare teams and platforms is composed of the time to activate the required personnel, the time to issue equipment, and the time to prepare deployment platforms. Personnel can be activated for the entire 24-hour period while team composition must be decided within 2 hours, all necessary personnel contacted within 2 hours, and personnel mustered within 20 hours. Equipment must be issued in less than 14 hours, of which no more than 12 hours will be spent for gathering specialized equipment and no more than 2 hours for providing arms, protective gear, and equipment. The remaining activity is to prepare the deployment platforms, which must be completed within 16 hours. During this time, all mission specific configurations will be set.

The forces must be deployed within 100 hours of the completion of the preparation of teams and platforms in order to get the teams and their equipment out to the merchant vessels traveling across the ocean with sufficient time to search the containers. The time to deploy the forces accounts for the times it takes for the teams to embark the deployment platforms, to move the deployment platforms into position, to move teams and their equipment to potential attacking vessels, and to recover the teams from the potential attacking vessels when their search is complete. The teams, with all their equipment, must embark the deployment platforms in less than 1 hour. After all teams are onboard, the deployment platforms must be moved into position in less than 96 hours. Once in position, the teams and all their equipment must be moved to the potential attacking vessel in less than 2 hours. Within this 2-hour period, the teams must be gathered for debarkation of the deployment platforms in less than 30 minutes, and they must be provided with a means of transport to the potential attacking vessel within the remaining 1.5 hours. After carrying out their search mission, they must be gathered for debarkation and then returned to the deployment platforms in less than 2 hours.

SAW Mission

As in the WMD mission, Prepare the Battlespace requires the execution of these three functions: Activate Security Measures, Assemble and Prepare Teams and Platforms, and Deploy the Forces. These functions must therefore be completed within 36 hours. Both the activation of security measures and the assembly and preparation of teams and platforms must occur within 24 hours from the arrival of the intelligence. Forces must be deployed within 12 hours from the time the teams and platforms have been assembled and prepared.

Activating security measures consists of preparing the critical infrastructure and simultaneously activating preplanned operational orders (OPORDS). Preparing the critical infrastructure must take place within 12 hours, while activating preplanned OPORDS must be completed in less than 1 hour. In order to prepare the critical infrastructure, the Homeland Security Advisory System (HSAS) level must be heightened in less than 1.5 hours and the existing security forces within the bay area must be upgraded and/or augmented in less than 12 hours. The process of heightening the HSAS level accounts for the time to initiate the command to the Department of Homeland

Security to heighten the level and the time to receive compliance that the level has been heightened. The time to upgrade and/or augment existing security forces accounts for notifying gas line personnel in less than 4 hours and upgrading and/or augmenting security teams at points of critical infrastructure in less than 12 hours. The 1-hour timing requirement for activating preplanned OPORDS accounts for placing specialized teams on alert within 1 hour and getting the United States Coast Guard to activate their specific MARSEC plan within 1 hour. In order to place the specialized teams on alert, the SoS must contact the specialized teams in less than 15 minutes, assemble them in less than 15 minutes, and activate them within the following 30 minutes.

The time to assemble and prepare teams and platforms is composed of the time to activate the required personnel, the time to issue equipment, and the time to prepare deployment platforms. Personnel can be activated for the entire 24-hour period while team composition must be decided within 2 hours, all necessary personnel contacted within 2 hours, and personnel mustered within 20 hours. Equipment must be issued in less than 6 hours, of which no more than 4 hours will be spent for gathering specialized equipment and no more than 2 hours for providing arms, protective gear, and equipment. The timing requirements reflect the fact that it takes less time to load a smaller amount of equipment for the SAW mission than the WMD mission. The remaining activity is to prepare the deployment platforms, which must be completed within 16 hours. During this time, all mission specific configurations will be set.

The forces must be deployed within 12 hours of the completion of the preparation of teams and platforms in order to get the teams and their equipment out to the merchant vessels traveling across the ocean with sufficient time to search the crew and escort them to their final destination. The time to deploy the forces accounts for the times it takes for the teams to embark the deployment platforms, to move the deployment platforms into position, to move teams and their equipment to potential attacking vessels, and to recover the teams from the potential attacking vessels when their search is finished. The teams, with all their equipment, must embark the deployment platforms in less than 1 hour. After all teams are onboard, the deployment platforms must be moved into position in less than 12 hours. Once in position, the teams and all their equipment must be moved to the potential attacking vessel in less than 1.5 hours. Within this 1.5-hour period, the teams must be gathered for debarkation of the deployment platforms in less than 30 minutes, and they must be provided with a means of transport to the potential attacking vessel within the remaining 1 hour. After carrying out their search and escort mission, they must be gathered for debarkation and then returned to the deployment platforms in less than 1 hour.

SBA Mission

As in the WMD and SAW missions, Prepare the Battlespace requires the execution of these three functions: Activate Security Measures, Assemble and Prepare Teams and Platforms, and Deploy the Forces. These functions must therefore be completed within 4 hours. The activation of security measures and the assembly and preparation of teams and platforms must begin immediately upon receipt of the intelligence. The activation of security measures must be completed within 24 hours from the arrival of the intelligence while the assembly and preparation of teams and platforms must be completed within 55 minutes from the arrival of the intelligence. Forces must be deployed within 30 minutes from the time the teams and platforms have been assembled and prepared.

Activating security measures consists of preparing the critical infrastructure and simultaneously activating preplanned OPORDS. Preparing the critical infrastructure must take place within 4 hours, while activating preplanned OPORDS must be completed in less than 1 hour. In order to prepare the critical infrastructure, the HSAS level must be heightened in less than 1 hour and the existing security forces within the bay area must be upgraded and/or augmented in less than 4 hours. The process of heightening the HSAS level accounts for the time to initiate the command to the Department of Homeland Security to heighten the level and the time to receive compliance that the level has been heightened. The time to upgrade and/or augment existing security forces accounts for notifying gas line personnel in less than 30 minutes and upgrading and/or augmenting security teams at points of critical infrastructure in less than 2 hours. The 1-hour timing requirement for activating preplanned OPORDS accounts for getting the United States Coast Guard to activate their specific MARSEC plan within 30 minutes and beginning the restriction of non-essential boat traffic within 1 hour. In order to begin that restriction, the SoS must initiate the command to the USCG to post a "Notice to

Mariners" in less than 30 minutes, receive compliance that "Notice to Mariners" has been posted in less than 30 minutes, and activate the boat traffic restriction teams in less than 30 minutes.

The time to assemble and prepare teams and platforms is composed of the time to activate the required personnel, the time to issue equipment, and the time to prepare deployment platforms. Personnel can be activated for the entire 55-minute period while team composition must be decided within 15 minutes, all necessary personnel contacted within 15 minutes, and personnel mustered within 25 minutes. Equipment must be issued in less than 50 minutes, of which no more than 30 minutes will be spent for gathering specialized equipment and no more than 20 minutes for providing arms, protective gear, and equipment. The remaining activity is to prepare the deployment platforms, which must be completed within 45 minutes. During this time, all mission-specific configurations will be set.

The forces must be deployed within 40 minutes of the completion of the preparation of teams and platforms in order to get the teams and their equipment out to the high value targets with sufficient time to carry out escorting/guarding missions. The time to deploy the forces accounts for the times it takes for the teams to embark the deployment platforms, to move the deployment platforms into position, to move teams and their equipment to potential attacking vessels (if necessary, depending on the architecture alternative), and to recover the teams from the potential attacking vessels when their search is finished (if necessary, depending upon the architecture alternative). The teams, with all their equipment, must embark the deployment platforms in less than 5 minutes. After all teams are onboard, the deployment platforms must be moved into position in less than 25 minutes. Once in position, the teams and all their equipment must be moved to the potential attacking vessel in less than 10 minutes. Within this 10-minute period, the teams must be gathered for debarkation of the deployment platforms in less than 30 seconds, and they must be provided with a means of transport to the potential attacking vessel within the remaining 9.5 minutes. After carrying out their escort/guard mission, they must be gathered for debarkation and then returned to the deployment platforms in less than 10 minutes.

5.2.2.3 Find/Fix the Threat

There are two types of system-level requirements for Find/Fix the threat—timing and probability of success. The required probability of success for Find/Fix the Threat is different for each mission: 96% for WMD, 99% SAW, and 94% for SBA. Trade studies are performed and subject matter experts are consulted in allocating the requirements to lower-level functional requirements. The requirement flow down for each mission follows.

<u>WMD Mission</u>

Find/Fix the threat requires the execution of three functions: Detection, Identification, and Assessment. These functions must be completed simultaneously within 160 hours. Detection consists of physically walking the ship while simultaneously following standard operating procedures (SOP). Detection must take place within 3 minutes per container.

As personnel proceed through the ship to prosecute each cargo container, the organic capabilities of the detection devices will help to identify what source is present within the range of the operator. The final portion of Find/Fix the nuclear threat is to assess the nuclear source once it is located and identified. This process is also required to take place simultaneously with the detection and identification, thus the 3-minute requirement.

<u>SAW Mission</u>

As in the WMD mission, Find/Fix the threat requires the execution of these three functions: Detection, Identification, and Assessment. These functions must therefore be completed upon boarding the vessel of interest. While stepping through the process to Find/Fix the threat, the functions of detection, identification and assessment need to be completed simultaneously. Detection consists of physically walking the ship to interrogate each member of the ship's crew while following SOP. As personnel proceed through the ship to scrutinize each crew member, the detection devices will also help to identify the person. The final portion of Find/Fix the terrorist threat is to assess the destructive potential of that person once he is located and identified. This process is also required to take place simultaneously with the detection and identification and has a goal of being completed before arriving in San Francisco.

SBA Mission

As in the previous two missions, Find/Fix the threat requires the execution of these three functions: Detection, Identification, and Assessment. These functions must therefore be completed within the time it would take the assets available to detect an incoming small boat at a sufficient range, issue a warning, identify the profile of the potential attacker and fire two warning shots. While stepping through the process to Find/Fix the threat, the functions of detection, identification and assessment need to be completed simultaneously. Detection consists of physically viewing the area of interest while simultaneously following SOP. As personnel scrutinize the actions of all vessels within the area they also have to be able to identify a potential attacking profile of small boats in the area. The final portion of Find/Fix the small boat threat while in the San Francisco Bay is to assess the potential that each small boat has in damaging or destroying the high value unit. This process is also required to take place simultaneously with the detection and identification and is an ongoing process.

5.2.2.4 Finish Threat

There are two system-level requirements for Finish—probability of success and time. The probability of success for Finish varies with mission. It is near unity (99.9%) for the WMD mission, 94% for the SAW mission, and 87.5% for the SBA mission. The time requirements also vary with mission. The time requirement is over five days for the WMD mission, 21 minutes for the SAW mission, and 15 seconds for the SAW mission. The probability of success is flowed down to all lower level functions. The probability of success and timing requirements only apply to functions that are necessary and sufficient for mission success (see Appendix B).

WMD Mission

Finish requires the execution of only one function—Sink/disable—because the scenario assumes a cooperative merchant and no terrorists onboard. Also, if a WMD is found on the vessel the response functions will be handled by specialized personnel from the Department of Energy (DOE). Per stakeholder guidance, those functions are out of the scope of the MTR SoS.

In unforeseen circumstances, or by order of DOE or higher authority, a suspect vessel may need to be sunk. All of the U.S. platforms considered in the study carry weaponry sufficient to accomplish this task in the time allotted. Other DHS and DoD assets are also presumed to be capable of assisting if so ordered. The time allowed for this function will be measured in days. It is reasonable to assume that the collective law enforcement and military assets of the United States could sink a stationary, unarmed merchant vessel at a known location in five days.

SAW Mission

Finish requires the completion of four functions in this scenario: Guard HVU from internal threat, Use of lethal measures, Disable, and Recapture. The probability of success and time required for these functions are listed in Appendix B.

The probability of success and timing requirements are best considered in conjunction with the Prepare Battlespace functions for the SAW mission. The Finish functions cannot occur or have any probability of success unless the PBS functions are successfully completed. The Find/Fix functions relating to SAW mission are also precursors to Finish in this mission. A near unity (99.9%) probability of success is assumed for the SAW mission.

SBA Mission

Finish requires the completion of 3 functions and 7 subfunctions in this mission. They are Guard HVU from external threat (Escort with other units, Place escorts on HVU), Conduct nonlethal weapon engagement, and Use lethal measures (Detect/Track, Classify, Target, Fire weapon, Assess engagement). The probability of success and time required for these functions are listed in Appendix B.

5.2.2.5 Sustain

There are two types of requirements for Sustain—timing and probability of success. Each system-level requirement is flowed down to all lower-level functions and is described in Appendix B.

WMD Mission

Based on the normal transit time of a commercial container ship transiting from Southeast Asia to a port in San Francisco, the WMD mission is assumed to last no longer than 20 days (not counting latency of intelligence concerning the container ships cargo). Long range ships used within the WMD mission therefore require supply of parts and consumables less than or equal to once per 20 days (assuming long range ships are capable of carrying at least 20 days' worth of consumable supplies such as food).

Based on stakeholder needs, the system must be capable of providing ships that can sprint from their home port of origin to the transiting container ship without being refueled prior to first intercept. Initially estimated time for a military ship to go from underway (from home port in San Diego) until intercept of the container ship is approximately five days. The system must therefore be able to refuel the military ships within five days of getting underway—assuming the military ships are the method used to transport the MTR search teams to the container ship. Another possibility for MTR search team transport is by long range, medium lift helicopter (large enough to carry the MTR team and equipment). According to the SMEs, the distance would be great enough that in-flight refueling would be required at a rate of six times per day.

Current joint military doctrine makes use of the Status of Resources and Training System (SORTS) for reporting unit location, identification and general status to the operational commander.[62] Updates to SORTS are required within four hours of a change in status, unless otherwise stated by a unit's standard operational procedure. Changes to manning and other unit needs would therefore be reported no more than six times per day (assuming constant change during a 24-hour period). Consequently, SORTS reports would be input and assessed no more than six times per day (per assessment), and actions taken in response to SORTS updates would be performed no more than six times per day.

An MTR team would either be transported to the container ship once and remain there until the conclusion of their search or require (worst case) three sections of teams working eight hour shifts each, being transported to/from the container ship every eight hours. A worst case requirement of transport is three times per day. A best case is twice per 20 days (one transport on, one transport off at conclusion of search).

[62] D. Schrady, "Combatant Logistics Command and Control for the Joint Force Commander."

MTR search teams onboard the container ships require berthing (i.e., sleeping quarters) once per day per team. Berthing can be reutilized for multiple search teams when working in shifts (i.e., hot-racking).

Units' organic maintenance and medical capabilities need only be identified once Prior to the start of the mission in order to asses their needs during the mission. Military ships normally will obtain or maintain an inventory of spare parts and supplies sufficient to maintain themselves for the duration of an assigned mission. Given that a ship understands its mission and the parts and components of vital use during the mission, it would require supply of those spare parts and replacement components prior to beginning the mission (assuming it could maintain all spares within its store-rooms).

The WMD mission is estimated to last no longer than 20 days. Should the mission duration be extended to several months or longer, an impact on post-unit readiness could become a factor if the unit were not allowed its normal rotational maintenance and leave schedules. Units with scheduled depot-level maintenance such as yard periods must be allowed to rotate duty with other units to ensure a future mission readiness is maintained. Because the mission duration is estimated at 20 days, rotational schedules will most likely not be affected.

The overall time to support the units can be estimated by the considering the most limiting subfunction (time to deliver consumables, time to refuel platforms, time to provide manning, time for barracks). This yields a requirement of less than or equal to six times per day to support the units involved in the WMD mission. The system-level requirement for Sustain is calculated in the same manner (consisting of the two second-level subfunctions, Support Units and Maintain Units). This yields a value of less than or equal to six times per day that the Sustain function must be performed, based on stakeholder needs and SME input.

<u>SAW Mission</u>

From a Sustain functional perspective the SAW mission does not differ drastically from the WMD mission with respect to the subfunctions and requirements involved. The CONOPS in both missions involve a ship intercepting a large tonnage commercial vessel. Upon intercept of the commercial vessel, rather than delivering search teams, the SAW mission delivers a Visit Board Search and Seizure (VBSS)-type team to retake the commercial vessel under hostile terrorist control. The VBSS team's actions to retake the commercial vessel will not last more than a few hours—therefore the requirement to sustain the VBSS team is limited to one delivery and pickup, by helicopter (fast-rope) or small boat transfer. Based on SME input helicopters fly a 4-hour mission (with 30 minutes in between operation included) and require refueling (at most) six times per day. All other subfunctions composing Sustain in the SAW mission have requirements assigned in the same manner as in the WMD mission as per WMD mission.

SBA Mission

The SBA mission involves small boats (i.e., RHIBs), medium-size ships (i.e., USCG 110-foot class ships), helicopters, Unmanned Surface Vessels (USVs), or Sea Marshal-type boarding teams. The SBA mission takes place within a harbor along the U.S. coast, extending out to the 12-NM mark at sea. All sustain functions occur by movement of units to a centralized shore-based site where they receive parts, supplies, fuel, spares, and/or conduct crew swap out. Based on the SBA scenario description (see Section 4) the duration of a unit's mission lasts (at most) 14 hours per day. Requirements assigned to Sustain subfunctions are therefore based on a 14-hour day, as shown below.

During the operational day, High-Value Unit (HVUs) commercial vessels (not including water taxis) transiting into or out of the harbor require escort to and from the 12-NM marker by their assigned MTR unit. Small boats assigned to escort water taxis in the harbor swap crews out every seven hours (for a total of two duty sections per day). Each duty section carries one meal per person. Based on stakeholder input, performing escort duty for non-water taxi HVUs must be continuous; maintaining the same escort unit throughout the transit is preferred. Small boats performing this escort function are unable to operate in crew "shifts" since they are unable to return to their home base during the 14-hour day. Therefore, they receive two meals per crew member per day. At the end of the operational day, small boats performing either HVU or water taxi escort return to their home base where maintenance and refueling are conducted. Small boat crews are housed and sleep at a shore facility until the beginning of the next duty day.

Medium-size ships operate continuously throughout the 14-hour day. Two meals per crew member are supplied to each ship per day. Like small boats, at the end of the duty day the ship's crew is housed and sleep at a shore facility until the beginning of the next duty day.

Helicopters require refueling once per four hours (including a 30-minute refueling period) or four times per operational day. In the 30-minute refueling period the crew will eat at the short facility (therefore requiring no meals to be carried during their mission). To affect a continuous escort of HVU and water taxis, two sections of helicopters are operated; when one helicopter requires refueling a second helicopter takes over escort duty for the next 3.5 hours. At the end of the second helicopter's 3.5 hours the first helicopter (now refueled) resumes the escort. Thus continuous coverage is provided. This also causes a helicopter crew to fly for no more than seven hours per day—thus no helicopter crew swap out is necessary. Maintenance on helicopters is conducted at the end of the operational day; helicopter crews are housed and sleep at a shore facility until the beginning of the next duty day.

A Note on Probability of Success Requirement for Sustain

Stakeholder input set P_s for Sustain at 99.99%. The flowed-down subfunctions composing Sustain combine in series and must therefore result in the value of .9999 for P_s. Subfunctions have therefore been calculated to reflect the aggregate value for Sustain. The values for each of the subfunctions (essentially unity) reflect a stakeholder desire for virtually no failures in any of the Sustain subfunctions. This has a profound effect on the number of units and spare parts required to allow the system of systems to function continuously without the threat of any system failure causing a delay in the mission.

6.0 THREAD ANALYSIS

Thread analysis allows functional traceability within a system. A thread or scenario is a sequence of system operations. It is an ordered list of events and actions which represents an important behavior. It normally does not contain branches; that is, it is a single serial scenario of operation, a stimulus/response thread. Branches are represented by additional threads."[63] Therefore, thread analysis is the evaluation of system functions with respect to a given scenario or mission. The analysis follows a thread through the sequence of system operations, to ensure for a designated mission the system meets the functional requirements set by the stakeholders.

By convention a thread is only traced within the same level from function to function. So, a thread traced at the top level functions would look very basic going from C4ISR to PBS to Find/Fix to Finish, for a very simple mission depiction, while threads traced amongst second-level functions show additional details (Figure 6-1). Threads enter a function as a functional input into the top of a function box and exit the function from the right side as a functional output to the next function. The outputs exiting the left side of the function box are for feedback to previous functions and are feedback inputs to the bottom of a previous function box.

At the third-level functions there is better identification of action sequences as well as feedback loops for a scenario within any mission. The first three levels of the SoS Functional Decomposition are seen in Table 6-1. In Appendix A, the functions are broken down into fourth-, fifth-, and even seventh-level functions in some cases. These provide more clarity to specific actions to be completed.

[63] Mark Maier and Eberhardt Rechtin, "The Art of Systems Architecting," 2nd Edition, March 2000.

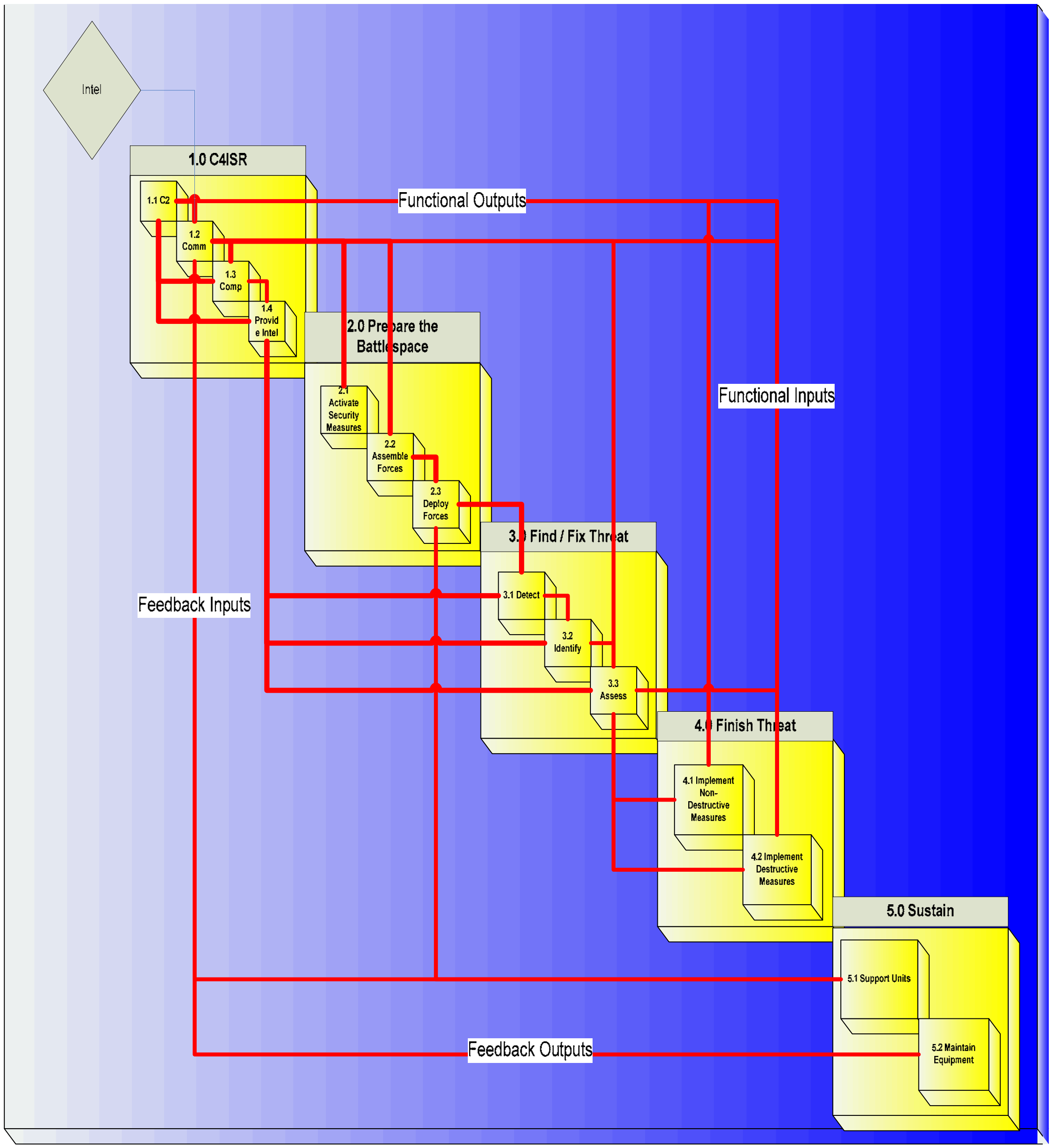

Figure 6-1: Second-Level Functional Threads

First Level	Second Level	Third Level
1.0 C4ISR	1.1 Command and Control	1.1.1 Command Forces
		1.1.2 Interface with External C2
	1.2 Communicate – Provide onshore, ship-based and sea-based communication network	1.2.1 Provide VOX/Data
		1.2.2 Network MTR Nodes
		1.2.3 Receive MDA Intel
	1.3 Computing	1.3.1 Information Assurance (Security Policy)
		1.3.2 Data Fusion (Redundant System)
	1.4 Provide Intelligence	1.4.1 Form Overall Operational Picture
		1.4.2 Analyze Operation Needs of Individual Functional Teams
		1.4.3 Provide Customized COP Overlays to Various Functional Teams Based on Operational Needs
2.0 Prepare the Battlespace	2.1 Activate Security Measures	2.1.1 Prepare Critical Infrastructure
		2.1.2 Activate Preplanned Operation Orders
		2.1.3 Restrict Nonessential Boat Traffic
	2.2 Assemble Forces	2.2.1 Activate Required Personnel
		2.2.2 Issue Equipment
		2.2.3 Prepare Deployment Platforms
	2.3 Deploy Forces	2.3.1 Embark Deployment Platforms
		2.3.2 Move Deployment Platforms into Position
		2.3.3 Move Teams to Attacking Vessel
		2.3.4 Recover Teams From Attacking Vessel
3.0 Find/Fix Threat	3.1 Detect Threat	3.1.1 Scan Area of Interest
		3.1.2 Process Data from Scan
	3.2 Identify Threat	3.2.1 Analyze Data On-Site
		3.2.2 Analyze Data Off-Site
		3.2.3 Quantify Threat
	3.3 Assess Threat	3.3.1 Determine Intent
		3.3.2 Determine Damage Potential
4.0 Finish Threat	4.1 Use Nonlethal Measures	4.1.1 Guard HVU From Internal Threat
		4.1.2 Guard HVU From External Threat
		4.1.3 Warn
		4.1.4 Conduct Nonlethal Weapon Engagement
		4.1.5 Shoulder
		4.1.6 Tow disabled vessel
		4.1.7 Conduct SAR
	4.2 Use Lethal Measures	4.2.1 Disable
		4.2.2 Sink/Destroy
		4.2.3 Recapture
5.0 Sustain	5.1 Support Units	5.1.1 Deliver consumables, parts and supplies to units
		5.1.2 Refuel platforms
		5.1.3 Be able to provide disposal services (both for vessels [within 12nm of land] and people)
		5.1.4 Provide appropriate manning for sustained operations
		5.1.5 Provide barracks (i.e., sleeping quarters) for sustained manning
	5.2 Maintain Equipment and People	5.2.1 ID units without organic maintenance/medical capabilities
		5.2.2 Provide trained bodies to conduct maintenance/health care where deficiencies exist
		5.2.3 Rotate units to conduct Preventative Maintenance Services (PMS)/Corrective Maintenance Services (CMS)/Stand-down

Table 6-1: Functional Architecture (showing first three levels)

Sample Mission Thread Analysis

A thread analysis is performed to show the relationships among all third-level functions for a sample SAW mission. The scenario begins when information is received about the intent of terrorists to use a ship as a weapon in the San Francisco Bay Area. The rest of this section explains the flow of the mission and is depicted through threads on the associated figures.

The C4ISR threads link subfunctions to other subfunctions, representing the flow of attributes through the C4ISR system. The subfunctions generate outputs which are inputs to different subfunctions. Figure 6-2 shows the thread diagram for the C4ISR system, and an explanation of this graphic representation follows. See Table 6-1 for the function associated with the numerical designations.

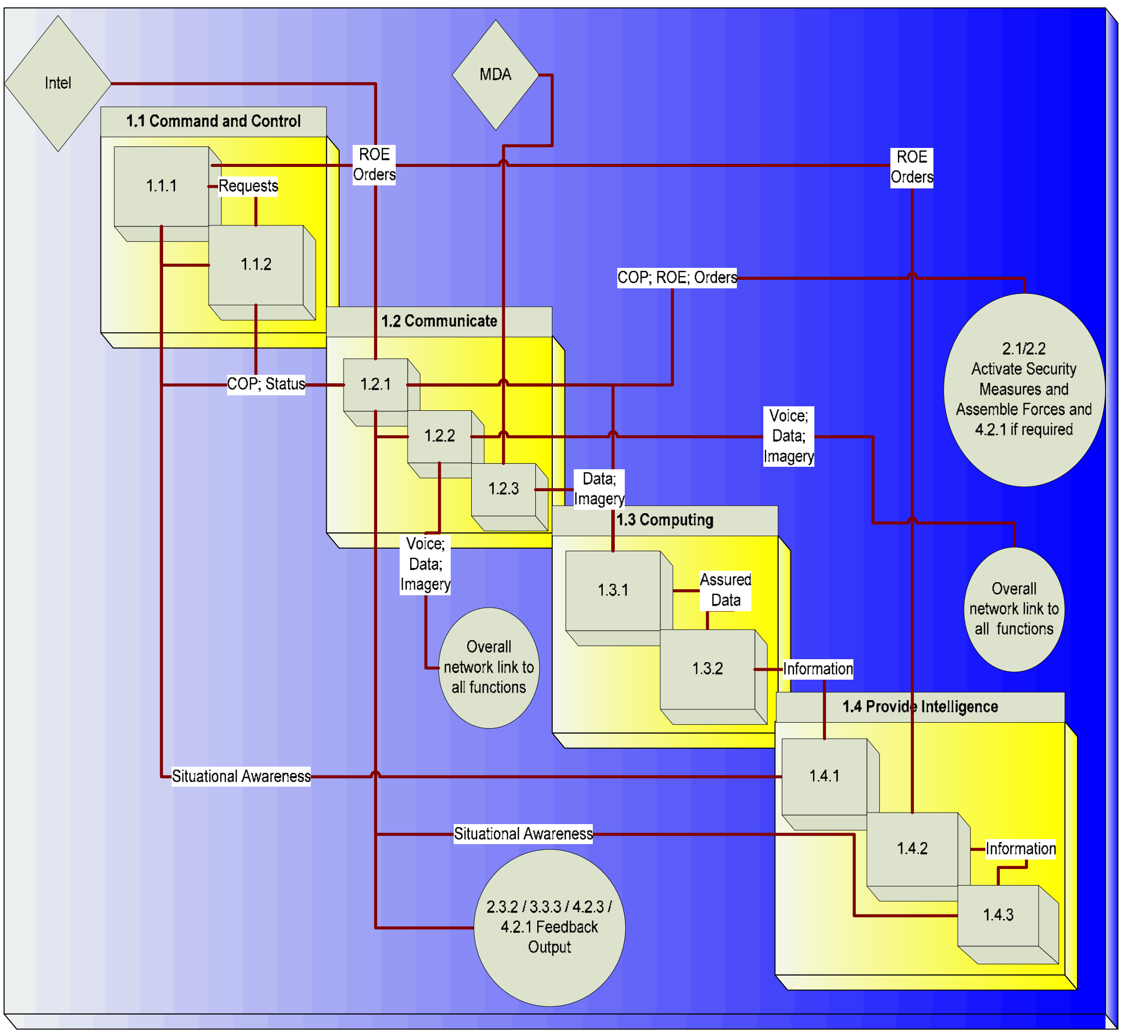

Figure 6-2: C4ISR SAW Thread Diagram

The C4ISR system is activated when an order is received from higher authority. The order comes in through the communicate function, interfaces with external C2 function, and passes to the Command Forces function. Command Forces either requests further information or permission via the Interface with External C2 function or sends orders and rules of engagement (ROE) through the function—Provide Voice/Data to the functions—Activate Security Measures and Assemble Forces within PBS. The ROE and orders are simultaneously sent to the Provide Intelligence function for use in creating customized operational pictures. Intelligence provided by the MDA system is received via the Communicate function. This intelligence is sent in the form of both data and imagery, which is next routed to the Compute function. Within the Compute function, the data and imagery are first passed through the Information Assurance function, which transforms the intelligence into Assured Data. The Assured Data next flows to the Data Fusion function, where it is correlated and exits as Fused Information. The Fused Information then flows into the Provide Intelligence function where it is transformed by the Form Overall Operational Picture function into Situational Awareness. This Situation Awareness flows into the Command Forces function where it is used to complete the generation of orders and ROE. The orders and ROE are used by the Analyze Operational Needs function to create information that is used by the Build Customized COPs function, wherein specialized views are developed for the individual teams based on their operational assignments. The overall COP and custom COPs are routed to the Communicate function which sends them to both the Interface with External C2 and the PBS Deploy function. Mission specific feedback from PBS, Find/Fix and Finish is routed to the communicate function Provide Voice/Data. Voice information is sent to Command Forces and while data and imagery is sent to Information Assurance for further routing through intelligence to become part of the COP and then routed back to Command Forces. All other system-level functions are linked to the overall network through the Communicate function 1.2.2 and can exchange voice, data, and imagery.

In Figure 6-3, the PBS third-level functions for the SAW mission receive direction from C4ISR via C4ISR 1.2.1 and is sent to Activate Preplanned OPORDs. These orders then are forwarded to Prepare Critical Infrastructure and Activate Required Personnel to and then flows to Issue Equipment. Activate Required Personnel receives input from the Sustain function Provide Appropriate Personnel. Next the thread is traced to Prepare Deployment Platforms. The thread is then traced through the Move Deployment Platform subfunction to position the Response Force ships to intercept the PAV, which sends a thread back to C4ISR for communication feedback and receives a thread from Sustain for resupply and replacements. The next PBS thread is progressed to the Boarding Teams embark on the PAV subfunction. This thread now flows to the Find/Fix set of functions.

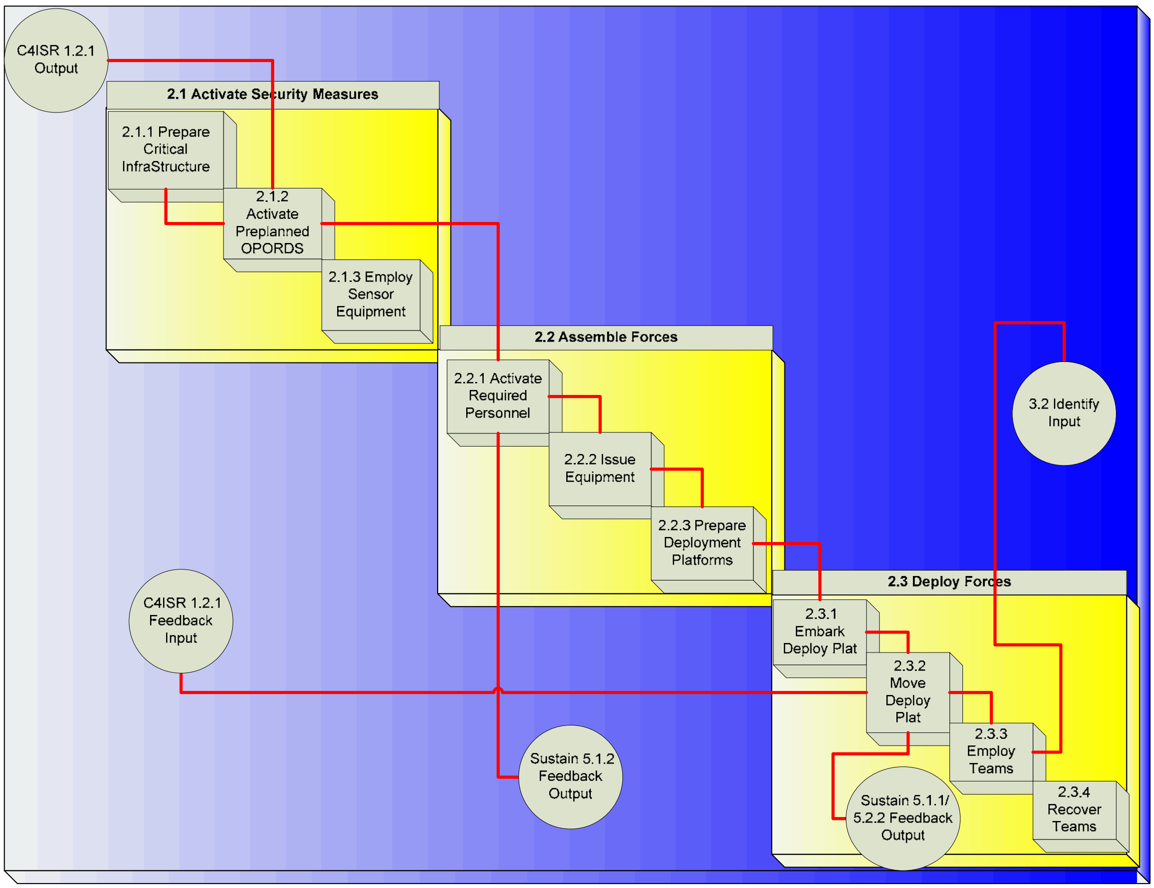

Figure 6-3: PBS SAW Thread Diagram

The Find/Fix functional threads are shown in Figure 6-4. The PBS Employ Teams function flows into Scan Area of Interest, which for SAW refers to taking crew information, pictures and fingerprints. The thread is then traced to Process Data from Scan and then to Analyze Data Onsite, this means the data is input into a recognition device and then analyzed. The thread flows to Quantify Threat and then Determine Intent. From here a thread is sent back to C4ISR to provide information feedback and a thread also progresses forward to the Finish functions in Implement Nondestructive Measures.

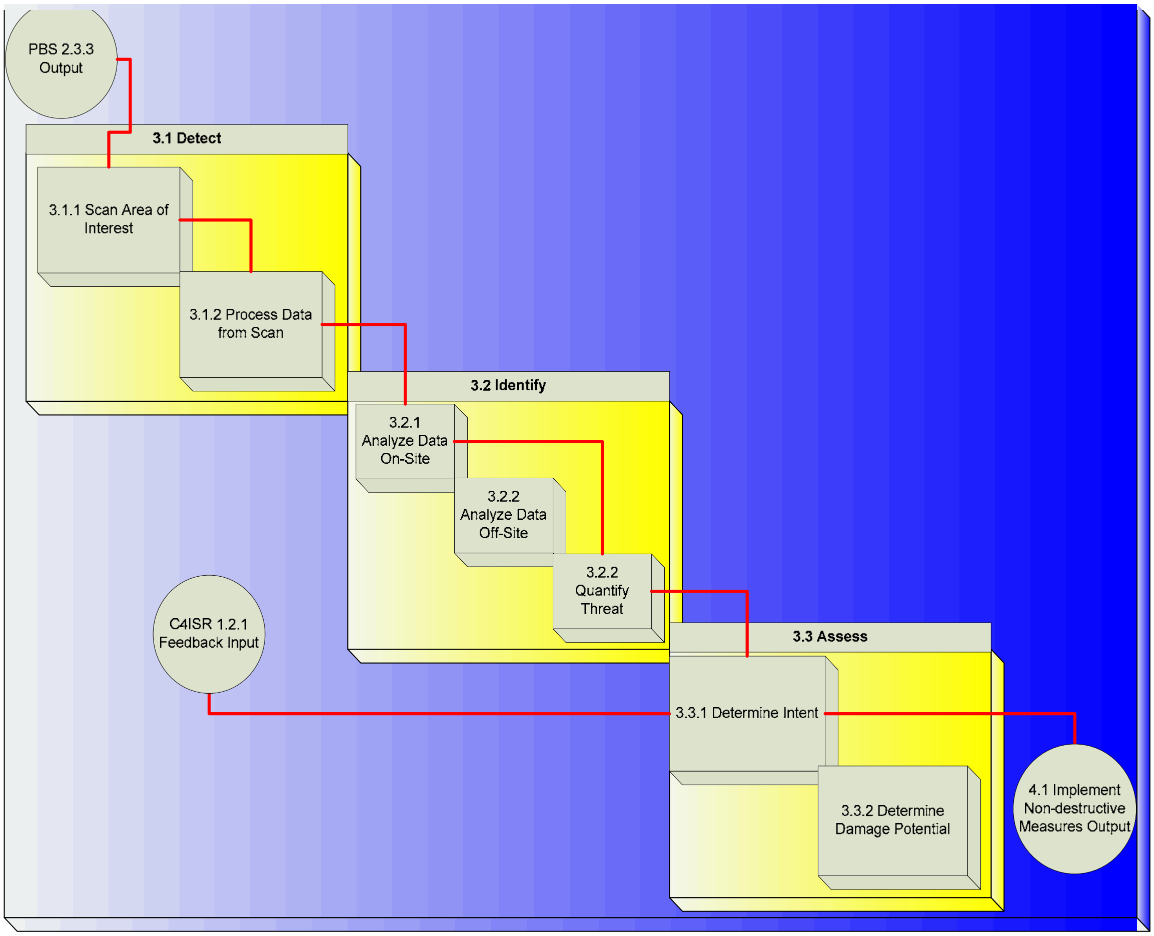

Figure 6-4: Find/Fix SAW Thread Diagram

To demonstrate threads to all main level subfunctions it is assumed no terrorists were found in the initial search so the boarding teams will assume an escort posture to escort the ship the remaining distance to the designated port facility. Under this assumption, Figure 6-5 shows the thread flow from Determine Intent to the Finish subfunction 4.1.1 Guard HVU from Internal Threat. Now the concealed terrorists reveal themselves and attempt to take control of the ship, so the thread progresses to the Recapture function for the embarked Boarding (Escort) team. Since the Recapture function failed, the feedback thread goes back to the C4ISR function Provide Voice/Data that eventually links to Command Forces which then through the Provide Voice/Data output gives the order to the Finish function, Disable, and the PAV is disabled so the terrorists are no longer able to control the ship. The next threads in this scenario are to report the status of the disabled PAV to the C4ISR function Provide Voice/Data, which links to Command Forces. Command Forces flows to Provide Voice/Data to direct another Recapture. Now that the PAV is recaptured, a report is then sent to C4ISR again and an order is sent to tow the disabled ship, as shown by the thread from C4ISR 1.2.2 Input to 4.1.6 Tow Disabled Vessel. This completes the interaction action portion of the mission, and the Sustain functions are also being accomplished between these interactions.

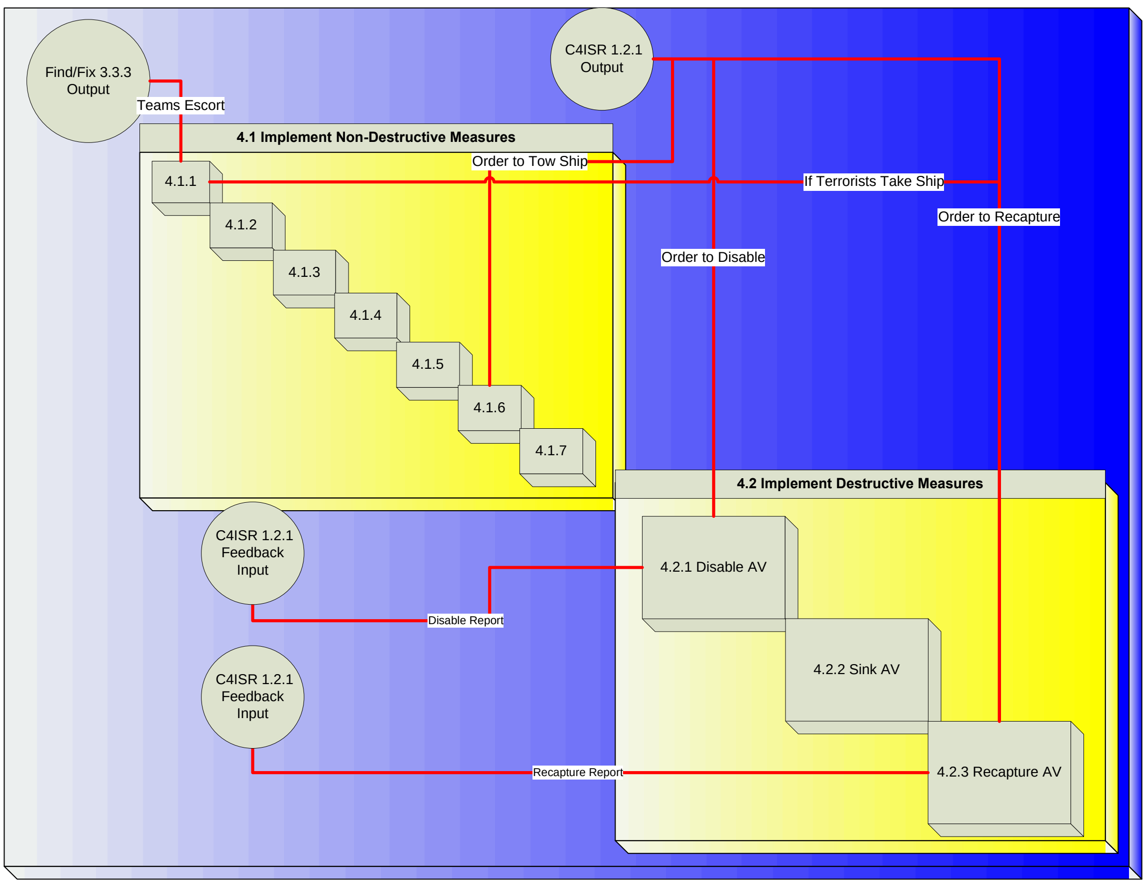

Figure 6-5: Finish SAW Thread Diagram

Sustain functions are accomplished concurrently throughout the duration of the mission as directed by the C4ISR Command Forces function through the Provide Voice/Data function. In this case the thread flows from the C4ISR functions previously mentioned to the 5.1.4 Provide Appropriate Manning function which then feeds back to the PBS Activate Required Personnel (Figure 6-6). After receiving the feedback from PBS Move Deployment Platforms that the Response Ships are underway, the C4ISR Provide Voice/Data function then directs the Sustain functions (Deliver Consumables, Parts and Supplies to Units and Refuel Platforms) to provide support to those deploying ships. This is shown with the threads that link Deliver Consumables, Parts and Supplies to Units and Refuel Platforms to the PBS Move Deployment Platforms. When the deployment platforms provide feedback to the C4ISR function that there is a need for external maintenance/medical support, a thread is then enacted from C4ISR to the Sustain function 5.2.2 (Provide trained bodies to conduct maintenance/health care where deficiencies exists) or to 5.2.3 (Rotate units to conduct Preventative Maintenance Services/Corrective Maintenance Services/Stand-down) as needed.

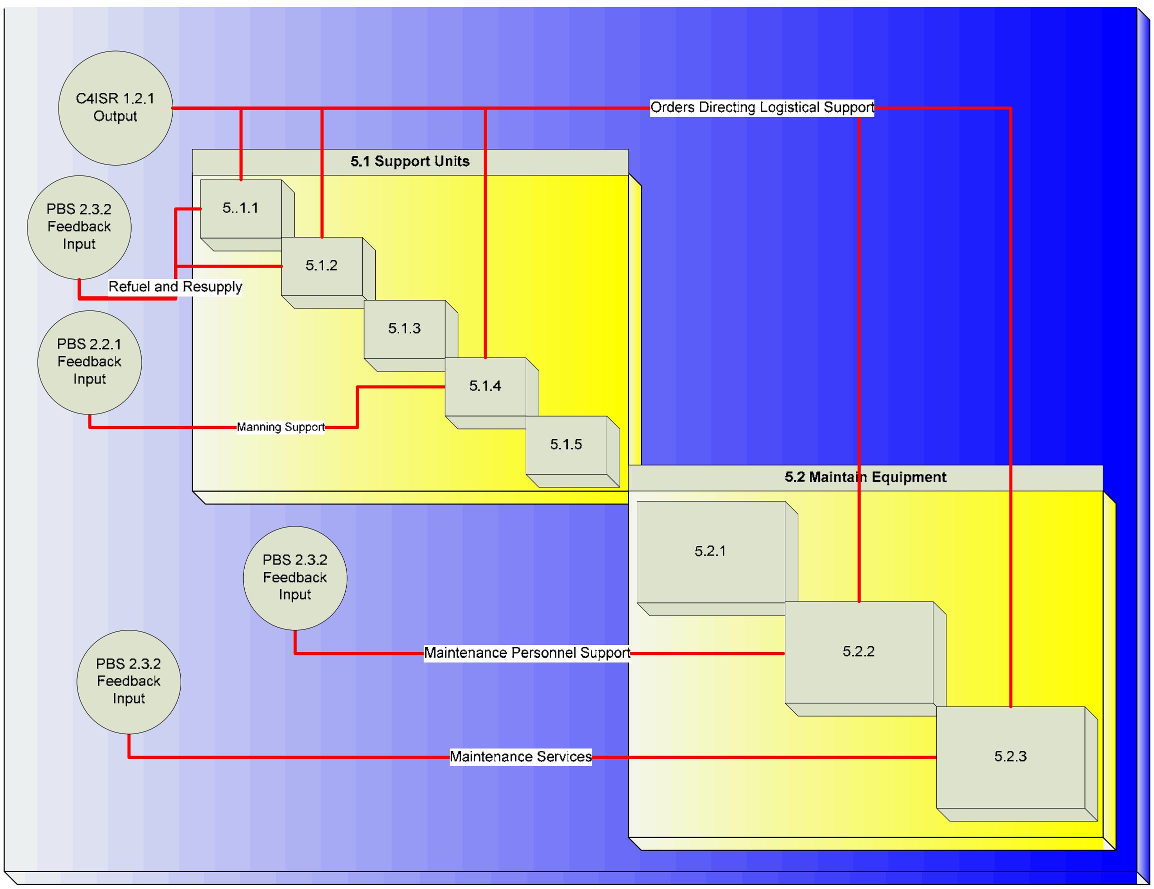

Figure 6-6: Sustain SAW Thread Diagram

This thread analysis shows one possible scenario out of several dozen. It demonstrates the flow of information and actions from beginning to end and how each is linked. Once the thread analysis is complete it will show if any disconnects exist or if an illogical step is taken. It also helps to identify if a needed function has been unknowingly omitted from the functional hierarchy. Once the thread flow is refined and unbroken, the mission is ready to be addressed with a SoS Architecture that can support it from beginning to end.

7.0 SYSTEM DESIGN AND ANALYSIS

7.1 MAPPING OF FUNCTIONS TO SYSTEM CONCEPTS

7.1.1 C4ISR

7.1.1.1 C4ISR System Framework

The essential function of the C4ISR system is to facilitate responsive decision making with respect to a threat in the maritime domain. The inputs to the C4ISR system are information from the Maritime Domain Awareness (MDA) system, data from local sensors, and inputs from higher command. All inputs, including inputs from higher command, are processed into intelligence, which is primarily manifested as a Common Operating Picture (COP) and sent to the operating units for mission execution. A graphic depiction of the MTR C4ISR system boundary, as well as its fundamental internal and external interfaces, is provided in Figure 7-1.

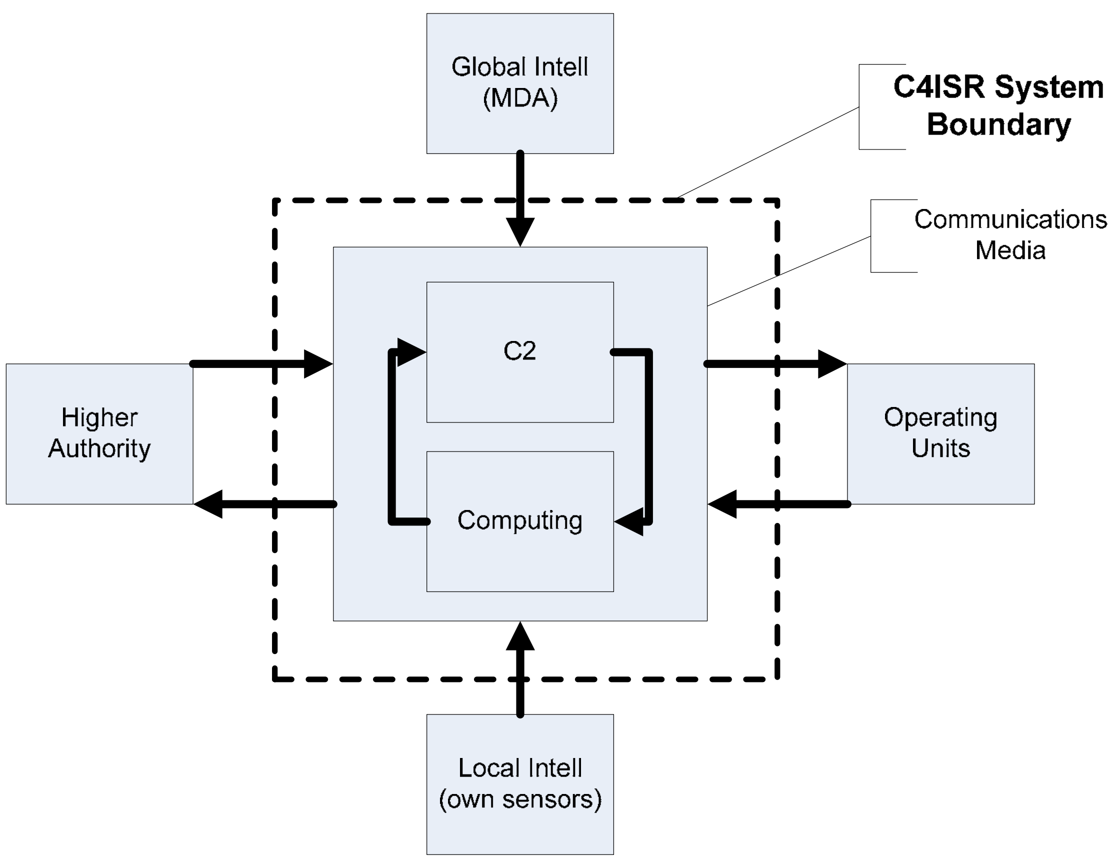

Figure 7-1: MTR C4ISR System Interfaces

Figure 7-1 indicates information, such as plans, weather conditions, sensor data, private sector data, vessel locations, and so on, flowing into the C4ISR system from both global and local intelligence sources. Information is also depicted flowing both into and out of the C4ISR system from higher authority and MTR operating units. Figure 7-2 shows the primary data flow through the C4ISR system.

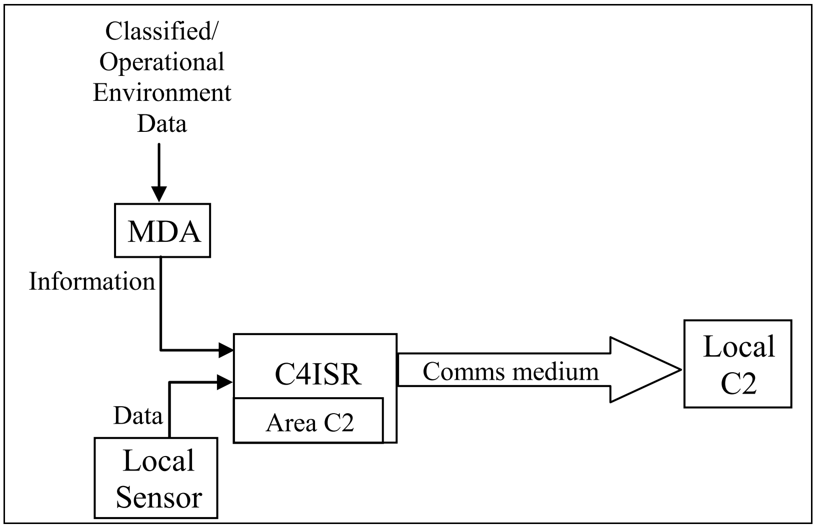

Figure 7-2: C4ISR Primary Data Flow

Figure 7-3 depicts the functions of a general C4ISR system. While detection and collection is external to the MTR C4ISR system, data processing, data fusion, analysis, and dissemination, and formulation of the appropriate response to the threat are internal to the MTR C4ISR system.

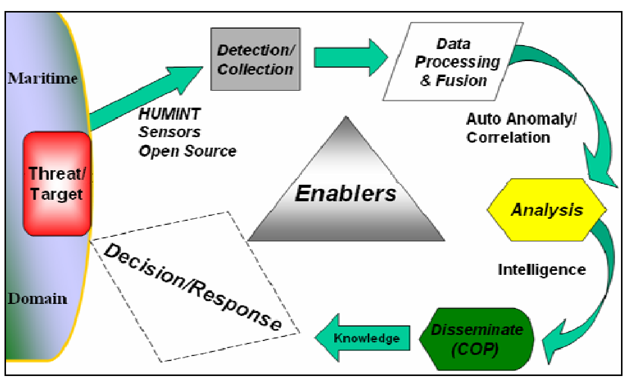

Figure 7-3: Decision-Making Enablers

7.1.1.2 C4ISR Concept Alternatives

The C4ISR system concept alternatives are based on open source information and are identified according to the functions to be performed by the C4ISR system.

Command and Control (C2)

The C2 functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander. The knowledge developed by the C2 system is utilized in planning, directing, coordinating and controlling forces or operations. The main design considerations are span of control, command structure, and the suite of communications and computing tools employed.

"Span of control" relates to the size of the geographic region as well as the number of operating units within that region being directly controlled by a single commander. The span of control for the MTR C2 system is either Area, Local, or some combination thereof. The MTR SoS must be able to neutralize threats across the breadth of the Pacific Ocean as well as within San Francisco Bay. An Area commander controls approximately 20 high-value commercial ships that must be searched and/or protected by MTR forces. A Local commander controls the forces to protect a single high-value unit (HVU).

As used in the militaries of the world, a command structure can be control-free, selective-control, mission-oriented, problem-bounding, problem-solving, objective-oriented, interventionist, or cyclic. First employed by the WWII German military, the control-free structure is highly distributed. In this structure, the commander seeks to assign missions to his subordinates, who then employ all the assets available to them to accomplish their missions. In a selective-control structure, the higher command issues mission orders and expects subordinates to take broad and deep initiatives. The higher command follows the battle in detail and is prepared to intervene. The Israeli Army employs this kind of C2 structure. In a mission-oriented structure, each command level assigns missions to its subordinates and permits them to define further details of the military situation, beginning with selecting the objectives necessary to accomplish the missions. In a problem-bounding command structure, as used by the British military, the higher command composes its directives in terms of the objectives to be accomplished, but couches them in very general terms. The U.S. military has traditionally used the problem-solving approach, which involves issuing directives that articulate both missions and objectives for two levels of subordinates. Substantial guidance as to how the objectives are to be achieved is also included. An objective-oriented structure allows some level of trust, creativity, and initiative in subordinate commands, but it stresses synchronization of assets and actions. This approach most closely reflects the ideas underpinning Network Centric Warfare. An interventionist structure, used by the modern Soviet military, relies heavily on central authority to issue directives, but it also maintains very detailed information about the battle and attempts centralized control through detailed directives. The greatest degree of centralization occurs in a cyclic structure, mainly used by the Chinese, in which the senior command issues orders to all subordinates and does so on the basis of a preset cycle time.

In the maritime domain, the objective-oriented structure is the most appropriate;[64] thus, it will be carried forward as a C2 command structure option. It incorporates the advantages of the problem-bounding and problem-solving structures. It also allows some level of trust, creativity, and initiative in subordinate commands, but the stress is on synchronization of assets and actions. Consequently, there will be greater coordination and more continuous contact between superior and subordinate commands, as well as among subordinate commands. Because the U.S. military has traditionally used the problem-solving approach, it will also be carried forward as a C2 command structure option. The problem-solving approach is used to represent a back-up command structure, which would be used in the event of either net-centric technology failure or lack of trust in either technology or subordinates.

The last critical C2 consideration is the suite of communications and computing tools needed to support the C2 function. MTR communications infrastructure must be near real-time, transoceanic, and interoperable across local law enforcement, National Fleet, and coalition forces. Computing tools must provide comprehensive decision support, including courses of action, resource pairings, optimal assignment

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[64] D.S. Alberts and R.E. Hayes, "Command Arrangements for Peace Operations," Command and Control Research Program (CCRP) Publications, National Defense University, [http://www.dodccrp.org], May 1995.

schemes, and targeted search plans. Fused products must enable a high level of situational awareness, while minimizing the chance of information overload.

Communicate

To network the entire force, the communications system provides links for the transfer of messages, data, voice or images between various parties in the MTR SoS. The aim is to ensure that information exchanged between parties is transmitted and received efficiently, with minimal delays so that necessary actions can be taken. The linkages can be divided into two categories: internal and external. Internal communications take place within a small group, task force, or agency, while external communications refers to communication links among all MTR actors. Different technologies are considered for these two communication system categories. The internal communications focus on local area networks, while the external communications are facilitated by wireless networks and paging systems.

Compute

The two main components of the computing system are: information assurance and data fusion. Information assurance refers to the "technical and managerial measures designed to ensure the confidentiality, possession or control, integrity, authenticity, availability and utility of information and information systems."[65] Typically, the information security measures are enforced from a security policy that is recommended by information technology (IT) personnel and approved by the top management. This security policy states the security measures that are taken to protect the systems and the information in the organization, during processing, transit, and storage. It also includes the risk remaining despite such measures and the roles and responsibilities of everyone in the organization. Lastly, it includes the training and awareness program that must be conducted to ensure everyone knows his role.

In the context of the MTR environment, because the information of most of the external systems is only known in the most general terms, it is assumed that these systems are secured. They are assumed to employ proper security measures and will be treated as trusted systems. Thus, the MTR information assurance system will concentrate

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[65] Answers.com™, "Information Assurance," [http://www.answers.com/information%20assurance], 2006, accessed in April 2006.

on protecting and securing the systems and information within the MTR domain. The MTR system ensures that information is protected against unauthorized access via encryption and authentication, that it is protected from modification without notice via hashing the information, and that the mission is protected against the loss of information via system redundancy. These protections are in force during the entire period that information is being transmitted, received, processed, and stored within the MTR domain. Computing systems are secured to minimize vulnerabilities to subversion and exploitation either by outsiders and insiders. Redundant systems are included for disaster recovery in order to prevent the loss of information or services to the commanders. The Defense in Depth Security Model presented in Figure 7-4 is the guiding framework for the MTR information assurance system concept.

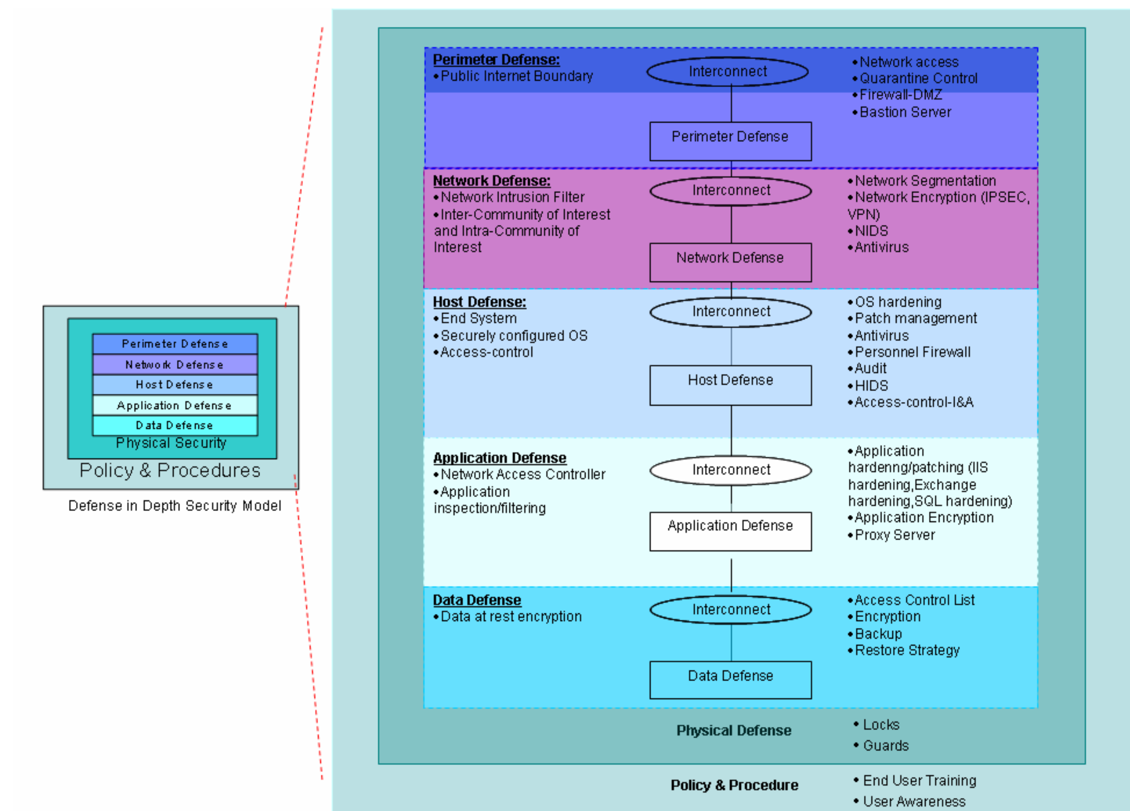

Figure 7-4: Defense in Depth Security Model

Having been certified as authentic from the trusted external sources, the information is sent to the fusing system. Here, the data/information is processed and correlated based on the set of rules and requirements provided by the commanders. Assured data is used to generate intelligence data that will eventually be supplied to the

COP. The correlation rules include the location and movement associated with the objects of interest, which include both targets and MTR forces.

Several technologies can be employed for computation of situation assessment and information fusion. Table 7-1 presents a comparison of these technologies.

Technology	Pros	Cons
Rule-based system	- Simple concept (based on "if…then" statement) - Can retrace logic structure underlying decision	- Cannot manage uncertainty and complexity - Hard to combine expert knowledge with data - Hard to maintain
Neural Networks	- Based on sound statistical learning techniques - Good in data rich domains	- Cannot understand logic underlying decision - Hard to combine data with expert knowledge
Classification trees	- Simple concept - Good in data rich domains	- Cannot handle rare events - May generate too many rules
Bayesian networks	- Intuitive framework - Sound theoretical basis - Can integrate data with expert knowledge	- In development

Table 7-1: Comparison of Computation Technologies

The concepts considered for data fusion include automated, man in the loop, and hybrid systems. Automated Data Fusion employs a self-learned algorithm architecture, which could be by means of either artificial intelligence (AI) or a neural network. The advantages of this "man-free" system are that it is fast, autonomous, and does not require trained personnel. However, the disadvantages include the complexity and cost of such a system, as well as the dependency on technology it would create if the machine-generated decisions came to be trusted. In contrast, the man-in-the-loop architecture employs a rule-based architecture, which is advantageous in that it is relatively less expensive, and that humans can verify and decide on the results. Because this option is less dependent on machines, it is slower, requiring highly trained personnel in the loop at all times. A hybrid concept seeks to combine the advantages of the two concepts by employing both a rule-based and a self-learned algorithm. Although the hybrid will still require a number of humans in the loop to provide verification and perform final decision making, the overall speed of the system is increased via its self-learned component.

Provide Intelligence

The different alternatives for the Provide Intelligence system include sending the entire fused COP to all operating units, sending the entire fused COP blended with the common intelligence picture to all teams, or sending specific fused COPs blended with the common intelligence picture to the appropriate teams.

Alternative Concepts Summary

The possible combinations of the alternative subsystem concepts discussed above form the C4ISR concept alternatives. Table 7-2 contains the alternative subsystem concepts.

Alternative	C2	Comms	Compute	Intell
1	Area	LAN	Defense in Depth	Overall COP
2	Local	WMAN	Automated Data Fusion	Overall COP + CIP
3	Problem Solving	WA Paging System	Man-in-the-Loop	Specific COP + CIP
4	Objective-Oriented	Combined System	Hybrid Fusion	—
5	Hybrid	—	—	—

Table 7-2: C4ISR Subsystem Concept Alternatives

Preferred Subsystem Concepts

A subsystem analysis is performed to select preferred concepts. The key performance parameters used in this analysis are speed and cost. The utility of all informational products is a function of the timeliness of their delivery to operating units, which places great emphasis on the throughput of the computational and communications pipeline. The aforementioned characteristics are the basis for the selection of the subsystem concepts that follow.

Communications Systems

The communications systems provide the links for transmit and receipt of messages, voice, videos and images between the various components of the MTR SoS. Three different means of communication are proposed: wireless network, local area network, and wide area paging.

Wireless Network

The 802.16 wireless can be employed for transmitting large amounts of information between the various parties separated by long distances. The 802.16 provides up to 70 megabits per second (Mbps) of shared point-to-multipoint transmission in the 10 to 66 gigahertz (GHz) frequency bands as far as 48 kilometers. It can be used to create a wireless metropolitan access network across the San Francisco Bay or across the Pacific Ocean (Figure 7-5). To increase coverage, more base stations can be set up on shore and possibly even floating buoys deployed in the sea. Preexisting base stations, such as satellites, can be utilized to minimize the need to step up additional base stations.

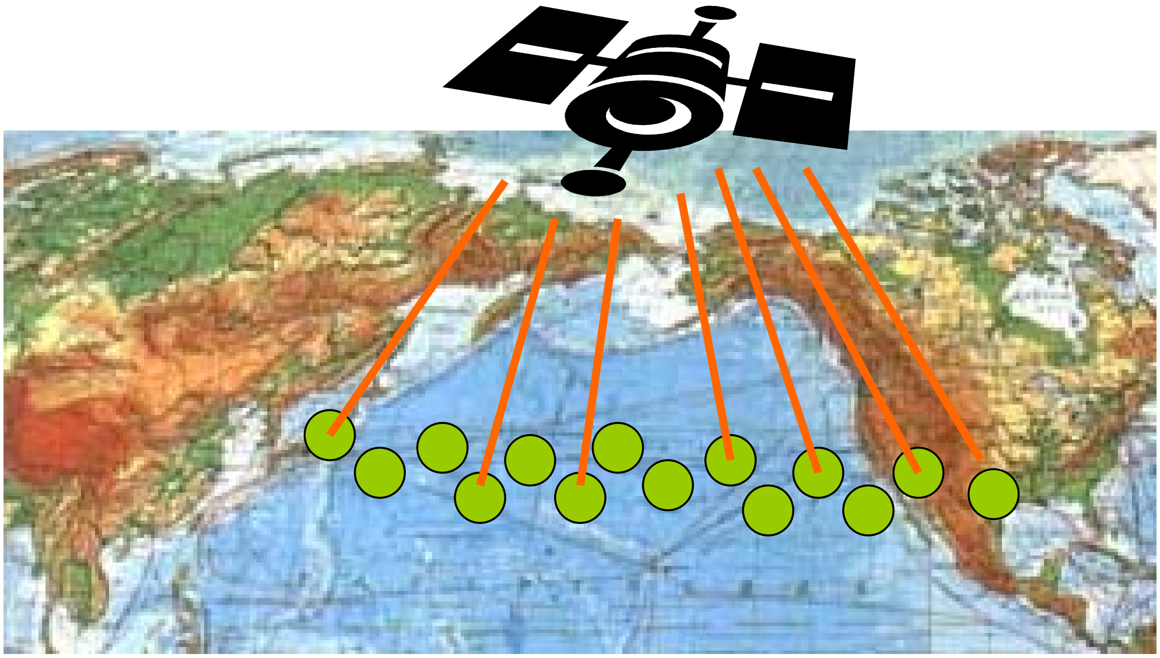

Figure 7-5: Notional MTR WMAN Satellite Connectivity

The 802.16 is chosen over the more well-known 802.11 mainly because of the coverage capability. The 802.11 is designed to cover only hundreds or thousands of square meters, operating at very low powers to prevent frequency interference from neighboring networks in the same area. Defined as a Wireless Metropolitan Area Network (WMAN), the 802.16 is designed to cover an area of tens or even hundreds of square kilometers.

Local Area Network (LAN)

Boarding teams onboard suspect vessels require connectivity for various activities such as biometric data gathering, radiation detection, text messages, voice, video, and other collaborative efforts. A LAN system is proposed to meet the connectivity requirement—connectivity within the vessel as well as connectivity to shore. In addition, the network has to be rapidly deployable. Ruggedized marine grade laptops, biometric scanners, satellite phones, storage devices, printers, and routers are some of the essential components that will form part of this rapidly deployable LAN system. Long range communications via satellite is possible, and existing satellite base stations can be used for this purpose. Figure 7-6 shows a schematic of the notional MTR LAN configuration.

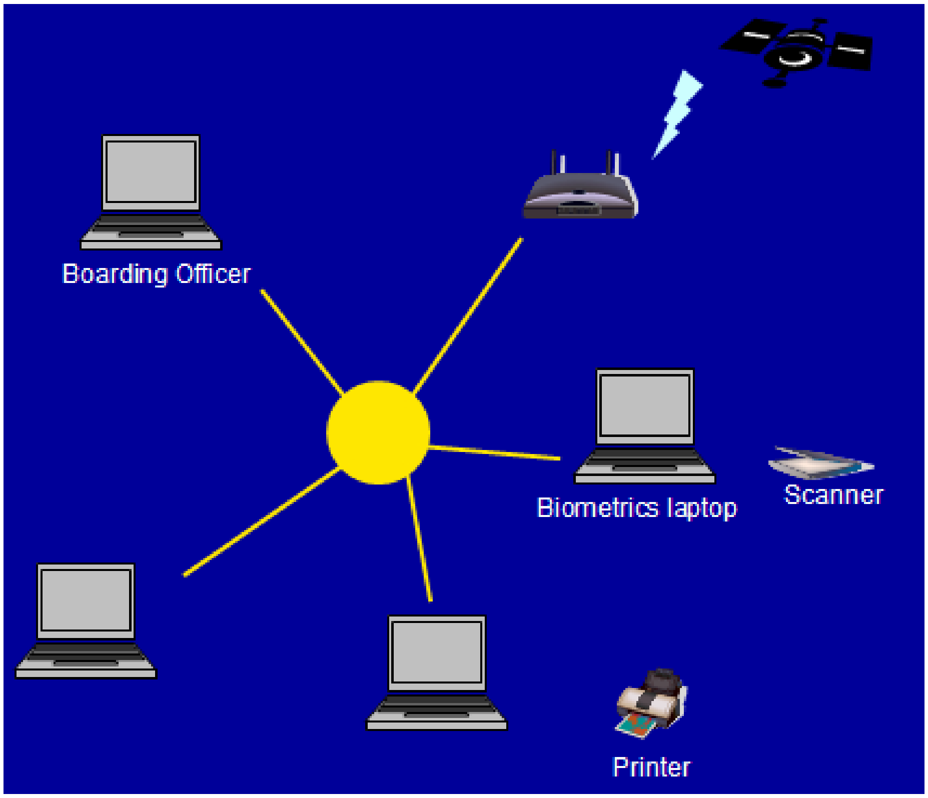

Figure 7-6: Notional MTR LAN

Wide Area Paging System

The wide area paging system provides the means to transmit short messages to any party subscribed to the paging system. Figure 7-7 depicts the various components that comprise the wide area paging system. It consists of a network of telephone lines, base station transmitters, and large radio towers that simultaneously broadcast a page from each base station. A message can be sent to selected parties via a phone keypad or modem. The paging control center then dispatches the page received from the public switched telephone network (PSTN) throughout the service area using base stations which then broadcast the page.

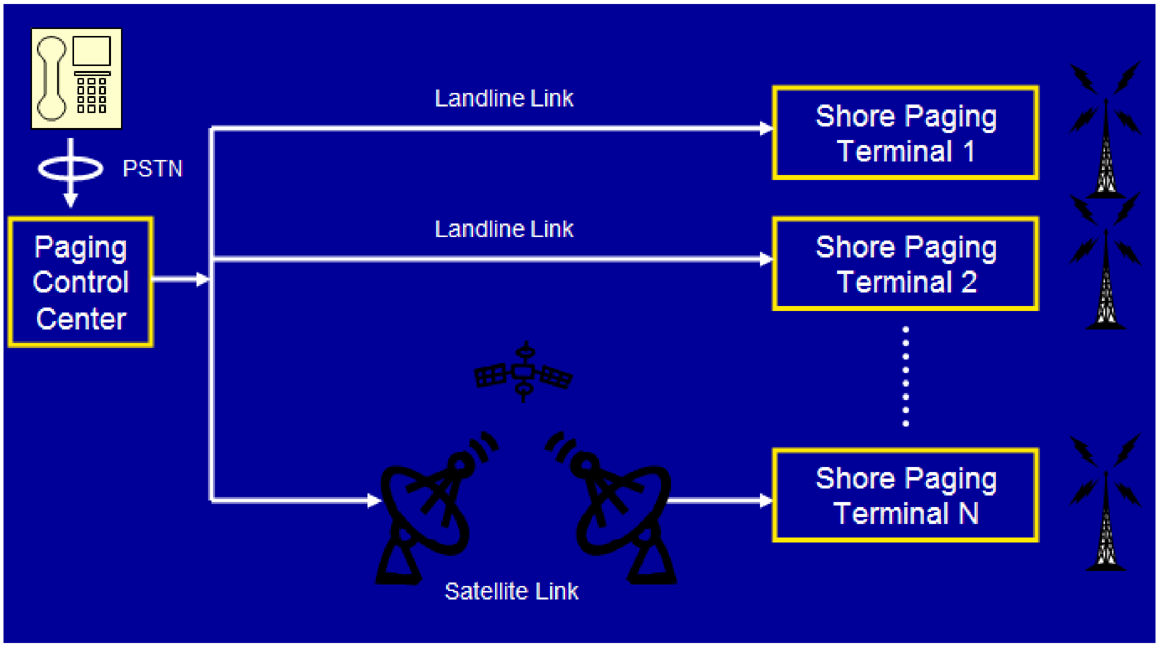

Figure 7-7: Notional MTR Wide Area Paging System

A summary of the three components comprising the preferred communications concept is provided in Table 7-3.

Concept	Brief Description	Typical size per info packet (average)	Frequency Band	Data Rate	Coverage	Remarks
Wireless network	Buoys as wireless LAN stations 802.16 connectivity Wireless Metropolitan Area Network (WMAN) designed to cover hundreds of square mile	text 16Mbits graphics 32Mbits vox/video 64Mbits	2-6GHz (802.16)	70Mbps	Within 48km of access points	802.16 provides up to 70 Mbps of shared point-to-multipoint transmission in the 10 to 66GHz frequency bands as far as 48 km.
Wire area paging system	Brief messages notifying the need to contact a particular location to receive further instructions	4000 bits	15kHz (FLEX)	3200bps	Worldwide	Limited capacity (typically 500 characters is the maximum practical message size). High latency, with messages potentially taking minutes or longer to be delivered.
Local area network	Provide connectivity while onboard suspect vessel for activities such as biometric data gathering, radiation detection, text messages, voice, video images	text 16Mbits graphics 32Mbits vox/video 64Mbits	2.4GHz (802.11g)	54Mbps throughput 27Mbps	Local (5 km, though some report success at up to 120km where LOS can be established)	Note that speed is distance dependent. Speed drops as distance increases. Also, the actual data throughput is generally no more than half of the rated speed because 802.11 uses a collision "avoidance" technology (CSMA/CA) rather than the collision "detection" method (CSMA/CD) in wired Ethernet. Wired systems can detect a collision, but wireless cannot, thus, the CSMA/CA method waits for an acknowledgment from the other end to determine if the packet was transmitted properly. A 54 Mbps rated speed yields only about 27 Mbps in real throughput.

Table 7-3: Combined Communications Concept

Compute

Defense in Depth Information Assurance

The preferred information assurance concept is in accordance with the Defense in Depth Security Model presented in Figure 7-4. The Compute system employs this strategy of defense in depth to protect its data and systems within the MTR domain. As illustrated in Figure 7-8, layer defense is operated by enforcing different security mechanisms in different layers. If one layer fails, the other layers will still be in place to impede any perpetrators from compromising MTR computing assets. This strategy is coupled with public key infrastructure (PKI) to ensure the information or data received from external sources are authentic and tamper-free. Details of the MTR information assurance concept follow.

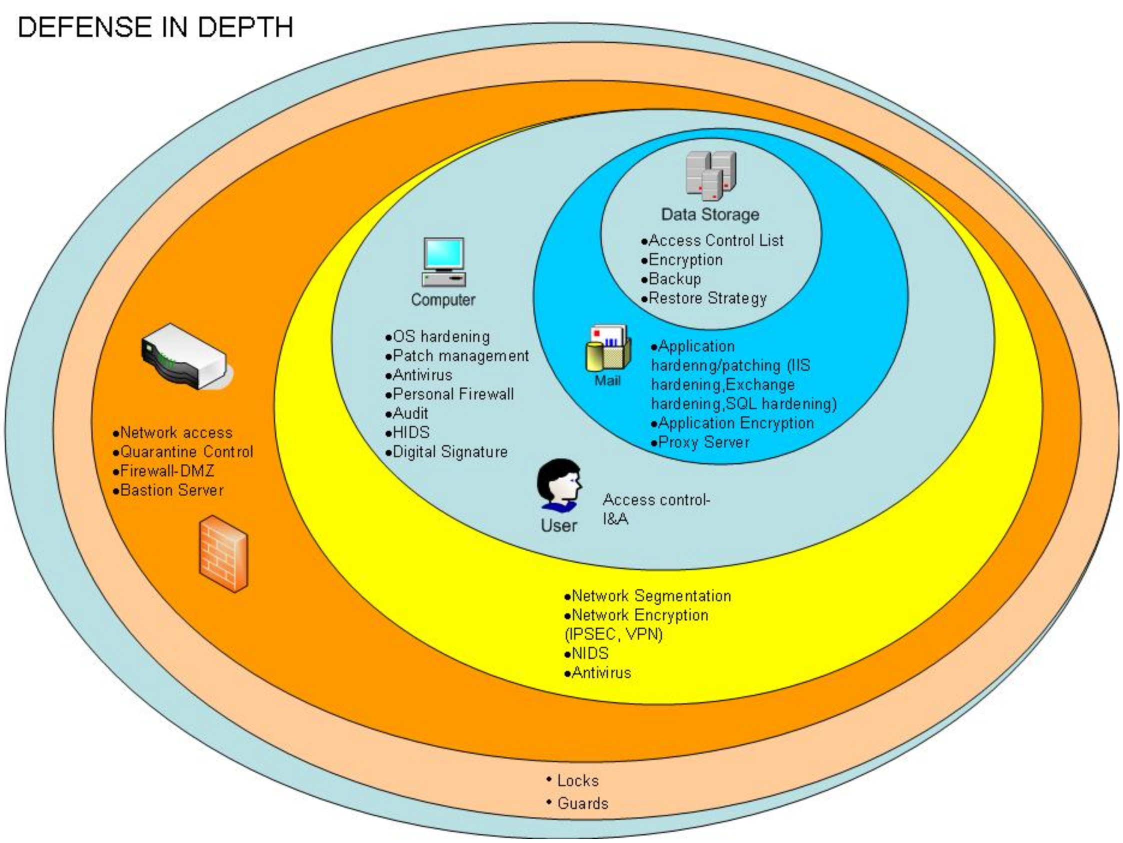

Figure 7-8: MTR Information Assurance Concept

When data is received from an external system, the data is first authenticated via a PKI. The PKI uses a paired public-private key mechanism. The sender will hash and digitally sign the information with his or her private key, creating a one-way encrypted output. The key is owned solely by the sender and proves the authenticity of the person. The recipient will decrypt the data with the sender's public key, which is issued either by the sender or by the certificate authority (CA) with whom the sender registers.

