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Systems Approach to Defeating Maritime Improvised Explosive Devices in U.S. Ports

by

Systems Engineering Analysis Cohort 14

December 2008

Prepared for: Naval Postgraduate School
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Insight gained from terrorist attacks, training excercises, and intelligence intercepts over the past few years has shown a renewed interest in the use of mining as an effective means of disrupting commerce and damaging critical infrastructure. In an attempt to develop a system of systems architecture to defeat mines and Maritime IEDs (MIED), the project team developed several system alternatives, or Adaptive Force Packages, that incorporate both existing systems and emerging technologies. Overall performance was assessed using a US Joint Forces Command sponsored wargame simulating an MIED attack on ports based on the geography of Seattle and Tacoma. A critical analysis of the alternatives based on performance, suitability, cost, and risk were carried out. The study results showed that increases in performance are attainable with mixed results in cost and risk, and highlighted necessary actions and considerations that must be taken by military and civilian leaders in order to adequately prepare for and counter MIEDs in U.S. Ports.

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ABSTRACT

Insight gained from terrorist attacks, training excercises, and intelligence intercepts over the past few years has shown a renewed interest in the use of mining as an effective means of disrupting commerce and damaging critical infrastructure. In an attempt to develop a system of systems architecture to defeat mines and Maritime IEDs (MIED), the project team developed several system alternatives, or Adaptive Force Packages, that incorporate both existing systems and emerging technologies. Overall performance was assessed using a US Joint Forces Command sponsored wargame simulating an MIED attack on ports based on the geography of Seattle and Tacoma. A critical analysis of the alternatives based on performance, suitability, cost, and risk were carried out. The study results showed that increases in performance are attainable with mixed results in cost and risk, and highlighted necessary actions and considerations that must be taken by military and civilian leaders in order to adequately prepare for and counter MIEDs in U.S. Ports.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABS	ASSAULT BREACHING SYSTEM
AFP	ADAPTIVE FORCE PACKAGE
AHP	ANALYTIC HIERARCHY PROCESS
ALMDS	AIRBORNE LASER MINE-DETECTION SYSTEM
AMCM	AIRBORNE MINE COUNTER-MEASURES
AMNS	AIRBORNE MINE NEUTRALIZATION SYSTEM
AO	AREA OF OPERATION
BAH	BASIC ALLOWANCE FOR HOUSING
BAS	BASIC ALLOWANCE FOR SUBSISTENCE
C2	COMMAND AND CONTROL
C3F	COMMANDER THIRD FLEET
CAC	COMMAND AND CONTROL
CAW	CENTER OF ASYMMETRIC WARFARE
CAD/CAC	COMPUTER-AIDED DETECTION / COMPUTER-AIDED CLASSIFICATION
CG	COAST GUARD
CI/KR	CRITICAL INFRASTRUCTURE / KEY RESOURCES
CMS	COUNTER-MINE SYSTEM
CNMOC	COMMANDER NAVAL METEOROLOGY AND OCEANOGRAPHY COMMAND
COI	CONTACT OF INTEREST
CONI	CONTACT OF NO INTEREST
CONOPS	CONCEPT OF OPERATIONS

CONUS	CONTINENTAL UNITED STATES
COTP	CAPTAIN OF THE PORT
CPFR	CONTINGENCY PLANS AND FORCE READINESS
CSTRS	CARRIAGE, STREAM, TOW AND RECOVERY SYSTEM
C.V.	CONTAINER VESSEL
DLS	DATA LINK SYSTEM
DOC	DEPARTMENT OF COMMERCE
DOD	DEPARTMENT OF DEFENSE
DON	DEPARTMENT OF THE NAVY
DOT	DEPARTMENT OF TRANSPORTATION
DTE	DETECT TO ENGAGE
DVO	DIRECT VIEW OPTICS
EOD	EXPLOSIVE ORDNANCE DISPOSAL
EODMU1	EXPLOSIVE ORDNANCE DISPOSAL MOBILE UNIT ONE
EMNS	EXPENDABLE MINE NEUTRALIZATION SYSTEM
EMS	EMERGENCY MEDICAL SERVICES
ERP	EMERGENCY RESPONSE PLAN
FBI	FEDERAL BUREAU OF INVESTIGATION
ICS	INCIDENT COMMAND SYSTEM
IED	IMPROVISED EXPLOSIVE DEVICE
IMO	INTERNATIONAL MARITIME ORGANIZATION
JAUS	JOINT ARCHITECTURE FOR UNMANNED SYSTEMS
JCATS	JOINT CONFLICT AND TACTICAL SIMULATION

JDAM	JOINT DIRECT ATTACK MUNITION
JFCOM	U.S. JOINT FORCES COMMAND
JHOC	JOINT HARBOR OPERATIONS CENTER
JIT	JUST-IN-TIME
LCC	LIFE-CYCLE COST
LCS	LITTORAL COMBAT SHIP
LCD	LITHIUM CRYSTAL DISPLAY
LHS	LAUNCH HANDLING SYSTEM
LIDAR	LASER IMAGING DETECTION AND RANGING
LLS	LASER LINE SCAN
LOS	LINE OF SIGHT
MARSEC	MARITIME SECURITY
MCDM	MULTI-CRITERIA DECISION MAKING
MCM	MINE COUNTER-MEASURE(S)
MCMUSV	MINE COUNTER-MEASURES UNMANNED SURFACE VEHICLE
MD	MARITIME DOMAIN
MDA	MARITIME DOMAIN AWARENESS
MEDAL	MINE WARFARE ENVIRONMENTAL DECISION AID LIBRARY
MHD	MARITIME HOMELAND DEFENSE
MHLD	MARITIME HOMELAND DEFENSE
MIED	MARITIME IMPROVISED EXPLOSIVE DEVICE
MIW	MINE WARFARE

MOE	MEASURE OF EFFECTIVENESS
MOP	MEASURE OF PERFORMANCE
MPCE	MISSION PACKAGE COMPUTING ENVIRONMENT
M/S	MODELLING AND SIMULATION
MTS	MARITIME TRANSPORTATION SYSTEM
NIMS	NATIONAL INCIDENT MANAGEMENT SYSTEM
NMAWC	NAVAL MINE AND ANTI-SUBMARINE WARFARE COMMAND
NOAA	NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION
NOMWC	NAVAL OCEANOGRAPHY MINE WARFARE CENTER
NPS	NAVAL POST GRADUATE SCHOOL
NRNW	NAVY REGION NORTHWEST
NSWC PC	NAVAL SURFACE WARFARE CENTER PANAMA CITY
NWP	NAVAL WARFARE PUBLICATION
O&S	OPERATION AND SUPPORT
OECD	ORGANIZATION FOR ECONOMIC COOPERATION DEVELOPMENT
OMOE	OVERALL MEASURE OF EFFECTIVENESS
OPNAV	OFFICE OF NAVAL PERSONNEL
OTH	OVER THE HORIZON
PA	POSITIONAL ACCURACY
PCDC	PRE-CRISIS DATA COLLECTION
Pd	PROBABILITY OF DETECTION
PEO LMW	PROGRAM EXECUTIVE OFFICE LITTORAL MINE

	WARFARE
Pfd	PROBABILITY OF FALSE DETECTION
Pfi	PROBABILITY OF FALSE IDENTIFICATION
PHPK	PROBABILITY OF HIT/PROBABILITY OF KILL
PMA	POST MISSION ANALYSIS
PNNL	PACIFIC NORTHWEST NATIONAL LABORATORIES
POT	PORT OF TACOMA
PPR	PRE-PLANNED RESPONSE
R&D	RESEARCH AND DEVELOPMENT
RD&TE	RESEARCH AND DEVELOPMENT, AND TEST AND EVALUATION
RAMICS	RAPID AIRBORNE MINE CLEARANCE SYSTEM
REMUS	REMOTE ENVIRONMENTAL MEASURING UNITS
RF	RADIO FREQUENCY
RFI	REQUESTS FOR INFORMATION
RMS	REMOTE MINE-HUNTING SYSTEM
RMMV	REMOTE MULTI-MISSION VEHICLE
SAR	SEARCH AND RESCUE
SAS	SYNTHETIC APERTURE SONAR
SBIR	SMALL BUSINESS INNOVATION RESEARCH
SEA	SYSTEMS ENGINEERING ANALYSIS
SEA-14	SYSTEMS ENGINEERING ANALYSIS COHORT FOURTEEN
SEDP	SYSTEMS ENGINEERING DEVELOPMENT PROCESS
SONAR	SOUND NAVIGATION AND RANGING

SOS	SYSTEM OF SYSTEMS
TACMEMO	TACTICAL MEMORANDUM
TCO	TOTAL COST OF OWNERSHIP
TOS	TIME ON STATION
TTS	TIME TO STATION
TTR	THE TRIDENT ROOM
TTX	TABLE TOP EXERCISE
UCC	UNIFIED COMMAND CENTER
US	UNITED STATES
USCG	UNITED STATES COAST GUARD
USCG HQ	UNITED STATES COAST GUARD HEADQUARTERS
USNORTHCOM	UNITED STATES NORTHERN COMMAND
USSR	UNION OF SOVIET SOCIALIST REPUBLICS
UAV	UNMANNED AERIAL VEHICLE
USV	UNMANNED SURFACE VEHICLE
UUV	UNMANNED UNDERWATER VEHICLE
VDS	VARIABLE DEPTH SONAR

EXECUTIVE SUMMARY

Insight gained from terrorist attacks, training excercises, and intelligence intercepts over the past few years has shown a renewed interest in the use of mining as an effective means of disrupting commerce and damaging critical infrastructure. Although the risk of an MIED attack could be considered a low probability event, the importance ports and waterways play in domestic and global commerce demands timely and effective mitigation of the extremely high consequences associated with restrictions to port access should we face MIEDs in our MTS. The students comprising Systems Engineering Analysis Cohort 14 were tasked to address this national concern as the focus of their capstone research project. Their initial research led to the following problem statement:

> *Design a system of systems that rapidly and efficiently mitigates the effects of a Maritime IED or Maritime IED threat to the Maritime Transportation System while protecting critical infrastructure and key port assets.*

Following a procedural-based approach known as the Systems Engineering Design Process (SEDP), the project team developed a series of high level functions a system of systems would need to perform in order to fulfill the problem statement. The high level system functions are Search, Detect, Classify, Identify, and Neutralize. The project team used these functions to engage a broad range of stakeholders involved in this problem, ranging from the Coast Guard and other Department of Homeland Defense entities, several US Navy commands, and business and industry leaders such as Northrop Grumman Corporation and Lloyd's of London insurance market. With stakeholder inputs, the project team translated the high level system functions into objective statements, measure of performance, and weighting criteria.

In order to address the immediate response needed to defeat this threat, a series of system alternatives were developed incorporating existing systems and technologies, emerging systems, and concepts under development that can be incorporated in the long term. These concepts were combined into a series of alternatives, which we called Adaptive Force Packages (AFP), that address the varying effects of port environments on sensors and neutralization assets. These force packages were analyzed for performance,

suitability, cost, and risk using a variety of decision tools including wargames, modeling and simulation, cost-performance analysis, and suitability prediction.

A baseline system, termed AFP 0, modeled current capabilities and served as the baseline reference for performance modeling and analysis. This AFP consists of REMUS unmanned vehicle platoons and explosive ordnace disposal (EOD) personnel. While acknowledging that the US Navy has traditional mine countermeasure (MCM) assets that could be used in certain port scenarios, the long stationing times of MCM ships and the limited availability of MCM aircraft limit the use of these assets, and were therefore not modeled in this system.

AFPs 1 and 2 incorporate systems that are to be delivered to the government in the near future. The timeframe these systems will become available ranges from 2009-2015. AFP 1 uses assets from the baseline AFP 0 and adds components of the Littoral Combat Ship (LCS) Mine Warfare Mission Modules. This package includes the AN/WLD-1 Remote Multi-Mission Vehicle (RMMV), the AN/AQS-20 mine hunting sensor, and the Mission Package Computing Environment (MPCE) needed to operate the equipment pier-side without services of the LCS ship. These additional components improve search performance but offer no additional neutralization capability.

AFP 2 incorporates emerging improvements to airborne MCM capabilities in addition to baseline components. Incorporated here are the AN/AQS-20, deployed via HH-60 helicopters, and the Airborne Laser Mine Detection System (ALMDS) for improvements in search and detection. For improved neutralization, the system adds the Rapid Airborne Mine Clearance System (RAMICS) and the Airborne Mine Neutralization System (AMNS), also deployed aboard HH-60 aircraft.

AFPs 3 and 4 are based on concepts that are more developmental and therefore scoped for implementation beyond 2015. AFP 3 is based on the concept of the "Silver Bullet", a single tool that can accomplish all mission functions. This AFP incorporates modifications to the Talisman M being developed by BAE Systems. This UUV carries in a single body sensors required for search, detection, and classification; two Archerfish Expendable Mine Neutralization System (EMNS) UUVs to identify and explosively neutralize contacts; and two conceptual SeaArcher chemical neutralizers that can neutralize underwater explosives without detonating them.

Lastly, AFP 4 uses search and neutralization components from previous alternatives, namely REMUS and Talisman M UUVs, and adds the capability for them to communicate underwater and ashore using an acoustic modem network. This network allows command and control (C2) commands and sensor data to be passed amongst the employed bodies and a shore based C2 center.

These force packages were analyzed for performance, suitability, cost, and risk using a variety of decision tools including wargames, modeling and simulation, cost-performance analysis, and suitability prediction. The results of this analysis are represented below:

AFP	Composite Performance Score	Reliability Prediction	Maintainability Prediction	Lifecycle Cost Estimation	Risk Assessment
0	0 (Baseline)	High	High	$43.9M	Low
1	0.39	High	High	$72.8M	Medium
2	0.64	Low	Medium	$84.3M	Medium
3	0.64	Medium	Low	$15.6M	High
4	0.70	Low	Low	$22.2M	High

Based on the data that SEA 14 obtained from war gaming, modeling, and critical analysis, developmental concepts based on unmanned vehicles, advanced underwater communications, computer aided detection and classification, and non-explosive neutralization offer great potential for a timely, efficient, and effective approach to defeating MIEDs in homeland security scenarios. These concepts ensure personnel safety, improved performance, reduced operation time, and low life cycle costs. For these capabilities to be attained, existing and new-start research and development efforts would need to be structured and funded at appropriate levels to ensure systems can be integrated, tested, and deployed in the near future.

SEA 14 learned other important lessons outside the initial project scope, and these lessons offer valuable insight into the MIED problem. One important lesson is that defeating MIEDs in any Homeland Security scenario involves more than just the significant tasks of determining appropriate systems and developing needed interagency cooperation. Possibly, the most important cornerstone of reducing the effects of an MIED attack to the Maritime Transportation System is a standardized, national structure that can conduct baseline bottom surveys of ports and harbors, process and retain the survey data, and provide a timely and infrastructure-safe means of neutralization.

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I. INTRODUCTION TO MARITIME IMPROVISED EXPLOSIVE DEVICES AND THE SYSTEMS ENGINEERING DESIGN PROCESS (SEDP)

1. PROJECT TEAM

1.1 SEA-14

SEA Cohort 14 (SEA 14) is composed of eleven students of the Systems Engineering Analysis (SEA) curriculum at the Naval Postgraduate School in Monterey, California. The SEA curriculum is a unique blend of systems engineering, operations analysis/research, and combat systems integration combined with joint professional military education. This unique course-load provides unrestricted line officers and defense civilians with a skill-set exceptionally adept at decomposing high-level problems, modeling the relationships of the realm in which the problem resides, creating technical solutions, and assessing the potential or demonstrated capabilities the designed solution presents.

SEA 14 is comprised of ten surface-warfare qualified officers and a Singaporean Ministry of Defense civilian. While the naval personnel bring a range of shipboard experience (including two with Fleet mine-warfare experience), the MOD civilian brings a wealth of knowledge from the contracting and program management fields.

The team used a modified matrix organization to capture the various fields of expertise brought to bear by team members, encapsulate the wide-variety of research areas and technical aspects of the problem, and distribute work evenly. The basic organizational structure of the team is shown in Figure 1.

In addition to the traditional project manager and deputy project manager positions, three integrated project teams were established to conduct initial research, functional decomposition, and metrics evaluation. Additional positions of systems integration lead and wargame designer were established to ensure proper use of SEDP principles and provide early focus on wargame, modeling, and simulation efforts.

Members were also assigned to specific areas of the project for advanced research. Such areas include unmanned vehicles, sensors, established programs of record, port operations and neutralization methods.

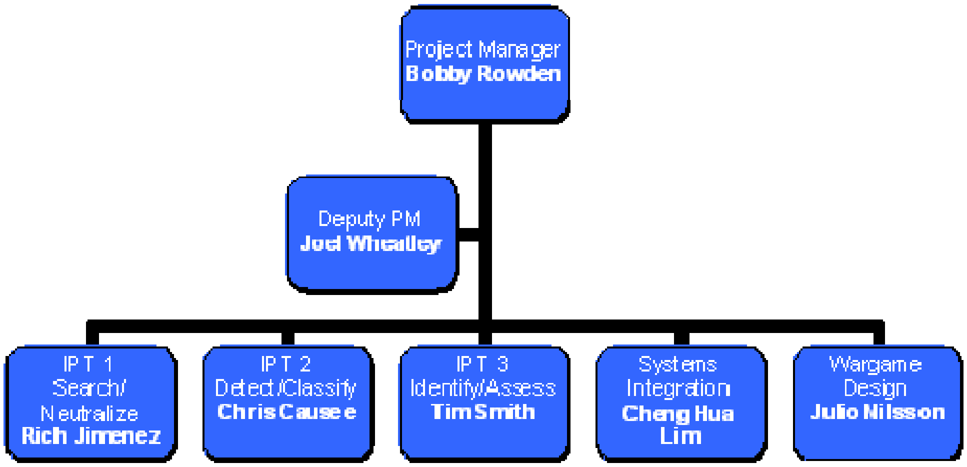

Figure 1 – Basic Organizational Chart

Project team members were also assigned to other ad hoc project teams for smaller objective teams charged with drafting SEDP products, wargame, modeling and simulation support, and research into emerging topics relevant to the study.

1.2. Tasking

Appendix 1 is the original tasking, as written, for the SEA Capstone Thesis Project. This tasking is developed by the Systems Engineering Analysis Committee, an interdepartmental committee of the Wayne E. Meyer Institute of Systems Engineering that, along with inputs from OPNAV sponsors, and assigns the thesis level project to SEA cohorts.

According to the original tasking letter, SEA 14 was to "employ the systems engineering and analytical methodology" in order to "establish homeland specific needs to counter a domestic mining threat in naval and civilian ports." Additionally, the team would "define program interdependencies in the Organic Mine Countermeasure System", essentially determining how the systems and methodologies analyzed for Maritime Homeland Defense could be applied in the emerging naval concept of Organic Mine Countermeasures, where assets have an inherent MCM capability and are not reliant on dedicated MCM assets.

This tasking served as the initial guidance in scoping and bounding the problem and lead to the research that would enable the project team to understand the current situation, historical references, and key stakeholders. After reviewing the initial guidance, the team set out to understand the need for the stated objective.

2. POTENTIAL FOR DISASTER

World trade is highly dependent on worldwide maritime transportation systems responsible for sustaining the expeditious and efficient flow of commerce on the sea. More than 80% of the world's trade travels via these oceanic routes and must transit a handful of international straits and chokepoints[1].+ With 50% of the world's daily oil consumption traveling through these chokepoints, the potential for disaster is great[2] In 2003, the Organization for Economic and Cooperation Development (OECD) conducted a study and concluded that a coordinated attack on the national MTS would be measured in the tens of billions of dollars, yet trade through MTS continues to grow annually[3].

Table 1, derived from a study conducted by the American Association of Port Authorities (AAPA) from the Institute of Shipping Economics and Logistics, shows that world seaborne trade increased 34% (averaging 4.9% growth per year) between 1990 and 2006[4].

Year	Crude Oil	Petrol Products	Iron Ore	Coal	Grain	Other Cargo	Total Trade	Increase
2006	1,814	517	711	755	262	3,128	7,187	5.0%
2005	1,784	495	652	710	251	2,954	6,846	4.6%
2004	1,800	465	590	650	250	2,787	6,542	6.7%
2003	1,673	440	524	619	240	2,637	6,133	9.6%
2002	1,588	414	484	570	245	2,294	5,595	1.5%
2001	1,592	425	452	565	234	2,245	5,513	1.5%
2000	1,608	419	454	523	230	2,200	5,434	5.3%
1999	1,548	410	411	482	220	2,090	5,161	2.0%
1998	1,524	402	417	473	196	2,050	5,062	-0.6%
1997	1,519	410	430	460	203	2,070	5,092	4.8%
1996	1,466	404	391	435	193	1,970	4,859	3.7%
1995	1,415	381	402	423	196	1,870	4,687	4.0%

[1] National Strategy for Maritime Security, White House, http://www.whitehouse.gov/homeland/maritime-security.html.
[2] World Oil Transit Chokepoints, www.doe.gov/cabs/world_oil_transit_chokepoint/full.html.
[3] Security in Maritime Transport: Risk Factors and Economic Impact. Maritime Transport Committee. July 2003. OECD.
[4] World Seaborne Trade 1975, 1980-2006. http: //aapa.files.cms-plus.com/statistics/world %5fseaborne%5ftrade.xls

1994	1,403	368	383	383	184	1,785	4,506	3.8%
1993	1,356	358	354	367	194	1,710	4,339	2.8%
1992	1,313	335	334	371	208	1,660	4,221	2.7%
1991	1,247	326	358	369	200	1,610	4,110	3.3%
1990	1,190	336	347	342	192	1,570	3,977	3.0%

Table 1 – World Seaborne Trade 1990-2006 (Millions of Metric Tons)

The United States is directly linked to the global economy and, thus, the global MTS. According to the AAPA, in 2006 there were eight US ports that ranked in the top fifty ports in the world for total cargo by volume and six based on total container traffic. Table 2 shows these US ports and their world ranking as of 2006[5].

Trade Volume Rankings		Container Traffic Rankings	
Rank	Port	Rank	Port
12	South Louisiana	10	Los Angeles, CA
14	Houston, TX	12	Long Beach, CA
20	New York/ New Jersey	18	New York/ New Jersey
42	Long Beach, CA	39	Oakland, CA
46	Beaumont, TX	46	Savannah, GA
48	Corpus Christi, TX	50	Tacoma , WA
49	Huntington – Tristate	-	-
50	New Orleans, LA	-	-

Table 2 – US Port Rankings Based on Volume and Container Traffic

Tables 1 and 2 show how the US is strategically tied to the global economy through the MTS. Not included in these figures, however, is the critical bi-national St. Lawrence Seaway System.

For nearly 50 years, the St. Lawrence Seaway has served as a vital transportation corridor for the international movement of bulk and general cargoes such as steel, iron ore, grain, and coal, serving a North American region that makes up one-quarter of the U.S. population and nearly half of the Canadian population. Maritime commerce on the Seaway System annually sustains more than 150,000 U.S. jobs, $4.3 billion in personal

[5] World Port Ranking-2006. http: //aapa.files.cms-plus.com/statistics/worldportrankings%5f2006.xls

income, $3.4 billion in transportation-related business revenue, and $1.3 billion in Federal, State, and local taxes[6].

The St. Lawrence Seaway System is representative of how crucial sea transport is to the US economy and similar statistics could be drawn from any of the major US ports. Should a terrorist organization want to cripple the US economy, attacking—or even feigning an attack on—a major port could prove to be disastrous particularly because of the way the economy is organized.

"Large U.S. firms held an average of 1.36 months of inventory in 2001, down from 1.57 months in the early 1990s."[7] David Closs of Michigan State University estimates this will increase to 1.43 months or more in the coming years. Just in Time economy (JIT) forces suppliers to rely on a constant stream of arriving goods to meet consumer demands. In this economic organization, if the stream is interrupted, the consumer demands will heavily outweigh the supply in a matter of weeks resulting in shortages, higher consumer costs, and staggering losses to the economy.

Figure 2 shows the average domestic ground transport over trucking routes. Clearly, the major hubs for all domestic shipping are major ports such as Seattle, Los Angeles, Chicago, Houston, and New York. If any of these hubs were compromised and the supply stream interrupted, the downrange effects would be felt all along routes stemming from the ports.

A supply stream interruption is not unprecedented. In a 2002 strike, the LA/Long Beach Longshoremen demonstrated just such an interruption. The strike, only a draw down, not full work stoppage—and anticipated ahead of time—resulted in a $1.9B per day loss to the national economy[8]. Should a full stoppage result as the effect of an MIED attack on a port, the expected economic loss would be even higher.

The idea of an international terrorist organization carrying out an attack on a US port or a global MTS chokepoint is not without merit. In April 2008, Osama Bin Laden

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[6] National Strategy for the Maritime Transportation System: A Framework for Action, presented by the Committee on the MTS, July 2008

[7] Carafano, J. and A. Kochems. 2005. Making the Sea Safer: A National Agenda fro Maritime Security and Counter-terrorism. The Heritage Foundation.

[8] Industrial College of the Armed Forces. 2006. Industry Study Final Report (Transportation) www.ndu.edu/icaf/industry/reports/2006.

Figure 2 – Average Domestic Ground Transport over Trucking Routes

called for "Chokepoint Terrorism"[9] and it is not unreasonable to assume an attack on either the US port system or the global MTS is in the near future.

3. BACKGROUND AND HISTORY

Mines and MIEDs are the ideal asymmetric naval weapons used for more than two centuries by weak powers against the strong. Since the American Civil War, naval forces have been battling the threat of sea mines and the devastating effects they can have on shipping. In that war, both the Union and the Confederacy experienced losses from this asymmetric threat. The first vessel sunk by such a device was the USS CAIRO in 1862[10].

The first mine deployed in combat was the Bushnell Keg developed by David

[9] "Al Qaeda Affiliated e-journal: 'The Sea is the Next Strategic Step Towards Controlling the World and Restoring the Islamic Caliphat'" The Jihad and Terrorism Threat Monitor, http://www.memrijttm.org/content/en/blog_personal.htm

[10] Nation Master. Encyclopedia>USS Cairo (1861). http://www.nationmaster.com/encyclopedia/uss-cairo-(1861).

Bushnell during the American Revolution[11]. It was simple in design: a watertight wooden keg, filled with gun powder and tethered to the bottom by rope. Bushnell laid several of these under the orders of General Washington in an attempt to destroy a fleet of British warships anchored near Philadelphia. Though unsuccessful in sinking a single ship, the potential for mining was seen and their place in the naval arsenal as both an offensive and defensive weapon was secured.

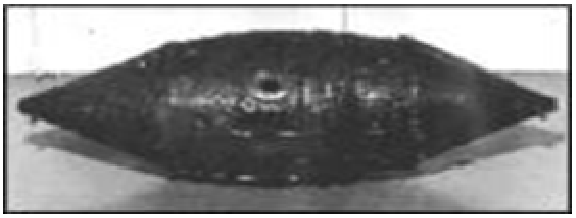

Figure 3 – Bushnell Keg

3.1 Historical Examples

In the 19th century, mines were called torpedoes—a name probably conferred by Dennis Fletcher after the torpedo fish which gives powerful electric shocks. A Spar Torpedo was a mine attached to a long pole and detonated when the ship carrying it rammed another one. The *CSS H. L. Hunley* (Figure 4) used one to sink the *USS Housatonic* on 17 February 1864. Another early mine, the Harvey Torpedo, was a floating mine towed alongside a ship and was briefly in service in the Royal Navy during the 1870s.

Figure 4 – Artists Rendition of *CSS H.L.Hunley* with a Spar Torpedo

[11] Commander Mobile Mine Assembly Group. The First Mine: Bushnell's Keg. http://www.comomag.navy.mil/mine%20history/bushnell%20keg.aspx

Since World War II, mines have damaged or sunk fourteen US Navy ships. The Korean War saw continued use of mine-laying by North Korean forces which damaged eleven US vessels, and as recently as the Iran-Iraq War, the *USS Samuel B. Roberts* (FFG-58) (Figure 5) struck an Iranian M-08/39 mine in the central Persian Gulf, wounding ten sailors. The *USS Princeton* (CG 59) and the *USS Tripoli* (LPH 10) were also successfully attacked by mines[12].

Figure 5 – *USS Samuel B. Roberts* Damaged Port Side

Simplistic design, effective results, and unknown locale will continue to enable these devices to exceed their design capabilities. Mines and MIEDs are perhaps the cheapest and most destructive weapon of choice of any potential adversary in the maritime domain.

3.2 Terrorist Mining

In 1980, the US temporarily lifted a grain embargo on the Soviet Union prompting an act of domestic terrorism. An unknown caller identifying himself as the "Patriotic SCUBA Diver" was ideologically opposed to the shipment of grain to the USSR and arranged a hoax mine threat against the port of Sacramento. After four days of

[12] Robert S Strauss Center. Mines. http://hormuz.robertstrausscenter.org/mines

searching and hundreds of thousands of dollars in lost ship lay days, the port was declared safe and reopened[13].

In the summer of 1984, 19 commercial vessels reported damage from underwater explosions in the Red Sea and Gulf of Suez, which generated a massive multinational MCM response, Operation INTENSE LOOK. Egypt, Great Britain, France, Italy, the Netherlands, the Soviet Union, and the United States provided support to clearing the waterway. Later it was determined that Libyan naval personnel used a commercial ferry to roll off the mines as it meandered throughout the waterway, completely unchallenged, for more than two weeks[14].

On 21 April 2004, a tugboat operator on Lake Ponchartrain, Louisiana, spotted a suspicious floating bag and called the U.S. Coast Guard. The Coast Guard contacted the Jefferson Parish bomb squad, which fished the bag out of the water. It proved to be an IED with a few pounds of explosive in plastic pipes and a timer wrapped in trash bags to keep it afloat. One possible target was presidential hopeful Senator John Kerry, who had been scheduled for a campaign stop on the lake[15].