The integrity of the source information is then verified by the comparing the hashed value of the digitally signed information with the hashed value of the original information. If the two hashed values match, the information is verified to be free from tampering or modification.

By definition, a security policy is a plan of action for tackling security issues, or a set of regulations for maintaining a certain level of security. In the MTR context, it refers to the security measures taken in relation to system, network and applications to protect the data and the system from being compromised. It contains the assets to be protected, the possible vulnerabilities, and the threats that might be encountered, so that a strategy can be formulated to mitigate and minimize the risk. Defense in Depth coupled with PKI is employed to protect the system and information. Each layer is protected with a set of security mechanisms to ensure vulnerabilities to all threats are minimized. In the event that one security mechanism fails, the remaining security mechanisms continue to protect the assets. The policy also includes the training to assist the IT people in configuring the security equipment and appliances in accordance with the security policy. User awareness is the final portion of the policy, ensuring that proper security procedures are practiced.

The best way to protect the assets is to prevent unauthorized access by non-authorized personnel. The most primitive way to enforce this measure is to secure the building and rooms physically with either physical or digital locks so that only authorized personnel are allowed access to the systems. Together with the locking system, guards ensure that personnel are identified physically before being allowed access to the building or room housing computer systems.

Analogous to physical defense to the user, perimeter defense serves as the first line of defense or the first door to the source traffic before it can enter the network. Several mechanisms are implemented to enforce this layer of defense. Network access control is enforced by the router that permits only authorized traffic into the network. Any traffic from unknown sources is blocked by this router. The demilitarized zone (DMZ) is a network segment that sits between an organization’s internal network and an external network. It allows contained servers to provide services to the external network while protecting the internal network from possible intrusions. The firewall enforces more stringent rules to restrict the traffic into the network. The router inspects not only the normal packet, but also the source and destination packets, and it does so in either a stateless or a stateful mode where the firewall creates a table to track the packets traversing during a communication session established between a conversational pair. Any packets not registered in the table are rejected. Bastion servers are another means to protect possible intrusion from external sources. Bastion servers accomplish this function by providing services to the external network and limiting direct external network access to the internal network. For example, quarantine control contains any viruses outside the internal network.

Network defense primarily deals with protecting the traffic or the systems within the internal network. Network segmentation by routers separates the systems and users so that no unauthorized users are able to access classified system segments. For example, Top Secret is separated from both Secret and Unclassified segments. Internet protocol security and virtual private network (IPSec/VPN) encrypts the information at the network layer so that data in transit is protected from unauthorized observation. The encryption starts and terminates between the end-to-end terminals where only end-to-end users or devices are able to observe and read the data. The Network Intrusion Detection System (NIDS) observes the network traffic traversing in the network and detects any malicious traffic. Upon detection, it both alerts the network administrator and triggers actions to mitigate this traffic. The NIDS increases the likelihood that timely measures can be taken to prevent the system or data from being compromised. Lastly, antivirus software is deployed to contain any outages so that impact is minimized.

Host defense protects the host system itself. It includes operating system (OS) hardening that turns off unwanted services which may otherwise provide a means for a perpetrator to compromise the systems and to access to the information. Patch management is implemented automatically by the system to fix any known vulnerabilities of the OS. Host antivirus software is updated regularly for new signatures; thus, viruses can be detected effectively and removed or quarantined within the system. This practice prevents viruses from either disrupting or bringing down the network or system, resulting in a loss of services or data. A Host Intrusion Detection System (IDS) is implemented to allow the host to detect any intrusion based on a signature. Identification and

Authentication (IA) by means of password, biometrics, or common access card (CAC) is used to ensure that the user is an authorized user. "Two-factor IA," which uses two types of the three possible methods, is deployed to ensure a strong IA security component. Lastly, audit is enabled at all times to account for all the events occurring in the system, which includes the user login and any changes made to the system; any compromise to the system or data can thus be traced.

Application defense is deployed in the application layer. Similar to OS hardening, the application can be hardened or patched to fix any known vulnerabilities so as to prevent it from being exploited to subvert the system or the data. Application encryption, such as a secured socket layer (SSL), is implemented to prevent the application content from being observed while it is on transit to the destination. The application proxy server checks the contents of the application to detect any malicious traffic or pattern and drops the application if any is detected. It also hides the server from the external traffic, acting as a middle server to protect the backend systems from subversion.

Data defense is the layer of defense focused on protecting the data. Access-control list (ACL) is implemented to permit authorized users the rights of access. Data is hidden from unauthorized users by encrypting it with a password or key. Furthermore, a backup and restore strategy provides redundancy. The disaster recovery center is implemented to ensure that no data is lost as a result of a breakdown of the system or the network.

Unfortunately, even with all of the above security mechanisms in place, foolproof protection is still not realizable. The information assurance protection measures minimize the possibility of a security breach or the compromise of data or systems, yet the system components themselves possess vulnerabilities. Proactive actions must be taken to ensure all the components are secured and patched when vulnerabilities are discovered. The security policy must also be periodically reviewed to ensure that the security measures are updated to reflect any changes to systems and their corresponding vulnerabilities.

Hybrid Data Fusion

A Hybrid Data Fusion concept is employed, which encompasses both automated and man-in-the-loop data fusion and analysis. A graphic overview of this concept is provided as Figure 7-9. The motivating factors for such a hybrid concept follow.

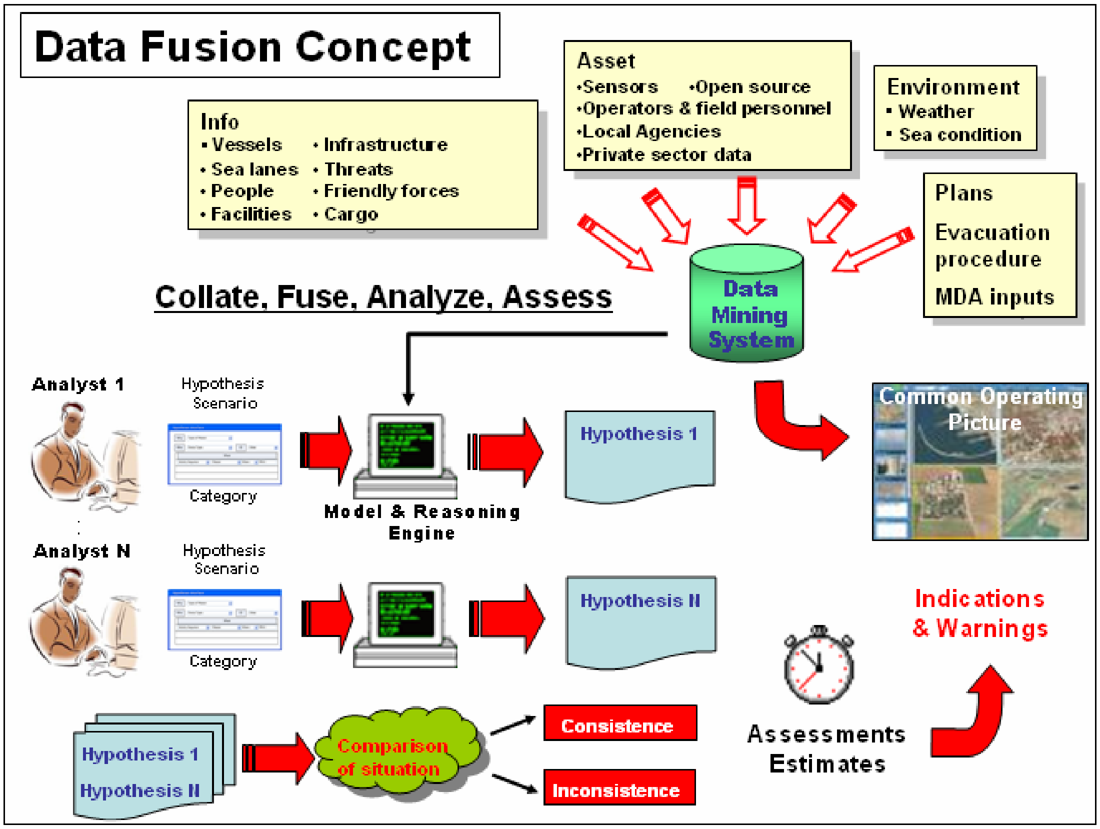

Figure 7-9: MTR Data Fusion Concept

The main idea is to substantiate or support the generated scenarios with evidence as the real world unfolds in time, and thereby continually adjusting system perceptions of the unfolding future so as to remain relevant and valid. To achieve this, each generated scenario is associated with indicators that are observable in the real world. Evidence for these indicators is collected to determine the extent to which the scenarios are actually happening as forecast.

Having evidential support for what is or what is not happening allows an analyst to check the correctness of previous analyses and perceptions. The analysis is revised as informed by the new and current evidence, which correspondingly revises the scenarios, if necessary, and also the plans or decisions associated to the scenarios. In a sense, an evidential feedback loop is implemented to continually correct the scenarios to ensure their relevance and congruence with reality, thus reducing or mitigating the risks in any scenario-based application.

To further reduce uncertainty, and also to mitigate or overcome natural human biases and limitations, multiple perspectives are exploited. Specifically, multiple interpretations of past data are enabled, which can lead to multiple perceptions of how the current state will change in time, and thus multiple scenarios. It is already an accepted technique in scenario planning to have more than one scenario; however, it is generally limited to only a few because the human mind has difficulty cognitively coping beyond a certain number. The MTR data fusion system allows for unlimited scenarios without overwhelming the human users' cognitive limits. Also, what constitutes the indicators for a given specific scenario and the degree of association can also be given to multiple interpretations and the degree of agreement or disagreement in these interpretations are exploited as indications of risk or "knowability" of a situation.

It is unlikely that the future can be forecast in its precise details, but a forecast can be very useful in certain situations. One of these situations involves the notion of convergence, in which all evidences point to one scenario, or a cluster of related or not inconsistent scenarios, as being far more likely than the rest, and the evidential support for this remains constant and stable over a certain period of time. The other notion is that of robustness, by which it is meant that the fusion system is indifferent to the remaining variability or uncertainty in the scenarios. Thus, convergence can be detected and lack of convergence is an indication of several possible errors in the prior analysis, namely, the failure to account for some scenarios, the incorrect identification and associations of the indicators, or the failure of collection to obtain the necessary evidential support. This is thus a trigger for revision or correction of the previous analysis and scenarios or of a review of the collection process.

Provide Intelligence

The preferred Provide Intelligence concept creates an overall fused COP, blends the COP with a common intelligence picture (CIP), and sends specific portions of the COP/CIP to operating units. The Provide Intelligence system displays and disseminates knowledge relevant to the coordination of forces. Intelligence is most rapidly derived from data that has previously been assured, correlated, and analyzed. This intelligence is then packaged in the form of the COP. The overall COP is provided to the global C2 system while customized COPs are provided to the different ground forces. Customization of the amount and types of information included in the COP allows the ground unit to better focus on the assigned mission and also reduces the analytical and decision cycle of the local operator. The customization is based on each particular asset's mission, location, operational influence, and capabilities. Capabilities include factors such as weapon range and response time. Figure 7-10 shows a possible scenario, in which the specific COP area and the size of that area are determined by the unit location and capability, respectively.

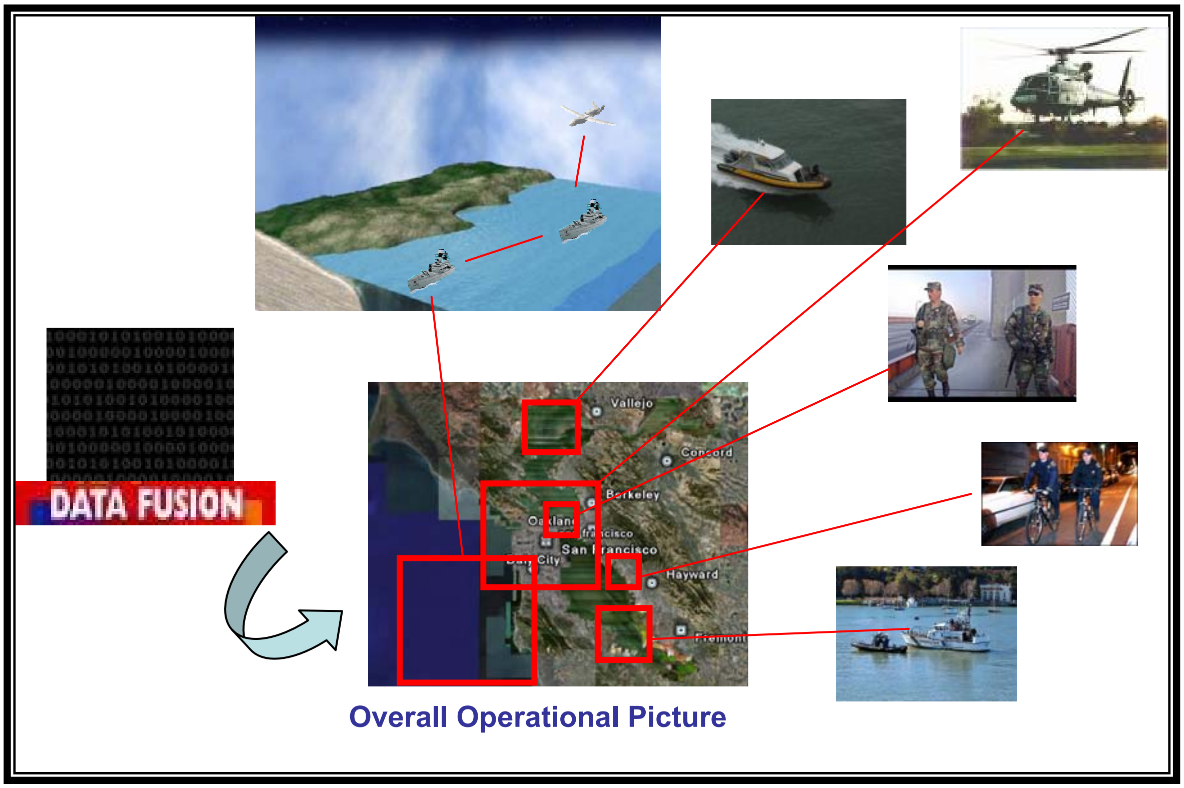

Figure 7-10: COP Customization Concept

System-Level Concept Alternatives

The subsystem analysis described in the preceding sections successfully selects the optimal communications, computing, and provide-intelligence concepts, determining the optimal C2 hybrid requires further study of the other four C2 concept alternatives. The four C4ISR concept options forwarded to the Modeling Phase are: Area Problem Solving (APS), Area Objective Oriented (AOO), Local Problem Solving (LPS), and

Local Objective Oriented (LOO). All four options include the same Communicate, Compute, and Provide Intelligence concepts, namely:

- Communicate–combined LAN, WMAN, and WAP
- Compute–Defense in Depth and Hybrid Data Fusion
- Provide Intelligence–Customized COP and CIP

The dual purpose of the C4ISR modeling effort is to both gain further insight into the performance of preferred Communicate, Compute, and Provide Intel concepts, as well as to better understand the implications of the four C2 alternative combinations of Area and Local span of control, and the Problem Solving and Objective Oriented command structures. Table 7-4 displays the complete composition of each of the C4ISR concept alternatives used as levels in the orthogonal array experiment.

Level	Option	Control	Command	Communicate	Assure	Fuse	Provide Intell
1	APS	Area	Problem Solving	Combined	Defense in Depth	Hybrid	Specific COP and CIP
2	AOO	Area	Objective-Oriented	Combined	Defense in Depth	Hybrid	Specific COP and CIP
3	LPS	Local	Problem Solving	Combined	Defense in Depth	Hybrid	Specific COP and CIP
4	LOO	Local	Objective-Oriented	Combined	Defense in Depth	Hybrid	Specific COP and CIP

Table 7-4: C4ISR Concept Alternative Components

7.1.2 PBS

WMD and SAW PBS Architecture Analysis

In the Weapon of Mass Destruction mission, Preparing the Critical Infrastructure and Activating Preplanned OPORDs are primarily centered on notifying the Department of Energy Joint Technical Operations (JTO) Teams as well as other existing chemical and biological specialists throughout the DoD and other various government and civilian agencies. For the SAW mission, those same functions would identify the critical structures and population centers that could be affected and take the necessary efforts to protect those areas to the greatest extent possible.

Assemble Forces will utilize the existing forces in the proximity of the deployment platforms. These forces can be Special operations forces, Marines, and trained boarding teams, specially trained on how to use the various types of search equipment (discussed in Section 7.1.1.3.1.) in addition to Visit, Board, Search, and Seizure (VBSS) tactics.

The linchpin in Assemble Forces and Deploy Forces is the platforms and transportation needed to facilitate positioning forces in the right place to intercept the potential threat approaching CONUS. The larger concentration of effort is on identifying the locations of the assets to be deployed and the response capability of those assets and platforms. The average cruising speed of a large commercial vessel is assumed to be 20 knots. Initial WMD mission research indicates that, based on transit and search time requirements, the platform needs to remain on station for 100 hours to enable a complete search of a container ship carrying a variable quantity of TEUs (2,000 to 10,000). The primary objective of the SAW mission is to intercept a potential threat vessel to determine the credentials of the personnel onboard. For both WMD and SAW missions, the platforms would need to be deployable for more than nine days to allow for the potential need to intercept multiple ships. With these requirements, the determination quickly narrows to the use of waterborne assets, specifically, DoD and DHS (USCG) vessels. Table 7-5 shows the potential ships available and the locations of these ships with respect to the Pacific Ocean operating area. The areas shown have been chosen to allow for intercept of a threat vessel along various points of a great circle route from East Asia to San Francisco.

Note that Table 7-5 shows only frigate, destroyer, cruiser and cutter locations for the Current Ship Systems. The Program of Record (PoR) ships considered are the LCS (Littoral Combat Ship) and WMSL (National Security Cutter), and a Commercial-Off-The-Shelf (COTS) option. The LCS and WMSL are being produced at this time and will be available in the very near future. The COTS option is a converted NASSCO Tote Orca car carrier used as a mother ship to position itself along a route that will allow it to deploy up to six smaller 118-ft high speed boats, “Wally,” to intercept multiple potential threat vessels.

LOCATION	U.S. NAVY[66]	U.S. COAST GUARD[67]
San Diego, California	6 CGs; 14 DDGs; 5 FFGs	2 WHECs
Kodiak, Alaska	N/A	2 WHEC (recommend alternative basing, currently four based in Alameda)
Pearl Harbor, Hawaii	3 CGs; 5 DDGs; 2 FFGs	2 WHECs
Yokosuka, Japan	2 CGs; 5 DDGs; 2 FFGs	N/A
Pacific Region (PoR)	~ 30 LCSs[68]	~ 4 WMSLs (NSC)[69]
Pacific Region (COTS)	3 Tote Orca Class modifications	

Table 7-5: United States National Fleet Assets in Pacific Ocean

Table 7-6 shows the ships to be evaluated and their associated characteristics.

Ship Type[70]	Speed	Crew	Weapons	Helicopters	Small Boat
FFG	28 knots	215	one Mk 75 76mm/62 cal. rapid firing gun, MK 32 ASW torpedo tubes, one Phalanx CIWS	2 SH-60	1- Launch
DDG	30 knots	380	one Mk-45 5-inch/62 cal. lightweight gun, two Mk-41 VLS for Standard missiles and Tomahawk ASM/LAM, two 20mm Phalanx CIWS, two Mk-32 triple torpedo tubes for Mk-50 and Mk-46 torpedoes	2 SH-60	1- Launch
CG	32 knots	400	Mk 41 VLS for Standard missiles, Tomahawk, ASROC; Mk 46 torpedoes, Harpoon missile launchers, two Mk 45 5-inch/54 caliber lightweight guns, two Phalanx CIWS	2 SH-60	1- Launch
WHEC[71]	25 knots	164	5-inch/38 caliber gun, 2- 20mm/Mk 67 MG, 2- triple torpedo tubes/Mk32	1 HH-60	1- Launch
LCS[72]	45 knots	15-50	Varies by module	1 MH-60R/S	11-m RHIBs or 40-ft High Speed Boats
NSC (WMSL)	27 knots	126	SeaRAM, 57 mm gun, .50 cal. machineguns	2 HH-60s	2 11-m RHIBs
NASSCO Tote Orca Class	24 knots	18	two Phalanx CIWS 8- .50 cal. machineguns	2 SH-60s	6 Wally interceptors

[66] U.S. Navy, "List of Home Ports," [http://www.chinfo.navy.mil/navpalib/ships/lists/homeport.html]. August 2005, accessed June 2006.

[67] U.S. Coast Guard, "378-foot High Endurance Cutter (WHEC)," [http://www.uscg.mil/datasheet/378whec.htm], September 5, accessed April 2006.

[68] Global Security, Littoral Combat Ship (LCS), [http://www.globalsecurity.org/military/systems/ship/lcs.htm], May 2004, (June 2006).

[69] U.S. Coast Guard, Integrated Deep Water System, National Security Cutter (NSC), [http://www.uscg.mil/deepwater/system/nsc.htm], 2006, accessed March 2006.

[70] Jane's Information Group Limited, *Jane's Fighting Ships*, *2003-2004*, Sentinel House, 2003, p. 832.

[71] Jane's Information Group Limited, *Jane's Fighting Ships*, *2003-2004*, Sentinel House, 2003, pp. 826-830.

[72] Jane's Information Group Limited, *Jane's Fighting Ships*, *2003-2004*, Sentinel House, 2003, p. 823.

Ship Type[70]	Speed	Crew	Weapons	Helicopters	Small Boat
118-ft Wally	30+ knots	6	.50 cal. machineguns		

Table 7-6: Ship Type Characteristics

The use of the ships discussed thus far does not preclude that of other ships already deployed in the vicinity of a potential threat; but for mission planning purposes the latter ships are assumed to be in port. The amphibious ships and carriers either lack the speed needed to intercept a threat in a timely manner or, with all the normally embarked operating systems, will take too long to prepare for deployment.

Current Ship Systems (CG, DDG, FFG, and WHEC) and the Program of Record Ships (LCS and WMSL) need AOE (underway replenishment ship) logistical support during the respective missions. The COTS modification option will be able to operate independently for over 20 days.

The concepts are grouped by availability—Current Ship Systems (CG, DDG, FFG, and WHEC), Program of Record Ship Systems (newly deploying systems), and COTS Modification (commercial existing systems capable of modification to meet the mission). The analysis assumes that one-half of Navy ships in any location are available for surge operations at any time. Ships stationed in Japan already operate in the Western Pacific and will be rerouted when a threat is identified; therefore all Yokosuka ships are assumed available. Likewise, all USCG assets are assumed to be available to respond to the maritime threat. The Tote Orca class modified ships are designed for the MTR purpose and therefore assumed to be on call at all times. Table 7-7 shows the three different PBS concepts; parenthetically, each could apply to both WMD and SAW missions.

Concept	Yokosuka	Kodiak	Pearl Harbor	San Diego
1 (Current Ship Systems)	2 CGs; 5 DDGs; 2 FFGs	1 WHEC	1 CG; 3 DDGs; 1 FFG; 2 WHECs	3 CGs; 7 DDGs; 3 FFGs; 2 WHECs
2 (PoR Ship Systems)	3 LCSs		6 LCSs; 2 WMSLs	6 LCSs; 2WMSLs
3 (COTS modification)	1 Orca w/6 Wallys		1 Orca w/6 Wallys	1 Orca w/6 Wallys

Table 7-7: PBS System Concepts by Ship Type

As shown in Table 7-7, a large number of ships are allocated in Concept 1, which, due to the speed of the ships being used and ships being intercepted, may be needed. The faster LCS employed in Concept 2 allows for shorter transit times and the potential to intercept more than one potential threat vessel. Concept 3 relies on the use of the Tote Orca class ship as a base from which to deploy the faster 118-ft Wally interceptors. One foreseeable concern with Concept 3 is the slow speed of the Tote Orca class ship coupled with any excessive intelligence latency, which would not give the ship the lead time necessary to pre-position along the transit route. For all three concepts, the ships and Wallys are considered to be in an escort profile while searching a potential threat vessel and are not anticipated to interact with multiple vessels simultaneously.

The home base of the Concept 1 ships and the potential home basing of Concepts 2 and 3 ships allow for each of the functions identified for PBS (in Appendix A) to be met. The level of success within each Concept will be dependent on the number of potential threat vessels to be intercepted, the distances to traverse to execute the intercept, and the latency of the information about the threat vessels.

SBA PBS Architecture Analysis

Determination of Platform Probability of Kill

The weapon analysis described in Section 4.2.3 produces the probability of kill for various combinations of weapons. The following analysis determines the probability of kill for a single platform.

Two types of platforms are considered: *Small escort* and *medium escort*. A *small escort* is a small boat, approximately 25-35 feet long, with a crew of four or five. It has a top speed of 40 knots and is very maneuverable. The 34-ft Dauntless used by Navy Inshore Boat Units (IBUs) is an example of a small escort. A *medium escort* is a larger craft ranging from 80-150 feet long and has a crew of 20. It features inboard engines and can reach a top speed of 35 knots. The 110-ft Coast Guard cutter is a medium escort.

The essential difference in armament between a small and medium escort is the ability to mount a medium caliber gun. The small escort cannot; the medium can (in the bow position only). The medium escort can mount two single weapons on the port and starboard positions, the small can mount one each. The medium escort also has a longer endurance (which affects the number of vessels required in an overall force structure.) More information on force endurance that topic can be found in Appendix E.

Figure 7-11 shows escort weapon mounts.

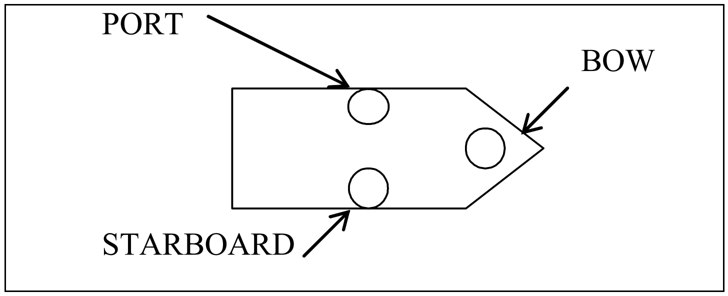

Figure 7-11: Small boat weapon mounts

The mounts cover "firing arcs" as shown below:

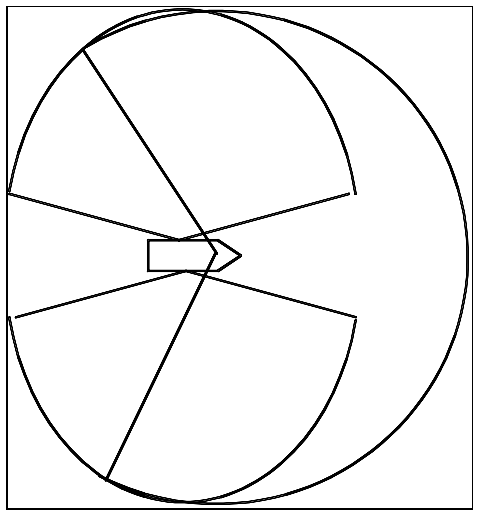

Figure 7-12: Small boat mount firing arcs

Both escorts have the same firing arcs. For both escorts, the weapon in the bow position and the weapon(s) in one of the two side positions can engage a target. This reflects the overlapping firing arcs as well as the maneuverability of the craft.

The escorts are armed as follows, reflecting inputs from the individual weapon analysis. The small escort mounts one MMG in each position. The medium escort has a MCG in the bow position and two MMG on each side position. The team onboard the HVU is treated in a slightly different manner. The team consists of six 2-man teams each armed with a LMG. The teams are evenly distributed around the HVU. The probability of kill is based on the number of teams engaging a target. All escorts follow the "Hold Fire" firing policy. The platform/team probabilities of kill are as follows:

Platform	P(kill), 500-yd Engagement	P(kill), 200-yd Engagement
Small escort	0.6158	0.4557
Medium escort	0.8708	0.7682
3 LMGs	0.6491	0.2666
2 LMGs	0.2932	0.0409

Table 7-8: Escort Platform Probabilities of Kill

Determination of Escort Option Probability of Kill

The next step of analysis is to determine the probability of kill of an escort option, which is comprised of combinations of platforms. The escort options are shown in Figure 7-13:

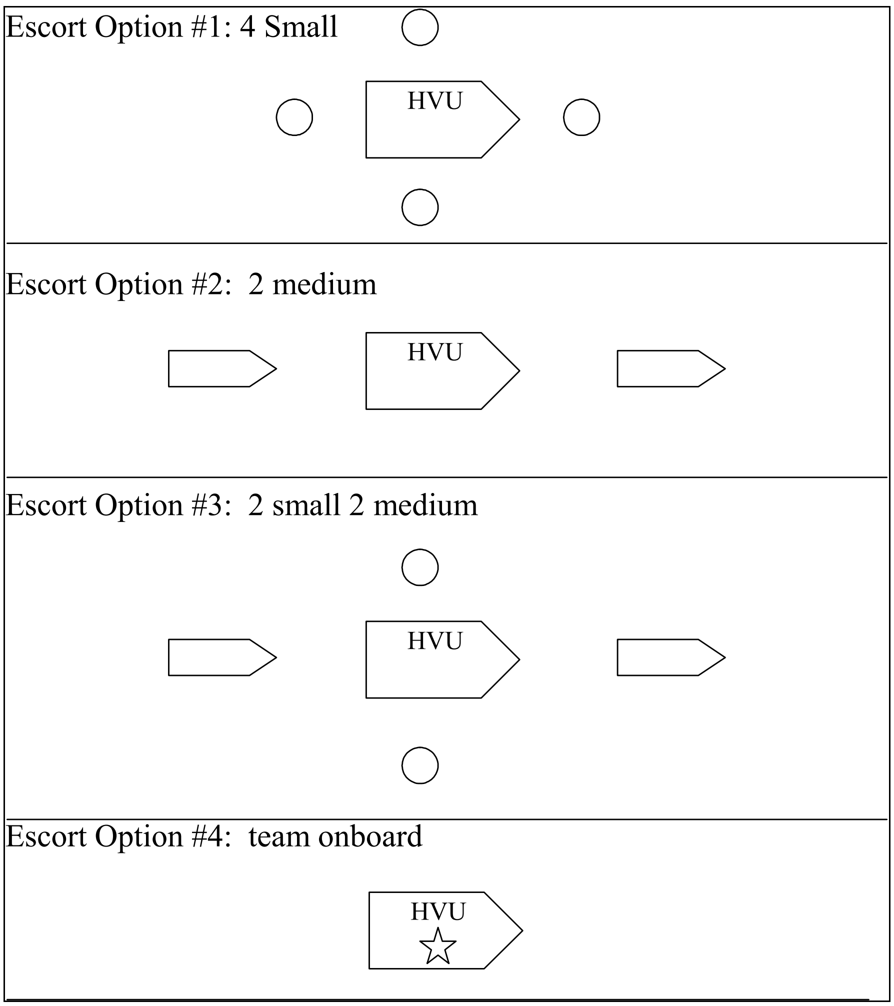

Figure 7-13: PBS(3) Concept Formations

Consideration of escort option probability of kill takes into account more than the combination of different platform probabilities of kill. It includes the initial distance of the engagement, the number of escorts, the distance of escorts from the HVU, the coordination of fires from more than one escort, and the relative movement between targets and escorts. It also considers the ability of the team onboard the HVU to reposition during an engagement. The analysis considers all of these factors by assigning a probability of engagement for the escorts based on initial engagement distance. In general, more escorts increase the likelihood that one can engage an attacker. Close spacing of small escorts increases the difficulty of coordinating fire, but contributes to the likelihood of engagement. Two escorts have fewer coordination issues but more maneuvering to accomplish to engage a target that may approach from any direction. The probabilities are summarized in Table 7-9.

Escort Option	500-yd Engagement	200-yd Engagement	500-yd P(kill)	200-yd P(kill)
#1 – 4 small	100% chance of 1 of 4	100% chance of 1 of 4	0.6158	0.4557
#2 – 2 medium	75% of 1 of 2	50% chance of 1 of 2	0.6531	0.3841
#3 – 2 small, 2 medium	100% chance of 1 of 4. Equal chance of small or medium	100% chance of 1 of 4. Equal chance of small or medium	0.7433	0.6120
#4 – team onboard	100% chance that 3 of 6 engage	50% chance that 3 engage, 50% chance that 2 engage	0.6491	0.3378

Table 7-9: PBS(3) Concept Probabilities of Kill

This method is an abstraction of a complex set of relationships. A detailed vector analysis, including acceleration of the units involved, would give more evidence concerning the number of escorts that can engage an attacker. Such an analysis is recommended as a follow-on topic for future SEA cohorts.

7.1.3 Find/Fix

WMD F/F Architecture Analysis

Find/fix of the WMD mission involves conducting a search of each container ship to determine if any of the containers have a nuclear device inside of them. In order to determine this, each detection and identification system must be evaluated in terms of its ability to detect nuclear devices and NORM, as well as its potential for false alarms. In addition, characteristics of individual systems include the distance from a given container as well as the integration or dwell time required to confidently search each container.

Some systems have unique qualities that offer significant advantages with respect to performance of the Find/Fix function of the WMD mission. In particular, the LRM detector system can be lowered down between the guide rails between individual containers. This affords the opportunity for the actual detector elements to be significantly closer (on the order of 1.5 m versus up to 6 m). It also allows for up to eight containers to be simultaneously scanned. In addition, the long potential dwell time of the Fission Meter enables it to be placed in a given cargo hold and collect neutron data over extraordinarily long periods of time, which is often necessary with lower energy emitting nuclear devices that may be shielded. The Fission meter also can search multiple containers because it is simply collecting neutron emissions throughout the hold, rather than being focused on any one particular container.

Appendix I offers an analysis of the expected numbers of containers that will alarm due to the presence of NORM, containers that will alarm due to false alarm from elevated random noise levels, and overall probabilities of success in detecting a device given the different potential search protocols. Appendix J describes the physics behind the detection of radiation.

SAW F/F Architecture Analysis

Find/Fix for the SAW mission involves searching for suspected terrorists among a merchant vessel's crew. The architectures developed for the SAW mission all included the same search and identification mechanisms. Those mechanisms are fingerprinting, database searches, and biometric data collection and comparison. Our analysis considers a functional biometric search system to be feasible within the next five years and thus satisfies our near-term requirement for emerging technology.[73]

SBA F/F Architecture Analysis

Find/Fix of the SBA mission involves only conducting a search for surface contacts during escort operations. This search can be done by visual means, radar, or a combination of both. Almost every modern vessel of appreciable size does both as a matter of routine. The distinction between the two is more important when discussing small craft, such as the small escort (described below). Small vessels with limited height of eye have a short visual detection radius. Visual search is also dependent on weather conditions. The EXTEND™ SBA model varies detection capability based on the

[73] For example, see Richard Hunton, "A Proposed Model for the Collection and Use of Biometric Identifiers Obtained at Sea as an Effort to Prevent Seaborne Terrorist Activity and Enhance Security at the Port of Charleston, South Carolina," Master's Thesis, Naval Postgraduate School, Monterey, CA, March 2005.

presence of visual detection mechanisms, radar detection mechanisms, or a combination of both; see below for details.

7.1.4 Finish

7.1.4.1 WMD Finish Architecture Analysis

As mentioned in Chapter 4.0, assumptions of the WMD scenario render detailed analysis of the Finish function unnecessary.

7.1.4.2 SAW Finish Architecture Analysis

There is one element considered in the SAW Finish analysis: the weapon system required to disable or sink a large merchant vessel. A variety of weapons and platforms could be employed to complete this task. Given the time constraints described, the weapon system must be available for use within minutes. This leads to consideration of weapons that can be deployed on receipt of initial intelligence and used immediately. The exact type, characteristics, and effectiveness of this weapon or weapon system are open to research by future cohorts of the SEA program.

According to research conducted in this project and subject matter experts, a command-activated, deployable mine or series of mines can accomplish this mission and could be fielded in the five-year timeframe, assuming that the mines and all assets required to deploy and recover the mines are feasible.

7.1.4.3 SBA Finish Architecture Analysis

Finish functions in SBA must be considered in conjunction with the PBS analysis described above. To this point analysis has focused on weapons, platforms, and combinations of platforms (escort options). The focus now shifts to the additional advantages the defender gains by employing two supplementary units.

Determination of Supplement Option Advantages

The supplementary units considered are armed helicopters and unarmed unmanned surface vehicles (USV). As with the escort options, these supplemental units are analyzed to offer a wide range of forces which may result in higher effectiveness or cost-effectiveness.

The armed helicopter offers two potential benefits to the defender. First, the helicopter offers additional capability to challenge suspicious small boat traffic and "clear a path" for the HVU. Second, the helicopter offers additional engagement capability. (See Section 4.2.3 for an analysis of helicopter engagements against small boats.)

The USV offers different capabilities. The SBA mission is challenging in a domestic port with a high volume of recreational and working boat traffic. An average of 300 to 400 vessels of all types can be found in Bay area waters in a single 24-hour period.[74] The USV allows friendly forces to physically impose themselves between suspicious vessels and the HVU without risk to personnel. The USV also allows challenges and warnings to be delivered at greater distances from the HVU. This increases the time available for a lethal engagement if required. Although unarmed, the USV could be outfitted with loudspeakers, police lights, various cameras and other sensors, pyrotechnics, or other low-cost measures to warn innocent boaters and classify surface contacts. A USV could also shoulder suspect vessels or ram identified targets. The USV could also complicate enemy plans by forcing the enemy to take action earlier than desired.

Details of the USV, including its control system, were not examined in great detail. Research and existing programs led to an assessment that a USV with the capabilities described could be fielded within the five-year time limit established for the scenario. A detailed analysis of the technologies, capabilities, and costs of USVs employed in this manner is recommended as a follow-on topic for future SEA cohorts.

The benefits of both helicopter and USV are incorporated in the SBA EXTEND™ mission model. An exact description of the benefits (greater initial attacker distance and reduced time to classify targets) can be found in the description of the model in Section 7.2.4.

[74] United States Coast Guard District 11, Summary of San Francisco Bay Area Vessel Transits, 2005 (2006) via email from LT D. Valadez, Vessel Tracking Center.

7.1.5 Sustain

7.1.5.1 WMD Mission

The WMD mission begins with receipt of intelligence that several commercially owned and operated container ships transiting from Southeast Asia to a port in the San Francisco harbor are carrying concealed nuclear devices. The concept of operations for the WMD search on the containership (described in Section 7.1.3 Find/Fix the Threat) requires as much time as possible for the search teams onboard to conduct their search. To support these requirements U.S. military ships must depart as soon as possible from their homeports to intercept each of the container ships. Upon intercept, each military ship will transfer the MTR Find/Fix search teams to the container ship to conduct their search. Military ships will transit at their maximum speed to intercept the container ships in order to allow the search teams the maximum possible search time. Military Sealift Command type ships (i.e., T-AO class) have a maximum speed of 20 knots or less[75] and will therefore lag behind the military ships during the sprint to intercept the container ships. Refueling will therefore not be available for the military ships until after intercept of the container ships. This creates a requirement that ships must sprint at their maximum possible speed, but have enough fuel remaining after intercept to meet the refueling ship.

Ships consume fuel at varying rates according to their speed of transit. Along with fuel efficiency, fuel capacity varies by ship class. Ships will vary in the amount of fuel remaining after sprinting to intercept the container ship, based on sprint speed, distance covered, and maximum fuel capacity. Section 7.2.5 shows the results of modeling various ship classes in their sprint to intercept the container ships.

Four locations currently utilized by the U.S. military will allow ships home ported (and in port at the beginning of the mission) to get underway and intercept the Eastward-transiting container ships: Yokosuka, Japan (U.S. Navy only), Kodiak, Alaska (U.S. Coast Guard only), Hawaii (U.S. Coast Guard and Navy), and U.S. West Coast ports (i.e., San Diego and San Francisco, California, and Everett, Washington). Ships from these four locations will be utilized based on the

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[75] United States Government Accounting Office, GAO/NSIAD-98-1, Navy Aircraft Carriers: Cost-Effectiveness of Conventionally and Nuclear-Powered Aircraft Carriers, August 1998.

latency of the intelligence received about the container ships possessing WMD: As the amount of time increases from container ships getting underway from Southeast Asia, the farther East their transit can potentially take them depending on their transit speed. Once past the Yokosuka base, Navy ships would be hard done by to intercept the container ships on an Eastward chase. Therefore, if intelligence is received early, more ships will be utilized from Yokosuka and Kodiak. If intelligence is received later, Yokosuka and Kodiak ships will not be utilized, and all U.S. West Coast ships will be employed.

MTR Team Transport from Military Ship to Container Ship

Stakeholders from the maritime industry indicate that most container ships do not have a flight deck or a helipad for helicopter boardings; the deck space will in general be fouled by mast-heads, lines, communications gear, etc. Additionally, the size of the MTR search team is larger than an SH-60B Seahawk (carried on most U.S. Navy ships) or H-65 Dolphin (carried on most USCG ships) can carry in one lift. Container ships are, however, designed for small boat transfers and boardings, normally conducted by pilots for waterway escort. Transfers of MTR search teams onto and off container ships will be conducted by either special-warfare tactics (i.e., fast-roping) or by small boat transfer (utilizing military ship's RHIBs).

Berthing the MTR Teams onboard the Container Ship

Based on stakeholder input, the majority of container ships do not contain sufficient number of additional berthing compartments for all of the MTR search team members to sleep in. Two arrangements are available for berthing the MTR search teams:

1) Search teams carry portable sleeping arrangements, such as light weight cots, sleeping bags, etc. onto the container ship. Team members then make use of any available location for a berthing area, allowing minimal impact on the container ship's company berthing spaces. Sleeping on the container ship therefore requires search teams to carry additional equipment onboard. Sleeping quarters will likely be haphazard and in rough seas not well suited for a portable cot. Search team members are likely not to get good sleep when off duty. The payoff is that military ship

support is minimized as the ship is not required to stay within small boat transport range of the container ship.

2) Search teams are transported off the container ship at the end of their shift. The search teams are recovered to the military parent ship where they are berthed. Most current military ships contain additional crew berthing ("overflow" berthing) that will be utilized. Search team members will get good sleep in their off-shift, and do not need to carry more than one shift's worth of food with them onto the container ship. The limitation of this arrangement is that the military parent ship must remain within the vicinity of the container ship.

The effect of sleep on the search team is modeled in Section 7.2.5 to observe how detrimental haphazard sleeping conditions become.

<u>Feeding the MTR Teams while onboard the Container Ship</u>

Stakeholders from the maritime industry stated container ships will only carry enough food for their organic crew, and only enough to get them from their point of departure to the next arrival destination. MTR search teams boarding the container ship therefore must carry all of their own food onto the container ship. Each MTR search team is envisioned to conduct a nominal 7-day search. Each team member will therefore carry 21 meals (nominally). A case of prepackaged Meals Ready-to Eat (MREs) contains 12 meals; each team member would therefore carry nominally two cases of MREs with them. The two arrangements described above imply the following for food:

1) Search teams carry up to two cases of MREs per person. For a nominal search team size of 9 people, 18 cases of MREs will be carried aboard.

2) Teams working in a nominal 2-section duty carry one MRE per person aboard the ship (or for a nominal search team size of 9 members, less than one case of MREs total, per day). At the end of the shift the search team is transported by small boat to the parent military ship where they will be fed, berthed, and re-supplied for the next day. The parent military ship must remain within a limited range (approximately 100 NM) of the container ship. Support equipment transferred with the search team is thus minimized.

7.1.5.2 SAW Mission

From a Sustainment perspective, the SAW mission is similar to the WMD mission in the following ways:

1) Military ships get underway from their homeport to intercept a commercial ship transiting eastward from Southeast Asia.
2) Military ships will transit at their maximum possible speed to intercept the container ship.
3) A boarding team will be transferred onto the container ship upon intercept. Sustainment is not required for the boarding team because their mission is to retake the container ship, rather than to search over several days.

7.1.5.3 SBA Mission

As discussed in Section 7.1.4, the SBA mission requires several small boats, medium size ships, helicopters or USVs to protect points of vital infrastructure, transiting commercial ships of high value, and water taxis. Operations will be conducted continuously for up to 30 days. While medium-size ships (i.e., USCG 110-ft long class or U.S. Navy PC ships) contain several redundant systems, small boats can be viewed as much simpler systems overall and therefore have lower operational availability and reliability. Platforms used within the SBA mission that do not have multiple redundant subsystems built into them are more susceptible to failure resulting in a complete loss of mission capability: therefore will yield a higher probability of failure to the overall Sustain function. The reliability of small boats and helicopters is modeled to observe quantity of spares required to support the Sustain probability of success.

7.1.6 System Concepts Summary

Table 7-10 shows the breakdown of different system concepts that are considered for implementation in the overall SoS architectures. Some functions have as many as four different system concepts to consider. Others had as few as two concepts. Only those areas where more than one system concept is modeled and considered are listed in the matrix. The areas of the SoS where only one system concept is considered are not listed in this table. For example, the solution for the Finish(1) function in the WMD mission is simply to turn over discovered devices to Department of Energy JTO teams for disarmament and disposal. The concept is preexisting and believed to be effective. As such, no other potential conceptual solutions with respect to this function in the system are considered.

Top Level Function \ System Concept	1	2	3	4
C4ISR	AREA-PS	LOCAL-PS	AREA-OO	LOCAL-OO
PBS(1,2) (WMD,SAW)	AO-CG/DDG/FFG/WHEC	AO-LCS/WMSL	MODIFIED MERCHANT	-
PBS(3) (SBA)	SMALL ESCORTS	MEDIUM ESCORTS	SMALL AND MEDIUM	HVU-BASED TEAMS
F/F(1) (WMD)	LRM & FISSION	LRM & HPGe	NaI & FISSION	NaI & HPGe
F/F(3) (SBA)	VISUAL	VISUAL AND RADAR	-	-
FIN(2) (SAW)	ESCORT / RECAPTURE	ESCORT / DISABLE	-	-
FIN(3) (SBA)	ORG WEPS	ORG WEPS & AIR SUPT	ORG WEPS & USVs	ORG WEPS, AIR & USVs

Table 7-10: System Concepts Considered for SoS Architecture by Function

The concepts considered include current operational systems, Program of Record systems such as Littoral Combat Ship (LCS) and National Security Cutter (WMSL), and commercial-off-the-shelf (COTS) technologies. It is not suggested that the system concepts listed encompass all possible system solutions. Rather, they were determined to be potential "best fit" solutions based on the research and analysis conducted during the study.

7.2 SYSTEM OF SYSTEMS ARCHITECTURE SELECTION

A two-pronged approach to architecture development and selection is employed. The first prong consists of objective, experiment-driven analyses to select an architecture based on a fractional experiment design seeking to optimize the overall system effectiveness. This approach is used to first identify an optimum architecture in terms of effectiveness alone, without regard to cost, and then to seek out a suboptimum architecture that balances the values of low cost with high effectiveness. In this approach, potentially hidden or counter-intuitive interactions among the system concepts would be highlighted and their synergistic benefits or adverse costs could be determined. The details of this approach will be discussed in Section 7.2.1.

The second prong is to develop and select an architecture from a subjective, bottom-up approach focusing on cost-effectiveness. Such an approach allows insights of the experienced members of the SEA-9 MTR team to be brought forward into the development of an overall SoS architecture. This approach is equivalent to the so-called heuristic approach to systems architecting (M&R). The details of this approach will be discussed in Section 7.2.2.

7.2.1 Selection of Architecture via Orthogonal Array Experimentation

As highlighted in Section 7.1.6, seven separate system functions (factors), each of which could be satisfied by two to four different system concepts. The number of possible combinations of these system concepts, 3,072, need be evaluated for their effectiveness. The evaluation is done by simulation. Each simulation run takes more than three minutes. It would therefore take 704 days (or two years of around the clock) to evaluate all 3,072 potential architectures (combinations), with each architecture requiring 100 simulation runs in order to evaluate each architecture (combination). This would be impractical.

An efficient form of fractional experiment design is needed, which would enable the optimization of overall system performance, but dramatically reduce the overall number of experiment trials and simulation time. The most efficient form of experiment design is known as the Taguchi Method™, most commonly associated with measures to achieve higher levels of quality control during a manufacturing process.[76] The method involves the use of orthogonal arrays, obtaining the so-called response from each combination, an analysis of the effects and interactions of the different system concepts, and determining an optimal architecture from the analysis. In the Taguchi parlance, the system functions are called factors, and the various system concepts corresponding to the system functions are called levels. This method amounts to optimally assigning the levels (system concepts) to each factor (system functions) in order to achieve the best possible result for some response function. The application of the Taguchi method to this

[76] Ranjit K. Roy, *A Primer on the Taguchi Method*, Van Nostrand Reinhold, 1990, p. xi.

assignment problem is motivated by a successful extension of the Taguchi method to solve assignment problems.[77] In the case of the MTR project, the response function is taken to be both the overall SoS probability of success in stopping a terrorist attack and the cost-effectiveness measure. Given the number of factors (7) and levels (2-4), the standard orthogonal array $L_{32}(2^1 \times 4^8)$ is selected and modified as shown in Table 7-11. Note that each level is used in each factor and each appears an equal number of times. As an example, each of the four levels for C4ISR has eight trials (combinations or rows) dedicated to them. The different combinations are varied throughout the array so that each level has at least one trial with every level from every other factor.

TRIAL	C4ISR	PBS(1,2)	PBS(3)	F/F(1)	F/F(3)	FINISH(2)	FINISH(3)
1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2
3	1	3	3	3	1	1	3
4	1	1	4	4	2	2	4
5	2	1	1	2	2	1	3
6	2	2	2	1	1	2	4
7	2	3	3	4	2	1	1
8	2	2	4	3	1	2	2
9	3	1	2	3	2	1	2
10	3	2	1	4	1	2	1
11	3	3	4	1	2	1	4
12	3	3	3	2	1	2	3
13	4	1	2	4	1	1	4
14	4	2	1	3	2	2	3
15	4	3	4	2	1	1	2
16	4	1	3	1	2	2	1
17	1	1	4	1	2	2	3
18	1	2	3	2	1	1	4
19	1	3	2	3	2	2	1
20	1	2	1	4	1	1	2
21	2	1	4	2	1	2	1
22	2	2	3	1	2	1	2
23	2	3	2	4	1	2	3
24	2	3	1	3	2	1	4
25	3	1	3	3	1	2	4
26	3	2	4	4	2	1	3
27	3	3	1	1	1	2	2
28	3	1	2	2	2	1	1
29	4	1	3	4	2	2	2
30	4	2	4	3	1	1	1
31	4	3	1	2	2	2	4
32	4	2	2	1	1	1	3

Table 7-11: L_{32} Orthogonal Array for MTR SoS Architecture Optimization

[77] Huynh, T.V., "Optimal File Allocation in a Distributed Computer Network by Orthogonal Array Experiments," IEEE, Vol. 0-7803-3741-7/97, 1997, pp. 105-114. Huynh, T.V. and D.C. Gillen, "Dynamic Bandwidth Allocation in a Satellite Communication Network," IEEE Aerospace Applications Conference Proceedings, Vol. 3, 2000, pp. 1221-1232.

7.2.1.1 Architecture Development for Maximum Effectiveness

In the first iteration of system architecture development via orthogonal array experiment, the objective is to generate the maximum performing system architecture. In this case, the response is the system probability of success, which is the system probability of success for each of the three DRM as well as their average. Each of the 32 different experiments is performed by running the EXTEND™ model 100 times. The experimental (simulation) results are then analyzed using MINITAB™ Analysis of Variance (ANOVA) tables. The ANOVA table for Overall SoS Ps can be found in Table 7-12. Figure 7-14 depicts the main effects of the different system concepts for each of the system functions with system probability of success considered in aggregate, and independent of system cost. Figure 7-15 shows the interactions among the different system concepts.

Analysis of Variance for SoS Ps, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C4	3	0.0042465	0.0041186	0.0013729	3.29	0.050
PBS1,2	2	0.0021319	0.0000791	0.0000395	0.09	0.910
PBS3	3	0.0719979	0.0718044	0.0239348	57.36	0.000
F/F1	3	0.0022190	0.0021207	0.0007069	1.69	0.211
F/F3	1	0.0007508	0.0008956	0.0008956	2.15	0.164
FIN2	1	0.0126655	0.0127015	0.0127015	30.44	0.000
FIN3	3	0.0098204	0.0098204	0.0032735	7.84	0.002
Error	15	0.0062592	0.0062592	0.0004173		
Total	31	0.1100911				

S = 0.0204274   R-Sq = 94.31%   R-Sq(adj) = 88.25%

Table 7-12: ANOVA Table for Overall SoS Ps for All System Concepts

An examination of the ANOVA table indicates that choices of C4 system, PBS(3) system, FIN(2) system, and FIN(3) systems significantly affect, with high confidence, the overall SoS Ps. Figure 7-14 shows that the “best” options for those categories are Option 4 for C4ISR, Option 3 for PBS(3), Option 1 for FIN(2), and Option 4 for FIN(3). Referring to Figure 7-15, as there is a significant crossing of lines in any one interaction block, an interaction between different system concepts for the two different system functions may exist. As an example, the interaction between C4 concept and FIN(2) concepts implies that longer delays associated with some C4 concepts prevented the FIN(2) disable option from succeeding because the forces in question may not receive permission to act in time. Such insights lead to a change in the postulated Rules of Engagement (ROE) and SOP for the MTR forces. Some interactions are found to have no significance and to be the result of chance occurrence within the fractional experiment. In other words, a crossing of lines does not mean that there is a definitively an interaction, but there cannot be an interaction without a crossing of the lines.

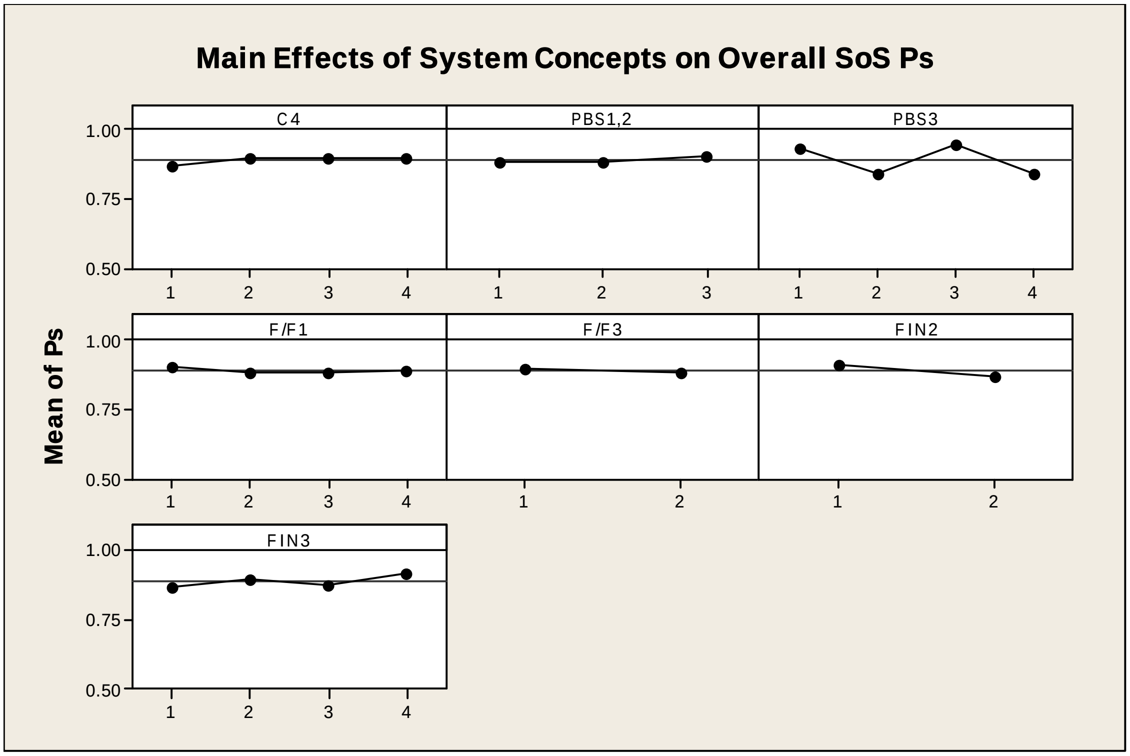


Figure 7-14: Main Effects of System Concepts on Overall SoS Ps

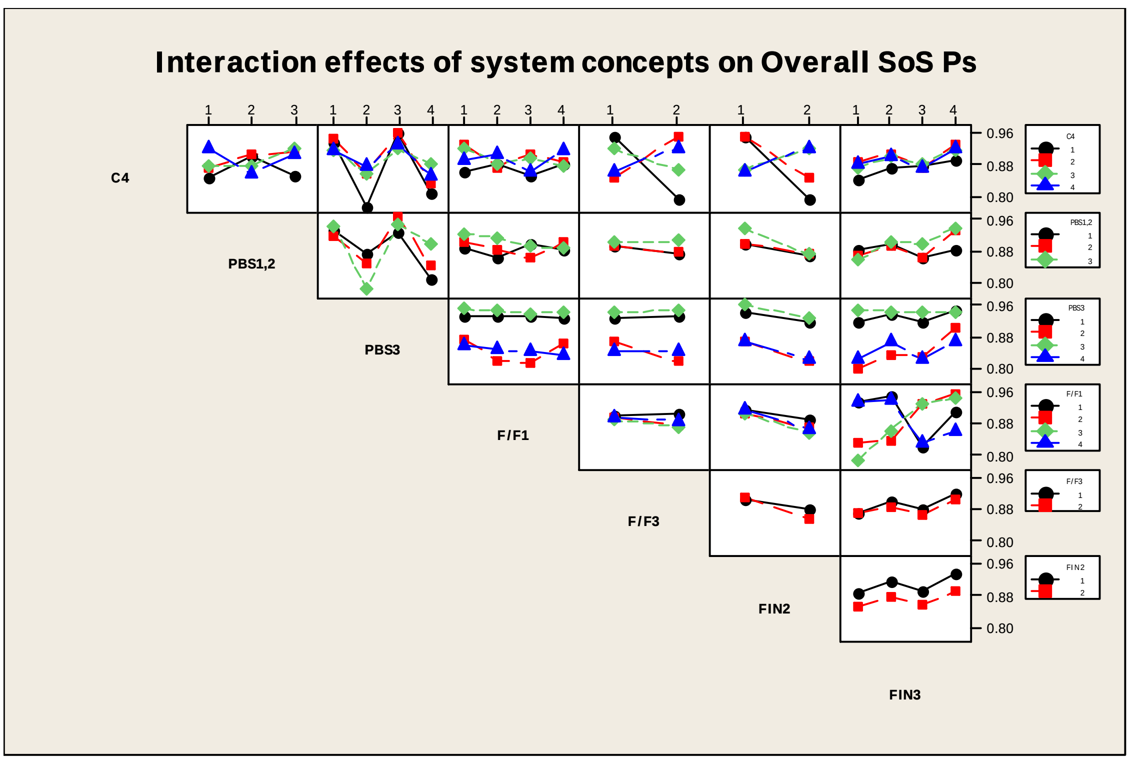


Figure 7-15: Interaction Effects of System Concepts on Overall SoS Ps

The data are also analyzed with each of the three missions' individual probability of success as the response function in MINITAB™. Table 7-13 displays the ANOVA SBA mission Ps as the response with only the SBA system concepts considered. Figure 7-16 shows the main effects of system concepts, while Figure 7-17 shows the interaction effects of system concepts pertaining to the SBA mission. Slight variations are noted in selections for system concepts between individual mission probability of success responses and all three mission probabilities of success aggregated. In such instances, the p-value calculated from the ANOVA table often indicates a lack of statistical confidence in the selection of one system concept over another. The system concept is then selected by the individual response. An example of one such occurrence where the difference was thought to be significant can be seen with respect to the selection of system concepts for Find/Fix(3) for SBA. Option 1 referred to using a visual look-out detection scheme for incoming attackers. Option 2 referred to using a combination of visual look-out with surface search radar support to detect incoming attackers. This system function applies only to SBA and does not impact the other two missions at all. When considered in aggregate, as shown by Figure 7-14, a slight bias exists in favor of Option 1. As shown in Table 7-12, the p-value of 0.164 for Find/Fix(3) is not insignificant, and there is thus approximately a 16% chance that the result is random and not a function of the selection at all. For the SBA mission alone, a stronger bias is demonstrated in favor of Option 2, as the p-value for Find/Fix(3) reduces to a more significant 0.09 (Table 7-13). It does not meet the often used standard of 95% confidence, but it comes closer to suggesting an actual effect. In this case, based on the results of the individual response, Option 2 is selected for the final architecture design.

Analysis of Variance for Ps, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C4	3	0.000453	0.000453	0.000151	0.03	0.991
PBS3	3	0.299557	0.299557	0.099852	23.11	0.000
F/F3	1	0.013654	0.013654	0.013654	3.16	0.090
FIN3	3	0.261554	0.261554	0.087185	20.17	0.000
Error	21	0.090752	0.090752	0.004322		
Total	31	0.665970				

S = 0.0657384   R-Sq = 86.37%   R-Sq(adj) = 79.88%

Table 7-13: ANOVA Table for SBA Ps for SBA System Concepts

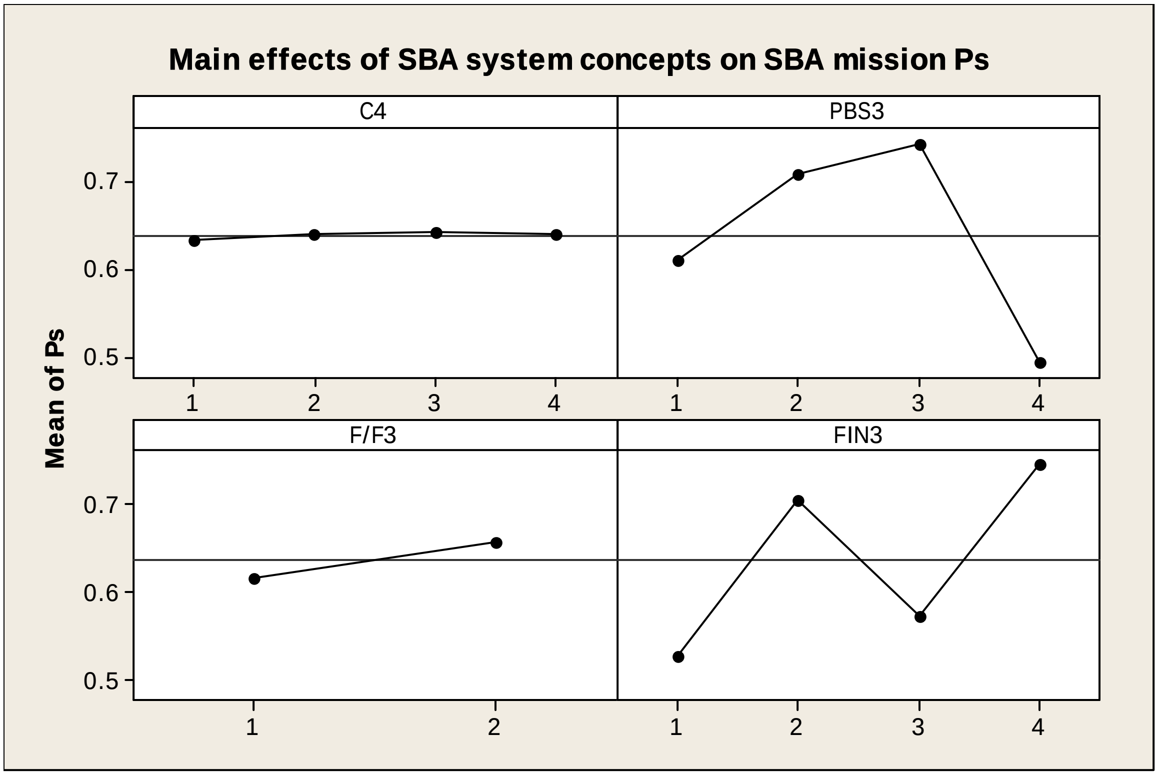


Figure 7-16: Main Effects of SBA System Concepts on SBA Mission Ps

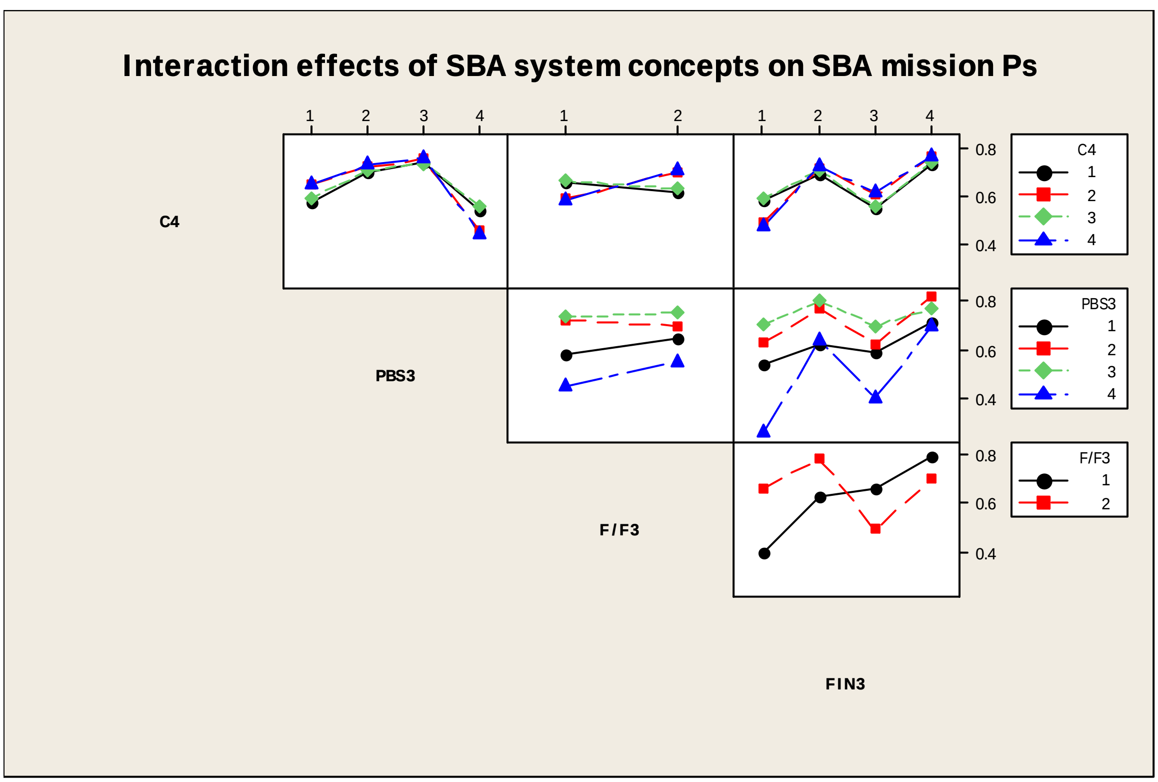


Figure 7-17: Interaction Effects of SBA System Concepts on SBA Mission Ps

A Taguchi analysis of the aggregated response, the three individual responses, and the interactions between concepts yields the final architecture for maximum effectiveness. Displayed in Table 7-14, this architecture is known as the Maximum Performance Architecture.

System Function	Option #	System Concept
C4ISR	4	Locally controlled, objective-oriented approach
PBS(1,2)	2	Littoral Combat Ships and Maritime Security Cutters supported by Oil tankers
PBS(3)	3	Small escort boats combined with medium escort ships
F/F(1)	1	Linear Radiation Monitor and Fission Meter
F/F(3)	2	Visual look-out backed up by radar search
FIN(2)	1	Escort potential attackers and recapture seized vessels
FIN(3)	4	Organic weapons, armed helicopters, and USV support

Table 7-14: SoS Architecture selected based on maximum effectiveness criterion

7.2.1.2 Architecture Development Balancing Cost and Effectiveness

As solutions to the problem of maritime security have to minimize cost to commerce and impact on global trade, this cost must also be incorporated into the response in the orthogonal array experiment in order to develop an architecture that minimizes this cost while maximizing mission effectiveness. To this end, the cost and the probability of success are amalgamated into a single, dimensionless quantity by normalizing the results from the 32 experiments for cost and probability of success into dimensionless quantities of values ranging from 0 to 100. The trial that yields the most expensive system architecture is assigned a score of 0 for cost, while the trial that yields the least expensive system architecture a score of 100 for cost. Likewise, the trial that yields the highest aggregate probability of success is assigned a score of 100 for effectiveness, while the trial that yields the lowest aggregate probability of success a score of 0 for effectiveness. For each of the 32 trials, the normalized cost and probability of success are then added to yield a "cost-effectiveness" quantity that has a minimum value of 0 and a maximum value of 200. Table 7-15 shows the overall Ps, system cost, normalized scores, and total cost-effectiveness score for each of the 32 trials.

TRIAL	Ps	COST($M)	EFF SCORE	COST SCORE	COST-EFF SCORE
1	0.841667	$290.31	55.47264	95.82896	151.3016
2	0.899833	$1,628.21	84.41128	62.47898	146.8903
3	0.8945	$4,100.46	81.75788	0.853089	82.61097
4	0.7995	$174.11	34.4942	98.72555	133.2197
5	0.862	$309.93	65.58872	95.33992	160.9286
6	0.917833	$1,650.88	93.3665	61.91388	155.2804
7	0.893833	$4,077.79	81.4262	1.418188	82.84439
8	0.841	$122.98	55.14096	100	155.141
9	0.92	$1,721.68	94.44444	60.14899	154.5934
10	0.816167	$286.20	42.78607	95.93128	138.7173
11	0.901833	$1,364.97	85.4063	69.04084	154.4471
12	0.856333	$4,134.68	62.76949	0	62.76949
13	0.931167	$1,699.01	100	60.71409	160.7141
14	0.8235	$266.59	46.43449	96.42032	142.8548
15	0.871667	$1,384.59	70.39801	68.5518	138.9498
16	0.873167	$1,850.18	71.14428	56.94602	128.0903
17	0.751167	$246.78	10.44776	96.9141	107.3619
18	0.918167	$1,664.42	93.53234	61.57649	155.1088
19	0.773833	$4,065.67	21.72471	1.720228	23.44494
20	0.8655	$184.71	67.33002	98.46117	165.7912
21	0.730167	$239.05	0	97.10679	97.10679
22	0.928333	$1,714.43	98.59038	60.32967	158.92
23	0.839833	$4,015.65	54.56053	2.967048	57.52758
24	0.901667	$1,377.54	85.32338	68.72751	154.0509
25	0.863833	$1,785.24	66.50083	58.56478	125.0656
26	0.791833	$215.32	30.67993	97.69814	128.3781
27	0.853667	$1,434.43	61.44279	67.30932	128.7521
28	0.8695	$1,765.37	69.32007	59.05998	128.38
29	0.889667	$1,735.22	79.35323	59.8116	139.1648
30	0.743333	$223.05	6.55058	97.50546	104.056
31	0.879667	$1,426.70	74.37811	67.50201	141.8801
32	0.874167	$1,752.37	71.64179	59.38399	131.0258

Table 7-15: Normalized Cost-Effectiveness Scores by Trial Number

As in the original experiment, for each trial 100 simulation runs are made. The simulation results are then analyzed using MINITAB™ ANOVA tables. In this case, the response is the cost-effectiveness score. The ANOVA table for Overall SoS Cost-effectiveness can be found in Table 7-16. Figure 7-22 depicts the main effects of the different system concepts for each of the system functions with system probability of success considered in aggregate, and independent of system cost. Figure 7-8 shows the interactions among the different system concepts.

Analysis of Variance for Cost-Eff, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C4	3	918.0	1063.8	354.6	1.95	0.165
PBS1,2	2	9827.6	10016.0	5008.0	27.52	0.000
PBS3	3	5398.1	5500.0	1833.3	10.07	0.001
F/F1	3	1477.3	1415.5	471.8	2.59	0.091
F/F3	1	310.8	205.0	205.0	1.13	0.305
FIN2	1	3217.0	3303.5	3303.5	18.15	0.001
FIN3	3	12885.2	12885.2	4295.1	23.60	0.000
Error	15	2730.1	2730.1	182.0		
Total	31	36764.2				

S = 13.4910   R-Sq = 92.57%   R-Sq(adj) = 84.65%

Table 7-16: ANOVA Table for Overall SoS Cost-Effectiveness for All System Concepts

The ANOVA table indicates that choices of PBS(1,2) system, PBS(3) system, FIN(2) system, and FIN(3) systems significantly affect, with extraordinarily high confidence, the overall SoS Ps and are not due to chance. Figure 7-18 shows that the "best" options for those categories are Option 2 for PBS(1,2), Option 1 for PBS(3), Option 1 for FIN(2), and Option 2 or 4 for FIN(3). The cost-effectiveness scores for FIN(3) Options 2 and 4 are extraordinarily close, as can be seen in Figure 7-18. Option 2 scores 148.525, while Option 4 scores 147.471—a difference of less than 0.7%. A runoff in the model of both concepts with all other system concepts remaining unchanged indicates that Option 4 generates a 10% increase in SBA mission Ps for only \$21.9M, or approximately 7.6% in added system cost. FIN(3) with Option 4 is therefore selected. Referring to Table 7-14, once cost is accounted for, PBS(3) now has a different result than when effectiveness was considered on its own. In other words, PBS(3) Option 3 is no longer the optimum choice because it is so expensive. Interaction effects, depicted in Figure 7-19, are again considered and evaluated.

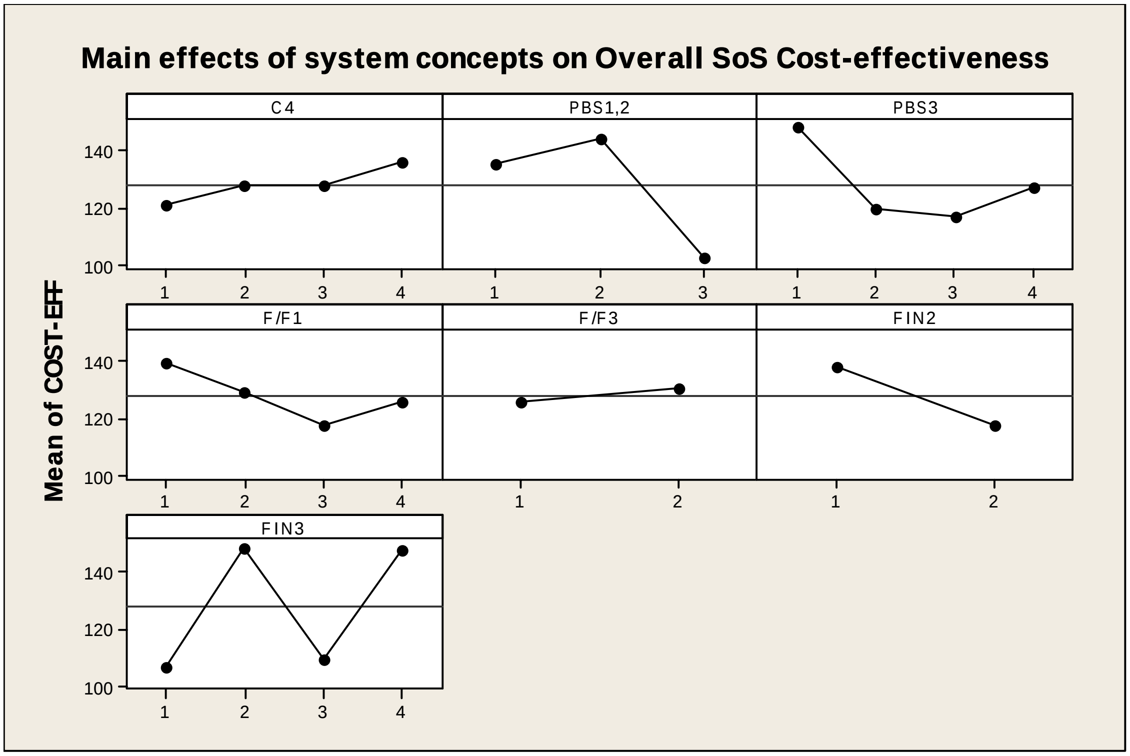


Figure 7-18: Main Effects of System Concepts on Overall SoS Cost-Effectiveness

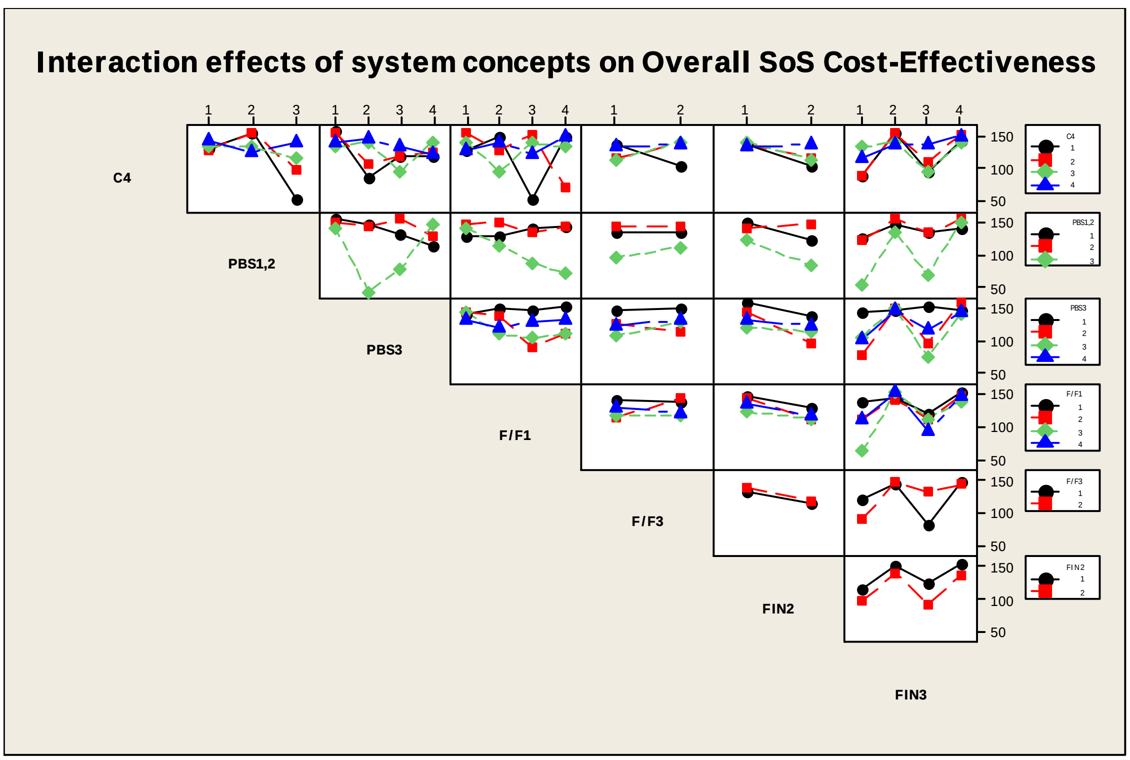


Figure 7-19: Interaction Effects of System Concepts on Overall SoS Cost-Effectiveness

A Taguchi analysis of the cost-effectiveness scores and the interactions between concepts yields the final architecture for maximum cost-effectiveness. Displayed in Table 7-17, this architecture is known as the Top-Down Cost-Effective Architecture.

System Function	Option #	System Concept
C4ISR	4	Locally controlled, objective-oriented approach
PBS(1,2)	2	Littoral Combat Ships and Maritime Security Cutters supported by Oil tankers
PBS(3)	1	Small escort boats only
F/F(1)	1	Linear Radiation Monitor and Fission Meter
F/F(3)	2	Visual look-out backed up by radar search
FIN(2)	1	Escort potential attackers and recapture seized vessels
FIN(3)	4	Organic weapons, armed helicopters, and USV support

Table 7-17: SoS Architecture Selected Based on Cost-Effectiveness Criterion

7.2.2 Architecture Development Based Upon Bottom-Up Approach

The third alternative architecture is heuristically developed. Based on the cost and performance data and experience, the lowest cost options from the potential system concepts for the system functions that would meet system effectiveness requirements are selected. High performance, but costly, systems are disregarded as long as there is a cheaper system that meets requirements, even if its overall performance is below that of the high performance system. The selected options together form a cost-effective architecture, shown in Table 7-18. The principal differences between this architecture and that derived by the orthogonal array experiment lie in two concepts. The first is the application of "Sea Marshall" teams and disabling protocols rather than escorting potential SAW ships across the Pacific and recapturing the vessels if they have been seized for FIN(2). The second is the absence of USVs to support the escort vessels within San Francisco Bay for FIN(3). This architecture is known as the Bottom-Up Cost-Effective Architecture.

System Function	Option #	System Concept
C4ISR	2	Area controlled, objective-oriented approach
PBS(1,2)	2	Littoral Combat Ships and Maritime Security Cutters supported by Oil tankers
PBS(3)	1	Small escort boats only
F/F(1)	1	Linear Radiation Monitor and Fission Meter
F/F(3)	1	Visual look-out
FIN(2)	2	"Sea Marshall" teams with harbor pilots, disable seized vessels via shore battery concept
FIN(3)	2	Organic weapons and armed helicopters

Table 7-18: SoS Architecture Selected Based on Subjective Cost-Effectiveness Criterion

7.2.3 Existing "As Is" Architecture

The existing "as-is" system architecture consists of those systems currently fielded to at least an initial operating capability (IOC). The performance of such systems, the numbers of forces allocated, the level of readiness, and the concepts of operations for employment of such forces are classified. The performance analysis of this as-is system architecture is classified. The performance of this as-is system serves as a basis for a comparison of the three architectures discussed above.

7.3 ARCHITECTURE RANKING APPROACH

An analysis of governing policy documents, such as *The National Strategy for Maritime Security*, leads to the definition of several measures of system effectiveness. They are the probability of stopping the impending terrorist attack and the cost associated with stopping the attack. A combination of modeling, simulation, and analysis is used to evaluate the performance of the different architectures with respect to these two measures.

At least 100 simulation runs are made for each architecture for each of the three design reference missions. The SoS architecture probability of failure in each mission area is obtained by dividing the numbers of terrorist attack successes in a given mission by the total number of simulation runs. The probability of success in each mission area for each SoS architecture is then obtained.

The architectures are then ranked in terms of their probabilities of mission success and also in terms of their cost-effectiveness.

The cost associated with stopping the attack consists of two separate and distinct elements. The first element is the cost to commerce associated with the architecture and its concept of operations. The amount of delay time suffered by any container ship is calculated and converted into an economic cost assumed to be at most $20,000 per container per day, taking into account direct costs and indirect costs associated with the stoppage of container traffic at U.S. ports and the resulting impacts on the economy.[78] In addition, economic damage costs to shipping are also included, as damage may occur to

[78] Bruce Arnold et al., United States Congressional Budget Office, "The Economic Costs of Disruptions in Container Shipments," Report to the Permanent Subcommittee on Investigations, Committee on Homeland Security and Governmental Affairs, United States Senate, 29 March 2006, pp. 2-21.

shipping during the course of attempting to prevent a terrorist attack and in particular to recapture a seized vessel or disabling a seized vessel.

The second element in the overall cost is the actual cost of system research and development, procurement, and operations and support. For the most part, there is not significant cost for system research and development, procurement, because the system concepts in the architectures considered consist of systems that have been already procured (existing systems, programs of record, COTS technologies) and make use of mature technologies that could be procured within the next five years. The costs of operations and support (O&S) are calculated, using analogy and extrapolation from actual. Since the systems envisioned would only be performing MTR missions in response to impending attack, operations and support costs are adjusted to reflect only the time that they are performing the MTR missions as a share of their total annual O&S costs. These costs together represent the total system procurement and operations costs for each architecture.

The total cost is calculated by adding the total system procurement and operations costs and damage and delay costs. This total cost is then used in assessing the cost-effectiveness of each architecture.

7.4 MODELING AND SIMULATION

Maritime Threat Response modeling and simulation aids in the evaluation of the effectiveness of the proposed SoS architectures. The models represent the capabilities of the various subsystems and equipment to be employed in the three missions as well as the operating limitations of the personnel and equipment. Also incorporated in the models are the location and availability of assets to be used in each mission and the relative distances to be traversed in order to respond to the maritime threat. The probabilities of detection, false alarm, and success discussed in Section 5 are included in the models. Simulation models are broken down by functional application to mission, as listed in Table 7-19. Results from individual functional models are compiled as modules into architectures for the three missions (WMD, SAW, and SBA). Architecture modules, using output from the functional models, is then modeled using 100 simulation trials within Extend to determine the overall SoS effectiveness. The modeling and simulation of each architecture is independent of cost so as to strictly evaluate the capability of the SoS. Cost will be applied later to determine affordability and the possible need for tradeoff considerations.

Function	**Model**	**Mission**		
		WMD	**SAW**	**SBA**
C4ISR	Receiving Communications	X	X	X
	Command and Control	X	X	X
	Compute	X	X	X
	Transmit Communications	X	X	X
PBS	Mission Database	X	X	X
	PAV Generator	X	X	
	Ship Intercept	X	X	
	Sea State Generator	X	X	
Find/Fix	Initial Orders			X
	Container Search	X		
	Ship Search and Engagement		X	
Finish	Small Boat Attacker Generator			X
	Helicopter Engagement			X
	MTR Escorts or Teams Onboard Engagement			X
	Delay to Commerce			X
Sustain	Ship Fuel Consumption	X	X	
	Watch Team Sleep Analysis	X	X	X
	Small Boat Availability and Reliability			X
	Helicopter Availability and Reliability			X

Table 7-19: Functional Model to Mission Application

The modeling tools used consist of Microsoft Excel, Extend v6, and the Fatigue Avoidance Scheduling Tool (FAST) v1.0.26. Excel processes probabilistic outcomes from each mission. Extend v6 model each mission with respect to how it would have to be conducted via a logical sequence of events as applied to the SoS Functional Architecture. The Extend model allows parameters to be set so that decisions can be made within the model, based on the random results from probabilities of success at each node. The Extend model allows random variation of search and detection times, vessel locations, actual threat location, vessel sizes, latency of information and actions of the terrorists. Specific assumptions with respect to each model will be addressed later as it applies to the individual mission. One general assumption is that the level of training and proficiency is assumed to be at peak performance for all units and personnel involved. This removes the variable of whether the individual or commander will make the appropriate decision at the appropriate time. The possibility of the human making a mistake is not considered.

The Excel model allows for determination of the sets of probabilities associated with each subfunction and subsystem to determine if the overall SoS will meet the minimum Probability of Success required for each mission (Appendix B). The Extend model determines the likelihood of the SoS to meet the MOEs of the mission and assesses which MOPs or asset quantities could be varied to ensure a successful mission.

The SBA mission is rigorous and has been also evaluated through the use of computer simulated war gaming. This tool is available at the Naval Postgraduate School through its War Gaming Department using the Joint Conflict and Tactical Simulation (JCATS) software applications. The previously determined probabilities and capabilities of each architecture are applied to the mission profile in the computer simulation. Multiple players face off as members of Red and Blue teams to better assess the difficulties associated with identifying an unknown enemy in a high traffic area. While it is still a two dimensional representation on a LCD screen, it does allow for the realism of the uncertainty associated with a small boat attack.

The WMD and SAW mission CONOPS have been evaluated using the Joint Theatre-Level Simulation (JTLS) software available through the NPS War Gaming Department. Missions are evaluated to determine the expected distances between multiple PAVS within the missions, as well as the average distances helicopters would fly in order to deliver search teams to the PAVS.

7.4.1 C4ISR Model

The Extend model of the C4ISR system determines the average time to issue initial activation orders to MTR operating units. In this simulation, the receipt of the initial tasking order from higher authority occurs at the beginning of the simulation run. The model simulates the multiple functions performed by the C4ISR system once this initial tasking has been received, namely, downloading intelligence data from both the MDA system and other sources, transforming the data into an optimal course of action and a common operating picture, activating and controlling MTR operating units, communicating with both higher authority and local operating units, and enabling the sharing of information between MTR SoS nodes. Many of these functions are performed in parallel.

The C4ISR model has four main sections, which are represented in Extend as hierarchical blocks. These four blocks are Comms In, C2, Compute, and Comms Out. Message traffic is generated within the Comms In block as one of four different item types: intelligence data, orders from higher authority, node permission or information requests, or node to node communications. The amount of each item type generated varies based on the C4ISR concept option being evaluated. This is performed via the input parameters database. Immediately after generation, the following attributes are assigned to all items: communications type, file size, and start time. With the exception of node to node communications, which are routed directly to the communications transmission section of the model, all items exiting the Comms In block then flow through the remaining sections of the C4ISR Extend model, where they are processed and transformed as appropriate. Intelligence data, orders from higher authority, and nodal requests are transformed into both ROE/Orders and a common operating picture. Node-to-node communications are routed directly to the Comms Out block. Within the Comms Out block, items exiting the system are sorted by communications type attribute, and their total time spent within the C4ISR model is recorded in the "C4ISR Delays" database described in Section 7.4.1.6. The four model sections, as well as the input and output databases, are described in more detail in the sections that follow.

7.4.1.1 Receiving Communications

Within the Comms In block shown in Figure 7-20, items are generated and attributes are assigned. While the file size assigned is random, the communications type attribute is assigned as follows:

Type 1 = Orders from higher authority

Type 2 = Node requests

Type 3 = Intelligence Data

Type 4 = Node to node communications

Next, items flow into a priority queue where their exit order is based on communications type. Type 1 receives the highest priority; Type 4 the lowest. Once exiting the queue, items proceed through one of three possible communications system routes: LAN, land-based WMAN, or satellite WMAN. The land-based WMAN route simulates messages being sent within 48 kilometers of either a land- or ship-based access point, while the satellite WMAN simulates messages being sent via satellite access points. All three communications routes feature a message size delay that is calculated based on message size and media bandwidth, as well as an exponential access delay to simulate collision avoidance.[79] The satellite WMAN incorporates an additional satellite access delay.[80] Lastly, items proceed to the next processing stage (either C2 or Compute) in accordance with their communications type.

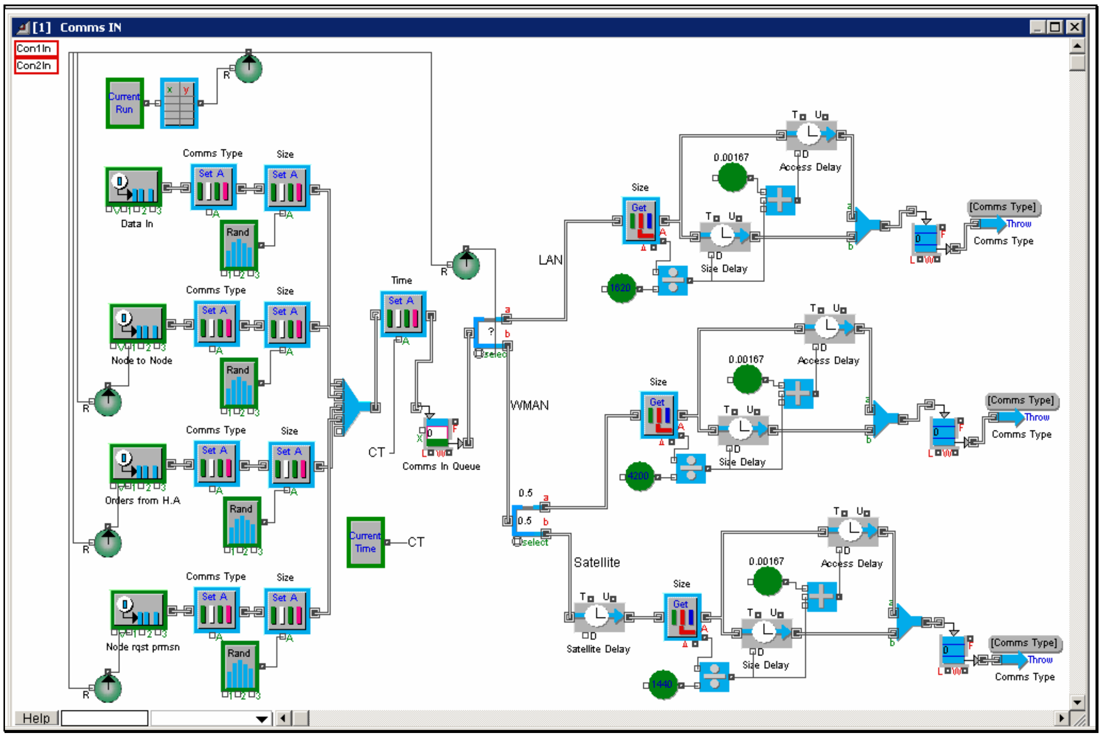


Figure 7-20: Comms In Hierarchical Block

7.4.1.2 Command and Control

Within the C2 block, which is shown in Figure 7-21, incoming items are transformed into either finished C2 products or queries to the Compute system. These functions are performed by the humans in the loop, which are modeled by resource pools. There is one commander and one operator resource in each pool, and both must split their available attention between responding to incoming communications and responding to

[79] Interview between Professor Richard Harkins, Naval Postgraduate School, Monterey, CA, and the authors, 5 April 2006.

[80] Interview between Professor Chris Olsen, Naval Postgraduate School, Monterey, CA, and the authors, 5 April 2006.

Compute system products. The commander resource receives Type 1 and 2 message traffic directly from the Comms In block. Type 5 message traffic is received from the Compute block and will be described in more detail in the following section. In both cases, the commander reviews the incoming communications and responds by either issuing orders or by requesting further processing from the operator/analyst resource. If further processing is requested, the operator inputs a query to the Compute block. The following C2 Product attributes are assigned in this block:

Type 6 = Queries to Compute

Type 7 = ROE/Orders

Type 9 = Approved Type 5 items

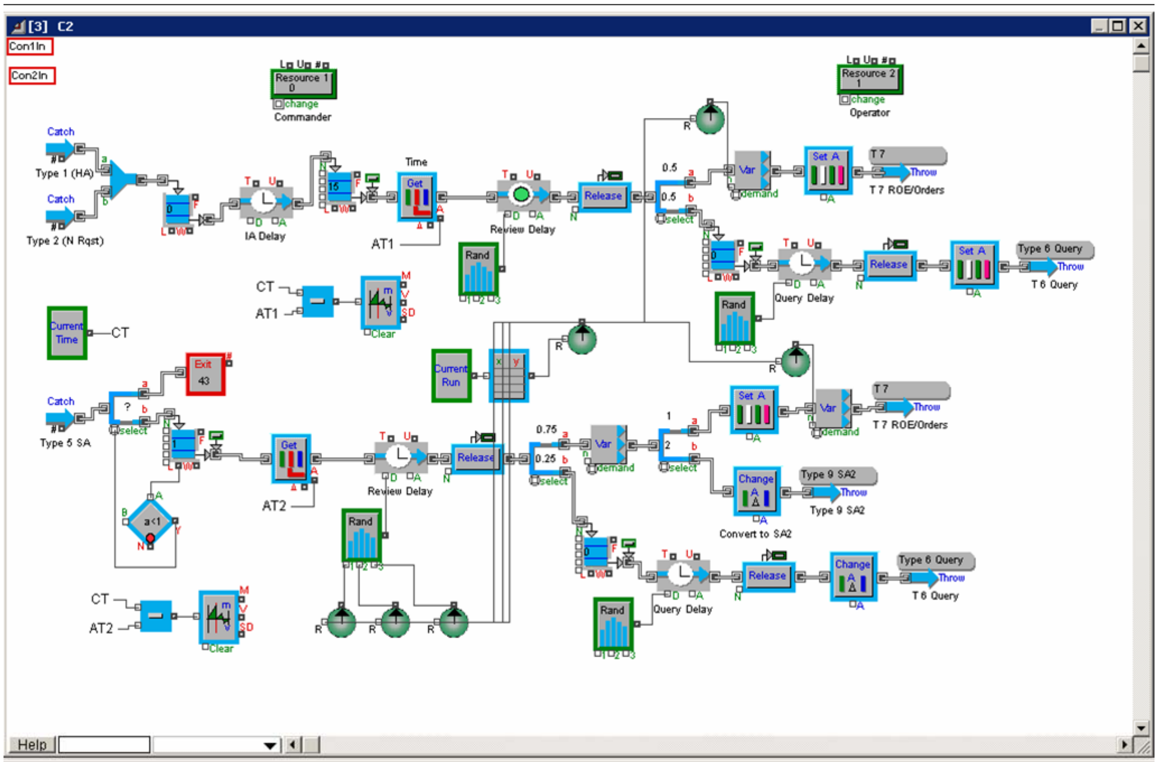


Figure 7-21: C2 Hierarchical Block

7.4.1.3 Compute

The Compute hierarchical block displayed in Figure 7-22 contains two product flow paths. On the upper path, Compute receives Type 3 communications traffic from Comms In, assures the data, and then fuses it. The processed data is transformed in various products that enable situational awareness, such as optimal resource pairings, alternative courses of action, the common operating picture, and answers to operator queries. Due to parallel processing, all the aforementioned products can be created simultaneously. Items exiting from this flow path are assigned the Type 5 C2 Product attribute and are routed to the C2 block for commander review.

In contrast, the lower Compute path receives approved C2 products from the C2 commander resource, transforming these items into customized operating pictures for each of the deployed units. The following C2 Product attributes are assigned in this block:

Type 5 = Situational Awareness (SA)

Type 8 = Customized COPs

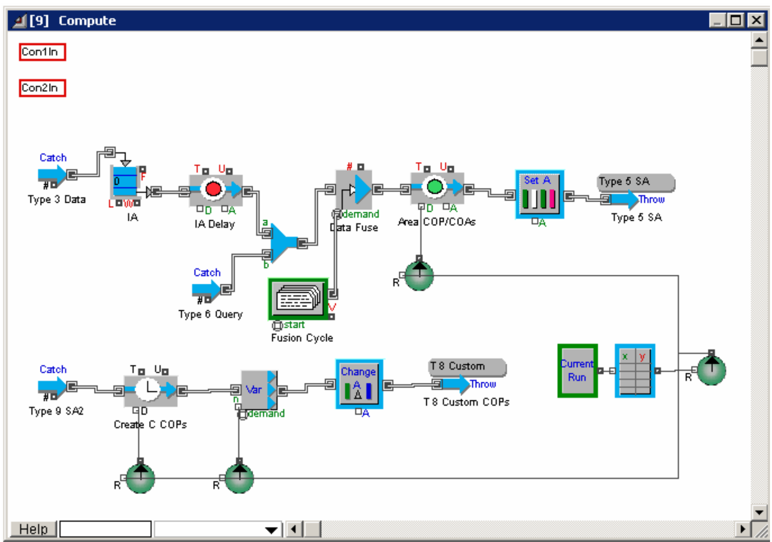


Figure 7-22: Compute Hierarchical Block

7.4.1.4 Transmitting Communications

The Comms Out hierarchical block is shown in Figure 7-23. As in the Comms In block, items flowing through the Comms out portion of the model traverse one of three possible communications system routes: LAN, land-based WMAN, or satellite WMAN. The Comms Out block also contains the Data Capture functionality, which is described in Section 7.4.1.6.

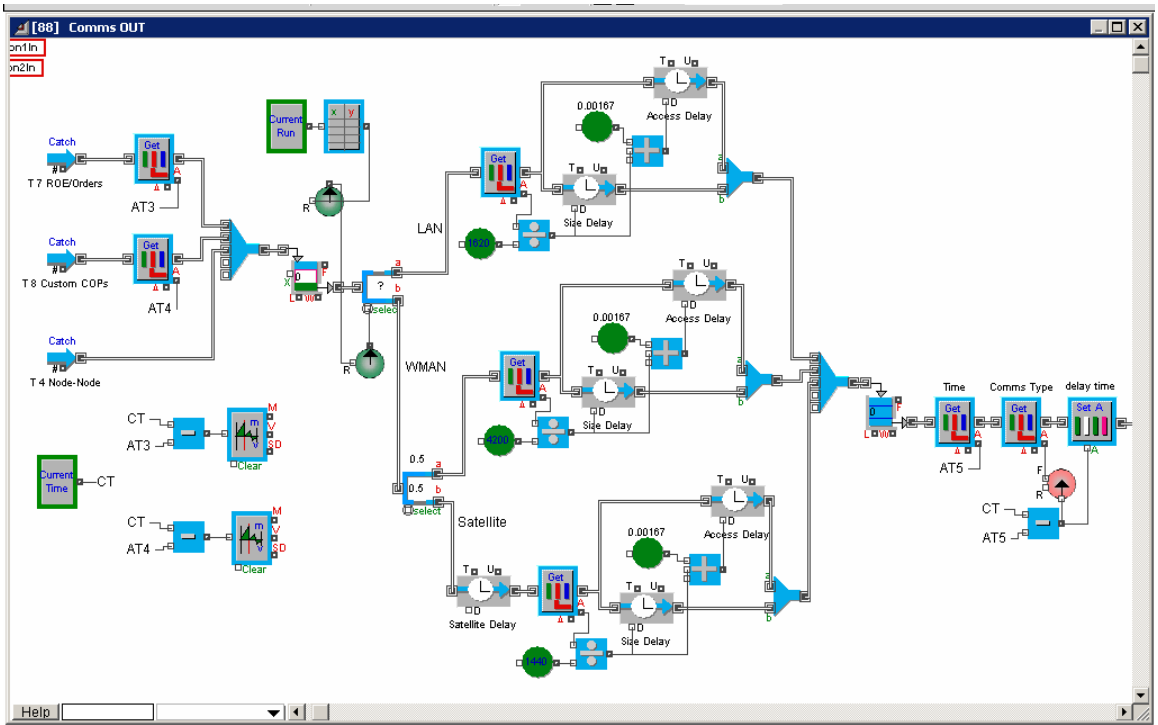
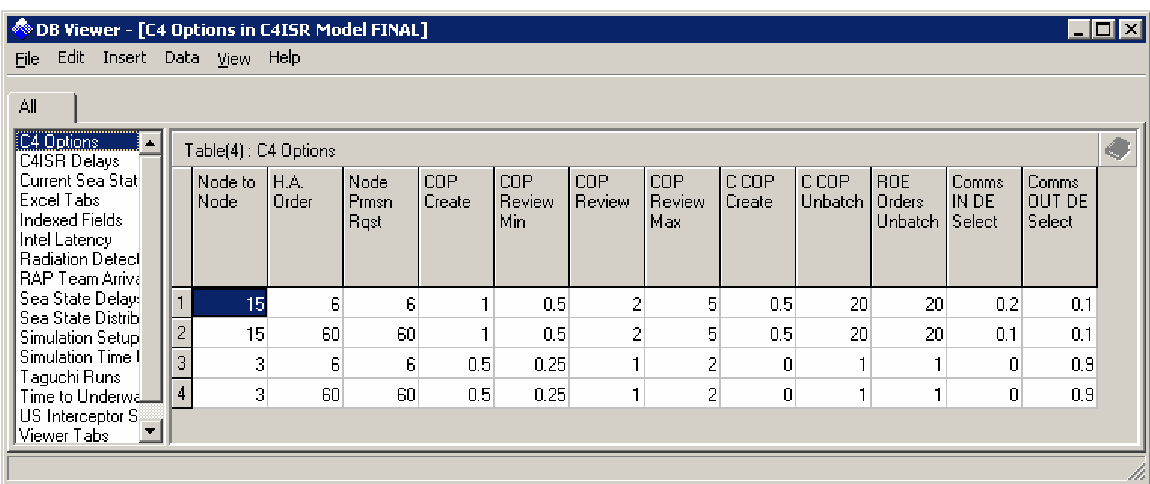


Figure 7-23: Comms Out Hierarchical Block

7.4.1.5 Input Parameters

In order to evaluate the four C4ISR concept options, input parameters are varied via the "C4I Options" Database. As displayed in Figure 7-24, this database contains one record per concept option, and each record is comprised of 12 data input fields. Record 1 represents APS, Record 2 represents AOO, Record 3 represents LPS, and Record 4 represents LOO. The rationale for each of the parameter values follows.



	Node to Node	H.A. Order	Node Prmsn Rqst	COP Create	COP Review Min	COP Review	COP Review Max	C COP Create	C COP Unbatch	ROE Orders Unbatch	Comms IN DE Select	Comms OUT DE Select
1	15	6	6	1	0.5	2	5	0.5	20	20	0.2	0.1
2	15	60	60	1	0.5	2	5	0.5	20	20	0.1	0.1
3	3	6	6	0.5	0.25	1	2	0	1	1	0	0.9
4	3	60	60	0.5	0.25	1	2	0	1	1	0	0.9

Figure 7-24: C4ISR Options Database

The Node to Node parameter represents the message generation rate. It is the amount of node to node communications per hour, and its units are in minutes. Message arrival time follows an exponential distribution and is in minutes. Since four node to node messages per hour are estimated for Area control, items are randomly generated every 15 minutes for Options 1 and 2. Local control requires twenty messages per hour; thus, items are randomly generated every 3 minutes for Option 3 and 4. The increased communications rate represents the Local C2 nodes performing deconfliction among themselves via node to node message traffic. Also, the NPS Tactical Network Topology Group (TNT) exercise communication logs[81] are used to validate the amounts of messages generated per hour.

The H.A. Orders parameter represents the generation rate of messages from higher authority. This is the number of H.A. orders sent to MTR C4ISR system per hour. As with the Node to Node parameter, the database value is the mean of the exponential distribution. Thus, the 10 messages per hour for PS Options 1 and 3 are randomly generated every 6 minutes (on average), and the one message per hour for OO Options 2 and 4 is randomly generated every 60 minutes.

The rate of Node Permission (or information) Requests parameter follows similar logic. Generation rate is higher for PS command structure. Messages are generated every 6 minutes for Options 1 and 3 and every 60 minutes for Options 2 and 4.

The COP Creation activity delay parameter represents the processing time required to generate SA products. There is a longer time delay for Area since there is much more data to process. One minute is used for Area span of control (Options 1 and 2); 0.5 minutes for Local Options 3 and 4.

The COP Review time parameters represent the processing time of the human in the loop when presented with Compute SA products. COP Review time follows a triangular distribution. There is a longer time delay for Area since the humans in the loop are reviewing information for 20 PAVs, vice only 1 PAV for Local. For Area Options 1 and 2, the minimum review time is 0.5 minutes, the most likely review time is 2 minutes, and the maximum review time is 5 minutes. For Local Options 3 and 4, the

[81] R. Dash, B. Rideout, and B. Creigh, TNT 06-2 Groove Chat NPS TNT 06-2, (Winter 2006) and R. Dash, B. Rideout, and B. Creigh, TNT 06-2 Event Log NPS TNT 06-2, (Winter 2006).

minimum review time is 0.25 minutes, the most likely review time is 1 minute, and the maximum review time is 2 minutes.

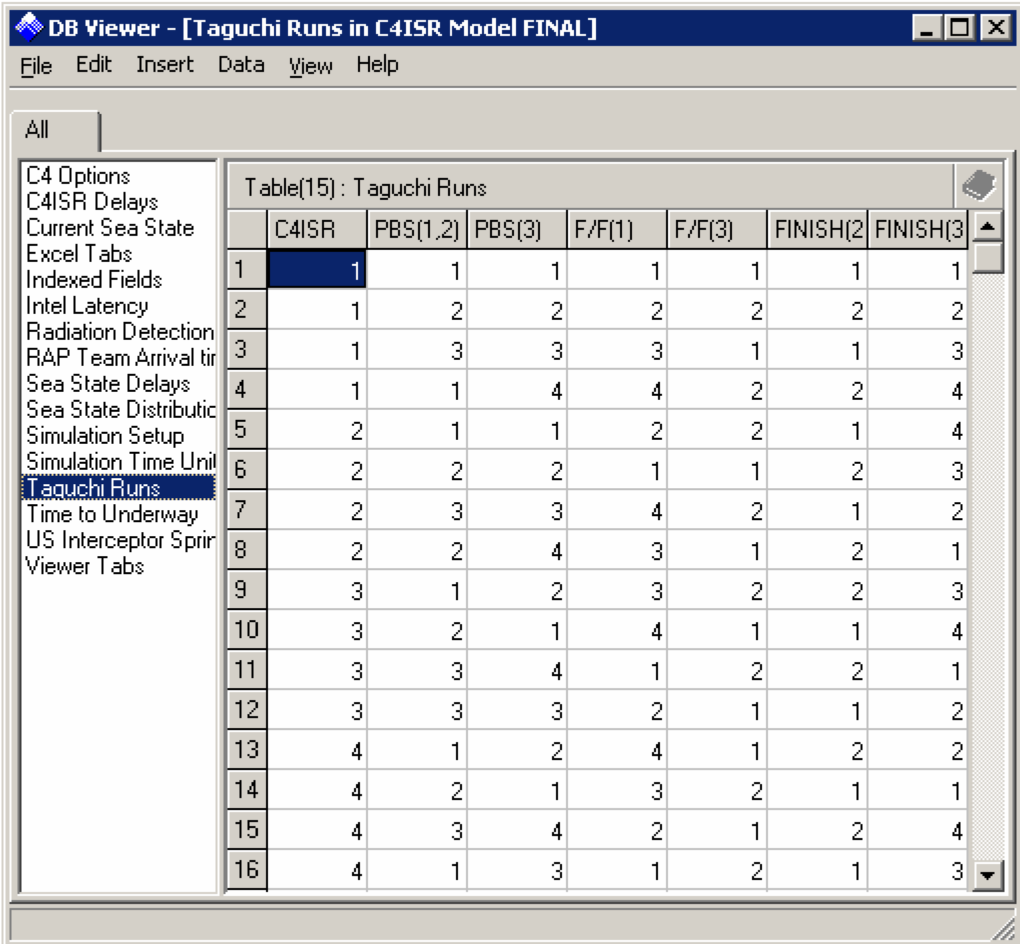
The COP Create parameter applies to the Area options only. For Area options 1 and 2, this parameter represents the additional processing time required to create customized COPs for each of the 20 operating units. For Local Options 3 and 4, this activity is not required and is therefore set to zero.

Both the COP Unbatch and ROE/Orders Unbatch parameters apply only to Area control. For Options 1 and 2, this parameter represents the 20 different sets of orders and customized COPs produced by the C4ISR system and sent to operational units. For Local control (Options 3 and 4), this activity is not required and a single item is therefore issued at the Unbatch block output.

The Comms In DE Select parameter represents the percentage of incoming message traffic that is received over the LAN. Option 1 APS has the highest percentage (20%) due to the increased number of orders coming from higher authority. Option 2 AOO has a reduced percentage (10%), but is still able to receive some intelligence data via the LAN. Both Local options receive all communications over the WMAN; therefore, this value is set to zero for Options 3 and 4.

The final parameter, Comms Out DE Select, represents the percent of outgoing message traffic that is transmitted over the LAN. Both Area options transmit only 10% over the LAN, while both Local options transmit over the LAN 90% of the time.

These parameters are applied to the C4ISR model in concert with the concept option under evaluation via the Taguchi Runs database, a portion of which is shown in Figure 7-25. The first column of the Taguchi Runs table represents the experiment number, while the values in the C4ISR column specify which C4ISR Options database record to apply during the 100 runs of the overall mission simulation.



	C4ISR	PBS(1,2)	PBS(3)	F/F(1)	F/F(3)	FINISH(2	FINISH(3
1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2
3	1	3	3	3	1	1	3
4	1	1	4	4	2	2	4
5	2	1	1	2	2	1	4
6	2	2	2	1	1	2	3
7	2	3	3	4	2	1	2
8	2	2	4	3	1	2	1
9	3	1	2	3	2	2	3
10	3	2	1	4	1	1	4
11	3	3	4	1	2	2	1
12	3	3	3	2	1	1	2
13	4	1	2	4	1	2	2
14	4	2	1	3	2	1	1
15	4	3	4	2	1	2	4
16	4	1	3	1	2	1	3

Figure 7-25: Taguchi Runs Database

7.4.1.6 Data Capture

In order to obtain initial C4ISR Delays table values, the C4ISR simulation is run for 1,000 time units (in this case, minutes), and processing delay data is captured for all four communications types at the culmination of the Comms Out process. This portion of the model is provided in Figure 7-26. From these data, Extend calculates the mean delay values, which are then manually recorded and used as initial values in the C4ISR Delays table. This process is performed for each of the four C4ISR concept options. Initial time delays are in minutes and are displayed in Table 7-20.

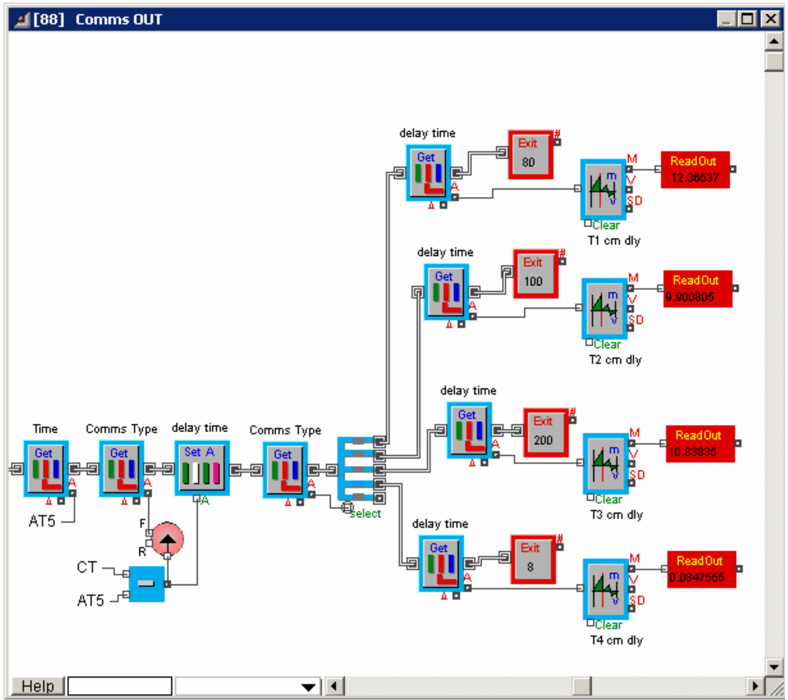


Figure 7-26: Data Capture Portion of the C4ISR Model

C4ISR Option	Comms Type Field #	H.A. Order 1	Node Request 2	Intel Data 3	Node to Node 4
	Area PS	25.1	24.9	19.8	0.060
	Area OO	9.5	9.9	7.3	0.054
	Local PS	11.6	14.8	5.6	0.051
	Local OO	6.7	7.2	3.05	0.047

Table 7-20: C4ISR Delay Table Initialization Values

The C4ISR module is then run simultaneously with the mission models. During the simulation, a delay time is exported to the C4ISR Delays database, shown in Figure 7-27, as each item exits the simulation, overwriting the previous value. The appropriate value from the C4ISR Delays table is pulled by the mission models whenever a C4ISR delay is required. Type 3 communications are used to approximate the time to issue initial orders since Type 3 messages must pass through all four sections of the C4ISR model.

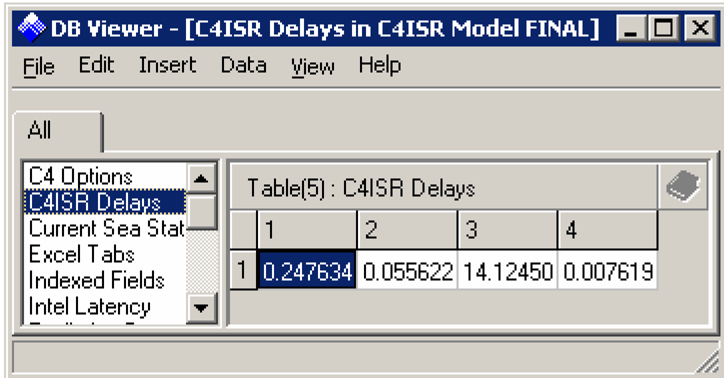


Figure 7-27: C4ISR Delays Database

7.4.1.7 C4ISR Insights

This same model is used to generate an initial-orders time delay for all three mission models. Because the model is not used to generate delays during operations, certain aspects of the C4ISR concept are not modeled. Specifically, these are the wide area paging (WAP) system and the time critical COP update capability. For the SBA mission, time criticality requires providing the most rapid dissemination of information in a way that immediately causes the operator to take notice. Both WAP and COP updates can be employed to serve this purpose.

In addition to meeting the need of the mission models, the C4ISR model provides some very interesting lessons learned in and of itself. The most important discovery is the bottleneck in the C2 block at the upper commander review delay block. Despite the fact that review time for all incoming communications is limited to no more than 5 minutes, the queue preceding the upper commander review consistently grows without limit for the PS command structure. After 1,000 time units (approximately 17 hours), the delays begin to exceed the self-imposed 30-minute operational time delay. If the C4ISR module had been used for operational time delays in the larger mission models, the C4ISR system would not have provided the required near-unity probability of successfully producing products within the required time window. While further division and delegation of command functions is certainly a possible solution to this queuing problem and could be modeled by increasing the number of resources in one or both of the resource pools, this bottleneck seems to clearly indicate that the OO structure better supports time critical operations. By decreasing the percent of the time that the commander's attention is divided between requesting/giving permission and producing useful guidance products for the units under command, OO increases the likelihood that the commander will be able to produce high quality SA products in a timely fashion.

Important C4ISR insights are also gained during the SBA war gaming exercise. First, war gaming shows that directly controlling more than one small boat in a PS fashion results in a lack of timely response to neutralize the threat. Second, the exercise illustrates the necessity of being able to both see and hear own force actions. A suspected small boat's response to warnings provides important clues as to whether or not the boat is actually a threat. If other units on the escort team are not privy to communications sent to suspected small boats, these clues provided by their actions are either missed or can be misinterpreted. Lastly, the war game display screen indicates that there would be value in displaying warning and buffer zone boundaries on the COP, as well as using the color scheme to indicate the estimated threat level of all contacts.

7.4.2 Weapon of Mass Destruction (WMD) Mission Model

The WMD mission model consists primarily of an EXTEND™ model that accepts inputs and processes outputs from surrounding Excel™ spreadsheets. The spreadsheets are used for data storage and management as well as the processing of some lower level model functionality associated with certain stochastic Monte Carlo simulations performed in Excel. The model is constructed and functions in a modular format.

7.4.2.1 WMD Mission Database Module

The WMD Mission Database Module is where the various characteristics associated with each of the different potential system concepts are stored and drawn from during a simulation run. For each specific experiment the WMD mission model is run 100 times and then shifts characteristics to the parameters of the new experiment based on the information that it pulls out of the overall database. The model could also be adjusted through manipulation of the database module such that the parameters and characteristics could be adjusted based on new information or to change the systems represented in any one experiment.

The module itself consists of the Database Manager block in EXTEND™. This block is connected to the Discrete Event Executive and serves as the principal interface to adjust parameters and record as well as retrieve data. Throughout the model, Database Write blocks are used to take information generated within the model and post it into one of the tables. Database Look-up blocks are used throughout the model to pull information from the tables in the database from the Database Manager at such times as the information is needed by different modules of the model. Within the Database Manager is a Database Viewer, which allows access the different tables stored in the database. As an example, the C4ISR model writes to the overall Database Manager the amount of time it takes for the MTR C4ISR system to process orders and respond to units in the field. This information is posted to the "C4ISR Delays" table within the database. It is passed to a specific field (which in EXTEND™ parlance refers to columns in the table) depending on the type of delay in question. For C4ISR, theses delays can be delays from higher authority requests, delays from operational unit requests to headquarters, initial delays in sending out orders to units once intelligence is received, or delays in processing communications between different operational units. Depending on the type of C4ISR system selected by the experiment, in addition to what events are going on in the model at that time, the values written to those fields will vary. When another element of the model needs the delay time associated with C4ISR decisions, it uses a Database Look-up block to pull the current delay time for orders processing out of the Database. Figure 7-28 shows how the database is viewed and manipulated within the EXTEND™ program.

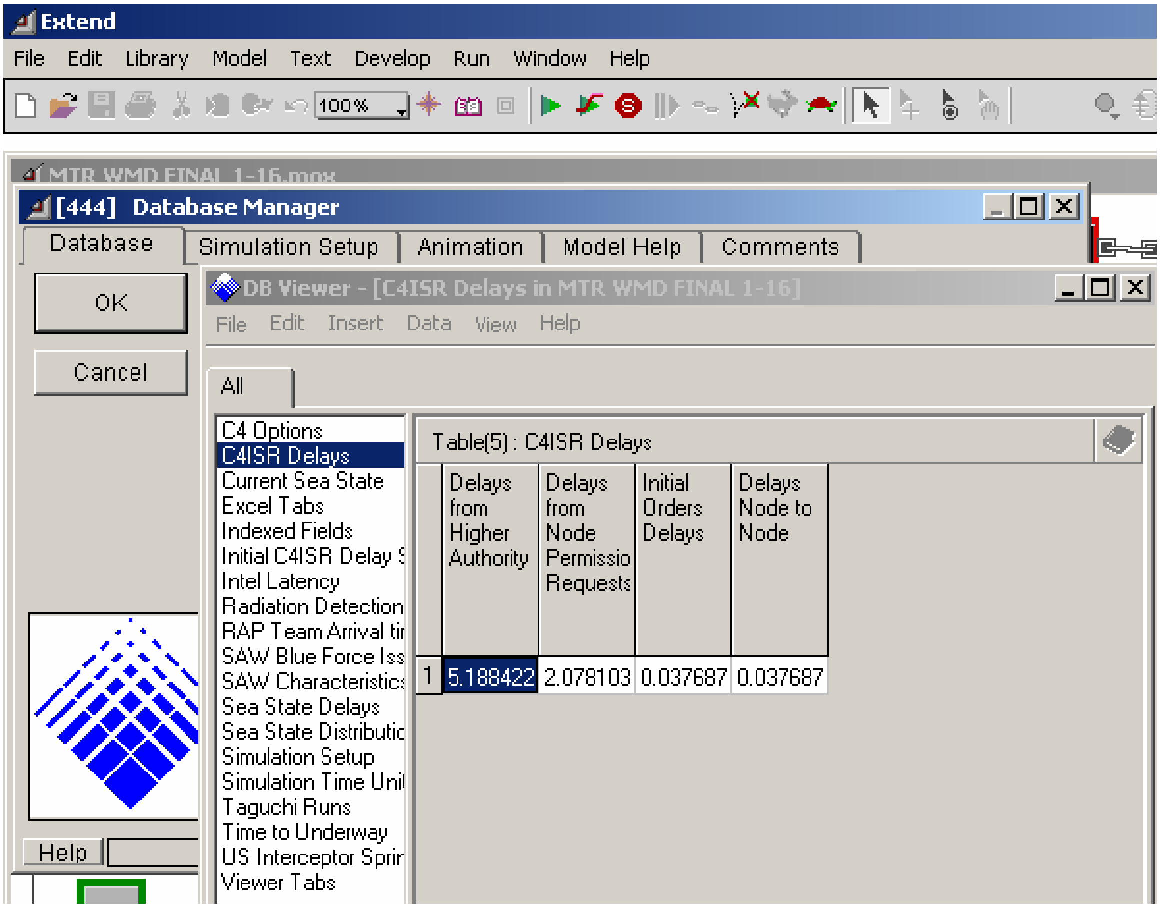


Figure 7-28: Database Manager and Viewer Interface in EXTEND™

To accomplish the experiment defined by the L_{32} orthogonal array as described in Section 7.1.2.1, there is a table within the database that consists of all of the values listed in Table 7-11. As the simulation begins, the model seeks out the values that correspond to a given system concept from each of the different fields, C4ISR or PBS(1,2), as examples. The model runs the first 100 times looking at the values in record one (in EXTEND™ parlance, rows are referred to as records). These are the system concepts for experiment one in the orthogonal array. By pulling out values that identify which system concept is being explored from this table, that information can be used as an input to draw out values associated with a given concept's parameters from other tables. After the first 100 runs of the simulation, the model will shift to examining record two for the second experiment, and so on, until it proceeds through all 32 experiments over the course of 3,200 simulation runs. In this manner, the entire experiment can be performed without user involvement or interface. Such a construct enables fairly simple re-running of the experiment if modifications to system concept parameters and the like are desired or required.

Following is an illustration of a situation within the Ship Intercept module of the WMD Mission model. The simulation is assumed to be currently running trial number 754. The current run number is pulled out via a System Variable block. The current run of 754 instructs the Database Look-up block to seek out the value in the eighth record (for runs 701 through 800). The Database Look-up block is set to look-up the PBS(1,2) field in the eighth record. In this case, based on the orthogonal array set-up, the value 2, associated with Littoral Combat Ship (LCS) and Maritime Security Cutter, is pulled out of the database. This information tells the Ship Intercept module that LCS is the type of ship being used for this particular intercept. The value of 2 also tells another Database Look-up to select the second record when it looks up the U.S. ship sprint speed. The second record returns a value of 45 knots associated with LCS in this case, which is then used in the calculation of the time for an intercept to occur and the location where such an intercept occurs.

7.4.2.2 Potential Attack Vessel Generator Module

The Potential Attack Vessel (PAV) Generator module is a fairly simple and straightforward. As the simulation begins, 20 PAVs are generated by a Generator block. They are then passed through a Set Attribute block, where their attributes are randomly assigned based on the results of a series of Input Random Number blocks at the beginning of each simulation run. The values assigned to each attribute are intended to reflect the expected value that only 1 of the 20 PAVs will have a bomb onboard as well as all other attributes intended to reflect the representative characteristics of the trans-Pacific container shipping flight in terms of speeds, stops, and sizes. The details of the different distributions are found listed in Table 7-21.

Random Attribute	Value Generated	Comment
Does the PAV have a bomb onboard?	0.95 probability of 0 (No bomb) 0.05 probability of 1 (Bomb onboard the ship)	On average, one vessel will contain a WMD device, but some runs will have no devices and some runs will have two or more devices, based on binomial distribution.
How many containers does the ship carry?	0.05 probability of 2,000 (Min) 0.05 probability of 3,000 0.05 probability of 4,000 0.15 probability of 5,000 0.30 probability of 6,000 (Mean) 0.20 probability of 7,000 0.10 probability of 8,000 0.05 probability of 9,000 0.05 probability of 10,000 (Max)	Based on estimates of the actual distribution of ship sizes in the global merchant fleet, an empirical table generates discrete results with the parameters listed at left.[82]
How many stops does the vessel make after leaving Singapore prior to heading to the West Coast of the United States?	0.2 probability of 0 stops 0.3 probability of 1 stop 0.2 probability of 2 stops 0.2 probability of 3 stops 0.1 probability of 4 stops	Based on review of typical shipping companies planned routes and schedules for vessels departing Singapore eventually en route to the United States.
How fast is the vessel's normal speed of advance?	0.4 probability of 20 knots 0.3 probability of 22 knots 0.2 probability of 25 knots 0.1 probability of 26 knots	Based on analysis of typical shipping companies planned speeds of advance from route schedules.

Table 7-21: Random distributions of attributes assigned to each PAV per simulation run

Following the assignment of attributes, the PAVs exit the module and enter the Ship Intercept Module. The attribute assignment distributions are designed to be easily modified to reflect new or different assumptions as well as to change the size and scope of the problem.

7.4.2.3 Ship Intercept Module

The Ship Intercept Module models the plotting of PAV track across the Pacific towards the United States, the readying of the U.S. ships to intercept them, and the actual intercept of the PAVs by their associated U.S. escorts.

The module begins with the calculation of the random times for each PAV to move through their intermediate stops, if they make any, en route to the United States.

[82] The random ship sizes generated were adjusted to reflect anticipated increases in average size of container ships expected over the course of the next five years. For some estimates of current ship size distribution for all container ships, see Rob Harrison, *Does Size Matter? The Potential Impacts of Megaship Operations on Gulf Port*, The University of Texas at Austin, Center for Transportation Research, [http://uts.cc.utexas.edu/~harrison/presentations_pdf/megaships.pdf], accessed on 13 March 2006.

The delay time of each PAV in any given en route port visit is follows a normal distribution with a mean of 12 hours and a standard deviation of 2 hours. Simultaneously, U.S. ships are readied to get underway once they receive word to surge in response. The intelligence latency inhibits any efforts by U.S. ships to get ready until the latency has expired and they have received orders from the MTR C4ISR system to surge. Upon receipt of orders, the ships will spend a variable amount of time preparing to get underway, usually distributed triangularly with a most likely time of 24 hours with a minimum time of 21 hours and a maximum time of 27 hours. At the same time, the model can be set up to delay the ships' departure until such time as a specialized search team arrives from the United States with its equipment. This is normally selected to occur within the prescribed 24 hour requirement specified in the system.

As the PAVs begin to track across the Pacific, they are placed in queues placed appropriately for potential intercepts from the four different U.S. bases: Yokosuka, Japan; Kodiak, Alaska; Pearl Harbor, Hawaii; and San Diego, California. The intercept priority begins with Yokosuka, then Kodiak, Pearl Harbor, and then finally San Diego.[83] This priority scheme seeks to maximize the amount of time from intercept to the time of the PAV arrival in San Francisco. If a priority base either runs out of possible interceptors or if a PAV has gotten far enough along in its track that it would make more sense to intercept it from a lower priority base, the PAV is moved to the next priority base from its current queue. For example, once a PAV, traveling at normal speeds, is more than 300 nautical miles past Yokosuka on the great circle route towards San Francisco, an intercept will be culminated more quickly from a vessel on a closing intercept from Kodiak than from a vessel in a rundown intercept coming out of Yokosuka. In similar fashion, PAVs are passed from the Kodiak queue to the Pearl Harbor queue to the San Diego queue. Figure 7-29 shows the general great circle route of traffic from Singapore through the strait between Taiwan and the Philippines to

[83] In initial iterations of the model, it was examined to use Guam as one of the U.S. intercept locations. Upon review of the tracks of the PAVs it was determined that Guam did not offer significant benefit versus intercepts originating out of Yokosuka, Japan. This came as a result of study that indicated almost all trans-Pacific shipping traffic would venture towards the northern, great circle route rather than steering considerably south due to the excess time associated with the transit. In addition, since no U.S. surface combatants were already home-ported in Guam, there would be additional cost in placing vessels there on a full-time basis. For these reasons, Guam was removed from consideration as a potential staging base for MTR forces.

San Francisco along with the locations of the primary interceptor bases. Table 7-22 displays the available number of ships assumed to be at each base.

Staging Base	**Ships**
Yokosuka, Japan	2 Cruisers, 5 Destroyers, 2 Frigates - Alternately, 9 LCSs or 1 Car Carrier - 4 in-port available - 5 at-sea, recalled within 72 hours
Kodiak, Alaska	2 High Endurance Cutters - Alternately, 2 Maritime Security Cutters
Pearl Harbor, Hawaii	3 Cruisers, 6 Destroyers, 2 Frigates - Alternately, 11 LCSs or 1 Car Carrier - 50% of ships assumed deployed and unavailable
San Diego, California	6 Cruisers, 14 Destroyers, 4 Frigates - Alternately, 24 LCSs or 1 Car Carrier - 50% of ships assumed deployed and unavailable

Table 7-22: Ship Availability at Each Staging Base

The logic of flow from one queue to the next lower queue is a function of one of the following events: 1) there are no more intercept vessels located in the priority intercept base that may surge to intercept the PAV in question; and 2) the PAV reaches such a point in its track across the Pacific that the intercept will be culminated more expeditiously from the lower priority base than the higher priority base. The latter typically occurs when intelligence is highly latent or a U.S. interceptor vessel is abnormally late to respond to its tasking to surge to intercept the PAV. In either case, the PAV is not held in the queue unless there is a chance that an optimized intercept can take place from the location in question.

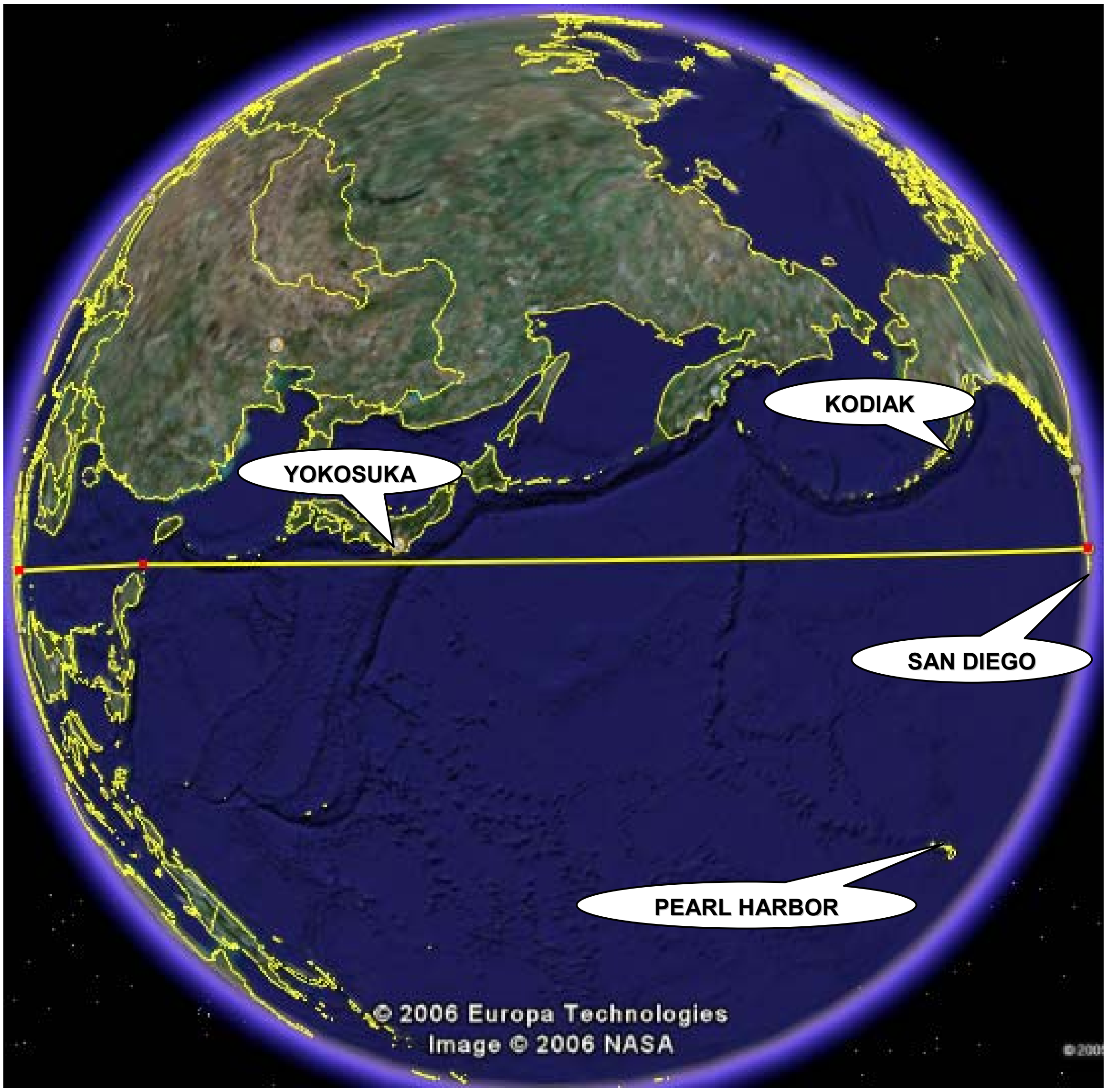


Figure 7-29: Great Circle Route, Singapore to San Francisco, with U.S. Intercept Bases

The intercept equations resident in the Ship Intercept module compute the time it takes to consummate an intercept and the distance that the PAV travels during the course of the intercept. This enables computation of how much time there is between the time at which a U.S. vessel arrives to escort the PAV to the time at which the PAV arrives in San Francisco. It is assumed that once a U.S. vessel closes within 100 nautical miles of San Francisco that the search team can be ferried to the PAV via helicopter. The speeds for the PAVs and the U.S. vessels are adjusted from their normal cruising and sprint speeds according to the sea state that is output from the Sea State module discussed in Section 7.2.2.5. The amount of time available to search is input to the

Container Search module discussed in Section 7.2.2.4, which determines if any PAV is delayed from its normal arrival time in San Francisco because the container search of its cargo has not been completed.

7.4.2.4 Container Search Module

Once a PAV has been intercepted by a U.S. escort vessel, it is sent to the Container Search module of the overall WMD model. As it enters the module, the ship is checked to determine if there is a WMD device onboard from the Ship Generation module. If there is, the module randomly determines which of the containers onboard contains the actual device.

The PAV itself as an item in the discrete event simulation is then converted into a given number of containers based on the number of containers determined in the Ship Generation module. This process helps with the flow of the model and will enable the group of containers to be converted back into a ship to exit the module once all the containers have been searched.

Using Database Look-up blocks, the probability of detection, probability of false alarm, dwell (or integration) time for the type of detector selected for the given experiment, and the number of detectors per team are pulled out of the Database Manager. These variables drive the performance of the search team in the module itself.

The probability of detection for each detector is obtained either from external agencies or from a Monte Carlo simulation run in Excel to determine the probability of detection of a given type of WMD device against a given detector at a given range. The Monte Carlo simulation in Excel is provided by Lawrence Livermore National Laboratory.[84]

For some of the detectors considered, a probability of false alarm of 0.01 has been used as a basis for setting the threshold for detection. As a result, an expected

[84] The Excel spreadsheets were provided by Dr. Thomas B. Gosnell. For information regarding his efforts in modeling probabilities of detection for different types of detectors against different types of nuclear devices at different ranges, see Thomas B. Gosnell, "The Challenges of Passive Detection of Fissile Material: Analytic Methods for Nuclear Nonproliferation and National Security," presentation given at Lawrence Livermore National Laboratory, 28 July 2005; and Thomas B. Gosnell, "Statistical Considerations for Nuclear Search: Determination of the Maximum Detection Range of a Radiological Monitoring Instrument," Lawrence Livermore National Laboratory Report UCRL-TR-200393, October 2003, pp. 5-49.

number of 60 false alarms per 6,000 container ships, using a single look search doctrine, is considered unacceptable. By applying a "two out of three required" detections approach prior to declaring a valid detection, the probability of false alarm for any one container could be reduced to 0.000298, with an expected value of 1.78 containers false alarming per 6,000 containers searched.[85] Figure 7-30 shows the number of false alarms for each 6,000 container ship searched.

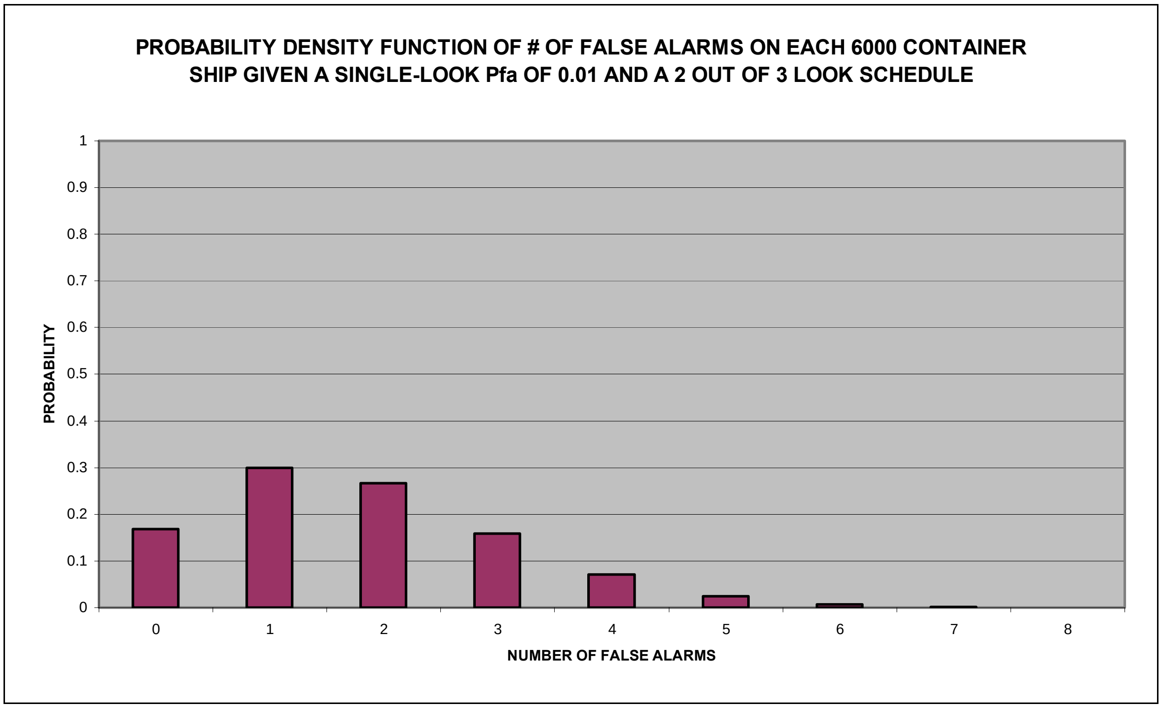


Figure 7-30: PDF of Number of False Alarms per 6,000 Containers

The same look doctrine increases the net probability of detection from the single-look probability of detection, since a target can be missed once and still be detected as long as it is seen on the other two looks. In this manner, the overall probability of detection for a detector whose single-look probability of detection is 0.9 will be 0.972.[86]

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[85] The 2 out of 3 look doctrine turns the false alarm probability into a binomial distribution with 3 total trials, a probability of success (false alarm) of 0.01, and a requirement to have either 2 or 3 successes. When this is calculated, the probability becomes 0.000298. Once again trade studies were conducted to determine the appropriate number of trials and required number of successes within those trials.

[86] The same logic applies to probability of detection. A binomial distribution with 3 total trials, a probability of success of 0.9, and a requirement to have 2 or 3 successes yields a net probability of detection of 0.972.

The default value stored in the database is for a search team consisting of six passive detector teams per PAV. Figure 7-31 shows the predicted time to search container ships of varying sizes with six or nine passive detectors, assuming a 180-s dwell time and a two-out-of-three look doctrine. Since intelligence latency of less than 210 hours affords at least 100 hours of search time on average, six detector teams are found to be sufficient.[87]

The Container Search module then processes each container, simulating the passive detections against each container, whether it contains a WMD device or not. Once every container has been passively searched, the model reconverts the group of containers into a ship and evaluates the elapsed time. If the elapsed time exceeds the time available to the 100-nautical mile point from San Francisco, the ship will be considered delayed at that point and the delay time is calculated in economic cost. If the elapsed time is less than the time available to the 100-nautical mile point, the ship will be considered completely searched in such time to avoid any delay and no delay cost was assessed to the system.

If a WMD device is present on the ship in question but not passively detected, then the system has failed to perform and the WMD device is allowed to reach San Francisco. This is a more conservative estimate than would actually occur, since the concept of operations involves attempting identification of any containers that were assessed via manifest to contain potential sources of naturally occurring radioactive materials (NORM) as well as any other containers thought to be suspicious based on prior intelligence-gathering and analysis of the registered contents. As such, it is estimated that the system would have a chance to stop some WMD that the model otherwise calculated as having made it through without detection.

[87] Trade studies were performed between mean time required to conduct the search based on dwell time, number of containers found on a ship, and "look doctrine" selected in terms of number of queries performed on any given container and number of positive replies required before a "hit" was considered to have been made upon the container in question. Based on a series of analyses, it was determined that six passive detectors would be sufficient to cover an entire vessel in the amount of time typically afforded by the surge deployment scheme.

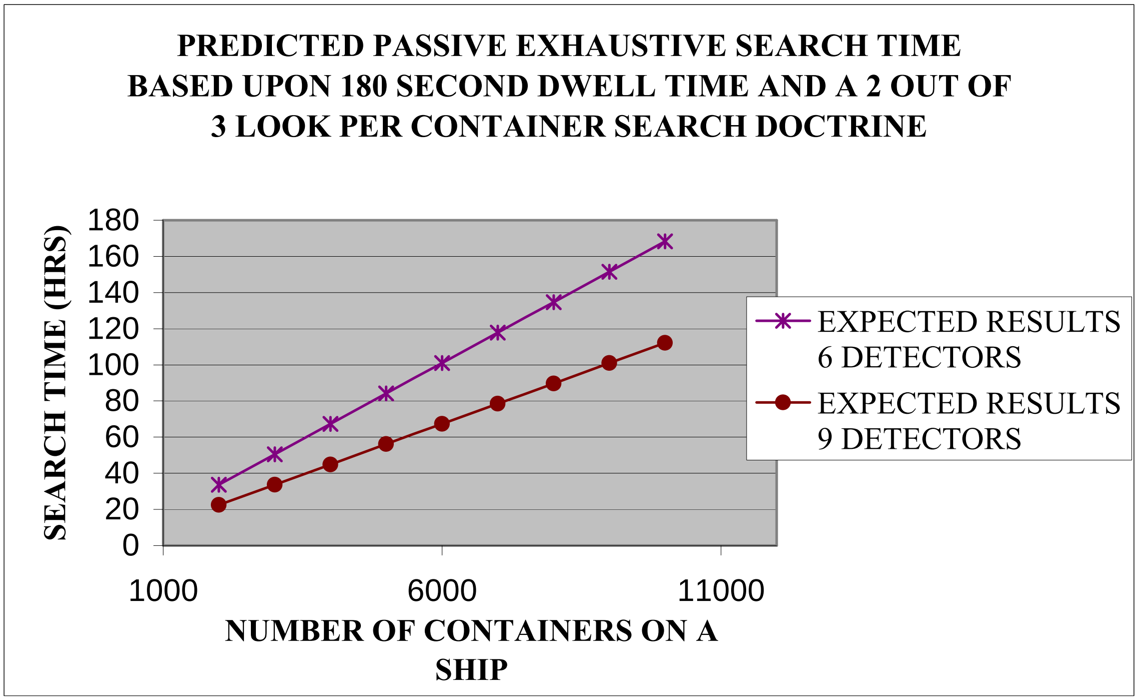

Figure 7-31: Predicted Search Time as a Function of the Number of Containers and Detector Teams

7.4.2.5 Sea State Generator Module

The Pacific Ocean encompasses an enormous amount of the surface of the earth and has widely disparate conditions across its entirety. Significant weather in the form of high sea states are often encountered, particularly when transiting the northern reaches of the Pacific as is done on a great circle route between East Asia and North America. As such, it is expected that U.S. ships proceeding to intercept as well as the container ships themselves will be slowed from their normal sprint and cruising speeds.

The module employs the concepts implemented in the model of a previous Systems Engineering and Analysis cohort examining the problems of Joint Expeditionary Logistics.[88] The module adjusts existing sea states over time and then varies the impact of such sea states on the ship speed. For a surface combatant traveling at a nominal 20 knots wave height generally reduces the ship speed by between 5% (for a 4-ft wave

[88] Matthew Boensel and David Shrady, "JELO: A Model of Joint Expeditionary Logistics Operations," Naval Postgraduate School Technical Report NPS-OR-05-001, Monterey, CA, October 2004, pp. 4-42.

height) and 60% (for a 28-ft wave height)[89] Generally, the sea state is updated every six hours, but for modeling purposes, the speeds of the PAVs and the intercept ships are set at the beginning of each phase throughout the intercept model. For the PAVs, this consists of when they depart Singapore for their first stop and subsequent stops, when they have left their last port prior to transiting the Pacific before being intercepted, and when they have been intercepted and are en route to San Francisco being escorted by a U.S. vessel. The same methodology applies to the approximation of the reduction in the speed of the U.S. vessels as a function of wave height, as the U.S. vessels are affected to a greater degree than are the larger container vessels.

7.4.2.6 WMD Mission Model Results Administration

The simulation results, stored in Excel, indicate whether or not a bomb has been allowed to enter the United States without detection and identification and include the delay cost associated with the time required to complete the search of each individual ship. The simulation results for each experiment are then used in the calculation of the overall mission probability of success (number of successes in 100 trials) and the average delay cost associated with each of the 32 experiments. These outputs are used to obtain the response calculated in MINITAB 14 for purposes of identifying the "best" systems in terms of effectiveness as discussed in Section 7.5. These same outputs, combined with the cost analysis as discussed in Section 7.6, make up the cost-effectiveness results as discussed in Section 7.7.

7.4.3 Ship as a Weapon (SAW) Mission Model

The Ship as a Weapon (SAW) model bears strong resemblance to the WMD model and is built using the WMD model as the baseline. The primary differences between the two models reside in activities that occur once a U.S. ship has intercepted a PAV.

[89] Charts depicting such impacts are available on-line at Naval Meteorology and Oceanography Operational Support Web, [https://www.cnmoc.navy.mil/nmosw/thh_nc/gendisc/graphics/fig1-4.gif], accessed on 17 January 2006.

7.4.3.1 SAW Mission Database Module

The Database module for SAW is very similar to the WMD Database module. The difference lies in the storage of information pertaining to the specifics of the SAW mission in terms of the actions and characteristics of the potential terrorists onboard a PAV as well as the U.S. search and escort teams coming onboard. Specifically, the database includes the normally distributed random time required to search a PAV per ton of ship size, the exponentially distributed number of casualties that blue forces will suffer during insertion onto the PAV and during Close Quarter Battle (CQB) with the terrorists, the probability of successful recapture of a seized PAV, the amount of damage in economic cost suffered by the ship during CQB between blue forces and terrorists as well as during non-lethal disabling, the probability of U.S. forces successfully disabling a PAV, along with the time from San Francisco when the terrorists would choose to seize the PAV, the number of terrorists onboard the ship, the reaction of terrorists to the attempted boarding of U.S. forces, as well as the relative capabilities of terrorists versus blue forces for use in Lanchester attrition equations used during CQB (Close Quarter Battle). The use of the Database module as an interface between other modules and lower-level models remains the same as in the WMD model.

7.4.3.2 Potential Attack Vessel Generator Module

The Potential Attack Vessel Generator Module is almost identical to that in the WMD model. The only difference is that, rather than determining the existence of a WMD device onboard a given ship, the module randomly determines the presence of a terrorist cell onboard each ship. As in the WMD model, every ship has a 5% chance of having a terrorist cell onboard. The potential numbers of ships with terrorists onboard out of 20 are depicted in Figure 7-32.

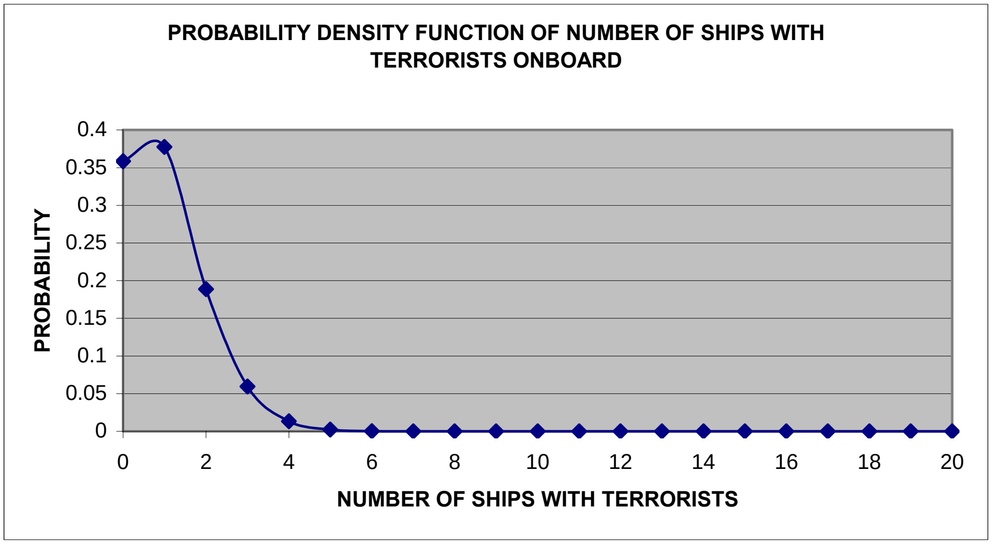

Figure 7-32: Probability Density Function of Commandeered Ships

7.4.3.3 Ship Intercept Module

The Ship Intercept module is the Ship Intercept Module in the WMD mission model.

7.4.3.4 Ship Search and Engagement Module

The biggest difference between the WMD model and the SAW model occurs in the Ship Search and Engagement Module once U.S. forces have arrived on the scene of a PAV. The manner in which they arrive is dependent upon the Finish(2) option selected for a given experiment or architecture. In Finish(2) Option 1, such arrival occurs by ship intercept in the exact same manner as in the WMD model. The PAV is intercepted by a U.S. ship and a Search and Escort team is conveyed onto the PAV to search the ship. In Finish(2) Option 2, the arrival occurs when a Search and Escort team is conveyed onto the PAV with the Harbor Pilot prior to reaching the Golden Gate Bridge and the mouth of San Francisco Bay.

When the U.S. team arrives onboard the PAV, the first thing that the module determines is whether or not terrorists are onboard. If no terrorists are onboard, the U.S. team is allowed to board without incident and the ship proceeds through the model, typically without any delay. If the terrorists are onboard, the model determines whether or not they have already seized control of the ship prior to the arrival of

U.S. forces. If the terrorists have already seized control when U.S. forces arrive, the terrorists will automatically resist the insertion of U.S. forces onto the vessel.

If the terrorists are onboard, but are not yet in control of the vessel, their response to the introduction of U.S. forces depends upon a random distribution to determine their reaction. They will either remain covert and attempt to avoid detection or attempt to resist at that point and forcibly resist the boarding by U.S. forces. If they do remain covert, the U.S. forces will not suffer any casualties during the insertion. If they expose themselves and resist, the U.S. forces may suffer casualties during the insertion and then will commence CQB with the terrorists with the surviving forces from the insertion.

If the terrorists remain covert during insertion, the U.S. forces will continue to search the vessel and perform screening of all personnel onboard the vessel in accordance with the concept of operations for finding terrorists. Once they come across the terrorists, if any, CQB between the U.S. forces and the terrorists commences.

If the terrorists are already in control of the PAV or if they choose to resist the insertion of the U.S. forces even if they were not yet in control, the model routes the situation based on the selection for Finish(2) option for the given experiment. If Option 1 is selected, the U.S. forces will continue to attempt to insert under fire and then attempt to recapture the vessel by killing or capturing all of the terrorists. If Option 2 is selected, the U.S. forces will withdraw from the vessel, abandon efforts to insert themselves, and then use quasi nonlethal means to disable the ship by damaging its rudders and propellers. If the first attempt to disable fails, the model determines if sufficient time is available to attempt to disable the vessel again; if time is not available, the model assesses that the terrorists have succeeded in getting a ship as a weapon into San Francisco Bay.

If Option 1 is selected, the model proceeds to simulate the flow of events as depicted in Figure 7-33. The amount of time taken to board as well as the casualties suffered during insertion is calculated. From there, a Lanchester attrition differential equation in the Engagement module is implemented to determine numbers of casualties on each side during the ensuing CQB between the U.S. forces and the terrorists. The model assumes a “fight to the finish” mentality such that whichever side is reduced to zero is considered the losing side and the other side becomes the winning side of the CQB. If the U.S. forces are the winners of the CQB, the ship is considered recaptured and the model simply calculates the amount of damage suffered by the ship in economic cost.

If the terrorists are the winning side in the CQB, the model then enables the U.S. forces to attempt to disable the PAV. If the PAV is successfully disabled, damage cost due to disabling is calculated and the ship is considered no longer a threat. The model does not pursue events that would take place subsequent to the successful disabling of a merchant vessel with terrorists still onboard and potentially in control of the ship.

If the PAV is not successfully disabled and sufficient time is not available to re-attempt disabling, the ship is considered to have successfully penetrated U.S. defenses and to enter San Francisco Bay ready to perform its suicide mission.

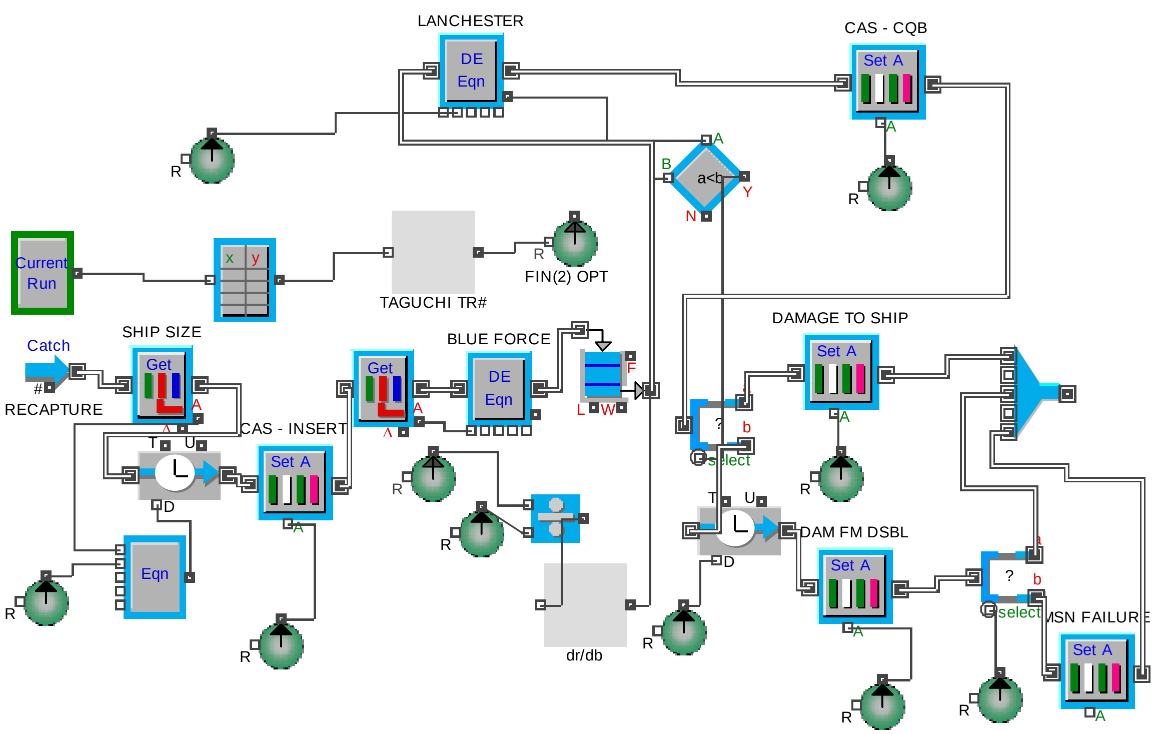

Figure 7-33: EXTEND™ Ship Recapture Submodel of Ship Search and Engagement Module

7.4.3.5 SAW Mission Model Results Administration

Once each run of the simulation is completed, the results are sent to an Excel spreadsheet. The results indicate whether or not a ship in terrorist control has been allowed to enter the United States and include the amount of damage cost associated with the clearing, recapture, and/or disabling of each ship under terrorist control or with terrorists onboard. The results from the 100 simulation runs for each experiment are then used to calculate the overall mission probability of success (number of successes in 100 runs) and the average damage cost associated with each of the 32 experiments. These outputs are used as inputs to calculate the response in MINITAB 14 for purposes of identifying the "best" systems in terms of effectiveness as discussed in Section 7.3. These same outputs, combined with the cost analysis as discussed in Section 7.4, make up the cost-effectiveness results as discussed in Section 7.5.

7.4.4 Small Boat Attack (SBA) Mission Model

The SBA mission model consists primarily of an EXTEND™ model that accepts inputs based on the different system concepts being modeled. The SBA model simulates a high-value target being attacked by a small boat attacker. MTR forces are assumed to be either 100% or 0% effective. The MTR forces are 100% effective when they successfully stop the small boat attacker before it hits the high value target. The MTR forces are 0% effective when the small boat attacker hits the high-value target.

7.4.4.1 SBA Mission Database Module

The various characteristics associated with each of the different potential system concepts are stored in and drawn from the SBA Mission Database Module during the course of a simulation run. For each specific experiment 2,000 simulation runs are made, the values of the parameters for each experiment are pulled out of the overall database.

The module itself consists of the Database Manager block in EXTEND™. This block is connected to the Discrete Event Executive and serves as the principal interface to adjust parameters and record as well as retrieve data. Throughout the model, Database Write blocks are used to take information generated within the model and post it into one of the tables. Database Look-Up blocks are used throughout the model to pull information from the tables in the database from the Database Manager at such times as the information is needed by different modules of the model. Within the Database

Manager is a Database Viewer which enables one to access the different tables stored in the database.

To accomplish the experiment defined by the L_{32} orthogonal array, there is a table within the database that consists of all of the values listed in Table 7-11. As the execution of the model begins, it obtains the values that correspond to a given system concept from each of the different fields, C4ISR or PBS(3), as examples. The model runs the first 2,000 times looking at the values in record one (in EXTEND™ parlance, rows are referred to as records). These are the system concepts for experiment one in the orthogonal array. By pulling out values that identify which system concept is being explored from this table, that information can be used as an input to draw out values associated with a given concept's parameters from other tables. After the first 2,000 runs of the simulation, the model will shift to examining record two for the second experiment, and so on, until it proceeds through all 32 experiments over the course of 64,000 simulation runs. In this manner, the entire experiment can be performed without user involvement or interface until the data analysis phase after experiment completion. Such a construct enables fairly simple re-running of the experiment if modifications are desired or required to system concept parameters and the like. To see how this is carried out in practice within the model, an example is discussed for the WMD mission in Section 7.4.

7.4.4.2 Initial Orders Module

The first module in the SBA mission model is the Initial Orders Module. Within this module, the initial orders are given to the MTR forces via the C4ISR Module. Depending upon the C4ISR alternative being modeled, there are four different time delays associated with the action of giving initial orders. Initial orders are given upon receipt of intelligence that a small boat attack might occur. If the SBA takes place before or in the time it takes to give the initial orders, to assemble and prepare teams and platforms, and to deploy the forces, then the MTR system will be unsuccessful in stopping the attack. However, if the SBA is generated after initial orders are given, teams and platforms have been assembled and prepared, and the forces have been deployed, then the MTR system has a chance to succeed in stopping the attack.

7.4.4.3 Small Boat Attacker Generator Module

The small boat attacker is created using a Generator block. The small boat attacker is given an initial attacking distance from the high-value target. This distance represents the range at which the small boat attacker will begin their attack. The distance follows a normal distribution with mean of 500 yards and standard deviation of 150 yards. The distance may then be adjusted depending on the PBS(3) and Finish(3) alternatives for that given run. The initial attacking distance will increase by the amounts shown in Table 7-23 for each of the alternatives.

Alternative	PBS(3) (yards)	Finish(3) (yards)
1	250	0
2	500	500
3	333	0
4	0	500

Table 7-23: Change in initial attacking distance based on PBS(3) and Finish(3) alternatives

The output of this module is the small boat attacker with an adjusted initial attacking distance. The Small Boat Attacker Generator Module sends the small boat attacker to the Helicopter Engagement Module, if the given alternative includes a helicopter in the MTR force structure. If there is no helicopter, then the Small Boat Attacker Generator Module sends the small boat attacker to the MTR Escorts or Teams Onboard Engagement Module.

7.4.4.4 Helicopter Engagement Module

The input to this module is the small boat attacker with adjusted initial starting distance. The MTR forces are given time to identify and classify the small boat attacker. If the Find/Fix(3) alternative is visual only, then the MTR forces need 10 seconds to identify and classify the small boat attacker. If the Find/Fix(3) alternative is visual and radar, then the MTR forces only need 5 seconds to identify and classify the small boat attacker.

The small boat attacker is then taken through a series of decisions depending on how much distance remains between the small boat attacker and the high-value target before the small boat attacker impacts the high-value target. This distance is determined using the following equation, assuming that the small boat attacker's speed is 40 knots at all times during their attack,

$$\text{Remaining Distance} = \text{Initial Distance} - (40\textit{knots}) * (\text{Elapsed Time})$$

The first decision is whether or not there is enough remaining distance to allow the helicopter to warn and/or engage the small boat attacker. If there is not enough distance, then the Helicopter Engagement Module outputs the small boat attacker to the MTR Escorts or Teams Onboard Engagement Module. If there is enough distance, then a decision is made as to whether or not enough distance remains to give a non-lethal warning to the small boat attacker. If there is enough distance, the helicopter is given 10 seconds to carry out the nonlethal warning. If the Finish(3) alternative being modeled includes USVs, then the MTR forces only need 5 seconds to carry out the nonlethal warning.

After the nonlethal warning takes place or if there is not enough distance for a non-lethal warning, the helicopter fires lethal warning shots at the small boat attacker for 5 seconds. If the Finish(3) alternative being modeled includes USVs, then the MTR forces only need 2.5 seconds to fire lethal warning shots at the small boat attacker. The next decision is whether or not there is enough distance remaining for the helicopter to lethally engage. If there is not enough distance remaining, then the Helicopter Engagement Module sends the small boat attacker to the MTR Escorts or Teams Onboard Engagement Module for lethal engagement by the MTR escorts or teams located onboard the high-value target. If there is enough distance remaining, the helicopter lethally engages the small boat attacker.

The chance that the helicopter kills the small boat attacker is determined by the amount of distance over which the helicopter can engage. If the small boat attacker is closer than 1,200 yards from the high value unit, then the probability of kill is 61%. If the small boat attacker is greater than 1,200 yards, then the probability of kill is 91%. If the small boat attacker gets killed by the helicopter, then the SoS is 100% effective for that run. If the helicopter does not kill the small boat attacker after lethal engagement, then the Helicopter Engagement Module sends the small boat attacker to the MTR Escorts or Teams Onboard Engagement Module.

7.4.4.5 MTR Escorts or Teams Onboard Engagement Module

The input to this module is the small boat attacker either just after being generated or after exiting the Helicopter Engagement Module for those architecture alternatives that involve a helicopter. This module resembles the Helicopter Engagement Module in that there are a series of decisions made based on the remaining distance between the small boat attacker and the high-value target after identifying and classifying the small boat attacker. The MTR forces are given 10 seconds to identify and classify the small boat attacker if the Find/Fix alternative being modeled is visual detection only and 5 seconds if the Find/Fix alternative is visual and radar detection. A decision is then made as to whether or not there is enough distance remaining between the small boat attacker and the high-value unit for MTR forces to nonlethally warn the small boat attacker. If there is enough distance, then the MTR forces take 10 seconds to nonlethally warn the small boat attacker. If the architecture alternative includes USVs, then the MTR forces need only 5 seconds to do the nonlethal warning. If the entity being nonlethally warned happened to be an innocent boater, then it would be deterred by the nonlethal warning and would not continue driving toward the high-value unit. If there is not enough distance or if the nonlethal warning is unsuccessful, then a decision is made as to whether or not there is enough distance to carry out a non-lethal engagement on the small boat attacker. If there is enough distance, then the MTR forces will spend 10 seconds carrying out a nonlethal engagement. If the entity being nonlethally engaged happened to be an innocent boater, then they would be deterred by the nonlethal engagement and would not continue driving toward the high-value unit.