Even popular culture has demonstrated the potential hazards posed by MIEDs. In Season 4: Episode 2 of CSI: New York, the high-tech crime-fighters discover an attempt to assassinate a foreign official by detonating an MIED under a helipad over the East River. Fortunately, the Crime Scene Investigators are able to thwart the villains and prevent the MIED from exploding, but a real case of life-imitating-art-imitating-life could be disastrous.

4. DEFINING THE PROBLEM

Initially, the project team was tasked with creating a System of Systems (SoS) to mitigate the effects of an MIED placed in a United States port. The initial tasking proved far too broad so the project team narrowed the scope of the problem to employ the Systems Engineering Design Process (SEDP) and develop a solution.

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[13] Truver, Scott. “Mines and Underwater IEDs in U.S. Ports and Waterways: Context, Threats, Challenges and Solutions”. *Naval War College Review*, Winter 2008, Volume 61, No. 1, pp-106-127.

[14] Truver, Scott, “The Mines of August: An International ‘WhoDunit’”, U.S. Naval Institute Proceedings (May 1985).

[15] Truver, Scott. “Mines and Underwater IEDs in U.S. Ports and Waterways: Context, Threats, Challenges and Solutions”. *Naval War College Review*, Winter 2008, Volume 61, No. 1

4.1 Narrowing the Scope

SEA projects are assigned by the Systems Engineering Analysis Curriculum Committee with inputs from project sponsors such as OPNAV N85 or N71. The project assignment for SEA 14 can be found in Appendix 1. After receipt of tasking, the project team first scoped the issue to include and understand the full spectrum of complicated, political, technical, and administrative issues. Figure 6 displays a rich diagram illustrating the considerations taken into account in this phase.

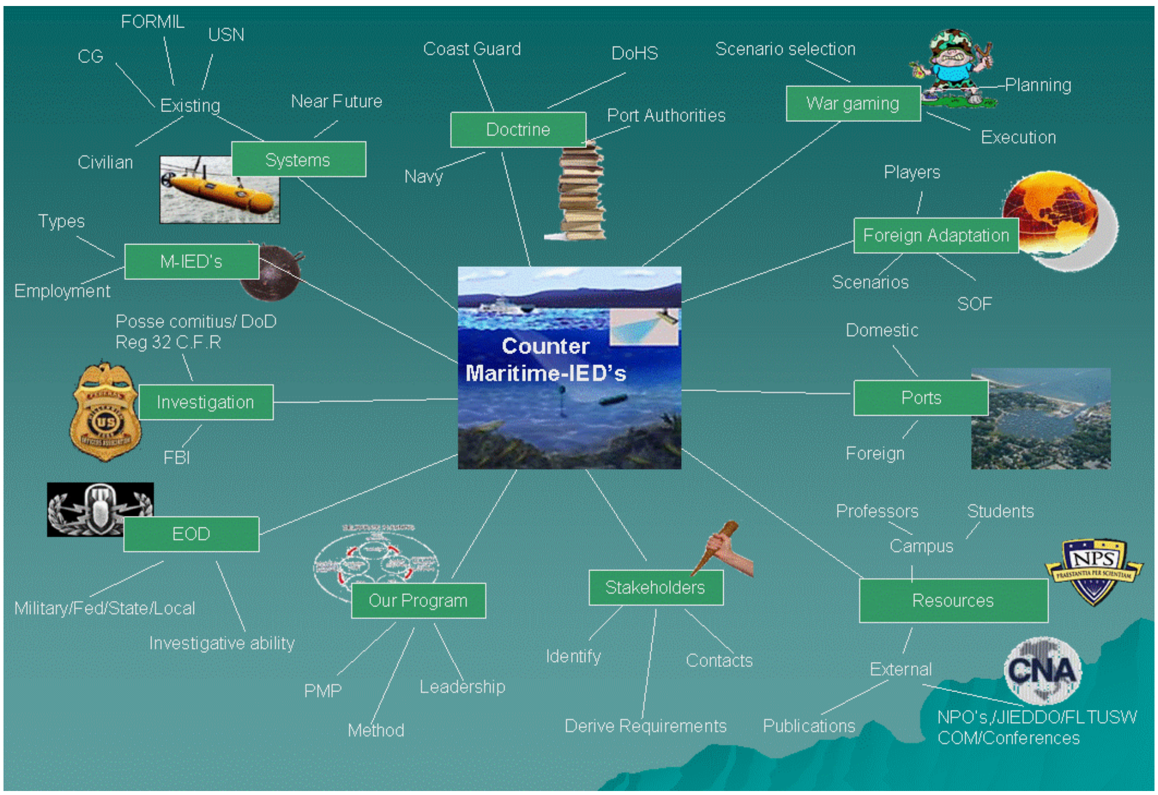

Figure 6 - MIED Rich Diagram

Once the problem had been scoped, the project team then used a series of design tools to bound the problem to a point where an achievable solution could be designed in the allotted project timeframe using available resources.

4.2 Problem Definition

One method used to scope and bound the problem was to develop a problem statement the solution would be designed to address. This problem statement was established early to guide initial project work, but was repeatedly iterated throughout the project schedule.

After receiving the initial project tasking, enclosed in Appendix 1, the project team formulated the following initial problem statement:

> *Develop a system of systems to prepare and defend commercial ports, commercial transit space, and the associated inland waterways from the threat of maritime improvised explosive devices. If defense fails, the system of systems will enable port recovery via the effective and timely search of above-stated waterways, conduct of command and control activities, and the mitigation of commercial impact to the port, regional, and national economies.*

A series of statements to further scope the problem were also developed. They were:

a. Geographic space includes transit lanes and adjacent waters that impact the flow of commerce or the local economy of a domestic port,

b. Solution shall be available to be implemented in US strategic ports by 2015,

c. Focus on domestic ports, but assess solutions applicable to international implementation and

d. Focus on the Underwater, Floating, and Infrastructure Borne subsets of maritime improvised explosive devices

As research, exercise analysis, and interviews were conducted, it became evident that the problem could be categorized as having an extremely high impact on the economy with reaching political concerns but was of such low probability that funding and dedication to prevention, preparation, and process ownership might negate effective response in these areas. Under advisement from port security and Coast Guard stakeholders, the project team decided to create a product that would operate in an environment with very little battle space preparation, could work within existing port security measures, and would provide a cost effective means of mitigating lost commerce should a threat response be necessary. A revised problem statement was finalized to reflect this change in project scope:

Design a system of systems that rapidly and efficiently mitigates the effects of a Maritime IED or Maritime IED threat to the Maritime Transportation System while protecting critical infrastructure and key port assets.

Within the revised problem statement, the phrase "system of systems" (SoS) references the SEDP process the project team used (described in Chapter I, Section 5) and implies the system's ability to interoperate with other components of the SoS and within existing port security measures. "Rapidly and efficiently" refers to both the timeliness and effectiveness of the system along with an importance on system suitability factors. The MTS is defined in the Maritime Transportation System Security Recommendations, one of the eight documents supporting the National Strategy for Maritime Security. Critical infrastructure and key assets are also defined in the National Strategy for Maritime Security and its supporting documents.

The four scope supplements (a.– d. above) were maintained and a fifth was added. Due to budgeting and acquisition processes, a 2015 solution would not be able to incorporate emerging technologies or developmental systems and would not be available in the near term to combat threats that could occur at any time. Therefore, a two-stage approach was adopted. First, a system comprised of existing technologies and methodologies would be developed to combat a near-term threat as soon as 2009. The second step would develop a true SoS an incorporate acquisition timeline concerns and be fielded by 2015.

4.3 MIED Definitions

An Improvised Explosive Device (IED) can be made of any type of material and/or initiator and is designed to inflict damage to an unsuspecting victim. These devices are traditionally homemade devices and are designed to cause death or injury by using explosives alone or in combination with toxic chemicals, biological toxins, or radiological material. IEDs can be produced in varying sizes, functioning methods, containers, and delivery methods and can utilize commercial or military explosive components.

The project team defined MIEDs as improvised explosive devices employed in the maritime domain and can be found in four varieties: Floating, Watercraft Borne, Maritime Infrastructure Borne, and Underwater.

4.3.1. Floating MIED

A non-tethered explosive device placed or fabricated in an improvised manner, which is visible on the surface and/or free-floating in the water column. Floating MIEDs may be difficult to detect and neutralize because they are free-floating—following the currents—and may be found above the swath width of the detection devices employed for convention mine hunting operations.

4.3.2. Watercraft Borne MIED

An explosive device attached to watercraft. The project team defined this device as “any vessel or craft designed specifically and only for movement on the surface of the water”. These craft may be unmanned, manned, or remotely controlled and may motor driven vessels, sailboats, or submersible/semi-submersibles. This MIED may be targeted against the water borne craft itself or used in combination against external target.

4.3.3. Infrastructure Borne MIED

An explosive device placed—or fabricated—in an improvised manner and attached to any maritime infrastructure embodiment (e.g., piers, buoys, markers, bridges, etc) with the intent of disrupting the maritime domain.

4.3.4. Underwater MIED

An explosive device placed and detonated in the water column with no protrusions above the surface of the water from either itself or propulsing vehicle. These devices may be bottomed, tethered or buried.

5. SYSTEMS ENGINEERING DESIGN PROCESS

In order to facilitate and monitor the progress of the design for the proposed SoS to counter the threat of mines or MIEDs, the SEDP was adopted. The process is comprised of four sections: initial research, problem formulation, analysis of alternatives and implementation. The project schedule is then tied in with the SEDP with the project end date fixed. Figure 7 shows the mapping of SEDP with the board project schedule.

5.1. Initial Research

With the problem and task outlined, initial research was conducted covering the wide-variety of MIED topics and their relation to the SEDP. Such research areas include the conduct of mission analysis, the development of threat scenarios

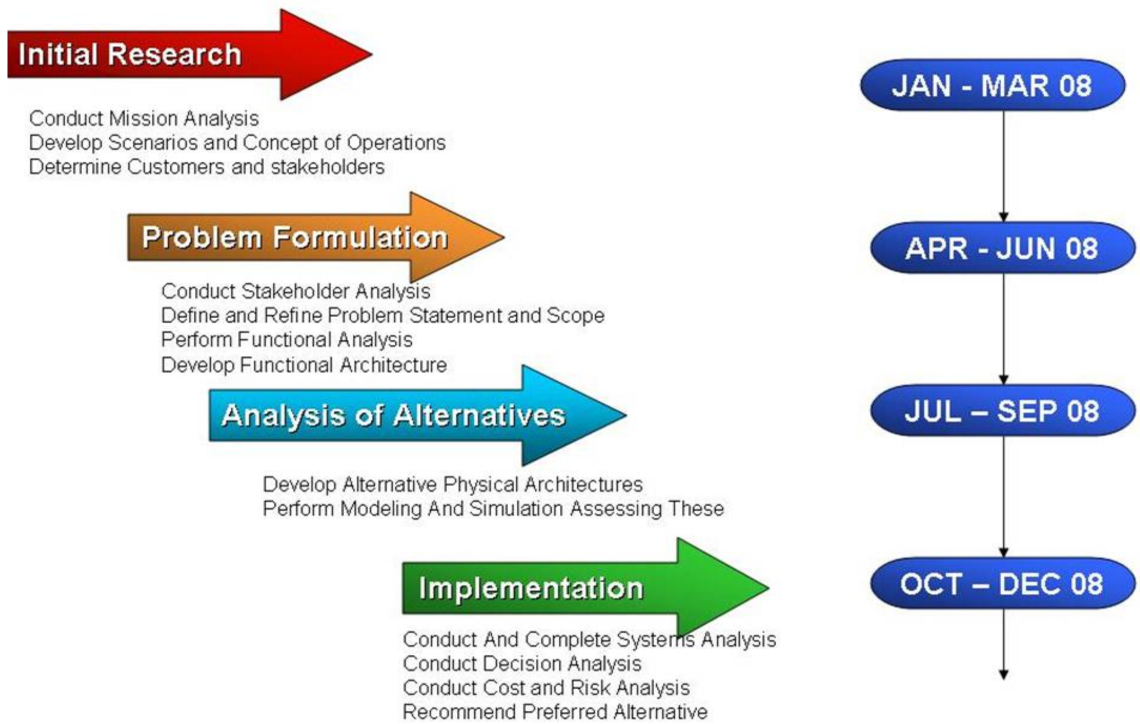

Figure 7 – Systems Engineering Design Process

to test our alternative solutions, the development of a Concept of Operations (CONOPs) and determining of customers and stakeholders. At the same time, the project team conducted research into current solutions, systems, methodologies, and technologies that have been used or are in use to counter the threat of mines and MIEDs.

5.2. Problem Formulation

After the initial research on the problem, the project team then conducted problem formulation. In this phase, the project team worked to establish a problem definition and scope it within the timeline and boundary of the project. This process involved the conduct of stakeholder analysis to gain insight into the desires of project teams and entities involved in the problem, constant feedback and revision to the problem statement and scope as we became more aware of pertinent issues, performance of functional analysis to understand what the system must accomplish, and the development of a functional architecture that outlines the sequence and structure of the tasks identified during functional analysis.

5.2.1. Stakeholder Analysis

In the stakeholder analysis, the interested project teams and entities of the system were identified and project teamed according to their influences on the system. This phase resulted in a weighted scale that allowed the stakeholders that were most closely-related to the problem have precedence in the decision-making process while still being able to evaluate the concerns and desires of project teams and entities with lesser involvement.

The views of the stakeholders were gathered through survey and interview. These inputs were then translated into requirements/needs and were rated according to their importance. To quantify the desires of stakeholders for use in later analysis, the Analytic Hierarchy Process (AHP) was used to compare the relative importance of the various requirements/needs.

5.2.2. Refine Problem Statement

With the inputs from the stakeholders gathered and the initial research on the problem completed, the initial problem statement was refined to focus on the areas of concern and perceived gaps in the status quo while simultaneously bounding the problem to an attainable scope within the project timeframe.

5.2.3. Perform Functional Analysis

Functional analysis is a critical step in implementing SEDP. Functional terms were used to define the systems needs and basic requirements from top-level down. The objective of functional analysis is to specify the "whats", not the "hows", that need to be accomplished. It is intended to translate the system tasks/requirements into "functional" terms. A convenient mechanism for communicating this information is the functional hierarchy. Figure 8 shows the final functional hierarchy developed by the project team. This functional hierarchy was used to model the actions required to effectively prevent, counter, and recover from an MIED placement. As discussed later, this functional hierarchy changed as the project team narrowed the scope of the project.

5.3 Analysis of Alternatives

Upon completion of the problem formulation—which also draws out the functional architecture of the proposed system—the project team then developed the

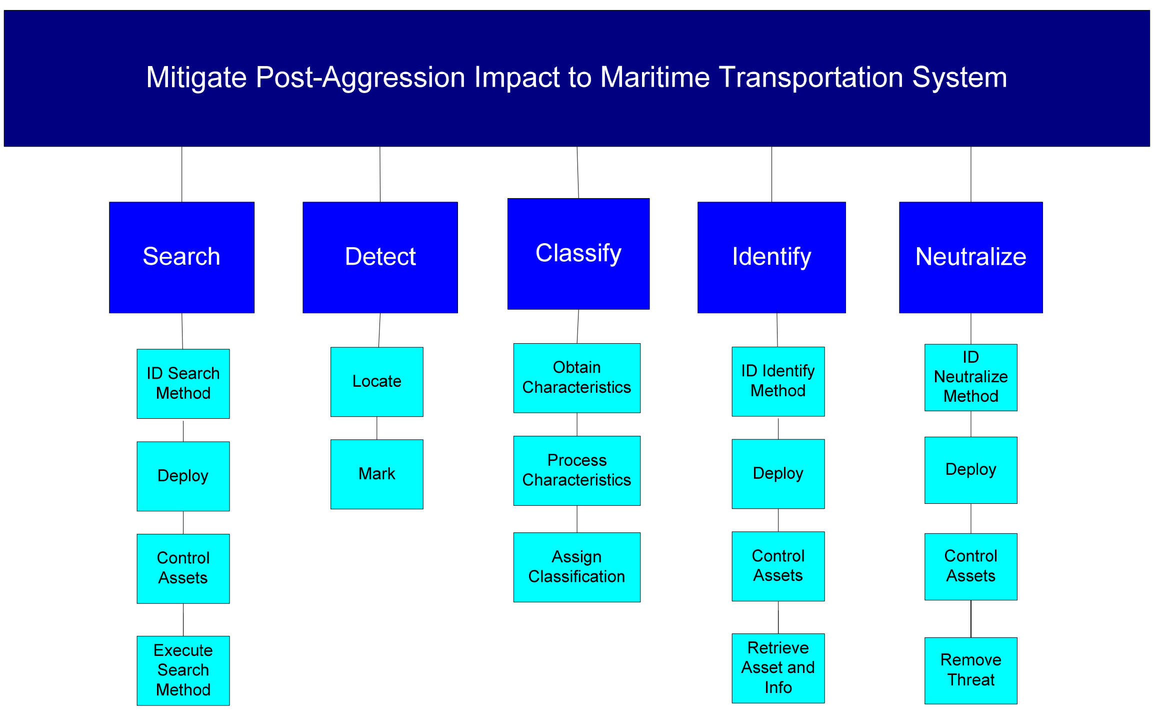

Figure 8 –Functional Hierarchy

physical architectures and generated various system alternatives. At the same time, the metrics to measure these alternatives and methodologies used to evaluate the performance of the alternatives were generated.

5.3.1. Developing Alternatives

Morphological charts were used to assist the project team in the development of alternatives. This structured brainstorm methodology helped to generate multiple potential solutions to the problem. Figure 9 depicts and example of a morphological chart.

5.3.2. Generate Metrics to Measure Effectiveness/Performance

Metrics and system architecture were generated during this stage. The objective of metrics is to provide a quantitative evaluation of the effectiveness and performance of the various alternatives. Measures of effectiveness (MOEs) and measures of performance (MOPs) were developed to provide a snapshot of the system as a whole and at the sub-system level.

Search				Detect		Classify	
ID Search Method	Deploy	Control Assets	Exe Search Method	Locate	Mark	Obtain Char.	Process Char.
DoD Decision Maker	Air Deploy (Helo, Fixed wing, self)	Autonomous (UUV/AUV/ Marine Mammal)	DoD Search Team	DoD Detect Team	Electronic	DoD Classify Team	DoD Classify Team
Civilian Decision Maker	Ground (Train, Truck, etc)	Remote-Controlled	Civilian Search Team	Civilian Detect Team	Physical	Civilian Classify Team	Civilian Classify Team
ICS Unified Commander	Sea (Ship, Barge, self)	Manned				USCG Classify Team	USCG Classify Team
	Site Launch (Crane, Ramp, Drop, Disembark)	Pre-programmed					

Figure 9 – Example of Morphological Chart

5.3.3. Modeling and Simulation

At this stage, various modeling and simulation techniques were developed and conducted to obtain the data necessary to calculate the MOEs and MOPs for the various alternatives. War gaming, computer modeling, and spreadsheet simulation were carried out.

5.4 Implementation

The final phase of SEDP is the implementation phase. The goal for this phase is to carry out the decision analysis of the alternatives with reference to the MOEs and MOPs obtained from the modeling and simulation exercise. It involved cost analysis, risk analysis, sensitivity analysis, trade-off study and finally the recommendation of preferred alternatives.

5.4.1. Decision Analysis

Decision analysis is the procedure and methodology for identifying and assessing the important aspects of a decision by applying the maximum expected utility action to a well-informed representation of the decision. Cost analysis, risk analysis, sensitivity analysis and trade-off study were conducted for the study.

5.4.2. Cost Analysis

The goal for cost analysis is to estimate the total cost of the various identified alternative systems. Total cost of ownership (TCO) is used to estimate the cost of the identified alternative systems. TCO is the life cycle cost (LCC) of the system plus the sum of the indirect cost components—such as costs associated with research, development, procurement, operation, logistical support and disposal of an individual system including the total supporting infrastructure that plans, manages and executes that system program over its full life.

5.4.3. Risk Analysis

Risk analysis was conducted to identify and manage the risk associated with the proposed alternatives. The goal is to identify cost, schedule, and technical risk so that they can be controlled, and that the consequences of courses of action can be determined early in the process. Risk consists of mainly two parts, i.e. the probability (likelihood) of failing to achieve a particular outcome and the consequences (impact) of failing to achieve that outcome. Figure 10 shows an example of the risk matrix plot.

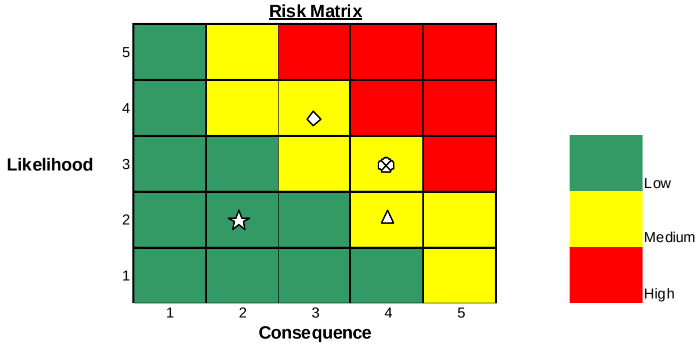

Figure 10 – Example of Risk Matrix Plot

5.4.4. Sensitivity Analysis

Sensitivity analysis was conducted to investigate the robustness of the study by varying the different weights used for decision-making criteria. In general, sensitivity analysis tried to identify what sources of uncertainty affected the study's conclusions most.

5.4.5. Trade-off Study

A trade-off study is the activity of finding the solution to a problem that simultaneously satisfies a series of measures or cost functions. These measures describe the desirable characteristics of a given solution. Multiple Criteria Decision Making (MCDM) methodology such as min-max methods, min-max regret methods, weighting methods (decision matrix), etc. were used to compare the alternatives.

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II. PROBLEM FORMULATION

1. STAKEHOLDER IDENTIFICATION

The following entities were identified as potential stakeholders:

a. National Oceanic and Atmospheric Administration (NOAA) – Federal agency focused on the condition of the oceans and the atmosphere.

b. Program Executive Officer Littoral & Mine Warfare (PEO LMW) – Responsible for development and acquisition of Littoral & Mine Warfare Naval Systems.

c. Office of the Chief of Naval Operations (OPNAV) – Senior military officer in the Navy, responsible to the Secretary of the Navy for command, utilization of resources, and operating efficiency of the operating forces of the Navy and of the Navy shore activities assigned by the Secretary.

d. U. S. Coast Guard Headquarters (USCG HQ) - Its core roles are to protect the public, the environment, and U.S. economic and security interests in any maritime region in which those interests may be at risk, including international waters and America's coasts, ports, and inland waterways.

e. U.S. Coast Guard Sector Charleston and District 13 & 14.

f. Naval Surface Warfare Center Panama City (NSWC PC) – Division of Naval Sea Systems Command focused on research, development, test and evaluation, in-service support of mine warfare systems, mines, naval special warfare systems, diving and life support systems, amphibious/expeditionary maneuver warfare systems, other missions that occur primarily in coastal (littoral) regions.

g. Commander Naval Meteorology and Oceanography Command (CNMOC) – Operational arm of the Naval Oceanography Program, focused on providing critical environmental to warfare disciplines of Anti-Submarine Warfare, Naval Special Warfare, Mine Warfare, etc.

h. Naval Oceanography Mine Warfare Center (NOMWC) – Provides ongoing support for the Navy's mine warfare forces to neutralize threats and to allow for assured access of maritime assets.

i. Naval Mine & Anti-Submarine Warfare Command (NMAWC) – Assure access for Joint, Coalition, and Maritime Homeland Security operations by providing able and quick reaction combat capability across the full spectrum of Mine Warfare.

j. Explosive Ordnance Mobile Unit One (EODMU1)

k. Mine Warfare Training Center (MINEWARTRACEN)

l. U.S. THIRD Fleet (C3F) – Delivers combat-ready naval forces, executes fleet operations, and defines future fleet requirements in order to deter aggression, preserve freedom of the seas, and promote peace and security.

m. U.S. Northern Command (USNORTHCOM) – Anticipates and conducts Homeland Defense and Civil Support operations within the assigned area of responsibility to defend, protect, and secure the United States and its interests.

In addition to the above listed Department of Defense (or DoD affiliated) stakeholders, there also included numerous secondary stakeholders. These include:

a. Klein Associates – Manufacturer of Unmanned Underwater Vehicles and other technologies.

b. Northrop Grumman - Manufacturer of Unmanned Underwater Vehicles and other technologies.

c. Lockheed Martin - Manufacturer of Unmanned Underwater Vehicles and other technologies.

d. Lloyd's of London – UK based, worldwide insurance underwriter serving many of the world's largest maritime transportation companies.

e. Orca Maritime – Employs today's technology, executed by experienced operators, to provide solutions for today's undersea security challenges.

f. Federal Bureau of Investigation (FBI) San Francisco.

g. The following Ports: Port of Portsmouth, Port of Charleston, Port of Savannah, Port of Honolulu, Port of Oakland, Ports of Seattle/Tacoma.

2. NEEDS ANALYSIS

Having identified potential stakeholders, the project team conducted phone interviews, email correspondence, and site visits to gain an understanding of the problem as viewed by the various stakeholders, and encapsulate the differing needs of each. It was understood that with the wide variety of stakeholders in the problem, ranging from insurance companies, military commands, Coast Guard activities, and industry representatives, that some priorities would not be consistent across the stakeholder spectrum. Therefore, after understanding the needs, the project team reconciled conflicting priorities by assigning general weights to stakeholders depending on their involvement in the end-use of the product and by the level at which our system solution would benefit them. From this analysis, the functions the system would need to perform and their relative importance to mission completion would be determined, weighted, and used in decision analysis.

2.1. Stakeholder Analysis

The Stakeholders in the MIED system development process are persons with a vested interest in the system being promoted. These stakeholders are grouped into the following categories: Primary, Secondary, and External. The fundamental goal of the stakeholder analysis was to identify person(s) with a vested interest to either support or encourage reform or propose systems and alternatives.

Stakeholders were interviewed initially to determine weaknesses with the current process and their desires for improvement. Each stakeholder has a different paradigm that is relative to their function in the maritime trade process and their "closeness" to the problem of an MIED. Key stakeholders are identified in the above table as "Primary". That is, those who are responsible to keep a port open and respond to an MIED threat. Secondary Stakeholders have a large stake in the system, are high profile, and are affected either directly or indirectly by a port closure. External Stakeholders are those who are affected by an MIED or a system to assist in its recovery, but have very little if any direct input or involvement in the solution.

The Relative Priority of Interest is defined as the following:

1 – The stakeholder cannot make decisions regarding the use of the resources.

2 – The stakeholder is one of several persons that can make decisions regarding the resources.

3 – The stakeholder can make decisions regarding the use of the resources in their particular organization or area.

4 – The stakeholder is ultimately accountable for the process

2.1.1. Primary Stakeholders:

a. Commercial Port Security Departments - The Port Security Department incorporates security as a priority into their business strategies to ensure the uninterrupted flow of goods from ships to the rest of the country. With goals to reinforce safety and security at all port assets, they collaborate with other organizations and governments for an integrated security approach, and participate in national and global security efforts to facilitate the smooth flow of international commerce.

b. Coast Guard - The Coast Guard is ultimately accountable for the safety of ports and harbors. As such, the Captain of the Port as the likely Incident Command System (ICS) Incident Commander is the primary end user of any counter-MIED system.

c. Local Authorities - The local police, fire departments and medical services may be involved during any response or recovery effort resulting from an MIED. Therefore, they are deemed as a primary stakeholder who will benefit immediately and directly from any system that may keep them out of harm's way and expedite a cohesive response.

d. Department of Defense - The U.S. Navy is currently the recognized expert in the field of mine warfare, and the best executer for an MIED response due to their equipment and training. The Navy is also funding and training personnel in efforts to combat mines and MIEDs.

2.1.2. Secondary Stakeholders

a. Department of Commerce - By definition, the Department of Commerce has the historic mission "to foster, promote, and develop the foreign and domestic commerce" of the United States. This has evolved, as a result of legislative and administrative additions, to encompass broadly the responsibility to foster, serve, and promote the Nation's economic development and technological advancement. A disruption in trade via the ports would trickle down through all inter-modal means and spread throughout the country.

b. Federal Bureau of Investigation - The FBI is tasked with protecting communities and businesses from the most dangerous threats and responsible for the criminal investigation of a maritime terrorist act. The closure of a port would affect the port itself and the trading partner nation, but additionally the rail and trucking industry, small business who receive trade the received goods and industry and consumers that use the goods. The effects of a port closure due to an MIED are far reaching, and therefore shall easily fall into the FBI's area of concern.

2.1.3. External Stakeholders

a. Lloyds of London - As a major insurer of cargo and cruise vessels, they have a substantial monetary concern that cold result from the damage to a ship or its cargo.

b. Wholesalers/Retailers - Wholesalers and retailers rely on the flow of goods in a timely manner to their businesses so they may trade or consume the products for industrial needs. The loss of a single port, if even for a short period, would be felt by commerce nation-wide.

c. Environmentalists - The explosion of an MIED can cause fuel leaks, contamination, kill wildlife, etc. Therefore, the safe identification and disposal of such a device is the environmentalist's best interest. Environmentalist groups may also be concerned about the counter-MIED system itself, as the technology it employs may have an impact on the environment or wildlife.

2.2. Needs and Constraints Analysis

A needs and constraints analysis was carried out to study the present needs and constraints faced by the various stakeholders in dealing with the stated problem. At the same time, the analysis was conducted to help to outline the general direction and approach toward finding the proposed solution.

2.2.1 Needs Assessment

In order to assess the needs of the stakeholders for the problem, the project team uses the following tools to help to identify the key issues/needs and prioritize them: Functional flow diagram and Stakeholder survey.

a. Functional flow diagram - A functional flow diagram shows the functions that the system must perform to satisfy the system needs statement or system goal in accordance with the contents of the overall mission. In view of the problem of countering MIED, the team first formulated the functional flow of a terrorist attack and identifies the key problem/issue that the US ports may face. Figure 11 illustrated the functional flow of a terrorist attack of US ports.