The next decision determines whether or not enough distance remains to lethally warn the small boat attacker. If there is enough distance, then the MTR forces will lethally warn the small boat attacker for 5 seconds or 2.5 seconds for alternatives which have USVs. Again, if the entity being lethally warned happened to be an innocent boater, then they would be deterred by the lethal warning and would not continue driving toward the high value unit. If there is not enough distance for lethal warning or if lethal warning fails, then the MTR forces lethally engage the small boat attacker once they are within 500 yards of the high-value unit. The chance that the MTR forces will be able to kill the small boat attacker depends on the remaining distance between the small boat attacker and the high-value unit and the corresponding probability of kill values for the architecture alternative being modeled. Table 7-24 contains the probability of kill values as input to this module.

PBS(3) Alternative	Pkill for 50 to 200 yards	Pkill for 200 to 500 yards
1	0.4557	0.6158
2	0.3841	0.6531
3	0.612	0.7433
4	0.3378	0.6491

Table 7-24: Probability of kill for a given range of engagement and PBS(3) alternative

If the small boat attacker is within 50 yards of the high-value unit, then the MTR forces do not have enough time to lethally engage the attacker so the SoS will be 0% effective for that simulation run.

7.4.4.6 SBA Delay to Commerce Module and Results

An EXTEND™ model is used to determine the number of hours of delay that MTR forces would inflict on ferries and tankers traveling within the area of operations. The goal is to determine the most cost-effective number of escort teams. Inputs to the model include the number of days that the operation will last, the number of ferries that need to be escorted, and the number of oil tankers that need to be escorted.

There are three types of units simulated in the EXTEND™ model: eight ferries traveling between the hours of 0700 and 1900 everyday; five oil tankers per day, equally spaced throughout each 24-hour period; and the escort teams available each day. The number of teams available is dependent on the MTR force structure and is varied to see the impact of adding or subtracting teams from the MTR forces. The variables are the number of escort teams available each day and the number of days over which the operations take place. The concept of operation for the MTR forces in the simulation is to give oil tankers priority for escorting. That is, if an escort teams become available and there is an oil tanker and a ferry requiring an escort, the escort team will choose the oil tanker to escort. This choice is based on the fact that the impact to commerce due to delaying an oil tanker is greater than the impact to commerce due to delaying a ferry. Given the fixed number of oil tankers and ferries each day, the number of escorts required to cause zero delay to either the oil tankers or the ferries is 13.

Additional inputs to the model include the amount of time required to escort each oil tanker and each ferry. Assuming that the ferries run constantly from 0700 to 1900 everyday, they will each need to be escorted for the entire 12-hour period. The model assumes that each oil tanker needs to be escorted for 10 hours.

The simulation results from the SBA Delay to Commerce Module indicate that the delay times to commerce decrease as the number of escort teams increase. Figure 7-34 shows the total hours of delay to oil tankers, given the number of days over which the operation takes place and the number of escort teams available. Figure 7-35 shows the total hours of delay to ferries given the number over which the operation takes place and the number of escort teams available.

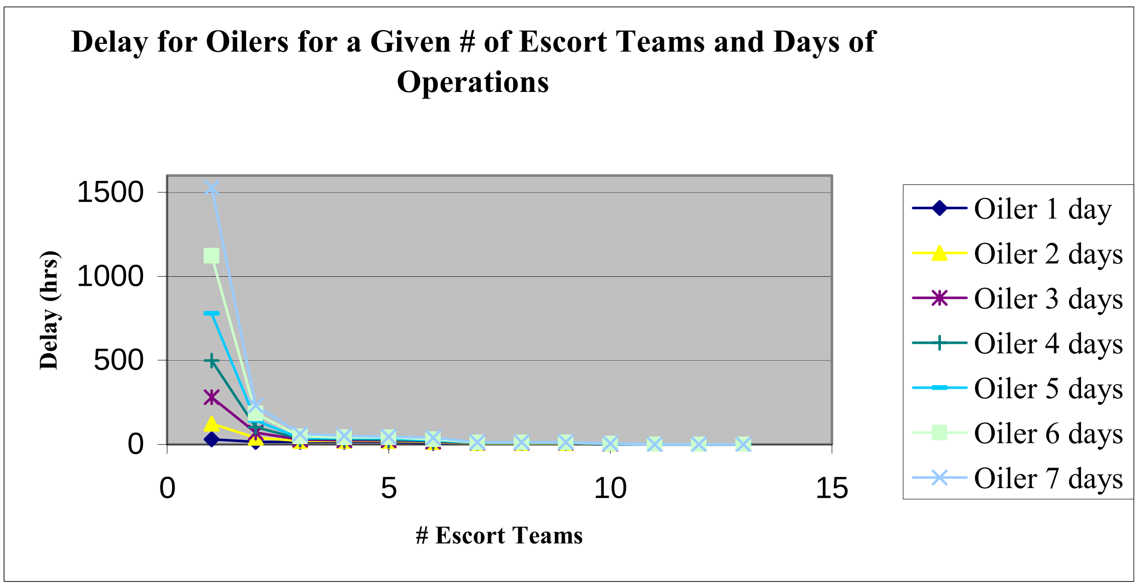

Figure 7-34: Delay to oil tankers given the number of days over which the operation takes place and the number of available escort teams

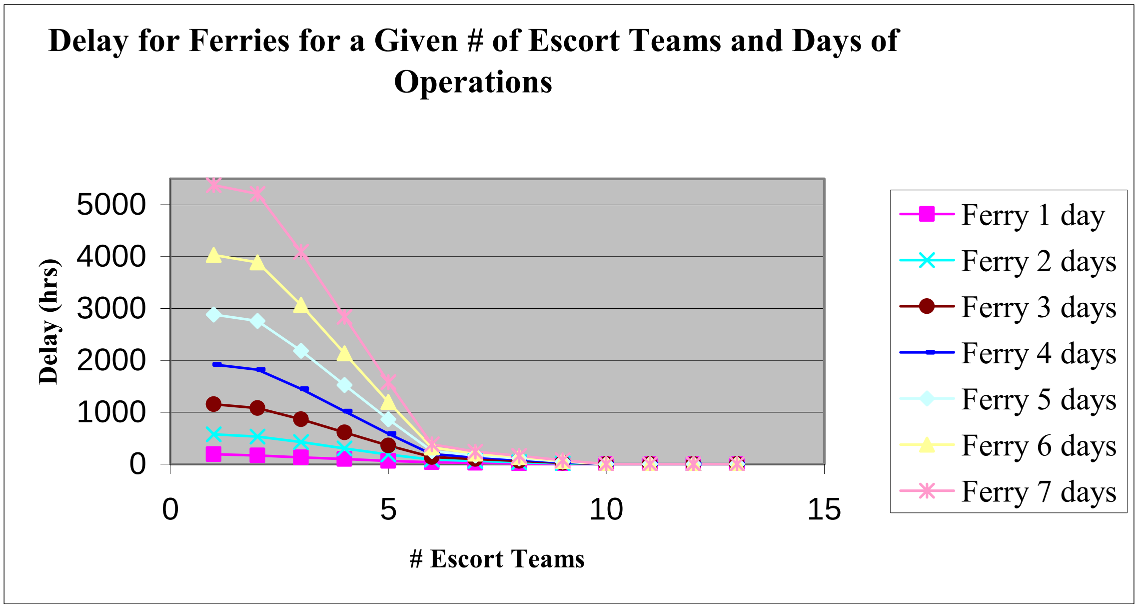

Figure 7-35: Delay to ferries given the number of days over which the operation takes place and the number of available escort teams

The outputs of the SBA Delay to Commerce Module are used in the cost analysis to evaluate the cost-effectiveness of alternative architectures as discussed in Sections 7.5, 7.6, and 7.7.

7.4.4.7 SBA Mission Model Administration

Once each run of the simulation is completed, the results are sent to an Excel spreadsheet. The results indicate whether or not the MTR forces were successful in stopping the small boat attacker from carrying out their attack. Additionally, the SBA Delay Commerce Module results are used to determine the most cost-effective number of escort teams to use. As each experiment is run 2,000 times, this enables calculation of overall mission probability of success (number of successes in 2,000 trials) associated with each of the 32 experiments. These outputs are used as inputs to the response function in MINITAB 14 for purposes of identifying the "best" systems in terms of effectiveness as discussed in Section 7.5. These same outputs, combined with the cost analysis as discussed in Section 7.6, make up the cost-effectiveness results as discussed in Section 7.7.

7.4.5 Sustain Module

Four Sustain functional models—Ship Fuel Consumption Model, Watch Team Sleep Analysis Model, Small Boat Availability and Reliability Model, and Helicopter Availability and Reliability Model—are created to evaluate mission CONOPS and determine logistical requirements for the different architectures.

7.4.5.1 WMD/SAW Mission Ship Fuel Consumption Model (ShiFCoM)

The purpose of the WMD/SAW mission ship fuel consumption model is to determine the following:

1) Maximum sprint speed of ships transiting from each of the four homeports to intercept target container ships while maintaining sufficient fuel reserves to escort a container ship eastward for up to 24 hours.
2) Approximate percentage of fuel remaining after sprinting to intercept a container ship, by ship class.
3) Choice of ships to use from each port ranking maximum sprint speed and amount of fuel consumed during mission.

<u>Assumptions</u>

Ships executing the WMD/SAW mission are berthed in various home ports. Upon receipt of intelligence pertaining to the WMD or terrorist transport ships, selected national fleet assets (i.e., U.S. Navy and USCG) ships get underway and sprint to intercept target ships. Simultaneously a nominal value of 72 hours is assigned for the latency of the intelligence. Military Sealift Command (MSC) refueling ships (i.e., T-AO class) get underway and sprint to rendezvous to conduct underway replenishment (UNREP). Within 24 hours, after the container ships have been intercepted, it will take up to 24 hours after intercept of target ship to rendezvous with the MSC ship for refueling. A transit speed of 21.9 knots is assumed for the escort portion of the mission (Table 7-30).

Table 7-5 lists the home ports and the force distributions from which military ships will begin the WMD mission.

Based on the modular nature of LCS, it is assumed an additional fuel storage tank can be installed into the LCS mission module bay. The resulting LCS is titled “LCS+.”

The additional fuel tank has a capacity of 10% of the volume available within the normal General Dynamics LCS mission module bay.[90]

Method

Amount of fuel consumed for each ship class is calculated using the following equation:[91]

Fuel consumed (Kgal) = fuel consumption rate @ sprint speed (Kgal/hr) x distance traveled (NM)/sprint speed (NM/hr).

The percentage of fuel remaining in a military ship's tanks once it has intercepted its assigned container ship are calculated using the following equation:[92]

Fuel remaining (%) = fuel consumed during sprint (Kgal)/maximum fuel capacity (Kgal).

Equation 1 is used to calculate fuel consumption rate-curves for CG-47, DDG-51, FFG-7, and AOE-1 class ships;[93] Equation 2 is used for WMSL and WHEC-378 class ships.[94] The U.S. Army Vessel (USAV) Joint Venture HSV-X1 ship was utilized as an analogous ship class to estimate fuel consumption rate data for the LCS-class ship. Equation 3 is used for the LCS-class ship.[95] The T-AO-187 Henry Kaiser-class MSC ship was utilized as an analogous ship class to estimate fuel consumption rate data for the modified merchant TOTE-Orca-class ship listed in Table 7-6. Equation 1 is used to calculate fuel consumption rate curve (Figure 7-37) for the modified merchant class TOTE-Orca ships. Coefficients and assumptions for variables for each ship class are shown in Table 7-25.

Equation 1: Kgal/hr = b0 + b1 * exp(b2 * (speed/100)^3)

Equation 2: Kgal/hr = b0 + b1*exp(b2*speed)

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[90] Data based on Bath Iron Works – A General Dynamics Company, "Fact Sheet: General Dynamics Littoral Combat Ship," [http://www.gdbiw.com], 27 May 2004, accessed on 6 April 2006.

[91] Additional fuel required for intercept maneuvering is not considered.

[92] No reserve capacity for unexpected operations is considered.

[93] D.A. Schrady, G.K. Smyth, and R.B. Vassian, *Predicting Ship Fuel Consumption: Update*, Naval Postgraduate School, July 1996.

[94] Integrated Coast Guard Systems, S012-07, *NSC Endurance Fuel Calculation*, 9 March 2005; and E. Diehl and W. McCarthy, "Summary of Cutter Energy Management Audit Results and Recommendations," U.S. Coast Guard Research and Development, CG-D-14-00, May 2000.

[95] David D. Rudko, "Logistical Analysis of the Littoral Combat Ship," Master's Thesis, Naval Postgraduate School, Monterey, CA, March 2003.

Equation 3: Kgal/hr = b0 + b1*displacement + b2*speed^3 + b3*average wave height

Coefficient	AOE	CG-47	DDG-51	FFG-7	LCS	WHEC-378	NSC
b0	–27553.4	–1429.04	–764.433	–545.716	–7997.87	0	0
b1	27821.2	2215.39	1379.62	951.117	3.281	27.127	43.329
b2	12.2579	37.4831	51.5925	51.8843	0.129	0.1769	0.1386
b3					647.403		
full displacement (long tons)					1671.4		
average wave height (feet)					6		

Table 7-25: Fuel consumption rate-curve coefficients and variable assumptions

Ship Intercept Module data provides mean distance (and standard deviation) military ships must travel to intercept the container ships. These two metrics are input into the ShiFCoM model to calculate maximum sprint speed to intercept container ships, based on ship's home port.[96] 95% confidence intervals are calculated based on two standard deviations surrounding the mean. The upper and lower confidence intervals bracket 95% variation in the expected distance ships must travel to conduct the mission, based on a normal distribution of trials.[97] Applying the ship fuel consumption rate curves for each respective ship's maximum speed, fuel expended during the sprint from home port to intercept the container ship is calculated.

After intercept of the container ship and refueling from MSC ship the military ships escort the container ships east towards their final destination port (San Francisco, CA). Weighted escort speeds shown (outputted from the Intercept Module, section 7.2.2.3) in Table 7-26 are used to calculate an average container ship transit speed (and matching escort speed for military ships). Weights are assigned based on SME estimates of percentage of time container ship will transit at the respective speed. Weighted average escort speed is input into SFCM model to calculate total amount of fuel consumed during container ship escort by ship class, per home port of origin. Fuel consumed during the sprint phase to intercept is added with fuel consumed during escort of container ship, to calculate total mission fuel consumed by ship class, per home port of

[96] Ships already at sea that could potentially become opportunistic participants are not considered.

[97] The calculations are therefore accurate for ships traveling distances within two standard deviations of the mean travel distance. Based on a normal distribution of trials, 5% of the population is expected to travel distances outside that considered.

origin. Results are shown as percentage of respective ship maximum fuel capacity, displayed in Figures 7-41, 7-45, 7-49, and 7-53.

Weight	Escort Speed (knots)
0.4	20
0.4	22
0.1	25
0.1	26
Weighted Average	**21.9**

Table 7-26: Container ship escort speed and assigned value weights

Results

The distance military ships will travel to intercept the container ships, starting at each of the four bases (Table 7-5). Using the data from Figures 7-36 and 7-37, and the outputted distance ships travel to intercept target container ships from the Intercept Module (Section 7.2.2.3), the fuel remaining after intercept, per ship class, is calculated. By adjusting the sprint speed of each ship, amount of fuel remaining at intercept of container ship is adjusted to ensure ships have 10% or more (of their max capacity) remaining. This is necessary to allow up to 24 hours for refueling ships to rendezvous with the military ships. Ships sprinting at speeds higher than those calculated as optimized maximum sprint speeds will arrive at intercept with their assigned container ship at less than 10% capacity fuel remaining, and therefore will be unable to continue transiting with the container ship until they have been refueled.

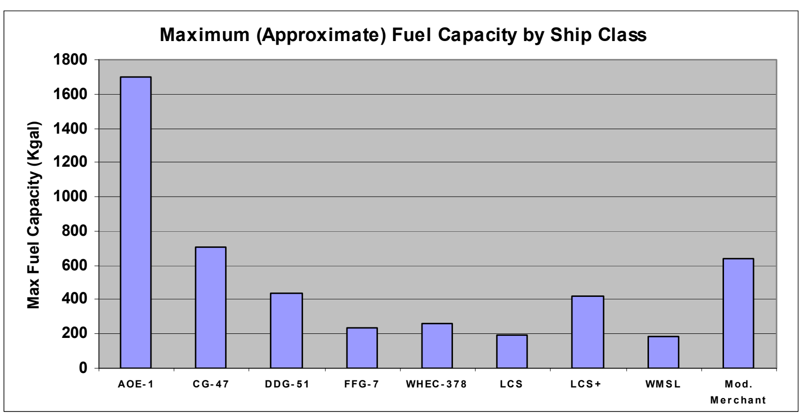

Figure 7-36: Maximum Fuel Capacity by ship class.[98] The source data was multiplied by a factor of 1.5 to account for absolute maximum fuel capacity, vice operational fuel capacity.[99]

[98] Data for ship fuel capacity based on David D. Rudko, "Logistical Analysis of the Littoral Combat Ship," Master's Thesis, Naval Postgraduate School, Monterey, CA, March 2003; and Bath Iron Works – A

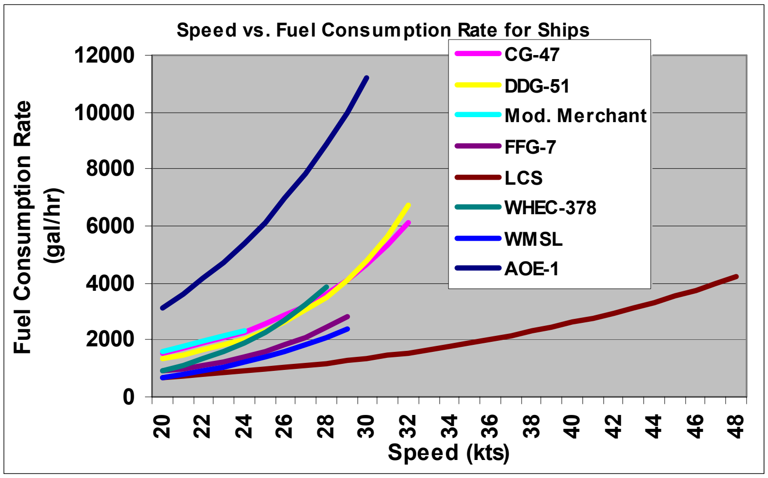

Figure 7-37: Fuel consumption rate for ships.[100] Note that these fuel curves are only accurate for speeds greater than 20 knots.

General Dynamics Company, "Fact Sheet: General Dynamics Littoral Combat Ship," [http://www.gdbiw.com], 27 May 2004, accessed on 6 April 2006.

Global Security, "Littoral Combat Ship (LCS)." [http://www.globalsecurity.org/military/systems/ship/lcs.htm]. May 2004, accessed June 2006; Integrated Coast Guard Systems, "Deepwater Cutters: National Security Cutter." [http://www.icgsdeepwater.com/objectives/cutters/NSC.php] February 2005, accessed on April 6, 2006; and GlobalSecurity.Org, [http://www.globalsecurity.org/military/systems/ship/index.html.

[99] In general, unclassified data available on ship fuel capacity is based on an "operational mission range" at a given speed. The "operational" range does not account for actual distance ship could transit at the given speed until out of fuel. It is the authors' opinion that this data is intentionally obscured to hide actual (classified) information. To account for this, the authors have included the multiplicative factor (of 1.5), though the resultant values continue to be incorrect.

[100]Data based on the following sources: D.A. Schrady, G.K. Smyth, and R.B. Vassian, "Predicting Ship Fuel Consumption: Update," Naval Postgraduate School, Monterey, CA, July 1996; Integrated Coast Guard Systems, S012-07, *NSC Endurance Fuel Calculation*, 9 March 2005; E. Diehl and W. McCarthy, "Summary of Cutter Energy Management Audit Results and Recommendations," United States Coast Guard Research and Development CG-D-14-00, May 2000; and David D. Rudko, "Logistical Analysis of the Littoral Combat Ship," Master's Thesis, Naval Postgraduate School, Monterey, CA, March 2003.

Yokosuka, Japan

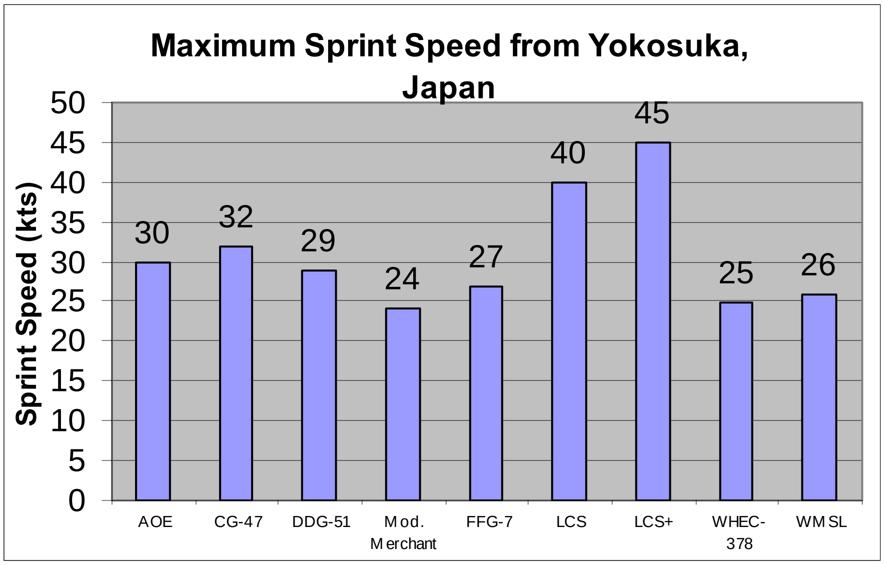

Figure 7-38: Maximum Sprint Speed from Yokosuka, Japan

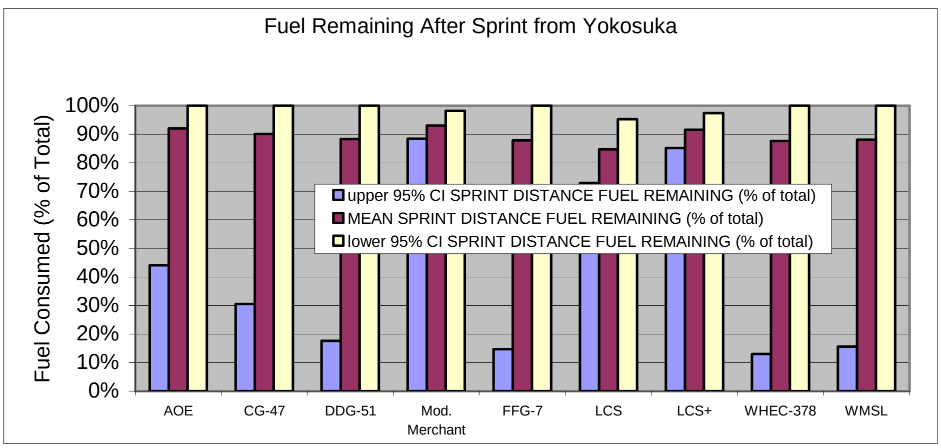

Figure 7-39: Fuel remaining after sprinting to intercept container ships, shown by ship class, ships based in Yokosuka, Japan. Upper and lower 95% confidence intervals based on two standard deviations in distance ships will travel, resulting from container ship intercept simulation.

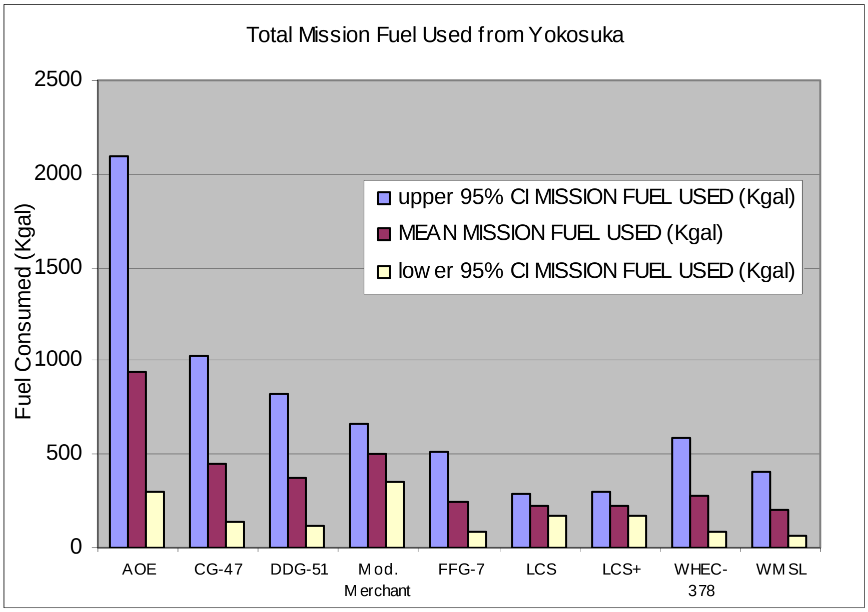

Figure 7-40: Total fuel used by each ship, originating from Yokosuka, for the duration of the mission

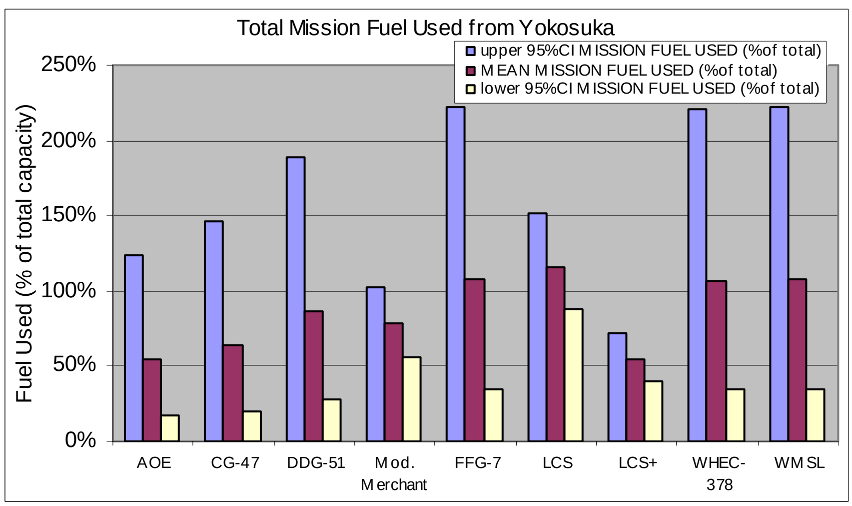

Figure 7-41: Total fuel used by each ship, originating from Yokosuka, for the duration of the mission. Fuel consumed shown in percentage of total respective ship capacity.

WMD/SAW mission CONOPS call for ships to get underway on receipt of intelligence concerning the mission. Intelligence latency greater than approximately 160 hours precludes the use of ships home ported in Yokosuka: Container ships underway for greater than 160 hours will the pass acceptable intercept position for Yokosuka-based ships; resulting in an eastward chase without being able to intercept prior to the 100-nm point (should they attempt to intercept the container ship). Based on the results (Figure 7-42), LCS (both with the addition of the mission module fuel tank

[LCS+] and without [LCS]) allows for the highest sprint speed out of Yokosuka. Sprinting at higher speed causes LCS to have a lower mean fuel percentage remaining upon container ship intercept, as seen in Figure 7-41. The upper 95% confidence interval involves larger distance sprinted to intercept the container ships. Due to LCS' more economical fuel consumption rate curve (Figure 7-41), LCS consumes a smaller amount of fuel over the upper 95% confidence interval sprint distance than the other ships home ported out of Yokosuka. LCS+ shows an even smaller percentage of fuel consumed for both the mean and upper and lower 95% confidence intervals due to its increased maximum fuel capacity. FFG-7, DDG-51, and CG-47 class ships have an upper 95% confidence interval value of approximately 100% (Figure 7-41). This upper 95% confidence interval limit for the FFG-7, DDG-51, and CG-47 class ships is due to their lower sprint speeds causing them to intercept the container ship in the immediate vicinity of Yokosuka (therefore the ships travel a smaller distance to intercept the container ship than the LCS and LCS+, since their path to intercept is shorter). This indicates that although LCS and LCS+ have a maximum sprint speed higher than the other ship classes, sprint speed out of Yokosuka at greater than approximately 32 knots causes them to consume more fuel at little gain (the payoff is intercept of the container ships further west along their transit). However, because of LCS' improved fuel economy, capability for higher sprint speed, and lower total mission fuel consumed, the LCS affords the PBS option 2 a greater capability value per dollar cost than the other PBS options.

Figure 7-40 shows the AOE and CG-47 class ships consume the largest amount of fuel for the mission, while LCS and LCS+ consume the least. LCS+ consumes only a slightly higher total amount of fuel during the mission due to a slightly higher sprint speed (45 knots for LCS+ compared to 40 knots for LCS; Figure 7-38). The additional fuel capacity present in the LCS+ allows it to perform the entire mission with a mean total mission fuel consumed of 54%, 95% confidence interval bands of 41%-70% of the its total capacity. The LCS without the added mission module fuel tank, on the other hand, consumes approximately twice its total fuel capacity in fuel throughout the mission (compared to the LCS with the added fuel tank). This means the added mission module fuel tank affords the LCS the capability to perform the entire mission without being refueled, whereas the LCS without the mission module fuel tank requires at least one refueling during the mission.

Kodiak, Alaska

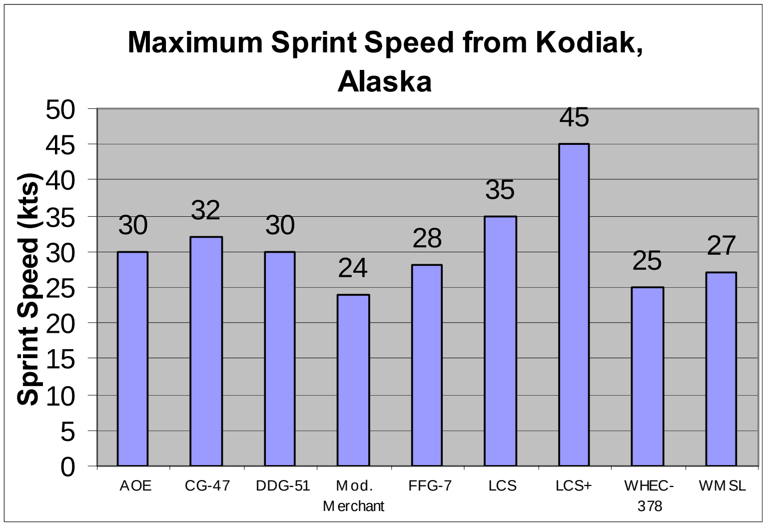

Figure 7-42: Maximum Sprint Speeds from Kodiak, Alaska

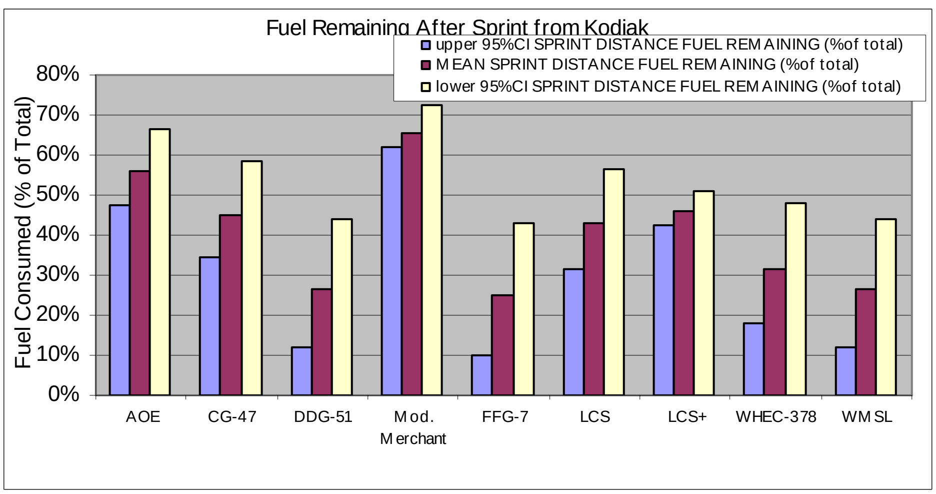

Figure 7-43: Fuel remaining after intercept of container ships, by ship class home ported in Kodiak, Alaska. Upper and lower 95% confidence intervals based on two standard deviations in distance ships will travel, resulting from container ship intercept simulation.

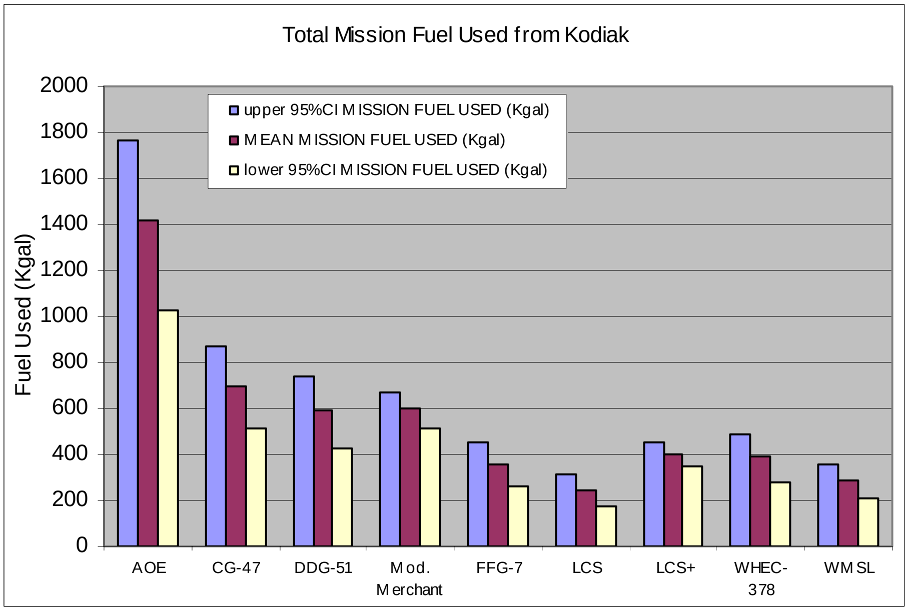

Figure 7-44: Total fuel used by each ship, originating from Kodiak, for the duration of the mission

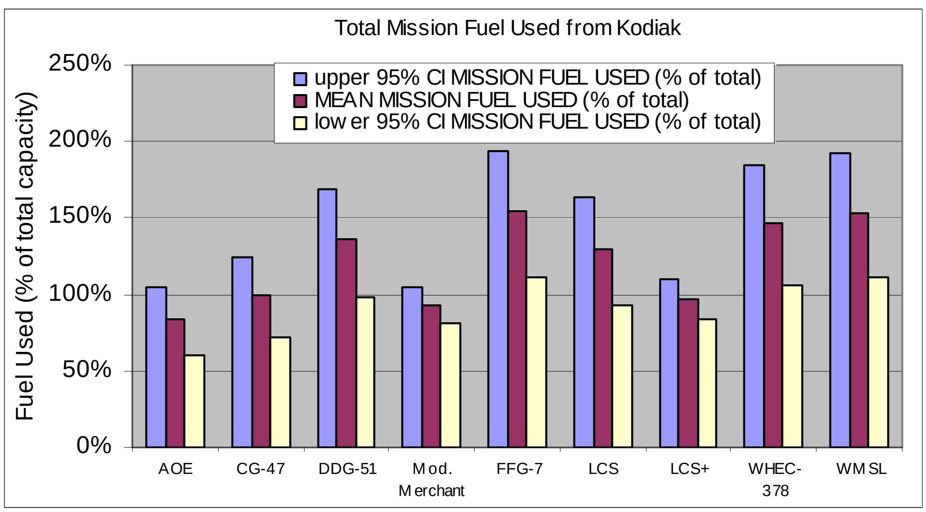

Figure 7-45: Total fuel used by each ship, originating from Kodiak, for the duration of the mission. Fuel used shown in percentage of each ship's maximum fuel capacity.

There are currently no U.S. Navy warships permanently home ported in Kodiak, Alaska.[101] The listing of ship classes shown in the above figures therefore allows ship classes that are or potentially will be stationed in Alaska (i.e., the WHEC-378 and WMSL) to have their capabilities compared. The WMSL-class ship offers improved fuel efficiency over the WHEC-378 at speeds over 20 knots (Figure 7-37), resulting in a

[101] United States Department of Defense, Defense Manpower Data Center, "SITES," [http://www.dmdc.osd.mil/appj/sites/lookupinstallation.do], version 4.1.5.31, accessed on April 2006.

higher maximum sprint speed for the WMSL (Figure 7-42), since it will consequently consume less fuel at the same speeds as the WHEC-378. The improved fuel efficiency of the WMSL over the WHEC-378 results in the WMSL consuming less total fuel during the duration of the WMD/SAW mission (Figure 7-44). However, due to the WMSL having a slightly smaller fuel capacity than the WHEC-378 (Figure 7-36), the WMSL's resulting endurance is slightly less than the WHEC-378 (Figure 7-45). Therefore, the WMSL may require more frequent replenishment in long-duration missions, compared to the WHEC-378 class ships.

The WMSL's slightly higher maximum sprint speed allows it to intercept the container ship at a point further west in its transit than the WHEC-378. Intercepting the container ship further west in its route allows the search teams (for the Find/Fix teams in the WMD mission or the VBSS teams in the SAW mission) more time to conduct their mission, which in the WMD mission translates into a higher probability of successfully finding a WMD aboard the container ship prior to entering port (and therefore a higher probability of mission success).[102] The WMSL's increased maximum sprint speed and lower total mission fuel consumed (compared to the WHEC-378) affords PBS option 2 a higher mission capability per dollar cost than the other options.

[102] Effects of search time on probability of detecting WMD aboard the target container ship are shown in Section 7.2.2.4 Container Search Module.

Hawaii

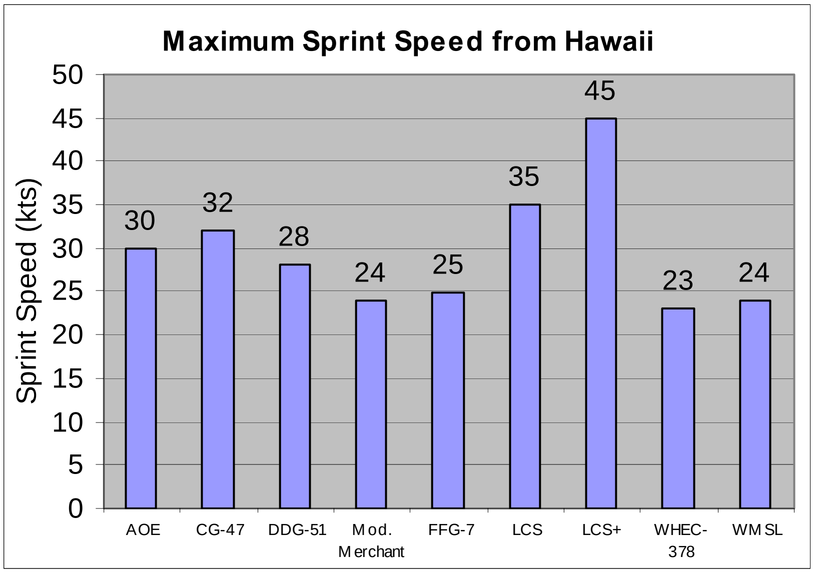

Figure 7-46: Maximum Sprint Speed from Hawaii

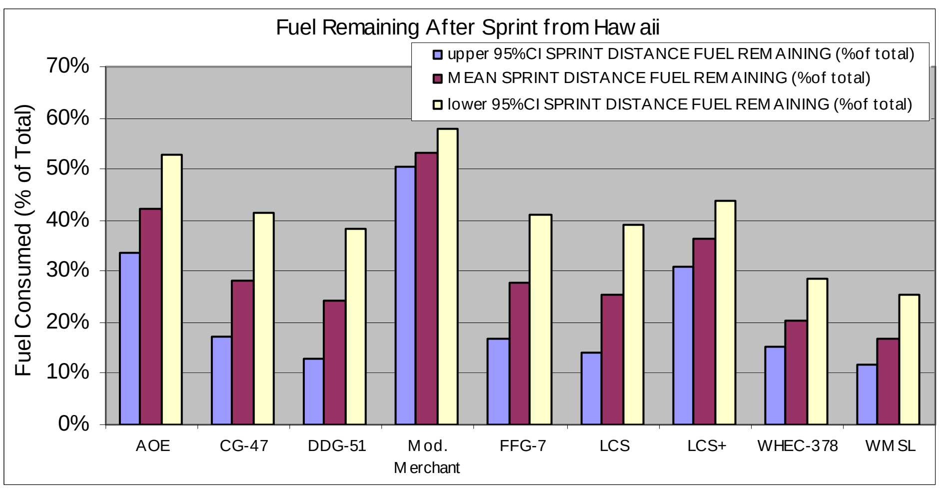

Figure 7-47: Fuel remaining after intercept of container ships, by ship class from Hawaii. Upper and lower 95% confidence intervals based on two standard deviations in distance ships will travel, resulting from container ship intercept simulation.

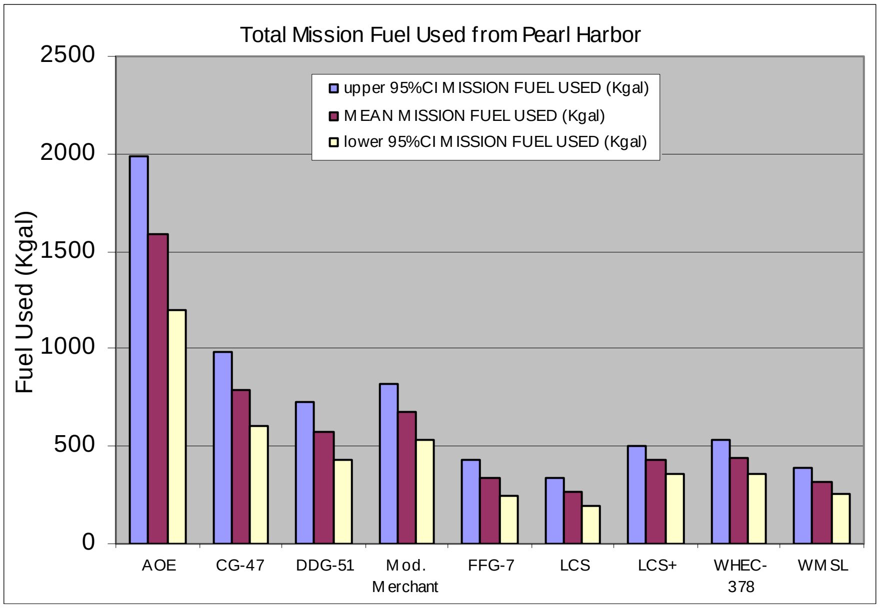

Figure 7-48: Total fuel used by each ship, originating from Hawaii, for the duration of the mission

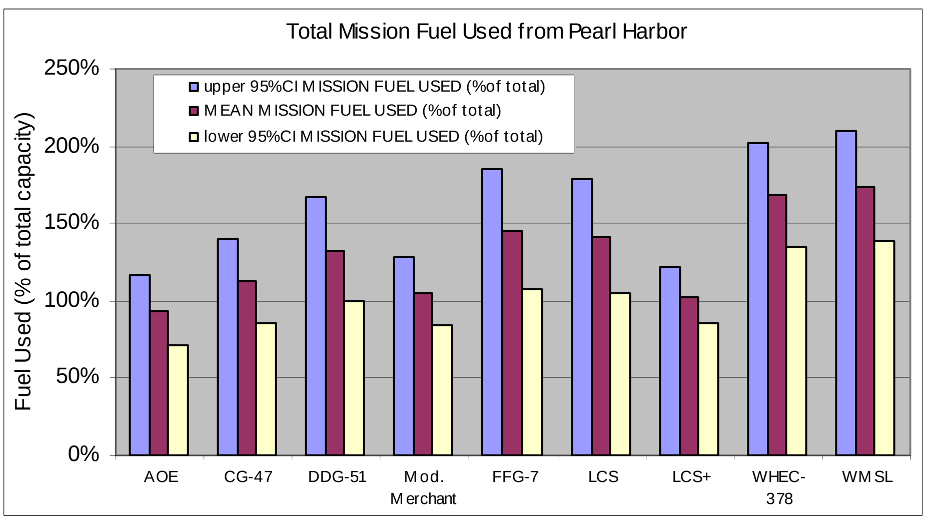

Figure 7-49: Total fuel used by each ship, originating from Hawaii, for the duration of the mission. Fuel used shown in percentage of each ship's maximum fuel capacity.

Of the nine ship classes considered for the mission, the LCS' more economical fuel consumption rate (Figure 7-36) results in the largest maximum optimized sprint speed during the sprint to intercept (Figure 7-46). Consequently, LCS consumed a greater percentage of its fuel (Figure 7-47) though of the ship classes the LCS has one of the smallest fuel capacities (Figure 7-36). The hypothetical additional fuel tank in LCS+ afforded the LCS a much higher maximum optimized sprint speed (45 knots compared to

35 knots), while only consuming a slightly larger percentage of its fuel during the sprint to intercept. Due to the LCS' efficiency in fuel consumption, the LCS consumed the least amount of total mission fuel, as compared to the other ship classes. The LCS+ consumed almost twice as much fuel as the LCS (Figure 7-48); however, with the increased sprint speed affords a large advantage in getting the search teams onboard the container ships.[103]

San Diego

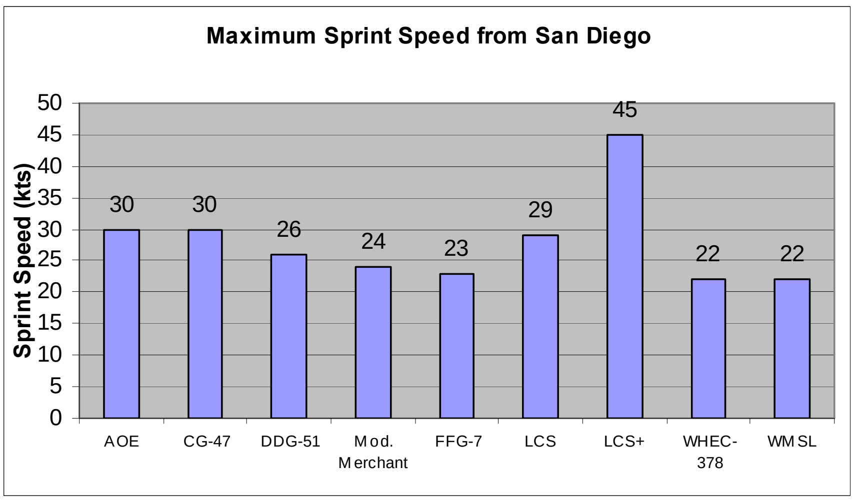

Figure 7-50: Maximum Sprint Speed from San Diego

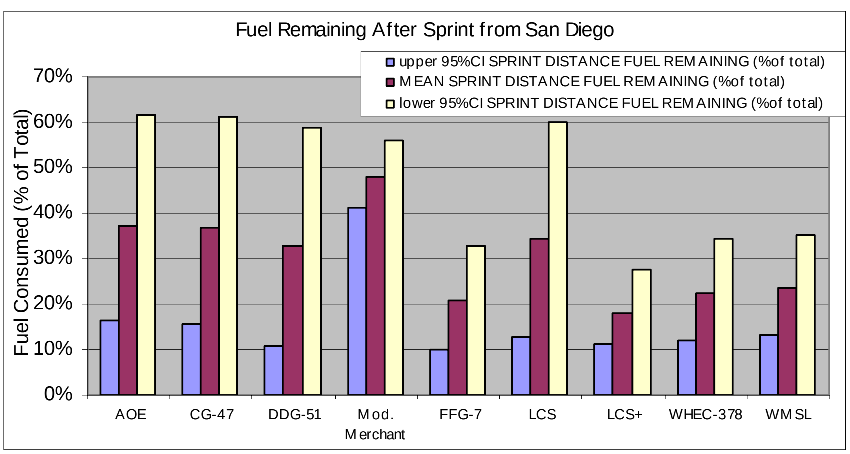

Figure 7-51: Fuel remaining after sprint to intercept, by ship class from San Diego. Upper and lower 95% confidence intervals based on two standard deviations in distance ships will travel, resulting from container ship intercept.

[103] Weight from additional fuel in the hypothetical mission module tank is assumed to be incorporated into the fuel consumption rate curve equation.

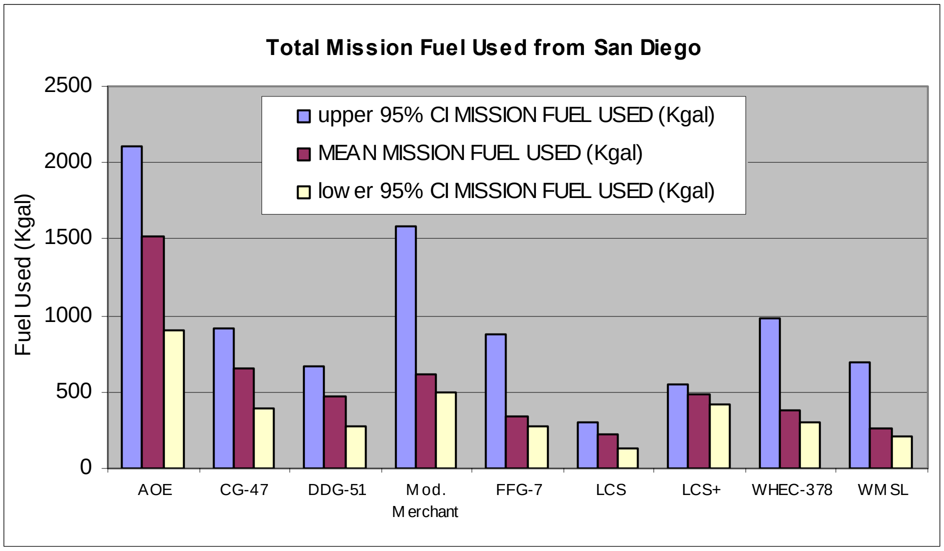

Figure 7-52: Total fuel consumed by each ship, originating from San Diego, for the duration of the mission

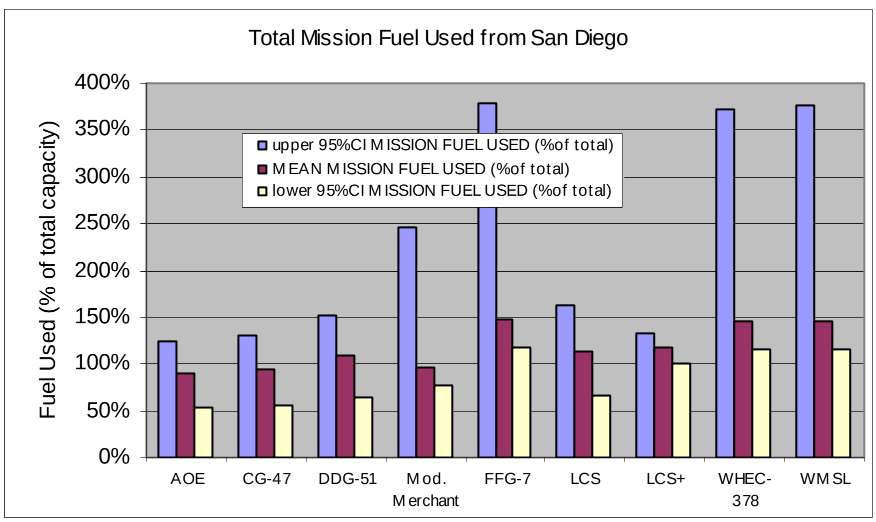

Figure 7-53: Total fuel used by each ship, originating from San Diego, for the duration of the mission. Fuel used shown in percentage of each ship's maximum fuel capacity.

Of the ships available for the WMD/SAW mission home ported in San Diego, the FFG-7, WHEC-378 and WMSL result in the lowest sprint speeds (< 24 knots) for intercepting the container ship (Figure 7-50). Due to these low sprint speeds, these ships are therefore less desirable choices for use in the mission when stationed along the

West Coast of the United States.[104] The modified merchant ship class considered is based on a hypothetically modified TOTE Orca class merchant ship, designed for a maximum speed of 24 knots.[105] The modified merchant's maximum optimized speed is therefore constrained more by its maximum achievable speed than its fuel consumption rate and fuel capacity. Consideration of a different modified merchant-class ship, one designed with a higher maximum speed, may result in a higher maximum optimized transit speed, though high-speed, large-tonnage commercial vessels are not normally designed due to low fuel consumption efficiency.

The AOE, CG-47 and LCS class ships have approximately the same maximum optimized sprint speeds (Figure 7-49) as well as the same approximate percentage of fuel remaining after the container ships have been intercepted (Figure 7-50). The LCS, however, consumes a vastly smaller amount of fuel throughout the mission compared to the AOE and CG-47 (Figure 7-51). When compared to the other ship classes, the smaller fuel capacity of the LCS causes it to consume a greater percentage of its fuel than the AOE and CG-47 classes. The addition of the hypothetical mission module fuel tank in LCS+ makes up for the LCS' smaller fuel capacity, allowing a much higher maximum optimized sprint speed (45 knots; Figure 7-49), while still reaping the benefits of LCS' improvement over AOE and CG-47 in fuel consumption efficiency. Thus, while the AOE and CG-47 class ships (and to a lesser extent the DDG-51) afford a sprint capability slightly better than LCS, the LCS' fuel consumption efficiency results in a vast savings in total mission fuel usage. LCS+ affords the LCS a vast increase in sprint speed capability, while only slightly increasing the total amount of fuel consumed (seen in Figures 7-50 and 7-52).

[104] FFG-7, WHEC-378 and WMSL may instead be used to intercept "leaker" target container ships that are closer to the coast. Therefore, while not the optimum ship classes to use for the mission from San Diego, they are still of great value and use within the mission from all bases.

[105] TOTE Ships | TOTE – Shipping Cargo to Alaska, [http://www.totemocean.com/ts-ships.htm], accessed in February 2006.

Conclusions

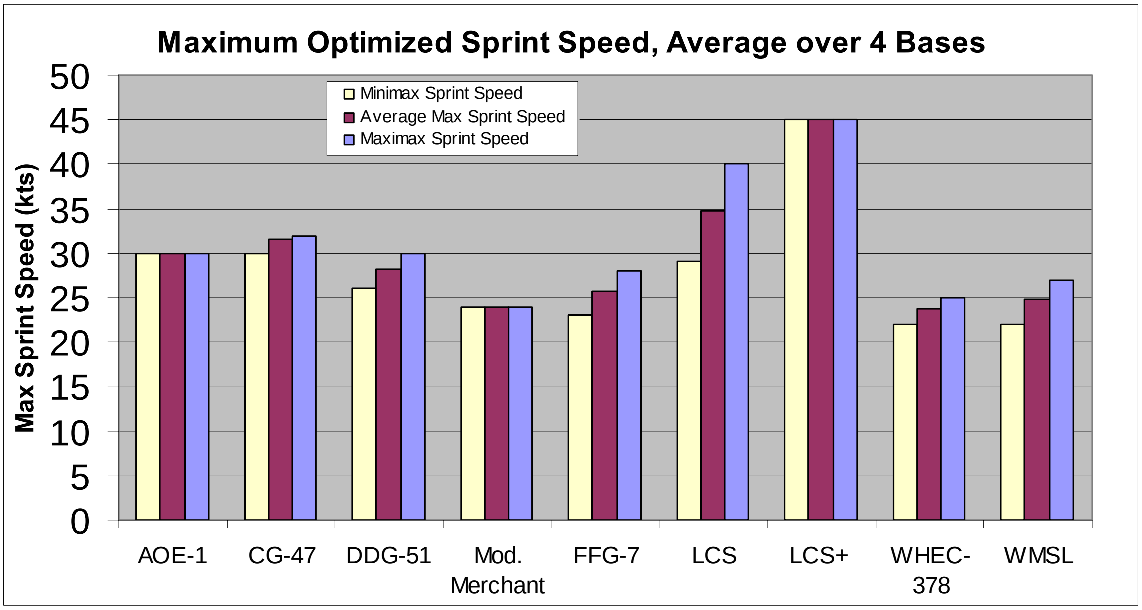

Figure 7-54: Maximum optimized sprint speed by ship class, averaged over the four bases considered (Yokosuka, Kodiak, Hawaii, San Diego)

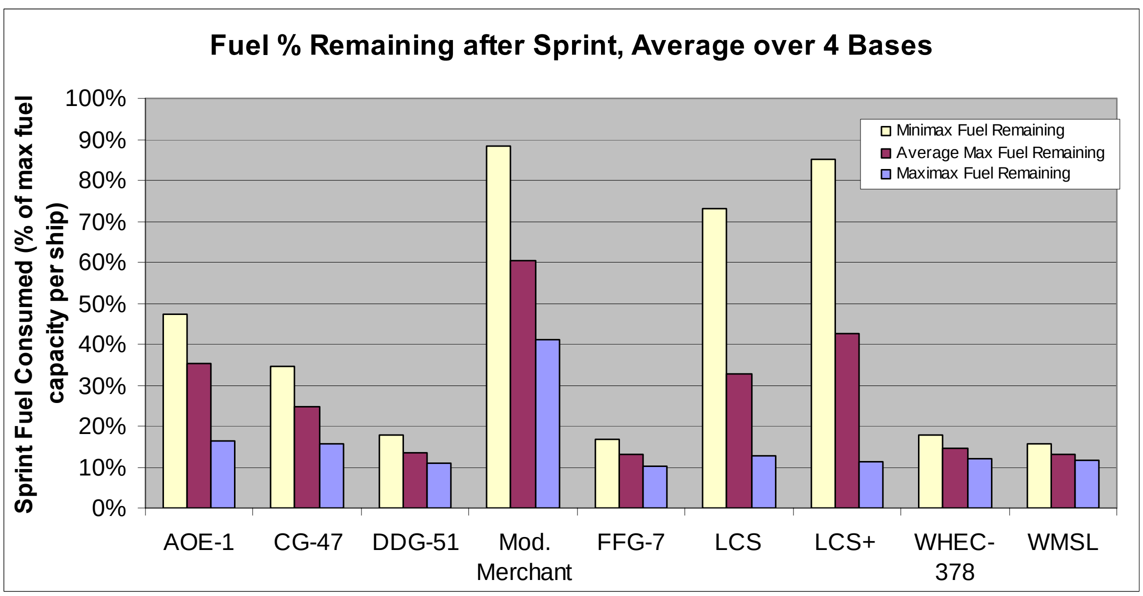

Figure 7-55: Fuel percentage remaining, by ship class, after sprinting to intercept the container ships in the WMD/SAW mission, averaged over the four bases considered (Yokosuka, Kodiak, Hawaii, and San Diego)

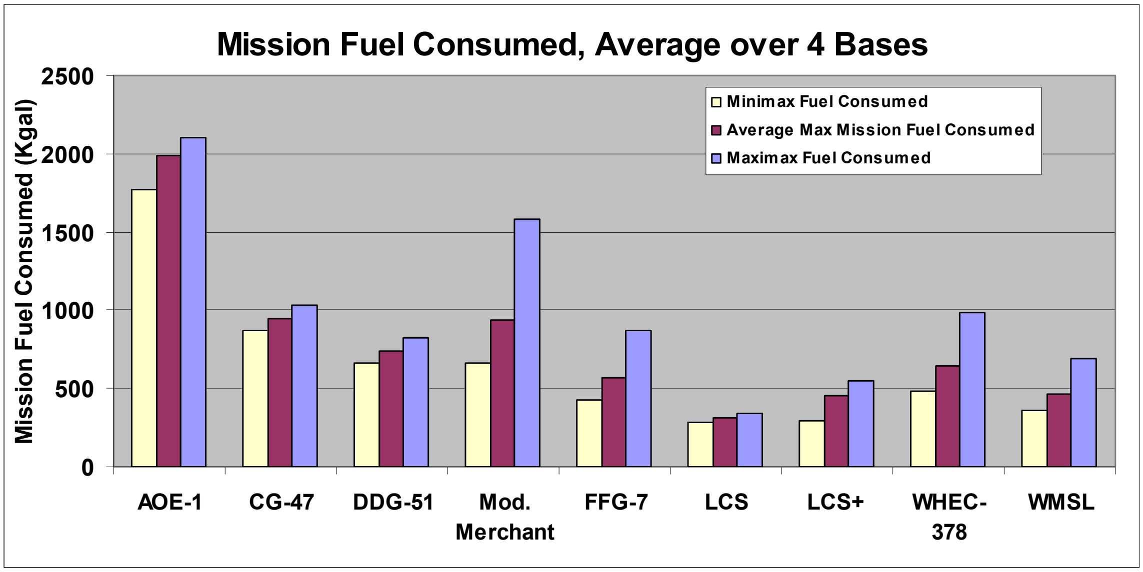

Figure 7-56: Total fuel consumed, by ship class, for entire mission, averaged over the four bases considered (Yokosuka, Kodiak, Hawaii, and San Diego). Mission fuel is measured from departing from home port, sprinting to intercept container ships, then escorting container ships into port with the San Francisco harbor.

Figure 7-54 shows that LCS has, from almost all bases, the highest maximum optimized sprint speed out of the ship classes considered. Of the four home ports considered, when based out of San Diego LCS experiences a drop in its maximum optimized sprint speed due to the longer distance it must travel in order to intercept its assigned container ship. The smaller fuel capacity of LCS causes the sprint speed to be reduced when traveling long distance, in order that it will have at least 10% or more of its fuel remaining after intercept (one of the mission constraints). The additional fuel tank offered in LCS+ shows a very large payoff in sprint speed from all bases, at only a small increase in total mission fuel expended (Figure 7-56), compared to LCS (sans additional fuel tank).[106] If the mission module fuel tank in LCS+ is, in fact, turns out to be more than just hypothetical, the implications would be to vastly increase the endurance and transit speed of LCS, while continuing to afford a lower fuel cost option (compared to other CRUDES ships).

The AOE class ship affords a high sprint speed even when averaged over the four considered bases (Figure 7-54). AOE's high sprint speed comes at a large price in terms

[106] WMD/SAW missions consider target container ships transiting eastward only. Missions where both target container ships and national fleet assets travel westward may yield less importance in the utility of the LCS+ over the LCS; however, this is left for further study.

of fuel consumed for the mission, as seen in Figure 7-56. The CG-47 class ship offers comparable if not better sprint speeds with a very large savings in fuel over the total mission. The difference in sprint speeds and fuel usage seen amongst the various ship classes can all be related to the ship fuel consumption rates (Figure 7-37). The end result of a more fuel consumption efficiency is translated into maximum allowable transit speed (i.e., sprint speed) and fuel consumed throughout the mission.

Fuel capacity contributes to the mission depending on the frequency of refueling available. For missions where refueling is quickly available, sprint speeds may be increased (resulting in larger sums of fuel being consumed). Replenishment ships tend to be larger and slower than Navy warships, thus restricting their ability to enter the theatre as quickly. Replenishment ship prepositioning becomes a trade-off for speed; however, the UNREP ship's lack of speed still limits the mission by constraining the maximum optimized sprint speed for ships, as presented in the above results.[107]

7.4.5.2 WMD/SAW Watch Team Sleep Analysis Model (WaTSAM)

The Find/Fix search teams require adequate sleep to maintain a vigilance level that ensures a probability of success in noticing alarms from their search equipment. The VBSS team must likewise remain in a state of high alertness in order to properly recognize signs of deceit from potential sleeper-cell terrorists onboard the ship. Due to the limited amount of space available on most container ships, the maximum search team size is constrained: while a larger team allows a larger volume of containers to be searched, the time spent not working is constrained by the amount of space available to live in while minimizing inconvenience to the ship's organic crew. In order to minimize the size of the search team crew, the working duty sections must be minimized, but must still allow adequate sleep to provide the workers with a minimum vigilance level necessary to conduct their search and not miss or fail to recognize an alarm. By reducing the probability for operator error, the overall probability of success in detecting WMD or terrorists on the commercial ship search is maximized.

[107] UNREP will further restrict ships in the mission due to the slower speed at which UNREP is normally conducted (e.g., less than 15 knots), as well as the amount of time required to conduct the replenishment underway (determined by amount of replenishment needed, sea state, weather, etc.).

Sleep loss analysis is used to determine the level of ship-based support necessary to allow the Find/Fix and VBSS teams to conduct their search while meeting the minimum vigilance level. As ship support is minimized, the number of hours each member of the search team must operate continuously (without sleep) increases. As sleep is lost, operator errors will increase due to the drop in vigilance levels. As vigilance levels drop and operator errors increase, the overall probability of detecting the WMD or sleeper-cell terrorists aboard the container ship is reduced. By keeping the military ships closer to the container ship, personnel transfers can be conducted more frequently, thus allowing team members the ability to work in shifts while sleeping and eating aboard the military ship. Amount of sleep, therefore, becomes an important factor in determining the CONOPS for the WMD and SAW mission.

Work and sleep schedules are modeled using the Fatigue Avoidance Scheduling Tool (FAST) to determine the maximum number of hours the Find/Fix team personnel can operate. Results of the WaTSAM analysis are used to determine WMD and SAW mission CONOPS.

The WaTSAM is utilized to determine the manning levels necessary to ensure a minimum probability of detection for searching in the WMD, SAW and SBA missions. WaTSAM results are used to adjust CONOPS within each of the missions to ensure the effects from crew fatigue are accounted for and minimized, in order that the overall mission probability of success is maximized (at least from as many factors as possible).

Assumptions

Manning requirements from the WMD mission search model were used as input for the WaTSAM assumptions (see Appendix H). In particular, a nominal container search team size of nine people was calculated, performing a container search over a 7-day period. SME input concerning container ship searches in the WMD mission indicated the majority of commercial container ships would likely be limited in the amount of berthing available for the MTR search teams. The limited amount of berthing poses a constraint on either the maximum size of the search team or the necessity for providing off-ship support (in order that the search teams may be transferred off board the container ship to sleep). In order to limit the search team size, two watch sections were set as the upper limit in the case where off-ship support is not provided. In the case where off-ship support is provided, a four-section watch rotation was set, where two sections would be onboard the container ship at any time performing the search. These teams, supported by military ships within the vicinity of the container ship, would conduct their search for 24 hours, then be transferred off the container ship to the military ship where they will eat and sleep (i.e., a "recovery" period) for 24 hours. While the first two watch sections are resting off-ship, another two watch sections are continuing the search on the container ship. Every 24 hours the teams are swapped in order to maintain a continuous 24-hour search over 7 or more days.

Subject Matter Experts (SMEs) in the field of human sleep analysis were referred to in order to determine the minimum vigilance level necessary to carry out the WMD and SAW search mission, though results can be applied to the SBA mission as well. The Fatigue Avoidance Scheduling Tool© (FAST)[108] (developed for the Department of Transportation (DoT), the U.S. Army and U.S. Air Force) was used to model fatigue and vigilance levels as a result of sleep loss. Based on comparisons between alcohol-induced impairment and impairment due to fatigue, vigilance levels have been related to blood-alcohol (BAC) level with some degree of confidence.[109] The U.S. Air Force, Army, and DoT have determined an effectiveness level should be maintained above 77.5%,[110] since a lower effectiveness level (due to sleep loss) relates to a BAC higher than .05.[111] BAC of .05 was chosen as the baseline due to its legal definition "Driving While Intoxicated" in most states.[112] (The vigilance effectiveness level must therefore be kept higher than 77.5% to ensure its comparable BAC level is less than .05.)[113] For simplicity, 77.5% was rounded down to 77% for the duration of the modeling.

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108 FAST version 1.0.26U, developed by SAIC and CTI, Inc.

A.M. Williamson, A. Feyer, R.P. Mattick, R. Friswell, and S. Finlay-Brown, "Developing Measures of Fatigue Using an Alcohol Comparison to Validate the Effects of Fatigue on Performance," *Accident Analysis and Prevention*, 33, 200), pp. 313-326.

110 One hundred percent effectiveness refers to zero errors being made during task work.

111 BAC .05 equates to .05 grams of ethanol per 100 milliliters of blood (Oracle ThinkQuest Education Foundation, "BAC and BAL," [http://library.thinkquest.org/23713/effects/bac.html], accessed in May 2006).

112 James B. Jacobs, "The Law and Criminology of Drunk Driving," Crime and Justice: An Annual Review of Research, edited by Norval Morris and Michael Tonry, Vol. 10, Fall 1988, pp. 171-229.

113 A.M. Williamson, A. Feyer, R.P. Mattick, R. Friswell, and S. Finlay-Brown, "Developing Measures of Fatigue Using Alcohol Comparison to Validate the Effects of Fatigue on Performance," Accident Analysis and Prevention, 33, 2001, pp. 313-326.

The CONOPS for the WMD search team was developed and assumed to be the following:

a) The U.S. ship is underway, destined to meet the suspect container ship along its eastward voyage in the Pacific Ocean. Actual location of the container ship was not taken into account, but it was assumed the latency of intelligence would allow the U.S. ship to meet the container ship at a minimum of seven days prior to entering port in the United States.

b) The U.S. ship is on a course that will allow the MTR search team to make its initial transfer onto the container ship at 0600 on day 1.

c) The MTR search team spends day 0, resting; although the sleep schedule is designed to allow the teams to operate at or above the minimum vigilance level (.77), the teams are assumed to be in surge operations and therefore not use to a two-section shift work schedule (i.e., the teams have not had time to accustom themselves to working at night time or under such extreme circumstances). Normal daytime working circadian rhythms still affect the teams' performance, although given time the teams' circadian rhythms will adjust to the new schedule.

d) 30 minutes per 8-hour period has been taken into account for meals and personal hygiene. This is an extreme understatement of the normal amount of time people take to eat, clean, relax, etc.; however, it was chosen to represent the severity of the mission. Analysis of the resultant watch bill will reveal how restricted a real schedule would need to be in order work within the given constraints.

<u>Method</u>

The FAST© program was used to model sleep loss for two sections of "unsupported" watch teams and four sections of "supported" watch teams over a 7-day search. For the unsupported two-section watch teams, a 6-, 8-, and 12-hour duration work/sleep schedule was considered and modeled. The supported four-section watch team utilizes a 6-hour work/sleep rotation. During modeling, when worker effectiveness levels dropped below 77% the watch team work/sleep schedule within the FAST program was altered to allow the team that was "on watch" a break. The effect from this was to allow a temporary reprieve to the “on watch” team, however at the expense of the “off watch” team’s rest. By allowing one team a break in work, the other team therefore would suffer later on, when it was their “on-watch” time. The effects were generally compounding: altering the work/sleep schedule never resulted in a long-term benefit to either of the two watch sections. Therefore, the original work/sleep schedule, without break, was used for analysis. It should be noted this was a nominal way of approaching the problem, and future studies are recommended to determine a more complete effect on watch rotation considering many different options, such as assigning extra workers to enable individual work/break rotation.

Results

The FAST program charts display a generic individual worker effectiveness level over the 7-day period (seen as the squiggly sinusoidal-looking line). The comparison to BAC level is shown to the right of the chart. The dotted line represents the 77% effectiveness level (comparable to .05 BAC). The red triangles to the bottom of the graph represent the drop off and pick of the teams to and from the container ship (thus their start time and end time). The red highlighted section indicates the working hours, while the blue section indicates the sleeping hours (sections without red or blue highlighting is time spent not working, but not sleeping). FAST model results are shown below in Figures 7-61 through 7-68. Results are grouped according to whether or not the search teams are supported by (allowing rotation off-ship) nearby military ships and the number of hours each team conducts their mission working/not working (i.e., 6-, 8-, or 12-hour watches).

Unsupported 6-on/6-off Watch Rotation

Figures 7-57 and 7-58 display the resultant effectiveness levels from the unsupported 6-on/6-off watch bill rotation over seven days (Figure 7-57 represents team A, Figure 7-58 represents team B).

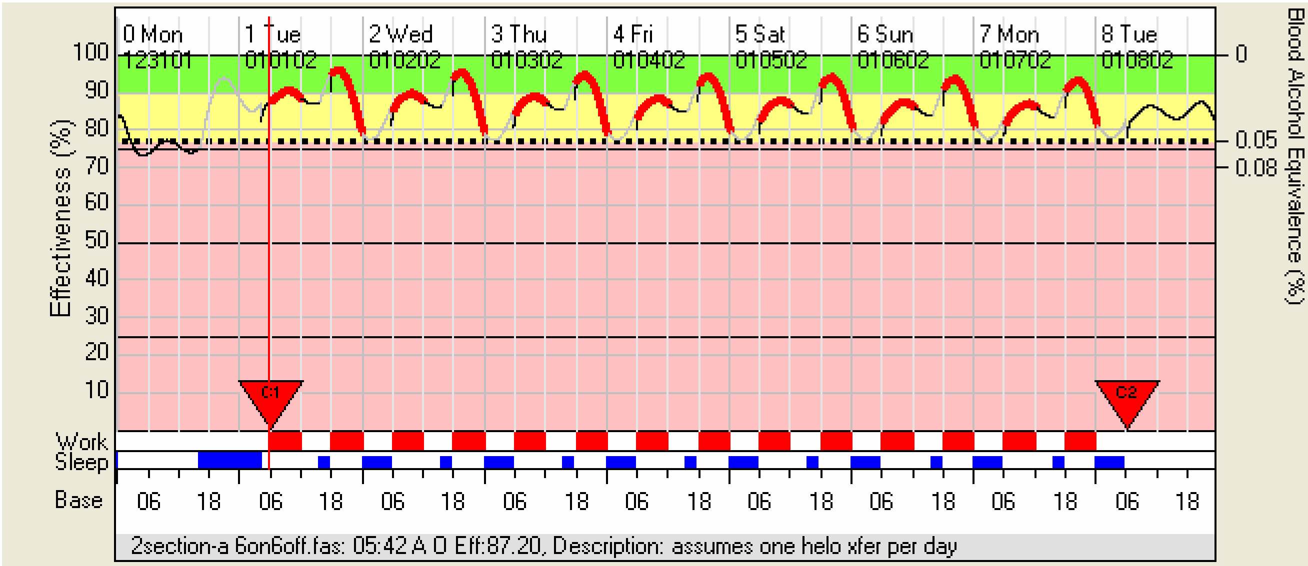

Figure 7-57: Basic 6-hour on/6-hour off section watch-schedule for Team A, Vigilance Level (Effectiveness) and BAC over seven days

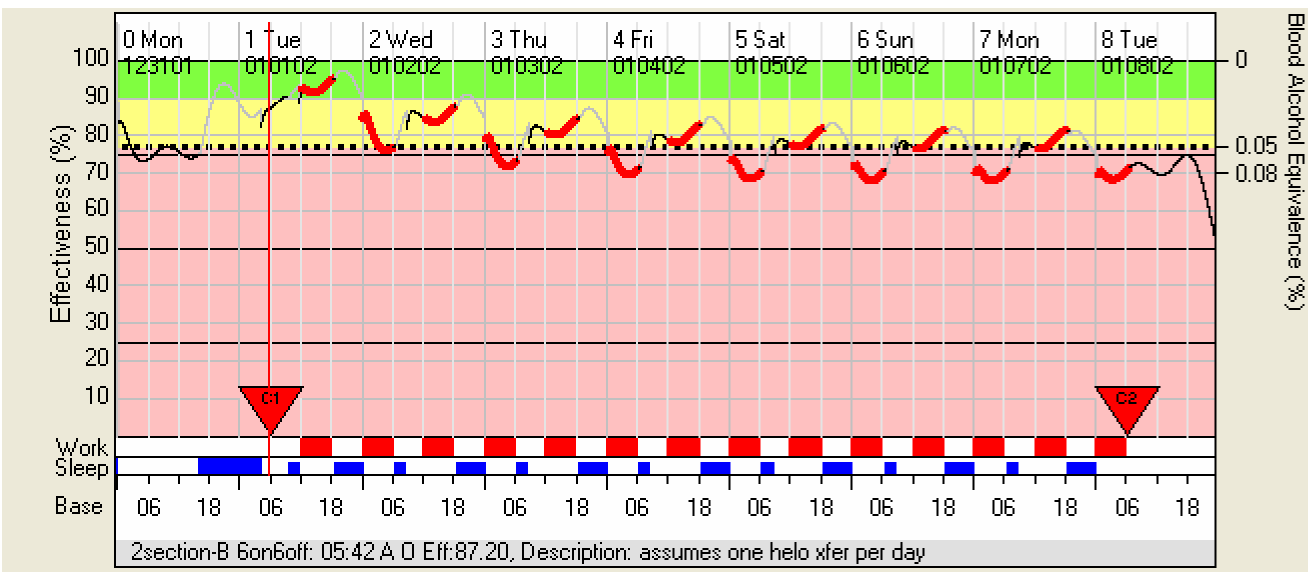

Figure 7-58: Basic 6-hour on/6-hour off section watch-schedule for Team B, Vigilance Level (Effectiveness) and BAC over seven days

Team A, as seen in Figure 7-57, is able to maintain vigilance level above 77% throughout the duration of the seven days. This is due to a match-up between their normal circadian rhythm (being "adjusted" for daytime working hours) and adequate sleep to keep fatigue levels at bay. By the morning of day 2, however, Team B has fallen below the minimum vigilance level by approximately 0314 hours. The schedule does not allow adequate sleep to counteract their normal circadian rhythm—thus Team B continues to have a drop in their vigilance level that is below the 77% requirement.

Unsupported 8-on/8-off Watch Rotation

Figures 7-59 and 7-60 display the resultant effectiveness levels from the unsupported 8-on/8-off watch bill rotation over seven days (Figure 7-59 represents Team A, Figure 7-60 represents Team B).

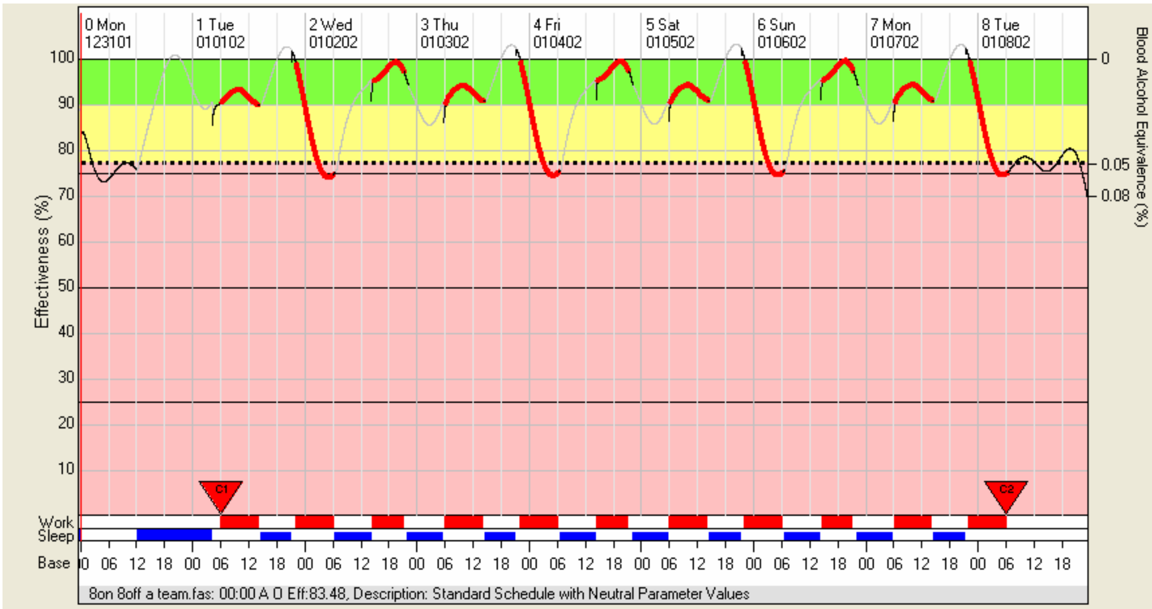

Figure 7-59: Basic 8-hour on/8-hour off section watch-schedule for Team A, Vigilance Level (Effectiveness) and BAC over seven days

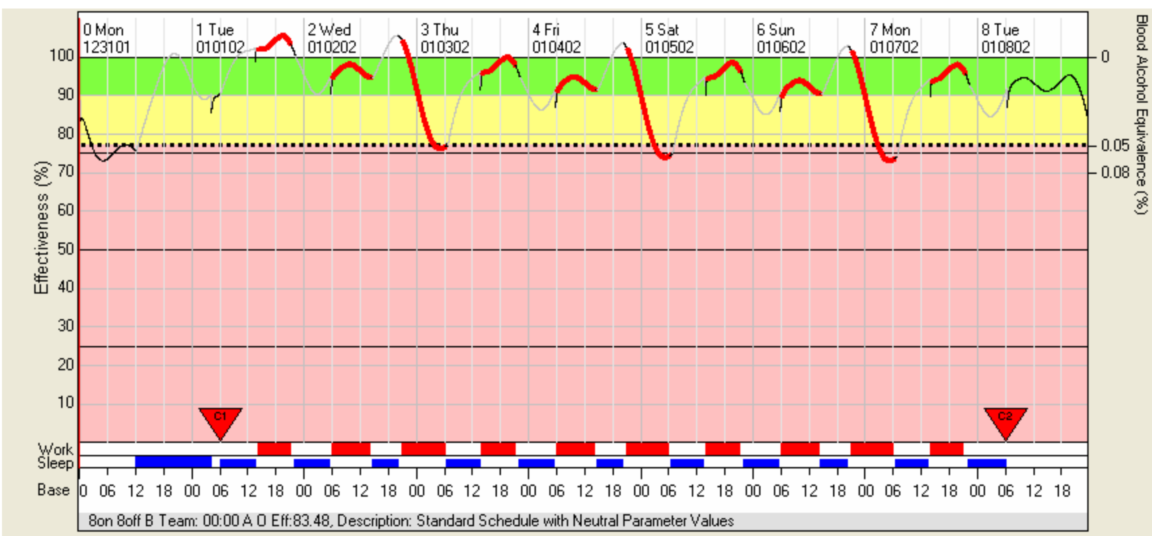

Figure 7-60: Basic 8-hour on/8-hour off section watch-schedule for Team B, Vigilance Level (Effectiveness) and BAC over seven days

Both Teams A and B experience drops in their effectiveness level below 77% over the duration of their watches. Though the 8-on/8-off watch rotation allows more sleep for the workers than the 6-on/6-off watch rotation, the result of splitting a 24-hour period into three 8-hour "watches" results in a rotating sleep schedule that does not align with human circadian rhythms. The workers thus find themselves working during hours they would normally be sleeping, resulting in a natural drop in effectiveness level during the times when they would otherwise be sleeping. Because the workers do not maintain a consistent schedule from day to day (every other day a worker finds himself sleeping the opposite hours he had on the previous day), they are unable to recover from the mismatch of their circadian rhythm with their sleep routine. Though not included in the modeling results for Figures 7-59 and 7-60, this would result in the degradation of the quality of the worker's sleep—ultimately resulting in a much more rapid drop in effectiveness level below the 77% requirement.

Unsupported 12-on/12-off Watch Rotation

Figures 7-61 and 7-62 display the resultant effectiveness levels from the unsupported 12-on/12-off watch bill rotation over seven days (Figure 7-61 represents Team A, Figure 7-62 represents Team B).

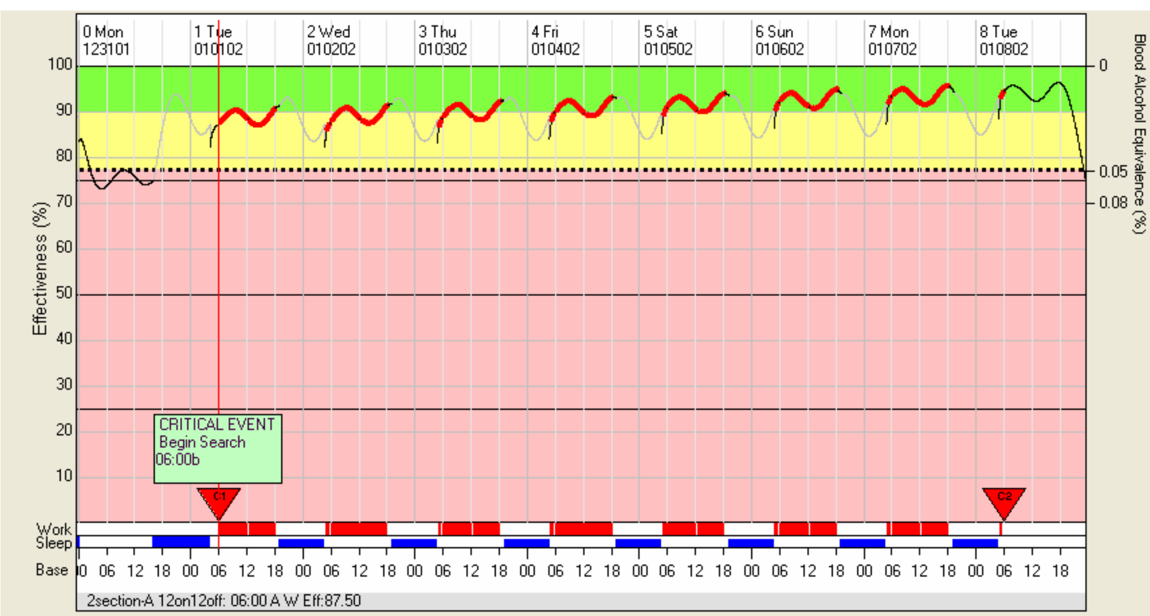

Figure 7-61: Basic 12-hour on/12-hour off section watch-schedule for Team B, Vigilance Level (Effectiveness) and BAC over seven days

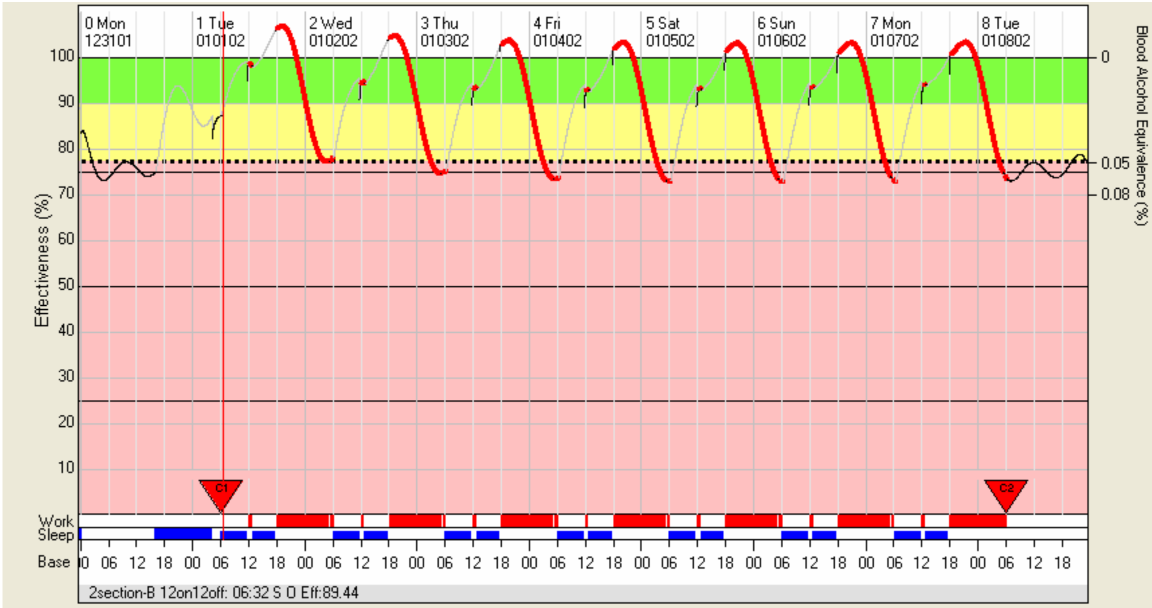

Figure 7-62: Basic 12-hour on/12-hour off section watch-schedule for Team B, Vigilance Level (Effectiveness) and BAC over seven days

Like the 8-hour watch rotation schedule (seen in Figures 7-59 and 7-60), the 12-hour watch rotation schedule enables teams to get a good deal of sleep when off watch. This contributes to a higher effectiveness level at the beginning of each watch period, per team. The effects from mismatch of circadian rhythm and sleep schedule can be corrected in the 12-on/12-off watch rotation because a consistent work/sleep routine can be maintained for the duration of the mission (i.e., workers sleep the same hours each day). Though not shown in the model, this would contribute to more "effective" sleep, resulting in a more rested worker and thus higher starting effectiveness levels. The effects of a "meshed" circadian rhythm/sleep schedule are clearly seen in Figure 7-61, where watch Team A is able to work during hours they are naturally awake and alert. Watch Team B also benefits from a routine sleep schedule; however, because they are forced to work the "night" shift, the B workers find themselves having to adapt to a different routine (seen in Figure 7-62). Though not seen in the FAST model, eventually the watch Team B workers' circadian rhythm would adapt to their work/sleep routine, likely enabling higher continuous effectiveness levels. Based on the WMD and SAW mission CONOPS, the search conducted by the watch teams is not expected to last longer than 20 days; therefore, the period of time it would take the workers to adapt their circadian rhythm with their sleep routine would still affect the first few days' worth of the mission (assuming the teams have not already been preconditioned to work in this environment before starting the mission). Thus, even with the routine sleep schedule available in the 6- or 12-hour watches, the workers' effectiveness levels is still degraded for a percentage of the mission.

The effects from working hours as long as 12 continuous hours were not input into the WaTSAM FAST models.[114] Longer duration work periods have a similar effect upon human vigilance levels as fatigue due to sleep loss.[115] Thus the 12-hour work period, while providing plenty of time for sleep and allowing a routine work/sleep schedule, will likely result in a drop in effectiveness level over time as workers' arousal levels declines with the continued monotonous searching required in the mission. The 12-hour watch rotation is therefore not preferable because of the length of the "on watch" hours.

Supported 6-on/6-off

One of the advantages of providing a military ship in the vicinity of the container ship in the WMD/SAW mission is the ability to transfer on and off multiple sections of search teams. With more workers available to swap on and off watch, more frequent breaks become possible for the working watch sections while maintaining a continuous search. The supported 6-on/6-off watch rotation includes four groups of workers, two of which will be onboard the container ship continuously for a 24-hour period. Note that other watch rotation schedules (such as having three sections of watch teams working 8-hours on and 16-hours off) are also made possible by providing a military ship to support the container ship search. It is also possible to transfer watch teams on and off a few container ships using medium to long-range helicopters, such as the V-22 Osprey. The difficulty lies mainly in the actual transfer of personnel on and off of the container ship: SMEs indicated most container ships do not have flight decks and are not familiar with a sort of multiple-person transfer that would need to occur without a flight deck. Additionally, the commercial ship design may not support personnel transfer by

[114] Other than the 30 minutes break per 8-hour period, no other work-break is considered during a work shift.

[115] C. Wickens et al., *An Introduction to Human Factors Engineering*, 2nd Edition, Pearson/Prentice Hall, 2004.

helicopter at all, since top-side deck space may not be free of fouling elements such as masts, antennae, lines, etc.

Regardless of the actual method of transfer, a supported 6-on/6-off watch team rotation is shown below in Figures 7-63 and 7-64. After 24 hours of searching on the container ship, the two "working" sections are transferred off, and the two "fresh" sections are transferred on to continue the search (the watch team swap out is depicted in Figures 7-67 and 7-68 by the red triangles).

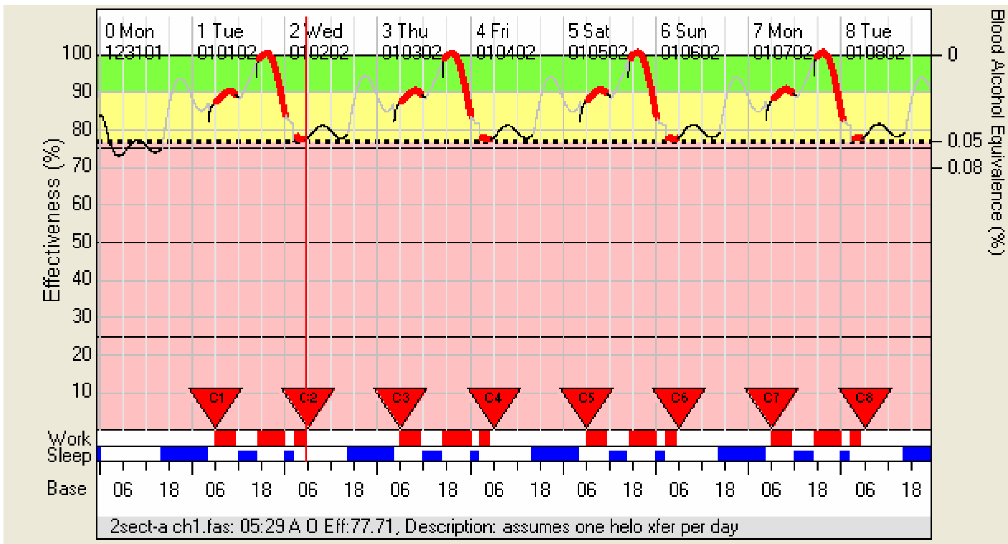

Figure 7-63: 6-hour on/6-hour off (with breaks) section watch-schedule for Team A, Vigilance Level (Effectiveness) and BAC over seven days

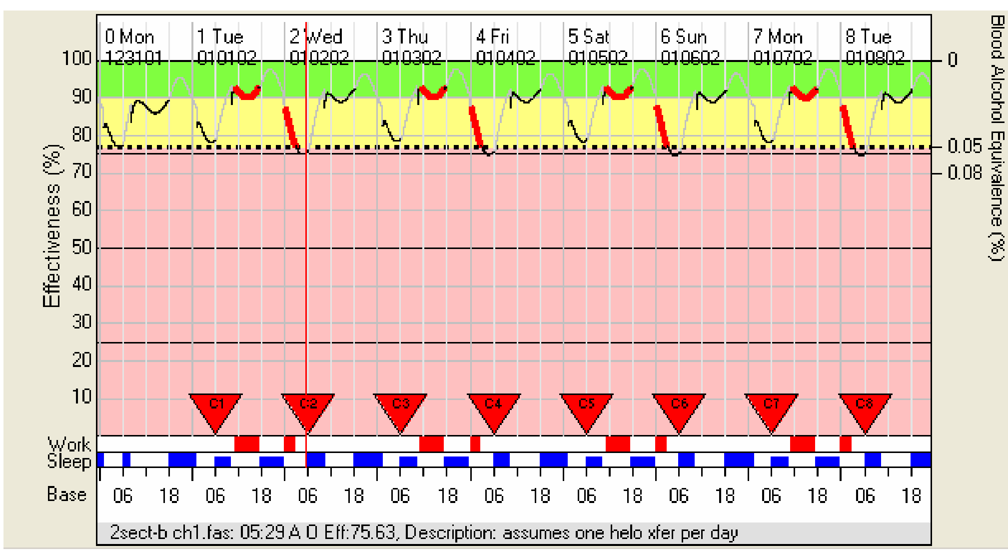

Figure 7-64: 6-hour on/6-hour off (with breaks) section watch-schedule for Team B, Vigilance Level (Effectiveness) and BAC over seven days

The rotation off-ship for a 24-hour period allows the A and B watch teams a "sleep recovery" period onboard the military support ship. This allows them to reduce their accumulated sleep debt from continuous operations on the container ship. Since their sleep debt is cleared every 24 hours, all teams are able to conduct the search mission at effectiveness levels > 77% for the duration of the container ship's voyage. An additional bonus from the off-ship crew rotation is a schedule that has no more than five hours of work for any team at any point (work breaks are possible due to the additional workers available from the support ships). This may serve to ensure that fatigue levels accumulated from actual work are maintained within acceptable limits. Thus the watch teams, when supported, are able to maintain continuous operations without a drop in efficiency below the minimum required value; work breaks are enabled, as well as shorter work shifts; thus, overall watch team readiness is maintained rather than placed into a degrading situation over time.

Conclusions

Figures 7-57 through 7-62 show that unsupported two-section watch teams will fall below the minimum require effectiveness level at some point during their working periods over the duration of the mission. Drops in effectiveness increase the probability of "accidents" occurring: for example, 60%of class A aircraft mishaps in the Air Force are attributed to fatigue (Palmer et al., 1996). Increasing the number of workers to allow for work breaks or shorter work shifts is limited by the capacity for a container ship to berth the workers in their off-shift hours. Introducing a military support ship, to provide berthing for the workers, solves the dilemma; however, then requires constant support from the ship. If drops in effectiveness (which will reduce the overall probability of detection and therefore probability of success for the mission) are allowable, the trade-off of not providing a support ship will likely save money due to the fuel requirements for the support ship alone. However, to maximize the mission probability of success, shorter work shifts and therefore more workers are required, as shown by comparing the drops in effectiveness in Figures 7-63 and 7-64 to those in Figures 7-57 though 7-62.

In addition to allowing the teams adequate sleep and working hours to maintain generally higher vigilance levels than if unsupported, rotating the crew off the container ship every 24 hours partially solves the dilemma of carrying food and hygiene by each of the teams. Since a support ship would be within 24 hours of the container ship, each team need only bring enough food for 24 hours. Additionally, assistance is more readily available should a piece of search equipment malfunction or break and need to be fixed. Allowing the crews to sleep on a support ship (vice the container ship) allows much more comfortable rest since berthing can be assigned (for example, use of an 18-man berthing compartment aboard a DDG would be available).

The negative side of using a support ship during the container ship search mission is that it ties a support ship to the search teams, keeping it always within 24 hours of the container ship's navigation track. Since one of the entering assumptions to the WMD and SAW mission was that no more than 20 container ships would be implicated, if the navigation tracks of each of the 20 container ships varies more than 24 hours apart, up to 20 support ships would be necessary for all of the search teams (one support ship per container ship). Though this mission is by nature a surge operation, the cost to operate up to 20 support ships must be balanced against the possibility of allowing lower effectiveness levels in the search teams, subsequently allowing an increased probability of false detection (Type I error) or failure to detect true signal (Type II error).

7.4.5.3 Small Boat Availability and Reliability Model (SARM)

The SBA mission CONOPS consists of military units patrolling a commercial U.S. port (the port of San Francisco) to protect vital points of infrastructure (such as the Golden Gate bridge) and commercial high-value units (such as water taxis and transiting large-tonnage merchant ships) from terrorist surface-ship-based attack. The mission is assumed to last for up to 30 days, though further analysis will be useful to determine the impacts of extended SBA mission duration. Time and probability of success objective values were set by stakeholders, as described in Section 5.2.2.5 Sustain Non-Functional Requirements. An overall probability of success value of 99.99% was set for the Sustain subfunctions; this is translated as a stakeholder need for a system with Sustain functions that work properly *virtually every time they are used* (Section 5.2.2.5 provides a detailed discussion of the reasoning behind stakeholder needs for a Ps set at this value). The Sustain subfunctions that apply to systems used by U.S. forces in the SBA mission, such as small boats or helicopters, must therefore be capable of accomplishing the flowed-down requirement from the original stakeholder needs.

Sustain function flow-down applies to the PBS and Finish SBA-mission architecture options resulting from Orthogonal Array Experiment and BUCE. Orthogonal Array Experiment selections resulted in PBS architecture option 3 and Finish architecture option 4. BUCE selections resulted in PBS architecture option 1 and Finish option 2. Each architecture option is composed of different types and numbers of platforms required to conduct the SBA mission within the Ps requirements. Analysis of CONOPS for each architecture option resulted in a number of hours per day that each platform will be required to perform its mission to meet the stakeholder-derived functional requirements for probability of success. The various platforms composing each of the selected architecture options and the respective number of hours they will operate during the course of the 30-day SBA mission is shown in Table 7-27.

PBS Option 1 (Small Escort)	**Quantity**	**Hours of Operation/Day**	**Total Hours Operated**
Small Boats	124	8	240
Teams	120	8	240
PBS Option 3 (Mixed Escort)	**Quantity**	**Hours of Operation/Day**	**Total Hours Operated**
Small Boats	72	8	240
Ships	44	8	240
Teams	120	8	240
FIN Option 2 (Helo)	**Quantity**	**Hours of Operation/Day**	**Total Hours Operated**
Helicopters	26	7	210
FIN Option 4 (Helo + USV)	**Quantity**	**Hours of Operation/Day**	**Total Hours Operated**
Helicopters	26	7	210
USV	92	8	240

Table 7-27: Unit Quantities and Operational Hours for the SBA Mission

Interviews with stakeholders and SMEs identify ships used in the SBA mission (such as U.S. Navy PC-class ships and USCG WPB-110 class ships) as able to meet the Sustain functional requirements (see Appendix B) for the following reasons: Vessels of this size are generally considered to include redundant systems within their design, such that they are highly reliable as well as containing crew capable of performing repairs. Thus, depot-level maintenance is not generally required to repair ship systems (except for major system failures or scheduled yard periods). Ship operational availability is assumed to be such that they will always be operationally available during the 30-day SBA mission.

Small boats are not designed with multiple redundant systems and therefore do not share the high level of operational availability and reliabilities ships enjoy. Additionally, small boats are generally unable to conduct maintenance while operating, therefore requiring a portion of the 30-day SBA mission to conduct maintenance. The availability and reliability assumptions afforded to ships therefore do not apply to small boats. The Small Boat Availability and Reliability Model (SARM) models small boat availability and reliability to determine the total number of small boats required to meet the functional requirements composing the Sustain function. For model simplification the Naval Special Warfare (NSW) 11-meter Rigid Hulled Inflatable Boat (RHIB) is used to represent the plethora of small boats available for use within the SBA mission.

RHIB Reliability Model

Reliability and operational availability data for the NSW 11-m RHIB is used to represent the community of small boats available for use in the SBA mission. NSW 11-m RHIB data is listed in Table 7-28.

Reliability	0.91
Availability	0.99
Range (NM)	200
Cruise Speed (knots)	33

Table 7-28: NSW 11-m RHIB Operational Data[116]

Dividing the cruise speed by the range at cruise speed yields an operational cruise time of approximately six hours. This is assumed to be the period over which reliability for the NSW 11-m RHIB is measured. Reliability is defined as: $R(t) = \exp(-\lambda \cdot t)$, where t is time in hours, λ is the number of failures per hour. Setting $t = 6$ hours and $R(6) = .91$ for the 11-m RHIB, then solving for λ, yields .0155 failures per operational hour. The reciprocal of this $(1/ \lambda) = 64.3$ operating hours until failure (approximately). This value is input into the Extend RHIB Reliability Model as the expected amount of time a RHIB operates until failure. The SBA mission is assumed to take place on short notice, thus relocating small boats from a variety of different locations for use in the port of

[116] Federation of American Scientists, "Rigid-Hull Inflatable Boat," [http://www.fas.org/man/dod-101/sys/ship/rhib.htm], 10 February 2000, accessed in March 2006.

San Francisco for the mission. The operational lives[117] of each of the RHIBs is unknown, therefore some RHIBs may be closer to "breaking" than others. A uniform distribution of RHIB operational "lives" is used because this represents a generally random distribution of lives, with no specific mean about which the RHIBs lives would fall within a standard deviation. The "failure point" of the RHIBs will therefore occur, on average, any time within the 64.3-hour period.

Once "broken" the RHIB is removed from the pool of RHIBs in use and sent to repair facilities (Figure 7-65). No limit is placed on the number of RHIBs the repair facility can work on simultaneously, as in reality if one repair facility was backlogged, enough civilian small boat repair facilities exist within the greater San Francisco area that, if needed, they could be utilized. A triangular distribution is used to determine the amount of time the repair facility takes to repair and return the RHIB to operation. Within the triangular distribution, a minimum value of 1 hour, maximum value of 48 hours, and most likely value of 6 hours is used. These times include the time it would take to transport the RHIB to the repair facility, fix the broken part it, and return the RHIB to a waiting pool.

[117] Operational life of a RHIB refers to the age of the RHIBs components in terms of requiring major service and/or replacement.

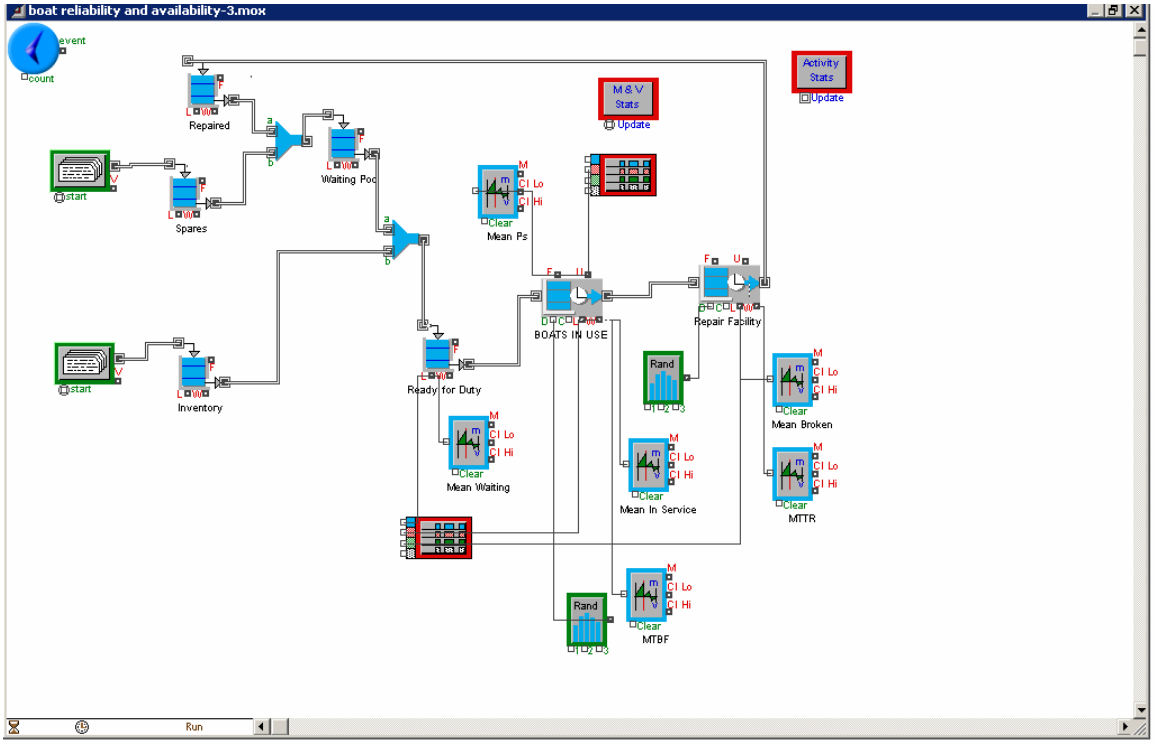

Figure 7-65: EXTEND™ RHIB Reliability Model

As shown in Table 7-27, 72 RHIBs are required to meet the PBS P_s requirement. Based on the availability and reliability shown in Table 7-28, each of the 72 RHIBs is not expected to remain continuously operational for the duration of the SBA mission (30 days, 14 hours of operation per day, or 420 operational hours total). As RHIBs "break" they are removed from service and transported to the repair facility. To meet the operational requirement of 72 RHIBs in use continuously, a "spare" RHIB (held in a "waiting" pool) is then put into service to resume operation where the broken RHIB stopped. For the purposes of modeling, transportation RHIBs to and from the designated area of operations within the port, as well as crew turnover, is considered instantaneous. The number of spare RHIBs is then varied to determine what mean minimum value allows a 99.99% probability of success in meeting the operational requirement (where the operational requirement is defined by the PBS functional analysis as maintaining 72 RHIBs in service at all times). The model is run for 100 trials with the mean results displayed in Figure 7-66.

A second model, the Poisson RHIB Reliability Model, using the Poisson distribution is calculated. This model yields a mathematical expected probability of success, where success is defined as completing a 14-hour period with at least k out of n RHIBs still operating. K is set at the operational requirement, 72. N is defined as the total force size, or k + the number of spare RHIBs provided. The number of spare RHIBs is varied to show affect on P_s. Results are compiled in Figure 7-66.

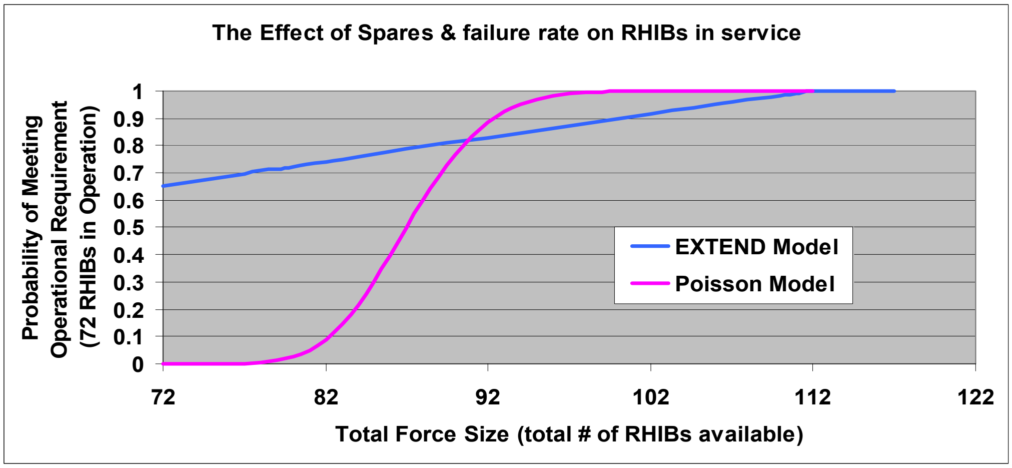

Figure 7-66: The Effect of spare RHIBs (in waiting) on meeting the requirement to maintain 72 RHIBs in continuous operation

For the Extend RHIB Reliability Model, Figure 7-66 shows a positive linear increase in the mean probability of meeting the 72-RHIB operational requirement as the number of spare RHIBs is increased (until $P_s = 1$). Treating the 72-RHIB operational requirement as a constant "customer" demand, the number of RHIBs required to meet the "demand" can be considered the stock level. For the Extend RHIB Reliability Model, the demand is met when the stock level (i.e., number of spare RHIBs) is 40 or greater. Thus to maintain 72 RHIBs in continuous operation for the duration of SBA mission, the Extend model yields a total force size of 112 or greater to ensure that the P_s requirement for both Sustain and PBS functions is met. The Poisson RHIB Reliability Model meets the Ps requirement at a stock level of 104 total RHIBs (32 spare RHIBs). The Poisson and Extend models agree at total RHIB inventory = 91 (corresponding to $P_{s\,=}$ .83) and 112 (corresponding to $P_{s\,=}$ .9999). The difference in necessary total force inventories yielded by the two models stems primarily from the difference in RHIB operational-life assumption made by the distributions utilized within the models: Poisson, being a "memory-less" distribution, implicitly fails to account for different points a RHIB may be in its service life—therefore causing the time of failure for all RHIBs to occur about a mean (the expected failure time for RHIBs). The Extend model, on the other hand, accounts for differences in service life and so does not result in a majority of RHIBs failing at approximately the same time. The Extend model therefore may reflect real-life situations more closely and can be considered the more conservative estimate for total force inventory required between the two models. For this reason, the Extend model results were inputted into the architecture cost vs. effectiveness for PBS options 1 and 3.

RHIB Availability Model

The RHIB Availability Model is used to determine the effects of operational availability on the total force size. Based on PBS assumptions (Table 7-27), each day a RHIB is required to be operational for 14 hours to conduct the SBA mission. Using 72 RHIBs as the required number to be in operation during a 14-hour work day, a binomial distribution is used to determine the probability of success of providing the required number of RHIBs, given a variable number of spares. Two operational availability values were input into the model in order to reflect total RHIB inventory sensitivity (.99 is the stated availability of the NSW 11-m RHIB, .90 is used to determine sensitivity).

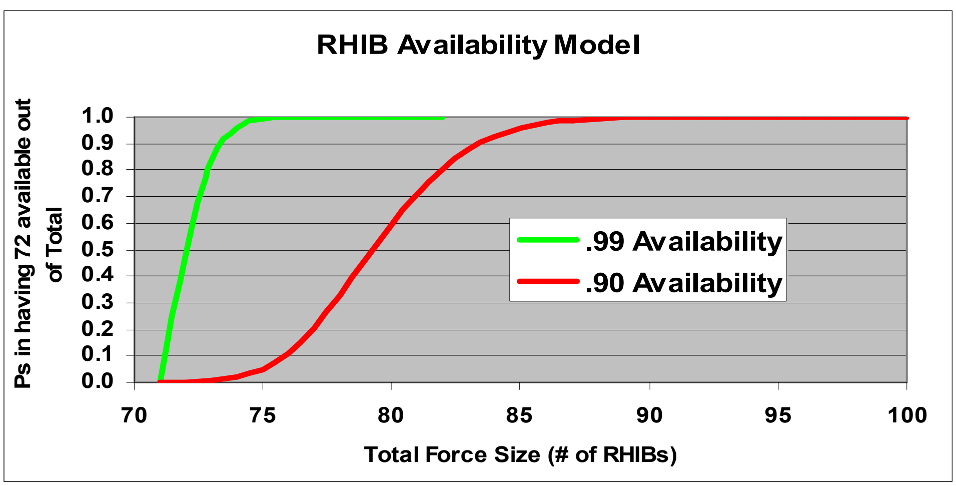

Figure 7-67: Availability-based model for determining total force size necessary to maintain 72 RHIBs in operation at any given time

As shown in Figure 7-67, for RHIB operational availability = .99, the probability of success requirement (.9999) is met when 6 spare RHIBs are provided, for a total force size of 78 RHIBs. When the RHIB operational availability is decreased to .9, the number of RHIBs required to meet the P_s requirement is increased to 22 (for a total force size of

94). Thus, as RHIB operational availability is decreased the number of spares required to meet the probability of success requirement increases. The RHIB Reliability Model places a requirement of 40 spare RHIBs (for a total RHIB force size of 112) in order to meet the P_s requirement of .9999. By providing 40 spare RHIBs, both Availability and Reliability requirements for spares is met. If the total force size is set at 112 RHIBs (as required by the Extend RHIB Reliability Model), the RHIB Availability Model allows for RHIBs utilized in the mission with operational availabilities of .74 or greater (equivalent to spending approximately 26% or less time not in service due to maintenance/supply issues).

7.4.5.4 Helicopter Availability and Reliability Model (HARM)

Helicopters contain multiple redundant systems for many subsystems, but in general require more maintenance than ships. Operational availability is lower for helicopters than ships due to rigorous maintenance and inspection requirements placed upon aircraft. The HARM models helicopter availability and reliability to determine the total number of helicopters required to meet the flowed-down functional requirements composing the Sustain function. For model simplification the Sikorsky SH-60B Seahawk is used to represent the plethora of helicopters available for use within the SBA mission.

Assumptions

Reliability and operational availability data for the SH-60B is used to represent the community of helicopters available for use in the SBA mission. Five-year averaged data obtained from NAVAIR is displayed in Table 7-29.

t (hours) =		7.0
L (lambda, failures per hour)		0.0009
R(t) =		0.9935
Operating Hours Until Failure		1077.0242
Full Mission Capable		36.39%
Mission Capable		25.48%
Non-Mission Capable	Maintenance	28.45%
	Supply	9.68%
Combined Non-Mission Capable		38.14%
Total		0.00%
Operational Availability (%)		61.86%

Table 7-29: NAVAIR 5-Year Average Data for SH-60B

SH-60B overall vehicle failure rate (λ) is the number of overall system failures per time period that result in a change of status from Mission Capable (MC) to Non-Mission Capable (NMC). Reliability is defined as: $R(t) = \exp(-\lambda \cdot t)$, where t is time in hours, λ is the number of failures per hour. $1 - R(7) = .0065$, the probability an SH-60B will "fail" after a 7-hour flight period. This value is input into a binary decision gate within the HARM model. SH-60Bs enter "service" for a 7-hour period. At the conclusion of the 7-hours they are passed through the binary decision gate, with a .0065 probability of passing into a NMC status due to a system failure. The NMC helicopters are transported to a centralized repair facility. The repair facility uses a triangular distribution to determine amount of time to return the helicopter to MC status. The triangular distribution is set at a minimum value of 1 hour, maximum value of 96 hours, and most likely value of 12 hours. These represent the estimated amount of time an SH-60B will take to be repaired, including administrative and supply delay time. Upon repair, the helicopter is transferred into a MC pool, awaiting return to flight.

Method

SH-60Bs falling into the .9935 probability in the binary decision gate pass into a second binary decision gate to determine if daily maintenance is required (Figure 7-68). The operational availability (Table 7-33) is input into the second binary decision to determine whether the SH-60B requires daily maintenance or not. The SH-60B is passed to a "no maintenance required" pool with a .6186 probability, or to a "maintenance required" pool with a .3182 (or 1-.6186) probability. SH-60Bs not requiring daily maintenance are passed into a MC pool awaiting flight. SH-60Bs in the "maintenance required" pool are passed to a centralized maintenance facility. The maintenance facility utilizes a real, uniform distribution to determine time required to complete maintenance. The real, uniform distribution is used to simulate a range of possible events that could happen with an equal likelihood (such as administrative or supply delays, backlogged work, variations in available maintenance personnel, variations in time required for different maintenance checks, etc.). The real, uniform distribution is given a minimum value of 1 hour, maximum value of 6 hours based on SME estimation. Upon completion of maintenance the helicopter is passed to the MC pool awaiting flight.

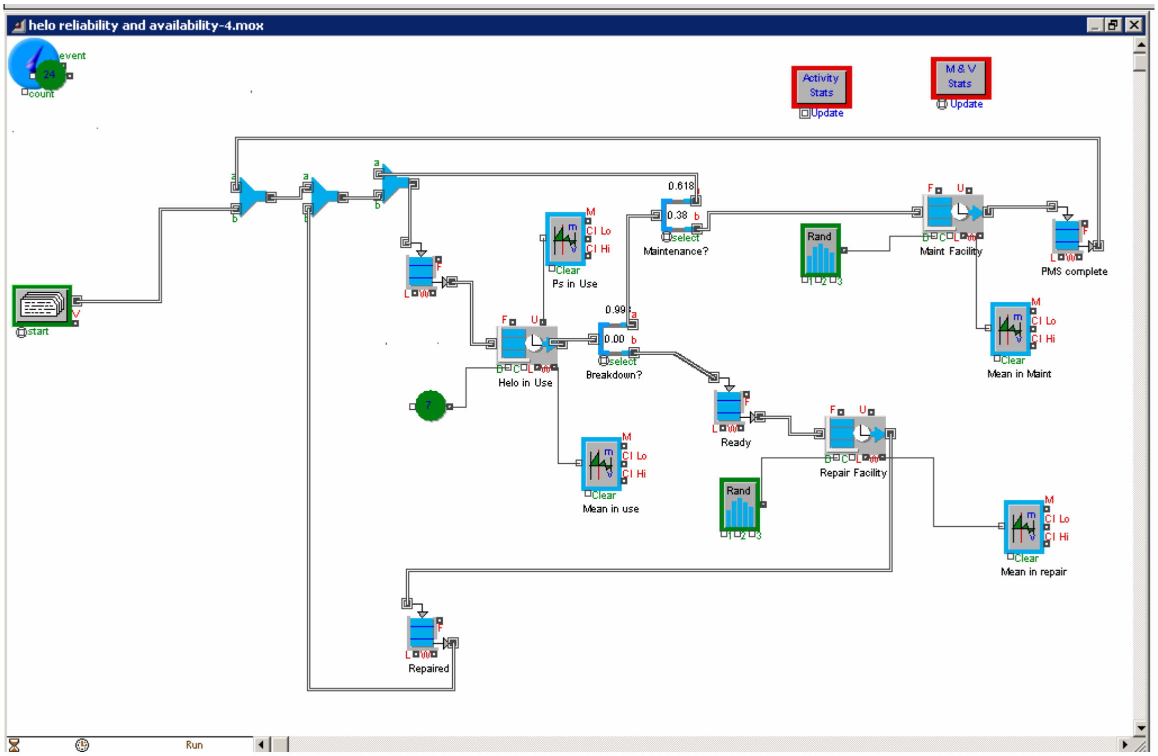

Figure 7-68: EXTEND™ Helicopter Availability and Reliability Model

Finish function helicopter operational requirements from Table 7-31 are used as input for the number of helicopters in starting inventory (26 SH-60Bs total). Based on PBS requirements (see Appendix E), each mission day 14 hours of continuous air coverage are required. SH-60Bs have an endurance of approximately 3.5 hours,[118] therefore to ensure continuous air coverage two SH-60Bs will be utilized in shifts of 3.5 hours (at a time). This results in 7 hours of flight per SH-60B per day, or 210 flight hours over the 30-day mission. Two hundred ten flight hours is input into the HARM model as the total continuous simulation time a model trial will run for. One hundred trials are run for the HARM model; inventory of SH-60Bs are varied to observe the probability of maintaining 26 helicopters in continuous operation (the operational requirement). Results are displayed in Figures 7-73 and 7-74.

[118] GlobalSecurity.Org, "SH-60B," [http://www.globalsecurity.org/military/systems/aircraft/sh-60b-specs.htm], 29 March 2006, accessed in April 2006; and Federation of American Scientists, "SH-60 LAMPS MK III Seahawk," [http://www.fas.org/man/dod-101/sys/ac/sh-60.htm], 27 December 1999, accessed in April 2006.

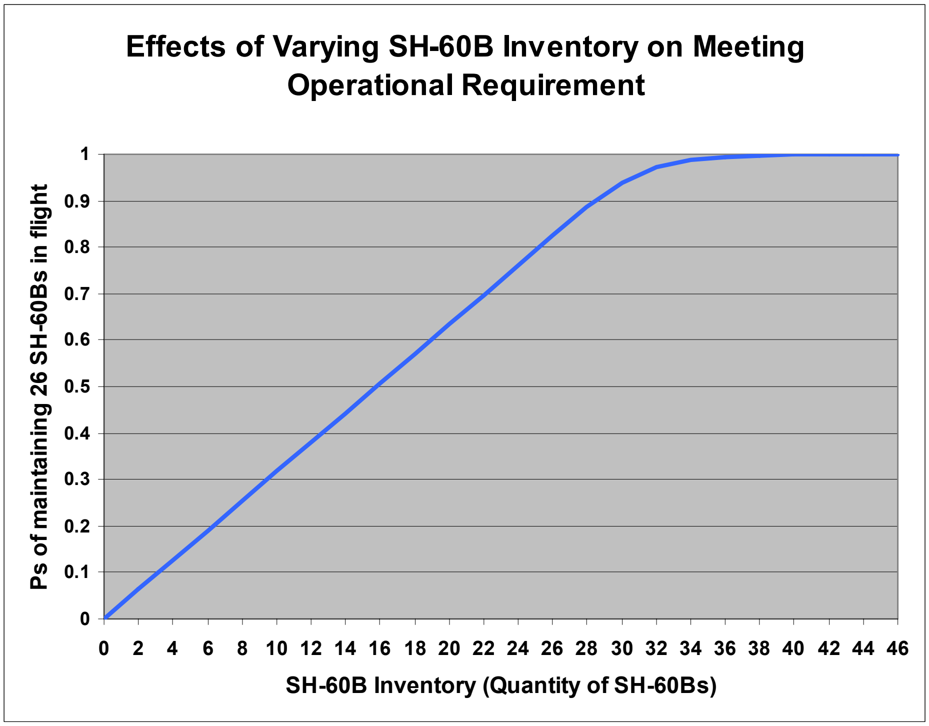

Figure 7-69: Mean Probability of Success in meeting the operational requirement (26 SH-60Bs operational during a 7-hour flight day)

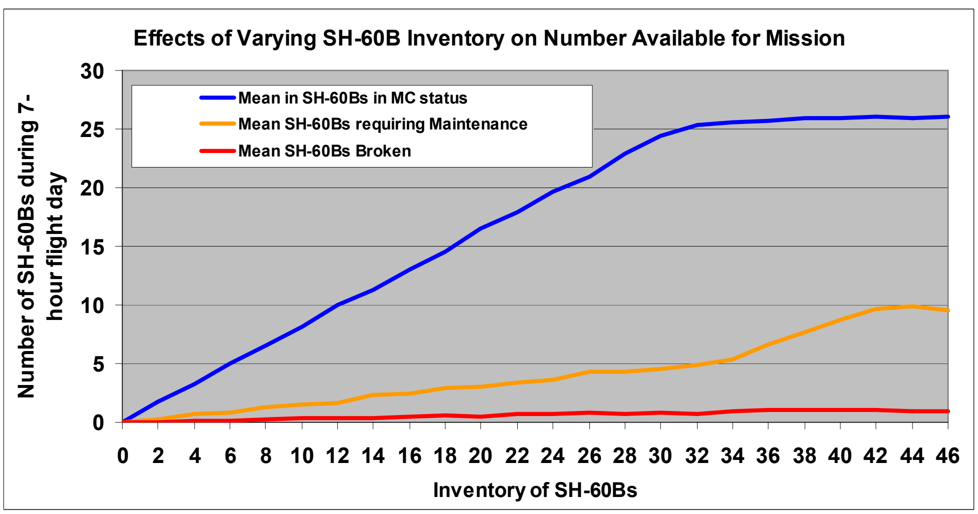

Figure 7-70: Number of SH-60Bs in MC status, requiring Maintenance, and requiring Repair

Results

For an SH-60B inventory of 0 to approximately 34 there is a positive linear increase in the mean Probability of meeting the operational requirement (Figure 7-69). The positive linear increase is also seen in Figure 7-70, for mean number of SH-60Bs in MC status. An "elbow" appears in the rate of increase of Ps (Figure 7-69) and mean number of SH-60Bs in MC status (Figure 7-70) when the total inventory size is approximately 34, and levels out thereafter. From the PBS requirements (Table 7-31), the Sustain requirement (.9999) is met at a total SH-60B inventory of approximately 43. At this point (43 SH-60Bs in inventory), both the PBS operational requirement and the Sustain operational requirement are met or exceeded. Therefore, 43 SH-60Bs are required to meet both operational requirements. However, the "elbow" at inventory level of 34 SH-60Bs indicates a decreasing payoff in meeting both requirements thereafter. An inventory of 34 SH-60Bs provides .9881 probability of success in meeting the Sustain functional requirement. The payoff for the additional probability of success capability is .0013 P_s increase per SH-60B, after 34 are placed in the total SH-60B inventory.

As the number of SH-60Bs is increased the number requiring maintenance or repair after each 7-hour flight day increases according to an approximately positive linear slope (Figure 7-70, orange and red lines). This is due to the static value used for operational availability and reliability within the HARM model. In reality some SH-60Bs may be maintained in a NMC status for cannibalization purposes (i.e., "hangar queens"). This, however, is not reflected in the HARM model. The variability in the slope for maintenance and repairs (Figure 7-70) occur for unknown reasons, possibly due to failures in the HARM model to account for realistic conditions. Another possibility may be the distributions used to represent the maintenance and repair times (triangular for the repair time; real, uniform for the maintenance time) would better reflect reality if modified. Exploration of these details is left for future study.

7.5 SYSTEM EFFECTIVENESS ANALYSIS AND RESULTS

The performance of each architecture previously defined is evaluated across each of the three missions. The results of the architectures' performance are then compared in order to evaluate the relative merit of the different architectures.

For each architecture 500 simulation runs for the WMD and the SAW missions, and 2,000 simulation runs for the SBA mission Figure 7-75 displays the average performance of each architecture in the MTR missions.

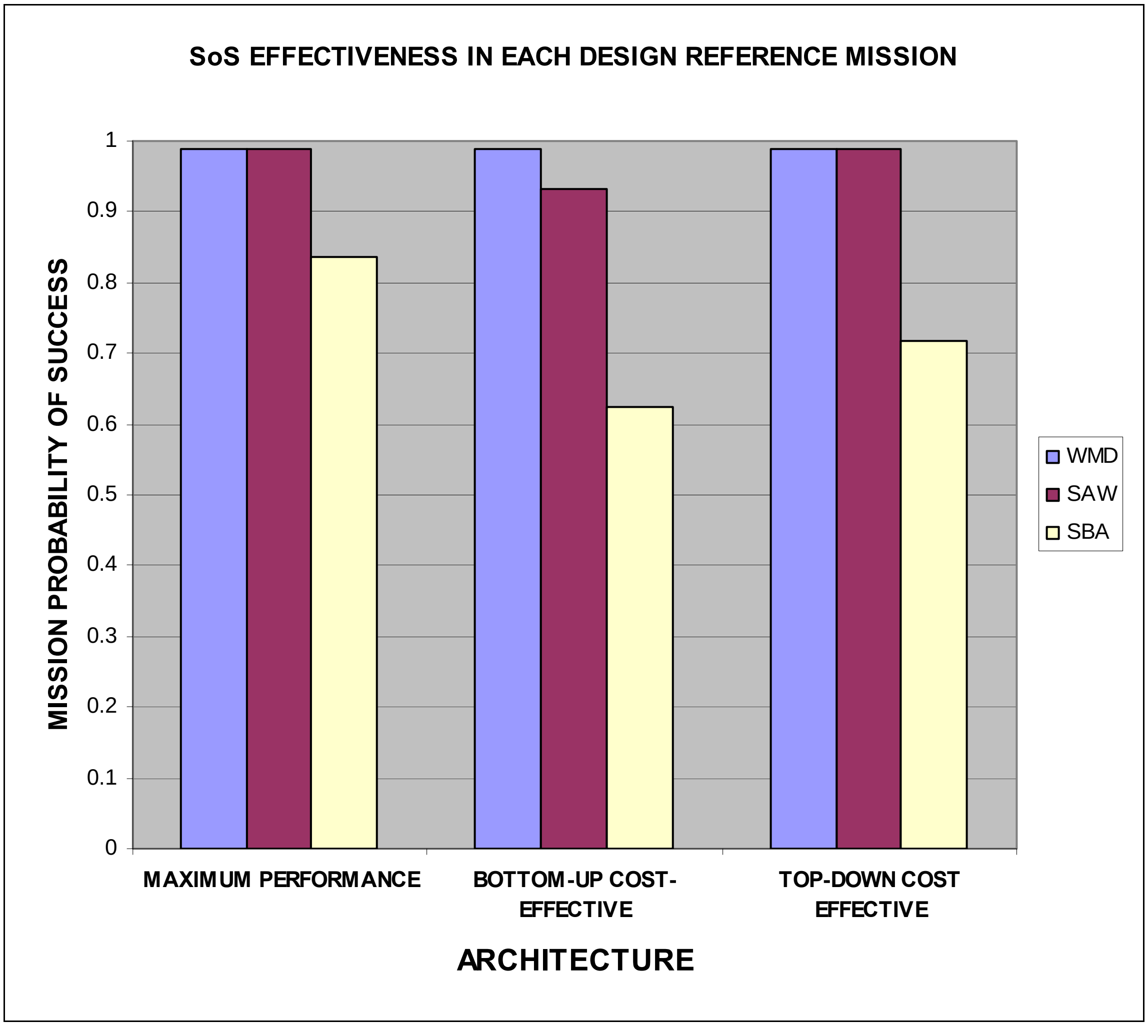

Figure 7-71: Architecture Effectiveness in Each DRM

As shown by Figure 7-71, each of the three architectures has virtually identical performance with respect to the WMD mission. Each uses similar system concepts without any significant difference noted over the course of 500 simulation runs. However, differences in the effectiveness of the different architectures exist with respect to the SAW and SBA missions.

The Bottom-Up Cost-Effective architecture and the other two architectures are somewhat close in performance in the SAW mission. The Bottom-Up architecture uses Finish(2) Option 2 ("Sea Marshalls" with the Harbor Pilot, and disabling if terrorists were in control) while the other two architectures use Finish(2) Option 1 (Surge deployment with escort and recapture if terrorists were in control) for the SAW mission. A statistical analysis is then performed to evaluate the difference between the two potential architectures.

A two-sample t-test indicates that there is a 99.9% chance that the two architectures are statistically different, with a t-value of 6.74. The 95% confidence interval in the amount of increased effectiveness in terms of probability of success between Option 1 and Option 2 was determined to be between 0.03 and 0.08, with an estimated difference of 6.6% in favor of Option 1. Figure 7-72 displays the raw data.

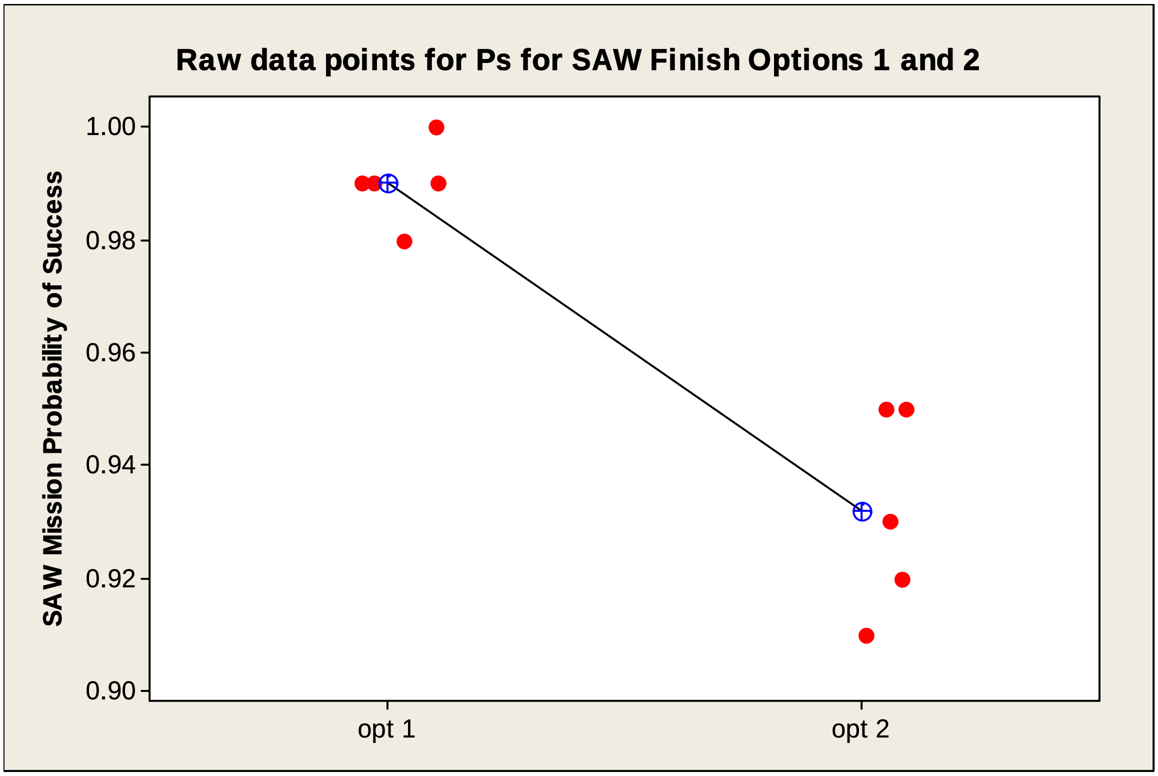

Figure 7-72: SAW Mission Experiment Results

Based on the number of trials conducted, a two sample t-test indicates that there is a 100% chance that the Maximum Performance architecture out-performs the Top-Down Cost-Effective architecture and the Bottom-Up Cost-Effective architectures with t-values of 9.36 and 15.73, respectively. The estimated difference between the mean probabilities of success is 11.7% and 21.0%, respectively. Figures 7-73 and 7-74 display the raw data for the Maximum Performance architecture versus the two other architectures. An analysis of the systems incorporated into the architectures and their impact on architecture performance demonstrates that the addition of the higher firepower weapons on the medium-sized escort ships in the Maximum Performance architecture leads to a significant improvement in SBA mission Ps. The larger improvement in SBA mission Ps as compared to the Bottom-Up Cost-Effective architecture is attributed to the Unmanned Surface Vessels (USV) incorporated in the Maximum Performance architecture, but absent from the Bottom-Up Cost-Effective architecture.

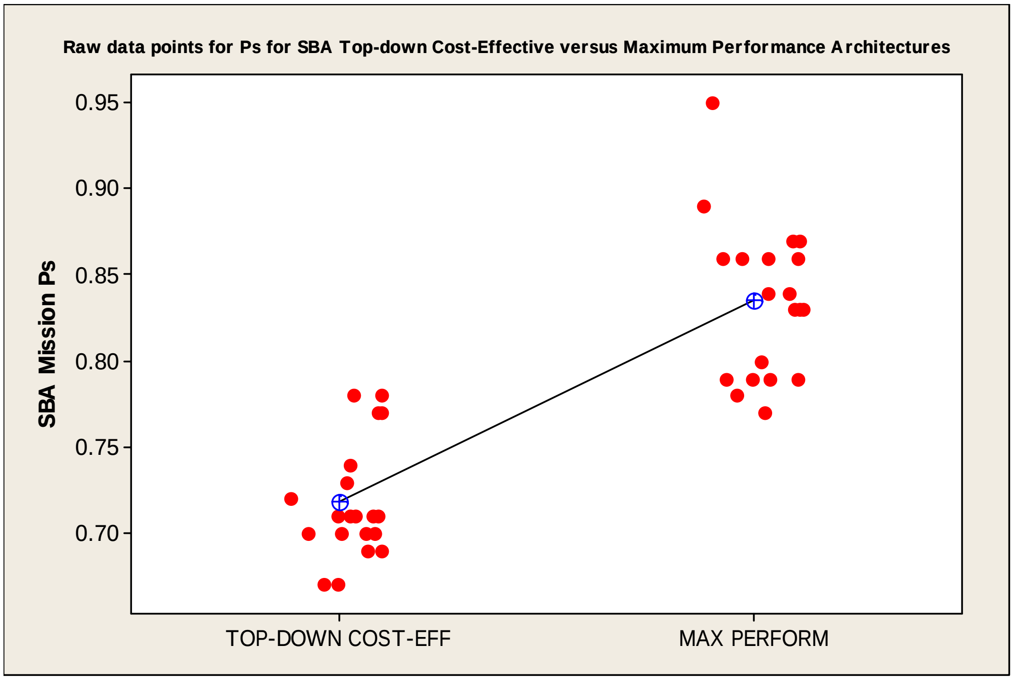

Figure 7-73: SBA Mission Results between TDCE and Max Perform Architectures

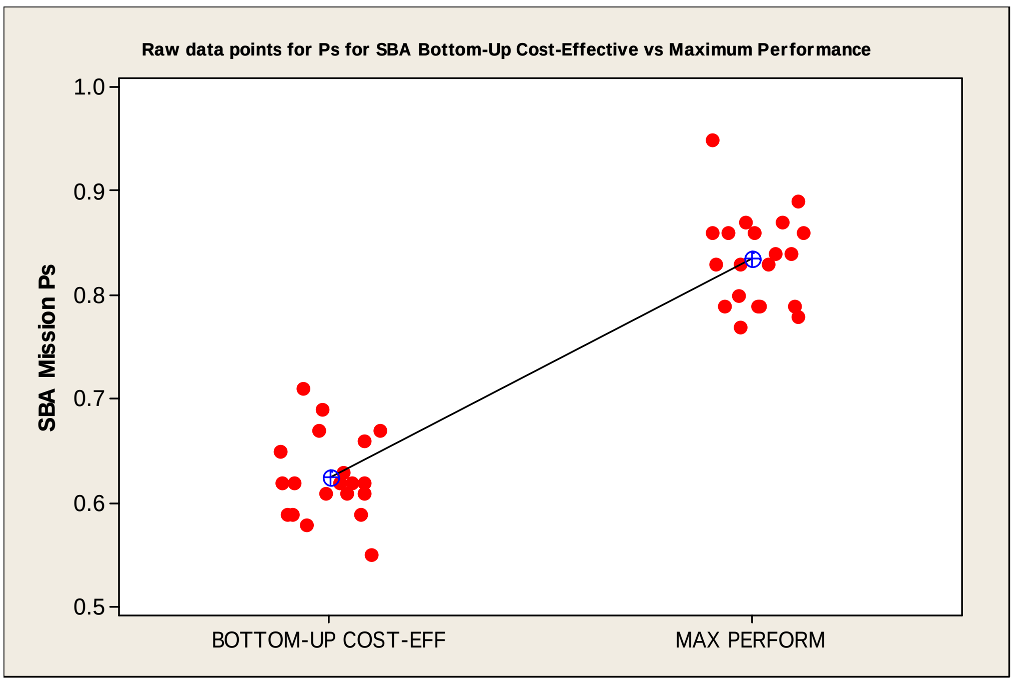

Figure 7-74: SBA Mission Results between BUCE and Max Perform Architectures

Based on the number of trials conducted, a two-sample t-test indicates that there is a 100% chance that the Ps for the Bottom-Up and Top-Down Cost-Effective architectures are also statistically different, with a t-value of 7.98. The 95% confidence interval for the amount of increased effectiveness in terms of probability of success between BUCE and TDCE was determined to be between 0.116 and 0.069, with an estimate of 9.25% better performance from the TDCE. Figure 7-75 displays the raw data points for Ps for the SBA mission for the BUCE and the TDCE architectures. An analysis of system components in the architectures and their performance show that the difference is attributed to the additional benefit associated with the USVs used in the TDCE architecture that are absent in the BUCE architecture.

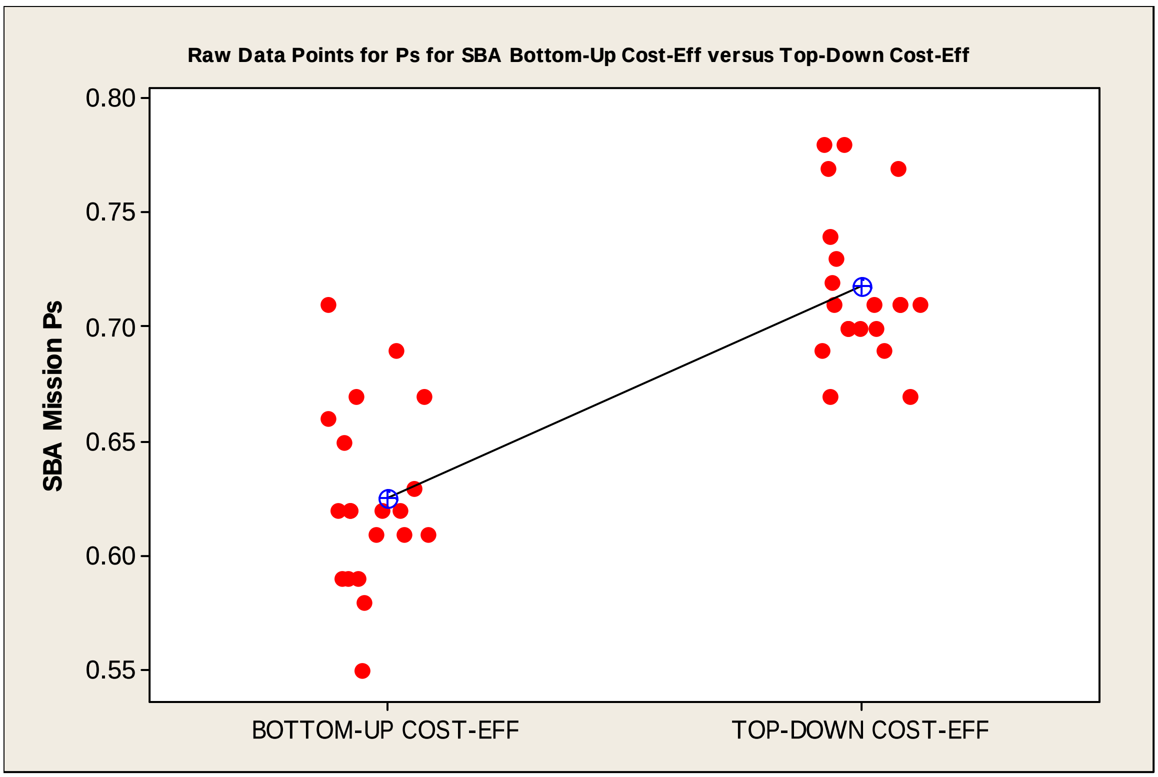

Figure 7-75: SBA Mission Results between BUCE and TDCE Architectures

7.6 COST ANALYSIS AND RESULTS

7.6.1 Overview of Method

There are three main categories of costs considered in the comparison of different MTR architectures: procurement cost, operating and support costs, and delay and damage cost. Delay cost is determined in terms of time delay to commerce via the mission-level Extend models described in Section 7.4. Damage cost is determined from these same models in terms of percent of system failures to neutralize the terrorist threat. The derivation of all other cost estimates is described in this section.

For each system-level concept described, the costs of the main components are determined, and the total cost for each option is then calculated via Excel. All cost figures are normalized to fiscal year 2006 millions of dollars (FY2006$M), and are used as selection criteria for the Bottom Up Cost Effective architecture. Additionally, a grand total cost is calculated for each of the 32 trials in the orthogonal array experiment, and used as a response in determining the Top-Down Cost Effective architecture. Lastly, the grand total cost of the three final candidate architectures is calculated and used as one criterion in the final MTR SoS selection.

7.6.1.1 MTR O&S Costs

For platforms that already exist in the immediate vicinity of the MTR operating area, and in the numbers needed, official Navy operations and support (O&S) data are used to determine an MTR O&S cost. These data are drawn from the Naval Center for Cost Analysis VAMOSC (Visibility and Management of Operating and Support Costs) Website[119] as average annual O&S costs, adjusted for the expected amount of time that these resources would be involved in MTR-related training, exercises, and operations per year. Where VAMOSC data do not exist, existing analogous VAMOSC data are scaled.

VAMOSC

VAMOSC data includes all costs for personnel, maintenance, fuel, and expendables incurred over a year's time. The average O&S cost for selected classes of ships and aircraft is the basis for MTR SoS platform O&S estimates, and is divided by 365 to obtain a daily O&S rate.

A daily O&S rate was similarly obtained for MTR personnel. The most recent annual outlay for all officer and enlisted pay and allowances for both the Navy and Marine Corps were totaled, then divided by the total number of full time equivalents

[119] Naval Center for Cost Analysis, Visibility and Management of Operating and Support Costs Database, http://www.navyvamosc.com

(FTEs) in both services for that year. Dividing this figure by 365 days yields a standard daily rate per person.

Standard durations are assumed for MTR-related training, exercises, and operations. A two-week annual training course is assumed for boarding/search teams for each of the MTR missions. Additionally, all platforms are assumed to participate in one ten-day exercise for each mission per year. One actual operation per year is assumed for each mission. The WMD and SAW missions are assumed to last for 20 days each, while the SBA mission continues for 30 days. Thus, the annual O&S cost for the MTR SoS is a product of the number of days per year during which the platforms would be involved in MTR-related activities and the daily VAMOSC O&S rate. The only exception to this practice is that when assets are involved in transoceanic intercept missions for either WMD or SAW, VAMOSC fuel costs are replaced by the cost of sprint speed fuel usage. This procedure is described in more detail in Section 7.6.2.5.

7.6.1.2 MTR Procurement Costs

In the case that additional units of existing platforms are required, official DoD budget documents[120] are used to the maximum extent possible to obtain platform unit costs. If official DoD budget documents can not be located, another reputable source, such as Jane's or the original equipment manufacturer (OEM) Website, is used. The costs of USCG Deepwater assets are based on official USCG Website materials.[121] Where entirely new systems are required, appropriate analogous systems are identified, and their costs are scaled as appropriate. The entire cost of both additional units and of new platforms is attributed to MTR SoS procurement costs, even if these platforms could be used for additional missions outside the MTR domain. As in the O&S cost calculation, there is one important exception: Program of Record National Fleet assets, such as the Littoral Combat Ship (LCS) and the National Security Cutter (WMSL), are assumed to be sunk costs and are therefore not included in the total cost computation.

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[120] Office of the Under Secretary of Defense (Comptroller), DoD Summary Budget Materials/Budget Links, http://www.dod..mil/comptroller/budgetindex.html

[121] United States Coast Guard Fact File, Fiscal Year 2004 Coast Guard Report: FY2003 Performance Report and FY2005 Budget in Brief, http://www.uscg.mil/hq/g-cp/comrel/factfile/index.htm

7.6.2 System Concept Cost Estimates

7.6.2.1 C4ISR

The main components of the C4ISR system are the Boarding Team Communications Pack (BTCP), correlation engine software, software training, headquarters workstations, shipboard combat information centers (CIC), small boat communications equipment, space and land-based base stations, and the planning effort required to develop ROE and SOP for MTR missions. Of the preceding components, all are assumed to exist in an adequate form with the exception of the BTCP, correlation engine, and dedicated personnel for software and communications gear currency and readiness requirements.

The detailed cost estimate for a single BTCP is shown in Table 7-30. The BTCP is costed based on manufacturers' Websites and analogous equipment.

Item	Qty	Unit Cost	Total Cost	Data Source
Marine grade ruggedized laptops	4	$2,289	$9,156	http://www.consumersmarine.com
100Mbps switch	1	$50	$50	http://www.compusa.com
Biometrics scanner	1	$1,000	$1,000	Estimate based on analogous equipment
UWB antenna	2	$300	$600	Estimate based on analogous equipment
Skymate Communicator kit	1	$1,199	$1,199	http://www.consumersmarine.com
Miscellaneous	1	$3,000	$3,000	Power supplies, batteries, chargers, mounts, etc.
		TOTAL	**$15,005**	

Table 7-30: Boarding Team Communications Pack (BTCP)

The Rosetta Stone Advanced Capability Technology Demonstration is used as the analogy for correlation engine algorithm development and technology demonstration. It is assumed that Area C2 requires only one correlation engine, while Local C2 requires an engine for each HVU escort team, of which there are approximately 20. An additional $2.5 million per C2 location is assumed for hardware/software integration costs, and the rule of thumb for software O&S is 20% of RDT&E.

Five full time equivalents (FTEs) for 44 days per year are assumed per software-installed location. FTEs include the commander, two analyst/operators, one boarding team communications expert, and one boarding team gear maintainer/storekeeper. The 44-day duration is comprised of one 20-day operation, one 10-day exercise, and two weeks of either training or planning. No cost differential was identified between the problem-solving and the objective-oriented command structures. The total C4ISR cost estimate is shown in Table 7-31.

	CE Cost	Qty	CE Total	BTCP Cost	Qty	BTCP Total	O&S	Total	Option
Area C2	7.687	1	10.187	0.015	20	0.3	1.569	12.056	1 & 2
Local C2	7.687	20	57.687	0.015	20	0.3	2.162	60.149	3 & 4

Table 7-31: C4ISR Cost Estimate

7.6.2.2 PBS

PBS(1,2)

The main components of the PBS system for the WMD and SAW missions are National Fleet assets, replenishment ships, and boarding teams. For Option 1, the Current Ships O&S is an average of VAMOSC daily O&S rates for the CG-47, DDG-51, and FFG-7 classes of ships. Boarding team members are drawn for ship's company. Option 2 Program of Record (POR) Ships O&S uses the average of FFG O&S for the NSC and PC O&S for the LCS. For both Options 2 and 3, each boarding team is an additional detachment of 12 personnel. The VAMOSC standard FTE cost discussed in Section 7.4.1.1.1 is applied. Option 3 also uses a modified COTS merchant ship with six interceptors carried onboard. The manufacturer's cost for the NASSCO Tote Orca and the Wallypower 118 are used for procurement costs, plus an additional $100M for Tote Orca modifications including a boat handling system. O&S costs are assumed as follows: Tote Orca equals MSC Fast Supply Ship (FSS) class average, Wallypower equals 80% of PC class average, and boat handling system equals aircraft elevator average. Table 7-32 displays these costs and the total by option.

	Unit Cost	Qty	O&S Cost	Duration	Total	Grand Total	Option
Current Ships + AO	n/a	20	1.848	30	55.451	55.451	1
POR Ships + AO	Sunk Cost	20	1.005	30	30.145	31.691	2
Boarding Teams	n/a	20	0.002	44	1.546		
Modified Merchant	250.000	3	0.021	30	751.846	1,224.067	3
Interceptors	25.934	18	0.010	22	470.675		
Boarding Teams	n/a	20	0.002	44	1.546		

Table 7-32: PBS(1,2) Cost Estimate

PBS(3)

The main components of PBS(3) are escort boats and boarding teams. Small escort boats are either RHIBs or other light patrol/security craft. The small boat unit cost estimate is an average of the USCG Long Range Interceptor (LRI), the Sea ARK Marine "Dauntless" craft, and SOF combatant craft systems. Small escort O&S is assumed to be 20% of PC O&S, the scaling factor based on boat length and crew requirements. The mid-sized escorts used in options 2 and 3 are similar to the Navy PC or the USCG Fast Response Cutter (FRC). PC O&S cost and FRC procurement costs are used. The total number of small and mid-sized craft required are reduced by the 20 USCG boats currently assigned to San Francisco Bay. For simplicity, it is assumed that half of these existing boats are mid-sized. Lastly, while the 12-man boarding teams could be drawn from USMC FAST, USN MSD, or USCG MSST teams, the USCG MSST in San Francisco is assumed to function as the base for boarding team staging and replenishment. Table 7-33 presents the total costs of the four different PBS(3) options.

	Unit Cost	Qty	O&S Cost	Duration	Total	Grand Total	Option
Small Boats	1.01981	82	0.002442	40	91.636	92.584	1
Boarding Teams	n/a	10	0.001756	54	0.948		
Mid-Sized Boats	43.637	34	0.012212	40	1,500.279	1,534.753	2
Small Boats	1.01981	30	0.002442	40	33.525		
Boarding Teams	n/a	10	0.001756	54	0.948		
Mid-Sized Boats	43.637	34	0.012212	40	1,500.279	1,583.923	3
Small Boats	1.01981	74	0.002442	40	82.696		
Boarding Teams	n/a	10	0.001756	54	0.948		
Boarding Teams	n/a	27	0.001756	54	2.561	36.086	4
Small Boats	1.01981	30	0.002442	40	33.525		

Table 7-33: PBS(3) Cost Estimate

7.6.2.3 Find/Fix

Find/Fix(1)

For the WMD mission, the main components of the Find/Fix system are the radiological sensors. Six of each sensor are required per PAV, with eight assumed to account for any reliability issues. Detector O&S is assumed to be $200K per year per detector class, which includes one or two FTEs, storage, equipment checks, and any servicing. Table 7-34 shows the total cost by option.

	Unit Cost	Qty	O&S Cost	Duration	Total	Grand Total	Option
LRM	0.074	160	0.000548	365	12.040	36.240	1
Fission Meter	0.150	160	0.000548	365	24.200		
LRM	0.074	160	0.000548	365	12.040	21.040	2
HPGe	0.055	160	0.000548	365	9.000		
Nal Detector	0.019	160	0.000548	365	3.240	27.440	3
Fission Meter	0.150	160	0.000548	365	24.200		
Nal Detector	0.019	160	0.000548	365	3.240	12.240	4
HPGe	0.055	160	0.000548	365	9.000		

Table 7-34: Find/Fix(1) Cost Estimate

Find/Fix(2)

The main components of Find/Fix(2) are the Biometrics Kit and the server at headquarters. Two kits are required per VOI: a primary and one spare. Similar to Find/Fix(1), detector O&S is assumed to be $200K annually. The cost total is shown in Table 7-35.

	Unit Cost	Qty	O&S Cost	Duration	Total
Biometrics Kit	0.0010	40	0.000547945	365	0.290
Server	0.05	1			

Table 7-35: Find/Fix(2) Cost Estimate

Find/Fix(3)

The main components of Find/Fix(3) are the search teams and surface search radar. Because the costs associated with the teams are previously assessed under PBS(3), and the radar is organic to both the small- and mid-sized escorts, there is no additional cost for either of these two options.

7.6.2.4 Finish

Finish(1)

There is no additional cost for Finish(1). The Finish(1) concept consists of handing off any suspected WMD device to existing DOE experts for assessment and disposal.

Finish(2)

The main component of Finish(2) Option 1 is a recapture team inserted via helicopter. The H-60 VAMOSC data is applied to obtain a daily helicopter O&S rate. The VAMOSC per person rate is used for the recapture team, plus a 25% factor to account for their specialized equipment. The recapture component is in addition to the assets contained in PBS(1,2). In order to appropriately cost Finish(2) Option 1, both PBS(1,2) and the corresponding Sustain fuel cost must be included a second time in the total architecture cost. This is accomplished via the "Finish(2) Enable" column in Table 7-40.

Finish(2) Option 2 is comprised of escort teams that board with the harbor pilot, as well as controlled mines. The controlled mine concept uses converted MK-48 torpedoes; thus, the Improved Submarine-Launched Mobile Mine (ISLMM) MK-48 torpedo conversion program is an appropriate analogy. Torpedo O&S is estimated at $200K per year plus the expenditure of one torpedo at $2.5M unit cost. The total cost calculation for both options is displayed in Table 7-36.

	Unit Cost	Qty	O&S Cost	Duration	Total	Grand Total	Option
PBS(1,2) and Sustain Cost	*Varies by Option (see the "Fin(2) Enable" column of Orthogonal Array)*					1.219	1
Insertion Team	N/A	1	0.002196	44	0.0966		
H-60	N/A	3	0.012467	30	1.1220		
ISLMM (MK-48 conversion)	0.143	3	0.000548	30	2.6926	4.2383	2
Escort Teams	N/A	20	0.001756	44	1.5457		

Table 7-36: Finish(2) Cost Estimate

Finish(3)

Finish(3) employs the escort teams and platforms already costed under PBS(3). The number of teams is consistent with PBS(3): 10 teams for Options 1, 2, and 3; 27 teams for Option 4. Additionally, Finish(3) main components include hand-held weapons, helicopters, and unmanned surface vehicles (USVs). The MK-19 Grenade Launcher procurement cost was used as the standard hand-held weapon cost. Hand-held weapon O&S is assumed to be 25% of procurement cost. Helicopter O&S uses the same daily rate as Finish(2), which is based on the Navy H-60. The SeaFox USV is used as an analogy for USV procurement cost. Because the SeaFox is built atop an 8-meter RHIB, the same scaling factor used for PBS(3) small boats is applied here, namely that SeaFox O&S is equivalent to 20% of PC O&S. The cost estimate summary table is provided as Table 7-37.

	Unit Cost	Qty	O&S Cost	Duration	Total	Grand Total	Option
MK-19 GL (4 per team)	0.020	40	1.377E-05	54	0.834	0.834	1
MK-19 GL (4 per team)	0.020	40	1.377E-05	54	0.834	13.799	2
H-60	N/A	26	1.247E-02	40	12.965		
MK-19 GL (4 per team)	0.020	40	1.377E-05	54	0.834	21.270	3
SeaFox	0.100	92	3.053E-03	40	20.435		
MK-19 GL (4 per team)	0.020	108	1.377E-05	54	2.252	35.653	4
H-60	N/A	26	1.247E-02	40	12.965		
SeaFox	0.100	92	3.053E-03	40	20.435		

Table 7-37: Finish(3) Cost Estimate

7.6.2.5 Sustain

Nearly all critical sustainment costs are captured in the VAMOSC data. For example, food is included through the Basic Allowance for Subsistence (BAS) cost in the VAMOSC personnel data. The VAMOSC reports also account for the majority of SoS maintenance requirements. Any spares needed to meet reliability requirements are included in unit quantities. For example, although only 4 USVs are required per high value commercial shipping unit (HVU), a total of 92 must be procured to account for refueling, maintenance, and breakage. Training cost is included via the duration of MTR activities and is standardized as one 10-day exercise per year per mission, plus one 2-week school for boarding team members on MTR mission-specific equipment and procedures.

As mentioned in Section 7.6.1.1, VAMOSC fuel costs are not used for the high-speed transoceanic intercept concept used in PBS(1,2). Instead, the annual VAMOSC fuel cost is subtracted from the total O&S cost before the daily O&S rates are calculated. Sprint speed fuel rates are used to calculate more accurate fuel costs for each of the PBS(1,2) options. Table 7-38 shows the operational and exercise fuel costs for all three PBS(1,2) options. Option 1 and 2 include the fuel cost for 20 ships and 3 oil tankers, while Option 3 uses only the fuel cost for three oil tankers to approximate the modified merchant fuel burn rate. For the 10-day exercise, a reduced number of ships is assumed to operate at sprint speeds. Specifically, only 15% of the Options 1 and 2 ships sprint during exercises, and only one of the Option 3 ships sprints. These operational and exercise fuel costs are summed to obtain the total cost for Sustain Options 1, 2, and 3 (Table 7-38).

	Operational Fuel Cost		Exercise Fuel Cost				
PBS(1,2)	**FY2005$**	**FY2006$M**	**# Ships**	**# Days**	**Fuel Cost**	**Total Cost**	**Sustain**
Option 1	16,468,837	16.830	0.15	0.5	1.262	18.092	1
Option 2	9,415,517	9.622	0.15	0.5	0.722	10.343	2
Option 3	2,569,696	2.626	0.33	0.5	0.438	3.064	3

Table 7-38: Sustain Cost Estimate

7.6.3 Orthogonal Array Experiment (OAE) Costs

Costs for all system concepts are tabulated and combined for the 32 OAE trials as shown in Table 7-39. Columns within the table correspond to each of the concept cost estimates previously described in Section 7.4.2. The "Finish (2) Enable" column accounts for the dual use of the PBS(1,2) system in both the WMD and SAW missions in the case of Finish(2) Option 1, and it includes both the PBS(1,2) O&S cost and the Sustain sprint speed fuel cost. The total costs shown in the right-hand column of the table are normalized and used as a response in the orthogonal array analysis described in Section 7.1.2 to statistically derive the Top-Down Cost Effective architecture.

												FY2006$M
Trial	C4ISR	PBS(1,2)	PBS(3)	F/F(1)	F/F(2)	F/F(3)	)	Fin(2) Enable	Finish(3)	Sustain	Total Cost
1	12.056	55.451	92.584	36.240	0.290	0.000	1.219	73.543	0.834	18.092	290.309
2	12.056	31.691	1,534.753	21.040	0.290	0.000	4.238	0.000	13.799	10.343	1,628.211
3	12.056	1,224.067	1,583.923	27.440	0.290	0.000	1.219	1,227.130	21.270	3.064	4,100.458
4	12.056	55.451	36.086	12.240	0.290	0.000	4.238	0.000	35.653	18.092	174.106
5	12.056	55.451	92.584	21.040	0.290	0.000	1.219	73.543	35.653	18.092	309.927
6	12.056	31.691	1,534.753	36.240	0.290	0.000	4.238	0.000	21.270	10.343	1,650.881
7	12.056	1,224.067	1,583.923	12.240	0.290	0.000	1.219	1,227.130	13.799	3.064	4,077.788
8	12.056	31.691	36.086	27.440	0.290	0.000	4.238	0.000	0.834	10.343	122.979
9	60.149	55.451	1,534.753	27.440	0.290	0.000	4.238	0.000	21.270	18.092	1,721.683
10	60.149	31.691	92.584	12.240	0.290	0.000	1.219	42.034	35.653	10.343	286.204
11	60.149	1,224.067	36.086	36.240	0.290	0.000	4.238	0.000	0.834	3.064	1,364.968
12	60.149	1,224.067	1,583.923	21.040	0.290	0.000	1.219	1,227.130	13.799	3.064	4,134.682
13	60.149	55.451	1,534.753	12.240	0.290	0.000	4.238	0.000	13.799	18.092	1,699.013
14	60.149	31.691	92.584	27.440	0.290	0.000	1.219	42.034	0.834	10.343	266.585
15	60.149	1,224.067	36.086	21.040	0.290	0.000	4.238	0.000	35.653	3.064	1,384.587
16	60.149	55.451	1,583.923	36.240	0.290	0.000	1.219	73.543	21.270	18.092	1,850.177
17	12.056	55.451	36.086	36.240	0.290	0.000	1.219	73.543	13.799	18.092	246.776
18	12.056	31.691	1,583.923	21.040	0.290	0.000	4.238	0.000	0.834	10.343	1,664.416
19	12.056	1,224.067	1,534.753	27.440	0.290	0.000	1.219	1,227.130	35.653	3.064	4,065.671
20	12.056	31.691	92.584	12.240	0.290	0.000	4.238	0.000	21.270	10.343	184.712
21	12.056	55.451	36.086	21.040	0.290	0.000	1.219	73.543	21.270	18.092	239.046
22	12.056	31.691	1,583.923	36.240	0.290	0.000	4.238	0.000	35.653	10.343	1,714.435
23	12.056	1,224.067	1,534.753	12.240	0.290	0.000	1.219	1,227.130	0.834	3.064	4,015.652
24	12.056	1,224.067	92.584	27.440	0.290	0.000	4.238	0.000	13.799	3.064	1,377.538
25	60.149	55.451	1,583.923	27.440	0.290	0.000	4.238	0.000	35.653	18.092	1,785.237
26	60.149	31.691	36.086	12.240	0.290	0.000	1.219	42.034	21.270	10.343	215.323
27	60.149	1,224.067	92.584	36.240	0.290	0.000	4.238	0.000	13.799	3.064	1,434.432
28	60.149	55.451	1,534.753	21.040	0.290	0.000	1.219	73.543	0.834	18.092	1,765.371
29	60.149	55.451	1,583.923	12.240	0.290	0.000	4.238	0.000	0.834	18.092	1,735.218
30	60.149	31.691	36.086	27.440	0.290	0.000	1.219	42.034	13.799	10.343	223.053
31	60.149	1,224.067	92.584	21.040	0.290	0.000	4.238	0.000	21.270	3.064	1,426.702
32	60.149	31.691	1,534.753	36.240	0.290	0.000	1.219	42.034	35.653	10.343	1,752.373

Table 7-39: Orthogonal Array of MTR SoS Costs

7.6.4 Candidate Architecture Costs

The total costs are obtained for each of the three candidate architectures, using the cost estimates in Section 7.4.2. All costs are reported in FY2006$M and are broken out according to the SoS components, procurement, and O&S. The architecture costs are presented both individually and in combination in the sections that follow.

7.6.4.1 Individual Architecture Cost Results

Maximum Performance Architecture

The costs of the Maximum Performance architecture are displayed in tabular and graphical form in Table 7-40 and Figure 7-76, respectively.