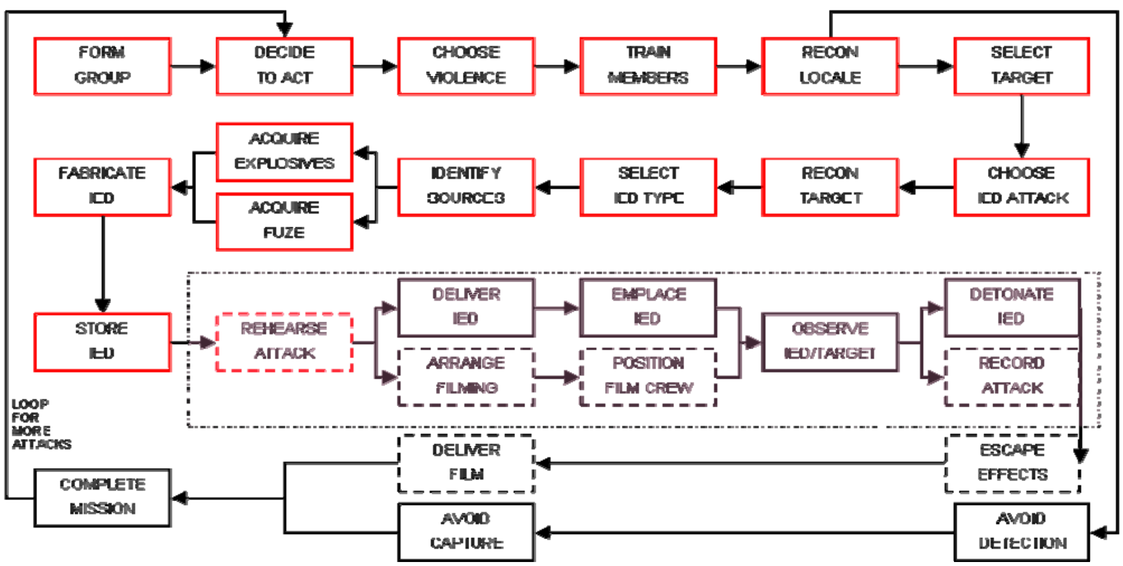

Figure 11 – Functional Flow Diagram of a Terrorist Attack of a US Port (Courtesy of Dr. Robert Harney, NPS)

From the functional flow diagram shown in Figure 11, it is noted MIEDs being delivered, emplaced and detonated would be the main concern of any US ports (i.e. the function block highlighted in Figure 10). This also displayed the need for a system to prevent the delivery and emplacement of the MIED and a system to quickly locate and neutralize the MIED in order to minimize impact on the shipping operation to and out of the port.

b. Stakeholder Survey - A stakeholder survey was also conducted to gather feedback and view from the stakeholders on the needs to counter the MIED / mines problem (focusing mainly on mitigation of MIED attack). An electronic survey was sent to the following stakeholders to gather their view on the importance of each of the function identified in mitigating the impact of MIED attack.

a. USCG Captains of the Port
b. Port Security Representatives
c. Associates of ORCA Maritime, Inc
d. Maritime Union Members
e. Mine Warfare Association Members
f. Lloyd's of London Joint War Committee
g. US Northern Command Staff
h. Law Enforcement Personnel
i. Representative from PEO LMW
j. Navy Mine and ASW Command Civilian and Military Staff
k. Coast Guard Head Quarters Staff
l. Engineers from Naval Surface Warfare Center

Feedback from the stakeholders was compiled and analyzed using an AHP. The AHP carried out a pairwise comparison of the various functions and ranked the relative importance of each function according to the stakeholders input. From the input gathered, it was noted that the key objective is to clear the MIED in the shortest possible time without incurring damage to infrastructure and resume normal port operation as soon as possible.

2.2.2 Constraints Analysis

Constraints analysis is a methodology for identifying a critical path among all the actions potentially needed to create the design of a SoS for the stated problem. It was carried out to examine and quantify the factors that limit the current available and possible future solutions in solving the problem. The steps in identifying the constraints and gaps in current systems were as follows.

1) Identify current situation,
2) Identify the desired situation,
3) List the gaps and constraints between desired and current situation, and
4) Study the causes of the performance gaps and constraints.

2.2.1.1 Current Situation

Based on the feedback obtained from the various MCM exercises attended by the members of the team, the team envisage the MCM process and worked out a typical function flows diagram of the MCM operation in a local port if there is a MIED threat. The detail function flow is shown in Figure 12.

Presently, the entire operation from report of threat to return to normal operation for the port would typically take a few days, up to a week or even a month, to complete. During this period of time, active shipping would be restricted resulting in potentially huge loses to commercial throughput and downrange through the supply chain management.

2.2.2.2 Desired Situation

The desired situation is to minimize the impact of the MIED threat by shortening the port closure duration such that commercial shipping can re-commence operation with minimum impact to the economy and reduce the threat the device poses to Critical Infrastructure/Key Resources (CI/KR).

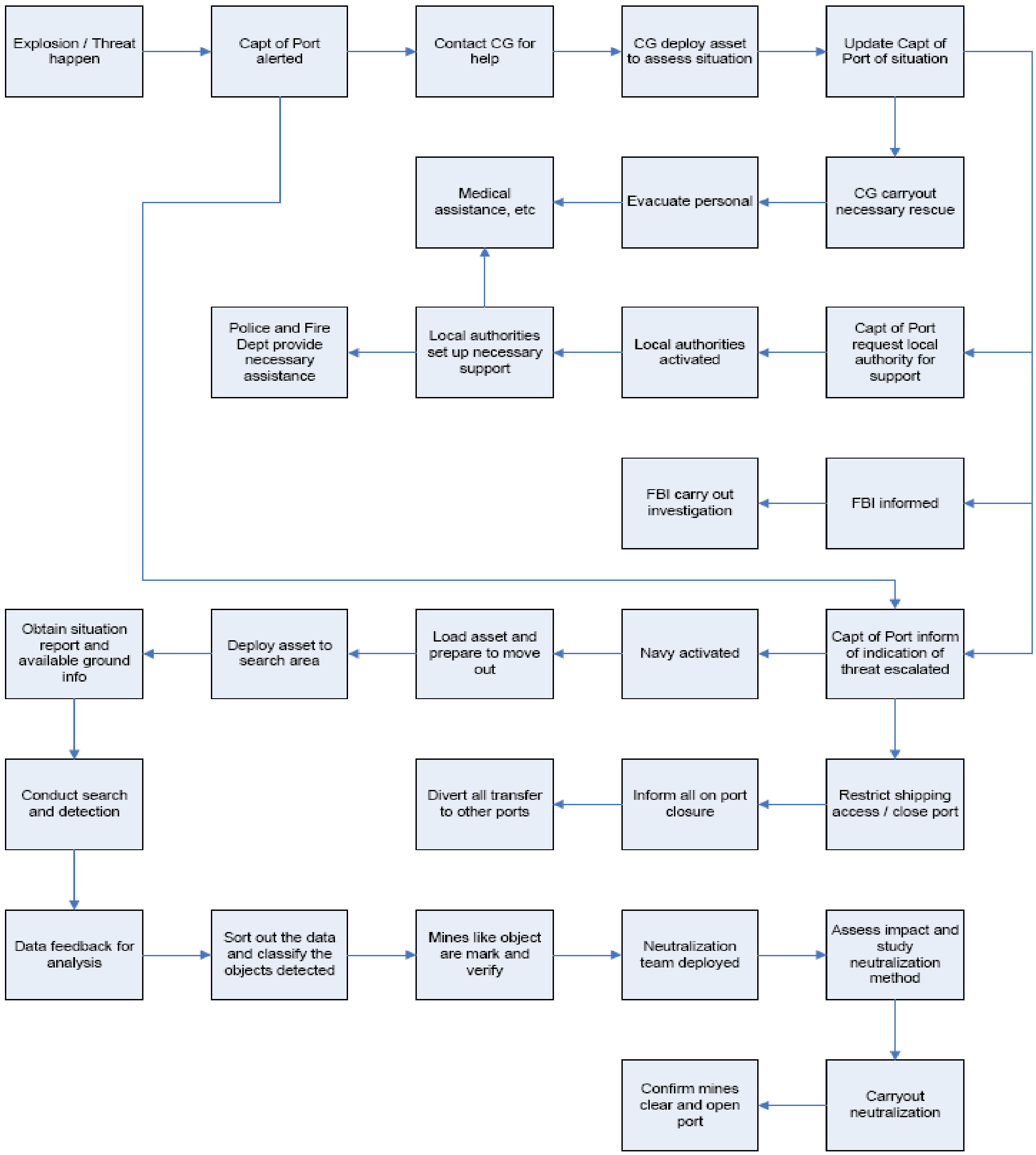

Figure 12 – Functional Flow for Counter MIED Threat

2.2.2.3. Gaps and Constraints

From the above functional flow, the gaps and constraints identified are shown in Figure 13 and listed below.

a. Constraints

- Interagency co-operation required

- Limited resources / assets

b. Gaps

- Operation procedure for interagency cooperation
- Limited non-destructive neutralization technology
- Performance of search, detection and identification technology
- Required highly trained personnel and large amount of time to carry out post mission analysis
- Regular updated port survey needed

2.2.3 Proposal Outline

Based on the gap and constraint identified, the team reviewed and outlined the problem and direction toward solving the problem. Thus, the team objective was to proposal a System of Systems to counter MIED, focusing on searching, detection, classification, identification, assessing impact and neutralization.

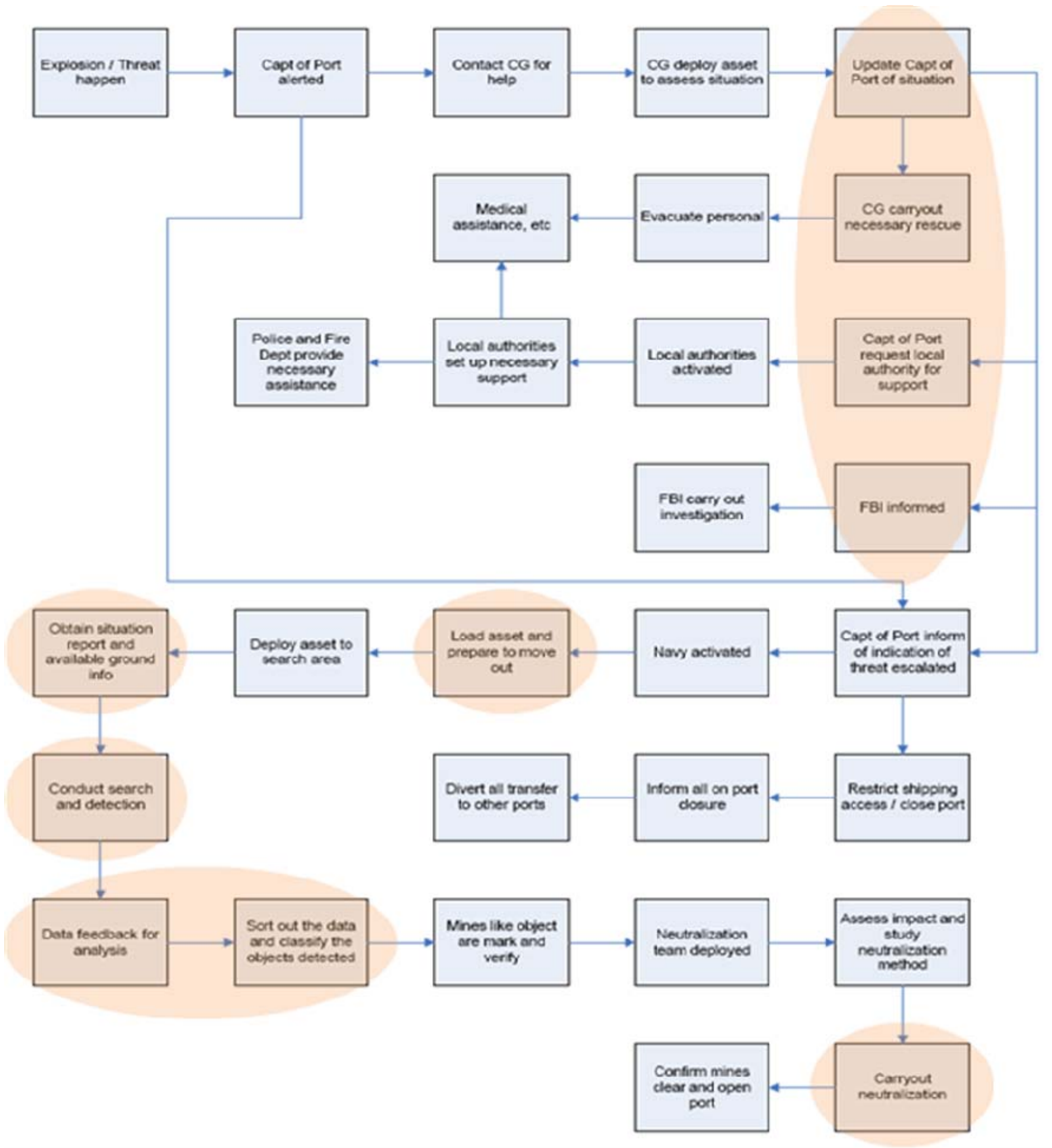

Figure 13 – Primary Gaps / Constraints Identified

2.3. Input/Output Model

To better understand how to construct a SoS, the project team developed an Input/Output model. This model—derived from stakeholder needs—incorporates controllable and uncontrollable aspects and displays the intended and unintended outputs from the SoS.

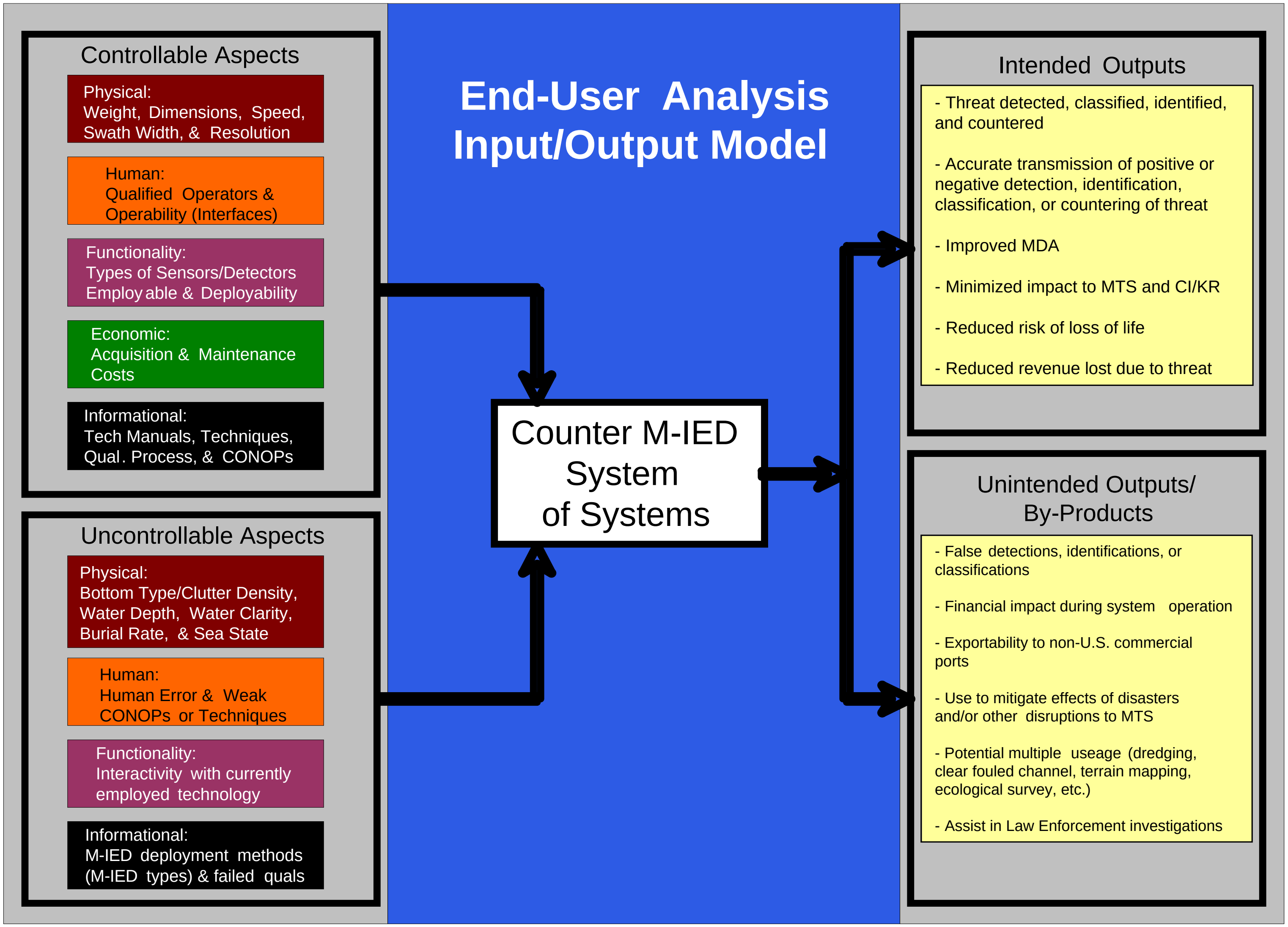

Figure 14 – Counter MIED System of Systems Input/Output Model

2.3.1. Controllable Aspects

Controllable aspects are those that can be measured, calculated, built, or compiled by the designers in the developmental and test and evaluation phases. These range from the physical characteristics such as size and speed to the human aspects such as the interface systems and the qualification of specific operators. Also considered controllable are the economic considerations—or how much it costs—and the informational aspects, which will dictate how the SoS will be employed.

2.3.2. Uncontrollable Aspects

Uncontrollable aspects are that that are beyond the control of the designers. These vary from the physical aspects (i.e. environmentals) to human error, interactivity issues, and doctrinal problems.

2.3.3. Intended Outputs

Intended outputs are those which are key to the SoS desired end state. Several key outputs were identified:

a. Detection, Classification and Identification.

b. Threat Countering.

c. Ability to accurately transmit information (i.e. knowing when the threat has been detected, classified, identified, and countered).

d. Improved Maritime Domain Awareness (MDA).

e. Minimization of the operational impact to the port's key resources and critical infrastructure.

f. Reduced risk of loss of life.

g. Reduced capital lost due to the threat.

2.3.4. Unintended Results

Though the SoS is designed to counter MIEDs, several unintended outputs will inevitably result. Some potentially negative unintended outputs, or by-products, were identified:

a. Potential false sense of security provided should the data be wrong.

b. The financial impact having the SoS operating in a port.

c. Other by-products may provide additional incentive to pursue development of the SoS. These include:

- Exportability to non-U.S. ports,
- Mitigate the effects of natural disasters and/or disruptions to the MTS
- Assist in normal port operations (i.e. dredging)
- Assist in law enforcement investigations

3. FUNCTIONAL ANALYSIS

3.1 Functional Decomposition

In order to understand the purpose of the system, the project team conducted research on all the actions the system would need to do to accomplish the mission. After conducting this research, the project team had a brainstorming session and developed a full spectrum of functions that must be accomplished to prevent, respond to, and counter MIED actions. These functions are found in Figure 15.

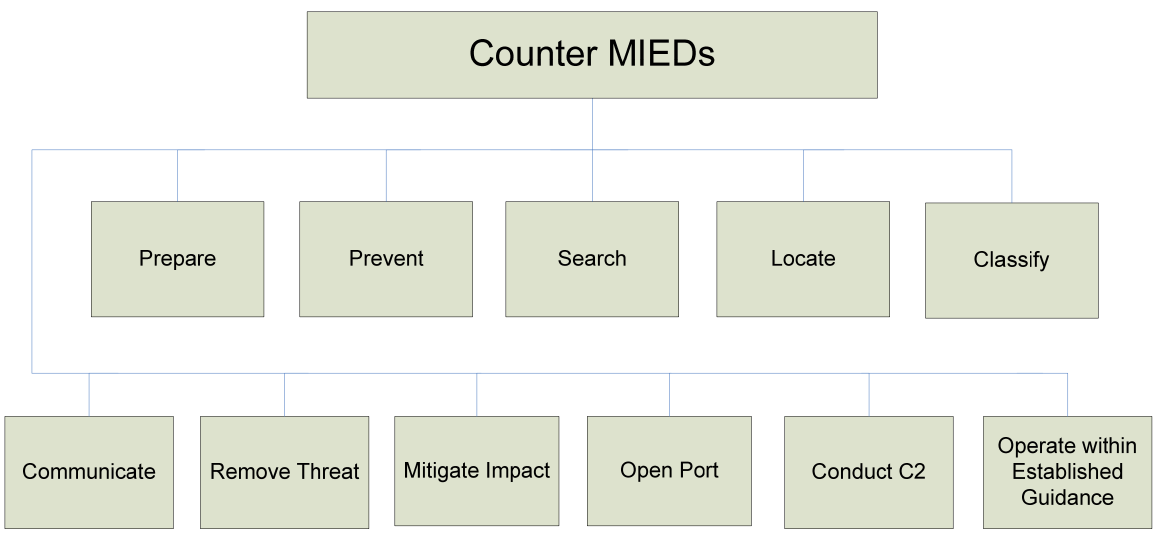

Figure 15 – Initial Functional Hierarchy

As the figure shows, this system would employ a full range of counter MIED functions, including preparing ports for threats, a full suite of sub-functions meant to prevent MIED emplacement, all actions required to detect and remove an MIED, and the actions taken once a threat is removed to restore the port or waterway to normal operations.

A significant research opportunity was met through the project team attending the Mine Warfare Association 8th International Symposium on Technology and the Mine Problem hosted at the Naval Postgraduate School. The general theme of this conference, which was collaborated by the individual interview of several stakeholders, was the organizational and political constraints associated with the problem that has slowed the allocation of funds and resources to combating this problem. Further highlighting the difficulty is the notion that this problem has "high impact, but very low probability" of occurrence. In short, funds and resources are short due to the lack of requirements for any service or agency to address the MIED problem systemically, and the predominant paradigm views an MIED threat as a low probability occurrence.

With this paradigm in mind, the project team decided to address the problem by developing a system that would respond to a threat once it occurs. Although this system to a large extent does not address preventive and preparation concerns, the project team does acknowledge that the most successful way to mitigate the effects of an MIED attack is to prevent one from being placed and, barring that, ensure ports and waterways are fully prepared to deal with the threat in short order. However, preventive and preparatory programs could require huge costs in training, manning, and technical development and acquisitions. These costs, coupled with the political and organizational issues already addressed, led the team to focus on a response that could be fielded in the near term that would mitigate the effects of aggressive actions, either the placement of an MIED or the threat of one, until the full spectrum of counter-MIED operations could be addressed.

Having revised the functional hierarchy to reflect this change in the project team's scope, the functions were further decomposed into sub-functions that must be completed in order to fulfill the higher order function. The revised functional hierarchy including sub-functions is included in Figure 16. A description of these functions and the metrics used to assess the system's performance can be found in the following sections.

3.2. Search

The project team's definition of Search lends itself to a greater breadth of

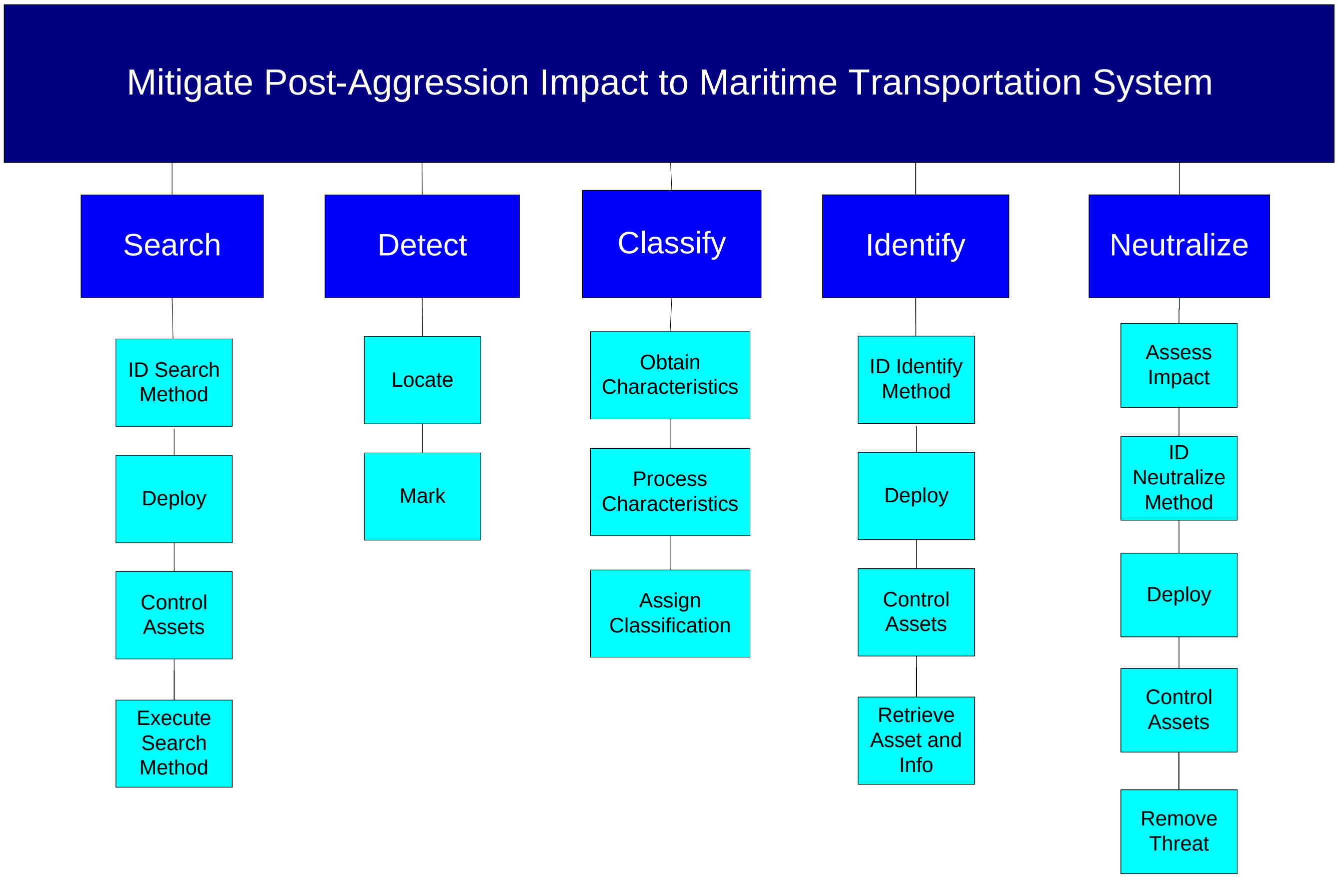

Figure 16 – Revised Functional Hierarchy

complexity. For instance, our problem includes non-conventional mines and a more restricted operating environment within the Maritime Domain (MD). To focus the problem, we have defined Search as all efforts to effectively achieve maximum coverage of a desired search area with a particular sensor/platform. It is the first operational function of our system and is comprised of the following sub-functions: Identify Search Method, Asset Deployment, Control Asset, and Execute Search. Combined, these sub-functions constitute the 1st tier, basic actions required to conduct a search.

3.2.1. Identify Search Method

Prior to conducting a search, mission requirements and environmental conditions are evaluated to determine the most effective search method. In this sub-function, plans are evaluated and decisions are made for which asset or combination of assets will be used, search speed, track spacing and layout as well as priorities for search efforts.

3.2.2. Asset Deployment

Asset deployment includes all actions necessary to begin a search operation with the asset(s) identified in part A. This sub-function allows us to account for the length of time required for an asset, its operators, support equipment and resources to arrive on station, but also accounts for additional processes or special considerations that are needed for the asset and its support structure to be employed. The reasons for considering these factors are due to the limited use of conventional mine warfare assets that can be brought to bear in Maritime Homeland Defense (MHD) and the uncertainty of where an attack may occur within the 93,000 miles of U.S. coastline.

3.2.3. Control Asset

This involves the actions to direct a particular system in searching an area for MIEDs. Asset control is influenced by time, space and the ability to communicate with the search asset.

3.2.4. Execute Search Method

The execution of a search is the culmination of planning and identifying the search method, asset deployment and control efforts that are transpired into actively searching an area. Figure 17 shows the completed tracks of REMUS UUV's searching areas of Honolulu Harbor during the Honolulu Harbor Experiment, July 2008.

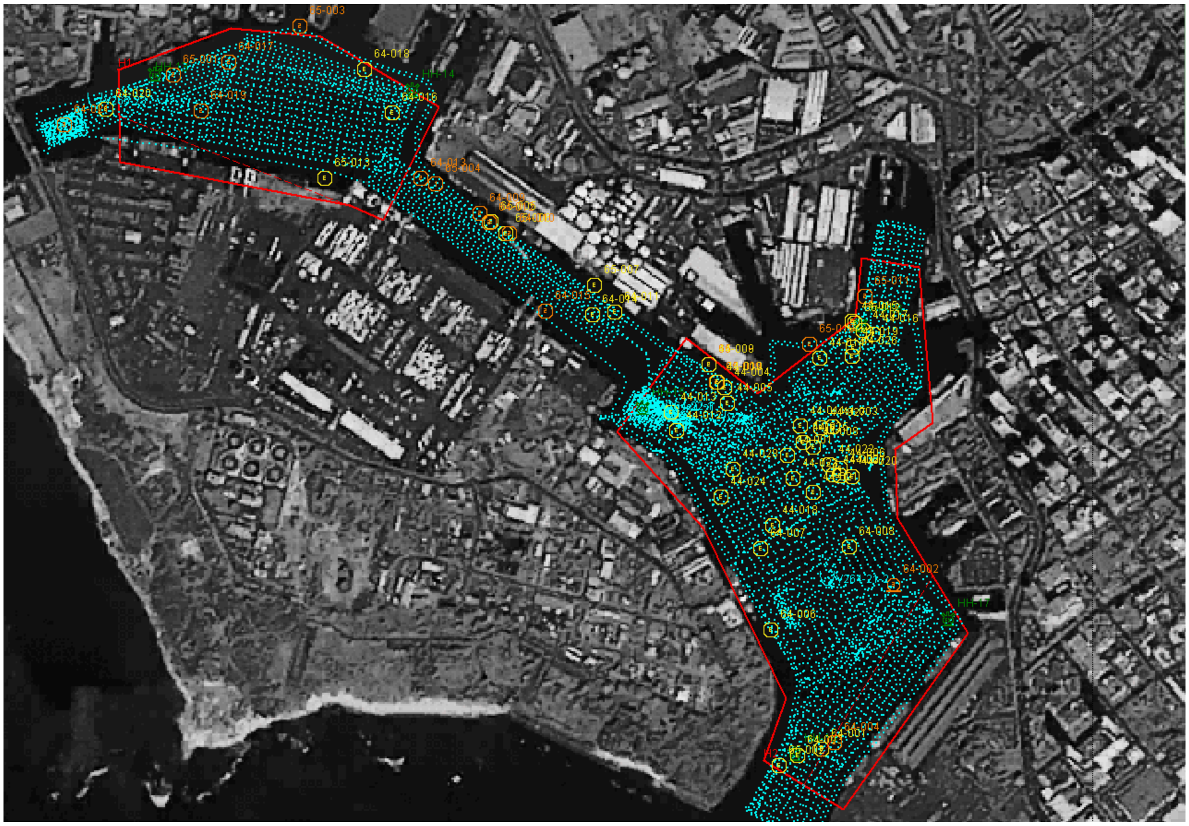

Figure 17 – Honolulu Harbor Search Areas, HHX 2008

3.2.5. Metrics

In order to evaluate the performance of a search, metrics have been established to quantify the effectiveness of minimizing the time to completion. Our metrics for search will be inputs into determining the Overall Measure of Effectiveness (OMOE) which is the time required to restore commerce to an affected port after a MIED attack.

3.2.5.1. Area Search Rate

Area Search Rate is a measure of how quickly a search can be conducted and is a function of the search platform's speed and effective swath width. It is also dependent on the type of search being conducted, such as an exhaustive search, random search or spiral search. The units for Area Search Rate are expressed in (area/time).

3.2.5.2 Time to Station

Time to Station is the time required for a search asset to be deployed from a forward staging area to the area of intended search. The unit for TOS is expressed in time (t).

3.2.5.3. Deployability Rating

Deployability Rating is a scaled metric that measures how well and easily a search asset can be positioned for readiness and put into use. The dependant factors for scoring Deployability are:

a. Integration. How seamlessly a search asset can integrate with static assets already present at the affected site. Static assets can be personnel, material or procedures.

b. Operators. How many operators are needed to conduct a search and the resource requirements they need such as facilities, training and footprint?

c. Size and Weight. Size and weight of the search asset affects how effectively it can be transported to the affected site quickly while minimizing the cost and special requirements to do so.

Specifically, the deployability rating of a given system or alternative provides decision makers with a quick-look at how rapidly it can be prepared for operation. The deployability has several components for which the rating is derived including time, manpower, required operational tests, environmental limitations, etc. The time phase for the rating begins from the point that all required equipment is on station to when the system has completed all preparations and is ready for use. Table 3 depicts an example chart used to document the Deployability Rating. The following metrics derive the deployability rating:

a. Movement. The movement accounts for manpower and other system requirements to transfer the system to its area of operation. Movement does not account for the transit requirements from another location to the area of need.

Scale
1 – Requires heavy equipment to move the system.
2 – *Requires significant resources.*
3 – Requires four personnel and light equipment.
4 – *Requires minimal resources.*
5 – Requires two or less personnel to move

b. Assembly. Upon arrival of the system to the scene, the ultimate time required for detection of an object is hampered by assembly and/or mounting requirements of the search vehicle. The ability to rapidly assemble a system from its transporting carrier will benefit the on scene commander by expediting the total timeline of the process.

Scale
1 – Greater than 8 hours to assemble.
2 – *Requires significant time.*
3 – Requires 4 hours to assemble.
4 – *Requires minimal time.*
5 – Less than 1 hour to assemble

c. Operational testing. The time required to warm up the system and perform all tests, including mechanical, program, network, etc.

Scale
1 – Greater than 4 hours to test.
2 – *Requires significant time.*
3 – Requires 2 hours to test.
4 – *Requires minimal time.*
5 – Less than ½ hour to test.

d. Fueling and Charging. The time required to either fill fuel tanks or charge onboard batteries in preparation for deployment.

Scale
1 – Greater than 1 hour.
2 – *Requires significant time.*
3 – Requires ½ hour.
4 – *Requires minimal time.*
5 – Less than .1 hours.

Trait	System A	System B	System C	System D
Movement				
Assembly				
OPTEST				
Fuel & Charge				
Rating				

Table 3 - Example Deployability Rating Chart

3.3. Detect

Detection is the phase of an operation where potential mine-like contacts are identified for further classification and identification[16]. Unlike traditional mine hunting taxonomies, all objects must be accounted for due to the inherent definition of an MIED.

3.3.1. Locate

The method of utilizing various unmanned systems within the threat area to locate objects floating on the surface of the water, within the water column or buried on the bottom.

3.3.2. Mark

Once an object has been located, a means of recording or designating the location must be made. The location data must contain a degree of accuracy needed to reacquire the object for future comparison and analysis. Figure 18 shows various contacts of interest marked using MEDAL software.

3.3.3. Metrics

There are two primary metrics involved with the Detect function. These are the Probability of Detection (Pd) and Probability of False Detection (Pfd)

a. Probability of Detection: Probability of Detection is the probability that a system can make the proper determination that an object is present. Probability of Detection considers the performance of the sensor, the means by which

[16] Naval Warfare Publication 27-2(Rev. B), Section 1.8.4.1(unclassified)

detection analysis is conducted, and the presence of human operators in the determination.

b. Probability of False Detection: Probability of False Detection is the probability that a system makes the wrong determination as to the presence of an object, which results overall performance degradation of the system.

Figure 18 – Marked Contacts Using MEDAL Software

3.4. Classify

Traditional Surface Mine Countermeasure operations define Classify as the phase of a mine hunting operation where detected contacts within the MD are further investigated and classified as a mine-like or non-mine-like object[17].

In the case of an MIED, Classification is the phase in which a contact, once detected, is further investigated, determined to be MIED-like and classified as a

[17] Naval Warfare Publication 27-2, Section 1-9

contact of interest (COI) or determined to be non-MIED-like and classified as a contact of no-interest (CONI). For example, a refrigerator on the sea floor would quickly be designated a CONI using conventional MCM methodologies. However, the same refrigerator filled with explosives could pose a threat as serious as a conventional mine and must be treated as such.

The ability to classify is determined by the conduct of three sub-functions, obtaining characteristics, processing characteristics and assigning classification.

3.4.1. Obtain Characteristics

In order to classify a contact it is necessary to obtain characteristics about the contact. This process of collecting key and essential distinctive elements may include but is not limited to characteristics of size, shape, shadow length, proximity to other contacts, and if it correlates with any previous detection attempts within the MD. The characteristics obtained from each contact will be processed utilizing human and computer systems to determine classification.

3.4.2. Process Characteristics

The method of analyzing obtained contact characteristics, utilizing a combination human and computer system to determine the classification of the contact. Human systems may include various operators and technical experts within each detection and post mission analysis system. Other detection systems may have incorporated classification algorithms where a human interface is not required.

3.4.3. Assign Classification

After processing the contact's unique characteristics a decision will be made to assign a specific classification. The classification designates the contact as either a COI or CONI.

This classification designation differs from the conventional mine countermeasure definition of classifying a contact as mine-like or non-mine-like in that the data necessary to correctly classify a mine is not sufficient to make the distinction of whether a contact is MIED-like or not. Unlike traditional naval mine hunting, consideration must be taken to not only include naval mines but also various improvised devices with an unlimited range of options for employment must be considered as a possible threat within the MD.

3.4.4. Metrics

a. Resolution: Resolution describes the amount of detail an image used by a computer system or operator in making the determination of an object's Classification. Resolution is a function of the frequencies used by the sensor and the display resolution of the display system used by the operator.

b. Search/PMA Time Ratio**:** In most current systems collected search data can only be processed after the search is complete. The current goal is a 1:1 ratio; for every hour of search time, it takes a nominal hour of data processing, or post mission analysis (PMA). In practice, this ratio is closer to 1:2 or even 1:3. A desired goal is to reduce this ratio below 1:1 by allowing the search and data processing to proceed concurrently.

3.5. Identify

Mine watching can be best described as the procedure of detecting, locating and identifying mines during the act of laying. The ease of locating a Maritime IEDs could be greatly enhanced if the objects were visually sighted during deployment, however, due to the clandestine nature of mine or IED laying, this will most likely not be the fact.

Identification of a Maritime IED is further hindered by the physical components of the actual explosive. These objects can be constructed of fiberglass or plastic, making them extremely difficult to detect and therefore identify.

Traditional mine warfare doctrine is explicit on determining the existence or non-existence of a mine in the water column.

3.5.1. Determine Identification Method

There are limited means of identifying an underwater contact, but there are options that must be determined. An EOD diver trained and equipped to identify a contact may provide the most confident identification, but the presence of a diver adds risk to personnel. Other options include electro-optical sensors or other sensors with the required resolution may be safer, but may not be able to provide adequate data to confirm the identity of an improvised device. These sensors may be complemented by chemical detectors, resonance sensors, or other emerging methods. These considerations must be taken by the decision maker to ensure the safety of the asset being used while developing a high enough confidence in the Identification to formulate follow-on actions as required.

3.5.2. Deploy Asset

Just as assets required for other functions have different deployment considerations. This sub-function incorporates all actions that need to be taken to move the Identify asset from forward staging to the location of the threat.

3.5.3. Control Asset

All functions required to control, coordinate, and direct the asset throughout the process of Identification. Asset control is influenced by time, space and the ability to communicate with the search asset.

3.5.4. Retrieve Asset and Information

In some systems, the actual asset must be recovered from its operating environment before data supporting the Identification can be retrieved. Even if data can be collected during the process, the asset must be retrieved and the data accumulated for processing.

3.5.5. Metrics

3.5.5.1. Accuracy of Identification:

This metric determines the probability that the system can make an accurate determination to the Identity of the contact. This metric is determined by resolution of the sensor, the presence of a trained person in the loop, the level of improvisation of the device, and its surrounding environment.

3.5.5.2. Time to Identify:

The time required to identify a single contact.

3.5.5.3. Positional Accuracy (PA):

Positional Accuracy is the precision to which a contact is reported. Poor accuracy leads to longer time required to reacquire a contact for further prosecution. Positional Accuracy is a function of the plotting and reporting features and the reliability of the reported data.

3.6. Neutralization

Neutralization is defined as, "the action taken on an individual basis against a detected, classified, localized…[MIED] to eliminate it"[18]. The following are methods used in traditional mine warfare to neutralize a threat:

a. Render-Safe Procedure (RSP): Renders the mine inoperative by interruption of operating functions or separation of essential components. This can be carried out on the mine in-situ or after removal or recovery[19].

b. Removal: Relocation of a mine to an area where it presents no hazard[20].

c. Recovery: Used to obtain mine for exploitation for intelligence purposes[21].

d. Countermining: The process of causing a high order detonation of the mine by placement of a charge. Countermining destroys the contact and removes it from the environment[22].

In the case of countering an MIED, neutralization is carried out in the same manner as in traditional mine warfare, however, additional factors must be considered. For instance, implantation of an MIED is regarded as a criminal act and the necessity for a criminal investigation—either before, during, or after neutralization—must be considered.

Also, before neutralization takes place consideration must be paid to the location of the threat. Should the MIED be placed near some critical infrastructure or a key port resource (CI/KR), blow in place may cause more harm than good and mark and

[18] Naval Warfare Publication 27-2, p 1-6
[19] Naval Warfare Publication 27-2, p 1-9
[20] Naval Warfare Publication 27-2, p 1-9
[21] Naval Warfare Publication 27-2, p 1-9
[22] Naval Warfare Publication 27-2, p 1-9

ignore may not be plausible if the MIED is planted such that if it is left in place, it will prevent normal port operations.

With those factors in mind, the project team performed a functional decomposition of Neutralization. The following were identified as its lower level functions:

3.6.1 Assess Impact

Assess Impact is the sub-function that incorporates the added level of consideration to the safety of surrounding infrastructure that must be taken in port environments. Standard MCM neutralization methods that involve detonation of the MIED or devices used to render the MIED safe may not be suitable in an environment where critical infrastructure can be damaged by such neutralization means. Assess Impact requires the decision maker to consider the risk the neutralization method poses to critical infrastructure, assets, and personnel involved in the process.

3.6.2. Identify Neutralization Method

Upon examining the threat, the on-scene decision-maker will confer with his subject matter experts and determine the best approach to remove it. Factors he will consider include: location in relation to CI/KR, composition of the explosive (if known), projected blast radius, and potential risk to the personnel carrying out the neutralization. With all this in mind, the decision-maker will select the method most likely to effectively neutralize the threat while producing the least collateral damage.

3.6.3 Deploy Asset

After the method is selected, the asset required to carry out the mission will be deployed. The process of deployment will vary depending on the method selected, but this key step cannot be overlooked during the selection of the neutralization method because the port must have the capability (i.e. electric power supply, crane, sufficient pier access, etc.) to support the deployment. Figure 19 shows the Mine Counter Measure Unmanned Surface Vehicle (MCM USV) being deployed from CG Station St.

Petersburg via port crane in St. Petersburg, Florida, during the Tampa Bay Homeland Security Experiment (see Appendix 2).

Figure 19 - Deployment of MCMUSV Using Pier Services

3.6.4. Metrics

3.6.4.1. Neutralization Rating: Neutralization Rating is a weighted score given to a neutralization method that considers the effectiveness of neutralization and the potential risk the method poses to CI/KR, personnel, and assets.

3.6.4.2. Time to Neutralize: Time to Neutralize is the time required to neutralize a single contact.

3.6.5. Control Asset

After the method has been selected and deployed, it must be controlled in order to receive useful data to relay to the decision-makers. Controlling the asset can vary from remotely maneuvering an unmanned vehicle to maintaining lines of communication with an Explosive Ordnance Disposal (EOD). Maintaining situational awareness is essential to this lower level function.

3.6.6. Remove Threat

Once the MIED has been located by the neutralization asset, the threat must be removed in the manner identified by the decision-maker.

4. SUITABILITY OBJECTIVES HIERARCHY

Using the revised problem statement discussed above as an effective needs statement, the project team used the functional hierarchy and the sub-functions listed therein as the basis for a series of objective statements pertaining to system performance.

These objectives were drafted from inputs provided by stakeholders, resources, and academic advisors. These inputs also identified the need for suitability objectives that in combination with the performance objectives would better define overall system capability.

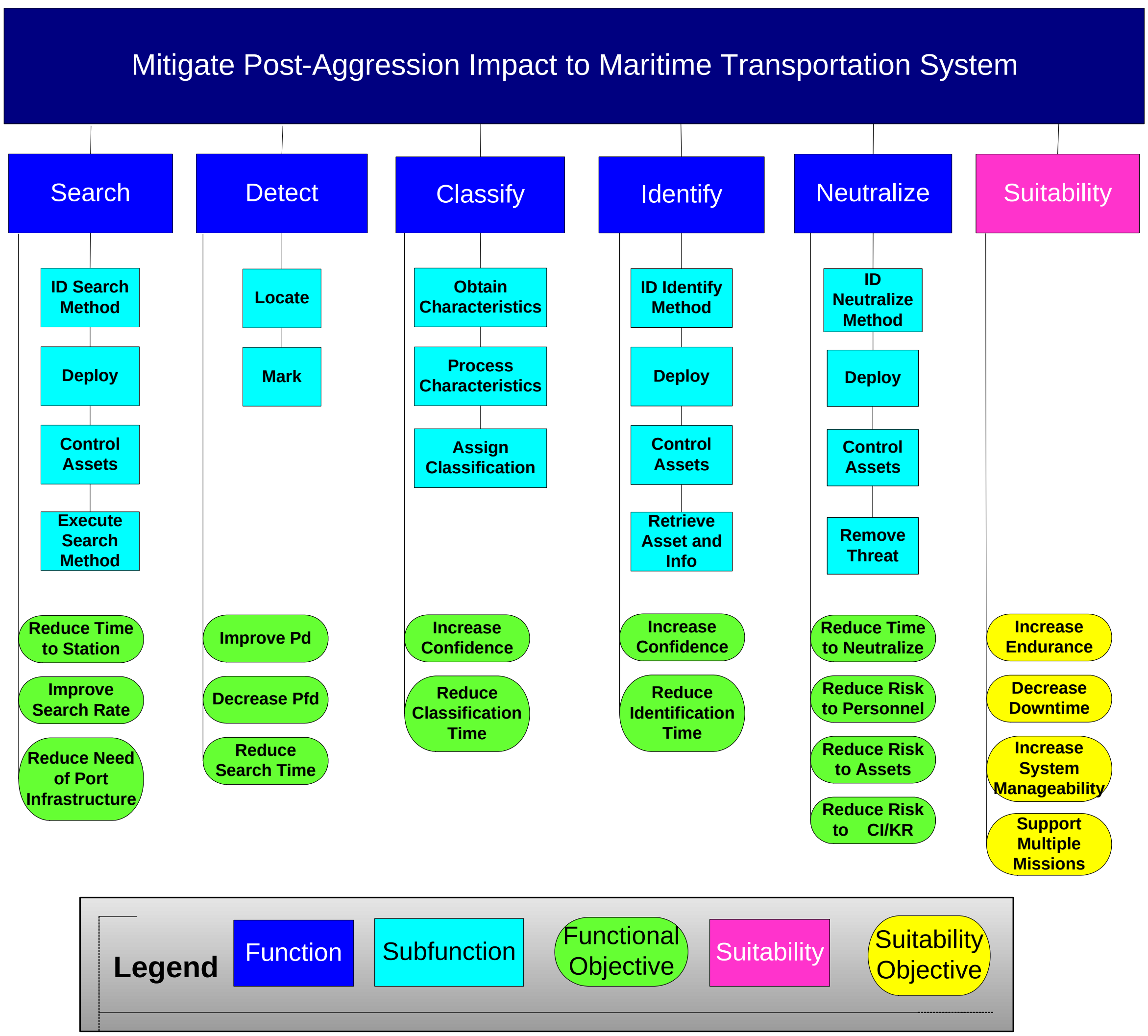

Figure 20 – Objectives Hierarchy

4.1. Performance Objectives

As Figure 20 shows, the overarching objective is to mitigate post-aggression impact to the Maritime Transportation System. This means that the success of the system will rely on its ability to reduce the time use of a waterway is restricted once an aggressive act is known or believed to have occurred and its ability to reduce the damage produced by the placement of an explosive device.

4.1.1 Search Objectives.

Three performance objectives were developed for the Search function: Reduce Time to Search, Improve Search Rate, and Minimize Reliance on Port Infrastructure. An explanation of these objectives is as follows:

a. Reduce Time to Station – By reducing the time it takes for search assets to arrive on station and commence searching, the overall search time is reduced. This objective is measured by the Time to Station metric.

b. Improve Search Rate – A system capable of a higher search rate, given that there is a negligible affect on sensor performance, is better suited to reducing the time taken to search a given area. This objective is measured by the Area Search Rate metric.

c. Minimize Reliance on Port Infrastructure – Systems that are more easily transported to their operating environment and do not rely on port-maintained infrastructure such as storage, cranes, or ramps make asset deployment, mission planning, and manpower use simpler and more effective. This objective is measured by the Deployability Rating.

4.1.2. Detect Objectives.

Three performance objectives were developed for the Detect function: Improve Probability of Detection (Pd), Reduce Probability of False Detection (Pfd), and Reduce Search Time. An explanation of these objectives is as follows:

a. Improve Probability of Detection – The detection of an object by a sensor is the tripwire that leads to the classification and identification of a potential MIED. By increasing the probability of object detection, the possibility of an MIED going unnoticed and causing debilitating damage is inversely decreased. Probability of Detection is a metric of this function.

b. Reduce Probability of False Detection – The false assessment that a contact is present when the opposite is true leads to wasted time and assets prosecuting ‘ghost contacts” and increases the time of the overall search. Probability of False Detection is a metric of this function.

c. Reduce Detection Time – Reducing the time it takes to search an area and note all detected objects directly affects the overall problem time. This objective is measured by the Probability of Detection, as a higher probability will lead to reduced overall detection time.

4*.1.3. Classify Objectives*.

Two objectives were developed for the Classify function: Increase Confidence and Reduce Classification Time. Increase Confidence is the improvement in the probability that an object classified as MIED-like is actually an MIED. Accurate Classification reduces the chance of an MIED going unnoticed and causing damage. The metric of Resolution measures this objective. Conversely, the metric Probability of False Classification (Pfc) measures the probability an object given the classification of MIED-like will be further prosecuted, thereby wasting time and resources. The second objective, Reduce Classification Time, is vital to reducing overall problem time and is measured by the Search Time/PMA time ratio.

4.1.4 Identify Objectives.

Two objectives, Increase Confidence and Reduce Identification Time were developed for the Identify function. Increase Confidence is the improvement in the probability that an object identified as an MIED is actually an MIED. Accurate Identification reduces the chance of an MIED going unnoticed and causing damage. The metrics of Probability of Identification (Pi) measures this objective. Conversely, the metric Probability of False Identification (Pfi) measures the probability an object given the identification of MIED will be further prosecuted, thereby wasting time and resources. The second objective, Reduce Identification Time, is vital to reducing overall problem time and is measured by Positional Accuracy and Identification Time per Contact.

4.1.5 Neutralize Objectives.

Four performance objectives were developed for the Neutralize function: Reduce Time to Neutralize Threat, Reduce Risk to Personnel, Reduce Risk to Assets, and Reduce Risk to Critical Infrastructure/Key Resources. An explanation of these objectives is as follows:

a. Reduce Time to Neutralize Threat – Reducing the time it takes to neutralize each MIED reduces the overall problem time. This objective is measured by the Time Required to Neutralize per Contact rate.

b. Reduce Risk to Personnel – By reducing the risk to personnel engaged in counter MIED operations, the overall risk of the operation is reduced. This objective is measured in the Neutralization Rating metric.

c. Reduce Risk to Assets - By reducing the risk to assets used in counter MIED operations, the overall risk of the operation is reduced. This objective is measured in the Neutralization Rating metric.

d. Reduce Risk to Critical Infrastructure/Key Resources – By reducing the risk to critical infrastructure/key resources from MIEDs, the overall risk of the operation is reduced. This objective is measured in the Neutralization Rating metric.

4.2. Suitability Objectives

In order to capture the desired but non-functional attributes of the system, several suitability objectives were derived from stakeholder input. The collection of this data, particularly for emerging or developmental systems, proved to be more difficult than the timeline of the project would allow. Therefore, a comparison of suitability data for each alternative was decided to be taken out the scope of the project. However, a detailed discussion of the objectives, implications of each alternative, and a general process for suitability requirements generation is included in Chapter V, Section 2.

4.2.1. Weighting

After developing the objectives previously discussed the project team then took the objectives back to the stakeholders and asked them to quantitatively weigh each function, suitability trait, and objective in the form of a survey. These weights were used to compare alternatives in order to properly assess the value of the various components in each alternative. The Performance Design Value Diagram in Figure 21 shows the results of the survey and the flow from functions to objectives, metrics, and weight scores.

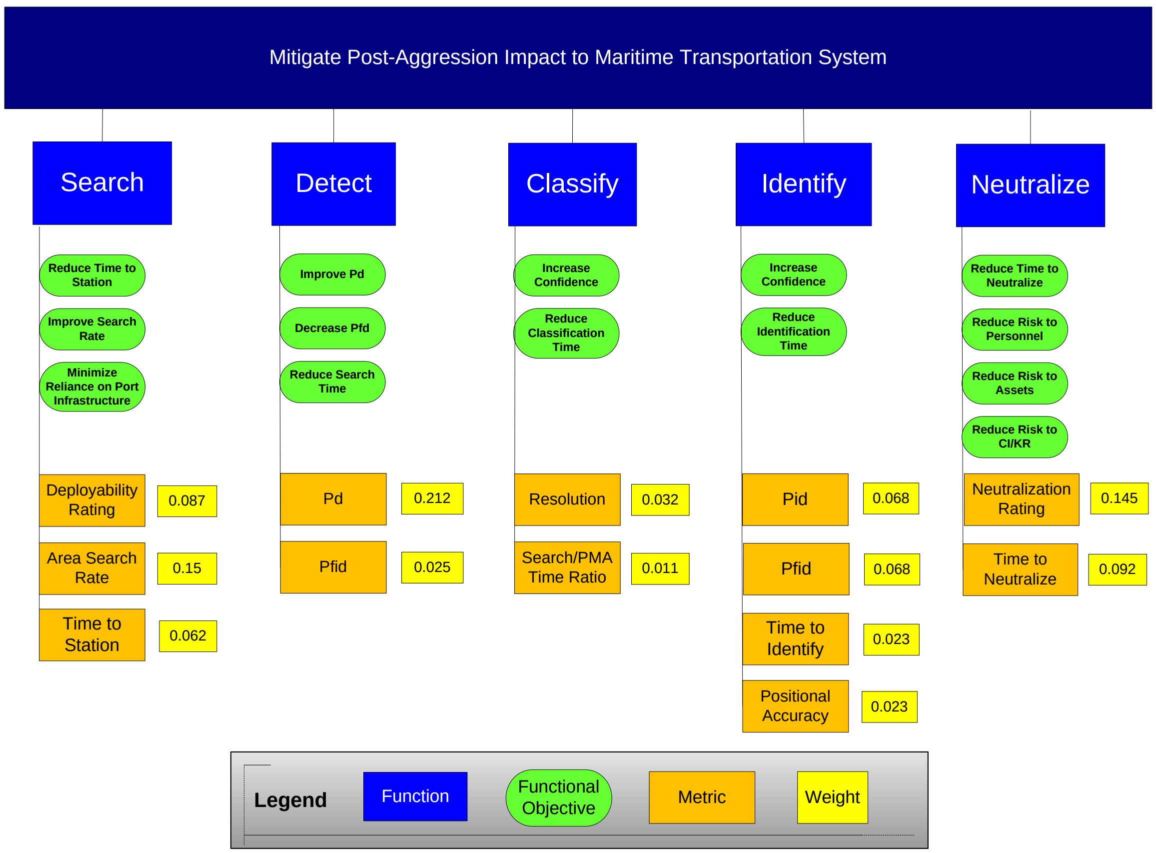

Figure 21 – Performance Design Value Diagram

4.2.2. Analysis of Stakeholder Survey

Having identified high-level functions and their sub-functions using stakeholder input, the project team then needed to determine the relative importance of each function. This weighting would be crucial for performance analysis and the determination of which systems performed best overall, when taking into consideration these weights.

The survey was also conducted to gather priority data from the stakeholders on the needs to counter MIEDs. An electronic survey was sent to the following stakeholders to gather their view on the importance of each of the functions identified in mitigating the impact of an MIED attack.

a. USCG Captains of the Port
b. Port Security Representatives
c. Associates of ORCA Maritime, Inc
d. Maritime Union Members
e. Mine Warfare Association Members
f. Lloyd's of London Joint War Committee
g. US Northern Command Staff
h. Law Enforcement Personnel
i. Representative from PEO LMW
j. Navy Mine and ASW Command Civilian and Military Staff
k. Coast Guard Head Quarters Staff
l. Engineers from Naval Surface Warfare Center

4.2.2.1 Stakeholder Survey

The survey questionnaire consisted of two sections. The first section sought the stakeholder view on the relative importance of the main functions to counter MIED threat (i.e. search, detect, identify, classify and neutralize). The second section aimed at determining the relative importance of the objectives within the high level functions. Figure 22 is a sample question from the electronic survey.

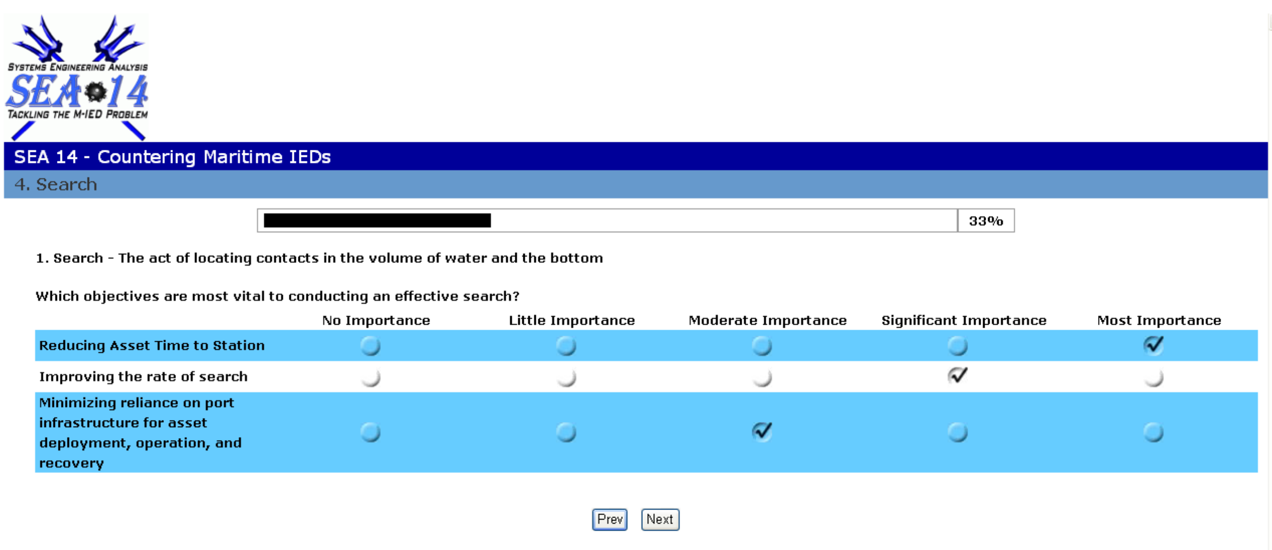

Figure 22 – Sample Electronic Survey Question

4.2.2.2 Analytic Hierarchy Process (AHP)

From the survey data, the team utilized the Analytic Hierarchy Process (AHP) tool to evaluate the relative importance of the various objectives and functions. The AHP carried out a pairwise comparison of the various objectives and ranked the relative importance of each function according to the stakeholders input.