Max Perf.	Component	Procurement	O&S	Total
4	C4	57.987	2.162	60.149
2	PBS(1,2)	0.000	63.382	63.382
3	PBS(3)	1,559.136	24.787	1,583.923
1	Find Fix(1)	35.840	0.400	36.240
1	Find Fix(2)	0.090	0.200	0.290
1	Finish(2)	0.000	1.219	1.219
4	Finish(3)	11.372	24.281	35.653
2	Sustain	0.000	20.687	20.687
	Total	**1,664.426**	**137.118**	**1,801.543**

Table 7-40: Maximum Performance Architecture Cost

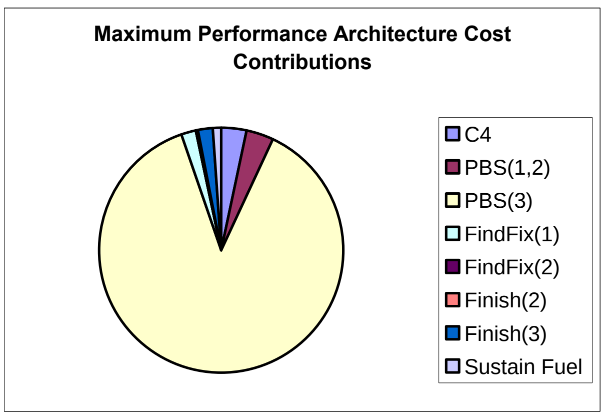

Figure 7-76: Maximum Performance Architecture Cost

Bottom-Up Cost-Effective (BUCE) Architecture

The costs of the BUCE architecture are displayed in tabular and graphical form in Table 7-41 and Figure 7-77, respectively.

BUCE	Component	Procurement	O&S	Total
2	C4	10.487	1.569	12.056
2	PBS(1,2)	0.000	31.691	31.691
1	PBS(3)	83.624	8.960	92.584
1	Find Fix(1)	35.840	0.400	36.240
1	Find Fix(2)	0.090	0.200	0.290
2	Finish(2)	0.143	4.095	4.238
2	Finish(3)	0.804	12.995	13.799
2	Sustain Fuel	0.000	10.343	10.343
	Total	**130.989**	**70.253**	**201.242**

Table 7-41: BUCE Architecture Cost

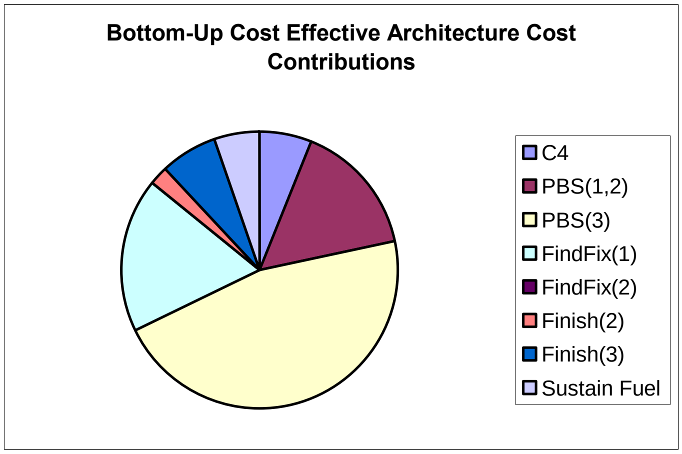

Figure 7-77: BUCEe Architecture Cost

Top-Down Cost-Effective (TDCE) Architecture

The costs of the TDCE architecture are displayed in tabular and graphical form in Table 7-42 and Figure 7-78, respectively.

TDCE	Component	Procurement	O&S	Total
4	C4	57.987	2.162	60.149
2	PBS(1,2)	0.000	63.382	63.382
1	PBS(3)	83.624	8.960	92.584
1	Find Fix(1)	35.840	0.400	36.240
1	Find Fix(2)	0.090	0.200	0.290
1	Finish(2)	0.000	1.219	1.219
4	Finish(3)	11.372	24.281	35.653
2	Sustain Fuel	0.000	20.687	20.687
	Total	**188.914**	**121.290**	**310.204**

Table 7-42: TDCE Architecture Cost

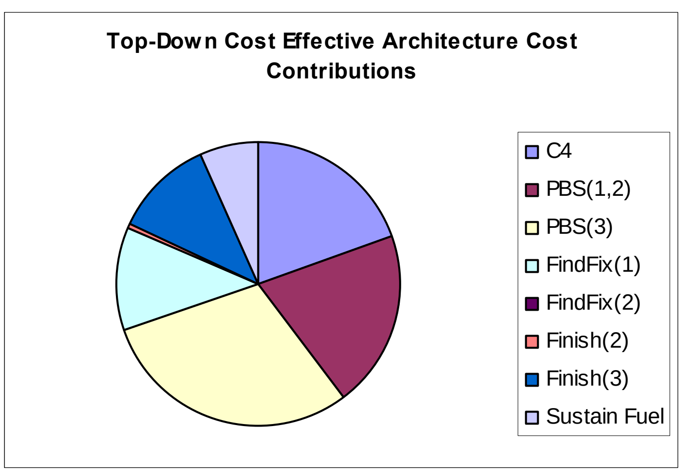

Figure 7-78: TDCE Architecture Cost

Architecture Cost Comparison

The costs of the three candidate architectures are compared side by side in both tabular and graphical format in Table 7-43 and Figure 7-79, respectively. Table 7-44 displays the costs of all three candidate architectures by mission.

Architecture	Procurement Cost	Annual O&S Cost	Delay/Damage Cost	Total Cost
Maximum Performance	1,664.426	137.118	4.912	1,806.455
BUCE	130.989	70.253	25.306	226.549
TDCE	188.914	121.290	4.912	315.116

Table 7-43: Candidate Architecture Cost Comparison

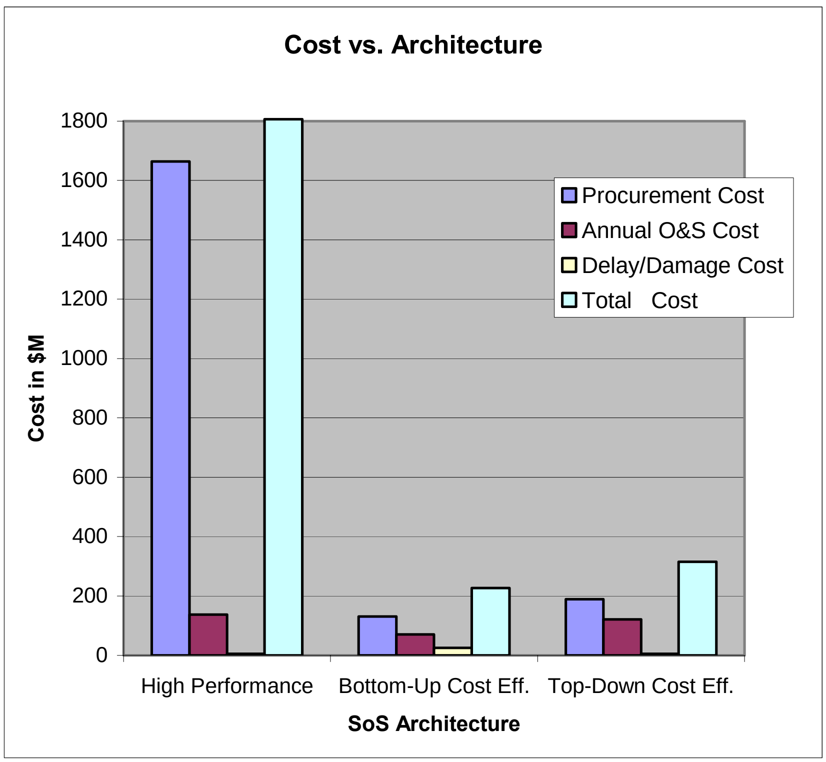

Figure 7-79: Candidate Architecture Cost Comparison

Cost by Mission	Architecture		
	Max Performance	**BUCE**	**TDCE**
WMD			
C4	20.050	4.019	20.050
PBS(1,2)	31.691	31.691	31.691
Find Fix(1)	36.240	36.240	36.240
Sustain	10.343	10.343	10.343
WMD Total	**98.324**	**82.293**	**98.324**
SAW			
C4	20.050	4.019	20.050
PBS(1,2)	31.691	0.000	31.691
Find Fix(2)	0.290	0.290	0.290
Finish(2)	1.219	4.238	1.219
Sustain	10.343	0.000	10.343
Delay/Damage	4.912	25.306	4.912
SAW Total	**68.504**	**33.853**	**68.504**
SBA			
C4	20.050	4.019	20.050
PBS(3)	1583.923	92.584	92.584
Finish(3)	35.653	13.799	35.653
SBA Total	**1,639.626**	**110.402**	**148.287**
GRAND TOTAL	**1,806.455**	**226.549**	**315.116**

Table 7-44: Candidate Architecture Cost by Mission

7.7 ARCHITECTURE SELECTION

As previously discussed, three MTR SoS architectures are considered: the TDCE architecture, the BUCE architecture, and the Maximum Performance architecture. The architecture ranking and selection process uses the processed EXTEND^{TM} data output consisting of probability of success along with delay and/or damage costs.

7.7.1 Architecture Selection Process

The performance of each architecture in each of the three mission areas is measured. The results are post-processed to include the delay and damage costs sustained as a result of the implementation of the system. The architectures are then compared in with respect to each individual mission area along with all three missions considered in aggregate. The selection process then involves assessment of system total cost versus effectiveness for each architecture.

7.7.2. Architecture Selection Analysis

Section 7.5 discusses the overall effectiveness of each architecture. Given the emphasis placed on limiting the impact on global maritime commerce, the MTR solution being sought has been conjectured from the beginning of the project to correspond to the most cost-effective architecture rather than the most effective architecture. As will be seen later, the analysis results will support this conjecture and lead to the best cost-effective architecture. Following is a discussion of the selection of the "best" overall architecture for the MTR mission.

7.7.2.1 Architecture Selection with Regard to Mission

Figures 7-80, 7-81, and 7-82 show the cost-effectiveness curves for the WMD, SAW, and SBA missions, respectively. The so-called cost-effectiveness curve depicts the total SoS cost against the probability of mission success for each architecture. As shown by these curves, the BUCE architecture would nominally be selected for the WMD and SAW missions, while the TDCE architecture would be selected for the SBA mission.

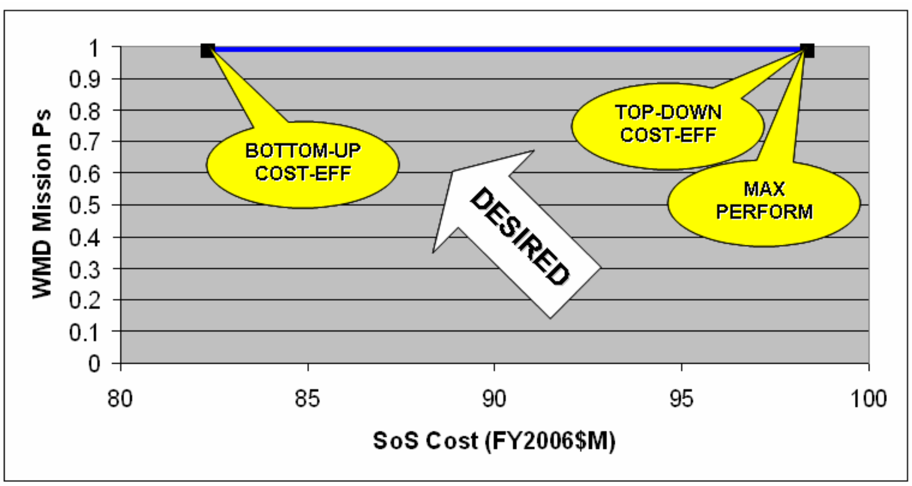

Figure 7-80: SoS Cost-Effectiveness for WMD Mission

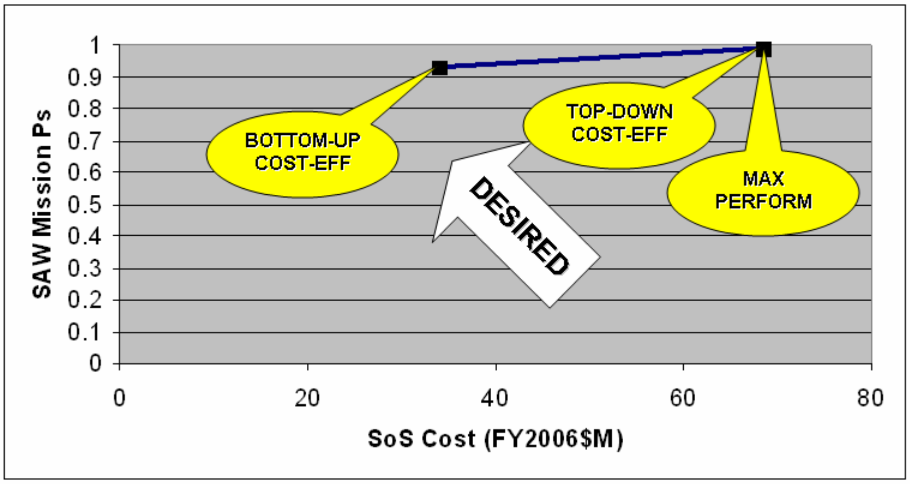

Figure 7-81: SoS Cost-Effectiveness for SAW Mission

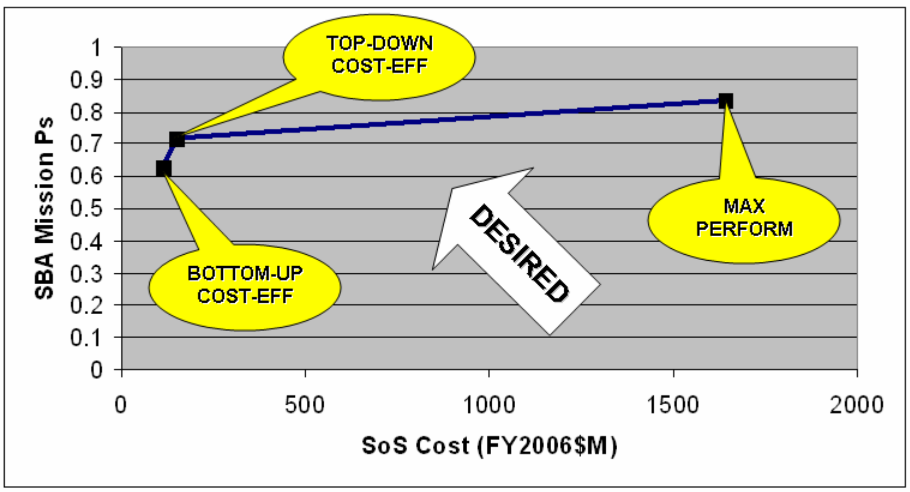

Figure 7-82: SoS Cost-Effectiveness for SBA Mission

7.7.2.2 Overall Architecture Selection

Figure 7-83 shows the cost of each architecture against the aggregated probability of success across all three missions. The "knee" in the cost-effectiveness curve corresponds to the TDCE architecture. The reason for the "knee" and hence the selection of this "best" architecture is now elaborated.

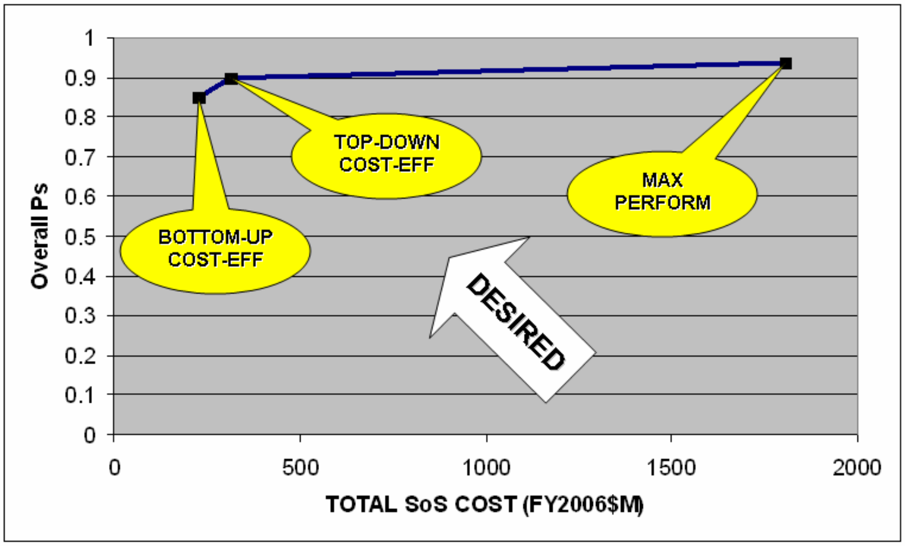

Figure 7-83: SoS Cost-Effectiveness for Combined Missions

Firstly, the large difference between the cost of the Maximum Performance architecture and the two cost-effective architectures is caused by the cost of the procurement of the requisite number of medium-sized escort ships for the SBA mission. As discussed in Section 7.6, the cost for procurement alone of the combined SBA force in the architecture is $1,559.1 million in FY2006 dollars. The cost for procurement alone of the small escort only SBA force in the TDCE architecture is $83.6 million. The result is a 1385% increase in the overall SBA mission cost for only a 12% increase in SBA mission effectiveness.

Secondly, although the TDCE architecture is slightly more expensive than the BUCE architecture, it delivers 5% improvement in aggregated mission probability of success. This causes the "knee" well beyond the tiny increase in improved mission effectiveness from the TDCE to the Maximum Performance architecture, as can be seen in Figure 7-83.

The TDCE architecture can be procured and operated for a cost of $315.1 million in FY2006 dollars. Table 7-45 shows the cost estimated for the results of the three different missions without the MTR system in place as well as the expected value of damage cost associated with the TDCE architecture in place. As the table shows, the expected value of damage suffered without the MTR system in place drops from $1,900 million to $127 million. This drop in expected value of damage of

$1,773 million is obtained through the expenditure of only $315.1 million in FY2006 dollars. In other words, the procurement of the TDCE architecture should save $5.63 for every dollar spent. Even independent of the non-quantitative value in preventing a terrorist attack, the architecture would appear to have exceptional value given that such attacks may be a possibility or a probability.

MTR Mission Type	TDCE System P_s (%)	Raw Damage Cost from Attack ($M)	Relative Probability of Occurrence	Expected Damage without TDCE System ($M)	Expected Damage with TDCE System ($M)
WMD	99	500,000	0.001	1,000	10
SAW	99	2,500	1.0	500	5
SBA	72	1,000	2.0	400	112

Table 7-45: Damage Cost and TDCE Architecture System P_s

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8.0 CONCEPTS OF OPERATIONS

Each of the Design Reference Missions (DRM) required mission-specific, pre-planned Concepts of Operations (CONOPS) that needed to be executed to effectively respond to the type of terrorist attack underway. The following CONOPS are not the only way to achieve the desired results, but were proposed by the team as to be simple, reliable, effective solutions.

For each mission, the CONOPS are initiated when the Joint Inter-agency Task Force (JIATF) for Counter-Terrorism is alerted to an impending attack against the United States, in our example, in San Francisco.

8.1 COUNTER-WMD MISSION CONOPS

- Intelligence is received that a WMD device has been smuggled onto one of 20 container ships coming from East Asia en route to San Francisco Bay. The Maritime Operational Threat Response (MOTR) plan is exercised among the national level command centers in conference with the JIATF-CT headquarters and appropriate allocations of assets are decided.
- Any PAV that is closer than 100 NM from CONUS is directed to turn around and proceed to 100 NM holding point and await boarding by U.S. search teams.
- Up to 23 National Fleet (USN and USCG) vessels in the Pacific are given surge orders to be underway within 24 hours once specialized nuclear search teams have arrived at their homeport for boarding.
- Specialized Department of Energy and other agency nuclear search teams within CONUS are alerted, activated, and transported via fastest means to ports in Yokosuka, Japan, Kodiak, Alaska, Pearl Harbor, Hawaii, and San Diego, California.
- Once ships are ready and teams are onboard, ships surge at maximum sprint speed from their homeports to intercept PAVs emanating from

East Asia. Priority is given first to Yokosuka, then to Kodiak, then to Pearl Harbor, and lastly to San Diego.

- JIATF Staff Officers work through Department of State and Department of Homeland Security to obtain approval from vessel flag governments for search and inspection of their vessels underway.
- National Fleet vessels intercept their respective PAV and deploy their search teams to the vessels via small boat and/or helicopter.
- National Fleet vessels remain alongside PAV in order to support and sustain their search teams during the transit.
- Within 24 hours after intercept culmination, surged vessels are UNREPed by MSC refueling ships that surged from appropriate bases to refuel escort vessels.
- Search teams conduct exhaustive passive search of containers. Simultaneously, JIATF intelligence and national laboratory specialized support analysts screen manifests of cargo for potential WMD locations along with expected normally occurring radioactive material (NORM) that will likely set off initial detector searches.
- Search teams employ passive identification of all exhaustive search detections along with containers expected to contain NORM or other potentially suspicious containers from intelligence analysis.
- Search teams employ "reach back" through ad hoc, agile networks to transmit data pertaining to detected WMD characteristics for analysis by technical experts at national laboratories.
- If a WMD device is detected, DoE Joint Technical Operations (JTO) teams are called in to dismantle and dispose of the threat device.
- If a PAV being searched reaches the 100-NM holding point prior to the search being completed, the vessel is directed to hold at that point until such time as the search is completed and the vessel is cleared to proceed.
- Once a PAV is searched and the team concludes no WMD device is resident, the PAV in question is cleared to proceed to enter the CONUS.

8.2 COUNTER-SAW MISSION CONOPS

- Intelligence is received that a terrorist cell has made it onto 1 of 20 merchant ships coming from East Asia en route to San Francisco Bay. The Maritime Operational Threat Response (MOTR) plan is exercised among the national level command centers in conference with the JIATF-CT headquarters and appropriate allocations of assets are decided.
- Any PAV that is closer than 100 NM from CONUS is directed to turn around and proceed to 100-NM holding point and await boarding by U.S. search and escort teams.
- Up to 23 National Fleet (USN and USCG) vessels in the Pacific are given surge orders to be underway within 24 hours.
- Once ships are ready, ships surge at maximum sprint speed from their homeports to intercept PAVs emanating from East Asia. Priority is given first to Yokosuka, then to Kodiak, then to Pearl Harbor, and lastly to San Diego.
- JIATF Staff Officers work through Department of State and Department of Homeland Security to obtain approval from vessel flag governments for search and inspection of their vessels underway.
- National Fleet vessels intercept their respective PAV and deploy their search teams to the vessels via small boat and/or helicopter.
- If terrorists are in control of PAV and resist boarding, commanders evaluate situation and determine whether to proceed with opposed boarding if qualified personnel are already onboard escort vessel, to continue to shadow the PAV until such time as available qualified personnel can attempt to recapture the PAV, or to potentially disable the PAV to stop its progress and reevaluate the situation.
- If terrorists are in control and they successful resist boarding and recapture attempts, National Fleet escort vessel disables PAV to prevent it to close to CONUS.
- If terrorists are not in control of PAV, search and escort teams board PAV and conduct search of ship in order to seek out any terrorists hiding

onboard and to verify the identities of the crew personnel onboard the PAV. Any identified terrorists are taken into custody for turnover to appropriate authorities.

- Once ship has been searched and secured, escort teams remain onboard PAV until it is safely docked in CONUS port.
- National Fleet vessels remain alongside PAV in order to support and sustain their search teams during the transit.
- Within 24 hours after intercept culmination, surged vessels are UNREPed by MSC refueling ships that surged from appropriate bases to refuel escort vessels.

8.3 COUNTER-SBA MISSION CONOPS

- Intelligence received by JIATF Headquarters that SBA will take place within San Francisco Bay within some timeframe.
- MOTR plan exercised.
- Coast Guard MARSEC (Maritime Security) level elevated in San Francisco Bay to MARSEC – 3, indicating that an attack is imminent.
- All nonessential recreational boat traffic is prohibited in the Bay during anticipated attack timeframe.
- Local law enforcement and Coast Guard auxiliaries are detailed to boat ramps and civilian yacht harbors to help enforce recreational boat restriction and to seek out intelligence on impending attack.
- Navy and Coast Guard counter-SBA forces are alerted and activated.
- Coast Guard units assume defensive positions at static points of critical infrastructure such as refueling piers and ferry terminals.
- Coast Guard teams are dispatched to essential commercial boat traffic such as passenger ferries.
- Navy and Coast Guard small boats, armed helicopters, and USVs begin close escort patrols of essential boat traffic and points of critical infrastructure.

- Helicopters and USVs serve as primary warning to small boats that are close to penetrating 500-yard bubble around escorted merchant traffic.
- Vessels penetrating 500-yard bubble are verbally warned.
- Vessels continuing are engaged by nonlethal weapons intending to dissuade further closure on escorted vessel.
- Vessels continuing are engaged by lethal weapons from all available escort platforms in accordance with ROE.

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9.0 CONCLUSION

In this AY2006 integrated project, the MTR SEA-9 team, through the Meyer Institute for Systems Engineering at the Naval Postgraduate School, was tasked by Office of the Assistant Secretary of Defense for Homeland Defense (OASD HD) to develop a conceptual, near-term, joint and interagency system of systems (SoS) in the 5-year timeframe to respond to terrorist threats to the United States that emanate from the Maritime Domain by (1) generating SoS architecture alternatives using existing systems, programs of record, and COTS technologies and developing concepts of operations and (2) recommending a cost-effective SoS that must minimize impact on commerce. The SoS would be deployed in three missions: prevention of a nuclear WMD attack, prevention or defeat of an attack using a merchant ship (SAW), and defeat of a suicide SBA on a high-value target (such as an oil tanker or passenger ferry).

To execute this tasking, the MTR SEA-9 team, as project manager and as lead systems engineer, developed a project management plan (PMP) with which to manage the project and employed the systems engineering approach and the SoS architecting methodology (Section 3) to design the recommended SoS. The PMP provided guidelines and procedures for team formation, project schedule tracking, configuration management, quality assurance, risk mitigation, and contingency planning. The SoS architecting methodology provided an SoS architecture design framework for scoping the problem, generating, modeling and analyzing SoS alternatives, scoring the SoS alternatives, and selecting and implementing the most cost effective and best-performing SoS. Three SoS alternative architectures were considered: TDCE, BUCE, and the Maximum Performance Architecture (Section 7). As integral parts of the SoS architecting methodology, a cost analysis and a simulative analysis (supported by EXTEND™, MINITAB™ 14, FAST, and Excel) led to the following findings of this project.

9.1 OVERALL MARITIME THREAT RESPONSE KEY FINDINGS

- Adequate intelligence is a necessary, but not sufficient, component of a successful homeland security posture. Knowledge of an impending attack must be complemented by robust forces and their concept of operations in order to effectively stop an attack once it is determined with some confidence that it is underway. With such forces in place and with established concepts of operation and rules of engagement, a variety of terrorist attacks can be successful repulsed without significant damage or impact on the homeland or the economy. Intuitively, increased specificity with respect to the intelligence itself makes the problem of acting on such intelligence and responding to the emerging threat easier to handle.

- Responding to maritime terrorist threats requires an integrated, interagency response taking advantage of the specific capabilities and authorities resident in different organizations within the U.S. national security apparatus. Such a response needs to leverage off of preexisting command relationships to maximize the overall probability of system success.

9.1.1 WMD Mission Key Findings

- The majority of research effort in the field of radiation detection is centered on conducting a search as rapidly as possible. Given reasonable intelligence latency of less than 160 hours, search teams could be placed onboard container ships to search the ship for over a week before the ships enter U.S. territorial waters. Such search time enables minutes to be spent on individual container searches and multiple hours spent on individual cargo holds. The potential application of such available time requires a different mindset in terms of detector development and specifications. Use of the Littoral Combat Ship's high speed sprint capability (45+ knots) along with a small fuel capacity addition in its mission module spaces enabled the greatest time to search among all potential Navy and Coast Guard search and escort vessels (over 200 hours to search with 72 hours of intelligence latency; see Figure 9.1). Figure 9.2 shows the relationship between intelligence latency and mean time to search a vessel using LCS to ferry teams to the vessels. Figure 9.3 shows the bases in the Pacific from which such vessels can be intercepted as a function of intelligence latency. As intelligence gets more latent, the forward bases such as Yokosuka become less useful.

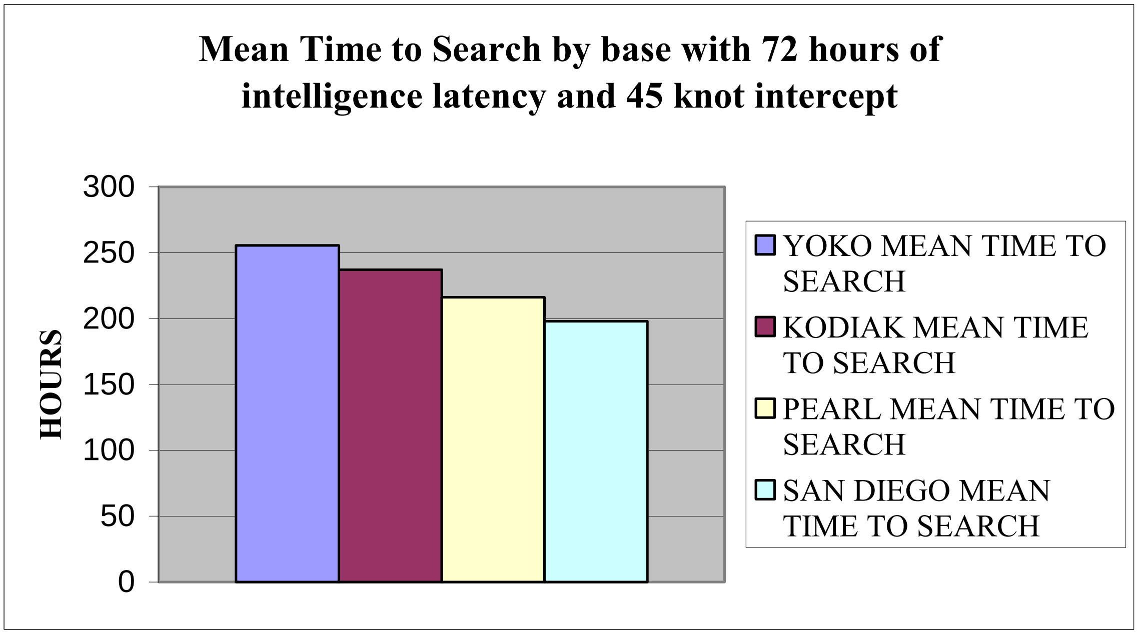

Figure 9-1: Mean Time to Search by Base with LCS and 72 Hours of Intelligence Latency

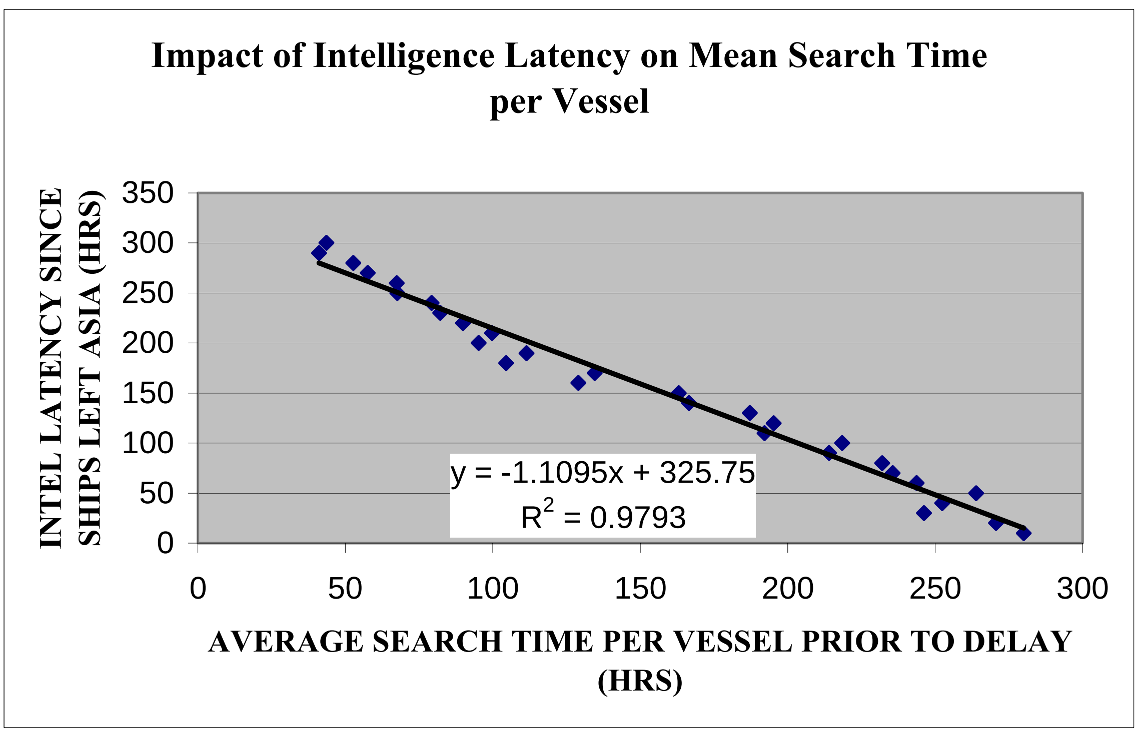

Figure 9-2: Available Search Time as a Function of Intelligence Latency

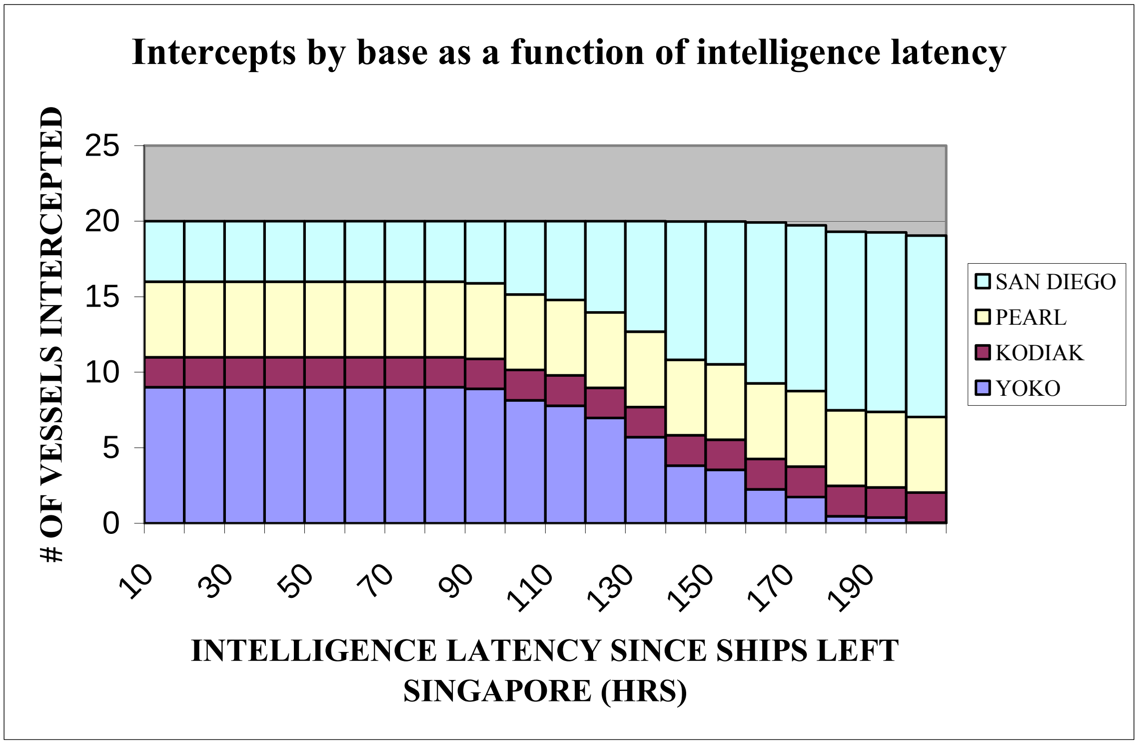

Figure 9-3: Origination Points of Intercept Vessels as a Function of Intelligence Latency

- A layered search protocol involving shipping manifest review, data mining, passive radiation detection, and passive radiation identification appears to be the most useful approach to stopping an attack when intelligence could not specify an exact ship and an exact container. Fusion of sensor data to create a composite picture of radiation amounts, types, and locations on a ship appeared to show promise in quickly determining potential threats on a sizeable container ship. Given search times ranging from 100 to 200 hours per ship, nuclear devices could be detected with high confidence even with slightly vague intelligence.

9.1.2 SAW Mission Key Findings

- The threat of a commandeered ship can be effectively countered through the employment of 10-man "Sea Marshall" teams that are placed onboard potentially threatened vessels with the Harbor Pilot approximately 12 miles beyond the Golden Gate Bridge. These teams serve to secure the five critical control spaces of the vessel in question (Bridge, Engineering

Control, Aft Steering, Engine Room #1 & #2) until the vessel is safely docked within the port. This approach needs to be complemented by a "shore battery" of some kind that can disable the vessel nonlethally, typically by fouling of its propellers and rudders, if it is found that the terrorists are in control of the vessel when the Harbor Pilot and Sea Marshalls attempt to board. There are a variety of weapons technologies that can perform this function. Such a CONOPS precludes any opportunity to recapture the vessel in question once it is determined to be under terrorist control because the time from Harbor Pilot boarding until the vessel might reach the Golden Gate Bridge is potentially only 22 minutes.

- A different concept of operations can be employed that consists of surging Navy and Coast Guard vessels forward to intercept potentially threatened vessels as they come across the Pacific. These vessels can then be boarded and searched to determine the crew's status and use biometrics to attempt to identify any terrorists that are covertly onboard. If terrorists are in control of the vessel in question in this case, there is adequate time to attempt to recapture the vessel from the terrorists, and if such a recapture attempt is not successful, then the ship can be disabled prior to becoming a threat to the United States. This particular approach, while highly effective, places more U.S. personnel in mortal danger and is more costly in resource utilization than the Sea Marshall option. It is more costly in terms of resource utilization because it involves surging up to 20 vessels in the national fleet to intercept the incoming merchant traffic and escort them into San Francisco, all the while supporting the search and escort teams onboard the merchant in question.

- Little data exists with regard to the difficulty and challenges of attempting recapture of a commandeered, large merchant vessel at sea. As such, it is difficult to predict the prospects for success of such action and the amount of damage that such a ship might suffer during an ensuing firefight between U.S. forces and the terrorists onboard, as well as what potential exists for the terrorists in question to facilitate the sinking of the vessel if their plans were interrupted by U.S. MTR force action.

9.1.3 SBA Mission Key Findings

- Even in the fairly narrow water-space areas of San Francisco Bay, attached, close escort of merchant vessels and passenger ferries prove to be approximately 40% more effective than the establishment of random, barrier patrols within the Bay. Further, separate escort vessels (typically four in number per defended asset) prove to be 2% more effective than the emplacement of escort teams onboard the defended merchant vessels and ferries themselves.

- Effective countering of the small boat attack would be much more likely if recreational boat traffic within the bay were prohibited by local authorities and traffic within the Bay were limited to essential commercial traffic. Such a prohibition would require the effective coordination of numerous local law enforcement agencies.

- "Red Cell" analysis of potential terrorist responses to MTR operations suggested that static points of critical infrastructure need to be defended as well as vessels to prevent SBA against refueling piers and the like. This is especially the case if one is to presume that the terrorists would be able to observe that vessels underway were being escorted by armed forces. The analysis also suggests that passenger ferries and oil tankers are more likely terrorist targets than container ships and other dry cargo-carrying vessels.

- While the increased numbers of crew-served weapon stations onboard mid-sized escort ships (over 60 feet in length) and the longer-range visual detection capability associated with the same is found to increase the likelihood of stopping a SBA by approximately 11%, it is an extraordinarily costly approach when compared to just using small escort boats, helicopters, and USVs.

- The use of USVs is a cost-effective option to counter terrorist small boat attacks when used as a complement to traditional escort forces. The USVs increase total time available to engage a threat because they reduce the amount of time required to warn off as yet unidentified incoming boats. The result is an approximately 9% increase in effectiveness for only a 7% increase in cost.

9.2 RECOMMENDATIONS

9.2.1 Recommended Architecture

As previously discussed, the recommendation of the study is to employ the TDCE architecture for purposes of a ready response force to counter maritime terrorist threats. While it is arguable that virtually no counterterrorism force can ever truly be "cost-effective" given the extraordinary cost to prevent acts of terror versus the relatively inexpensive cost of undertaking terrorist acts, the TDCE appears to balance reasonable cost with high levels of effectiveness in the representative missions examined.

9.2.2 MTR CONOPS

As outlined in Section 8, the CONOPS developed in the study for employment by MTR forces in response to emerging terrorist threats take advantage of existing systems but use them in new ways in order to comply with Presidential Directives. When attempting to minimize impact on global maritime commerce the force requirements tended to be significantly higher than what one would typically expect in a situation where ships could be delayed, grouped together in convoys, or other typical military solutions.

9.2.3 Standing Joint Interagency Task Force for Counter-Terrorism

Throughout the study, it is repeatedly demonstrated that the effective response to maritime terrorism requires the integrated efforts of the bulk of the national security apparatus of the United States. There are clear historical precedents demonstrating that preexisting command relationships are a pre-requisite for effective interagency operations. While leaving about 1.3 million Americans homeless causing an estimated

$100 billion in damages, Hurricane Katrina, which made landfall between Grand Isle, Louisiana and Buras-Triumph, Louisiana on Monday August 29, 2005, lends proof that a DoD Task Force is not sufficient to support the operations necessary for civil support in the areas of preplanning, search and rescue, evacuation, humanitarian assistance and pure military presence. Headed by the 82nd Airborne Division, Operation All American Assist's purpose was to evacuate all affected persons out of the area while stabilizing the civil environment to a level that could be maintained and improved on by local, state and federal agencies. Although orders were executed immediately upon receipt and appropriate assistance was provided, a key lesson learned by the 82nd during the Katrina efforts is that "a JTF is effective for Title 10 operations, but establishing a JIATF is the right answer for Defense Support to Civil Authorities (DSCA)."[122] In conjunction with the Homeland Security Act of 2002, the Homeland Security Presidential Directive 5 (HSPD-5), Management of Domestic Incidents, ensures that all levels of government across the nation have a single, unified, national approach toward managing domestic incidents. The Homeland Security Act also tasks the Secretary of Homeland Security to develop and administer a National Response Plan that integrates Federal government domestic prevention, preparedness, response and recovery plans into one all-discipline, all-hazards plan.[123]

The Secretary of Homeland Security is also to develop and administer a National Incident Management System (NIMS) that would unify federal, state and local government capabilities within a National Response Plan framework to prepare for, respond to and recover from domestic events regardless of cause, size or complexity. These three echelons of government capability are three mutually supporting pillars of emergency response and civil support. The intent behind the national response plan (NRP) is to provide the structure and mechanisms for establishing national level policy and operational direction regarding federal support to state and local incident managers. The NRP establishes the federal government's response policy, whereas the NIMS serve as the operational arm of the NRP. The NIMS improves the chain of national command

[122] BG James A. Cerrone, "View from the American Gulf," http://www.amc.army.mil/ausa/
[123] National Incident Management System (NIMS), March 1, 2004, http://www.nimsonline.com/

authority and coordination among the many federal, state, and local organizations; improves planning and readiness; and integrates crisis and consequence management.[124]

As it pertains to the threat response within the maritime domain, these plans have distinct disadvantages in that they identify clearly with what is domestic, whereas this problem needs a directive that can go beyond the homeland domain. Without altering existing authorities or responsibilities of the department leads and agency heads, (including authority to carry out operational activities or to provide or receive intelligence or information) the Maritime Operational Threat Response (MOTR) plan supplements the previously discussed directives and plans. It directs the establishment of an integrated network of national-level maritime command centers to achieve coordinated, unified, timely and effective planning and mission accomplishment by the U.S. government. The plan sets forth lead and supporting Federal agency roles and responsibilities for MOTR based on the following criteria:

- Existing Law
- Desired U.S. government outcome
- Greatest potential magnitude of the threat
- The response capabilities required
- Asset availability
- Authority to act

The MOTR plan directs clear coordination relationships and operational coordination requirements among the lead and supporting MOTR agencies, enabling the U.S. government to act quickly and decisively to counter maritime threats.[125]

However, clear evidence remains that the MOTR plan is not sufficient to counter self-imposed cultural barriers, "turf wars," and other forms of non-cooperation between agencies. A recent Department of Justice Inspector General Report found that during a major counter-terrorism exercises conducted in 2005 the FBI and Coast Guard actually worked against each other because of disagreements over which agency should be the "lead federal agency" during a mock terrorist strike against a passenger ferry.[126] The

[124] National Incident Management System (NIMS), March 1, 2004, http://www.nimsonline.com/
[125] National Strategy for Maritime Security: Maritime Operational Threat Response, October 2005.
[126] Eric Lipton, "Coast Guard, FBI Power Dispute Could Weaken Response to Attack," *The New York Times,* Volume 126, Number 15, 4 April 2006.

report went on to conclude that the MOTR plan has "not eliminated the potential for conflict and confusion in the event of a terrorist incident at a seaport."[127] Recognition of inherent problems in interagency operations without prior coordination predates the attacks of September 11th and the Global War against Terrorism. In particular, many military officers experienced with interagency operations point to the difficulties associated with "ad hoc" responses, and often cite them as "detrimental to mission success."[128] Somalia, Bosnia, Kosovo, and other areas where the United States has intervened over the last decade and a half are riddled with lessons learned of problems arising from a lack of pre-established command relationships among interagencies. According to an Institute for Foreign Policy Analysis (IFPA) April 2002 report (which helped Generals Holland (CINC USSOCOM) and Kernan (CINC USJFCOM) refine their thinking about homeland security),

> . . . based on the U.S. experience in counter-drug operations, establishing a JIATF is considered an important step in making the Interagency process more efficient. Reinforcing, regionally-oriented JIATFs would be useful in identifying resource shortfalls and developing burden-sharing routines, especially in the CT and Counter-WMD areas where expertise and capabilities are limited and found largely only in the military community.[129]

Another example of the model that could be used for a Counter-Terrorism JIATF is the Department of Justice Operation SEA HAWK in the Port of Charleston, South Carolina. There, over 50 local, state, and federal agencies have representatives at a single headquarters where they share information and pool resources to enhance the nation's ability to respond to incidents at the Port of Charleston. Numerous members of the interagency group made reference to how much better cooperation they could achieve between their agencies now that they were co-located and working together every day.

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[127] Eric Lipton, "Coast Guard, FBI Power Dispute Could Weaken Response to Attack," *The New York Times*, Volume 126, Number 15, 4 April 2006.

[128] Thomas Gibbings, Donald Hurley, and Scott Moore, "Interagency Operations Centers: An Opportunity We Can't Ignore," *Parameters*, *U.S. Army War College Quarterly*, Winter 1998, 6 November 1998.

[129] Institute for Foreign Policy Analysis (IFPA), "Homeland Security and Special Operations: Sorting Out Procedures, Capabilities, and Operational Issues," Workshop Report, April 2002.

It is the conclusion of this research team that in order to be prepared for any such terrorist attack, maritime or otherwise, there needs to be a standing interagency task force that is specifically trained and readied for any terrorist threat. Much like the JIATF South mission to plan, conduct and direct interagency detection, monitoring, and sorting operations of air and maritime drug smuggling activities; so to should there be a JIATF dedicated to the same mission regarding the terrorist threat response and the war on terrorism. Creating a counterterrorism JIATF will allow more effective coordination among federal, regional, state and local assets. It should be feasible to leverage off of the existing Standing Joint Force Headquarters—North (SJFHQ-N) and Joint Task Force—North (JTF-N) in existence at United States Northern Command (NORTHCOM) in order to stand up such a JIATF as recommended.

9.2.4 Operational Evaluations of Current Nuclear Detectors

Based upon the research conducted by the team, it is not clear that many of the devices that have been procured or are being considered for procurement by the various federal agencies for detecting nuclear devices or illicit nuclear material have undergone a coherent operational evaluation. From a military perspective, operational evaluations are critical for two reasons. The first is to ascertain whether or not the device being evaluated actually satisfies its performance requirements under operational conditions with representative users performing the required tasks. The second is to assist in developing the concept of operations, tactics, and techniques for how the device in question should be used in the field.

It is certainly possible that such evaluations have been made and are simply not available to the team for use in this study. However, it is the impression of the team throughout that most answers received regarding the performance of certain nuclear detectors against certain types of nuclear devices under certain environmental and other influencing conditions are estimates rather than factual data provided. The team does not feel that the specific questions asked are remarkable as would not have been asked previously during development of such devices. As such, it is felt that extensive operational testing has perhaps not been undertaken. The team concludes that such testing is critical and that the results of such testing would serve to make the entire system more effective at preventing the introduction of a nuclear device into the United States by terrorists.

9.3 FUTURE STUDY

While the findings of this integrated project provide some insights into the SoS solution to the problem of maritime threat response in the 5-year timeframe, further research is needed to provide additional insights and to assess the robustness of the findings. The following are recommendations for future research

- Helicopters are proven to be useful in the counter SBA mission. It is not clear within the context of the SBA model the extent to which such helicopters are useful because of their ability to scout sea space ahead of the protected vessel and warn incoming boats or because of their ability to be a rapid reaction engagement platform or both. Further study could better isolate the value added of armed helicopters to the overall SBA architecture and by determining it could lead to more effective use of such helicopters within the overall concept of operations for the architecture.
- Non-lethal weapons are found to be useful in warding off potential innocent boats that venture too close to protected vessels in the counter SBA mission. However, it is presumed that actual attacking vessels would continue to press their attack even in the face of such nonlethal weapons engagement by MTR forces. This is done to simplify the process and make the requirements of the system more stringent. Further analysis could investigate the extent to which such non-lethal weapons might be effective in countering the terrorist attack, with the added benefit of securing prisoners with potential intelligence value, as well as reducing the likelihood of civilian casualties suffered due to accidental lethal weapons employment.
- A preliminary analysis leads to a formation in which each protected vessel in the counter SBA mission has an escort vessel in front of it, behind it, and to each side of it. Further analysis might provide insight into other formations and their potential benefits including possible reductions in

overall required numbers of escort forces. Along with such analysis, the potential difficulties associated with multiple attackers, decoy attack boats, and other concerted terrorist efforts could be more fully examined than occurred during this study. The concept of the terrorist attack boats engaging the escort vessels rather than simply attempting to bypass the escort vessels en route to the protected vessel would also be worthy of exploration. War gaming found such enemy responses to be highly effective.

- The prohibition on recreational boat traffic upon receipt of intelligence suggesting a small boat attack is implemented effectively. However, what is the best manner to achieve the desired results of clearing the bay of nonessential boat traffic? An entire study could likely be devoted simply to analyzing the best method of clearing the Bay in the quickest amount of time.
- It appears that there is an opportunity for intelligence to be further refined and synthesized by the application of certain data mining principles to the cargo manifest in an attempt to narrow down the search for likely suspect containers in the counter WMD mission. Further study could investigate how such data mining might be achieved and measure its potential effectiveness.
- One Navy or Coast Guard vessel was assumed to be assigned to each of the incoming PAVs in the WMD or SAW mission. This vessel would be the logistical support for the search and escort teams while they were aboard the PAVs. A preliminary analysis suggested that many of the ships remain close enough to one another that multiple PAVs and their associated search and escort teams might be able to be serviced by one U.S. intercepting ship. The first assessment of this, using the Joint Theater Logistics System, showed that up to four vessels tend to remain within 350 miles of one another throughout the transit. However, requiring teams to be shifted and re-supplied via helicopter over several hundred miles enormously complicates the already difficult sustainment problem

encountered by the forces. A further study is warranted into the sundry issues pertaining to logistics support from a non-collocated platform to determine the appropriate number of U.S. interceptors to send out for a given number of incoming PAVs.

- The prospect of attempting to recapture a ship that has been seized by terrorists at sea is largely in the realm of hypothetical discussion. As such, significant assumptions had to be made with respect to the counter SAW mission with regard to the prospects for success as well as the damage potentially suffered by the ship in question. Further analysis, drawing on the expertise of special operations personnel trained in close quarter battle (CQB) as well as having knowledge of the uniqueness of the shipboard environment, would help clarify the potential difficulties as well as identify areas to exploit when attempting such operations.

APPENDIX A SYSTEM OF SYSTEMS FUNCTIONAL DECOMPOSITION

1.0 C4ISR
- 1.1 Command and Control
  - 1.1.1 Command Forces
    - 1.1.1.1 Plan Operation
      - 1.1.1.1.1 Assemble Data
        - 1.1.1.1.1.1 Acquire Intelligence
          - 1.1.1.1.1.1.1 Acquire Intelligence From MDA
          - 1.1.1.1.1.1.2 Acquire Own Force S&R
          - 1.1.1.1.1.1.3 Acquire Data from Port Authority
          - 1.1.1.1.1.1.4 Acquire AIS Data
        - 1.1.1.1.1.2 Acquire COP
          - 1.1.1.1.1.2.1 Acquire GCCS COP
          - 1.1.1.1.1.2.2 Acquire Own Force COP
        - 1.1.1.1.1.3 Acquire Peer Security Inputs
      - 1.1.1.1.2 Analyze Data
        - 1.1.1.1.2.1 Develop Situational Awareness
        - 1.1.1.1.2.2 Develop Courses of Action (COA)
          - 1.1.1.1.2.2.1 Establish Priority
          - 1.1.1.1.2.2.2 Develop Optimal Pairing Scheme
          - 1.1.1.1.2.2.3 Develop Optimal Intercept Tracks
          - 1.1.1.1.2.2.4 Develop Targeted Search Plan
      - 1.1.1.1.3 Select COA
        - 1.1.1.1.3.1 Update ROE
        - 1.1.1.1.3.2 Update Commander's Intent
        - 1.1.1.1.3.3 Disseminate Orders
          - 1.1.1.1.3.3.1 Transmit Orders
          - 1.1.1.1.3.3.2 Brief Orders
          - 1.1.1.1.3.3.3 Delegate Briefing
    - 1.1.1.2 Direct Operation
      - 1.1.1.2.1 Activate Forces
        - 1.1.1.2.1.1 Contact Deployed Forces
          - 1.1.1.2.1.1.1 Contact U.S. Forces
          - 1.1.1.2.1.1.2 Contact Coalition Forces
        - 1.1.1.2.1.2 Contact Surge Forces
      - 1.1.1.2.2 Assign Resources to AVs
        - 1.1.1.2.2.1 Assign Sensors
        - 1.1.1.2.2.2 Assign Weapons
      - 1.1.1.2.3 Direct Engagement
        - 1.1.1.2.3.1 Transmit COP

1.1.1.2.3.2 Issue Commands
1.1.1.2.3.3 Position Forces
1.1.1.3 Coordinate Operation
1.1.1.3.1 Disseminate COP Updates
1.1.1.3.2 Disseminate Priorities
1.1.1.3.3 Deconflict Forces
1.1.1.4 Control Operation
1.1.1.4.1 Monitor Operation
1.1.1.4.2 Receive Updates
1.1.1.4.3 Reassign Forces
1.1.2 Interface with external C2
1.1.2.1 Interface with Higher Authority
1.1.2.1.1 Request Permission to Act
1.1.2.1.2 Receive Permission to Act
1.1.2.1.3 Provide Status Updates
1.1.2.2 Interface with Coalition C2
1.1.2.2.1 Coordinate Operations
1.1.2.2.2 Transmit Information
1.1.2.2.3 Receive Information
1.1.2.3 Interface with GCCS
1.1.2.3.1 Receive GCCS Data
1.1.2.3.2 Provide GCCS Updates
1.1.2.4 Interface with MDA
1.1.2.4.1 Receive Intelligence Data
1.1.2.4.2 Request Intelligence Updates
1.1.2.4.3 Request Additional Intelligence Data
1.2 Communicate – Provide Onshore, Ship Based and Sea Based Communication Network
1.2.1 Provide VOX/Data
1.2.1.1 Transmit Voice, Data, Imagery
1.2.1.2 Receive Voice, Data, Imagery
1.2.2 Network MTR nodes
1.2.2.1 Provide Sufficient Nodes
1.2.2.2 Provide Robust Network
1.2.2.3 Minimize Downtime
1.2.2.4 Provide Redundancy
1.2.2.5 Minimize Data Corruption
1.2.2.6 Minimize Nodal Failures
1.2.2.7 Reroute Transmissions around Failed Nodes
1.2.3 Receive MDA Intelligence
1.2.3.1 Maintain Link with MDA
1.2.3.2 Collect, Prioritize, Fuse Information
1.2.3.3 Disseminate Information
1.3 Compute
1.3.1 Information Assurance
1.3.1.1 Provide Confidentiality

1.3.1.1.1 Support Multi-Security Level Login
1.3.1.1.2 Personnel and Physical Security
1.3.1.1.3 Provide Discrete Access/Mandatory Access Control
1.3.1.1.4 High Assurance System
1.3.1.1.5 Harden System
1.3.1.1.5.1 Software Patches
1.3.1.1.5.2 Turn off Unwanted Services
1.3.1.1.6 Prevent Unauthorized User from Accessing Data While in Transmission
1.3.1.1.7 Prevent Unauthorized User from Accessing Data in Storage
1.3.1.1.8 Separate Classified Data Storage Area
1.3.1.2 Provide Integrity
1.3.1.2.1 Prevent Unknown Data Modification
1.3.1.2.2 Perform Audit Check for Changes to Data
1.3.1.3 Provide Authenticity
1.3.1.3.1 Ensure the User/Data are Authentic
1.3.1.3.2 Provide Authentication by Password, Token, Biometric
1.3.1.3.3 Provide Authentication by Key, PKI
1.3.1.4 Provide Availability
1.3.1.4.1 Provide Timely Response to Data
1.3.1.4.2 Provide Redundant System for Synchronization, Backup and Disaster Recovery
1.3.1.4.3 Provide Non-Single Point of Failure
1.3.1.5 Network Security
1.3.1.5.1 Employ Defense in Depth Strategy
1.3.2 Data Fusion
1.3.2.1 Data Association
1.3.2.1.1 Filter Iirrelevant Data
1.3.2.1.2 Categorize Relationship to Scenario
1.3.2.2 Data Analysis
1.3.2.2.1 Refine Data – Classification and Identification Using Rule-Based Prediction
1.3.2.2.2 Refine/Update Situation – Deploy Function Status with Current Traffic
1.3.2.3 Threat Assessment Based on Scenarios
1.3.2.4 Automate Processes and Collaborative Tools
1.3.2.5 Request for Data Recollection
1.3.2.6 Collaborative Feedback
1.3.2.6.1 Provide Reasoning Engine
1.3.2.6.2 Predict Scenario Occurrence
1.3.2.7 Provide "No-MDA" Function
1.4 Provide Intelligence
1.4.1 Form Overall Operational Picture

1.4.2 Analyze Operation Needs of Individual Functional Teams
1.4.3 Provide Customized COP Overlays to Teams

2.0 Prepare the Battlespace
- 2.1 Activate Security Measures
  - 2.1.1 Prepare Critical Infrastructure
    - 2.1.1.1 Heighten HSAS
      - 2.1.1.1.1 Initiate Command to DHS to Heighten HSAS
      - 2.1.1.1.2 Receive Compliance that HSAS Has Been Heightened
    - 2.1.1.2 Upgrade/Augment Existing Security Forces
      - 2.1.1.2.1 Notify Gas Line Personnel on or Near Piers
      - 2.1.1.2.2 Add Security Teams Onboard Essential Boat Traffic
      - 2.1.1.2.3 Upgrade/Augment Security Teams at Points of Interest
  - 2.1.2 Activate Preplanned Operation Orders
    - 2.1.2.1 Place Specialized Teams on Alert
      - 2.1.2.1.1 Contact Specialized Teams
      - 2.1.2.1.2 Assemble Specialized Teams
      - 2.1.2.1.3 Activate Specialized Teams
    - 2.1.2.2 Get USCG to Activate Specific MARSEC Plan
    - 2.1.2.3 Restrict Non-Essential Boat Traffic
      - 2.1.2.3.1 Initiate Command to USCG to Post a "Notice to Mariners"
      - 2.1.2.3.2 Receive Compliance that "Notice to Mariners" Has Been Posted
      - 2.1.2.3.3 Activate Boat Traffic Restriction Teams
- 2.2 Assemble Forces
  - 2.2.1 Activate Required Personnel
    - 2.2.1.1 Decide Team Composition
    - 2.2.1.2 Contact all Necessary Personnel
    - 2.2.1.2 Muster Personnel
  - 2.2.2 Issue Equipment
    - 2.2.2.1 Gather Specialized Equipment
    - 2.2.2.2 Provide Arms and Protective Gear
  - 2.2.3 Prepare Deployment Platforms
    - 2.2.3.1 Set Mission Specific Configurations
- 2.3 Deploy Forces
  - 2.3.1 Embark Deployment Platforms
  - 2.3.2 Move Deployment Platforms into Position
  - 2.3.3 Move Teams to Attacking Vessel
    - 2.3.3.1 Gather Teams for Debarkation of Deployment Platforms
    - 2.3.3.2 Provide Teams with a Means of Transport to the Attacking Vessel
  - 2.3.4 Recover Teams from Attacking Vessel
    - 2.3.4.1 Gather Teams for Debarkation of Attacking Vessel

2.3.4.2 Provide Teams with a Means of Transport to the Deployment Platforms

3.0 Find/Fix Threat
- 3.1 Detect Threat
  - 3.1.1 Scan Area of Interest
    - 3.1.1.1 Scan Mechanically
      - 3.1.1.1.1 Position Automated Scan Device
    - 3.1.1.2 Scan Manually
      - 3.1.1.2.1 Position Search Crew Member
      - 3.1.1.2.2 Conduct Layout Specific Search
  - 3.1.2 Process Data from Scan
    - 3.1.2.1 Process Mechanically
    - 3.1.2.2 Process Manually
- 3.2 Identify Threat
  - 3.2.1 Analyze Data On-Site
    - 3.2.1.1 Analyze Mechanically
    - 3.2.1.2 Analyze Manually
  - 3.2.2 Analyze Data Off-Site
    - 3.2.2.1 Analyze Mechanically
    - 3.2.2.2 Analyze Manually
  - 3.2.3 Quantify Threat
    - 3.2.3.1 Quantify Mechanically
    - 3.2.3.2 Quantify Manually
- 3.3 Assess Threat
  - 3.3.1 Determine Intent
    - 3.3.1.1 Observe Declarations
    - 3.3.1.2 Observe Actions
  - 3.3.2 Determine Damage Potential
    - 3.3.2.1 Solicit Intelligence
    - 3.3.2.2 Determine Destructive Potential
    - 3.3.2.3 Determine Execution Time

4.0 Finish Threat
- 4.1 Use Non-lethal measures
  - 4.1.1 Guard HVU from Internal Threat
    - 4.1.1.1 Guard Control Spaces
    - 4.1.1.2 Guard Crew
  - 4.1.2 Guard HVU from External Threat
    - 4.1.2.1 Escort HVU with Other Units
    - 4.1.2.2 Place Forces on HVU
  - 4.1.3 Warn
    - 4.1.3.1 Use Visual
    - 4.1.3.2 Use Auditory
  - 4.1.4 Conduct Non-lethal Weapon Engagement
    - 4.1.4.1 Use Anti-Personnel NLW
      - 4.1.4.1.1 Target
      - 4.1.4.1.2 Fire Weapon

4.1.4.1.3 Assess Engagement
4.1.4.2 Use Anti-Vehicle NLW
4.1.4.2.1 Target
4.1.4.2.2 Fire Weapon
4.1.4.2.3 Assess Engagement
4.1.5 Shoulder
4.1.6 Tow Disabled Vessel
4.1.7 Conduct SAR
4.2 Use Lethal Measures
4.2.1 Disable
4.2.1.1 Target
4.2.1.2 Fire Weapon
4.2.1.3 Assess Engagement
4.2.2 Sink/Destroy
4.2.2.1 Detect/Track
4.2.2.2 Classify
4.2.2.3 Target
4.2.2.4 Fire Weapon
4.2.2.5 Assess Engagement
4.2.3 Recapture
4.2.3.1 Board AV
4.2.3.2 Secure Control Spaces
5.0 Sustain
5.1 Support Units
5.1.1 Deliver Consumables to Units
5.1.1.1 Deliver to Military Ships
5.1.1.2 Deliver to Non-Military Ships
5.1.2 Refuel Platforms
5.1.2.1 Refuel Ships
5.1.2.2 Refuel Boats
5.1.2.3 Refuel Aircraft
5.1.3 Provide Manning for Sustained Operations
5.1.3.1 Receive Manning Reports
5.1.3.2 ID Manning Deficiencies
5.1.3.3 Locate Manning Sources
5.1.3.4 Transport Manning to Units
5.1.3.4.1 Transport Manning to Military Units at Sea
5.1.3.4.2 Transport Manning to Non-Military Units at Sea
5.1.3.4.3 Transport Manning to Military Units Inport
5.1.4 Provide Barracks
5.1.4.1 Provide Barracks for Units Onboard Military Ships at Sea
5.1.4.2 Provide Barracks for Units Onboard Non-Military Ships at Sea
5.1.4.3 Provide Barracks for Units Inport
5.2 Maintain Units
5.2.1 Identify Maintenance Deficiencies

- 5.2.1.1 Receive Unit Capability Reports
- 5.2.1.2 Asses System Capability
- 5.2.1.3 Correct System Deficiency

5.2.2 Provide Non-Depot Level Maintenance
- 5.2.2.1 Identify Components
- 5.2.2.2 Stock Spares
- 5.2.2.3 Replace Components

5.2.3 Time to Provide Depot Level Maintenance
- 5.2.3.1 Identify Prescheduled Depot-Level Maintenance
- 5.2.3.2 Enable Unit Rotation
  - 5.2.3.2.1 Identify Unit Replacements
  - 5.2.3.2.2 Schedule Unit Turnover

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APPENDIX B REQUIREMENTS ALLOCATION

Requirements Allocation - C4ISR Time

Requirement	WMD	SAW	SBA
1.0 C4ISR	-	-	-
Activation Time ?	1 Hr	-	-
Orders/ROE Time ?	23 Hrs	-	-
Operational Response Time ?	30 Min	-	-
Initial Response Time ?	-	30 Min	1 Hr
1.1 Command & Control	-	-	-
Activation Time ?	49 Min	-	-
Orders/ROE Time ?	11 Hrs	-	-
Operational Response Time ?	19 Min	-	-
Initial Response Time ?	-	19 Min	49 Min
1.1.1 Command Forces	-	-	-
Activation Time ?	30 Min	-	-
Orders/ROE Time ?	6 Min	-	-
Operational Response Time ?	14 Min	-	-
Initial Response Time ?	-	14 Min	30 Min
1.1.2 Interface with external C2	-	-	-
Activation Time ?	19 Min	-	-
Orders/ROE Time ?	5 Min	-	-
Operational Response Time ?	5 Min	-	-
Initial Response Time ?	-	5 Min	19 Min
1.2 Communicate	-	-	-
Activation Time ?	10 Min	-	-
Orders/ROE Time ?	4 Hrs	-	-
Operational Response Time ?	10 Min	-	-
Initial Response Time ?	-	10 Min	10 Min
1.2.1 Provide VOX / Data	-	-	-
Activation Time ?	10 Min	-	-
Orders/ROE Time ?	4 Hrs	-	-
Operational Response Time ?	10 Min	-	-
Initial Response Time ?	-	10 Min	10 Min
1.2.2 Network MTR Nodes ?	-	-	-
Activation Time ?	10 Min	-	-
Orders/ROE Time ?	4 Hrs	-	-
Operational Response Time ?	10 Min	-	-
Initial Response Time ?	-	10 Min	10 Min
1.2.3 Receive MDA Intell	-	-	-
Activation Time ?	10 Min	-	-
Orders/ROE Time ?	4 Hrs	-	-
Operational Response Time ?	10 Min	-	-
Initial Response Time ?	-	10 Min	10 Min
1.3 Compute	-	-	-
Activation Time ?	34 Min	-	-
Orders/ROE Time ?	5 Hrs	-	-
Operational Response Time ?	14 Min	-	-
Initial Response Time ?	-	14 Min	34 Min
1.3.1 Information Assurance	-	-	-
Activation Time ?	1 Min	-	-
Orders/ROE Time ?	1 Min	-	-
Operational Response Time ?	1 Min	-	-
Initial Response Time ?	-	1 Min	1 Min
1.3.2 Data Fusion	-	-	-
Activation Time ?	33 Min	-	-
Orders/ROE Time ?	5 Hrs	-	-
Operational Response Time ?	13 Min	-	-
Initial Response Time ?	-	13 Min	33 Min
1.4 Provide Intell	-	-	-
Activation Time ?	1 Min	-	-
Orders/ROE Time ?	1 Min	-	-
Operational Response Time ?	1 Min	-	-
Initial Response Time ?	-	1 Min	1 Min
1.4.1 Form Overall Ops Picture	-	-	-
Activation Time ?	1 Min	-	-
Orders/ROE Time ?	1 Min	-	-
Operational Response Time ?	1 Min	-	-

Requirements Allocation - C4ISR Ps

Requirement	WMD	SAW	SBA
1.0 Ps of C4ISR ?	0.999	0.999	0.999
1.1 Ps of Command & Control ?	0.99975	0.99975	0.99975
1.1.1 Ps of Command Forces ?	0.999875	0.999875	0.999875
1.1.2 Ps of Interface with external C2 ?	0.999875	0.999875	0.999875
1.2 Ps of Communicate ?	0.99975	0.99975	0.99975
1.2.1 Ps of Provide VOX / Data ?	0.999917	0.999917	0.999917
1.2.2 Ps of Network MTR Nodes ?	0.999917	0.999917	0.999917
1.2.3 Ps of Receive MDA Intell ?	0.999917	0.999917	0.999917
1.3 Ps of Compute ?	0.99975	0.99975	0.99975
1.3.1 Ps of Information Assurance ?	0.999875	0.999875	0.999875
1.3.2 Ps of Data Fusion ?	0.999875	0.999875	0.999875
1.4 Ps of Provide Intell ?	0.99975	0.99975	0.99975
1.4.1 Ps of Form Overall Ops Picture ?	0.999917	0.999917	0.999917
1.4.2 Ps of Analyze Operational Needs ?	0.999917	0.999917	0.999917
1.4.3 Ps of Provide Customized COPs ?	0.999917	0.999917	0.999917

Requirements Allocation - Prepare the Battlespace Time

Requirement	WMD (Hrs)	SAW (Hrs)	SBA (Min)
2.0 Time to Prepare the Battlespace ?	124	36	240
2.1 Time to Activate Security Measures ?	24	24	240
2.1.1 Time to Prepare Critical Infrastructure ?	12	12	240
2.1.1.1 Time to Heighten HSAS Level ?	1.5	1.5	60
2.1.1.1.1 Time to Initiate Command to DHS to Heighten HSAS ?	0.5	0.5	30
2.1.1.1.2 Time to Receive Compliance That HSAS Has Been Heightened ?	1	1	30
2.1.1.2 Time to Upgrade/Augment Existing Security Forces ?	-	12	240
2.1.1.2.1 Time to Notify Gas Line Personnel On or Near Piers ?	-	4	30
2.1.1.2.2 Time to Add Security Teams Onboard Essential Boat Traffic ?	-	-	240
2.1.1.2.3 Time to Upgrade/Augment Security Teams at Points of Interest ?	-	12	120
2.1.2 Time to Activate Preplanned Operation Orders ?	24	1	60
2.1.2.1 Time to Place Specialized Teams on Alert ?	24	1	-
2.1.2.1.1 Time to Contact Specialized Teams ?	2	0.25	-
2.1.2.1.2 Time to Assemble Specialized Teams ?	12	0.25	-
2.1.2.1.3 Time to Activate Specialized Teams ?	10	0.5	-
2.1.2.2 Time to Get USCG to Activate Specific MARSEC Plan ?	1	1	30
2.1.2.3 Time to Begin Restriction of Non-Essential Boat Traffic ?	-	-	60
2.1.2.3.1 Time to Initiate Command to USCG to Post a "Notice to Mariners" ?	-	-	30
2.1.2.3.2 Time to Receive Compliance That "Notice to Mariners" Has Been Posted ?	-	-	30
2.1.2.3.3 Time to Activate Boat Traffic Restriction Teams ?	-	-	30
2.2 Time to Assemble and Prepare Teams / Platforms ?	24	24	55
2.2.1 Time to Activate Required Personnel ?	24	24	55
2.2.1.1 Time to Decide Team Composition ?	2	2	15
2.2.1.2 Time to Contact All Necessary Personnel ?	2	2	15
2.2.1.3 Time to Muster Personnel ?	20	20	25
2.2.2 Time to Issue Equipment ?	14	6	50
2.2.2.1 Time to Gather Specialized Equipment ?	12	4	30
2.2.2.2 Time to Provide Arms, Protective Gear, and Equipment ?	2	2	20
2.2.3 Time to Prepare Deployment Platforms ?	16	16	45
2.2.3.1 Time to Set Mission Specific Configurations ?	16	16	45
2.3 Time to Deploy Forces ?	100	12	50
2.3.1 Time to Embark Deployment Platforms ?	1	1	5
2.3.2 Time to Move Deployment Platforms into Position ?	96	12	25
2.3.3 Time to Move Teams to Attacking Vessel ?	2	1.5	10
2.3.3.1 Time to Gather Teams for Debarkation of Deployment Dlatforms ?	0.5	0.5	0.5
2.3.3.2 Time to Provide Teams with a Means of Transport to the Attacking Vessel ?	1.5	1	9.5
2.3.4 Time to Recover Teams from Attacking Vessel ?	2	1	10
2.3.4.1 Time to Gather Teams for Debarkation of Attacking Vessel ?	0.5	0.5	0.5
2.3.4.2 Time to Provide Teams with a Means of Transport to Deployment Platforms ?	1.5	0.5	9.5

Requirements Allocation - Prepare the Battlespace Ps

Requirement	WMD	SAW	SBA
2.0 Ps of Prepare the Battlespace ?	0.999	0.999	0.999
2.1 Ps of Activate Security Measures ?	0.999667	0.999667	0.999667
2.1.1 Ps of Prepare Critical Infrastructure ?	0.999833	0.999833	0.999833
2.1.1.1 Ps of Heighten HSAS Level ?	0.999833	0.999917	0.999917
2.1.1.1.1 Ps of Initiate Command to DHS to Heighten HSAS ?	0.999917	0.999958	0.999958
2.1.1.1.2 Ps of Receive Compliance that HSAS Has Been Heightened ?	0.999917	0.999958	0.999958
2.1.1.2 Ps of Upgrade/Augment Existing Security Forces ?	-	0.999917	0.999917
2.1.1.2.1 Ps of Notify Gas Line Personnel on or Near Piers ?	-	0.999958	0.999972
2.1.1.2.2 Ps of Add Security Teams Onboard Essential Boat Traffic ?	-	-	0.999972
2.1.1.2.3 Ps of Upgrade/Augment Security Teams at Points of Interest ?	-	0.999958	0.999972
2.1.2 Ps of Activate Preplanned Operation Orders ?	0.999833	0.999833	0.999833
2.1.2.1 Ps of Place Specialized Teams on Alert ?	0.999917	0.999917	-
2.1.2.1.1 Ps of Contact Specialized Teams ?	0.999972	0.999972	-
2.1.2.1.2 Ps of Assemble Specialized Teams ?	0.999972	0.999972	-
2.1.2.1.3 Ps of Activate Specialized Teams ?	0.999972	0.999972	-
2.1.2.2 Ps of Get USCG to Activate Specific MARSEC Plan ?	0.999917	0.999917	0.999917
2.1.2.3 Ps of Begin Restriction of Non-Essential Boat Traffic ?	-	-	0.999917
2.1.2.3.1 Ps of Initiate Command to USCG to Post a "Notice to Mariners" ?	-	-	0.999972
2.1.2.3.2 Ps of Receive Compliance that "Notice to Mariners" Has Been Posted ?	-	-	0.999972
2.1.2.3.3 Ps of Activate Boat Traffic Restriction Teams ?	-	-	0.999972
2.2 Ps of Assemble and Prepare Teams / Platforms ?	0.999667	0.999667	0.999667
2.2.1 Ps of Activate Required Personnel ?	0.999889	0.999889	0.999889
2.2.1.1 Ps of Decide Team Composition ?	0.999963	0.999963	0.999963
2.2.1.2 Ps of Contact all Necessary Personnel ?	0.999963	0.999963	0.999963
2.2.1.3 Ps of Muster Personnel ?	0.999963	0.999963	0.999963
2.2.2 Ps of Issue Equipment ?	0.999889	0.999889	0.999889
2.2.2.1 Ps of Gather Specialized Equipment ?	0.999944	0.999944	0.999944
2.2.2.2 Ps of Provide Arms, Protective Gear, and Equipment ?	0.999944	0.999944	0.999944
2.2.3 Ps of Prepare Deployment Platforms ?	0.999889	0.999889	0.999889
2.2.3.1 Ps of Set Mission Specific Configurations ?	0.999889	0.999889	0.999889
2.3 Ps of Deploy Forces ?	0.999667	0.999667	0.999667
2.3.1 Ps of Embark Deployment Platforms ?	0.999917	0.999917	0.999833
2.3.2 Ps of Move Deployment Platforms into Position ?	0.999917	0.999917	0.999833
2.3.3 Ps of Move Teams to Attacking Vessel ?	0.999917	0.999917	-
2.3.3.1 Ps of Gather Teams for Debarkation of Deployment Platforms ?	0.999958	0.999958	-
2.3.3.2 Ps of Provide Teams with a Means of Transport to the Attacking Vessel ?	0.999958	0.999958	-
2.3.4 Ps of Recover Teams from Attacking Vessel ?	0.999917	0.999917	-
2.3.4.1 Ps of Gather Teams for Debarkation of Attacking Vessel ?	0.999958	0.999958	-
2.3.4.2 Ps of Provide Teams with a Means of Transport to Deployment Platforms ?	0.999958	0.999958	-

Requirements Allocation - Find / Fix Time

Requirement	WMD (Min)	SAW (Min)	SBA (Sec)
3.0 Time to Find / Fix Threat ?	3	TBD	15
3.1 Time to Detect Threat ?	3	TBD	15
3.1.1 Time to Scan Area of Interest ?	3	TBD	15
3.1.1.1 Time to Scan Mechanically ?	3	TBD	15
3.1.1.1.1 Time to Position Automated Scan Device ?	3	TBD	15
3.1.1.2 Time to Scan Manually ?	3	TBD	15
3.1.1.2.1 Time to Position Search Crew Member ?	3	TBD	15
3.1.1.2.2 Time to Conduct Layout Specific Search ?	3	TBD	15
3.1.2 Time to Process Data from Scan ?	3	TBD	15
3.1.2.1 Time to Process Mechanically ?	3	TBD	15
3.1.2.2 Time to Process Manually ?	3	TBD	15
3.2 Time to Identify Threat ?	3	TBD	15
3.2.1 Time to Analyze Data On-Site ?	3	TBD	15
3.2.1.1 Time to Analyze Mechanically ?	3	TBD	15
3.2.1.2 Time to Analyze Manually ?	3	TBD	15
3.2.2 Time to Analyze Data Off-Site ?	3	TBD	15
3.2.2.1 Time to Analyze Mechanically ?	3	TBD	15
3.2.2.2 Time to Analyze Manually ?	3	TBD	15
3.2.3 Time to Quantify Threat ?	3	TBD	15
3.2.3.1 Time to Quantify Mechanically ?	3	TBD	15
3.2.3.2 Time to Quantify Manually ?	3	TBD	15
3.3 Time to Assess threat ?	3	TBD	15
3.3.1 Time to Determine Intent ?	3	TBD	15
3.3.1.1 Time to Observe Declarations ?	3	TBD	15
3.3.1.2 Time to Observe Actions ?	3	TBD	15
3.3.2 Time to Determine Damage Potential ?	3	TBD	15
3.3.2.1 Time to Solicit Intelligence ?	3	TBD	15
3.3.2.2 Time to Determine Destructive Potential ?	3	TBD	15
3.3.2.3 Time to Determine Execution Time ?	3	TBD	15

Ships = 20 and Maximum TEUs = 9400

Requirements Allocation - Find / Fix Ps

Requirement	WMD	SAW	SBA
3.0 Ps of Find / Fix Threat ?	0.9600000	0.9900000	0.9400000
3.1 Ps of Detect Threat ?	0.9600000	0.9900000	0.9400000
3.1.1 Ps of Scan Area of Interest ?	0.9797959	0.9949874	0.9695360
3.1.1.1 Ps of Scan Mechanically ?	0.9898464	0.9974906	0.9846502
3.1.1.1.1 Ps of Position Automated Scan Device ?	0.9898464	0.9974906	0.9846502
3.1.1.2 Ps of Scan Manually ?	0.9898464	0.9974906	0.9846502
3.1.1.2.1 Ps of Position Search Crew Member ?	0.9949102	0.9987445	0.9922954
3.1.1.2.2 Ps of Conduct Layout Specific Search ?	0.9949102	0.9987445	0.9922954
3.1.2 Ps of Process Data from Scan ?	0.9797959	0.9949874	0.9695360
3.1.2.1 Ps of Process Mechanically ?	0.9898464	0.9974906	0.9846502
3.1.2.2 Ps of Process Manually ?	0.9898464	0.9974906	0.9846502
3.2 Ps of Identify Threat ?	0.9999990	0.9999990	0.9999990
3.2.1 Ps of Analyze Data On-Site ?	0.9999997	0.9999997	0.9999997
3.2.1.1 Ps of Analyze Mechanically ?	0.9999998	0.9999998	0.9999998
3.2.1.2 Ps of Analyze Manually ?	0.9999998	0.9999998	0.9999998
3.2.2 Ps of Analyze Data Off-Site ?	0.9999997	0.9999997	0.9999997
3.2.2.1 Ps of Analyze Mechanically ?	0.9999998	0.9999998	0.9999998
3.2.2.2 Ps of Analyze Manually ?	0.9999998	0.9999998	0.9999998
3.2.3 Ps of Quantify Threat ?	0.9999997	0.9999997	0.9999997
3.2.3.1 Ps of Quantify Mechanically ?	0.9999998	0.9999998	0.9999998
3.2.3.2 Ps of Quantify Manually ?	0.9999998	0.9999998	0.9999998
3.3 Ps of Assess threat ?	0.9999990	0.9999990	0.9999990
3.3.1 Ps of Determine Intent ?	0.9999995	0.9999995	0.9999995
3.3.1.1 Ps of Observe Declarations ?	0.9999997	0.9999997	0.9999997
3.3.1.2 Ps of Observe Actions ?	0.9999997	0.9999997	0.9999997
3.3.2 Ps of Determine Damage Potential ?	0.9999995	0.9999995	0.9999995
3.3.2.1 Ps of Solicit Intelligence ?	0.9999998	0.9999998	0.9999998
3.3.2.2 Ps of Determine Destructive Potential ?	0.9999998	0.9999998	0.9999998
3.3.2.3 Ps of Determine Execution Time ?	0.9999998	0.9999998	0.9999998

Note: P(False Alarm) for Detect Threat in WMD Scenario must be ? .000001

Ships = 20 and Maximum TEUs = 9400

Requirements Allocation - Finish Time

Requirement	WMD (Min)	SAW (Min)	SBA (Sec)
4.0 Time to Finish Threat ?	21	21	15
4.1 Time to Use Non-Lethal Measures ?	21	21	15
4.1.1 Time to Guard HVU from Internal Threat ?	-	**	-
4.1.1.1 Time to Guard Control Spaces ?	-	**	-
4.1.1.2 Time to Guard Crew ?	-	**	-
4.1.2 Time to Guard HVU from External Threat ?	-	-	**
4.1.2.1 Time to Escort HVU with Other Units ?	-	-	**
4.1.2.2 Time to Place Forces on HVU ?	-	-	**
4.1.3 Time to Warn ?	A*	A*	A*
4.1.3.1 Time to Use Visual ?	a	a	a
4.1.3.2 Time to Use Auditory ?	b	b	b
4.1.4 Time to Conduct Non-lethal Weapon Engagement ?	A*	A*	A*
4.1.4.1 Time to Use Anti-Personnel NLW ?	a	a	a
4.1.4.1.1 Time to Target ?	b	b	b
4.1.4.1.2 Time to Fire Weapon ?	c	c	c
4.1.4.1.3 Time to Assess Engagement ?	d	d	d
4.1.4.2 Time to Use Anti-Vehicle NLW ?	A*	A*	A*
4.1.4.2.1 Time to Target ?	a	a	a
4.1.4.2.2 Time to Fire Weapon ?	b	b	b
4.1.4.2.3 Time to Assess Engagement ?	c	c	c
4.1.5 Time to Shoulder ?	A*	A*	A*
4.1.6 Time to Tow Disabled Vessel ?	**	**	**
4.1.7 Time to Conduct SAR ?	**	**	**
4.2 Time to Use Lethal Measures ?	21	21	15
4.2.1 Time to Disable ?	A*	A*	A*
4.2.1.1 Time to Target ?	a	a	a
4.2.1.2 Time to Fire Weapon ?	b	b	b
4.2.1.3 Time to Assess Engagement ?	c	c	c
4.2.2 Time to Sink/Destroy ?	A*	A*	A*
4.2.2.1 Time to Detect/Track ?	a	a	a
4.2.2.2 Time to Classify ?	b	b	b
4.2.2.3 Time to Target ?	c	c	c
4.2.2.4 Time to Fire Weapon ?	d	d	d
4.2.2.5 Time to Assess Engagement ?	e	e	e
4.2.3 Time to Recapture ?	-	A*	-
4.2.3.1 Time to Board AV ?	-	a	-
4.2.3.2 Time to Secure Control Spaces ?	-	b	-

Notes: A* = A* is sum of times for subfunctions, must be ? functional requirement
** = function/subfunction occurs automatically in this scenario or is not required for success
a,b,c,d,e indicate numbers to be summed into A*

Requirements Allocation - Finish Ps

Requirement	WMD	SAW	SBA
4.0 Ps of Finish Threat ?	0.9900	0.9100	0.8750
4.1 Ps of Use Non-lethal Measures ?	-	0.9100	0.8750
4.1.1 Ps of Guard HVU from Internal Threat ?	-	0.9100	**
4.1.1.1 Ps of Guard Control Spaces ?	-	0.9539	**
4.1.1.2 Ps of Guard Crew ?	-	0.9539	**
4.1.2 Ps of Guard HVU from External Threat ?	-	n/a	0.9900
4.1.2.1 Ps of Escort HVU with Other Units ?	-	n/a	0.9949
4.1.2.2 Ps of PlaceForces on HVU ?	-	n/a	0.9949
4.1.3 Ps of Warn ?	**	**	**
4.1.3.1 Ps of Use Visual ?	**	**	**
4.1.3.2 Ps of Use Auditory ?	**	**	**
4.1.4 Ps of Conduct Non-lethal Weapon Engagement ?	**	**	**
4.1.4.1 Ps of Use Anti-Personnel NLW ?	**	**	**
4.1.4.1.1 Ps of Target ?	**	**	**
4.1.4.1.2 Ps of Fire Weapon ?	**	**	**
4.1.4.1.3 Ps of Assess Engagement ?	**	**	**
4.1.4.2 Ps of Use Anti-Vehicle NLW ?	**	**	**
4.1.4.2.1 Ps of Target ?	**	**	**
4.1.4.2.2 Ps of Fire Weapon ?	**	**	**
4.1.4.2.3 Ps of Assess Engagement ?	**	**	**
4.1.5 Ps of Shoulder ?	**	**	**
4.1.6 Ps of Tow Disabled Vessel ?	**	**	**
4.1.7 Ps of Conduct SAR ?	**	**	**
4.2 Ps of Use Lethal Measures ?	0.9900	0.9100	0.8750
4.2.1 Ps of Disable ?	0.9900	0.9100	-
4.2.1.1 Ps of Target ?	0.9966	0.9690	-
4.2.1.2 Ps of Fire Weapon ?	0.9966	0.9690	-
4.2.1.3 Ps of Assess Engagement ?	0.9966	0.9690	-
4.2.2 Ps of Sink/Destroy ?	0.9900	0.9900	0.8838
4.2.2.1 Ps of Detect/Track ?	**	**	0.9900
4.2.2.2 Ps of Classify ?	**	**	0.9770
4.2.2.3 Ps of Target ?	0.9966	0.9966	0.9770
4.2.2.4 Ps of Fire Weapon ?	0.9966	0.9966	0.9770
4.2.2.5 Ps of Assess Engagement ?	0.9966	0.9966	0.9770
4.2.3 Ps of Recapture ?	-	0.9100	-
4.2.3.1 Ps of Board AV ?	-	0.9539	-
4.2.3.2 Ps of Secure Control Spaces ?	-	0.9539	-

Notes: ** = function/subfunction occurs automatically in this scenario or is not required for success

Requirements Allocation - Sustain Time

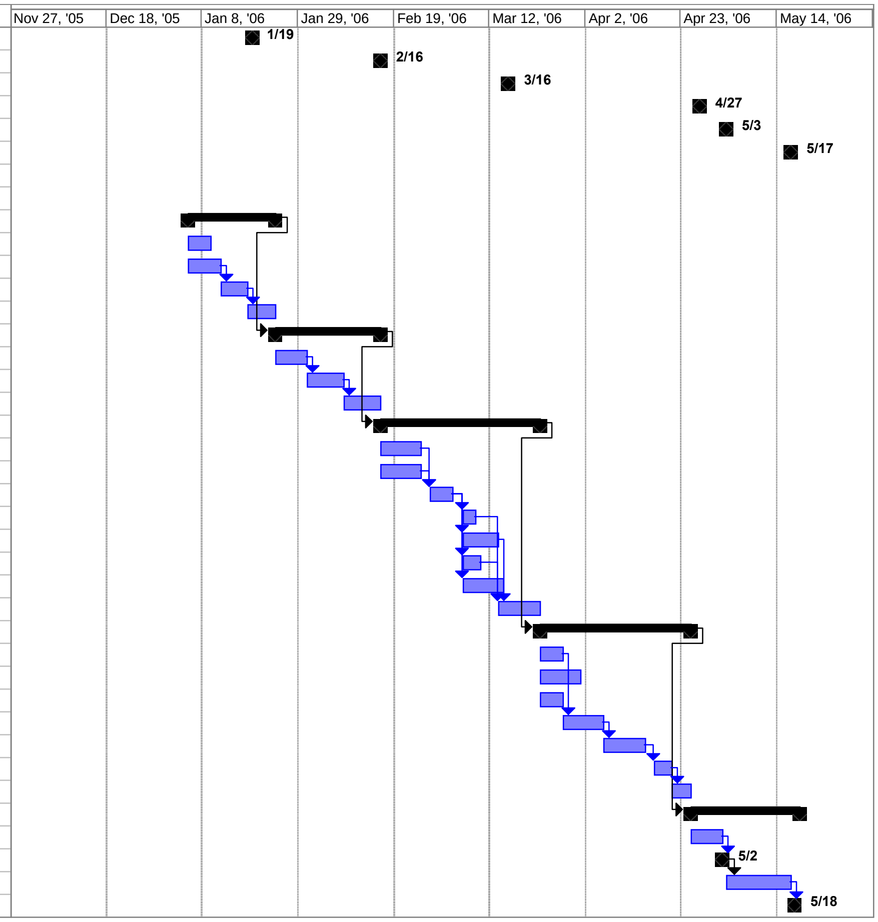
Requirement	WMD	SAW	SBA
	(all times are in per-days)		
5.0 Sustain	6	6	6
5.1 Time to Support Units ?	6	6	6
5.1.1 Time to Deliver Consumables to Units ?	3	1/10	1
5.1.1.1. Time to Deliver to Military Ships ?	1/20	1/20	1
5.1.1.2. Time to Deliver to Non-Military Ships ?	3	1/10	
5.1.2 Time to Refuel Platforms ?	1/5	1/5	6
5.1.2.1 Time to Refuel Ships ?	1/5	1/5	-
5.1.2.2 Time to Refuel Boats ?	-	-	1
5.1.2.3 Time to Refuel Aircraft ?	-	-	6
5.1.3 Time to Provide Manning for Sustained Operations ?	6	6	6
5.1.3.1 Time to Receive Manning Reports ?	6	6	6
5.1.3.2 Time to ID Manning Deficiencies ?	6	6	6
5.1.3.3 Time to Locate Manning Sources ?	6	6	6
5.1.3.4 Time to Transport Manning to Units ?	3	1/10	2
5.1.3.4.1 Time to Transport Manning to Military Units at sea ?	-	-	-
5.1.3.4.2 Time to Transport Manning to Non-Military Units at Sea ?	3	1/10	-
5.1.3.4.3 Time to Transport Manning to Military Units Inport ?	-	-	2
5.1.4 Time to Provide Barracks ?	3	3	3
5.1.4.1 Time to Provide Barracks for Units Onboard Military Ships at Sea ?	3	3	-
5.1.4.2 Time to Provide Barracks for Units Onboard Non-Military Ships at Sea ?	3	-	-
5.1.4.3 Time to Provide Barracks for Units Inport ?	-	-	3
5.2 Time to Maintain Units ?	6	6	6
5.2.1 Time to Identify Maintenance Deficiencies ?	6	6	6
5.2.1.1 Time to Receive Unit Capability Reports ?	6	6	6
5.2.1.2 Time to Asses System Capability ?	6	6	6
5.2.1.3. Time to Correct System Deficiency ?	1	1	6
5.2.2 Time to Provide Non-Depot Level Maintenance ?	0	0	1
5.2.2.1 Time to Identify Components ?	-	-	1/30
5.2.2.2 Time to Stock Spares ?	-	-	1
5.2.2.3 Time to Replace Components ?	-	-	1/2
5.2.3 Time to Provide Depot Level Maintenance ?	1/20	1/20	1
5.2.3.1 Time to Identify Pre-scheduled Depot-Level Maintenance ?	1/20	1/20	1
5.2.3.2 Time to Enable Unit Rotation ?	1/20	1/20	1
5.2.3.2.1 Time to Identify Unit Replacements ?	1/20	1/20	1
5.2.3.2.2 Time to Schedule Unit Turnover ?	1/20	1/20	1

Requirements Allocation - Sustain Ps

Requirement	WMD	SAW	SBA
5.0 Ps to Sustain ?	0.999900	0.999900	0.999900
5.1. Ps to Support Units ?	0.999950	0.999950	0.999950
5.1.1. Ps to Deliver Consumables to Units ?	0.999987	0.999987	-
5.1.1.1. Ps to Deliver to Military Ships ?	-	0.999987	-
5.1.1.2. Ps to Deliver to Non-Military Ships ?	0.999987	-	-
5.1.2. Ps to Refuel platforms ?	0.999987	0.999987	0.999950
5.1.2.1. Ps to Refuel Ships ?	0.999987	0.999987	-
5.1.2.2. Ps to Refuel Boats ?	-	-	0.999975
5.1.2.3. Ps to Refuel Aircraft ?	-	-	0.999975
5.1.3. Ps to Provide Manning for Sustained Operations ?	0.999987	0.999987	-
5.1.3.1. Ps to Receive Manning Reports ?	0.999997	0.999997	-
5.1.3.2. Ps to Identify Manning Deficiencies ?	0.999997	0.999997	-
5.1.3.3. Ps to Locate Manning Sources ?	0.999997	0.999997	-
5.1.3.4. Ps to Transport Manning to units ?	0.999997	0.999997	-
5.1.3.4.1 Ps to Transport Manning to Military Units at Sea ?	-	-	-
5.1.3.4.2 Ps to Transport Manning to Non-Military Units at Sea ?	0.999997	0.999997	-
5.1.3.4.3 Ps to Transport Manning to Military Units Inport ?	-	-	-
5.1.4. Ps to Provide Barracks ?	0.999987	0.999987	-
5.1.4.1. Ps to Provide Barracks for Units Onboard Military Ships at Sea ?	0.999994	0.999987	-
5.1.4.2. Ps to Provide Barracks for Units Onboard Non-Military Ships at Sea ?	0.999994	-	-
5.1.4.3. Ps to Provide Barracks for Units Inport ?	-	-	-
5.2. Ps to Maintain Units ?	0.999950	0.999950	0.999950
5.2.1. Ps to Identify Maintenance Deficiencies ?	0.999975	0.999975	0.999983
5.2.1.1. Ps to Receive Unit Capability Reports ?	0.999992	0.999992	0.999994
5.2.1.2. Ps to Asses System Capability ?	0.999992	0.999992	0.999994
5.2.1.3. Ps to Correct System Deficiency ?	0.999992	0.999992	0.999994
5.2.2. Ps to Provide Non-Depot Level Maintenance ?			0.999983
5.2.2.1. Ps to Identify Components ?			0.999994
5.2.2.2. Ps to Stock Spares ?			0.999994
5.2.2.3. Ps to Replace Components ?			0.999994
5.2.3. Ps to Provide Depot Level Maintenance ?	0.999975	0.999975	0.999983
5.2.3.1. Ps to Identify Pre-scheduled Depot-Level Maintenance ?	0.999987	0.999987	0.999992
5.2.3.2. Ps to Enable Unit Rotation ?	0.999987	0.999987	0.999992
5.2.3.2.1. Ps to Identify Unit Replacements ?	0.999994	0.999994	0.999996
5.2.3.2.2. Ps to Schedule Unit Turnover ?	0.999994	0.999994	0.999996

APPENDIX C MARITIME THREAT RESPONSE PROJECT SCHEDULE

ID	Task Name	Resource Names
1	Integrated Project Kick-off Meeting	
2	Interim Progress Review	
3	Preliminary Design Review	
4	Critical Design Review	
5	Draft Report Submission	
6	Final Presentation	
7		
8		
9	**Needs Analysis**	
10	Determine Threats	
11	Define Scenarios	
12	Define SoS Missions	
13	Analyze SoS Needs	
14	**Requirements Analysis**	
15	Perform Req Analysis	
16	Perform Functional Analysis	
17	Flowdown Requirements	
18	**SoS Architecture Alternatives**	
19	Identify Existing Systems	
20	Postulate Future Systems	
21	Identify Critical Elements	
22	Define SoS Comm Structure	
23	Define SoS C2 Structure	
24	Perform Functional Embedding	
25	Define SoS Force Composition	
26	Define SoS Architecture Options	
27	**SoS Architecture Ranking**	
28	Develop MOP/MOE	
29	Model Cost	
30	Identify Risk	
31	Perform Trade Studies	
32	Perform Modeling & Simulation	
33	Rank SoS Architectures	
34	Select SoS	
35	**Deliverables Preparation**	
36	Compile and Edit Draft Report	
37	Submit Draft Report	
38	Prepare and Practice Final Pres	
39	Give Final Presentation	



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APPENDIX D WEAPONS ANALYSIS

Note: In this appendix, #NUM! implies the data does not exist.

negbinom for hits to kill .

.50, 25mm, 40mm:

0	0.4000	0.6000	# successes needed:	1.00	
1	0.2400	0.7600	prob of 1 success:	0.40	(each compartment of 10-meter craft is 1/5 (2 m), so hit in engine or crew compartment is 2/5)
2	0.1440	0.8560			
3	0.0864	0.9136			
4	0.0518	0.9482			
5	0.0311	0.9689			
6	0.0187	0.9813			
7	0.0112	0.9888			
8	0.0067	0.9933			
9	0.0040	0.9960			
10	0.0024	0.9976			

7.62mm:

0	0.1600	0.8400	# successes needed:	2.00
1	0.1920	0.8080	prob of 1 success:	0.40
2	0.1728	0.8272		
3	0.1382	0.8618		
4	0.1037	0.8963		
5	0.0746	0.9254		
6	0.0523	0.9477		
7	0.0358	0.9642		
8	0.0242	0.9758		
9	0.0161	0.9839		
10	0.0106	0.9894		

Helo .50:

0	0.6000	0.4000	# successes needed:	1.00
1	0.2400	0.7600	prob of 1 success:	0.60
2	0.0960	0.9040		
3	0.0384	0.9616		
4	0.0154	0.9846		
5	0.0061	0.9939		
6	0.0025	0.9975		
7	0.0010	0.9990		
8	0.0004	0.9996		
9	0.0002	0.9998		
10	0.0001	0.9999		

Twin .50:

0	0.6000	0.4000	# successes needed:	1.00
1	0.2400	0.7600	prob of 1 success:	0.60
2	0.0960	0.9040		
3	0.0384	0.9616		
4	0.0154	0.9846		
5	0.0061	0.9939		
6	0.0025	0.9975		
7	0.0010	0.9990		
8	0.0004	0.9996		
9	0.0002	0.9998		
10	0.0001	0.9999		

Mixed WepCombined Shots .

p(kill) 1	0.0406	0.0203	
p(kill) 2	0.0406	0.0203	
p(kill) 3	0.0000	0.0000	
P(kill) 4	0.0000	0.0000	
p(kill) combined	0.0796	0.0402	0.0406

weapon/combo	range	# shots	# shots needed	p(kill)
1xLMG,1xMMG	500	12/6	4	0.4267
1xMCG,1xMMG	500	12/6	3	0.6577
1xMCG,1xLMG	500	14/6	4	0.4933
1xMCG,1xGL	500	10/5	3	0.5325
1xMCG,2xMMG	500	17/9	3	0.8708
1xMMG,2xLMG	500	19/9	4	0.7450
1xLMG,1xMMG	200	6	4	0.1792
1xMCG,1xMMG	200	6	3	0.4556
1xMCG,1xLMG	200	6	4	0.1792
1xMCG,1xGL	200	5	3	0.3174
1xMCG,2xMMG	200	9	3	0.7682
1xMMG,2xLMG	200	9	4	0.5174

Range band	dwell time	LMG	MMG	MCG	GL
500-1000	23	11	8	11	5
200-500	14	7	5	7	3
50-200	7	3	3	3	2

shots in 500-200	10	p(hit)	0.15
shots in 200-50	6	p(hit)	0.40

X	pdf	cdf	1-		X	pdf
0	0.1969	0.1969	0.8031	X=1	0	0.0467
1	0.3474	0.5443	0.4557	X=2	1	0.1866
2	0.2759	0.8202	0.1798	X=3	2	0.3110
3	0.1298	0.9500	0.0500	X=4	3	0.2765
4	0.0401	0.9901	0.0099	X=5	4	0.1382
5	0.0085	0.9986	0.0014	X=6	5	0.0369
6	0.0012	0.9999	0.0001	X=7	6	0.0041
7	0.0001	1.0000	0.0000	X=8	7	#NUM!
8	0.0000	1.0000	0.0000	X=9	8	#NUM!
9	0.0000	1.0000	0.0000	X=10	9	#NUM!
10	0.0000	1.0000	0.0000	X=11	10	#NUM!
11	#NUM!	#NUM!	#NUM!	X=12	11	#NUM!
12	#NUM!	#NUM!	#NUM!	X=13	12	#NUM!
13	#NUM!	#NUM!	#NUM!	X=14	13	#NUM!
14	#NUM!	#NUM!	#NUM!	X=15	14	#NUM!
15	#NUM!	#NUM!	#NUM!	X=16	15	#NUM!
16	#NUM!	#NUM!	#NUM!	X=17	16	#NUM!
17	#NUM!	#NUM!	#NUM!	X=18	17	#NUM!
18	#NUM!	#NUM!	#NUM!	X=19	18	#NUM!
19	#NUM!	#NUM!	#NUM!	X=20	19	#NUM!
20	#NUM!	#NUM!	#NUM!	X=21	20	#NUM!

hits to kill	2	3	4	5
	0.7667	**0.6158**	**0.3660**	**0.2077**
	0.76565	*0.43444*	*0.36597*	*0.14392*
	0.45570	*0.61577*	*0.17141*	*0.04764*
	0.76672	*0.17980*	*0.34939*	*0.20765*
		0.45568	*0.04997*	*0.13786*
			0.17920	*0.00987*
				0.04096

Case Descriptions

CASE	Open Fire Range	Rate of Fire	# of Weapons	Reload Policy
1	1000	best	1	individual
2	1000	best	2 = 1	coordinated *
3	1000	aimed	1	individual
4	1000	mix	1	individual
5**	1000	mix	4 = 2	coordinated
6	500	best	1	n/a
7	500	best	2	n/a
8	200	best	1	n/a
9	200	best	2	n/a

* One weapon reloads while other fires

** In case 5, LMG and MMG use coordinated reload policy, so 4 weps = 2 wep equivalent. MCG and GL are 2 weapons (no ammo issues

Case 1

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AV Spd	AV spd (yds/s)
40.0000	22.2222

Range band width	dwell time
500.0000	22.5000
300.0000	13.5000
150.0000	6.7500

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200.0000	20.0000	10.0000	2.0000
MMG	200.0000	20.0000	7.5000	2.6667
MCG	175.0000	6.0000	2.9000	2.0690
GL	48.0000	3.0000	0.6700	4.4776

Range band width	dwell time	LMG	MMG	MCG	GL
500.0000	22.5000	11.2500	8.4375	10.8750	5.0250
300.0000	13.5000	6.7500	5.0625	6.5250	3.0150
150.0000	6.7500	3.3750	2.5313	3.2625	1.5075

LMG 4 hits to kill

Range band width	dwell time	
500.0000	22.5000	11 shots then reload 10 seconds
300.0000	13.5000	leaves 9 seconds here - so 2 shots here
150.0000	6.7500	3 shots here

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf	1-
X=1	0.0000	0.3996	0.3996	0.6004	0.0000	0.7225	0.7225	0.2775	0.0000	0.2160	0.2160	0.7840
X=2	1.0000	0.3823	0.7819	0.2181	1.0000	0.2550	0.9775	0.0225	1.0000	0.4320	0.6480	0.3520
X=3	2.0000	0.1662	0.9481	0.0519	2.0000	0.0225	1.0000	0.0000	2.0000	0.2880	0.9360	0.0640
X=4	3.0000	0.0434	0.9915	0.0085	3.0000	#NUM!	#NUM!	#NUM!	3.0000	0.0640	1.0000	0.0000
X=5	4.0000	0.0075	0.9990	0.0010	4.0000	#NUM!	#NUM!	#NUM!	4.0000	#NUM!	#NUM!	#NUM!
	5.0000	0.0009	0.9999	0.0001	5.0000	#NUM!	#NUM!	#NUM!	5.0000	#NUM!	#NUM!	#NUM!
	6.0000	0.0001	1.0000	0.0000	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!	#NUM!
	7.0000	0.0000	1.0000	0.0000	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!	#NUM!
	8.0000	0.0000	1.0000	0.0000	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!	#NUM!
	9.0000	0.0000	1.0000	0.0000	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!
	10.0000	0.0000	1.0000	0.0000	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!

0.0000	0.0586
0.0178	
0.0079	
0.0000	
0.0586	
0.0106	
0.0475	

Range band width	dwell time	
500.0000	22.5000	11 shots t
300.0000	13.5000	leaves 9 s
150.0000	6.7500	3 shots he

5 hits to kill

	X	pdf	cdf
X=1	0.0000	0.3996	0.3996
X=2	1.0000	0.3823	0.7819
X=3	2.0000	0.1662	0.9481
X=4	3.0000	0.0434	0.9915
X=5	4.0000	0.0075	0.9990
	5.0000	0.0009	0.9999
	6.0000	0.0001	1.0000
	7.0000	0.0000	1.0000
	8.0000	0.0000	1.0000
	9.0000	0.0000	1.0000
	10.0000	0.0000	1.0000
	11.0000	0.0000	1.0000

0.0000	0.0213
0.0014	
0.0000	
0.0000	
0.0038	
0.0113	
0.0107	
0.0213	

MMG

dwell time	
23.0000	8 shots
14.0000	2 shots reload (10s)
7.0000	2 shots

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf	1-
X=1	0.0000	0.5132	0.5132	0.4868	0.0000	0.7225	0.7225	0.2775	0.0000	0.3600	0.3600	0.6400
X=2	1.0000	0.3570	0.8702	0.1298	1.0000	0.2550	0.9775	0.0225	1.0000	0.4800	0.8400	0.1600
X=3	2.0000	0.1087	0.9789	0.0211	2.0000	0.0225	1.0000	0.0000	2.0000	0.1600	1.0000	0.0000
X=4	3.0000	0.0189	0.9978	0.0022	3.0000	#NUM!	#NUM!	#NUM!	3.0000	#NUM!	#NUM!	#NUM!
X=5	4.0000	0.0021	0.9999	0.0001	4.0000	#NUM!	#NUM!	#NUM!	4.0000	#NUM!	#NUM!	#NUM!
	5.0000	0.0001	1.0000	0.0000	5.0000	#NUM!	#NUM!	#NUM!	5.0000	#NUM!	#NUM!	#NUM!
	6.0000	0.0000	1.0000	0.0000	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!	#NUM!
	7.0000	0.0000	1.0000	0.0000	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!	#NUM!
	8.0000	0.0000	1.0000	0.0000	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!	#NUM!
	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!
	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!

0.0000	0.0779	0.0865

Case 2	
AV Spd	AV spd (yds/s)
40.0000	22.2222

Range band width	dwell time
500.0000	22.5000
300.0000	13.5000
150.0000	6.7500

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200.0000	20.0000	10.0000	2.0000
MMG	200.0000	20.0000	7.5000	2.6667
MCG	175.0000	6.0000	2.9000	2.0690
GL	48.0000	3.0000	0.6700	4.4776

Range band width	dwell time	LMG	MMG	MCG	GL
500.0000	22.5000	11.2500	8.4375	10.8750	5.0250
300.0000	13.5000	6.7500	5.0625	6.5250	3.0150
150.0000	6.7500	3.3750	2.5313	3.2625	1.5075

LMG (presuming 2 LMG = 1 w/o reloads by coordinating fire/reload)
4 hits to kill

Range band width	dwell time	
500.0000	22.5000	11 shots
300.0000	13.5000	7 shots
150.0000	6.7500	3 shots

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0.0000	0.3996	0.3996	0.6004	0.0000	0.3206	0.3206	0.6794	0.0000	0.2160	0.2160
X=2	1.0000	0.3823	0.7819	0.2181	1.0000	0.3960	0.7166	0.2834	1.0000	0.4320	0.6480
X=3	2.0000	0.1662	0.9481	0.0519	2.0000	0.2097	0.9262	0.0738	2.0000	0.2880	0.9360
X=4	3.0000	0.0434	0.9915	0.0085	3.0000	0.0617	0.9879	0.0121	3.0000	0.0640	1.0000
X=5	4.0000	0.0075	0.9990	0.0010	4.0000	0.0109	0.9988	0.0012	4.0000	#NUM!	#NUM!
	5.0000	0.0009	0.9999	0.0001	5.0000	0.0012	0.9999	0.0001	5.0000	#NUM!	#NUM!
	6.0000	0.0001	1.0000	0.0000	6.0000	0.0001	1.0000	0.0000	6.0000	#NUM!	#NUM!
	7.0000	0.0000	1.0000	0.0000	7.0000	0.0000	1.0000	0.0000	7.0000	#NUM!	#NUM!
	8.0000	0.0000	1.0000	0.0000	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!
	9.0000	0.0000	1.0000	0.0000	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!
	10.0000	0.0000	1.0000	0.0000	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!

0.0435	0.1436
0.0998	
0.0578	
0.1162	
0.1334	
0.1436	

MMG (presuming 2 MMG = 1 MMG w/o reloads by coordinating fire/reload)

dwell time	
23.0000	8 shots
14.0000	5 shots
7.0000	3 shots

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0.0000	0.5132	0.5132	0.4868	0.0000	0.4437	0.4437	0.5563	0.0000	0.2160	0.2160
X=2	1.0000	0.3570	0.8702	0.1298	1.0000	0.3915	0.8352	0.1648	1.0000	0.4320	0.6480
X=3	2.0000	0.1087	0.9789	0.0211	2.0000	0.1382	0.9734	0.0266	2.0000	0.2880	0.9360
X=4	3.0000	0.0189	0.9978	0.0022	3.0000	0.0244	0.9978	0.0022	3.0000	0.0640	1.0000
X=5	4.0000	0.0021	0.9999	0.0001	4.0000	0.0022	0.9999	0.0001	4.0000	#NUM!	#NUM!
	5.0000	0.0001	1.0000	0.0000	5.0000	0.0001	1.0000	0.0000	5.0000	#NUM!	#NUM!
	6.0000	0.0000	1.0000	0.0000	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!
	7.0000	0.0000	1.0000	0.0000	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!
	8.0000	0.0000	1.0000	0.0000	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!
	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!
	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!

0.0640	0.0022	0.2123
0.1292	0.0022	
0.1958	0.1017	
0.2123	0.0802	
0.0266		
0.0211		
0.0722		
0.1958		

Case 3

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	Time of burst
LMG	200	20	4
MMG	200	20	5
MCG	175	6	5
GL	48	3	5

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	6	5	5	5
300	14	3	3	3	3
150	7	2	1	1	1

LMG 4 hits to kill

Range band width	dwell time	
500	23	6 shots
300	14	3 shots
150	7	1 shot reload OVER

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0.0000	0.6064	0.6064	0.3936	0.0000	0.6141	0.6141	0.3859	0.0000	0.6000	0.6000
X=2	1.0000	0.3164	0.9227	0.0773	1.0000	0.3251	0.9393	0.0608	1.0000	0.4000	1.0000
X=3	2.0000	0.0688	0.9915	0.0085	2.0000	0.0574	0.9966	0.0034	2.0000	#NUM!	#NUM!
X=4	3.0000	0.0080	0.9995	0.0005	3.0000	0.0034	1.0000	0.0000	3.0000	#NUM!	#NUM!
X=5	4.0000	0.0005	1.0000	0.0000	4.0000	#NUM!	#NUM!	#NUM!	4.0000	#NUM!	#NUM!
	5.0000	0.0000	1.0000	0.0000	5.0000	#NUM!	#NUM!	#NUM!	5.0000	#NUM!	#NUM!
	6.0000	0.0000	1.0000	0.0000	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!
	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!
	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!
	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!
	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!

0.0000	0.0119
0.0014	
0.0096	
0.0119	
0.0096	

MMG

dwell time	
23	5 shots
14	3 shots
7	1 shot

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	0.6591	0.6591	0.3409	0.0000	0.6141	0.6141	0.3859	0.0000	0.6000	0.6000
X=2	1	0.2866	0.9456	0.0544	1.0000	0.3251	0.9393	0.0608	1.0000	0.4000	1.0000
X=3	2	0.0498	0.9955	0.0045	2.0000	0.0574	0.9966	0.0034	2.0000	#NUM!	#NUM!
X=4	3	0.0043	0.9998	0.0002	3.0000	0.0034	1.0000	0.0000	3.0000	#NUM!	#NUM!
X=5	4	0.0002	1.0000	0.0000	4.0000	#NUM!	#NUM!	#NUM!	4.0000	#NUM!	#NUM!
	5	0.0000	1.0000	0.0000	5.0000	#NUM!	#NUM!	#NUM!	5.0000	#NUM!	#NUM!
	6	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!
	7	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!

0.0243	0.0217	0.0526
0.0000	0.0207	
0.0526		
0.0210		
0.0207		
0.0045		
0.0034		

Case 4

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	Time of burst, long rge	time of burst, short rge
LMG	200	20	4	2
MMG	200	20	5	3
MCG	175	6	5	2
GL	48	3	5	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	5	5	5	5
300	14	10	5	7	3
150	7	10	2	3	2

LMG 4 hits to kill

Range band width	dwell time	
500	23	5 shots
300	14	5 shots start reload
150	7	1 shot OVER

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0.0000	0.6591	0.6591	0.3409	0.0000	0.4437	0.4437	0.5563	0.0000	0.6000	0.6000
X=2	1.0000	0.2866	0.9456	0.0544	1.0000	0.3915	0.8352	0.1648	1.0000	0.4000	1.0000
X=3	2.0000	0.0498	0.9955	0.0045	2.0000	0.1382	0.9734	0.0266	2.0000	#NUM!	#NUM!
X=4	3.0000	0.0043	0.9998	0.0002	3.0000	0.0244	0.9978	0.0022	3.0000	#NUM!	#NUM!
X=5	4.0000	0.0002	1.0000	0.0000	4.0000	0.0022	0.9999	0.0001	4.0000	#NUM!	#NUM!
	5.0000	0.0000	1.0000	0.0000	5.0000	0.0001	1.0000	0.0000	5.0000	#NUM!	#NUM!
	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!	#NUM!	6.0000	#NUM!	#NUM!
	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!	#NUM!	7.0000	#NUM!	#NUM!
	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!	#NUM!	8.0000	#NUM!	#NUM!
	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!	#NUM!	9.0000	#NUM!	#NUM!
	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!	#NUM!	10.0000	#NUM!	#NUM!

0.0000	0.0225
0.0106	
0.0225	
0.0121	
0.0121	
0.0090	

MMG

dwell time	
23	5 shots
14	5 shots star reload
7	OVER

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	0.6591	0.6591	0.3409	0.0000	0.4437	0.4437	0.5563	0.0000	1.0000	1.0000
X=2	1	0.2866	0.9456	0.0544	1.0000	0.3915	0.8352	0.1648	1.0000	#NUM!	#NUM!
X=3	2	0.0498	0.9955	0.0045	2.0000	0.1382	0.9734	0.0266	2.0000	#NUM!	#NUM!

Case 5

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	Time of burst, long rge	time of burst, short rge
LMG	200	20	4	2
MMG	200	20	5	3
MCG	175	6	5	2
GL	48	3	5	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	5	5	5	5
300	14	10	5	7	3
150	7	10	2	3	2

Range band width	dwell time	LMG	4 hits to kill 4 weps = 2
500	23	8 shots	
300	14	12 shots	
150	7	6 shots	

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0.0000	0.5132	0.5132	0.4868	0.0000	0.1422	0.1422	0.8578	0.0000	0.0467	0.0467
X=2	1.0000	0.3570	0.8702	0.1298	1.0000	0.3012	0.4435	0.5565	1.0000	0.1866	0.2333
X=3	2.0000	0.1087	0.9789	0.0211	2.0000	0.2924	0.7358	0.2642	2.0000	0.3110	0.5443
X=4	3.0000	0.0189	0.9978	0.0022	3.0000	0.1720	0.9078	0.0922	3.0000	0.2765	0.8208
X=5	4.0000	0.0021	0.9999	0.0001	4.0000	0.0683	0.9761	0.0239	4.0000	0.1382	0.9590
	5.0000	0.0001	1.0000	0.0000	5.0000	0.0193	0.9954	0.0046	5.0000	0.0369	0.9959
	6.0000	0.0000	1.0000	0.0000	6.0000	0.0040	0.9993	0.0007	6.0000	0.0041	1.0000
	7.0000	0.0000	1.0000	0.0000	7.0000	0.0006	0.9999	0.0001	7.0000	#NUM!	#NUM!
	8.0000	0.0000	1.0000	0.0000	8.0000	0.0001	1.0000	0.0000	8.0000	#NUM!	#NUM!
	9.0000	#NUM!	#NUM!	#NUM!	9.0000	0.0000	1.0000	0.0000	9.0000	#NUM!	#NUM!
	10.0000	#NUM!	#NUM!	#NUM!	10.0000	0.0000	1.0000	0.0000	10.0000	#NUM!	#NUM!
	11.0000	#NUM!	#NUM!	#NUM!	11.0000	0.0000	1.0000	0.0000	11.0000	#NUM!	#NUM!
	12.0000	#NUM!	#NUM!	#NUM!	12.0000	0.0000	1.0000	0.0000	12.0000	#NUM!	#NUM!

0.4267	0.4267
0.2519	
0.2583	
0.1061	
0.3909	
0.0722	
0.1286	
0.0181	

dwell time	MMG
23	10 shots
14	10 shots
7	4 shots

X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf

Case 6

APPENDIX D

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200	20	10	2
MMG	200	20	7.5	3
MCG	175	6	2.9	2
GL	48	3	0.67	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	11	8	11	5
300	14	7	5	7	3
150	7	3	3	3	2

LMG Hold fire until 500 yards

Range band width	dwell time	
500	23	0
300	14	7 shots
150	7	3 shots

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	1	1	0	0	0.320577	0.320577	0.679423	0	0.216	0.216
X=2	1	#NUM!	#NUM!	#NUM!	1	0.396007	0.716584	0.283416	1	0.432	0.648
X=3	2	#NUM!	#NUM!	#NUM!	2	0.209651	0.926235	0.073765	2	0.288	0.936
X=4	3	#NUM!	#NUM!	#NUM!	3	0.061662	0.987897	0.012103	3	0.064	1
X=5	4	#NUM!	#NUM!	#NUM!	4	0.010882	0.998778	0.001222	4	#NUM!	#NUM!
	5	#NUM!	#NUM!	#NUM!	5	0.001152	0.999931	6.95E-05	5	#NUM!	#NUM!
	6	#NUM!	#NUM!	#NUM!	6	6.78E-05	0.999998	1.71E-06	6	#NUM!	#NUM!
	7	#NUM!	#NUM!	#NUM!	7	1.71E-06	1	0	7	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!
	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!
	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!
	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!
	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!
	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!
	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!
	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!
	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!
	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!
	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!

0.0435	0.0998
0.0998	
0.0578	
0.0121	

MMG Hold fire until 500 yards

dwell time	
23	0

Case 6 (improved)

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200	20	10	2
MMG	200	20	7.5	3
MCG	175	6	2.9	2
GL	48	3	0.67	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	11	8	11	5
300	14	7	5	7	3
150	7	3	3	3	2

		LMG	Hold fire until 500 yards
Range band width	dwell time		
500	23	0	
300	14	7 shots	
150	7	3 shots	

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	1	1	0	0	0.320577	0.320577	0.679423	0	0.216	0.216
X=2	1	#NUM!	#NUM!	#NUM!	1	0.396007	0.716584	0.283416	1	0.432	0.648
X=3	2	#NUM!	#NUM!	#NUM!	2	0.209651	0.926235	0.073765	2	0.288	0.936
X=4	3	#NUM!	#NUM!	#NUM!	3	0.061662	0.987897	0.012103	3	0.064	1
X=5	4	#NUM!	#NUM!	#NUM!	4	0.010882	0.998778	0.001222	4	#NUM!	#NUM!
	5	#NUM!	#NUM!	#NUM!	5	0.001152	0.999931	6.95E-05	5	#NUM!	#NUM!
	6	#NUM!	#NUM!	#NUM!	6	6.78E-05	0.999998	1.71E-06	6	#NUM!	#NUM!
	7	#NUM!	#NUM!	#NUM!	7	1.71E-06	1	0	7	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!
	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!
	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!
	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!
	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!
	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!
	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!
	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!
	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!
	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!
	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!

0.0435	0.0998
0.0998	
0.0578	
0.0121	

	MMG	Hold fire until 500 yards
dwell time		
23	0	

Case 7

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200	20	10	2
MMG	200	20	7.5	3
MCG	175	6	2.9	2
GL	48	3	0.67	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	11	8	11	5
300	14	7	5	7	3
150	7	3	3	3	2

		LMG	Hold fire until 500 yards
Range band width	dwell time		2 weapons
500	23	0	
300	14	14 shots	
150	7	6 shots	

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	1	1	0	0	0.10277	0.10277	0.89723	0	0.046656	0.046656
X=2	1	#NUM!	#NUM!	#NUM!	1	0.253902	0.356671	0.643329	1	0.186624	0.23328
X=3	2	#NUM!	#NUM!	#NUM!	2	0.29124	0.647911	0.352089	2	0.31104	0.54432
X=4	3	#NUM!	#NUM!	#NUM!	3	0.205581	0.853492	0.146508	3	0.27648	0.8208
X=5	4	#NUM!	#NUM!	#NUM!	4	0.099767	0.95326	0.04674	4	0.13824	0.95904
	5	#NUM!	#NUM!	#NUM!	5	0.035212	0.988472	0.011528	5	0.036864	0.995904
	6	#NUM!	#NUM!	#NUM!	6	0.009321	0.997793	0.002207	6	0.004096	1
	7	#NUM!	#NUM!	#NUM!	7	0.00188	0.999672	0.000328	7	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8	0.00029	0.999963	3.74E-05	8	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9	3.41E-05	0.999997	3.22E-06	9	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10	3.01E-06	1	2.02E-07	10	#NUM!	#NUM!
	11	#NUM!	#NUM!	#NUM!	11	1.93E-07	1	8.77E-09	11	#NUM!	#NUM!
	12	#NUM!	#NUM!	#NUM!	12	8.53E-09	1	2.35E-10	12	#NUM!	#NUM!
	13	#NUM!	#NUM!	#NUM!	13	2.32E-10	1	2.92E-12	13	#NUM!	#NUM!
	14	#NUM!	#NUM!	#NUM!	14	2.92E-12	1	0	14	#NUM!	#NUM!
	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!
	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!
	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!
	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!
	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!
	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!

0.4088	0.4933
0.4933	
0.3357	
0.1465	
0.1792	

	MMG	Hold fire until 500 yards
dwell time		
23	0	

AV Spd Case 8	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200	20	10	2
MMG	200	20	7.5	3
MCG	175	6	2.9	2
GL	48	3	0.67	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	11	8	11	5
300	14	7	5	7	3
150	7	3	3	3	2

		LMG	pop up target	
Range band width	dwell time		1 wep	4 hits to kill
500	23	0		
300	14	0		
150	7	3 shots		

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	1	1	0	0	1	1	0	0	0.216	0.216
X=2	1	#NUM!	#NUM!	#NUM!	1	#NUM!	#NUM!	#NUM!	1	0.432	0.648
X=3	2	#NUM!	#NUM!	#NUM!	2	#NUM!	#NUM!	#NUM!	2	0.288	0.936
X=4	3	#NUM!	#NUM!	#NUM!	3	#NUM!	#NUM!	#NUM!	3	0.064	1
X=5	4	#NUM!	#NUM!	#NUM!	4	#NUM!	#NUM!	#NUM!	4	#NUM!	#NUM!
	5	#NUM!	#NUM!	#NUM!	5	#NUM!	#NUM!	#NUM!	5	#NUM!	#NUM!
	6	#NUM!	#NUM!	#NUM!	6	#NUM!	#NUM!	#NUM!	6	#NUM!	#NUM!
	7	#NUM!	#NUM!	#NUM!	7	#NUM!	#NUM!	#NUM!	7	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!
	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!
	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!
	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!
	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!
	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!
	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!
	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!
	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!
	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!
	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!

0.0000	#NUM!
#NUM!	
#NUM!	
#NUM!	

	MMG	pop up
dwell time		
23	0	

Case 9

AV Spd	AV spd (yds/s)
40	22

Range band width	dwell time
500	23
300	14
150	7

Wpn	Ammo	Burst size	ROF (rps)	Time of burst
LMG	200	20	10	2
MMG	200	20	7.5	3
MCG	175	6	2.9	2
GL	48	3	0.67	4

Range band width	dwell time	LMG	MMG	MCG	GL
500	23	11	8	11	5
300	14	7	5	7	3
150	7	3	3	3	2

		LMG	pop up target	
Range band width	dwell time		2 weps	4 hits to kill
500	23	0		
300	14	0		
150	7	6 shots		

	X	pdf	cdf	1-	X	pdf	cdf	1-	X	pdf	cdf
X=1	0	1	1	0	0	1	1	0	0	0.046656	0.046656
X=2	1	#NUM!	#NUM!	#NUM!	1	#NUM!	#NUM!	#NUM!	1	0.186624	0.23328
X=3	2	#NUM!	#NUM!	#NUM!	2	#NUM!	#NUM!	#NUM!	2	0.31104	0.54432
X=4	3	#NUM!	#NUM!	#NUM!	3	#NUM!	#NUM!	#NUM!	3	0.27648	0.8208
X=5	4	#NUM!	#NUM!	#NUM!	4	#NUM!	#NUM!	#NUM!	4	0.13824	0.95904
	5	#NUM!	#NUM!	#NUM!	5	#NUM!	#NUM!	#NUM!	5	0.036864	0.995904
	6	#NUM!	#NUM!	#NUM!	6	#NUM!	#NUM!	#NUM!	6	0.004096	1
	7	#NUM!	#NUM!	#NUM!	7	#NUM!	#NUM!	#NUM!	7	#NUM!	#NUM!
	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!	#NUM!	8	#NUM!	#NUM!
	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!	#NUM!	9	#NUM!	#NUM!
	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!	#NUM!	10	#NUM!	#NUM!
	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!	#NUM!	11	#NUM!	#NUM!
	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!	#NUM!	12	#NUM!	#NUM!
	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!	#NUM!	13	#NUM!	#NUM!
	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!	#NUM!	14	#NUM!	#NUM!
	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!	#NUM!	15	#NUM!	#NUM!
	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!	#NUM!	16	#NUM!	#NUM!
	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!	#NUM!	17	#NUM!	#NUM!
	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!	#NUM!	18	#NUM!	#NUM!
	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!	#NUM!	19	#NUM!	#NUM!
	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!	#NUM!	20	#NUM!	#NUM!

	MMG	pop up
dwell time		
23	0	

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APPENDIX E PLATFORM AND ESCORT OPTION ANALYSIS

Note: In this appendix, #NUM! implies the data does not exist.

Mixed WepCombined Shots

p(kill) 1	0.2365	0.1183	
p(kill) 2	0.2392	0.1196	
p(kill) 3	0.0000	0.0000	
P(kill) 4	0.0000	0.0000	
p(kill) combined	0.4191	0.2237	0.2379

weapon/combo	range	# shots	# shots needed	p(kill)
1xLMG,1xMMG	500	12/6	4	0.4267
1xMCG,1xMMG	500	12/6	3	0.6577
1xMCG,1xLMG	500	14/6	4	0.4933
1xMCG,1xGL	500	10/5	3	0.4191*
1xMCG,2xMMG	500	17/9	3	0.8708
1xMMG,2xLMG	500	19/9	4	0.7450
1xMMG, 1xGL	500	8/5	3	0.3860*
1xLMG,1xMMG	200	6	4	0.1792
1xMCG,1xMMG	200	6	3	0.4556
1xMCG,1xLMG	200	6	4	0.1792
1xMCG,1xGL	200	5	3	0.0640*
1xMCG,2xMMG	200	9	3	0.7682
1xMMG,2xLMG	200	9	4	0.5174
4xLMG				

* combined p(kill) not shots - GL has different p(hit)

APPENDIX E

Range band	dwell time	LMG	MMG	MCG	GL
500-1000	23	11	8	11	5
200-500	14	7	5	7	3
50-200	7	3	3	3	2

shots in 500-200	7	p(hit)	0.15
shots in 200-50	3	p(hit)	0.40

X	pdf	cdf	1-		X	pdf
0	0.3206	0.3206	0.6794	X=1	0	0.2160
1	0.3960	0.7166	0.2834	X=2	1	0.4320
2	0.2097	0.9262	0.0738	X=3	2	0.2880
3	0.0617	0.9879	0.0121	X=4	3	0.0640
4	0.0109	0.9988	0.0012	X=5	4	#NUM!
5	0.0012	0.9999	0.0001	X=6	5	#NUM!
6	0.0001	1.0000	0.0000	X=7	6	#NUM!
7	0.0000	1.0000	0.0000	X=8	7	#NUM!
8	#NUM!	#NUM!	#NUM!	X=9	8	#NUM!
9	#NUM!	#NUM!	#NUM!	X=10	9	#NUM!
10	#NUM!	#NUM!	#NUM!	X=11	10	#NUM!
11	#NUM!	#NUM!	#NUM!	X=12	11	#NUM!
12	#NUM!	#NUM!	#NUM!	X=13	12	#NUM!
13	#NUM!	#NUM!	#NUM!	X=14	13	#NUM!
14	#NUM!	#NUM!	#NUM!	X=15	14	#NUM!
15	#NUM!	#NUM!	#NUM!	X=16	15	#NUM!
16	#NUM!	#NUM!	#NUM!	X=17	16	#NUM!
17	#NUM!	#NUM!	#NUM!	X=18	17	#NUM!
18	#NUM!	#NUM!	#NUM!	X=19	18	#NUM!
19	#NUM!	#NUM!	#NUM!	X=20	19	#NUM!
20	#NUM!	#NUM!	#NUM!	X=21	20	#NUM!

hits to kill	2	3	4	5
	0.5327	**0.2392**	**0.0998**	**#NUM!**
	0.53267	*0.22220*	*0.04348*	*0.00000*
	0.28342	*0.23916*	*0.05783*	*0.00949*
	0.35200	*0.07377*	*0.09976*	*0.01814*
		0.06400	*0.01210*	*0.02597*
			0.00000	*0.00122*
				#NUM!

PBS Architecture Options - Determination of P(kill) values

The following single weapon and two weapon p(kill) numbers are taken from the single weapon analysis completed seperately.
They were used throughout this determination.
When weapons were used in combination, we combined the shots from each weapon as trials in a single binomial. This is because any hit from either weapon will count towards the accumulated total of hits needed to kill the target. When weapons with different numbers of hits to kill were combined (such as the LMG and MMG), we used an average of the number of hits to kill. Detailed calculations appear on a separate spreadsheet. See Chapter 7 for a detailed explanation of the methodology used to derive the P(kill) numbers.

Definitions/assumptions:
All weapons use recommended firing policy (hold fire until 500 yds, use best ROF)
Pop-up means engagement begins at 200yds instead of 500yds
Single weapon means a single weapon as described (so 2-Twin MMG = 4 weapons)
LMG: light machinegun (ex: M60)
MMG: medium machinegun (ex: M2 .50cal)
MCG: medium caliber gun (ex: Mk38 25mm)
GL: automatic grenade launcher (ex: Mk19 40mm)

Weapon	1 Wep P(kill)	2 Wep P(kill)	1 Wep Popup P(kill)	2 Wep Popup P(kill)
LMG	0.0260	0.2932	0.0000	0.0409
MMG	0.1958	0.6158	0.0640	0.4557
MCG	0.2392	0.6879	0.0640	0.4557
GL	0.2365	0.7242	0.0000	0.4752
Twin MMG	0.4361	0.7667	0.3520	0.7667
1xMCG, 1xMMG	n/a	0.6577	n/a	0.4556
1xMMG, 1xLMG	n/a	0.4267	n/a	0.1792
1xMCG, 2xMMG	n/a	0.8708	n/a	0.7682
3xLMG	n/a	3 wep = .6491	n/a	3 wep = .2666

ARCHITECTURE DESCRIPTIONS

Option	Description
1	4 small boats Each boat has 3 hardpoints: one in the bow and one on each side. They can mount LMG, MMG, or GL Two of the three weapons can engage a target Based on individual weapon analysis, we armed the small escorts with one MMG on each mount, therefore 2xMMG engage an attacker There is a 50% probability that one of two escorts can engage an attacker, so the combined p(kill) is determined by two steps: 1st, .5*(Pkill#1) = A and .5*(Pkill#2)=B 2nd, A+B There is a 50% probability that one of two escorts can engage a POPUP attacker, so the combined p(kill) is determined by two steps: 1st, .5*(Pkill#1) = A and .5*(Pkill#2)=B 2nd, A+B Example: Navy 34' Dauntless, SOC-R, Coast Guard TPSB
2	2 medium escorts Each boat has one large mount forward and two hardpoints on each side. They can mount the MCG forward and the LMG, MMG, or GL on the side. The MCG and two other weapons (one side) can engage a target Based on individual weapon analysis, we armed the medium escorts with one MMG on each mount, therefore the MCG and 2xMMG engage an attacker There is a 75% probability that one of two escorts can engage an attacker and a 25% that no escort can engage an attacker, so the combined p(kill) is determined by two steps: 1st, .75*(Pkill#1) = A and .25*(Pkill#2)=B (in this case, P(kill)#2=0) 2nd, A+B There is a 50% probability that one of two escorts can engage a POPUPattacker and a 50% that no escort can engage a POPUP attacker, so the combined p(kill) is determined by two steps: 1st, .5*(Pkill#1) = A and .5*(Pkill#2)=B (in this case, P(kill)#2=0) 2nd, A+B Example: Coast Guard 110', 147' (FRC - Program of Record)
3	Mix of 2 medium, 2 small As above There is a 50% that one medium can engage an attacker and a 50% probability that one small escort can engage an attacker, so the combined p(kill) is determined by two steps: 1st, .5*(Pkill#1) = A and .5*(Pkill#2)=B 2nd, A+B There is a 50% that one medium can engage a POPUP attacker and a 50% probability that one small escort can engage a POPUP attacker, so the combined p(kill) is determined by two steps: 1st, .5*(Pkill#1) = A and .5*(Pkill#2)=B 2nd, A+B
4	Teams onboard A 12-man team onboard the HVU armed with up to 6 LMG, 4 MMG, or 4 GL, but never more than 6 weapons total. 3 weapons on each side Based on individual weapon analysis, we armed the team with three LMG on each side.

PBS FORCE STRUCTURE WORKSHEET

Assumptions

small escorts operate 8 hours out of 24
med escorts operate 24 hours out of 24
teams operate 12 hours out of 24
board by harbor pilot or on shore
assume "perfect" changeovers

small escort group = 4 boats
medium escort group = 2 ships
mix escort group = 2 medium escorts 2 small boats

Note: small escort is endurance of craft; crews switch throughout day as needed

Rules

one escort group per HVU per day
Ferries operate 12 hours per day
5 tankers inbound every day
tanker transit is 9 hours, return trip for escort is 4.5 hours
There are 3 0.5 hr ferry routes
There are 2 1 hour ferry routes

Weekdays

FERRIES

1 ferry does a 0.5 hr route for a 1 hr round trip
2 vessels do 1 hr route for a 1 hr round trip
so 7 ferries operating (4 on 1-hr routes and 3 on 0.5-hour routes)

TANKERS

5 inbound per day uniformly distributed

Weekends

FERRIES

2 ferries do 0.5-hr routes for a 0.5-hr round trip
1 ferry does 1-hr routes for a 2-hr round trip
so 8 ferries operating (6 on 0.5-hr routes and 2 on 1-hr routes)

TANKERS

5 inbound per day uniformly distributes

Note: These schedules result in a transit total of 3246 for a 30 day month with four weekends. If doubled to reflect two companies (6492), it is close to the 2005 average number of ferry transits (6706) reported by the USCG Vessel Tracking Service in San Francisco.

From this point, use weekend requirement to determine force structure.

FERRY ESCORT SCHEDULE

small escort group	4 per ferry	need 32 (8x4) for 8 hours and 32 (8x4) for 4 more hours so a total of 64 boats then 64/4 = 16 groups of 4
medium escort group	2 per ferry	need 16 (8x2) for 12 hours so a total of 16 ships then 16/2 = 8 groups of 2
mix escort group	one group escorts 1 ferry	small: need 2 for 8 hours and 2 for 4 more hours medium: need 2 for 12 hours so a total of 32 (2x8+2x8) small boats so then (32/4) = 8 groups of 4 so a total of 16 ships (2x8) so then (16/2) = 8 groups of 2
teams	one per ferry	team: need 12 (12x1) for 12 hours so a total of 12 teams

TANKER ESCORT SCHEDULE

small escort group	need 4 boats per tanker	need 20 (4x5) per day (each group can only do one HVU per day) so then 20/4 = 5 groups of 4
medium escort group	need 2 per tanker	need 10 (2x5) per tanker each group can do 2 per day so 3 groups of 2
mix escort group	one group escorts one tanker	6 medium can do one day 10 small boats per day (5x2) so then 10/4 = 2.5 round up to 3 groups of 4 so then 6/2 = 3 groups of 2
teams	one per tanker	need 5 (1x5) per day

APPENDIX E

FINISH FORCE STRUCTURE WORKSHEET

Assumptions

USV operate 8 hours out of 24
helo operates 4 hours out of 24
assume "perfect" changeovers during operations

USV group = 4 boats, 8 personnel (4 operators, 4 maintainers)
helo det = 2 aircraft

Rules

one USV group per HVU per day
Ferries operate 12 hours per day
5 tankers inbound every day
tanker transit is 9 hours, return trip for escort is 4.5 hours
There are 3 0.5 hr ferry routes
There are 2 1 hour ferry routes

Weekdays

FERRIES

1 ferry does a 0.5 hr route for a 1 hr round trip
2 vessels do 1 hr route for a 1 hr round trip
so 7 ferries operating (4 on 1-hr routes and 3 on 0.5-hour routes)

TANKERS

5 inbound per day uniformly distributed

Weekends

FERRIES

2 ferries do 0.5-hr routes for a 0.5-hr round trip
1 ferry does 1-hr routes for a 2-hr round trip
so 8 ferries operating (6 on 0.5-hr routes and 2 on 1-hr routes)

TANKERS

5 inbound per day uniformly distributes

Note: These schedules result in a transit total of 3246 for a 30 day month with four weekends. If doubled to reflect two companies (6492),
it is close to the 2005 average number of ferry transits (6706) reported by the USCG Vessel Tracking Service in San Francisco.

From this point, use weekend requirement to determine force structure.

FERRY ESCORT SCHEDULE

USV group	4 per ferry	need 16 (8x2) for 8 hours and 16 (8x2) for 4 more hours so a total of 32 USV then 32/4 = 8 groups of 4
helo	1 per ferry	need 8 (8x1) for 4 hours so a total of 24 aircraft (8x3 4-hr blocks) then 24/2 = 12 groups of 2

The high number of aircraft required and short distance of most ferry trips makes attached escort by helicopter logistically infeasible. Instead, we make an alternate disposition of helos as follows:

need 5 (5x1) for 4 hours
so a total of (5x3) = 15 aircraft per day
15/2 = 7.5 rounded up to 8, so 8 groups of 2

In this case, a helo patrols one ferry route for the duration of its 4 hour flight.

TANKER ESCORT SCHEDULE

USV group	4 per tanker	need 20 (4x5) per day (each group can only do one HVU per day) so then 20/4 = 5 groups of 4
helo	1 per tanker	need 2 (8hr/2) per tanker so then 5x2 = 10 helos per day 10/2 = 5 groups of 2

INFRASTRUCTURE PROTECTION

USV group	for 24hr protection, use 6 USV (2 for 8 hr, x 3 = 24hr) so then 6/4 = 1.5 round up to 2 groups of 4 USV then x5 (5 critical points) = 10 groups of 4 USV
Helo group	No helos assigned to infrastructure protection

<u>FINAL TOTALS:</u>

APPENDIX E

Helo Determination of P(kill) values

Recommended helo:	Armed with 1 MMG		
Existing helo:	Armed with 1 LMG (doorgunner)		
Assumptions:	Helo p(hit), 200-500 yards:	0.6	
	LMG hits to kill:	5*	5
	MMG hits to kill:	3*	

Given: A single engagement allows 3 shots (pursuing/engaging attacker for 500yds or roughly 15 to 20 seconds)
A 'long' engagement allows 5 shots (pursuing/engaging attacker for 1000yds or roughly 30 to 40 seconds)

Recommended helo P(kill):	single:	0.6480
	long:	0.9130
Existing helo P(kill):	single:	0.2160
	long:	0.6826

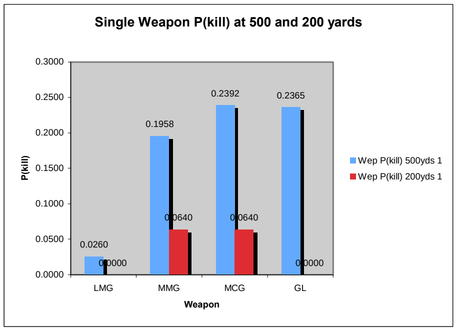
* from earlier discussions, see worksheet

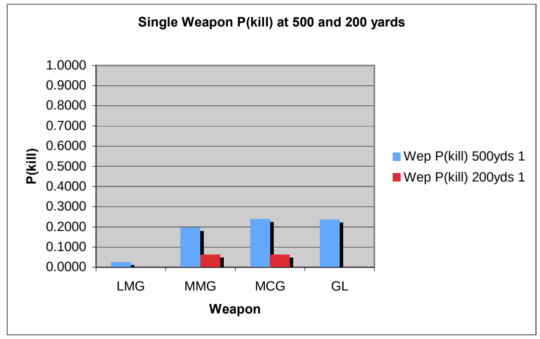
These architecture p(kill)s were used in our EXTEND Small Boat Attack model to determine architecture effectiveness against random attackers, with inclusion of the fopllowing parameters:

attacker initial distance
ID and classification time
Non-lethal warning time
Non-lethal engagement time
Lethal warning time
Lethal engagement time
presence of air and USV support

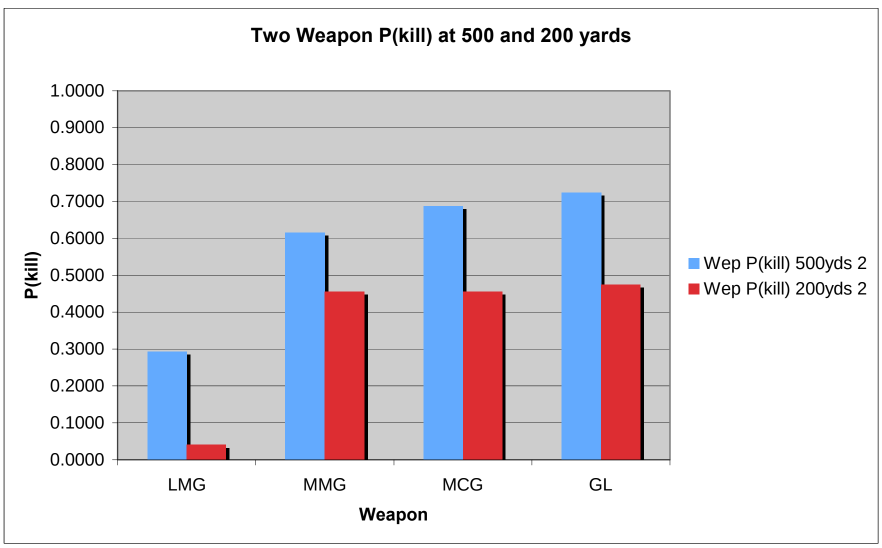
Graphs & Charts

Weapon	1 Wep P(kill) 500yds	1 Wep P(kill) 200yds	2 Wep P(kill)	2 Wep Popup P(kill)
LMG	0.0260	0.0000	0.2932	0.0409
MMG	0.1958	0.0640	0.6158	0.4557
MCG	0.2392	0.0640	0.6879	0.4557
GL	0.2365	0.0000	0.7242	0.4752
Twin MMG	0.4361	0.3520	0.7667	0.7667





Weapon	2 Wep P(kill) 500yds	2 Wep P(kill) 200yds	1 Wep P(kill) 500yds	1 Wep P(kill) 200yds
LMG	0.2932	0.0409	0.0260	0.0000
MMG	0.6158	0.4557	0.1958	0.0640
MCG	0.6879	0.4557	0.2392	0.0640
GL	0.7242	0.4752	0.2365	0.0000
Twin MMG	0.7667	0.7667	0.4361	0.3520



Weapon	2 Wep P(kill) 500yds	2 Wep P(kill) 200yds	1 Wep P(kill) 500yds	1 Wep P(kill) 200yds
MMG	0.6158	0.4557	0.1958	0.0640
Twin MMG	0.7667	0.7667	0.4361	0.3520
MCG	0.6879	0.4557	0.2392	0.0640
GL	0.7242	0.4752	0.2365	0.0000
LMG	0.2932	0.0409	0.0260	0.0000

APPENDIX F PLATFORM AND ESCORT OPTION ANALYSIS

APPENDIX F

LINEAR BARRIER PATROL

Given:

v =	40	patrol speed in knots
u =	40	attacker speed in knots
d =	1	length of barrier in nautical miles
w =	0.25	intercept range of patroller in nautical miles
d' =	*0.75*	*d - w*
r =	*1*	*v / u*
h =	*3*	*d' / w*

FORMULA: using p = (1-(((h-sqrt(r^2 + 1)-1)))/2)^2) * (1/((h*(h+1))) Where: p = probability of intercept

1.414213562
0.414213562
0.207106781
2.792893219
7.800252532
0.650021044
0.349978956

p = 0.3500

Some patrollers and results:

0.5 NM BARRIER		P(intercept)	ONE NM BARRIER		P(intercept)	TWO NM BARRIER		P(intercept)	THREE NM BARRIER		P(intercept)
small boat	spd 15 rge .25	0.5334	small boat	spd 15 rge .25	0.2669	small boat	spd 15 rge .25	0.1335	small boat	spd 15 rge .25	0.0890
small boat	spd 20 rge .25	0.5573	small boat	spd 20 rge .25	0.2792	small boat	spd 20 rge .25	0.1397	small boat	spd 20 rge .25	0.0931
med escort	spd 20 rge .25	0.5573	med escort	spd 20 rge .25	0.2792	med escort	spd 20 rge .25	0.1397	med escort	spd 20 rge .25	0.0931
helo	spd 100 rge .5	0.9882	helo	spd 100 rge .5	0.6135	helo	spd 100 rge .5	0.3238	helo	spd 100 rge .5	0.2190
helo	spd 60 rge .5	0.8208	helo	spd 60 rge .5	0.4373	helo	spd 60 rge .5	0.2225	helo	spd 60 rge .5	0.1490

APPENDIX F

Force structure calculations - barrier patrol

#'s req'd

8 hour endurance	boats per mile, tanker route	0
	boats per mile, ferry route	1

Route	Length		# routes	Total miles	1st 8 hrs	2d 8 hrs	3d 8 hrs	Total Req'd
Tanker	30	nm	1	30	0	0	0	0
Ferry, 0.5hr	3	nm	3	9	9	9	0	18
Ferry, 1.0hr	6	nm	2	12	12	12	0	24
Total	39	nm	6	51	21	21	0	42

12 hour endurance	boats per mile, tanker route	0
	boats per mile, ferry route	1

Route	Length		# routes	Total miles	1st 12 hrs	2d 12 hrs	3d 8 hrs	Total Req'd
Tanker	30	nm	1	30	0	0	0	0
0.5hr	3	nm	3	9	9	0	0	9
1.0hr	6	nm	2	12	12	0	0	12
Total	39	nm	6	51	21	0	0	21

Comparisons

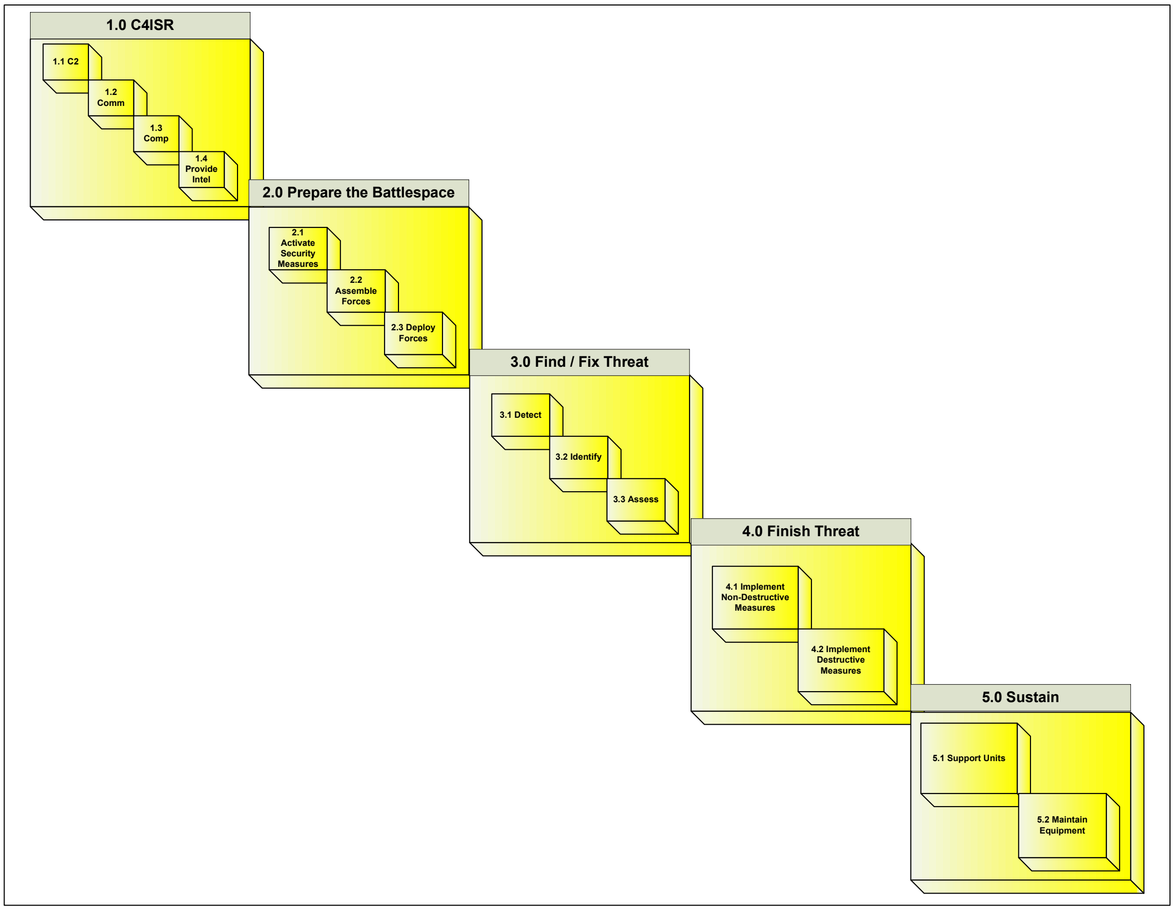
Type	Close escort	2 per nm mix	1 per nm mix
Endurance	8 hrs	8	8
ferry	64	84	42
tanker	20	20	20
CI	40	40	40
	124	144	102

Type	Close escort	2 per nm mix	1 per nm mix
Endurance	12	12	12
ferry	32	42	21
tanker	10	10	10
CI	20	20	20
	62	72	51

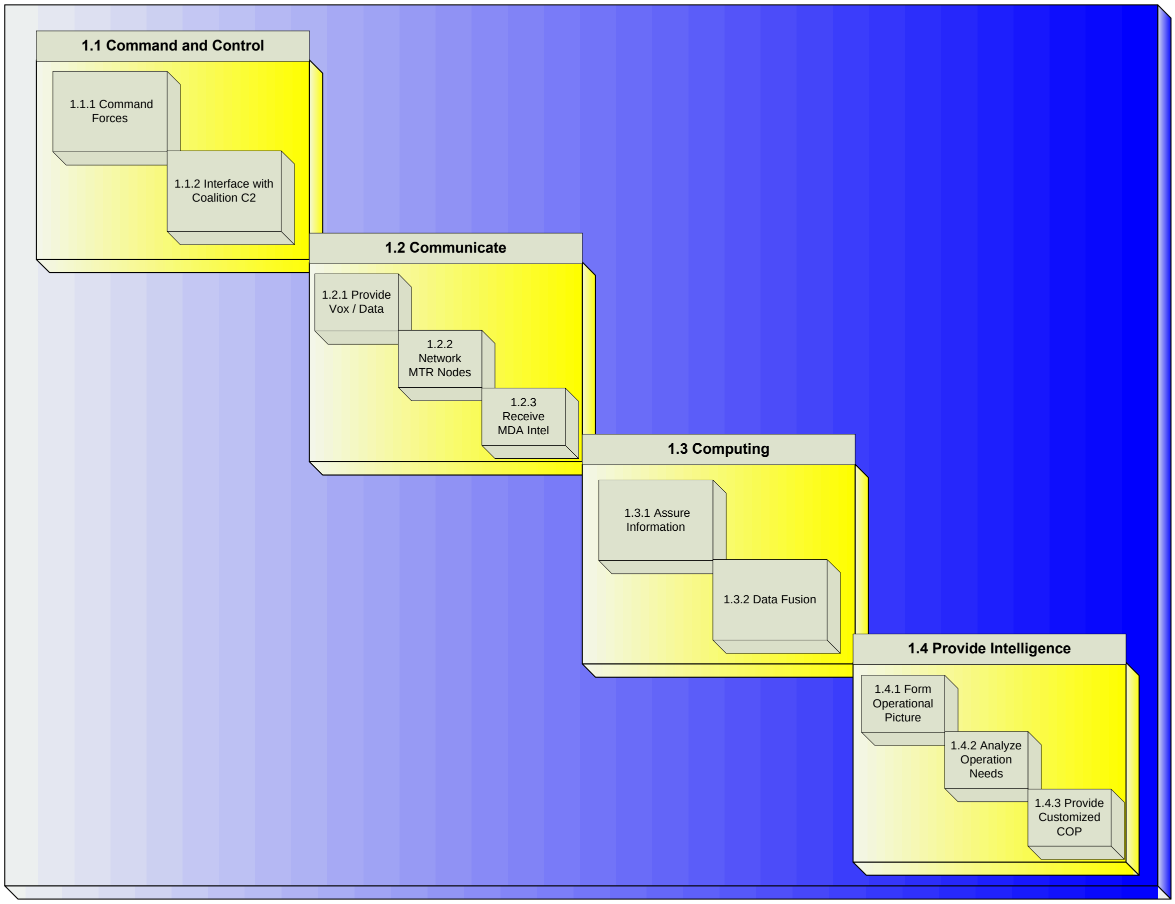
Equal effectiveness in barrier patrol results in greater number of forces required.
Lesser effectiveness required for barrier patrol to require fewer numbers, and "savings" in forces is 11 or 22 boats, respectively.
Given already low effectiveness for most architectures, reduction in forces is not sufficient justification to accept lower performance.