From the feedback obtained from the survey, it was noted that among the top level functions, stakeholders viewed Search, Detect and Neutralize as most important. Table 4 illustrates the pairwise comparison of these main functions and their relative weights.

Main Functions	Criteria	Search	Detect	Classify	Identify	Neutralize	
Criteria		**1**	**2**	**3**	**4**	**5**	Weights
Search	**1**	1	1	5	3	1	**28.05%**
Detect	**2**	1	1	5	3	1	**28.05%**
Classify	**3**	1/5	1/5	1	1/3	1/5	**5.09%**
Identify	**4**	1/3	1/3	3	1	1/3	**10.75%**
Neutralize	**5**	1	1	5	3	1	**28.05%**

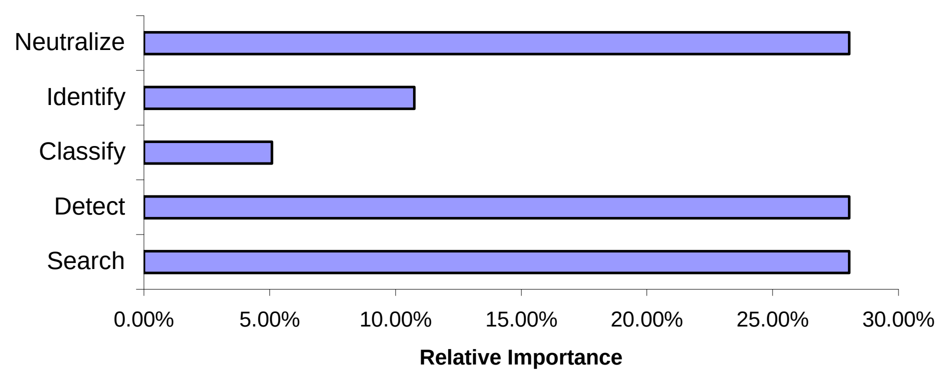

Table 4 – Pairwise Comparison of High Level Functions

The same AHP process was carried out to determine the relative weight of each objective within a given function. The results of this AHP are summarized in Table 5.

Function Weighting	Function	Objectives	Objective Weighting
28.05%	**Search**	Reduce time to station	26.05%
		Improve Area search rate	**63.33%**
		Minimize reliance on port infrastructure	10.62%
28.05%	**Detect**	Improve probability of detection	**63.30%**
		Decrease false detection rate	10.62%
		Reduce time required to complete detection	26.05%
5.09%	**Classify**	Increase confidence in object classification	**75.00%**
		Reduce time to classify an object	25.00%
10.75%	**Identify**	Reduce time to identify an object	25.00%
		Increase confidence of an object identification	**75.00%**
28.05%	**Neutralize**	Reduce time to neutralize	**38.89%**
		Reduce risk to personnel	15.35%
		Reduce risk to assets	6.87%
		Reduce risk to CI/KR	**38.89%**

Table 5 – Relative Objective Weights

With the relative weights for each sub-functions criteria computed, the stakeholder survey sub-function criteria was mapped to the performance metric as listed in the functional hierarchy to get the weights for every performance criteria. Table 6 shows the mapping of the stakeholder survey to the performance metric and the resultant weights of each performance criteria.

			Search			Detect		Classify		Identify				Neutralize	
Survey feedback		**Weights**	Area search rate	Time to station	Deployability rating	Probability of Detection	Probability of False Detection	Resolution	Search time / PMA time ratio	Positional accuracy	Probability of Identification	Probability of false identification	Identification time per contact	Time required to neutralize	Neutralization rating
Search	Reducing Asset Time to Station	0.0731		1	1										
	Improving the rate of search	0.1777	1												
	Minimizing reliance on port infrastructure for asset deployment, operation, and recovery	0.0298			1										
Detect	Improve probability of detection	0.1777				1									
	Decrease false alarm rate	0.0298					1								
	Reduce the time required to complete detections	0.0731				1									
Classify	Increase confidence in object classification	0.0382						1							
	Reduce the time it takes to classify an object	0.0127							1						
Identify	Reduce the time it takes to identify an object	0.0269								1			1		
	Increase the confidence of an objects identification	0.0807									1	1			
Neutralize	Reduce time to neutralize	0.1091												1	
	Reduce risk to personnel	0.043													1
	Reduce the risk to assets	0.0193													1
	Reduce the risk to critical infrastructure/key resources	0.1091													1
	Sub-total		0.18	0.07	0.10	0.25	0.03	0.04	0.01	0.03	0.08	0.08	0.03	0.11	0.17
	Normalized Values		**0.15**	**0.06**	**0.08**	**0.21**	**0.03**	**0.03**	**0.01**	**0.02**	**0.07**	**0.07**	**0.02**	**0.09**	**0.15**

Table 6 – Mapping of Stakeholder Survey and Performance Metric

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III. SYSTEM DESIGN

1 SYSTEM DESIGN PROCESS

1.1 Initial Methodology

Having established functions and objectives, the project team then went about the task of building and synthesizing physical architectures, the actual formulation of system alternatives based on physical components. All alternatives would simultaneously address the objectives previously discussed and be uniquely different so that decision analysis could properly determine the strengths and weakness inherent in both and attempt to make the assertion of which system alternative would be best to accomplish overall mission goals.

First, the project team established a baseline system that would model current counter-MIED capabilities. This baseline would serve as a basis for comparison to the other developed alternatives and provide the systems for inclusion in the wargame portion of the modeling and simulation plan. Detailed explanations of the baseline and system alternatives will be discussed later in this section.

In order to create distinct alternatives, the project team brainstormed possible themes that would be conducive for such distinction. A sample of the themes discussed by the project team is listed in Table 7.

Theme	Variants	Theme	Variants
Space	Air	**Manning**	High Manning
	Surface		Med Manning
	Subsurface		Low Manning
Employment	Local	**Timeline**	Long Term
	Regional		Mid Term
	National		Near Term
Technology	High Tech	**End User**	DoD
	Med Tech		DHS
	Low Tech		Civil-Industry

Table 7 – Initial Alternative Themes

After debating the advantages and disadvantages of each, the theme of *Space* was chosen to categorize alternatives. However, using this theme, it was determined that the function of Neutralize required a different set of physical components than the other functions. Therefore, the project team split the system into two subsystems, A and B. Subsystem A would entail the physical components necessary to Search, Detect, Classify, Identify and Assess Impact of an MIED, while Subsystem B would include the components necessary for its Neutralization. The project team then sub-divided into two groups, A and B, and began developing alternatives. Each group would develop four alternatives; one alternative that would encompass mostly airborne components, one that operated primarily from the water surface, on primarily based on subsurface components, and a hybrid that was unbound by space limitations and incorporated assets from all space areas. The understanding was that each alternative would not answer the question of "which operating space is best to mitigate MIEDs". Instead, the analysis would utilize the separation to determine the advantages and limitations of each alternative and combine them into one solution. This final solution, deemed as "hybrid", is unconstrained by space limitations and seeks to incorporate the best features of each space-based solution, and overcome any drawbacks.

Alternatives for Subsystems A and B are shown in Figures 23 and 24.

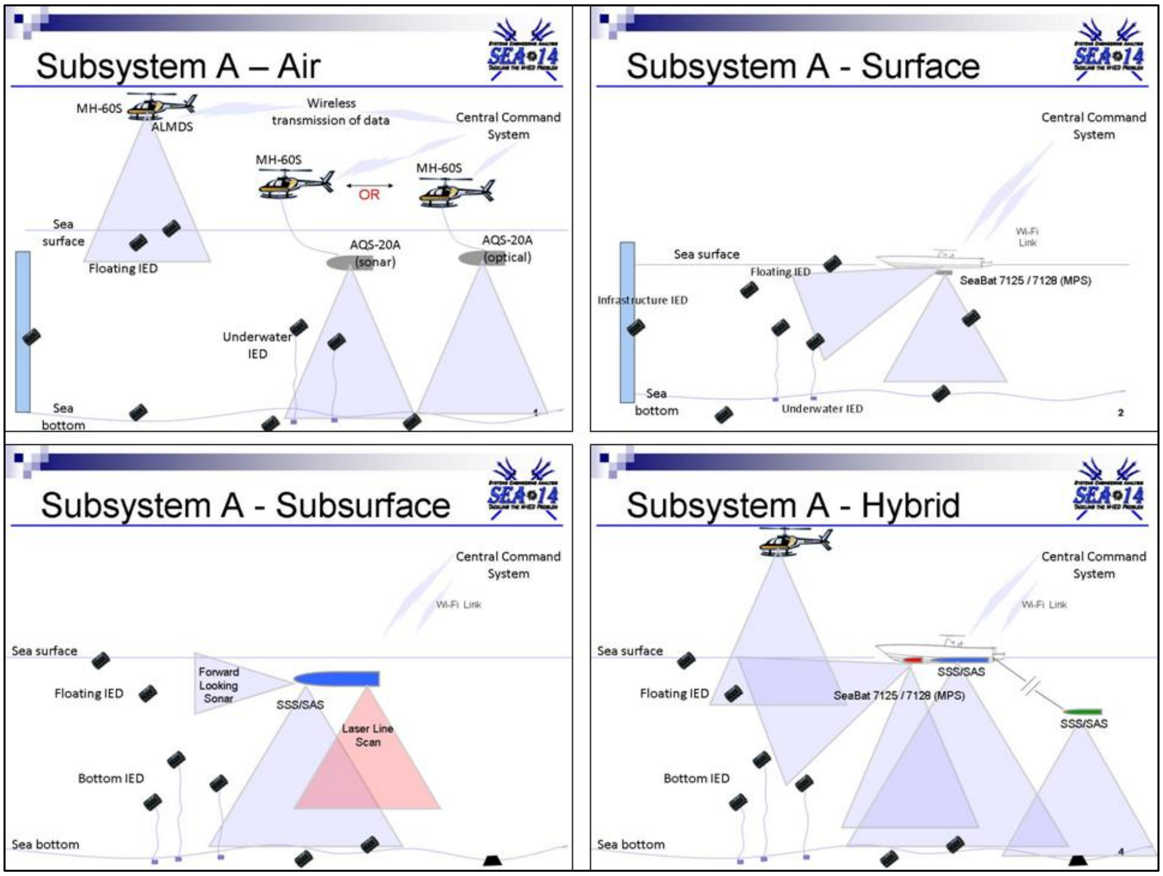

Figure 23 – Initial System of Systems Alternatives for System A

Subsystem A – Search, Detect, Classify, Identify, Assess Impact

1 – Air: Uses ALMDS and AQS-20 equipped helicopters

2 – Surface: Uses stabilized sonar and USV technologies

3 – Subsurface: Uses an integrated Synthetic Aperture Sonar and laser linescan onboard an AUV

4 – Hybrid: Uses ALMDS and a stabilized sidescan sonar on a UUV towing a secondary sonar suite or laser line scan

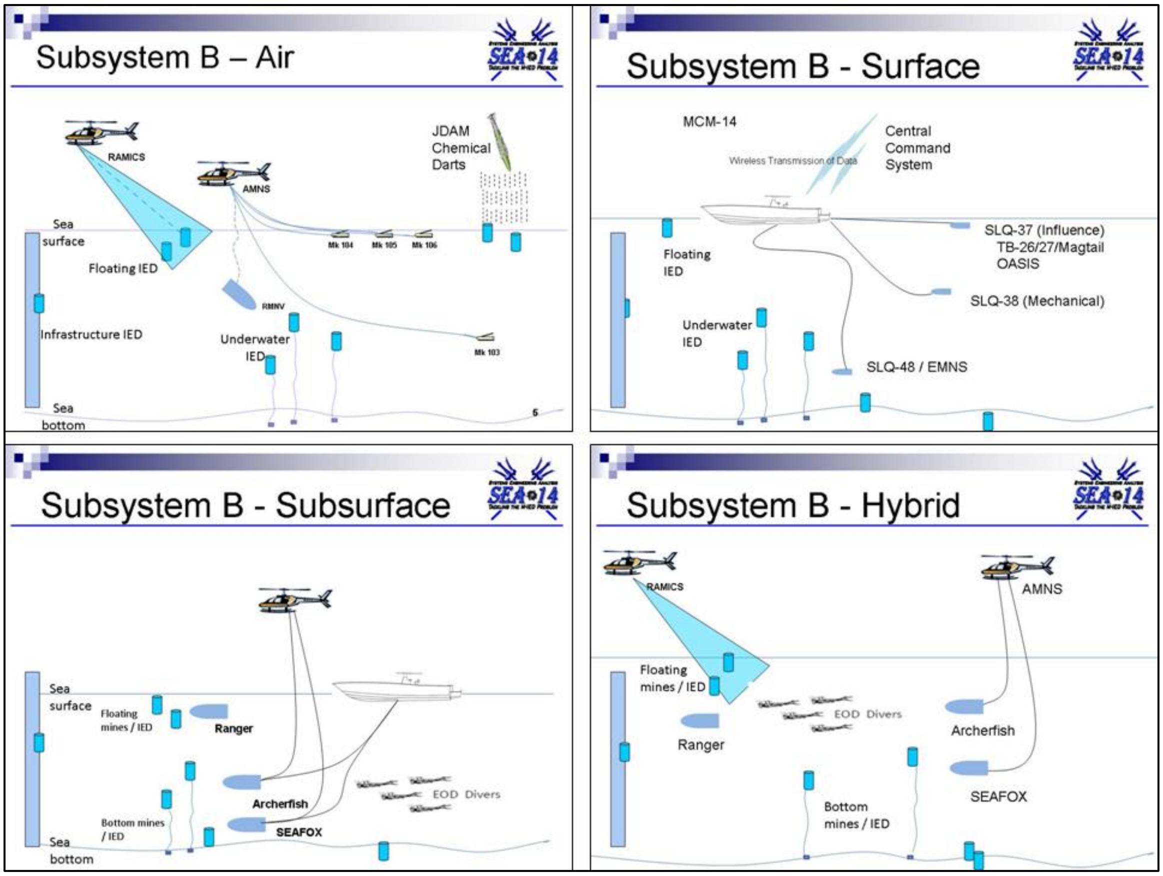

Figure 24 – Initial System of Systems Alternatives for System B

Subsystem B – Neutralize *(refer to page xviii for acronym glossary)*

1 – Air: Uses RAMICS, AMNS, and an assault breaching chemical dart-containing JDAM

2 – Surface: Uses conventional surface MCM ship capability

3 – Subsurface: Uses expendable submersibles operated from air or surface craft

4 – Hybrid: Uses RAMICS, AMNS, and other expendable submersibles

To compare each alternative to the established baseline capability, the subsystem alternatives would be paired together into systems of systems that accomplished the full spectrum of functions and objectives. A rendition of such pairings is shown in Figure 25.

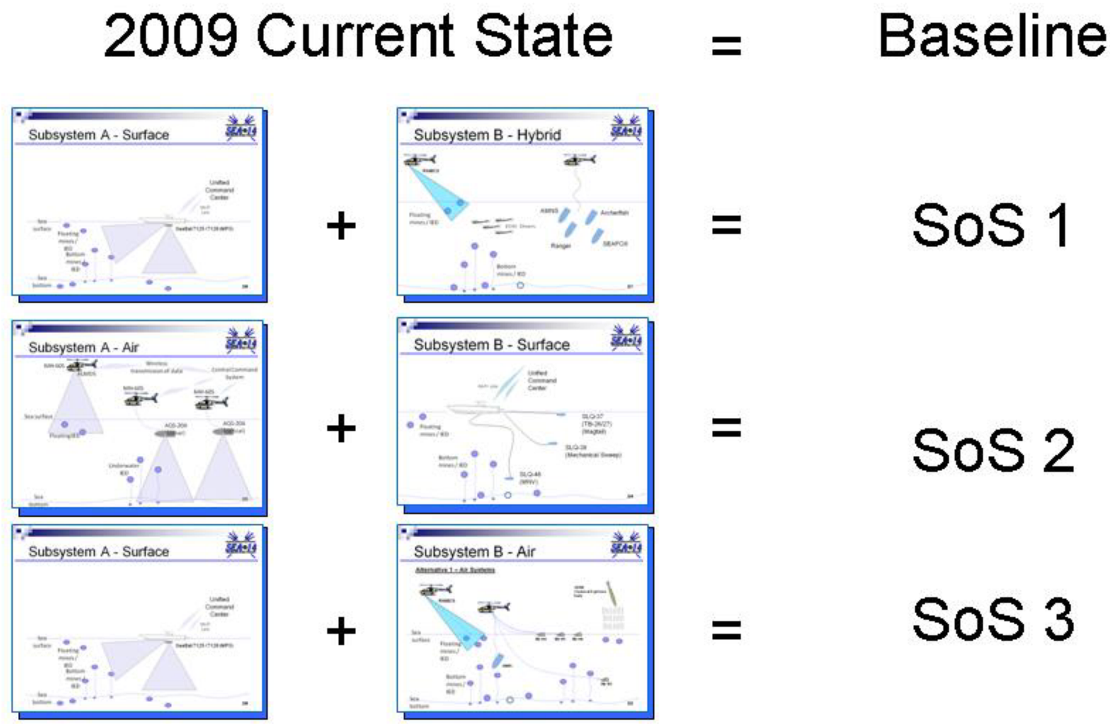

Figure 25 – Possible Systems of Systems Combinations

After reviewing the developed alternatives with mine warfare and systems engineering advisors and after briefing the alternatives at an in-process review, it was determined that this methodology was flawed in that it did not incorporate the near term technologies that are being developed and tested for this problem. Therefore, the project team reassessed the process to develop a different alternative scheme. The new process would utilize the previously established baseline and add capabilities that were on the horizon in a layered scheme. Alternative 1 and 2 add the capabilities that will be present in the 2009-2015 timeframe. Alternatives 3 and 4 do not incorporate the baseline, but rather represent a "blue sky" view of possible alternatives not bounded by baseline concepts using emerging technologies that would need to be developed before these systems can become a reality.

1.2. Alternative Generation

During discussions on how to implement the new systems design methodology, it was discovered that the subsystem approach could not adequately consider systems that could complete functions of Subsystem A and B. Essentially, a system that could Neutralize as well as perform Search, Detect, Classification, and Identification functions may not adequately be considered in the performance of both roles. Therefore, the project team decided to forego the subsystem method and focus on the overall Adaptive Force Package. For purposes of this project, we adapted the working definition of US Atlantic Command's concept of an adaptive joint force package. In response to the need of a highly skilled force, rapidly deliverable, and fully capable of operating effectively on arrival, the Adaptive Force Package is a capabilities centered grouping of forces and control elements trained and organized to meet the specific crisis requirements of the Incident Commander.

Table 8 shows a Morphological Box entailing the components and which functions they accomplish.

Alt	Type	Components	Quantity	Search/Detect/Classify	Identify	Neutralize
BL	Material (Baseline)	REMUS	4	Side Scan Sonar		
				Legacy PMA		
		EOD Divers	6		EOD Diver	Raise, Tow, Beach, Render Safe
						Underwater Detonation
1	Material (Added to Baseline)	WLD-1	1			
		AQS-20	1	Side Scan Sonar	Electro-optical	Baseline Neutralization
				Legacy PMA		
		Support Module	1			
		MPCE Module	1			
2	Material (Added to Baseline)	ALMDS	1	Laser Scan		
		RAMICS	1	Advance PMA		Remote Deflagration/Detonation
		AQS-20	1	Side Scan/Volume Search Sonar/ EO-ID	Electro-optical	
		AMNS	1		Electro-optical	Remote Detonation
		MH-60	2			
3	Blue Sky (Baseline not Included)	Talisman M	1	Synthetic Aperature Sonar	Laser Line Scan	
		Archerfish	2			Remote Detonation
		SeaArcher	2			Chemical Neutralization
4	Blue Sky (Baseline not Included)	Improved REMUS	4	Synthetic Aperature Sonar		
		Talisman M	1	Volume Search		
		Archerfish	2		Electro-optical	Remote Detonation
		SeaArcher	2			Chemical Neutralization
		Benthos Modem Network	1	In-situ PMA	Autonomous Asset Direction	Autonomous Asset Direction

Table 8 - Morphological Box

1.3. Adaptive Force Packages

A detailed account of each Adaptive Force Package is found in the following sections. Each description includes an explanation of the components, a discussion on employment considerations, and a broad-brush assessment of capabilities and limitations viewed from the paradigm of function completion, performance against the various MIED types, and any objectives that are inadequately met.

2 ALTERNATIVE 0 (SYSTEM BASELINE)

Alternative 0 (Alt 0) is the baseline Adaptive Force Package. It is the United States' most likely response today to a terrorist attack on the MTS using MIEDs in a HLS/HLD scenario. The technology, manning, equipment, and procedures are being tested and evaluated to determine the best alternative to conduct operations against MIEDs in a US port.

2.1 Components:

Alt 0 includes system components strictly from US Navy EOD and the Naval Oceanographic Mine Warfare Center (NOMWC).

EOD assets considered in Alt 0 are:

a. a five man EOD team (and equipment)

NOMWC assets considered in Alt 0 are:

a. a six man REMUS team

b. 12 man Post Mission Analysis (PMA) team

c. four REMUS vehicles

MCM-1 class SMCM ships are not included due to the unlikely chance they will be a plausible solution. Currently, there are fourteen Avenger Class ships in the US Fleet. Of those fourteen, six to eight are forward deployed leaving only six to eight INCONUS, often in limited states of readiness. Due to the limited stationing speed of these assets, unless the port that requires MCM operations is in proximity to the ships position, stationing time probably precludes SMCM from being a viable asset.

Similarly, no AMCM assets are used in this alternative due to the stationing times of AMCM assets to get to the area of operations and their probable lack of availability due to dedicated missions overseas. Additionally, the time it takes to prep an aircraft once it arrives on station and becomes ready for operations is significant due to the maintenance required after it has self-deployed, the fitting of equipment, and logistics constraints.

Additionally, both traditional AMCM and SMCM may have navigation and other problems conducting towing operations in many US ports due to narrow channels, shallow depths, and bridges or other infrastructure. Influence sweeping, which makes these assets very effective and timely in open-ocean mine sweeping are not well suited for some port environments. The remaining capabilities left in these systems offer no advantages over already included systems.

2.2 Employment Considerations

Alt 0 has the least footprint required of all the other alternatives, and the fastest deployability. Commercial and military air can be used to move the assets in Alt 0 (people and equipment) quickly into the area of operations from anywhere in the US.

Once on station the footprint of EOD teams are not intrusive. They advertise 72 hour deployability and are self-sufficient, needing only communications gear to allow them to communicate with local agencies in the area.

Figure 26 – Typical EOD Dive Teams

Figure 27 – Technicians Deploy a REMUS 100

The REMUS (100)s are two-man portable, requiring no crane or other pier services. The support and PMA teams come with their own computers and equipment, and only require communications gear to allow them to communicate with local agencies in the area.

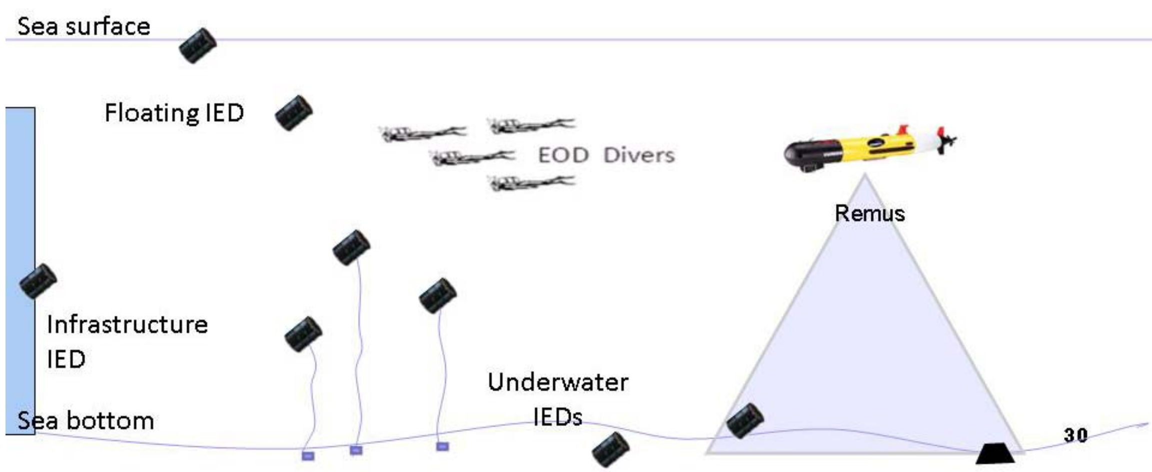

Figure 28 – Alternative 0 Concept Image

2.3 Capabilities and Limitations

The NOMWC REMUS platoons are the main sensors that conduct the Search function, but with sidescan sonar it is limited to bottom search and cannot detect objects floating in the water column. After the REMUS completes the search in its designated area, the data from the mission is extracted and analyzed during the PMA, at which time the Detection and Classification functions are performed.

The REMUS vehicles have the capability to rapidly search sea beds in the very shallow and shallow water regions (10-40 and 40-200+ feet). The vehicles have a maximum eight-hour mission life and require either change of batteries or a six-hour recharge before resuming Search operations. These vehicles can operate at night but are limited by currents above two knots, as the vehicles operate at 3-5 knots.

After Classification as MIED-like, the EOD personnel will reacquire the target to Identify and Neutralize threats that require further prosecution. While EOD has the capability to conduct localized volume searches, they cannot adequately cover large volumes of water and their presence in a potential mine-field increases the risk of the operation.

Limited methods of disposal are available with current technologies and practices. A target designated for prosecution is either detonated in place or must be disarmed manually, a very dangerous endeavor, and removed from the area. EOD divers prefer to operate in water depths less than 150 feet[23], well within typical port environments, but are limited to operations in currents less than one knot.

3 ALTERNATIVE 1 – LCS MISSION MODULE CONCEPT

Alternative 1 incorporates the baseline systems of EOD and REMUS and adds to it the LCS MIW Mission Module components of the WLD-1 Remote Mine Hunting Systems. The WLD-1 adds an increased on-station time, speed, and a forward looking over-the-horizon video and radar capability. WLD-1 also is the host platform for the AQS-20A which is designed to detect and identify moored and bottom IEDs. This system increases situational awareness for the mission commander and adds layered defense and redundancy for the baseline system.

3.1 Components:

The AN/WLD-1 Remote Mine Hunting System consists of 5 subsystems

a. Remote Multi Mission Vehicle (RMMV): Fueled for long endurance (200 gallon capacity), the RMMV's 370 hp Cummins diesel marine engine and high-efficiency propulsor can drive the 7 meter-long vehicle at speeds exceeding 16 knots. A streamlined snorkel/mast is the vehicle's only visible feature above the waterline. The snorkel draws air into the engine, and provides a platform for RF antennas and an obstacle avoidance video camera. The nose module features a forward-looking sonar for detection and avoidance of underwater objects.

Recent configuration changes to the *USS Arleigh Burke* (DDG 51) class guided-missile destroyers, DDG 91 through DDG 96 to handle the AN/WLD-1A remotely-operated mine countermeasures system, marks the return to a practice instituted

[23] Capt. Matthew Lesnowicz, USMC, interviewed by LT Tim Smith, USNR. Monterey, CA, June 13 2008.

at the end of the 1930s. The need for a rapid-response, reliable and autonomous platform designed primarily for Mine Warfare has not seen full production since the end of World War I. The Remote Multi-Mission Vehicle (RMMV) is entering the Navy inventory as part of the AN/WLD-1 Remote Minehunting System (RMS). RMS is currently installed onboard USS *Bainbridge* (DDG 96), and systems will transition to Littoral Combat Ship (LCS) as part of the Mine Warfare and ASW Mission Packages. The RMMV provides all-weather, low observable operations, high endurance, interchangeable mission systems with electronics and real-time data transfer capability beyond line-of-sight. Designed for deployment from surface combatants, as well as shore-based or ships of opportunity, the RMMV can provide a significant off-board capability for Combatant Commanders.

On August 28, 2004, the *USS Momsen* (DDG 92) became the first US Navy's surface ship to be equipped with organic mine reconnaissance capability using an unmanned, remotely operated vehicle. Shipboard testing was scheduled to begin in early September 2004[24]. The RMMV was also tested from August of 2007 through February 2008 onboard the *USS Bainbridge* (DDG 96) another U.S. guided missile destroyer, while operating in the Mediterranean Sea. In this deployment, as part of a NATO Naval Task Force exercise, the RMMV had many successes including successfully conducting mine reconnaissance operations off the coast of Spain.

b. Launch and Recovery System:The RMMV is launched and recovered as safely and simply as a ship's boat. A single capture/release device provides a 15-ft. reach from the host ship. Figure 29 shows an RMMV launch from an *Arleigh Burke* Class Flight IIA destroyer. This integrated launch and recovery system assists the host ship in rapidly and efficiently securing the RMMV. The ability to use existing infrastructure on the *USS Arleigh Burke* (DDG 51) destroyer to recover the RMMV is essential to the mission flexibility.

c. Data Link System (DLS): The DLS integrates communication and voyage information from the RMMV to the host platform. This enables the RMS to operate not only within the line of sight (LOS) of the host platform but also over the

[24] http://www.deagel.com/Underwater-Vehicles/ANWLD-1_a001521001.aspx

horizon (OTH). Real-time command and control of the RMMV—including operational status— are relayed to the

Figure 29 – Launching the RMMV

host ship via one of two encrypted data communications modes. For close-in operations, a high data rate RF link will send back continuous Variable Depth Sonar (VDS): sonar data and camera video. When over the horizon, a lower RF bandwidth will send snippets of sonar data and video imagery. Developing systems will incorporate satellite communications links.

d. Variable Depth Sonar (VDS): During its mine reconnaissance mission, the RMMV deploys and tows a version of the AN/AQS-20 mine hunting variable depth sensor. The VDS is designed to detect, classify, localize and identify bottom and moored mines. The AN/AQS-20 carries port and starboard Side-Looking Sonars, a Forward-Look Sonar, a Gap-Filler Sonar, a Volume-Search Sonar or an Electro-Optical Laser. Despite its important military applications, VDS has multiple civilian applications such as search and salvage missions. This technology can also be useful for harbor surveys and other maritime reconnaissance operations.

3.2 Employment Considerations

The WLD-1 RMMV is just one system included in U.S. Navy Unmanned Surface Vessel (USV) Master Plan, the first edition of which was published in July of 2007. The Master Plan incorporates many developing USVs for use in not only force protection applications but also as host platforms for mine hunting and sweeping. As mentioned previously, employment of the RMV is designed primarily from surface combatants, and the Littoral Combat Ship(LCS). However, operational testing as recent as August of 2008, have shown that a RMMV can be used as a stand alone system; provided that the shore installation is equipped with at least a 10 ton crane.

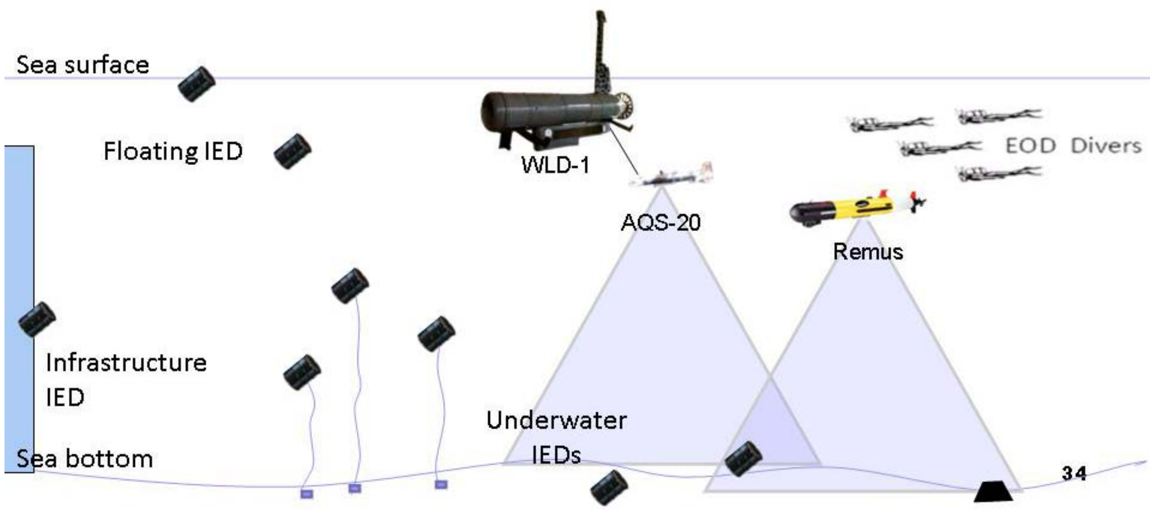

Figure 30 – Alternative 1 Concept Image

3.3 Capabilities and Limitations

The RMMV is designed to enhance the mine countermeasures capabilities of the DDG-51 class and the Littoral Combat Ship. The OTH data collection, long on station time, and diversity of missions enable this vehicle to provide the multi-mission capabilities that is desired by the U.S. military. The system, with organic handling, control and logistic support, is designed to be air transportable to forces anywhere in the world. The RMS will provide a rapidly deployable mine countermeasures system to surface combatant forces in the absence of deployable mine countermeasures forces.

a. Deployability: The RMMV can only be deployed by a host ship or a heavy lift crane. At a weight of 14,000 lbs, WLD-1 is unable to be deployed by a standard small boat lift. As part of RMMVs total systems of systems, a command and control module is required for mission planning and post mission analysis. The Tampa

Bay limited objective experiment in August of 2008 showcased the ability of a system designed for the LCS to be operated autonomously. Due to cost over-runs and the limited amount of LCS platforms available for the US Fleet, the modularity of the MIW Mission package is essential for success of WLD-1.

b. Navigation: Navigating in and around a potential mine or IED field is a challenge in initial positioning with regard to the terrain and avoid collisions with other vessels. A 2006 Navy Small Business Innovation Research (SBIR) solicitation proposed using navigation radar for collision avoidance — UUVs would passively listen for surface ships' radars, including Automated Identification System beacons mandated for larger, oceangoing vessels.

c. Propulsion: RMS is propelled by a 370 hp Cumming Diesel engine fueled by a 200 gallon tank. The vehicle can maneuver at speeds up to 16 knots with a loiter capability enabling for longer on station time. In sea trials RMMV has sustained over 15 hours of independent operations, however, there is currently no capability to refuel the vehicle en-mission. Advances in fuel cell technologies will increase the on station time which will enable RMMV advanced capabilities with clandestine operations.

4 ALTERNATIVE 2 – IMPROVED AMCM CONCEPT

This alternative utilizes the baseline system and includes several air-borne assets. All assets are designed to be employed from the MH-60S helicopter. This group of assets was chosen because both the ALMDS and RAMICS, and the AQS-20 and AMNS, are designed to work together, from the air, to provide rapid response to a mine threat. We felt this group of assets together would be well suited to defeating the threat of MIEDs in domestic ports.

4.1 Components

The additional components in this alternative include the Airborne Laser Mine Detection System (ALMDS), the RApid MIne Clearance System (RAMICS), the AQS-20 sonar, and the Airborne Mine Neutralization System; and the aforementioned MH-60 helicopter platform from which the components will be employed.

a. Airborne Laser Mine Detection System (ALMDS): The ALMDS utilizes a Laser Imaging Detection And Ranging (LIDAR) sensor in the blue-green field to visually detect mines and mine-like objects in the near-surface water volume. The system essentially mounts to the side of the helicopter and scans the water as the helicopter moves through an area of interest. This provides for a very fast search time.

b. Rapid Airborne Mine Clearance System (RAMICS): The RAMICS is designed to mount onto the same airframe as the ALMDS and utilizes data inputs from the ALMDS. The system then uses its own LIDAR to reacquire mines in the water column. After mines have been reacquired, the system neutralizes the mine with a 30mm MK 44 Bushmaster II gun. A critical component is the MK 258 Mod 1 armor-piercing, fin-stabilized round. This round is stable in air and upon entering the water, supercavitates to reduce drag and increase accuracy until the round strikes and destroys the mine or MIED in the near surface water volume. This method is not effective against bottom mines or MIEDs. These systems are depicted in Figure 31.

c. AQS-20: This is the same device mentioned in Alternative One. However, in this Alternative the AQS-20 is towed from the MH-60 helicopter platform, and shares a console with the AMNS.

Figure 31 – Artist Renditions of ALMDS and RAMICS

d. Airborne Mine Neutralization System (AMNS): The AMNS (see Figure 32) provides another method of mine neutralization from the MH-60S. After a mine has been located, AMNS employs the Navy's Common Neutralizer Vehicle to detonate the mine. This method is effective against near surface, moored, or bottom mines or MIEDs. The entire system is comprised of the Carriage, Stream, Tow and Recovery System (CSTRS); a Launch Handling System (LHS); the Common Neutralizer Vehicle; and the control console. After the MH-60S is on station above the mine, the LHS is deployed. The LHS houses four of the neutralizer vehicles that "swim" away from the LHS and reacquire the mine utilizing their onboard sonar. The neutralizers also have onboard cameras and feed imagery of the mine, or mine-like object, back to the console operator via fiber-optic cable. The operator can then decide to neutralize the mine by detonating the armor-piercing warhead on the neutralizer. AMNS is included in this alternative because it is effective against deep mines that are potentially out of the range of the RAMICS. There have been delays in the CSTRS system that will be covered in Section V.

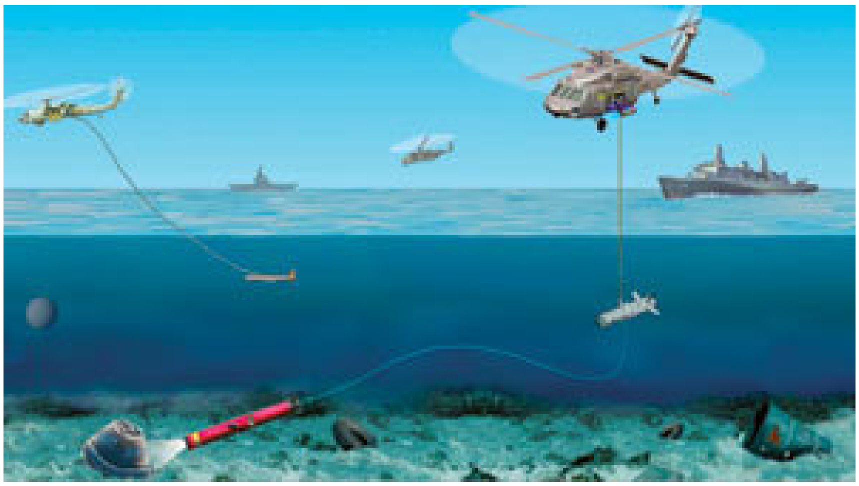

Figure 32 – Artist Rendition of AMNS

4.2 Employment Considerations

Because this alternative includes baseline systems in addition to those described above, the employment considerations of the baseline alternative apply here as well. Additionally, this alternative requires two MH-60S helicopters, one for the ALMDS and RAMICS and another for the AMNS.

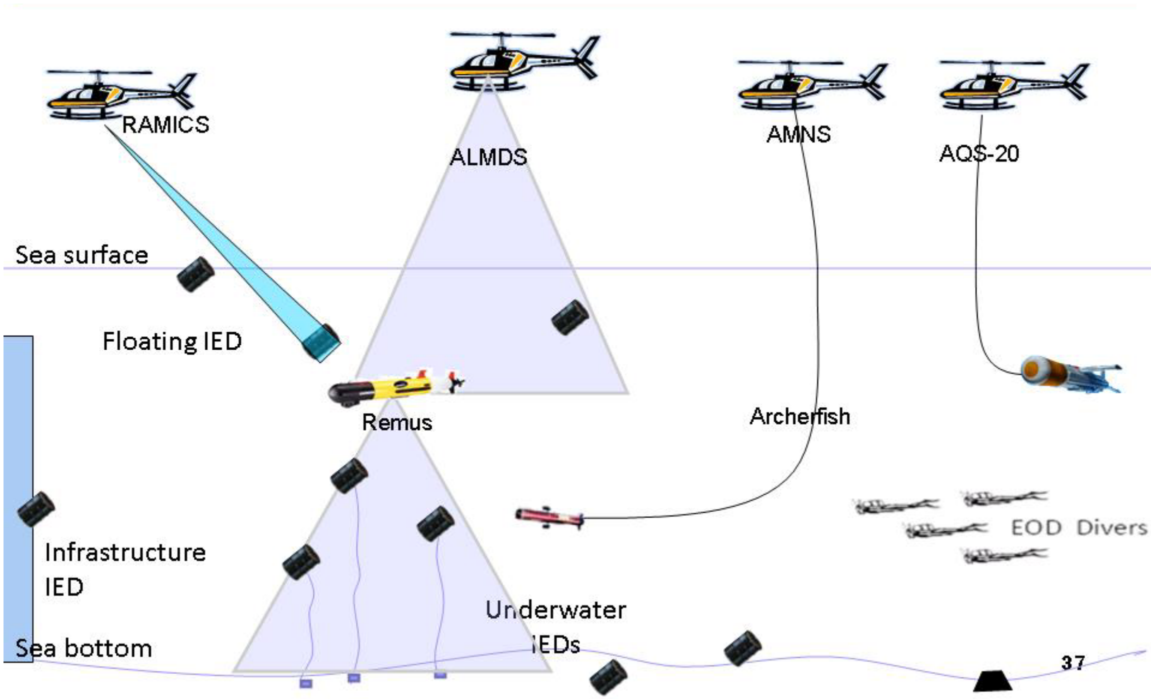

Figure 33 – Alternative 2 Concept Image

4.3 Capabilities and Limitations

This alternative provides two very attractive capabilities – it keeps personnel at a safe standoff distance from the threat, and it is extremely fast. Because the systems are employed from a helicopter, there is no "man in the minefield," which is an obvious benefit. In terms of speed, this alternative may have an advantage in two aspects. If the threatened port is within helicopter range of the assets, they would arrive on-station faster than any other non-organic alternatives. Once on-station, the ALMDS can search, detect, and classify near-surface threats faster than other alternatives, as it is airborne. The RAMICS or AMNS systems can also be employed for identification and neutralization much faster than other alternatives.

This alternative has its limitations as well. The systems and the helicopters that they operate from are expensive; prohibitively so for local and possibly regional use. A helicopter also offers limited time on station before refueling and/or maintenance is required. Another major limitation for the ALMDS and RAMICS systems are the depth of water in which they are effective.

5 ALTERNATIVE 3 - SILVER BULLET CONCEPT 2015+

Alternatives one and two incorporate existing or emerging technologies being developed for traditional navy mine countermeasures. Alternatives three and four attempt to step out of that paradigm and to fill gaps left in those systems using technologies and equipment not currently under development. The issues created by using non-conventional systems would tend to make the targeted service date beyond the timeframe scope of 2015, but bring advances to the MIED problem that would make early investment in the technology, integration, and R&D worth the cost. Realization of these systems in the given timeframe can only be made if investment into the composite systems begins in the near term.

Alternative three consists of a single body capable of performing all required functions. By packaging capabilities into a single body, capable of in-situ PMA, mission time is greatly reduced as the time lost to planning for and employing additional assets is mitigated, as is the time required to conduct conventional PMA. This body would need to contain: sensors for Search, Detect, and Classify: higher resolution sensors for Identification; and an organic means of Neutralization. Although there are several options, the following outlines a possible means of obtaining this all-in-one body.

5.1 Components

Although using an underwater platform brings inherent difficulties (communications, deploy and recovery, etc) and risks (platform is in the MIED danger area) the benefits of simplifying sensor equations, reducing cooling and other support equipment, and the ease of having the platform in close proximity still make it a desired option. To illustrate this alternative, the project team modeled the use of the Talisman M as representative of a similar system that could be modified to fill this role. Talisman M, depicted in Figure 34, is an advanced UUV produced by BAE Systems. This UUV is a modular, multi role vehicle capable of carrying search sensors, communication equipment, and four Archerfish single shot mine neutralizers, which are the neutralizing component of the EMNS and AMNS systems.

A nominal search sensor suite would include synthetic aperture array sonar which would provide resolutions of up to ten times higher than conventional side

Figure 34 – Talisman M

scan sonar. An additional sensor would be required for Identification purposes. This could be accomplished with a laser line scanning capability or electro-optical cameras. A laser line scan(LLS) could potentially provide a higher resolution at longer distances with higher swath width than the camera and is therefore included here.

For Neutralization, the Talisman M already comes equipped with four Archerfish mine neutralizers. To fill the gap of non-explosive neutralization, the integration of these Archerfish and a single-shot deployed chemical neutralization dart could fill that gap. This solution can be realized by incorporating darts from the Assault Breaching System (ABS) Countermine System (CMS). This program, under contract by Boeing, is developing a dart-equipped Joint Direct Attack Munitions (JDAMs) capable of delivering thousands of darts to chemically neutralize mines. Although this concept is being developed to support the rapid clearing of mine-laden areas in support of amphibious operations, the project team envisions a body capable of accurately launching a single dart that would penetrate the casing of a mine or MIED, disperse a reactive chemical agent, and chemically neutralize the explosive without detonation. The body and optics of the Archerfish could potentially be fitted with a launcher that will accurately deliver a single dart with enough kinetic energy to penetrate a mine or MIED. This "SeaArcher" variant of the Archerfish could provide non-explosive neutralization when the proximity to port infrastructure makes conventional neutralization impractical.

Figure 35 – Archerfish Single Shot Mine Neutralizer

5.2 Employment Considerations

Due to the added capability, the Talisman M is large compared to other UUVs such as the REMUS variants. Therefore, the Talisman would need pier support for launching and recovery. The launching and recovery equipment would need to provide adequate lift for its 2200 lbs and up to 1100 lbs of payload, but the advanced battery and recharging system, which allows for 24 hours of operation before recharging and an organic surface recharging generator, require few uses of pier services.

Although the chemical neutralization variant of the Archerfish would provide non-explosive neutralization in many cases, testing of this method and the effects on more improvised explosives have yet to be carried out. Therefore, EOD may still be required to safely remove explosives from a CIKR dense area.

5.3 Capabilities and Limitations

This system is capable of performing all functional requirements in a single body. Integration of the SAS adds the capability of detecting buried objects, a useful feature due to the rapidly changing environments found in port conditions. The

SAS and LLS integration also allow for redundant searching should water conditions not be optimal for either sensor. Additionally, the use of the optics on the Archerfish allow for the search of piers, quay walls, and other infrastructure and its maneuverability makes

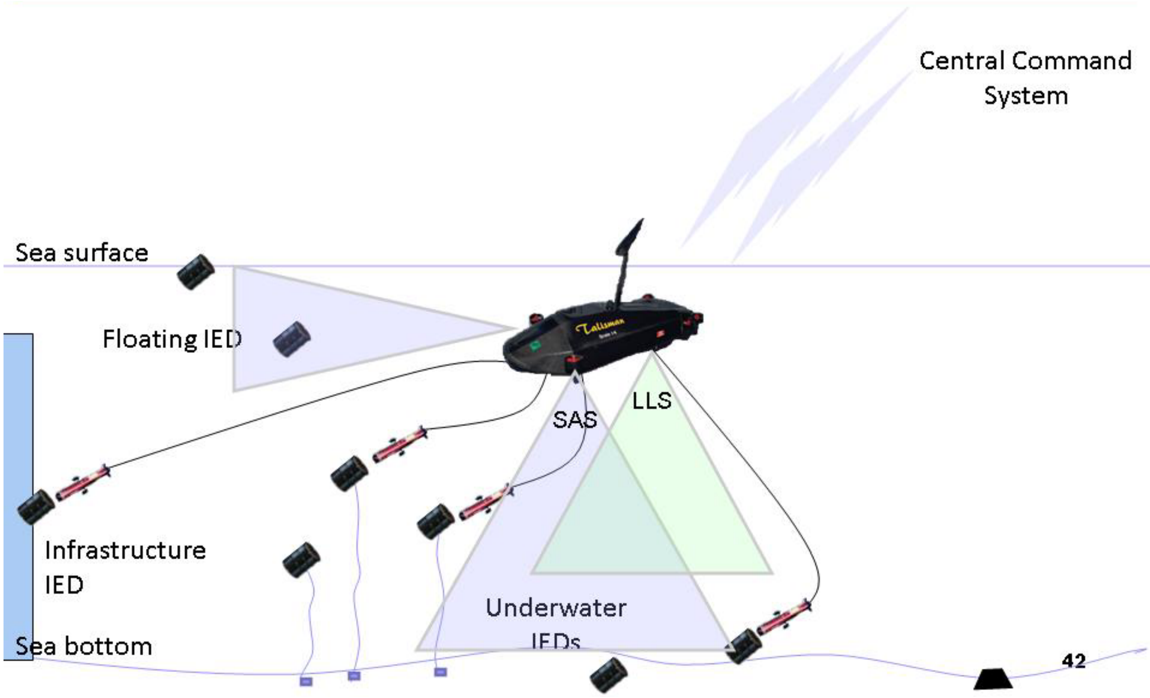

Figure 36 – Alternative 3 Concept Image

it well suited for operating close to such infrastructure, a feature not found elsewhere, particularly where a helicopter is the launch and control platform.

An all inclusive system does, however, inherit an increased risk of total system failure in the event of single component loss. In other systems, the loss of a single component only degrades overall system performance, but the loss of this system could result in overall mission failure. Additionally, one body with a slow search speed (5kts) could increase search time significantly.

6 ALTERNATIVE 4 – VEHICLE SENTRY CONCEPT 2015+

Alternative four adds advanced processing and underwater communications in order to connect UUV and static network modems into a semi-autonomous network of assets capable of conducting all high-level functions while minimizing human interface. This type of networking is being developed for unmanned vehicles, particularly UAV's, under the name of Unmanned Vehicle Sentry and has been championed in the NPS-led program called Seaweb.

6.1 Components

Alternative four requires UUV's equipped with sensors and auxiliary equipment used to conduct all high-level functions and communications and computer technologies allowing the passing of information to other underwater assets and shore nodes. For this alternative, we've built the network around advanced REMUS vehicles similar to the baseline, but equipped with forward looking sonar for volume search and synthetic aperture sonar for improved imaging and buried object detection.

For reacquisition and Neutralization, the project team has included the Talisman M, as already designed and marketed, equipped as in Alternative 3 with Archerfish EMNS and yet-to-be-developed SeaArcher CMNS.

In order to facilitate communications, the use of Benthos Underwater Modems (see Figure 37) is most logical choice due Benthos being the leader in underwater communications. To facilitate searching the areas modeled in the wargame discussed in Section IV, a network of approximately 14 acoustic modems would be used to pass data from the UUVs along the network to either a gateway buoy or to other UUVs. This gateway buoy would require both an acoustic modem for sending and receiving data in the network and means of wireless communications to send and receive data from a command and control station ashore. Such buoys have been used in Seaweb experiments using cellular, Iridium satellite communications, or military FreeWave.

Although the acoustic network technology is already reportedly capable of reliable data transmissions of 10-15 Kbps at ranges of 1-8 km, Professor Joe Rice at NPS reports that environmental constraints impose a more realistic performance of 140 bps at ranges of 300-3000 meters[25].

Modifications would need to be made to REMUS and Talisman M vehicles to enable them to participate in the network. Benthos has already been approved

[25] Professor Joe Rice, interviewed by Bobby Rowden, Naval Postgraduate School, November 21, 2008.

for a SPAWAR contract to develop a REMUS capable modem [26] but Talisman would need to be similarly equipped.

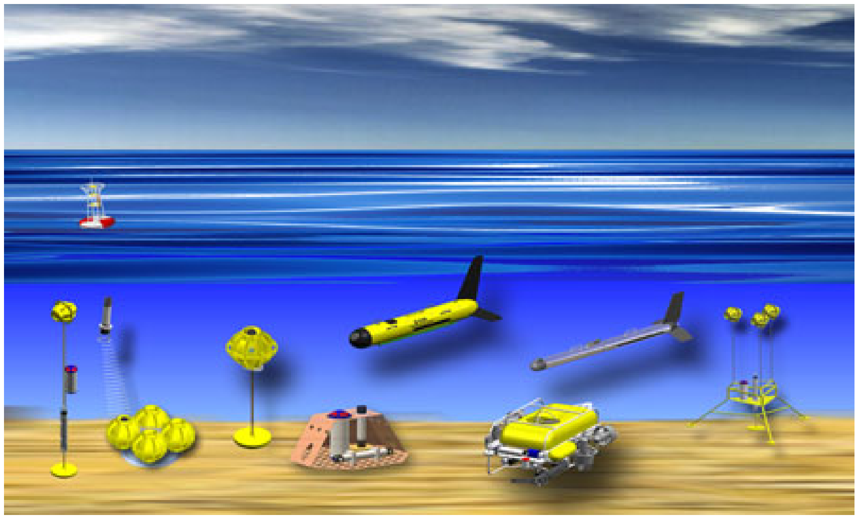

Figure 37 – Benthos Underwater Communication Equipment

6.2 Employment Considerations

Although the same considerations apply for previous alternatives for transportation, deployment, and retrieval of these components, the operational aspects are streamlined due to the autonomous nature of this system architecture.

The network is very mobile and could be on station within two days of notice, and deployed and operational within hours[27]. Although past experiments have used boats to emplace sensors, in order to avoid placing manned assets in the danger area the ideal delivery would be by helicopter. Although this has not yet been accomplished in trials, there is no reason an air deployment is ill-suited.

Once in place, all components begin Search, Detect, and Classification functions using onboard sensors and advanced CAD/CAC algorithms. Since the current bandwidth would not allow the streaming of sensor imagery, CAD/CAC would be necessary to capture important data and transmit in bursts back to human operators ashore that can make a classification determination. As with many autonomous systems, the sensors are much more mature than the algorithms used for change or anomaly

[26] Dale Green, telephone interview by author, November 24, 2008.
[27] Joe Rice, 2 "Underwater Networks", (lecture, Naval Postgraduate School, November 20, 2008).

detection, but efforts are underway to improve existing algorithms that will enable this employment scheme.

Once an object is determined to require further prosecution, the Neutralize vehicle (Talisman M) is automatically routed to the object to begin prosecution. Video or other data is streamed to the shore node where human interface makes the final determination to Neutralize, which is done using the Archerfish or SeaArcher neutralize bodies.

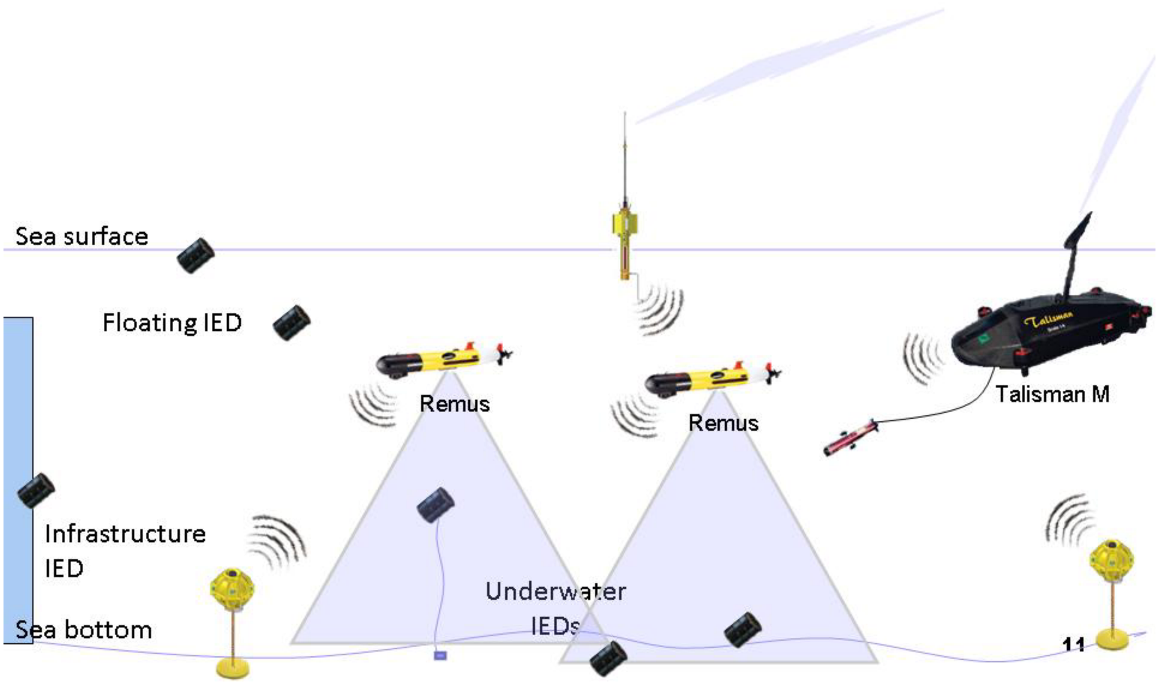

Figure 38 – Alternative 4 Concept Image

However, in addition to the search bodies, this architecture would require relays to collect and pass information. These bodies would also need to be placed in the environment in a matter conducive to data transfer. Depending on the area of the search, this could require extensive planning and placement of relay nodes.

6.3 Capabilities and Limitations

Although using mostly modified equipment already in use, the addition of the underwater networking allows a synergy that reduces the timeline of overall mine and MIED clearance operations. By allowing information to be passed from between nodes, processing, asset deployment and recovery, and decision making times are greatly reduced.

This alternative is based on two important assumptions: the development of a REMUS vehicle capable of using volume search and SAS sonars, and the development of a CAD/CAC algorithm that will enable specific imagery to be sent via the acoustic network. The use of UUVs operating within an acoustic network has had sufficient testing to prove its capability and the individual components have likewise been proven.

Before deployment, effort must be made to the battlefield in which the network will operate. The environmental factors affecting each port differently will have various effects on network performance. These factors must be understood in order to properly place nodes and optimize the network to allow proper communications paths.

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IV. MODELING AND ANALYSIS

1. WARGAME

As part of the SEDP this wargame was designed to perform the following tasks: 1) conduct an analysis of system of systems solution alternatives, 2) provide an infrastructure to validate the project problem statement, operational concept and scenario, and 3) serve as a knowledge-generating tool giving insight toward the main task and the additional complexities and issues that would encompass a Maritime Homeland Defense (MHD) MIED scenario. Using a simulation in this study offered a unique opportunity that would allow unlimited freedom to explore several options and ideas, change input parameters easily without extensive calculations and provide a venue to test virtually all the group's hypotheses prior to taking on this problem. The advantages of modeling and simulation (M&S) in a Systems Engineering project seemed to be a mutually beneficial venture, taking two very distinct processes and using them toward a common goal.