APPENDIX G FUNCTIONAL DECOMPOSITION N^2 CHARTS

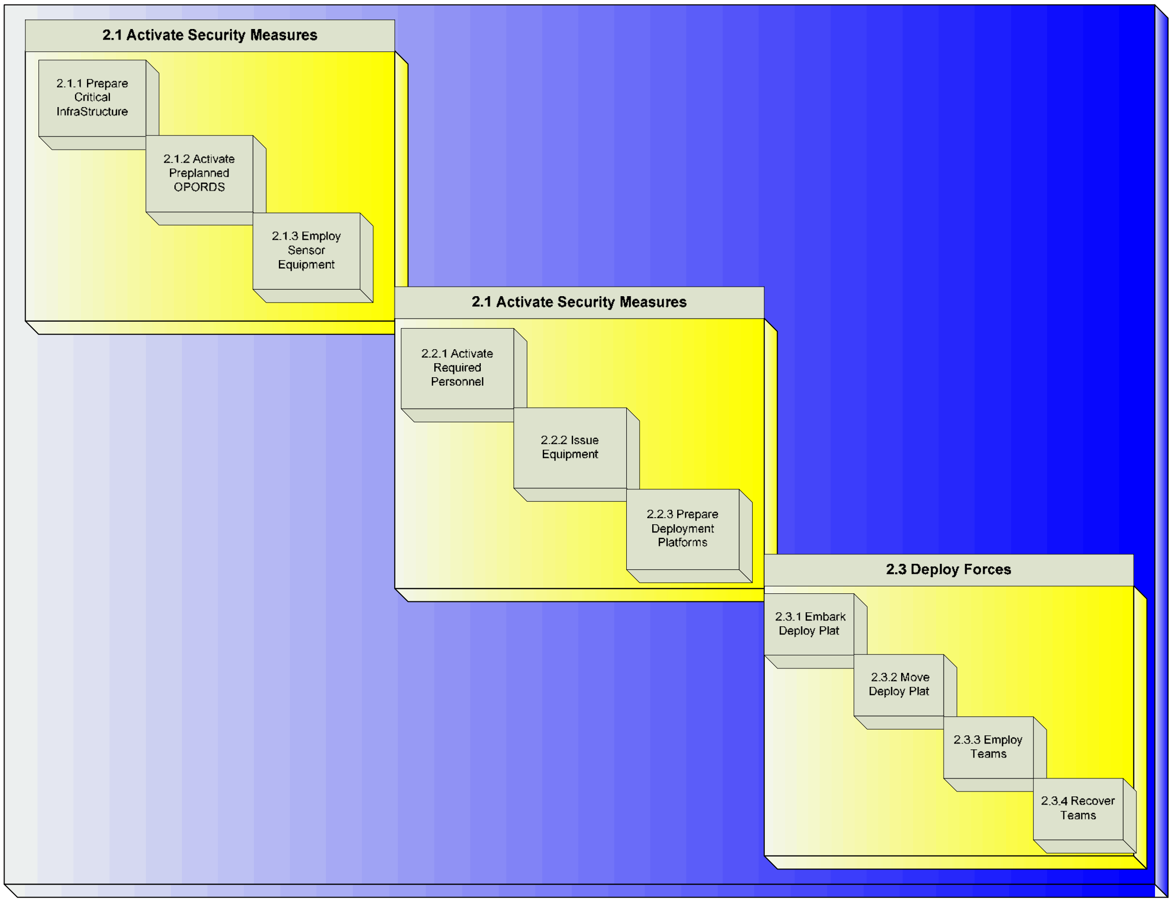
SoS



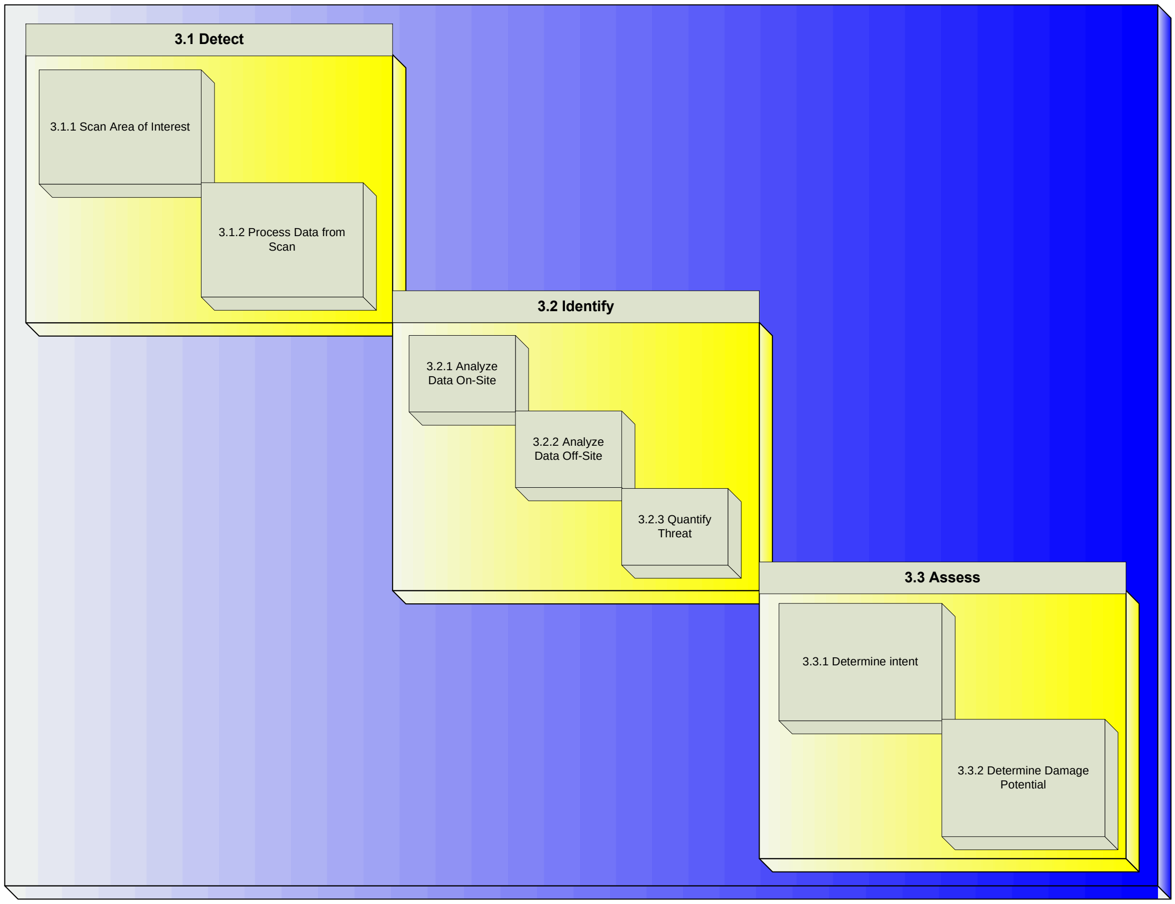
1.0 C4ISR


1.1 Command and Control
1.1.1 Command Forces
1.1.2 Interface with Coalition C2
1.2 Communicate
1.2.1 Provide Vox / Data
1.2.2 Network MTR Nodes
1.2.3 Receive MDA Intel
1.3 Computing
1.3.1 Assure Information
1.3.2 Data Fusion
1.4 Provide Intelligence
1.4.1 Form Operational Picture
1.4.2 Analyze Operation Needs
1.4.3 Provide Customized COP

2.0 PBS

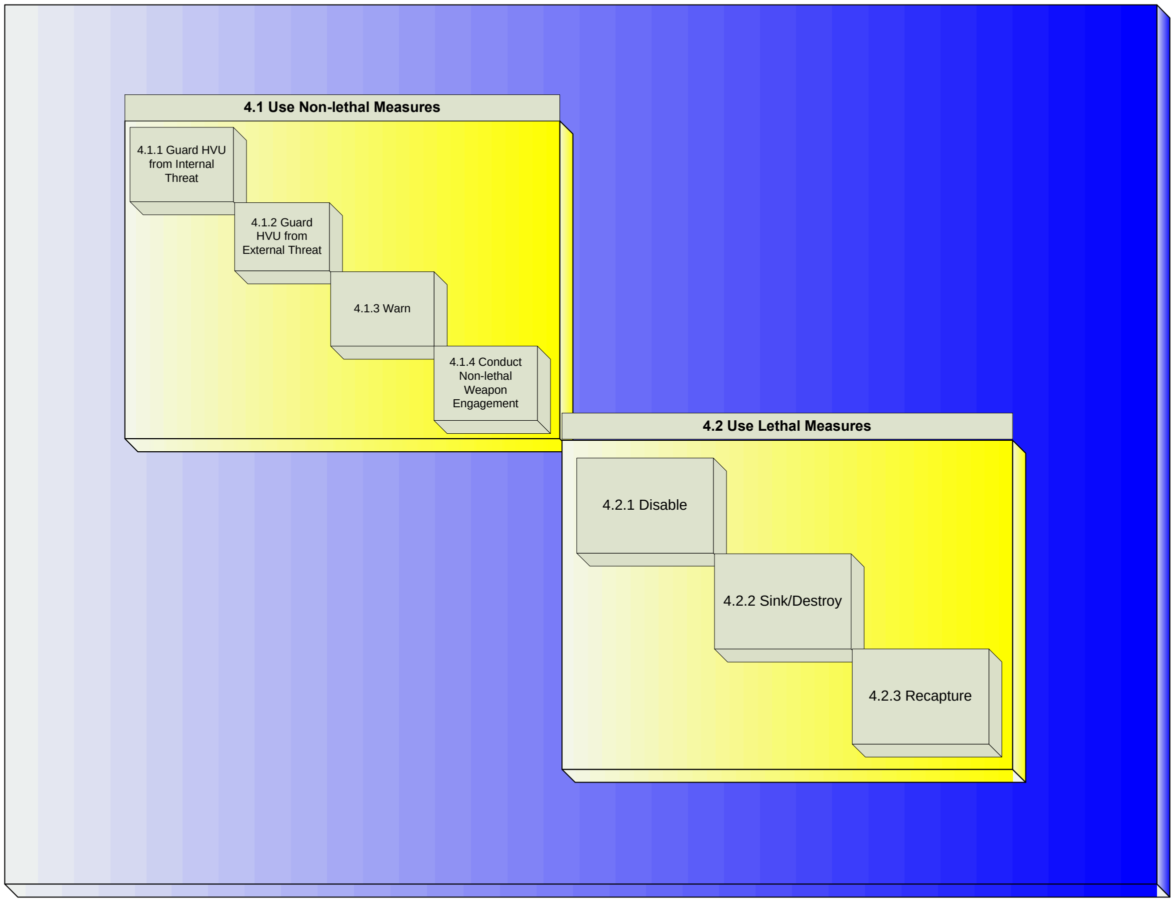

2.1 Activate Security Measures
2.1.1 Prepare Critical InfraStructure
2.1.2 Activate Preplanned OPORDS
2.1.3 Employ Sensor Equipment
2.1 Activate Security Measures
2.2.1 Activate Required Personnel
2.2.2 Issue Equipment
2.2.3 Prepare Deployment Platforms
2.3 Deploy Forces
2.3.1 Embark Deploy Plat
2.3.2 Move Deploy Plat
2.3.3 Employ Teams
2.3.4 Recover Teams

3.0 Find/Fix

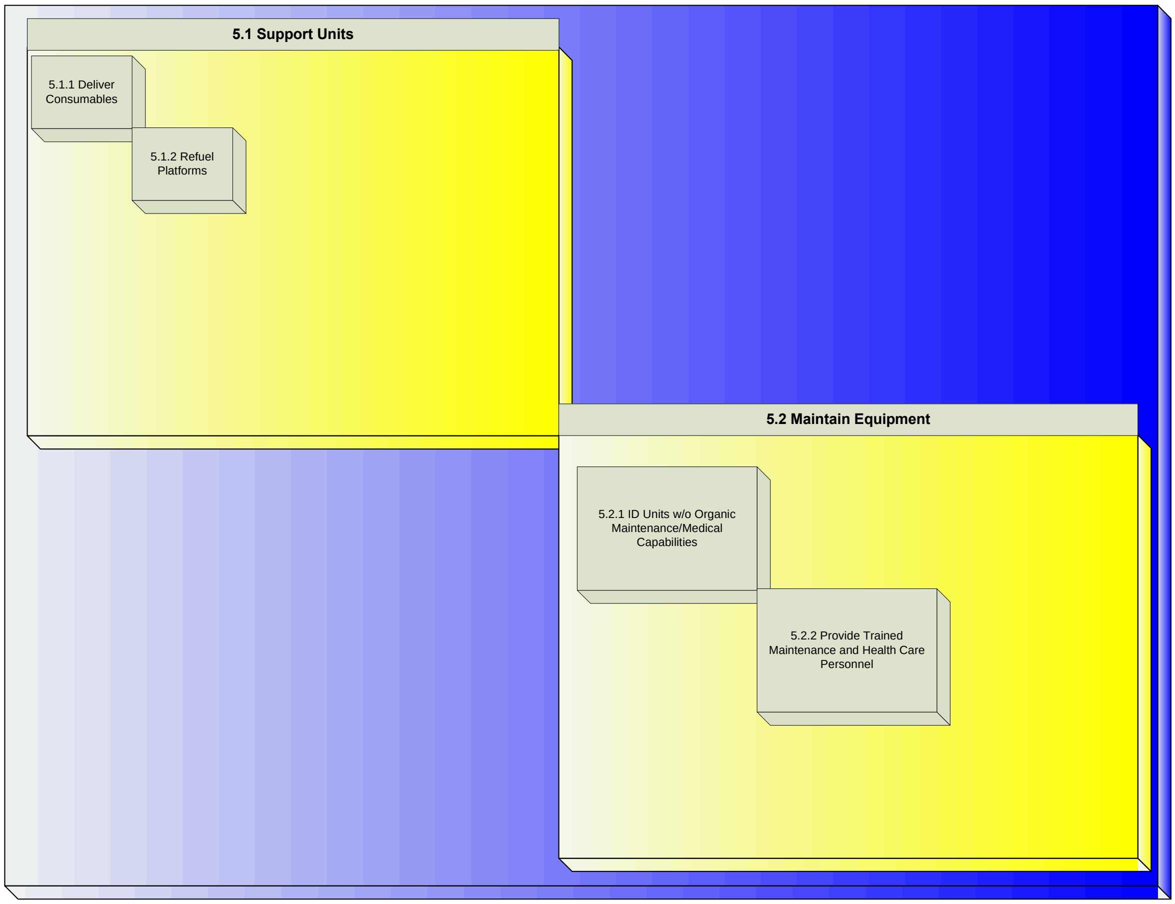


3.1 Detect
3.1.1 Scan Area of Interest
3.1.2 Process Data from Scan
3.2 Identify
3.2.1 Analyze Data On-Site
3.2.2 Analyze Data Off-Site
3.2.3 Quantify Threat
3.3 Assess
3.3.1 Determine intent
3.3.2 Determine Damage Potential

4.0 Finish


4.1 Use Non-lethal Measures
4.1.1 Guard HVU from Internal Threat
4.1.2 Guard HVU from External Threat
4.1.3 Warn
4.1.4 Conduct Non-lethal Weapon Engagement
4.2 Use Lethal Measures
4.2.1 Disable
4.2.2 Sink/Destroy
4.2.3 Recapture

5.0 Sustain


5.1 Support Units
5.1.1 Deliver Consumables
5.1.2 Refuel Platforms
5.2 Maintain Equipment
5.2.1 ID Units w/o Organic Maintenance/Medical Capabilities
5.2.2 Provide Trained Maintenance and Health Care Personnel

APPENDIX H DETECT OR TEAMS VERSUS TIME REQUIRED ANALYSIS

# detectors needed	# containers	Time/container (minutes)	Total Time (min)	Total Time (hrs)	Total Time (days)	Distance from US (miles) Assume SOA=20 kts	Distance from US (miles) Assume SOA=25 kts	Distance from US (miles) Assume SOA=30 kts	# shifts	# crew / detector	total crew needed to operate detector
1	9400.00	3.00	28200.00	470.00	19.58	9400.00	11750.00	14100.00	3.00	3	9
2	9400.00	3.00	14100.00	235.00	9.79	4700.00	5875.00	7050.00	3.00	3	18
3	9400.00	3.00	9400.00	156.67	6.53	3133.33	3916.67	4700.00	3.00	3	27
4	9400.00	3.00	7050.00	117.50	4.90	2350.00	2937.50	3525.00	3.00	3	36
5	9400.00	3.00	5640.00	94.00	3.92	1880.00	2350.00	2820.00	3.00	3	45
6	9400.00	3.00	4700.00	78.33	3.26	1566.67	1958.33	2350.00	3.00	3	54
7	9400.00	3.00	4028.57	67.14	2.80	1342.86	1678.57	2014.29	3.00	3	63
8	9400.00	3.00	3525.00	58.75	2.45	1175.00	1468.75	1762.50	3.00	3	72
9	9400.00	3.00	3133.33	52.22	2.18	1044.44	1305.56	1566.67	3.00	3	81
10	9400.00	3.00	2820.00	47.00	1.96	940.00	1175.00	1410.00	3.00	3	90
11	9400.00	3.00	2563.64	42.73	1.78	854.55	1068.18	1281.82	3.00	3	99
12	9400.00	3.00	2350.00	39.17	1.63	783.33	979.17	1175.00	3.00	3	108
13	9400.00	3.00	2169.23	36.15	1.51	723.08	903.85	1084.62	3.00	3	117
14	9400.00	3.00	2014.29	33.57	1.40	671.43	839.29	1007.14	3.00	3	126
15	9400.00	3.00	1880.00	31.33	1.31	626.67	783.33	940.00	3.00	3	135
16	9400.00	3.00	1762.50	29.38	1.22	587.50	734.38	881.25	3.00	3	144
17	9400.00	3.00	1658.82	27.65	1.15	552.94	691.18	829.41	3.00	3	153
18	9400.00	3.00	1566.67	26.11	1.09	522.22	652.78	783.33	3.00	3	162
19	9400.00	3.00	1484.21	24.74	1.03	494.74	618.42	742.11	3.00	3	171
20	9400.00	3.00	1410.00	23.50	0.98	470.00	587.50	705.00	3.00	3	180
21	9400.00	3.00	1342.86	22.38	0.93	447.62	559.52	671.43	3.00	3	189
22	9400.00	3.00	1281.82	21.36	0.89	427.27	534.09	640.91	3.00	3	198
23	9400.00	3.00	1226.09	20.43	0.85	408.70	510.87	613.04	3.00	3	207
24	9400.00	3.00	1175.00	19.58	0.82	391.67	489.58	587.50	3.00	3	216
25	9400.00	3.00	1128.00	18.80	0.78	376.00	470.00	564.00	3.00	3	225
26	9400.00	3.00	1084.62	18.08	0.75	361.54	451.92	542.31	3.00	3	234
27	9400.00	3.00	1044.44	17.41	0.73	348.15	435.19	522.22	3.00	3	243
28	9400.00	3.00	1007.14	16.79	0.70	335.71	419.64	503.57	3.00	3	252
29	9400.00	3.00	972.41	16.21	0.68	324.14	405.17	486.21	3.00	3	261
30	9400.00	3.00	940.00	15.67	0.65	313.33	391.67	470.00	3.00	3	270
31	9400.00	3.00	909.68	15.16	0.63	303.23	379.03	454.84	3.00	3	279
32	9400.00	3.00	881.25	14.69	0.61	293.75	367.19	440.63	3.00	3	288
33	9400.00	3.00	854.55	14.24	0.59	284.85	356.06	427.27	3.00	3	297
34	9400.00	3.00	829.41	13.82	0.58	276.47	345.59	414.71	3.00	3	306
35	9400.00	3.00	805.71	13.43	0.56	268.57	335.71	402.86	3.00	3	315
36	9400.00	3.00	783.33	13.06	0.54	261.11	326.39	391.67	3.00	3	324
37	9400.00	3.00	762.16	12.70	0.53	254.05	317.57	381.08	3.00	3	333
38	9400.00	3.00	742.11	12.37	0.52	247.37	309.21	371.05	3.00	3	342
39	9400.00	3.00	723.08	12.05	0.50	241.03	301.28	361.54	3.00	3	351
40	9400.00	3.00	705.00	11.75	0.49	235.00	293.75	352.50	3.00	3	360

ctors l	# containers	Time/container (minutes)	Total Time (min)	Total Time (hrs)	Total Time (days)	Distance from US (miles) Assume SOA=20 kts	Distance from US (miles) Assume SOA=25 kts	Distance from US (miles) Assume SOA=30 kts	# shifts	# crew / detector	total crew needed to operate detector
1	9400.00	3.00	28200.00	470.00	19.58	9400.00	11750.00	14100.00	3.00	2	6
2	9400.00	3.00	14100.00	235.00	9.79	4700.00	5875.00	7050.00	3.00	2	12
3	9400.00	3.00	9400.00	156.67	6.53	3133.33	3916.67	4700.00	3.00	2	18
4	9400.00	3.00	7050.00	117.50	4.90	2350.00	2937.50	3525.00	3.00	2	24
5	9400.00	3.00	5640.00	94.00	3.92	1880.00	2350.00	2820.00	3.00	2	30
6	9400.00	3.00	4700.00	78.33	3.26	1566.67	1958.33	2350.00	3.00	2	36
7	9400.00	3.00	4028.57	67.14	2.80	1342.86	1678.57	2014.29	3.00	2	42
8	9400.00	3.00	3525.00	58.75	2.45	1175.00	1468.75	1762.50	3.00	2	48
9	9400.00	3.00	3133.33	52.22	2.18	1044.44	1305.56	1566.67	3.00	2	54
10	9400.00	3.00	2820.00	47.00	1.96	940.00	1175.00	1410.00	3.00	2	60
11	9400.00	3.00	2563.64	42.73	1.78	854.55	1068.18	1281.82	3.00	2	66
12	9400.00	3.00	2350.00	39.17	1.63	783.33	979.17	1175.00	3.00	2	72
13	9400.00	3.00	2169.23	36.15	1.51	723.08	903.85	1084.62	3.00	2	78
14	9400.00	3.00	2014.29	33.57	1.40	671.43	839.29	1007.14	3.00	2	84
15	9400.00	3.00	1880.00	31.33	1.31	626.67	783.33	940.00	3.00	2	90
16	9400.00	3.00	1762.50	29.38	1.22	587.50	734.38	881.25	3.00	2	96
17	9400.00	3.00	1658.82	27.65	1.15	552.94	691.18	829.41	3.00	2	102
18	9400.00	3.00	1566.67	26.11	1.09	522.22	652.78	783.33	3.00	2	108
19	9400.00	3.00	1484.21	24.74	1.03	494.74	618.42	742.11	3.00	2	114
20	9400.00	3.00	1410.00	23.50	0.98	470.00	587.50	705.00	3.00	2	120
21	9400.00	3.00	1342.86	22.38	0.93	447.62	559.52	671.43	3.00	2	126
22	9400.00	3.00	1281.82	21.36	0.89	427.27	534.09	640.91	3.00	2	132
23	9400.00	3.00	1226.09	20.43	0.85	408.70	510.87	613.04	3.00	2	138
24	9400.00	3.00	1175.00	19.58	0.82	391.67	489.58	587.50	3.00	2	144
25	9400.00	3.00	1128.00	18.80	0.78	376.00	470.00	564.00	3.00	2	150
26	9400.00	3.00	1084.62	18.08	0.75	361.54	451.92	542.31	3.00	2	156
	9400.00	3.00	1044.44	17.41	0.73	348.15	435.19	522.22	3.00	2	162
	9400.00	3.00	1007.14	16.79	0.70	335.71	419.64	503.57	3.00	2	168
	9400.00	3.00	972.41	16.21	0.68	324.14	405.17	486.21	3.00	2	174
	9400.00	3.00	940.00	15.67	0.65	313.33	391.67	470.00	3.00	2	180
	9400.00	3.00	909.68	15.16	0.63	303.23	379.03	454.84	3.00	2	186
	9400.00	3.00	881.25	14.69	0.61	293.75	367.19	440.63	3.00	2	192
	9400.00	3.00	854.55	14.24	0.59	284.85	356.06	427.27	3.00	2	198
	9400.00	3.00	829.41	13.82	0.58	276.47	345.59	414.71	3.00	2	204
	9400.00	3.00	805.71	13.43	0.56	268.57	335.71	402.86	3.00	2	210
	9400.00	3.00	783.33	13.06	0.54	261.11	326.39	391.67	3.00	2	216
	9400.00	3.00	762.16	12.70	0.53	254.05	317.57	381.08	3.00	2	222
	9400.00	3.00	742.11	12.37	0.52	247.37	309.21	371.05	3.00	2	228
	9400.00	3.00	723.08	12.05	0.50	241.03	301.28	361.54	3.00	2	234

APPENDIX I CONTAINER SHIP SEARCH PROBLEM ANALYSIS

(Operations Research – Feasibility Study on Weapon of Mass Destruction Passive and Active Detectors)

INTRODUCTION

> In this century, countries benefit from healthy, prosperous, confident partners. Weak and troubled nations export their ill—problems like economic instability and illegal immigration and crime and terrorism. America and others . . . understand that healthy and prosperous nations export and import goods and services that help to stabilize regions and add security to every nation.[1]

President George W. Bush, November 20, 2004

The Port of San Francisco has security concerns that are much more varied and complex than almost any other port, encompassing not only a variety of maritime cargo terminals, but much more including dramatically increasing cruise ship activity, world-famous tourist attractions such as Fisherman's Wharf and Pier 39, excursion boat terminals, a commercial fishing harbor and fish processing terminal, a ship repair yard and dry dock, lay berths for Maritime Administration vessels, the strategically important western anchorage of the Bay Bridge, two major power plants, and numerous public waterfront piers and promenades. The average annual throughput in TEU is around 30,000 and growing (32,045 TEUs - in year 2004).[2]

A Weapon of Mass Destruction (WMD) attack would be devastating and unimaginable. The estimated damage for a successful attack costs about US$500 billion. This leads to the initiative to study the feasibility of searching for and detecting any WMD that is suspected to be onboard a Potential Attack Vessel (PAV) en route from Asia to the Port of San Francisco.

Currently, there are several nuclear detection capabilities that are available in the market. They range from handheld to machine based detectors. This report leverages on the passive detector and active interrogator concept to explore and gain insights. With limited technical knowledge of the devices, the report was based on an assumed detector capability as well as on the premise of desired Probability of Detection (P_d) and Probability of False Alarm (P_{fa}).

Sensitivity analysis was also performed to look into the tradeoffs between detector capability and quantity. In addition, without the ability to forecast the container ship manifest and predict the number of containers with high radiation that have to be scanned by an active interrogator, a range of quantity of containers with high radiation was input into the model to gain an insight on the point where having "a lot of high radiation containers" become "too many high radiation containers to handle."

SCENARIO OVERVIEW

This scenario is based on 20 PAVs traveling (Randomly distributed) from the Port of Singapore to the Port of San Francisco. There are three possible routes that the PAVs may take. Namely, the Northern route (from Singapore – China – San Francisco), the Direct route (from Singapore – Philippines – San Francisco) and the Southern route (from Singapore – Hawaii – San Francisco). However, our findings have concluded that the main route that the PAVs are taking is the Northern approach (see Figure I-1). Some of the PAVs may or may not stop at ports (e.g., the Port of Beijing) along the way. Assuming that the intelligence gathered about the PAVs is accurate; detection teams will be dispatched accordingly from their various locations to board and search the PAVs.

Figure I-1: Northern Shipping Route

ASSUMPTIONS

Our analysis has the following assumptions:

1. 100% accurate intelligence on suspected PAVs.
2. Detection Teams are on standby.
3. No administrative and logistic time lost due to last minute notice to move.
4. Successful boarding of PAVs by detection teams.
5. Zero resistance by crews or insurgents onboard suspected PAVs.
6. Time to board the PAVs is not taken into consideration.
7. A triangle distribution for the number of containers onboard PAVs was used.
8. Setting an upper and lower bound will prevent "extreme" results.
9. Number of containers range from 2,000 (min) to 10,000 (max) with an average of 6,000.
10. Transit times also follow a triangle distribution
    a. An EXTEND™ simulation was performed to model the possible times to port via three routes across the Pacific Ocean.
    b. Results showed that the time to port is between 70 hours to 200 hours, with an average of 135 hours.
    c. Setting the upper and lower bound will again prevent "extreme" results.
11. Dwell times for both passive and active detectors are unknown. This is one of the unknown capabilities that need to be quantified.
12. All containers have to be scanned by a passive detector. Only false alarms will be further scanned by an active interrogator.
13. All containers on the manifest listed as possibly high radiation will be scanned by passive detector AND active interrogator.
14. Sequential and non-stop scanning of the containers. Therefore, there is no time wasted installing and dismantling the detectors.
15. The process of scanning with the active interrogator is assumed to start immediately after the passive detector, i.e., the start of the active

interrogator scans do not need to wait for the completion of the passive detector scans.

16. Up to 20% of the PAVs' manifest is listed with high radiation. They will need to be scanned by the active interrogator.
17. It is assumed that up to 10 passive detectors and 3 active interrogators will be deployed per PAV, limited by resource and manpower constraints.
18. Probability of false alarm, P_{fa}, for the passive detector is assumed to be 1% (this is considered to be an underestimate of the capability of a passive detector available in the market currently).
19. Two triggers out of three looks of the passive detector will qualify as a false alarm.
20. Active interrogators have 0% false alarm and 100% detection.

METHODOLOGY

Scanning Process

Our model begins when the detector teams starting the scanning process. A total of 10 teams (each with 1 passive detector) will scan the containers concurrently. The first scan will be done by a passive detector. If the container triggers the passive detector at least twice out of three looks, then it will be tagged and an active interrogator will be employed to confirm the detection.

Total False Alarm Probability, P_{fa}

The total P_{fa} is computed using a Binomial distribution function of 2 or more false alarms out of 3 looks. The Binomial's probability is taken off the P_{fa} of the Passive detector (assume 1% in this case). With this total P_{fa}, we then proceed to find the factors involving PAVs. Each PAV is given a ship number for identification purposes.

Total Number of False Alarms for 20 PAVs

The individual ship's false alarm is obtained by multiplying the number of containers by the overall P_{fa} when scanning a single container. Thus the total number of false alarms can be easily obtained by summing all the 20 PAVs' false alarm. A Critical Binomial function is used in Excel and the number of trials will be the total number of containers scanned, while the probability is the total P_{fa} and Alpha is a random number.

Given all the facts and assumptions that have been generated earlier, we now proceed onto finding out recommendations for the detectors. For this research, we will focus on the following:

1) Dwell time of both passive and active detectors
2) Manifest

Dwell Time

Firstly, dwell time of the detector plays an important role in determining the accuracy of the scan. Generally, a longer dwell time equate to higher chance to generate a false alarm but a longer dwell time also equate to more time dedicated to scan a container. There must be a trade off between them.

Dwell Time of Passive Detector

The dwell time of the passive detector is computed using the hours to port, containers on each PAV and the upper bound of the passive detectors. The following equation is used to obtain the Dwell time:

$$\frac{\text{Hours to port}}{\left(\dfrac{\text{Containers on Ship}}{\text{Upper bound of Passive detectors}}\right)} \times 60\,(\text{minutes})$$

A total of 20 dwell times are obtained from the 20 PAVs. Thereafter the minimum of the maximum dwell time is taken for comparison.

Dwell Time of Active Interrogator and Manifest of PAV

The items carried in each PAV's containers may consist of items that are high in radiation. These containers are assumed to be highly dangerous which have to go through the active detector scan right from the start. Recalling the assumption that a

PAV can have up to 20% of its manifest being high radiation, there is a need to formulate an equation to determine the dwell time. The equation is very much similar to the passive detector.

$$\frac{\text{Hours to port}}{\left(\dfrac{20\%\text{ of containers on VOI}}{\text{Upper bound of Active detectors}}\right)}\times 60(\text{minutes})$$

Again, the minimum of the maximum dwell time is obtained the same way as before.

RESULTS AND DISCUSSION

First, the assumption of detector probability of detection needs to be analyzed. With the need to meet the WMD scenario detection probability of 0.99, and given the adoption of the "3-look" method, it can be calculated that the lowest detector probability that can be afforded is 0.9415. This is based on the fact that the detector has to register detection at least 2 out of 3 looks. Therefore, for a required probability of WMD detection of 0.99, the binomial function gives us the required passive detector Pd to be at least 0.9415.

With the P_{fa} of the passive detector assumed to be 1%, and adopting a "3-look" method and only recognizing 2 triggers and above out of 3 looks to be a false alarm, the revised probability of false alarm for each container scanned then becomes 0.000298.

Assuming that we place an upper bound of 10 passive detectors onboard each PAV, and under the constraint of no disruption to commerce, a Monte Carlo simulation of 10,000 runs gave the following for maximum average dwell time for the passive detector to be 2.489 min. The lowest occurrence of dwell time is 1.472 min. In other words, if the characteristic of the passive detector is such that the dwell time has to be more than 1.472 min, then we risk the event of delaying a container ship from entering the Port of San Francisco. The Monte Carlo result for max dwell time is shown below.

Summary Statistics		Notes
Average	2.489	
SD	0.3774	
Max	4.153	
Min	1.472	

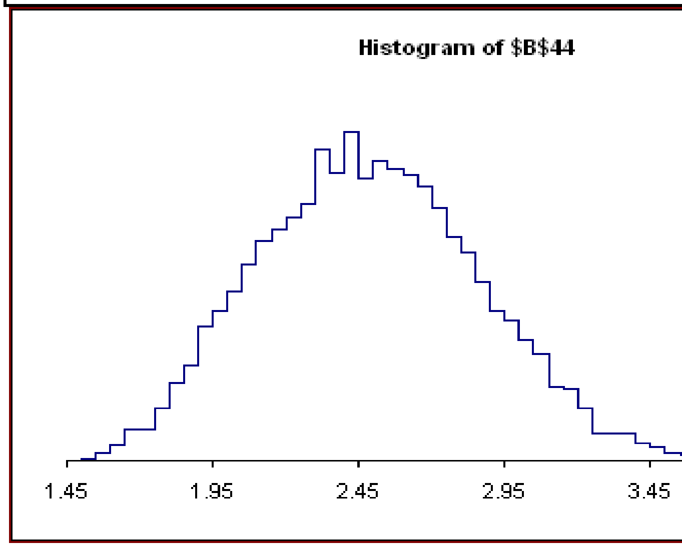


Figure I-2: Distribution of required dwell time (min) of passive detector with 10,000 runs (if we set upper bound of no of passive detectors deployed onboard each ship to be 10). Pfa of passive detector = 0.01, 2 triggers out of 3 looks to be considered a FA.

Using a Monte Carlo simulation of 10,000 runs, the average total number of false alarms across all ships is found to be 35.705 (shown below), and 64 false alarms was the worst case experienced.

Summary Statistics			Notes
Average	35.705		
SD	6.3576		
Max	64.000		
Min	17.000		

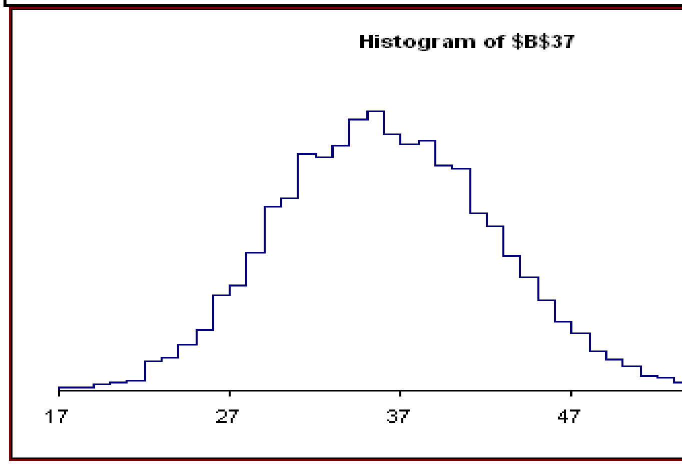


Figure I-3: Distribution of total no of false alarms with 10,000 runs. Pfa of passive detector = 0.01, 2 triggers out of 3 looks to be considered a false alarm.

It should be noted that this number is significantly smaller than the number of containers with high radiation, which is estimated to up to 20% of the total no of containers. At this point, we can conclude that the deciding factor that will influence the capability requirement of the active interrogator will not be the number of false alarms, but instead, will be the number of containers with high radiation as listed on the cargo manifest.

Using the pessimistic case of 20%, and assuming that the upper bound of active interrogators we can place in each PAV to be 3 (due to resource and manpower constraints), we went on to calculate the required dwell time that the active interrogator must achieve, as shown below.

Summary Statistics			Notes
Average	11.204		
SD	1.6889		
Max	18.477		
Min	6.672		

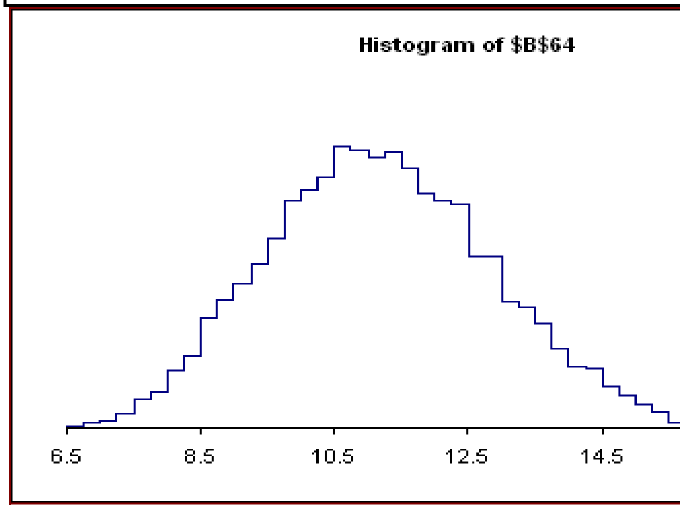


Figure I-4: Distribution of required dwell time (min) of active interrogator with 10,000 runs (if we set upper bound of no of active detectors deployed onboard each ship to be 3). Assumed 20% of containers on each ship listed with high radiation content.

The above shows that the dwell time of the active interrogator must be at most 11.204 min. In the most stringent case, we should target that the dwell time of the active interrogator must be below 6.672 min.

Conversely, if we set the dwell time of the active interrogator to be 10 min, using the same Monte Carlo simulation of 10,000 runs tell us that we will need 2.745 active interrogators onboard of each PAV to prevent any disruption to commerce. In the most stringent case where the combination of inputs (such as a high number of containers, very little time left to port, high number of containers with radioactive content), contribute to the longest search time out of the 10,000 runs, we will need up to 4.610 active interrogators.

Summary Statistics			Notes
Average	2.745		
SD	0.4216		
Max	4.610		
Min	1.614		

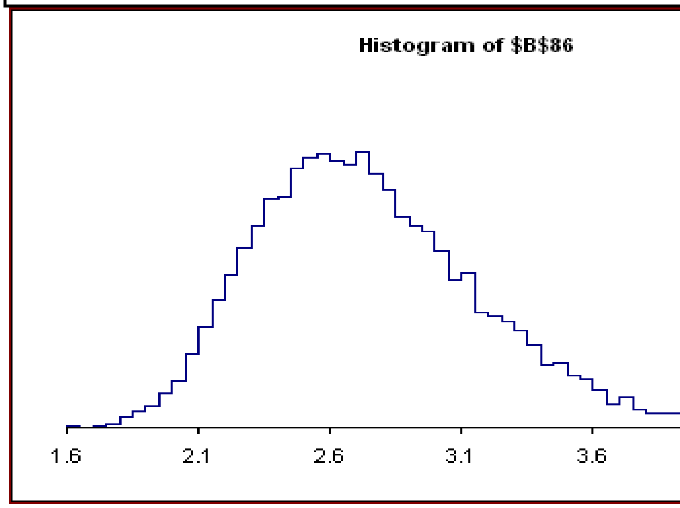


Figure I-5: Distribution of required no of active interrogators needed assuming dwell time of interrogator is fixed at 10 min (with 10,000 runs). Assumed 20% of containers on each ship listed with high radiation content.

SENSITIVITY ANALYSIS

Sensitivity Analysis was performed to look at the tradeoffs between the number of detectors deployed onboard each PAV and the dwell time required of the passive detector. It was found that the more passive detectors deployed in each ship, the less stringent the dwell time is for the passive detector. For example, if we are willing to place the infrastructure and setup for 25 passive detectors per ship, we could allow the dwell time of the passive detector to be an average of 6.239 min, or 3.707 min in the worst cast. The relationship can also be shown in the plot for the worst case of dwell times required.

Number of passive detectors per ship	10	15	20	25
Dwell time required from passive detector	2.489	3.742	4.985	**6.239**
SD	0.377	0.559	0.756	0.940
Max	4.153	6.163	8.099	10.910
Min	1.472	2.248	3.025	**3.707**

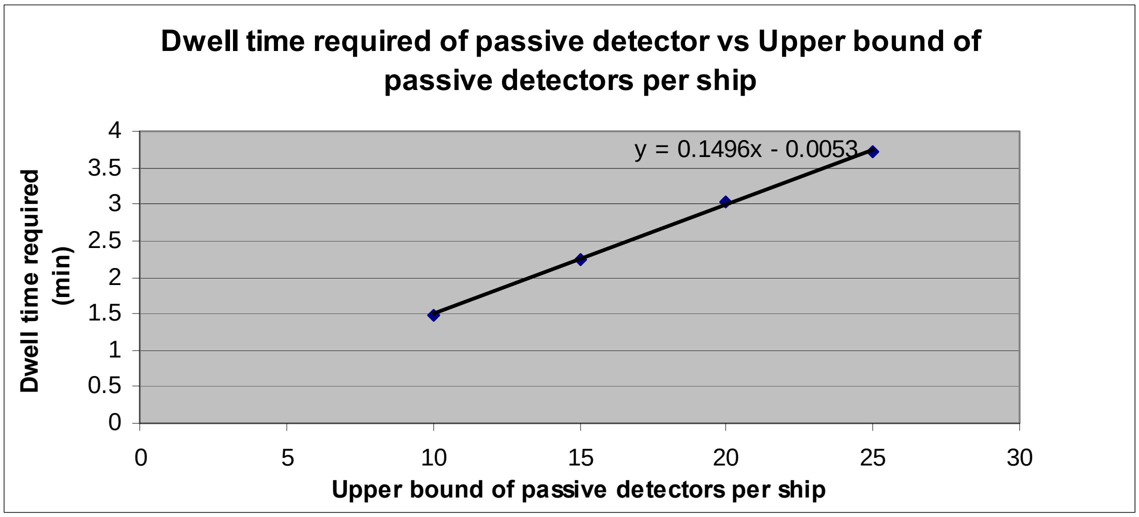


Figure I-6: Plot of Dwell time required of passive detector vs. Upper bound of passive detectors deployed per ship

From the above, we could observe that increasing the number of detectors by 1 will "buy" you an approximate 0.15 min increase in required dwell time of the passive detector.

As for the active interrogator, the number that can be deployed per ship was adjusted upwards from 3, which was our baseline. It can be found that if resources enable an increase to 6 active interrogators to be placed on each PAV, the dwell time required becomes 22.407 min and 13.466 min for the worst case.

Upper bound of active interrogator per ship	3	4	5	**6**
Dwell time required from active interrogator	11.204	14.931	18.630	**22.407**
SD	1.689	2.262	2.830	3.395
Max	18.477	23.511	28.885	37.054
Min	6.672	8.887	10.840	**13.466**

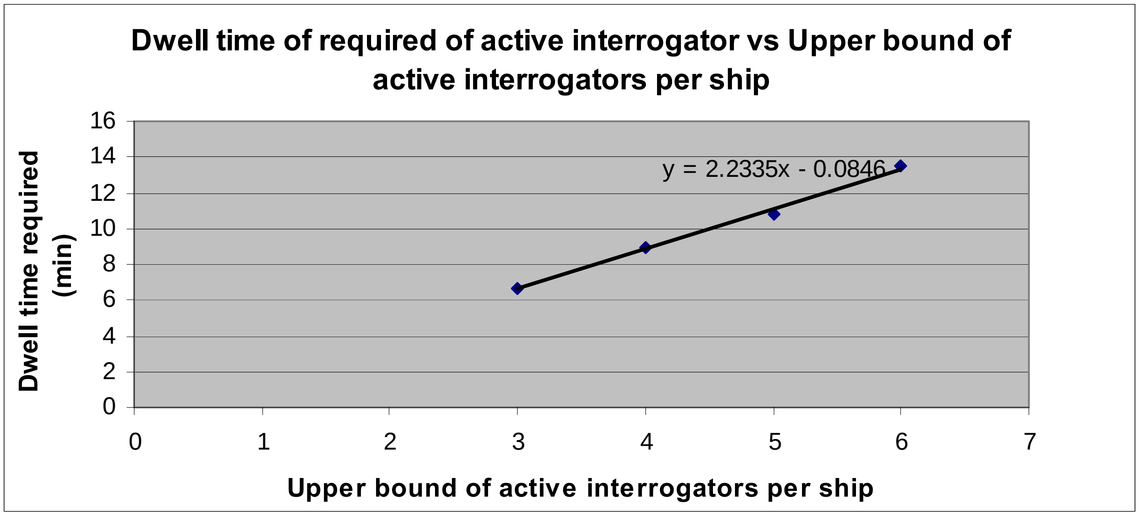


Figure I-7: Plot of Dwell time required of active interrogator vs. Upper bound of active interrogators deployed per ship.

In this case, increasing the active interrogator by 1 per PAV, will "buy" you an approximate increase of 2.23 min of dwell time required of the active interrogator.

Conversely, if we were given four different models of active interrogators with different characteristic dwell time, we are able to investigate the number of each we will need to deploy onboard each PAV. From the plot, if model D was much cheaper than model A, it may be more cost effective to purchase more model Ds, provided we have the manpower support to employ them. For a full analysis to be done, cost will need to be brought into the picture, as well as numerical manpower and infrastructure constraints.

Interrogator Model	A	B	C	D
Dwell time (min)	5	10	15	20
Number of active interrogators needed	1.368	2.745	4.108	5.484
SD	0.2132	0.4216	0.6382	0.8616
Max	2.161	4.61	6.774	8.896
Min	0.835	1.614	2.445	3.224

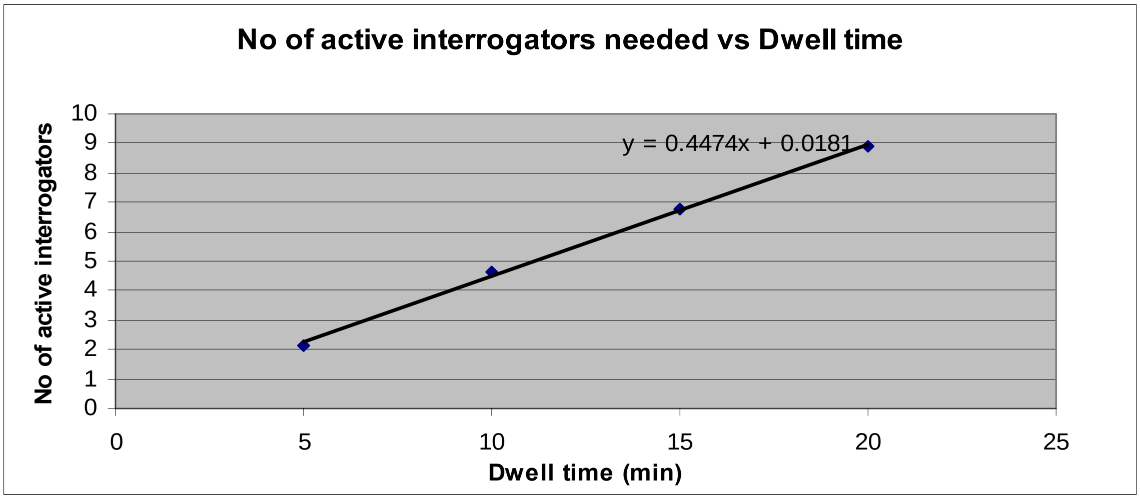


Figure I-8: Plot of No of active interrogators needed vs. Dwell time of active interrogator

FUTURE RESEARCH

This research may have laid the groundwork in determining the detectors' characteristics and also the numbers needed; however, there is a need to consider the following areas for further research so as to gain a better insight on the overall picture:

<u>Activation and Travel Time for the Units on Standby</u>

In this model, it is assumed that zero time is needed for activating the units. This is not applicable as one would expect time delay of maybe up to 30 minutes, depending on the sensitive bureaucracy levels for activation. The proximity of the units to the PAVs will also contribute to the delay. These two factors will greatly affect the total time taken to scan the PAV, as a minute is wasted, it equates to less scanning time for the teams.

<u>Probability of Successful Boarding of PAVs</u>

PAVs are mainly operated by private companies and they travel over the open seas. As the operator of the PAV, they might deny the boarding of search teams. This again will cause delay to the total scanning time.

Scanning Sequence and Setup Time of Detectors

Every PAV will have its own configuration of placing the containers. This requires a new set of scanning sequence for almost every PAV. The scanning of the containers will be further complicated if the PAV has very limited maneuver space to house the detectors. Every detector will have its own respective setup time; this setup time has direct impact on the total scan time.

Effects of Delay in Scanning Time

As discussed above, there are various ways in which delays can happen, starting from intelligence collection to the time where the scanning starts. These delays will have grave impact on the actual time spent on each PAV. This increase could lead to increase of detectors, cost, number of units and logistic implications

Deterministic vs Stochastic Model

This current model is based on a deterministic model. In actual fact, a model of stochastic nature will determine the selection of detectors better. There is a lot of variability that can exist in this WMD scenario.

Effects of Manifest List

In this study, the manifest list is based on 20% of the containers having radioactive content. The main bulk of containers to be scanned by the active interrogator actually come from the manifest list. If the manifest is not accurate, delays may again be expected as there will be more false alarms being triggered by the Passive detectors. With a rule of at least three scans needed for the first trigger, it could greatly increase the total scan time for a PAV. This increase in scan time will also contribute to the increase in active interrogators. Therefore, there is a need to look into the accuracy of the manifest list.

Peacetime Scanning Procedures when there is No Intelligence on any Imminent Threat

Given the high volume that the Port of San Francisco encounters daily, there is a need to look into the imminent threat. A random scanning process of ships before they reached San Francisco may be possible to curb this problem. However, to execute this pain-staking process, it takes a lot of planning and high cost. Therefore, an optimized random scanning for the incoming ships should be studied into. It may be possible to have compulsory scanning zones out in the Pacific Ocean. By having this proactive approach, it also serves as a deterrence factor.

CONCLUSION

It is concluded that the manifest of a PAV plays an important part in determining the number of detectors needed, rather than the number of false alarms. The unpredictability of the manifest list with radioactive content also causes modeling the scan procedures a difficult task. We can only go as far as by entering the number of radioactive containers based on the worst cast. Our sensitivity analysis has also shown that if a shorter dwell time is possible, fewer detectors will be required. This input can be interpreted to the decision makers, who can make use of this tradeoff study to objectively consider the cost effectiveness of each option.

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Appendix J Nuclear Detection BASICS

J.1 INTRODUCTION

Nuclear weapons are arguably the most destructive weapons of mass destruction. One only needs to look at what happened in Hiroshima and Nagasaki during the Second World War—the immense destruction and huge loss of lives, and what continues to happen many years after that—the radiation-linked birth defects and diseases that the some of their bombing victims still suffer. The economic, social and psychological losses are just catastrophic.

While it is debatable whether a terrorist group will be able to either get hold of a nuclear weapon or build one, what can equally likely occur is an attack using a radiological dispersion device (RDD) or "dirty bomb." In such a device, conventional explosives are packed around radioactive materials, [which could have been stolen from a medical or industrial facility, or even a nuclear plant in the form of spent reactor fuel. These places generally tend to have lower levels of security than the military installations in which the nuclear weapons are kept.

When an RDD is detonated, the explosion causes the radioactive material to disperse over the target area, usually a populated area. While the damage extent resulting from such an attack depends on many factors such as the type of radioactive material used, the weather and environment conditions such as wind and geography, and while an RDD attack is deemed less catastrophic than a nuclear one, a successful execution of the former will no doubt cause widespread panic and confusion, resulting in economic and psychological losses. A computer model, given in Figure J-1, indicates that fallout from a weapon using spent nuclear fuel could deliver a lethal dose in a 24-hour period over a broad area extending as far as 400 km.[130]

[130] S.M. Nichelson, Medlin DD, "Radiological Weapons of Terror," AU/ACSC/145/1999-04, Air Command and Staff College, 1999.

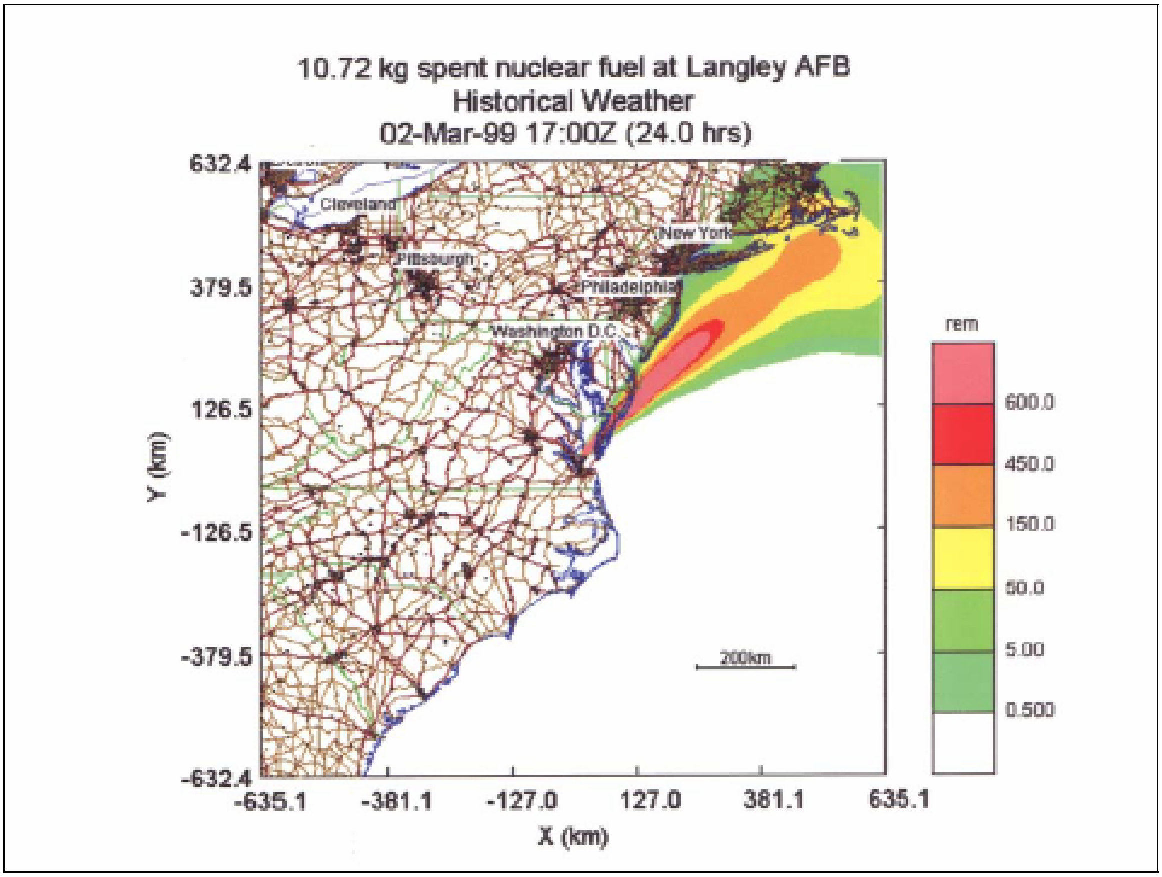

Figure J-1: Simulation of a radiological attack at Langley AFB, Virginia, using 10.27 kg of spent nuclear fuel. Cumulative dose contours after 24 hours are given in rem, which is the biological equivalent dose. A dose of 600 rem (6 Sv) or greater during a 24-hour period is usually fatal.[131]

There are an estimated ten million radioactive sources in existence around the world, with several hundred thousand radioactive enough to pose serious health problems. These sources are used to keep food safe, treat diseases such as cancer, and detect flaws in structures and welds. In industrialized countries, the more radioactive sources tend to be well guarded, but in less developed nations security is uneven. A well armed and trained terrorist group could attack one of these facilities in the night and make away with the radioactive sources they need.

One school of thought, however, believes it is unlikely a terrorist group would try this method for two reasons: (1) the more radioactive sources would kill them within minutes of exposure if they do not have extensive shielding and protection; and (2) the

[131] S.M. Nichelson, Medlin DD, "Radiological Weapons of Terror," AU/ACSC/145/1999-04, Air Command and Staff College, 1999.

radioactivity levels will be so high that existing detection technology will be able to detect shipments of these materials and render its mission a failure.

Nuclear explosives can be divided into three major categories: devices that release the majority of their energy through nuclear fission; devices that release the majority of their energy through nuclear fusion; and hybrid devices that release large amounts of energy through both fission and fusion.[132] In nuclear fission, energy is produced by splitting a fissile species such as Uranium-235 (^{235}U) or Plutonium-239 (^{239}Pu). In nuclear fusion, the energy is produced when two light nuclei combine into a single heavier nucleus.[133] The SoS will focus its search efforts on locating two materials, namely, Uranium (U) and Plutonium (Pu), since, according to the International Atomic Energy Association (IAEA), both of these elements may be suitable for direct use in an improvised nuclear explosive device with little or no additional processing.[134]

J.2 BASICS OF NUCLEAR PHYSICS

As a radioactive nuclide decays or goes through fission, by-products such as free neutrons, gamma rays and other nuclear fragments such as beta particles and alpha particles are emitted. However, the primary long-range observables from nuclear materials are gamma rays and neutrons.

Gamma rays form the highest-energy end of the electromagnetic spectrum which are emitted during the decay of radioactive nuclei while neutrons are emitted during spontaneous fission. These observables have mean free paths of the order of 100 meters in air and only about 10 cm in water. Observables can be shielded as it is strongly attenuated by high atomic number and high density materials such as lead. In addition to attenuation, the signal from a point source decreases with an inverse square proportionality with detection range.

[132] Robert Harney, Chapter 2, Combat Systems, Vol. 4, Naval Postgraduate School, Monterey, CA, January 2006.

[133] Ibid.

[134] International Atomic Energy Agency (IAEA), *Illicit Trafficking Database*, [http://www.iaea.org/] 2006, accessed in February 2006.

J.3 CHARACTERISTICS OF NUCLEAR MATERIALS

For uranium, the focus is on Highly Enriched Uranium (HEU) which contains more than 20% U-235 and Weapons Grade Uranium (WGU) which contains more than 90% of U-235. The decay of U-235 will emit gamma rays of energy 185 keV, while its by-product, U-238, will emit gamma rays with energy level of 1001 keV. The higher level gamma rays will be more difficult to shield and hence easier to detect. If the uranium is contaminated with U-232, as in reprocessed uranium from reactor fuel, then U-232 emits gamma rays at energies of 239, 511, 583 and 2614 keV, the latter of which will be easy to detect.

- U-235 source with depleted uranium tamper can produce as many as 10^5 1001 keV gamma rays per second from U-238.
- U-232 source can produce 2.68×10^{11} 2614 keV gamma rays per second.[135]

WGU also emits neutrons with an energy distribution of about 1 MeV. These neutrons have a mean free path of about 2-6 cm in shielding materials. Philips et al. show that a 12 kg WGU with 79 kg DU tamper can produce 1,400 neutrons per second.[136] This is considered low, and hence the observables for uranium are the gamma rays.

For plutonium, the focus is on Weapon Grade Plutonium (WGPu), which contains 93.8% of Pu-239 and 5% Pu-240, and Reactor Grade Plutonium (RGPu), which contains 60% of Pu239, 24.3% Pu-240, and 9.1% Pu-241. P-239 will emit gamma rays at energies of 375, 414, 646 and 769 keV, while Pu-241 will emit gamma rays at energies of 662 and 722 keV. One by-product, Am-241, will emit gamma rays at 59 keV. WGPu or RGPu emits a higher rate of neutrons. Philips also indicates that a 4-kg WGPu with 52-kg DU tamper can produce as many as 400,000 neutrons per second. These neutrons, with average energy of 1 MeV, will have a mean free path of 2-6 cm. The background rate is 50 neutrons per meter-squared per second. Also, WGPu can emit 54,000 neutrons per second per kilogram, while RGPu emits about 349,000 neutrons per second per kilogram. Thus, plutonium is easier to detect than uranium.

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[135] G.W. Philips, D.L. Nagel, and T. Coffey, "A Primer on the Detection of Nuclear and Radiological Weapons," Center for Technology and National Security Policy, National Defense University, 2005.

[136] Ibid.

- $n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.764$ MeV
- $n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79$ MeV
- $n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48$ MeV γ +2.3 MeV (93%)
  $\rightarrow {}^{7}Li + {}^{4}He$ +2.8 MeV (7%)
- $n + {}^{155}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{157}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{235}U \rightarrow$ fission fragments + ~160 MeV
- $n + {}^{239}Pu \rightarrow$ fission fragments + ~160 MeV

Figure J-2 shows computer simulations of the gamma-ray spectra of WGU and WGPu.[137]

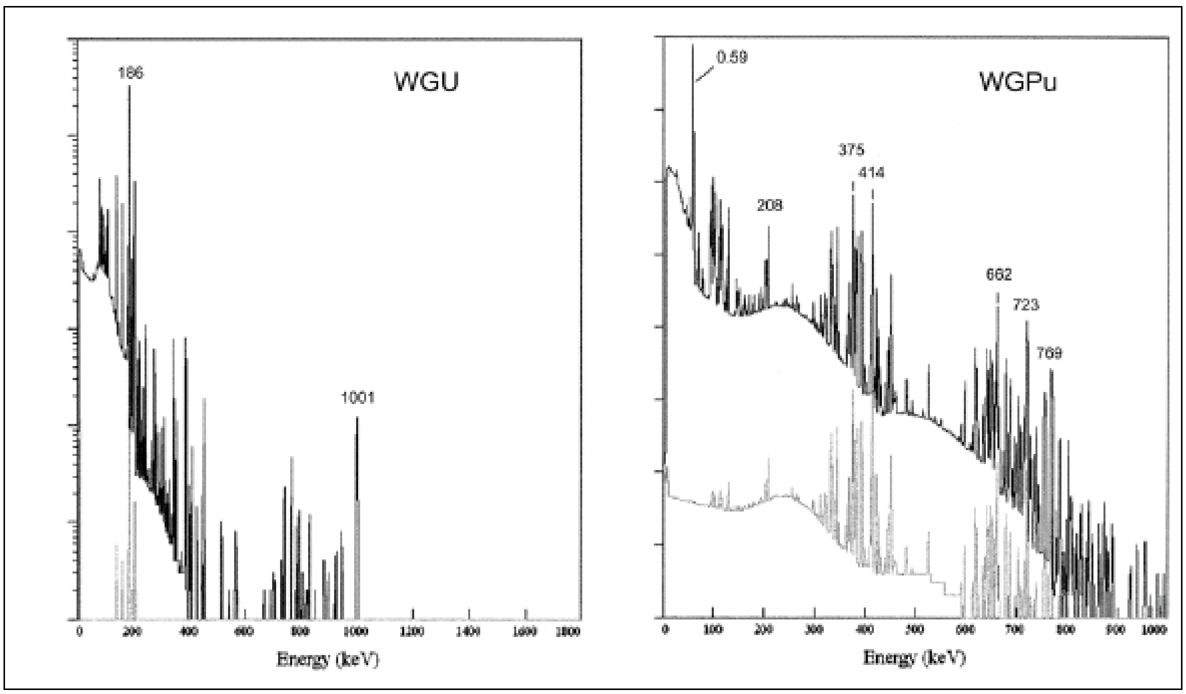

Figure J-2: Computer simulations of high-resolution gamma-ray spectra of WGU (left) and WGPu (right). The most prominent peaks are labeled with their energies in keV. Not included are the effects of the environmental background, which would obscure all but the strongest peaks. The WGPu peak labeled 59 keV is from the decay of 241 Am.

J.4 CHARACTERISTICS OF RADIOLOGICAL MATERIALS

The primary potential sources of material for radiological weapons are medical, industrial and research sources, and spent nuclear fuel. Grotto identifies eight of these

[137] S.C. Geelhood, C.W. Frank, et al., "Transient QCM Behavior Compared," *Journal of the Electrochemical Society*, 149(1), 2002, pp. H33-H38.

radioactive elements, given in Table J-1, based on a combination of radioactivity and relative prevalence in the industrial and medical world.[138] Table J-2 lists their half lives, the types of radiation emitted and their energies, which will prove very useful in determining the optimum detector system to use, if necessary.

Element	Symbol	Uses
Americium-241	^{241}Am	To detect petroleum deposits and calibrate instruments In industrial gauges
Californium-252	^{252}Cf	To detect petroleum deposits
Cesium-137	^{137}Cs	In industrial gauges and to treat diseases, sterilize food and medical equipment, detect petroleum deposits
Cobalt-60	^{60}Co	In industrial gauges and to treat diseases, sterilize food and medical equipment, detect hidden flaws in structures
Iridium-192	^{192}Ir	To detect hidden flaws in structures and treat diseases
Plutonium-238	^{238}Pu	To generate low levels of power
Radium-226	^{226}Ra	In industrial gauges and to produce radon for cancer treatment
Strontium-90	^{90}Sr	To generate low levels of power

Table J-1: Eight Common Radioactive Elements

Element	Half-Life	Type of Radiation	Energy (keV)
^{241}Am	430 years	Alpha	5,500
		Beta	52
		Gamma	33
^{252}Cf	2.6 years	Alpha	5,900
		Beta	5.6
		Gamma	1.2
^{137}Cs	30 years	Beta	190
^{60}Co	5.3 years	Beta	97
		Gamma	2.5
^{192}Ir	74 days	Beta	220
		Gamma	820
^{238}Pu	88 years	Alpha	5.5
		Beta	11
		Gamma	1.8
^{226}Ra	1,600 years	Alpha	4.8
		Beta	3.6
		Gamma	6.7
^{90}Sr	29 years	Beta	200

Table J-2: Half-Lives of Eight Common Radioactive Elements

[138] A.J. Grotto, "Defusing the Threat of Radiological Weapons: Integrating Prevention with Detection and Response," Center for American Progress, July 2005.

By their nature, all the radioactive sources produce energetic and penetrating gamma rays. They are hard to shield and difficult to transport safely. Table J-3 shows that that the materials in questions are being trafficked illicitly on the open global market.

Date	Location	Material Involved	Incident Description
1993-05-24	Vilnius, Lithuania	HEU/150 g	4.4 t of beryllium including 140 kg contaminated with HEU were discovered in the storage area of a bank. Beryllium was imported legally.
1994-03	St. Petersburg, Russian Federation	HEU/2.972 kg	An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility for sale.
1994-05-10	Tengen-Wiechs, Germany	Pu/6.2 g	The material was detected in a building during a police search.
1994-06-13	Landshut, Germany	HEU/0.795 g	A group of individuals was arrested in illegal possession of HEU.
1994-07-25	Munich, Germany	Pu/0.24 g	A small sample of PuO_2-UO_2 mixture was confiscated in an incident related to a larger seizure at Munich Airport on 1994-08-10.
1994-08-10	Munich Airport, Germany	Pu/363.4 g	PuO_2-UO_2 mixture was seized at Munich airport.
1994-12-14	Prague, Czech Republic	HEU/2.73 kg	HEU was seized by police in Prague.
1995-06	Moscow, Russian Federation	HEU/1.7 kg	An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility.
1995-06-06	Prague, Czech Republic	HEU/0.415 g	An HEU sample was seized by police in Prague.
1995-06-08	Ceske Budejovice, Czech Republic	HEU/16.9 g	An HEU sample was seized by police in Ceske Budejovice.
1999-05-29	Rousse, Bulgaria	HEU/10 g	Customs officials arrested a man trying to smuggle HEU at the Rousse customs border checkpoint.
1999-10-02	Kara-Balta, Kyrgyzstan	Pu/1.49 g	Two individuals were arrested trying to sell Pu
2000-04-19	Batumi, Georgia	HEU/770 g	Four individuals were arrested in possession of HEU.
2000-09-16	Tbilisi Airport, Georgia	Pu/0.4 g	Nuclear material including Pu was seized by police at Tbilisi Airport.
2000-12	Karlsruhe, Germany	Pu 0.001 g	Mixed radioactive materials including a minute quantity of plutonium were stolen from the former pilot reprocessing plant.
2001-01-28	Asvestochori, Greece	Pu/~3 g	245 small metal plates containing Pu were found in a buried cache in the Kouri forest near the Asvestochori village.
2001-07-16	Paris, France	HEU/0.5 g	Three individuals trafficking in HEU were arrested in Paris. The perpetrators were seeking buyers for the material.

Table J-3: Reported Incidents of Nuclear Material Smuggling

J.5 DIFFICULTIES IN DETECTION

For a particular detection system, the successful detection of a nuclear WMD or RDD in a container onboard a container ship depends on a number of factors:

- Type, rate and energy of the natural radioactivity
- Amount of shielding and type of shield material and its effect on attenuation
- Path loss due to the solid angle subtended by detector
- Background radiation level at detector
- Detector area, time
- Energy specificity
- Integration time

In the absence of shielding, nuclear weapons can be detected by neutron or gamma counters at a distance of tens of meters. Objects such as missile canisters can be radio graphed with high-energy X-rays to reveal the presence of the dense fissile core of any type of nuclear warhead, or the radiation shielding that might conceal a warhead. Subjected to neutron irradiation, the fissile core of any type of unshielded warhead can also be detected by the emission of prompt delayed-fission neutrons at a distance on the order of 10 meters.[139]

Detection of neutrons is not as easily amenable to analytical approximation as it is for gammas. For a comparison with gammas, Srikrishna et al. present the basics of neutron emissions and attenuation in the specific case of WgU. The lack of energy specific neutron detectors with sufficient portability is currently a technological limitation.

- WgU emits neutrons at the rate of roughly one sievert/kilogram with an energy distribution centered around one MeV—primarily due to spontaneous fission of Uranium isotopes, with each of 234, 235, and 238 contributing roughly equal numbers of neutrons given their relative composition in WgU.

139 S. Fetter, V.A. Frolov, M. Miller, R. Mozley, O.F. Prilutsky, S.N. Rodionov, and Roald Z. Sagdeevb, "Detecting Nuclear Warheads," *Science & Global Security*, 1990, Vol. 1, pp. 225-302.

- These energetic neutrons also have mean free path lengths of 2-6 centimeters in most shielding materials whereas one MeV gammas are only approximately one centimeter by comparison.
- A 12-kg WgU sample with Tungsten tamper emits 30 neutrons per second in addition to 301 MeV gamma rays per second at the surface of the sample. The path loss through free space is equivalent for both forms of radiation.
- The background rate of neutrons (per meter-squared per second) is about 50 whereas background rate for one MeV gamma rays is cited as being between 17 and 860.[140]

J.5.1 Self-Shielding

Gamma rays may be scattered as they escape from the core of the nuclear material, losing some fraction of their energy and making them less useful for detection. Fundamentally, the more surface area per gram of material, the higher the number of gamma rays will escape. The number of gamma rays that escape without scattering can be calculated precisely with radiation shielding theory and depends mainly on the geometry of the core. For this analysis, the nuclear material is considered to be contained in a sphere of radius **r** and have a linear attenuation coefficient **μ.** Srikrishna postulates a self-shielding attenuation coefficient **G** that describes the fraction of gamma rays emerging without scattering effect according to the following formula:[141]

$$G = (1-e^{-4\mu r/3}) /(4\mu r/3)$$

J.5.2 External Shielding

Shielding materials such as lead, steel, and concrete behave similarly in their absorption of lower-level energy gamma rays.

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140 D. Srikrishna, A.N. Chari, and T. Tisch, "Nuclear Detection: Fixed Detectors, Portals, and NEST Teams Won't Work for Shielded HEU on National Scale; a Distributed Network of In-Vehicle Detectors is also Necessary to Deter Nuclear Terrorism," Version 1.22, [http://www.devabhaktuni.us/research/disarm.pdf], 21 October 2005.

141 Ibid.

J.5.2.1 Passive Detection of Shielded HEU

As HEU emits very few neutrons, the primary observables are low-energy gamma rays. [Passive detection of shielded HEU is gamma rays at 1MeV from decay of U-238.] This can be most effectively implemented by the placement of gamma ray detectors with the largest possible area and most energy-specificity as close as possible and for as long a time as possible.

The signal strength drops off at an inverse square rate with range. At long distances, the solid angle subtended by the detector at the HEU source is likely to reduce the signal as much as any reasonable size shielding. With sufficient time for the detector to integrate photon counts within a narrow enough photon energy range signals below the background can be detected. Although trace quantities of U-232 can sometimes be present, resulting in more penetrating gamma rays of up to 2.4 MeV, they cannot be relied upon to be present in all HEU materials.

J.5.2.2 Passive Detection of Shielded WGPu

It is easier to detect emitting neutrons from WGPu than from WGU for the following reasons:

- The rate of neutron production is about four orders of magnitude higher for plutonium.
- The energies of the neutrons produced are identical.
- The path loss through shielding and free space is identical.
- The background rates of neutrons at the detector are identical.

The primary gamma ray observable from WGPu is that of 769 keV. Plutonium generates 1-2 orders of magnitude more gamma rays per kilogram per second than does WGU at one MeV.

The shield is assumed to be a spherical shell of thickness **x** surrounding the nuclear material core. Assuming a linear attenuation coefficient λ, the fraction of gamma rays emerging without scattering, F**,** follows an exponential distribution given by

$$F = e^{-\lambda x}.$$

Path Loss. The solid angle subtended by a detector of area **A** at a distance **d** from the center of the nuclear material core can be approximated by

$$P = A/4\pi d^2.$$

If the distance from the source is doubled, the power received by the detector will be reduced by a factor of four.

J.5.3 Background Radiation

J.5.3.1 Gamma Ray Background

The natural gamma-ray background is a combination of terrestrial, atmospheric, and cosmic-ray induced gamma rays. A typical gamma-ray background spectrum is shown in Figure J-3 with the most prominent background peaks marked.

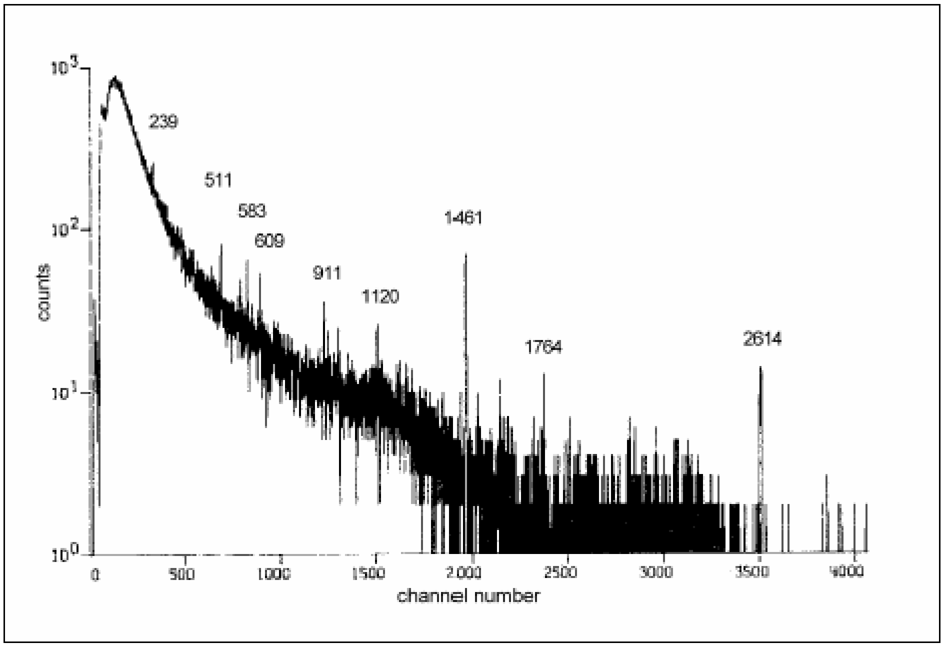

Figure J-3: A typical high-resolution gamma-ray background spectrum, taken for 4096 seconds with a 15% relative efficiency detector. The most prominent peaks are labeled with their energies in keV. The scatter in the spectrum is due to random statistical variations. [Philips 2005]

The terrestrial background is constant at a given location, unless there is a substantial change in nearby structures. This background has three main components from the decay of ^{232}Th, ^{238}U, and ^{40}K, generally referred to as thorium, uranium, and potassium. Thorium and uranium have long decay chains through short-lived "daughter" nuclei, primarily by alpha or beta particle emissions, which are not detectable. However, some of the intermediate decay products are also strong gamma-ray emitters. Some of the characteristics of thorium, uranium, and potassium are:

- Thorium activity is due to decay products from ^{232}Th, which has a half-life of $1.4x10^{10}$ years and is found in most rocks, soils, and building materials, such as concrete and brick. It decays through a series of short-lived isotopes ending in stable ^{208}Pb. The most prominent gamma rays are 239 keV from ^{212}Pb, 511, 583 and 2614 keV from ^{208}Tl, and 911 and 969 keV from ^{228}Ac. The ^{232}Th and ^{232}U decay chains are similar, with the exception that ^{228}Ac occurs only from ^{232}Th decay. Thus, the observation of the ^{228}Ac gamma rays serves to distinguish the spectrum of ^{232}Th from that of ^{232}U.
- Uranium activity is due to decay products from ^{238}U, which has a half-life of $4.5x10^{9}$ years and, like thorium, is found in most rocks, soils and, building materials. It decays through a series of shorter-lived isotopes ending in ^{206}Pb. The most prominent gamma rays are 609, 1120, and 1764 keV from ^{214}Bi.
- Potassium activity is due to decay of ^{40}K, which has a half-life of $1.28x10^{9}$ years. It has a single very prominent 1461 keV gamma ray.

The open-ocean background is similar to the terrestrial background, but has about one-tenth the strength of the background over land. Over fresh water and over the ocean near the shore, the background intensity depends on how much sediment is suspended in the water.

The atmospheric background can vary considerably with wind direction and meteorological conditions. This activity is mostly due to short-lived decay products from ^{222}Rn gas (3.8 day half-life), which is emitted from decay of soil deposits of ^{226}Ra (1,600-year half-life), a member of the ^{238}U decay chain. Radon gas often builds up in the soil and can then be released in a burst, which may travel tens of kilometers with the wind as a "radon cloud." The cosmic-ray background is characterized by a 511 keV gamma ray induced by cosmic-ray interactions. This comes about when high-energy cosmic rays (mostly muons at sea level with average energies of 100 MeV or greater) interact with matter, producing primarily neutrons and pairs of fast-moving positive and negative electrons. The positive electron or "positron" is the antiparticle of the ordinary negative electron. It eventually slows down enough to be attracted by and annihilate with a negative electron, producing two 511 keV gamma rays. The intensity of the cosmic-ray background increases rapidly above sea level and dominates the gamma-ray background spectrum at cruising altitudes of aircraft. Underlying the gamma-ray peaks is a strong, continuous background spectrum, which is highest at low energies. This is due primarily to higher-energy gamma rays that are only partially absorbed by the detector. At higher altitudes there is also a strong contribution to the background continuum from high-energy cosmic rays, which produce a continuous bremsstrahlung spectrum as they slow down in the material in the vicinity of the detector.

J.5.3.2 Neutron Background

The natural neutron background is mostly due to cosmic-ray interactions with the atmosphere, the ground, and massive objects such as buildings, ship superstructures and cargo (a phenomenon known as the "ship effect," because it was first observed in the neutron signal from large ships.) It peaks in energy at about 1 MeV and drops off rapidly above this. At sea level, the average cosmic-ray neutron production is about 20 neutrons per kg of material per second. This results in a neutron flux of 100-300 neutrons/m2/s. The average neutron background varies with geomagnetic latitude and is highest above 45 degrees, dropping to a low point at the equator. It also varies with solar activity and is approximately a factor of two higher during the solar minimum, when the shielding effect of the sun's magnetic field is lowest. During solar flares, the neutron background at high latitudes increases dramatically due to atmospheric interactions with the energetic charged particles emitted by the flare. This variability must be considered when using a neutron detector. In addition, an inspector must know the expected amplitude of the ship effect, or cosmic-ray induced neutron signature, from any massive cargo container, to avoid mistaking it for a suspect source.

J.5.3.3 Man-Made Background

Since the cessation of atmospheric nuclear testing, man-made background due to fallout has declined to levels well below the natural background. Except in regions contaminated by nuclear accidents, such as Chernobyl, or by an occasional lost medical or industrial source, man-made background will not be an appreciable contribution to the radiation background.

We can denote the gamma ray background radiation by **b** which is also dependent on the bandwidth of the channel in which the detector measures counts. A high-resolution detector with a large number of channels will have a small value of **b**. With the detector area of **A**, the average rate of background is given by

$$B = Ab.$$

Detector Efficiency and Time. Some fraction of the received gamma rays, denoted by **ε,** will not be counted due to the inefficiency in the detector. Hence, the number of counts **C** registered by the detector due to background radiation is given by

$$C = B\varepsilon.$$

The total signal received at the detector is

$$S = NGFP.$$

Signals below the background can be detected when the total counts due to the signal exceeds the fluctuations in the background. If a source is present, the former grows linearly with time while the latter is proportional to the square root of time. If **S** is the signal received at the detector and **t** is the time over which counts are integrated, then **Sεt** will be the counts due to the signal, while the standard deviation of fluctuations in the background will be proportional to $\mathbf{(Ct)^{1/2}}$. Therefore, the signal can be detected when the average signal exceeds a multiple **m** of standard deviations of the background, i.e., $S\varepsilon t > m\,(Ct)^{1/2}$.

The minimum time required for detection is then obtained according to $t = m^2Ab/(S^2\varepsilon)$. The larger the detector area, the more gamma rays will be collected. The longer the detector is exposed to the source, the more reliable the count reading is as enough counts of gamma rays would be obtained to ascertain a significant deviation from the background.

Detection. There are three basic ways to detect fissile material: passive detection of the radiation emitted by its radioactive decay, active detection involving either radio graphing an object to detect dense and absorptive materials or irradiating an object with neutrons or high-energy photons, and detecting the particles emitted by the resulting induced fissions.[142]

Passive detection is the preferred technique for verification purposes, because of its simplicity and safety. However, passive detection can probably be evaded with the added shielding or self-shielding.[143] Active detection can overcome some evasion scenarios, but only at much higher costs, inconvenience to the users, and complexity within the system. In addition, the process of irradiating objects may pose a danger to nearby humans and to the objects themselves.[144]

Unfortunately, nuclear weapons and the materials to make them are quite difficult to detect at any substantial range (particularly if equipped with radiation shielding, such as a layer of lead), as plutonium and highly enriched uranium are not intensely radioactive. To detect a nuclear weapon or nuclear material, a detector must not only be able to detect the radiation from this source, but also distinguish it from the natural background of radiation—placing fundamental limits on what can be detected. The decay rate—and therefore the rate of emission of radioactivity—of Pu-239, with its 24,000-year half-life, is hundreds of times less than that of 30-year half-life Cs-137. The decay rate of U-235 is 30,000 times lower than that of Pu-239.

In addition to having a low decay rate, the principal gamma ray from U-235 has a low energy as well, making it easy to shield the material to avoid detection (this gamma ray will travel through lead, on average, for only a millimeter); a daughter product of U-238 emits a more penetrating gamma ray, but such a signal would only indicate the presence of an unusual amount of uranium, not the presence of highly enriched uranium. For HEU, the other dominant uranium isotope, U-238 along with U-235 can provide an approximate estimate of uranium enrichment. However, even if the U-235 is detectable, the gamma rays from these two isotopes are sufficiently well separated in energy (notably at 186 keV for U-235 and 1001 keV for U-238) that unknown differential attenuation precludes knowledge of their true relative emission

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142 D. Srikrishna, A.N. Chari, and T. Tisch, "Nuclear Detection: Fixed Detectors, Portals, and NEST Teams Won't Work for Shielded HEU on National Scale; a Distributed Network of In-Vehicle Detectors is also Necessary to Deter Nuclear Terrorism," Version 1.22, [http://www.devabhaktuni.us/research/disarm.pdf], 21 October 2005.

143 The lowering of the flux density in the inner part of an object due to absorption in its outer layers, 1994, 66, *2525 IUPAC Compendium of Chemical Terminology*, 2nd Edition, 1997.

144 Ibid.

intensities. An exception to this statement is the "enrichment meter" method that examines the 186 keV peak and adjacent continuum to determine uranium enrichment. This method requires calibration against appropriate known standards, a condition unlikely to occur in many arms control scenarios. Because of its low energy, methods that exploit 186 keV gamma ray generally are not applicable to detection of shielded HEU because the may be dependent on the item configuration.[145] In short, HEU is quite difficult for passive detectors to find; for example, the pager-sized radiation detectors used by customs agents in many countries would have no chance of detecting HEU with even a very small amount of shielding.[146] Plutonium is substantially easier for passive systems to detect, since it has dramatically higher neutron and gamma ray emissions.[147]

According to *Science and Global Security* there are few methods to locate nuclear materials:[148]

Weight. If the type of nuclear material in a particular object or container is already well known, then its amount can be assessed simply by weighing it. Hence, highly accurate scales are a key part of nuclear material accounting systems.

Heat. Similarly, measurements of the heat output from a sample can be used to measure how much plutonium is present with surprising accuracy, if the isotopic mix is known. Unlike a weight measurement, a heat measurement is not affected by nonradioactive material mixed in with the plutonium.

Gamma Emissions. Each type of nuclear material emits gamma rays at characteristic energies. Hence, the spectrum of gamma rays emitted from a sample can be measured, using instruments known as gamma spectrometers, and the concentration of different isotopes in the sample can be assessed.

Passive Neutron Emissions. Unlike plutonium, HEU does not emit enough spontaneous neutrons to be very useful in measuring HEU quantities. A neutron

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145 Thomas B. Gosnell, *Uranium Measurements and Attributes*, Lawrence Livermore National Laboratory, UCRL-JC-139450, 1 July 2000.

146 Nuclear Threat Initiative (NTI), "A Tutorial on Nuclear Weapons and Nuclear-Explosive Materials," [http://www.nuclearthreatinitiative.org], 2006, accessed in February 2006.

147 To further understand the physics involved with detection difficulties refer to Steve Fetter, Valery A. Frolov, Marvin Miller, Robert Mozley, Oleg F. Prilutsky , Stanislav N. Rodionov, and Roald Z. Sagdeevb, "Detecting Nuclear Warheads," *Science and Global Security*, 1990, Vol. 1, pp. 225-302.

148 Ibid.

well counter, for example, can count the total neutron rate from a sample of material. This total count approach, however, has the disadvantage that it includes not only neutrons from spontaneous fission taking place in the sample, but also neutrons from the room background, and neutrons from interactions of the alpha particles emitted by the sample with lighter-element impurities. A complementary approach, known as neutron coincidence counting, counts only those neutrons that are detected at once (as would occur from fission) and excludes the other neutrons.

Active Neutron Emissions. Both HEU and plutonium will fission if struck by a neutron beam. Hence, a way of counting the neutrons from induced fissions is to bombard the sample with a neutron beam. While passive counting of neutrons effectively assesses the amount of Pu-240 (since its neutrons usually dominate all other spontaneous fission neutrons in the sample), an active approach can measure U-235 and Pu-239, using active neutron well coincidence counters, which are quite accurate and available commercially.

J.5.4 Detection and Identification Devices

In order to support the methods necessary to detect various nuclear materials, this project examined several tools available as COTS equipment.

High Purity Germanium-based (HPGe) Radioisotope Identifier (RID). Many handheld radioisotope identifiers have been introduced with the claim to perform both identification and detection of gamma-emitting sources, yet only a few claim to be able to locate neutron sources and still fewer perform well as identification tools due to the low resolution gamma-ray detectors employed. According to a R.M. Keyser et al., in their report on handheld RID, an HPGe RID has been shown to give superior performance in the identification of radionuclides in static conditions.[149] When coupled with a device that is capable of locating the source, this tool provides ample evidence to suggest that a high level of success can be accomplished when searching for illicit materials.[150]

149 R.M. Keyser, T.R. Twomey, and D.L. Upp, "An Improved Handheld Radioisotope Identifier (RID) for both Locating and Identifying Radioactive Materials," ORTEC, HPS Midyear Meeting, January 2005.

150 Static Conditions are where the source has been located and the device is now being used to identify the isotope.

The Detective EX, developed by the Tennessee-based company ORTEC, is a handheld radioisotope identifier based on a high purity germanium detector for the gamma ray detection and on moderated 3He tubes for neutron detection. The size of the detectors are based on the efficiency requirements of ANSI N42.34 for the detection of differing amounts of material and on the ability to correctly identify the various nuclides in mixtures. The mixtures specified in the standard are those which could be used to hide prohibited materials by masking it with other, innocent, radioactive materials.

The ORTEC Detective EX weighs 10.39 kg with a 50 mm x 30 mm detector cooled by a battery-operated Sterling cooler. The neutron detector consists of 4 ^{3}He tubes 10 cm x 1 cm active volume. The gas pressure is 20 atmospheres. The data collection is controlled by an internal personal digital assistant (PDA) with a color, touch-screen display and the spectra are stored on removable media.

Fission Meter. A complement to the gamma-ray identifier is a neutron detector.[151] With special nuclear material (SNM), gamma-rays are approximately 100 times more abundant than neutrons, so the concept of operation is to always use a high resolution gamma-ray identifier. Like the CONOP of the HPGe RID, the fission meter needs to be able to identify the source in order to be effective. Many neutron detectors exist, but like all other fieldable detectors with the capability for search and identification, are limited to basic counting. The fission meter is a way to check for a neutron source beyond what would be expected from background.[152]

The basic components of a fission meter are:

- A detector subsystem consisting of multiple moderated ^{3}He neutron detectors. The number, size and degree of moderation depends on the application. The detector subsystem includes the high voltage supplies for

151 Mark Rowland, CG-SMG-2 3.2.2, 3.2.3, 3.2.4, Lawrence Livermore National Laboratory.

152 The Fission Meter Principle – A characteristic of SNM sources is that the radioactive decay of each nucleus produces multiple neutrons, which are released as the nucleus flies apart in the so-called spontaneous fission process. Cosmic ray induced neutrons come from about seven different creation mechanisms that release neutrons in distinctly different ways from fission. A sensitive neutron detector can observe the differences in the neutron creation mechanisms, then associate the differences to their origin. Detections of these neutrons, which largely pass through heavy metal shielding provides a complimentary method to detect SNM.

The number of neutrons associated with a single nuclear fission varies from fission to fission and is referred to as "multiplicity," but the key factor is that the average is always greater than unity and the neutrons released come from a single decay and occur in a short time window. The neutrons are said to be correlated.

the ^{3}He tubes and the preamplifier-discriminator units required to collect the neutron events.[153]

- An electronic subsystem which processes the count data from the detection system. By measurement of the relative time intervals between neutrons arriving at a detection system the statistical distribution of the "multiplicity" may be built up by the electronic subsystem. The electronic coincidence system takes each neutron detected and looks in 512 time interval gates to record the time interval between each neutron and the others in the data stream from the detector.[154]

A software application which analyzes the output from the electronic subsystem to determine if it is consistent with an innocent neutron source or a fission.[155]

Sodium Iodide (NaI). In a scintillation detector, sodium iodide crystals are doped with thallium, NaI(Tl), then subjected to ionizing radiation which then emits photons (scintillate). NaI(Tl) is the most widely used scintillation material and has the highest light output. The crystals are usually coupled with a photomultiplier tube, in a hermetically sealed assembly. Fine tuning of some parameters (radiation hardness, afterglow, and transparency) can be achieved by varying the conditions of the crystal growth. Crystals with higher level of doping are used in X-ray detectors with high spectrometric quality.[156] As a tool this is useful when a point source is suspected, but can not be verified with the use of other tools. The size and weight of a sodium iodide detector limit its capabilities onboard a cargo carrying container ship.

Linear Radiation Monitor (LRM). The LRM is a 24.4 meter long, self-contained gamma-ray detector system for use in the interdiction and location of nuclear materials. Its composition is 18 gamma-ray detectors and 9 neutron detectors on a rope, with a control module at the operator end for display and alarms. When deployed from the top of a stack of intermodal containers, the gamma modules for the LRM are spaced such that there are two gamma-ray detectors measuring each container in the stack and one neutron detector measuring each container in the stack.

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[153] Mark Rowland, CG-SMG-2 3.2.2, 3.2.3, 3.2.4, Lawrence Livermore National Laboratory.
[154] Ibid.
[155] Ibid.
[156] Wikipedia, "Sodium Iodide," [http://en.wikipedia.org/wiki/Sodium_iodide], 13 May 2006, accessed in May 2006.

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