1.1 M&S Approach Development

The development of the wargame was carefully evaluated to ensure that it would be feasible and would meet its intended objectives. The objectives of the game listed in the introduction were considered on the basis of using the SEDP to address the problem statement. Once the requirements were established the focus shifted toward translating those requirements into a conceptual design that would be a hybrid of war-gaming to establish baseline metrics followed by closed form simulations of the solution alternatives. Within the conceptual design, the scenario planning, environment, player cell objectives, constraints, and design of experiments were considered. Following the conceptual design was the model implementation phase which involved constructing the wargame database for the baseline systems, asset allocation to the player cells, force layout, and data collection scheme for alternative system specifications to input into the database. The final step was the execution and revision for the purpose of understanding the behavior of systems and collecting desired information from the model's execution. The steps that were focused on for the wargame were one, objectives/requirements, two, conceptual design, three, model implementation, and four, experimentation and revision. Given the team's limited experience with modeling and simulation, the M&S process required two war games to meet the objectives. An illustration of the M&S process is given in Figure 39.

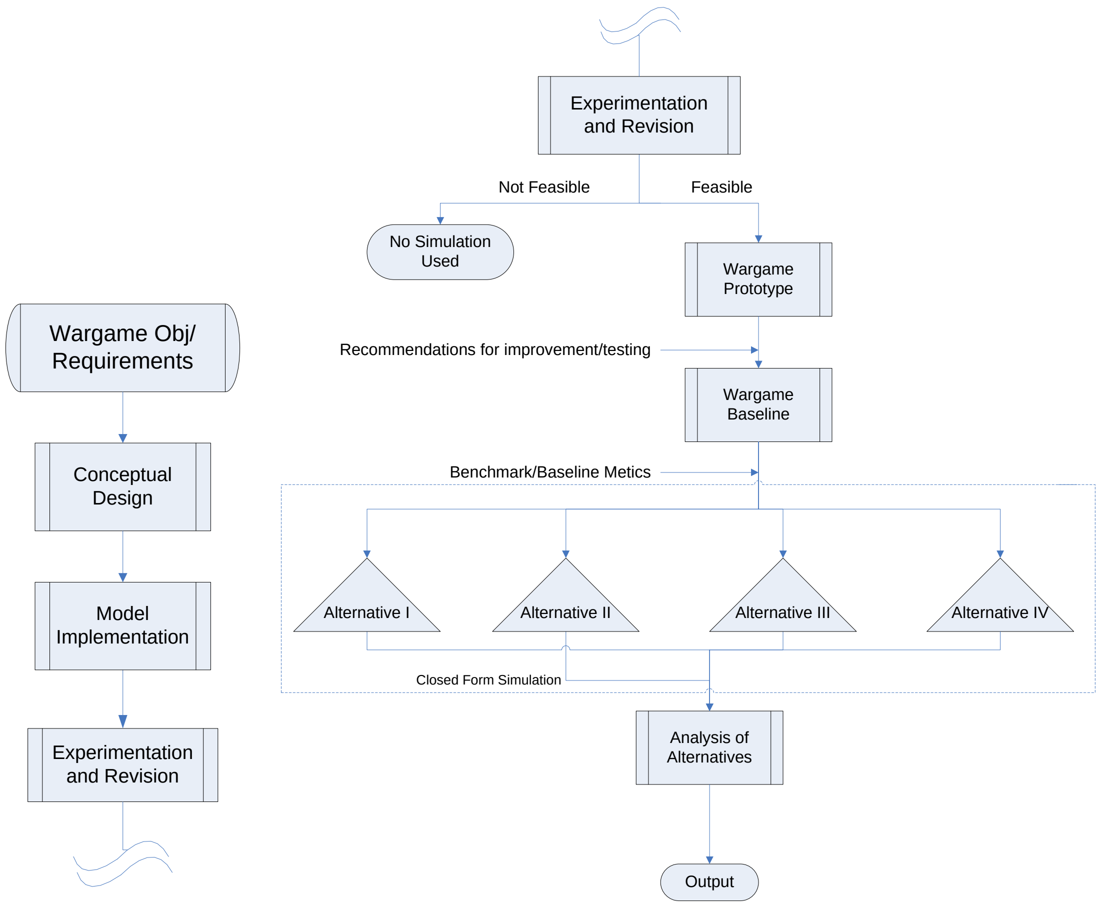

Figure 39 - Modeling and Simulation Process

The modeling tool selected is the Joint Conflict and Tactical Simulation (JCATS) program. The JCATS program is an interactive simulation tool sponsored by the U.S. Joint Forces Command (JFCOM) and has been used by Center for Asymmetric Warfare (CAW), a Department of the Navy operation associated with Naval Postgraduate School, for planning and executing Maritime Based Homeland Security/Homeland Defense exercises in the Northwest Region, specifically in the Puget Sound area.

1.2 Operational Concept

1.2.1 Scenario Development

A fishing vessel has inconspicuously planted MIEDs in the Elliot Bay. The attack is directed at a passenger ferry that makes routine transits to a nearby island. The terrorist attack is successful against the ferry with several civilian casualties. Chaos ensues in the bay. A Coast Guard first response unit becomes victim to terrorist mining as it attempts to render aid to the ferry. Simultaneously, the *C.V. Columbia* is enroute to the loading docks located in the Port of Tacoma (POT). A terrorist group towing a submerged kayak laden with explosives places the improvised bomb in the traffic separation lane directly in the path of cargo vessel *C.V. Columbia*. The C.Vs mobility is instantly degraded and the ship begins to flood. The ship experiences minor civilian casualties but the major concerns in this attack are the suspicion of additional mines and the loss of cargo containers in the channel which will require an extensive ship salvage operation. This portion of the wargame was not amendable and introduced the scenario to the player cells in a coherent sequence with the purpose of prompting the operational commander to shut down port operations forcing crisis mitigation actions. Figures 40 and 41 show the affected areas.

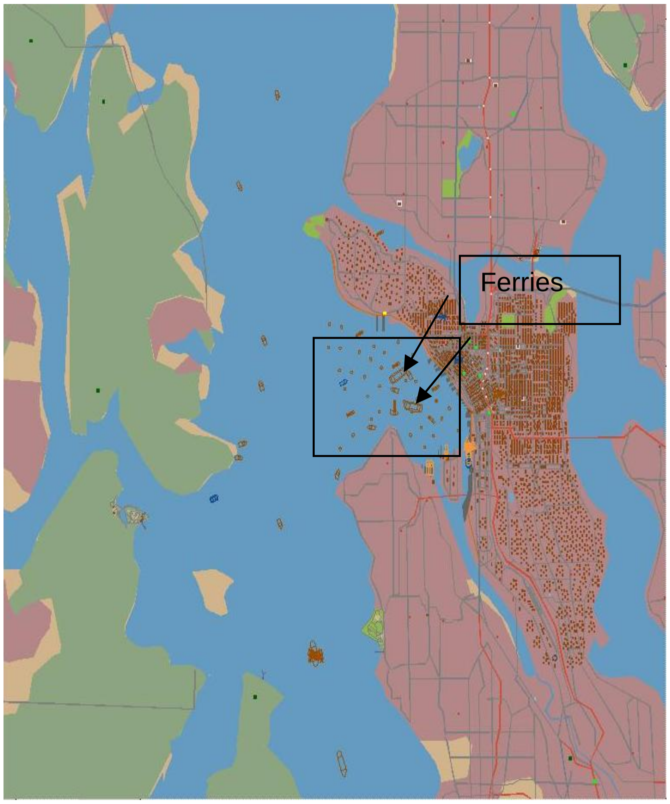

Figure 40 - Elliott Bay

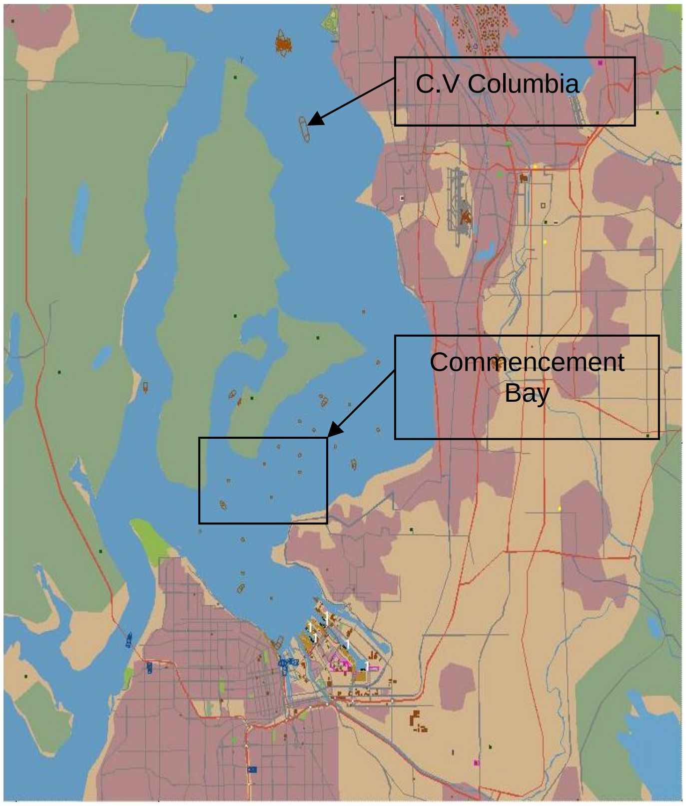

Figure 41 - Commencement Bay

1.2.2 Environment

The scenario takes place in Puget Sound primarily in Elliot Bay and in Commencement Bay near POT. The reason for selecting this area is that Puget Sound offers a vast area, numerous choke points and large volume of commercial traffic. However; before creating a virtual map of this area in JCATS, field research was conducted in order to gather sufficient data about the terrain, port infrastructure, vessel traffic, military and civil authority locations and the possible effects that an MIED attack would incur on the Port of Seattle area. Key features obtained from the field study were noted such as ferry routes, transit times to and from nearby islands as well as the average number of passengers per transit. One important feature considered was that the average water depth in Puget Sound is approximately 200ft. For practical purposes, we modified the water depth to 70ft in JCATS to make the environment more vulnerable to a MIED attack. An assumption about the environment was that a baseline underwater survey was completed within the last 6 months and any contacts detected during a search would be considered new contacts that were not detected in the underwater survey.

1.2.3 Supporting Elements

The exercise is designed to generate mitigation actions from the response cell, in this case, the BLUE cell. The exercise controller was responsible for coordinating the actions of the opposition force and all neutral forces in the simulation. Since the statement of our problem dealt with post attack, there was no need to have a dedicated RED cell because the only remaining RED cell assets were the MIEDs. The actions of the BLUE cell were not scripted but their responses needed to be able to accomplish key tasks in order to achieve the overall objective of re-opening the port. The following is a list of the supporting elements of the BLUE cell as well as the key operational tasks that each supporting element was required to complete:

a. Joint Harbor Operations Center (JHOC): Operational commander/decision maker responsible for the actions of all supporting elements and assets.

Key Tasks:

- Maintain C2 of the operation and coordinate the actions of supporting elements.
- Make the determination to implement MARSEC Levels.

b. Coast Guard: Lead element responsible for search and rescue (SAR) operations as well as area first responders to a crisis in and around the harbor.

Key Tasks:

- Emergency evacuation of ferry passengers to triage collection stations.
- Establish 2000 (yd) secure zone around the ferry, first response unit, and cargo vessel.
- Enforce MARSEC Level and report to JHOC.

c. Navy Region Northwest (NRNW): NRNW is responsible for mine hunting and mine clearance operations in the Puget Sound AO.

Key Tasks:

- Conduct area sweep of designated search areas.
- Ordnance disposal of localized MIEDs.
- Provide assistance during SAR operations.

d. Local Agencies: Local agencies cell is comprised of law enforcement, fire department, Emergency Medical Services (EMS) and Seattle Port Assets. This element provides support to the JHOC through law enforcement, firefighting capability, medical services and other crisis and consequence management resources.

Key Task:

- Setup Triage Collection Stations.
- Account for all personnel casualties.
- Assist with enforcement of secure zone.
- Provide firefighting capability.
- Conduct Ship Salvage Operations.

e. The WHITE/RED cell was responsible for controlling all neutral assets in the exercise as well as provide injects into the game. Injects were built into the script, however if the response cell was not taking the appropriate actions, the controller could initiate a detonation of additional mines, escalating the scenario and prompting additional unscripted responses.

1.2.4 Exercise Constraints

In order to accurately mimic a response to the scripted attack, we added constraints for the response cell to follow. The first of these constraints was that once the attack took place, none of the BLUE cell supporting elements would risk transiting the bay until the areas where cleared. Therefore, SAR operations could only be accomplished using helicopters that would operate during daylight hours and load only two passengers at a time. The constraints to the Navy where that once notified they could not begin to mobilize until after two hours. Minehunting operations using air assets could not take place at night, however; UUVs could operate at any time. Neutralization operations also had to be accomplished only during daylight hours and all searches/neutralization actions had to coincide with Naval Mine Warfare doctrine. The vehicle endurances of all BLUE force assets had to be considered and downtime for refueling was necessary. Finally, asset placement had to be accomplished with movement orders to prevent unrealistic repositioning of assets during game play.

1.2.5 Design of Experiments

As described above, the M&S plan for our project was to combine an interactive wargame with closed form simulation to assist in performing an analysis of system alternatives. The interactive wargame was conducted with the intent of collecting the metrics of the baseline which is composed of current systems. The closed form simulation would be conducted in order to gather data on the proposed system alternatives. The design of experiments for the wargame and the closed form simulations centered around obtaining measurements of the metrics established in the functional hierarchy. Combining the functionality of wargaming with that of closed form simulation improved the overall results by filling in the shortfalls of each with the advantages of the other. Data collection was accomplished through the recording of Microsoft Netmeeting© Chat postings and the JCATS data logger. This allowed for the review of an already played scenario where all actions from the game can be viewed in their entirety. The data collected was ultimately used for the performance analysis of each of the proposed systems.

1.3 Model Implementation

The model implementation phase entailed the translation of the conceptual model into an executable simulation. This involved building dynamic models of moving objects (vessels, helicopters, submersibles, etc.) into the JCATS database known as the Vista. In addition the Vista allowed the database operator to develop the force plan which assigns assets to different cells. The performance parameters of the various vehicles were collected from their manufacturers and/or operators but not all of the pertinent data could be attained due to either their classification level or the system's developmental phase. The performance parameters from open sources of legacy systems were used to fill the missing data. This data was then entered into the Vista to construct the new platforms used in the system alternatives.

1.3.1 Building the Database

Each of the modeled vehicles was constructed in the Systems Editor of the Vista. The systems editor is used to specify basic attributes of a system, specifically the mobility type and the symbols used for classification and identification during the game. In addition to physical dimensions and passenger capacities, the systems general editor allowed us to characterize the detectability, vulnerability and station characteristics of the asset. The detectability, vulnerability and station tabs of the general editor are the features that allowed us to establish relationships between all of the vehicles. Detectability allowed us to enter data about the sensor each asset carried and depending on inherent algorithms built into JCATS, it would provide a signature that another asset could see. Pairing the detectability of two assets allows them to be able to detect each other during game play. Similarly, the vulnerability of an asset allowed for each of the assets to be affected by the MIEDS used by the RED cell. Vulnerability also contains a series of inherent PHPK tables built into JCATS for each asset against each weapon system in its archive. The Station tab is used to assign sensor and weapons to a platform. The sensors used by our vehicles were configured in the Sensor Editor of the Vista and the weapons in the Munitions Editor.

In order to give similar characteristics to similar assets, the assets were grouped by mobility class. Starting with surface vessels, each was given their own specific physical characteristics and a unique identifier symbol. However, as a class they were given a common vulnerability to mines/MIEDs and were dependent on the physical dimensions of the vessel and the PHPK tables, which would dictate the various degrees of damage. The sensor for each surface vessel was standard sight, called Direct View Optics (DVO) in the VISTA. The range was from 0 to 2000 (m), with a 2 second scan interval and a horizontal field of view of 20 degrees. Helicopters were also given a generic DVO sensor with a range from 0 to 4000 (m) with a 2 second scan interval and a 135 degree horizontal view. REMUS (100) UUVs were given a range from 0 to 50 meters and a 90 degree horizontal field of view, with a continuous scan active sonar as the primary sensor. The active sonar detection is a pairing algorithm that allows the database manager to enter the types of platforms that the sonar can detect and then uses the built in probability tables based on user inputs. Dismounted persons used "unaided eye" as the primary sensor ranging from 0 to 1000 (m), a 20 horizontal field of view and continuous scan. Assigning attribute was done mainly for all generic vehicles, while some of the vehicles that contain special sensors such as the ALMDS was given a different sensor mounted to it in the station tab.

1.3.2 Asset Allocation

Table 9 shows the list of assets available to each cell. The exact number of units was unknown, so we determined the numbers based on our best estimates from the field study.

Placement of the assets was also determined from research conducted in Seattle, WA. The neutral forces were randomly placed throughout the Puget Sound. The goal was to re-enact a typical day in the Port of Seattle prior to the attack. Figure 42 shows the initial force lay-out. Asset placement also served as a venue for conducting functional tests for each vehicle. The operational testing was conducted at three levels: individual, force and game. At the individual level each asset was tested for functionality of characteristics developed in the Vista. The force level testing allowed us to view the collaboration of the assets and determine whether enough assets were available to accomplish the mission of objectives for the cell and the BLUE force as a whole. The final test was simply done to show movement of all elements and so that each asset could be seen and operated. This test was conducted independent of doctrinal procedures.

1.4 M&S Execution and Revision

In order to ascertain the effectiveness of the pre-exercise planning, we proceeded with conducting a scaled-down version of the wargame in the form of a feasibility experiment. The feasibility exercise was conducted over the course of a single day in which the scenario was run for six hours. The experimental wargame proved to be a very meaningful exercise and served as proof of concept for our overall approach to the

MIED problem. The validity of the scenario was supported by representatives from JFCOM as they were invited to participate in the game as JCATS operators for the cells. The simulated and free play portions of the game were executed as planned as each asset

CG	Asset	Number	Location
	HH-65 Dolphin	2	Everett
	EOD TM	1	Pier 36
	25ft Boat	3	Pier 36-North Pier
	25ft Boat	3	Pier 36-Central Pier
	CG Cutter Mellon	1	Pier 36-South Pier
	Utility Boat	2	Pier 36-Slip
Local Agencies	18ft RHIB	1	IVO Bainbridge Island
	17ft RHIB	1	Entering Elliot Bay
	Fire Boat	1	Pier 36
	Tug	2	Eastern Pier of West Seattle
	EOD TM	1	Eastern West Seattle Island
	Air Ambulance	2	City of Seattle
Navy	MH-53	4	NE Everett
	MH-60	2	NE Everett
	MH-60 w/RAMICS	1	SW Everett
	MH-53T	3	SW Everett
	MH-60T	2	SW Everett
	Skimmer	3	Central Everett
	Patrol Boat	2	Central Everett
	REMUS 100	3	SE Everett
	AQS-20A	1	SE Everett
	AQS-24	1	SE Everett
	EOD TM	2	SE Everett

was able to move and detect contacts using their sensors. Although the scenario was

Table 9 - Asset Allocation List

validated and each of the systems functioned properly, there were uncertainties in conducting the prototype wargame such as the amount of time necessary for the response cell to meet all of the objectives, game speed, and player experience level for reacting and employing assets. Although some of these elements could be taken directly from the prototype game, other factors, such as the interagency relationships, SOPs, and mitigation efforts that each agency would undertake given the scenario could not. During the game, the JHOC was unable to identify priority search areas, sequence of actions, information flow, and areas of responsibility. Since these considerations ultimately affect the overall timeline, they needed to be researched and implemented into the free play. The wargame experiment also identified the need for a more formalized data collection scheme. Reviewing chat files that had been saved from Netmeeting proved time consuming and ineffective. It identified the need to record the specific data that was necessary to conduct the analysis which could then be used in tandem with the JCATS logger. Overall, the prototype model proved that it was not only feasible, but it would provide a great opportunity to acquire realistic data for the analysis.

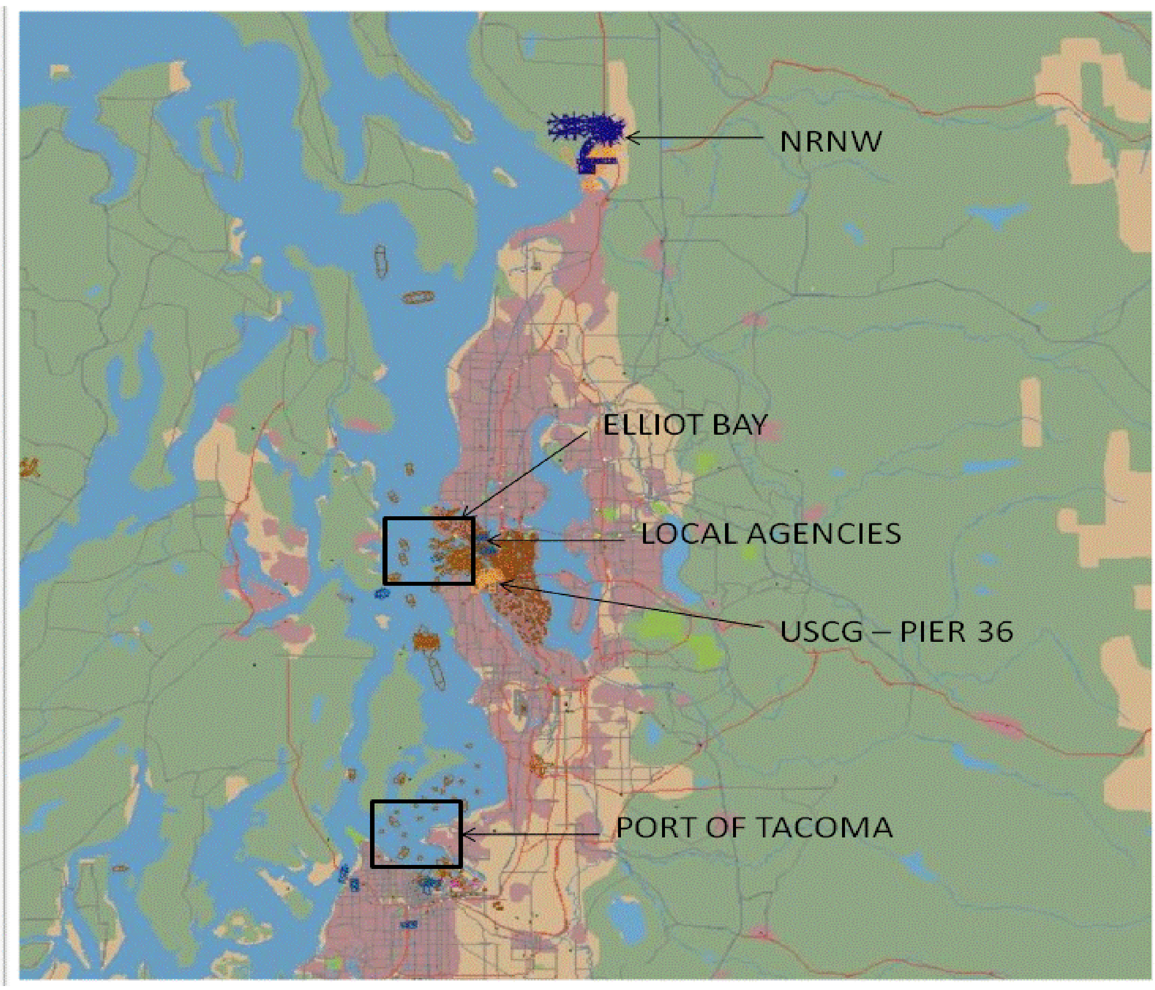

Figure 42 - Initial Force Layout

1.4.1 Prototype Improvements

Taking the lessons learned from the experiment, the first step was to present our scenario to the experts and get their responses. For this we consulted with Tom Coyle of Pacific Northwest National Laboratories (PNNL), who has coordinated numerous exercises with (CAW) dealing with disaster emergency response actions. Mr. Coyle was able to coordinate for us a table top exercise (TTX) with members of the USCG Sector Seattle, Contingency Plans and Force Readiness (CPFR) office . The CPFR is the key office of the DHS in Seattle responsible for policy and procedures for emergency responses. Those present at the TTX were Stephen J. Harvey, Supervisor Security Specialist USCG Seattle, LT Jim Erickson, USCG, Capt. Gerry Fiola, Seattle Police Department and Capt. Paul S. Foerster, Seattle Fire Department. Some of the topics of that discussion were:

- Unified Command Center (UCC) and Incident Command Element (ICE) structure communications and information flow that would be implement in our scenario.
- Priority Search Areas
- Actions required to resume port activities
- Integration with NRNW
- Sequence of actions
- Real-life timeline of our scenario

The conclusion from meeting with members of CPFR was an understanding of each agency’s goals and UCC relationships. The game lab was reconfigured to emulate a UCC so that online chat would no longer be required. The purpose for doing so was to provide the players the opportunity to act as contingency planners within their respective cells, provide them better situational awareness and allowing them to provide more useful analysis at the conclusion of the game. As an added bonus to our visit back to Seattle we also witnessed a live, full-scale exercise of a MRO, which involved twelve federal, state and local agencies. We learned that a MRO of the magnitude in the JCATS scenario may take several days vice several hours and would require an enormous amount of resources. These were all considerations that we hope to capture in our game.

1.4.2 Conducting the Final Wargame

The baseline wargame was executed over a period of two eight hour days. On day one, the first six hours were devoted to crisis management in which the BLUE cell was prompted to take actions in controlling the scenario, conduct maritime rescue operations and execute planning for the area searches. The first six hours of the wargame tested the ability of the command and control (C2) to deal with the complexity of the scenario. The JCATS program was ideal for supporting a “commander-in-the loop” simulation such as this through the use of Command and Control (CAC) files that allow graphics to be displayed as overlays onto the JCATS maps and situation awareness functionalities that focus on the human user. The second day was devoted to conducting area searches of the designated priority areas displayed by the CAC files. Figure 43 shows the areas that were searched by the REMUS 100 vehicles.

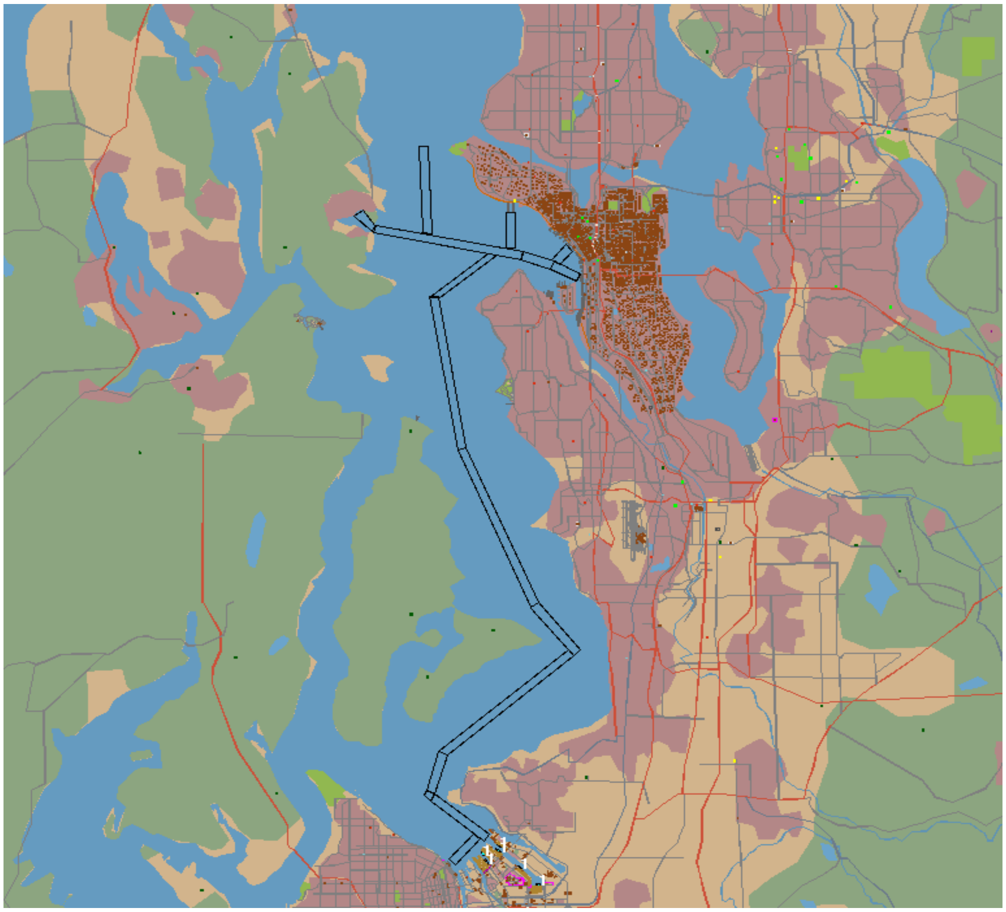

Figure 43 - JHOC Designated Search Areas

The searches were conducted using a speed ratio of 15 to 1 in order to complete search paths in the allotted time for the game. The mine classification and identification of each contact, which was characterized by a JCATS serial number, also had a picture associated with it. The Navy cell had to determine whether the pictures were either "mine-like" or "non mine-like" objects. The individuals that were tasked with making those determinations were mine warfare qualified individuals who have had experience with Naval Mine Warfare. This allowed for a sense of realism into the scenario and allowed for human error. The time required to extract the REMUS 100 and conduct the PMA was simulated. This process, which normally requires three hours for every hour of search conducted, was not incorporated into the wargame, but was included into the overall timeline on the data collection sheet. The contacts that were considered "mine-like" objects were further investigated using EOD teams in JCATS. Once the EOD teams were on station, we then determined that the mines were neutralized with the assumption that it would require a minimum of one hour per contact and three hours if that contact was identified as an MIED. This data was also recorded in data collection sheet.

The data collection strategy was carefully revised in order to maximize the tools available and to get the data that were required. From the experimental game it was understood that not all of the metrics could be measured. Area search rate and probability of detection for the baseline systems could be collected but inferences had to be made about some of the other metrics such as asset time to station, detection rate, and rate of neutralization per contact. The data collection sheets were condensed to record only the significant activities in the detect-to-engage (DTE) sequence of the game. The data collection sheets were an adaptation of an Incident Status Summary template taken from the National Incident Management System (NIMS) that was converted into a real-time report for the JHOC commander. The JCATS logger was then used in conjunction with data collection sheets to ensure accuracy of the data recorded.

1.4.3 Expected vs. Actual Results

The scenario was designed for the BLUE cell to accomplish three main objectives before the port could be re-opened. These objectives included a maritime rescue operation, mine clearance and ship salvage operations in Elliot Bay and Commencement Bay. It was anticipated that the game timeline for completion of the scenario would be much shorter than the timeline discussed in the TTX. According to interviews with USCG Sector Seattle, the maritime rescue operation alone would take several days vice several hours. This is due to the limited capacity of the triage centers which could not handle the volume of victims evacuated, the extreme difficulty of SAR using a helicopter and the likelihood of having to search for drowned victims. Concurrently the designated area searches which were conducted on a 15:1 ratio would have taken a combined 443 hours to complete in real time which was close to the predicted number and the time to completion that we calculated. The time for the Navy

Cell to deploy its assets from Everett Naval Station to Elliot Bay and Tacoma took 30 minutes when in reality it would take at least two hours for them to arrive. This does not include the 3 hours for set-up that is normally required for a UUV platoon and EOD team to set up a command center. These times did not play out in the wargame but were part of the expectations discussed in the TTX.

The six mines in the scenario were randomly distributed throughout Elliot Bay along with seventy non-minelike objects. During the area searches, the REMUS 100 UUVs were able to detect approximately .85 of the total number of objects which included all of MIEDs. The PMA team however identified 4 additional objects as mine-like. This prosecution of the additional contacts would have added significantly to the real-life timeline since those objects would be treated as mines. Although the TTX expected timeline varied from the simulation, we did record accurate data on the search times and detection rates in which the search time of all designated areas by the three vehicles was approximately 147.98 hours of per vehicle for a total of six days of area search at 460-550 m2/s which we were able to accomplish on a 15:1 ratio. In that sense the wargame served its purpose in establishing these baseline metrics.

1.4.4 Closed Form Simulation

The next step in the wargaming process was to conduct the performance analysis of the alternatives in a closed form simulation. The goal was to replicate the operating capabilities of the individual systems. Simulated test runs were conducted using only the individual platforms in order to obtain the detection rate and area search rates for each element in the alternatives. The individual systems were then grouped into their respective alternative systems and then were tested in a closed form miniature wargame that would encompass all of the free play actions specific to mine clearance operations. Other portions were not re-enacted. It was important for us to conduct both a simulated run of each asset individually and then the entire alternative made up of multiple assets operation as a system to get a side-by-side comparison of competing equipment and systems. The data that we collected on each of the alternatives from the simulation was verified by our team by employing theoretical formulas for area search rate and detection rate using an exhaustive search model. The resulting data is explained in the performance analysis section of the report.

1.5 Modeling and Simulation Conclusions

The wargame and closed form simulations conducted supported the SEDP as tools for comparing system solution alternatives. The process of developing a model is in itself an excellent tool from which to perform Systems Engineering by incorporating all of the steps of SE process. JCATS is an excellent modeling tool to support "commander-in-the-loop" interactive wargaming and is also capable of being used to perform closed form simulations. The JCATS program was ideal for meeting the objectives of the wargame and, ultimately, the project. SEDP geared strictly for M&S had to be adopted to meet the requirements of the project. The term "simulation systems engineering" encompasses what method of building the M&S model. It is highly recommended that the Systems Engineering Analysis curriculum incorporate some form of M&S using an interactive simulation model in future capstone projects and adopt discipline M&S planning into the SEA curriculum.

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V. DECISION ANALYSIS

1. PERFORMANCE ANALYSIS

Performance analysis was conducted to evaluate the performance and effectiveness of system alternatives in countering a MIED threat through the function decomposition and the metrics created for each function (refer to Chapter II Section 3). The various alternatives were evaluated and analyzed with reference to the current MCM system as the baseline model and threshold for the other alternatives. Similarly each metric was weighted according to the feedback gathered from stakeholder surveys and used in an Analytical Hierarchy Process (AHP) tool to rank the relative importance of the metrics.

1.1 Alternative 0 - Baseline

Alternative 0 is the current MCM system and is set as the baseline system. It consists of a REMUS UUV platoon performing the functions of search and detection, and EOD divers carrying out identification and neutralization functions. Classification is performed off-site through PMA. Based on this configuration, the team conducted extensive research to obtain the technical specifications of this system. This information was subsequently translated into the metric or MOP for each function as discussed in Chapter II.

These MOPs were set as the threshold values for the subsequent alternatives, which constitute the minimum requirements to be met for other alternatives proposed. At the same time, the desired performance for each MOP was set as the goal or upper limit for that MOP. Tables 10, 11 and 12 illustrate the threshold and goal for the MOP for alternative 0.

Threshold values for the MOPs were obtained from the manufacturers, system operators, data obtained from modeling and simulation, subject matter experts and feedback gathered from various Navy sponsored exercises. Data was also collected from the 8th International Symposium on Technology and the Mine Problem hosted by the Naval Postgraduate School on May of 2008. The goals for the MOPs in general were set at 20% higher than the threshold value. However, a range of performance figures was given, so that information was used in lieu of the 20% increase.

Alternative 0 - Baseline		Threshold	Goal	Units
Search	Area search rate	460	550	m2/s
	Time to station	1	0.5	hr
	Deployability rating	4	5	-
Detect	Probability of Detection	85	95	%
	Probability of False Detection	5	1	%
Identification	Probability of Identification	95	99	%
	Probability of False Identification	5	1	%
	Identification time per contact	1.5	1	hr
	Positional accuracy	15	3	m
Classification	Resolution	4	3	cm
	Search time / PMA time ratio	3	1	-
Neutralization	Time required to neutralize	3	2	hr
	Neutralization rating	3.26	4	-

Table 10 - Alternative 0 Performance Data

		Wt	Data	Value
Deployability	Movement	0.25	5	1.25
	Assembly	0.25	5	1.25
	Operational testing	0.25	5	1.25
	Fueling & Charging	0.25	1	0.25
	TOTAL	1.00	4	4.00

Table 11 - Deployability Rating for Alternative 0

		Wt	Data	Value
Neutralization Rating	Effectiveness in neutralizing	0.2	5	1.00
	Damage to facilities	0.33	4	1.32
	Damage to personnel	0.14	2	0.28
	Damage to assets	0.33	2	0.66
	TOTAL	1.00		3.26

Table 12 - Neutralization Rating for Alternative 0

Deployability rating was computed based on the metric discussed in Chapter II. The deployability rating for the baseline alternative had an excellent rating for movement, assembly and operational testing. It required only 2 personnel to move, less than 1 hour to assemble and less than ½ hour to conduct operational testing. The deployability rating of the baseline system was only slightly hindered due to REMUS 100 requiring approximately six hours to fully charge from about 20% power. The rating for deployability was assigned as per Table 11.

A similar process was conducted to derive the standardized neutralization rating for all of the systems. Since the baseline system used EOD divers as the primary neutralization method, it had an excellent neutralization effectiveness given that it is a man-in-loop operation. Having a man-in-loop minimized the damage to the facilities and infrastructure, but also carried a high risk to personnel because of close contact with the MIED. Rating for neutralization was assigned as per Table 12.

1.2 Alternative 1

Alternative 1 was an augment to alternative 0 but also included the LCS MIW Mission Module which consisting of the WLD-1 with the AQS-20 sonar suite. Based on this configuration, the team gathered the necessary technical specification for the system and translated them into the MOP tabulated in Tables 13, 14 and 15, respectively. These technical specifications and MOPs were then compared to the threshold and goal values of the baseline (alternative 0) to generate a fraction for the MOP (where 0 is equal or worst than threshold and 1 is equal or better than goal).

Alternative 1		Data	Units
Search	Area search rate	630	m2/s
	Time to station	2	hr
	Deployability rating	4.5	-
Detect	Probability of Detection	88	%
	Probability of False Detection	5	%
Identification	Probability of Identification	95	%
	Probability of false identification	5	%
	Identification time per contact	1	hr
	Positional accuracy	10	m
Classification	Resolution	1	mm
	Search time / PMA time ratio	2	-
Neutralization	Time required to neutralize	3	hr
	Neutralization rating	3.26	-

Table 13 - Alternative 1 Performance Data

		Wt	Data	Value
Deployability	Movement	0.25	3	0.75
	Assembly	0.25	5	1.25
	Operational testing	0.25	5	1.25
	Fueling & Charging	0.25	5	1.25
	TOTAL	1.00		4.50

Table 14 - Deployability Rating for Alternative 1

		Wt	Data	Value
Neutralization Rating	Effectiveness in neutralizing	0.2	5	1
	Damage to facilities	0.33	4	1.32
	Damage to personnel	0.14	2	0.28
	Damage to assets	0.33	2	0.66
	TOTAL	1.00		3.26

Table 15 - Neutralization Rating for Alternative 1

The key performance differences in this alternative were an enhanced search rate, probability of detection, resolution and improved ratio of search time/PMA time. Similar to the baseline system, Alternative one utilized EOD divers as the neutralization method and therefore had the same neutralization rating. Alternative one had a better deployability rating as it did not require re-charging and could be easily assembled. On the other hand the WLD-1 would require more personnel and some light equipment in order to deploy.

1.3 Alternative 2

Alternative 2 consisted of the baseline system and the AQS-20, ALMDS, RAMICS and AMNS. Tables 16, 17 and 18 show the technical specifications for Alternative 2. As with Alternative 1, the technical specification and MOPs were compared to the threshold and goal values of the baseline (Alternative 0) to generate a fraction for the MOP (where 0 is equal or worst than threshold and 1 is equal or better than goal).

Alternative 2		Data	Units
Search	Area search rate	6650	m2/s
	Time to station	2	hr
	Deployability rating	4.5	-
Detect	Probability of Detection	95	%
	Probability of False Detection	1	%
Identification	Probability of Identification	95	%
	Probability of false identification	5	%
	Identification time per contact	1	hr
	Positional accuracy	10	m
Classification	Resolution	0.01	mm
	Search time / PMA time ratio	2	%
Neutralization	Time required to neutralize	0.5	hr
	Neutralization rating	3.48	-

Table 16 - Alternative 2 Performance Data

		Wt	Data	Value
Deployability	Movement	0.25	3	0.75
	Assembly	0.25	5	1.25
	Operational testing	0.25	5	1.25
	Fueling & Charging	0.25	5	1.25
	TOTAL	1.00		4.50

Table 17 - Deployability for Alternative 2

		Wt	Data	Value
Neutralization Rating	Effectiveness in neutralizing	0.2	4	0.8
	Damage to facilities	0.33	1	0.33
	Damage to personnel	0.14	5	0.7
	Damage to assets	0.33	5	1.65
	TOTAL	1.00		3.48

Table 18 - Neutralization rating for Alternative 2

The main additions to this alternative were the AQS-20, ALMDS, AMNS and RAMICS. With the laser sensor mounted to a MH-60, the ALMDS was able to achieve a high probability of detection and a significantly faster search rate. The laser provided a higher resolution, which also improved the search time/PMA time ratio. In terms of deployability, this alternative would require light equipment and a few personnel to deploy it. It would also require less than one hour to refuel as compare to alternative 0, but would have to refuel more frequently due to the on-station limitations of the MH-60. Table 16 illustrates the deployability rating assigned for this alternative.

The neutralization function in this alternative is accomplished by the AMNS and RAMICS neutralization systems. These systems use remote control operation which minimized the risk to asset and personnel. Equipped with an optical camera the AMNS could provide the operator with a verifiable battle damage assessment (BDA). This alternative also was extremely effective at neutralizing threats on or near the surface as well as submerged threats. However; a drawback was that both neutralization systems had an increased potential for damage to existing infrastructure. Neutralization rating was assigned as per Table 18.

1.4 Alternative 3

Alternative 3 consisted of the Talisman M and an advanced UUV produced by BAE Systems. This UUV is a modular, multi role vehicle capable of carrying search sensors, communication equipment, and four Archerfish single shot mine neutralizers, which are the neutralizing component of the EMNS and AMNS systems. The nominal search sensor suite includes synthetic aperture array sonar which would provide resolutions of up to 10 times higher than conventional side scan sonar. An additional sensor would be required for Identification purposes. This would be accomplished with a bathymetric laser line scanning sensor or electro-optical camera. A laser line scan could potentially provide a higher resolution at longer distances and have a wider swath width than a camera.

For neutralization, the Talisman M is equipped with four Archerfish mine neutralizers. To fill the gap of non-explosive neutralization, the integration of the Archerfish and a single-shot chemical neutralization dart would be used. This solution can be realized by integrating: a dart from the Assault Breaching System (ABS) Countermine System (CMS), a program under contract by Boeing to provide dart-equipped JDAMs capable of delivering thousands of darts to chemically neutralize mines; the body and optics of the Archerfish, and a launcher that will accurately deliver a single dart with enough kinetic energy to penetrate a mine or MIED. This "SeaArcher" variant of the Archerfish could provide non-explosive neutralization when the proximity to port infrastructure makes conventional neutralization impractical. The potential MOPs for this alternative are listed in Tables 19, 20 and 21.

Alternative 3		Data	Units
Search	Area search rate	184	m2/s
	Time to station	2	hr
	Deployability rating	5	-
Detect	Probability of Detection	95	%
	Probability of False Detection	1	%
Identification	Probability of Identification	95	%
	Probability of false identification	5	%
	Identification time per contact	1	hr
	Positional accuracy	10	m
Classification	Resolution	0.01	mm
	Search time / PMA time ratio	1	-
Neutralization	Time required to neutralize	0.5	hr
	Neutralization rating	4.47	-

Table 19 - Alternative 3 performance data

		Wt	Data	Value
Deployability	Movement	0.25	5	1.25
	Assembly	0.25	5	1.25
	Operational testing	0.25	5	1.25
	Fueling & Charging	0.25	5	1.25
	TOTAL	1.00		5.00

Table 20 - Deployability rating for Alternative 3

		Wt	Data	Value
Neutralization Rating	Effectiveness in neutralizing	0.2	4	0.8
	Damage to facilities	0.33	4	1.32
	Damage to personnel	0.14	5	0.7
	Damage to assets	0.33	5	1.65
	TOTAL	1.00		4.47

Table 21 - Neutralization rating for Alternative 3

The synthetic aperture array sonar and laser line scan give the system search, detect and identification performance equivalent or better than the ALMDS. Additionally, the real-time data processing capability would enhance the search time/PMA time ratio and ultimately lessen the overall clearance time. The main disadvantage of this system was the slow speed of the Talisman in which the area search rate was worse than the other alternatives.

Simultaneously, the non-explosive neutralization method employed by the Archerfish would minimize the potential risk of damage to facilities, personnel and assets, and provide visual control of the neutralization efforts through use of optical cameras built into the system.

The deployability rating of the Talisman and Archerfish was rated high since both are relatively small and could be easily moved with a minimum of two persons without the need of heavy equipment. This system could be easily assembled at the test/operation site and incorporates a built-in generator which eliminates the charging time required.

1.5 Alternative 4

Alternative 4 consists of the Talisman M with Archerfish mine neutralizers similar to that of the Alternative 3. The search and detection functions will be carryout by an improved REMUS UUV with synthetic aperture array sonar offering a better resolution as compare to present REMUS vehicle. Alternative 4 also features the use of Joint Architecture for Unmanned Systems (JAUS) that inter-links the components through a Benthos Underwater LAN system that enhances the communication among the various sub-systems and provides real-time PMA. Potential MOPs for this alternative are listed in Tables 22, 23 and 24.

Alternative 4		Data	Units
Search	Area search rate	644	m2/s
	Time to station	1	hr
	Deployability rating	4	-
Detect	Probability of Detection	95	%
	Probability of False Detection	1	%
Identification	Probability of Identification	95	%
	Probability of false identification	5	%
	Identification time per contact	1	hr
	Positional accuracy	10	m
Classification	Resolution	0.01	cm
	Search time / PMA time ratio	1	-
Neutralization	Time required to neutralize	0.5	hr
	Neutralization rating	4.47	-

Table 22 - Alternative 4 Performance Data

		Wt	Data	Value
Deployability	Movement	0.25	5	1.25
	Assembly	0.25	5	1.25
	Operational testing	0.25	5	1.25
	Fueling & Charging	0.25	1	0.25
	TOTAL	1.00		4.00

Table 23 - Deployability Rating for Alternative 4

		Wt	Data	Value
Neutralization Rating	Effectiveness in neutralizing	0.2	4	0.8
	Damage to facilities	0.33	4	1.32
	Damage to personnel	0.14	5	0.7
	Damage to assets	0.33	5	1.65
	TOTAL	1.00		4.47

Table 24 - Neutralization Rating for Alternative 4

The synthetic aperture array sonar gives the system search and detection characteristics that were equivalent to that of the Alternative 3. Additionally, wireless communication among the sub-systems gave the system the real-time processing capabilities for PMA.

Simultaneously, the non-explosive neutralization method employ by the Archerfish would minimize the potential risk of damage to facilities, personnel and assets, yet provide visual control in the neutralization through the optical camera attach to the system.

As for the deployability rating, the Talisman and Archerfish, which are relatively small can be easily move with two men without the need of heavy equipment. Another advantage of this system is that it can be easily assembled at the test/operation site. But the time required to charge the REMUS is the only disadvantage in term of deployability requirement, because the REMUS would required a charging time of six hours.

1.6 Comparison of All Alternatives

With the data and MOPs obtained for all the alternatives, the MOE (measure of effectiveness) of each alternative was computed. The MOP for each function was multiplied by the weights gathered from the stakeholder survey and then summed up to form the MOE of the alternative. Refer to the Table 25 for the summary of the overall comparison of all the alternatives. The comparison shows that for presently available technologies and systems, Alternative 2 is the most effective SoS to counter an MIED threat. With its high resolution, probability of detection and speed of the MH-60 as the employment platform, Alternative 2 gives a much higher MOE compare to Alternative 1.

However, in comparison Alternative 4 had an even better MOE in countering MIEDs. The synthetic aperture sonar gives an almost equivalent search and detection performance as the ALMDS. Conversely, the non-explosive neutralization method coupled with the optical camera provides an enhanced effectiveness in neutralization without risks to infrastructure, assets and personnel.

Evaluation Criteria		Weights	Baseline			AFP 1			AFP 2			AFP 3			AFP 4		
			Threshold	Goal	units	Data	units	Value	Data	units	Value	Data	units	Value	Data	units	Value
Search	Area search rate	0.15	460	550	m2/s	630	m2/s	1.00	6650	m2/s	1.00	184	m2/s	0.00	644	m2/s	1.00
	Time to station	0.06	1	0.5	hr	2	hr	0.00	2	hr	0.00	2	hr	0.00	1	hr	0.00
	Deployability rating	0.09	4	5	-	4.5	-	0.50	4.5	-	0.50	5	-	1.00	4	-	0.00
Detect	Probability of Detection	0.21	85	90	%	88	%	0.60	95	%	1.00	95	%	1.00	95	%	1.00
	Probability of False Detection	0.03	5	1	%	5	%	0.00	1	%	1.00	1	%	1.00	1	%	1.00
Identification	Probability of Identification	0.07	95	99	%	95	%	0.00	95	%	0.00	95	%	0.00	95	%	0.00
	Probability of false identification	0.07	5	1	%	5	%	0.00	5	%	0.00	5	%	0.00	5	%	0.00
	Identification time per contact	0.02	1.5	1	hr	1	hr	1.00	1	hr	1.00	1	hr	1.00	1	hr	1.00
	Positional accuracy	0.02	15	3	m	10	m	0.42	10	m	0.42	10	m	0.42	10	m	0.42
Classification	Resolution	0.03	4	3	cm	1	cm	1.00	0.01	cm	1.00	0.01	cm	1.00	0.01	cm	1.00
	Search time / PMA time ratio	0.01	3	1	-	2	-	0.50	2	-	0.50	1	-	1.00	1	-	1.00
Neutralization	Time required to neutralize	0.09	3	2	hr	3	hr	0.00	0.5	hr	1.00	0.5	hr	1.00	0.5	hr	1.00
	Neutralization rating	0.15	3.26	4	-	3.26	-	0.00	3.48	-	0.30	4.47	-	1.00	4.47	-	1.00
	Total	1.00					**MOE**	**0.39**		**MOE**	**0.64**		**MOE**	**0.64**		**MOE**	**0.70**

Table 25 - Comparison of All Alternatives

2. SUITABILITY ANALYSIS

In addition to the performance and capability of the proposed system, the availability and dependability of the proposed system would also affect the system effectiveness. Reference to Figure 44 (extracted from Benjamin S. Blanchard and Wolter J. Fabrycky), the system availability and dependability depend on it ability to minimize the downtime and enhance the uptime. Based on this approach, the team analyzes and compares the maintainability and reliability of the various alternatives to gauge the suitability of the proposed alternative.

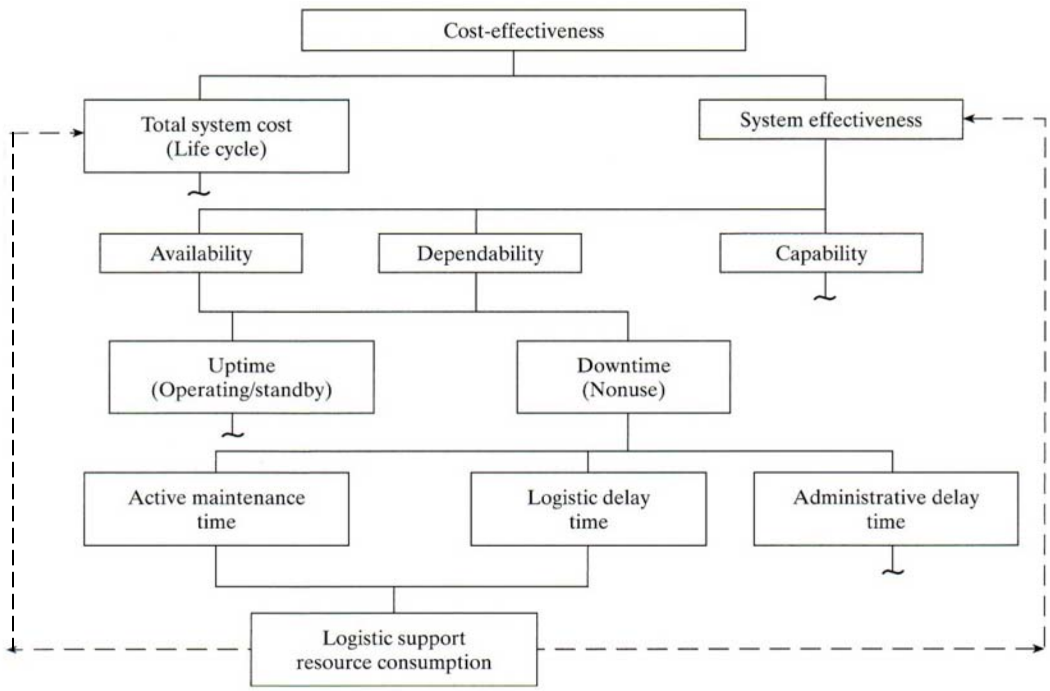

Figure 44 - Relationship Between Maintenance Downtime and Logistics Factors (extracted from Benjamin S. Blanchard and Wolter J. Fabrycky)

However, as most of the proposed systems are still in it development or research stage, the reliability and maintainability data are not easily obtainable. Thus, the team conducted a prediction of the reliability and maintainability for the various alternatives based on combination of the following prediction techniques.

a. Analysis of similar equipment
b. Estimate of active element groups
c. Equipment parts count
d. Mechanical parts

e. Electrical parts
f. Software complexity
g. Spare parts availability (supply responsive)
h. Test and support equipment effectiveness
i. Maintenance facility availability
j. Maintenance organization (personnel and training availability)
k. Data and information process capability

2.1 Reliability Prediction

Basing on the prediction techniques highlighted above, the team conducted research and sought expert advice with regard to the various proposed system and its components. Among these techniques, the prediction based on similar equipment, active element group, equipment parts count, mechanical parts, electrical parts and software complexity were used for analysis of the reliability of the alternatives.

a. The prediction, based on similar equipment, looked at equipment available or currently in use as a reference to guide the team when comparing the relative reliability of the proposed system to the baseline system.

b. The active element group-based prediction referred to the active element of various components within the alternative system as a guide. This was required to compare the relative reliability of the proposed system to the baseline system.

c. The equipment-parts-count is a factor of the prediction for the system reliability. Systems with more parts or components would more likely have a higher failure rate than those with fewer components.

d. The mechanical parts prediction compares the components mechanical parts to determine the relative reliability of the proposed alternative. Mechanical parts that are subject to more movement, friction, wear and tear, etc, tend to have a likelihood of higher failure.

e. Predictions based on electrical parts compare the extensiveness and complexity with respect to the individual electrical components used in the system. The more complex the electrical design of a system is, preludes to a higher failure rate (as compared to those using proven technology and simpler designs).

f. Systems that have a more complex software suite and require extensive interface would be more likely to have a higher failure rate than those having less interface.

Referencing these prediction techniques, the team compiled the necessary information to compare the relative reliability of the various alternatives. The relative scale is from one to nine. One demonstrates the lowest reliability, five representing the baseline, and nine being the highest possible reliability. The team then performed a prediction analysis of the relative reliability utilizing the baseline system. Table 26 tabulated the data regarding the various components of the alternatives.

From the comparison in Table 26, it is noted that the reference to the baseline system, alternative 1 would be the most reliable system followed by alternative 3. Alternative 2 and 4 were the least reliable systems. The main contribution to the low reliability for alternatives 2 and 4 were parts count and software complexity.

2.2 Maintainability Prediction

Similar to reliability, the prediction technique was used to predict the maintainability since the data and information on maintainability for the various alternatives were not easily obtainable. The criteria used to predict the maintainability included required spare parts, test and support equipment, maintenance facilities and organizations, and system capability to record and process maintenance data and information. Only corrective maintenance is used to determine maintainability. This is because the team assessed that the preventive maintenance for all the alternatives would be conducted at the unit level, thus the maintainability would be similar for all alternatives.

The predictions based on spare parts looked at the availability of the spare parts for the proposed system. A commercially available part would enhance the system maintainability. On the other hand, parts that were only available through the Navy (such as explosives, etc) would constrain the availability of parts, making the system less maintainable. Similarly, the availability of test and support equipment for the proposed system (whether available commercially or through the Navy) is also used to predict the system maintainability.

Alternative	Components	Reliability prediction based on similar equipment		Reliability prediction based on active element group		Reliability prediction based on equipment parts count		Reliability prediction based on mechanical parts		Reliability prediction based on electrical parts		Reliability prediction based on software complexity		Relative Nett Score
0	REMUS	Proven and reliable	5	Battery, gps system, propulsion system, sonar sensor	5	Few equipment and parts	5	Propulsion system, control system	5	Gps system, sensors	5	Simple and least interface required	5	30
	EOD Divers	Allowable diving time is 2 hrs		Human, diver equipment		Few equipment and parts		N.A		N.A				
1	REMUS	Proven and reliable	5	Battery, gps system, propulsion system, sonar sensor	4	Few equipment and parts	3	Propulsion system, control system	4	Gps system, sensors	5	Slightly more complex software and interface required	4	25
	EOD Divers	Allowable diving time is 2 hrs		Human, diver equipment		Few equipment and parts		N.A		N.A				
	AQS-20	Similarity to REMUS		Sonar sensor, optical camera		Relatively more parts		Assembly and connection		Sonar sensor, optical camera, RF link				
	WLD-1	Similarity to diesel engine		Propulsion system, gps system		Relatively more parts		Propulsion system, control system		Electrical circuit and components				
	Support Module	Similarity to main frame computer		Software, electronic components		Relatively more parts		N.A		Electrical circuit and components, computer system				
2	REMUS	Proven and reliable	5	Battery, gps system, propulsion system, sonar sensor	3	Few equipment and parts	2	Propulsion system, control system	2	Gps system, sensors	4	More complex software and interface than alternative 1	3	19
	EOD Divers	Allowable diving time is 2 hrs		Human, diver equipment		Few equipment and parts		N.A		N.A				
	ALMDS	Similarity to AQS-20 (laser)		Pulse laser, receiver, computer system		Relatively more parts		assembly		laser, computer sys				
	AQS-20	Similarity to REMUS		Sonar sensor, optical camera		Relatively more parts		Assembly and connection		Sonar sensor, optical camera, RF link				
	RAMICS	Similarity to gun and AQS-20		Laser guidance, firing system, gps system		Relatively more parts		Firing system, train and elevation system		Laser, computer system				
	AMNS	Similarity to REMUS		Battery, gps, sonar, propolusion, firing system		Relatively more parts		Propulsion system, firing system, gear system		Remote control, optical camera, computer system, sonar				
	MH-60	Similarity to any helicopter		Rotor, engine, gps, control system, etc		Relatively more parts		Rotor, engine, control system, etc		Navigation system, etc				
3	Talisman M (c/w Archerfish, SeaArcher)	Similar to AQS-20 + AMNS + WLD-1	5	Laser, sonar, firing system, propolusion system, gps system (all in 1 vehicle)	2	More equipment and parts than alternative 1 but less than alternative 2	4	Propulsion system, gear system	5	Firing ssytem, sonar, laser, gps, control system	3	More complex software and interface than alternative 2	2	21
4	Improved REMUS	Similarity to present REMUS	5	Battery, gps system, propulsion system, sonar sensor	2	Few equipment and parts	3	Propulsion system, control system	5	Gps system, sensors	3	Most complex software and interface	1	19
	Talisman M (c/w Archerfish, SeaArcher)	Similar to AQS-20 + AMNS + WLD-1		Laser, sonar, firing system, propolusion system, gps system (all in 1 vehicle)		More equipment and parts than alternative 1 but less than alternative 2		Propulsion system, gear system		Firing ssytem, sonar, laser, gps, control system				
	Benthos Modem Network	REMUS reference Bouy		WIFI		Few equipment and parts		N.A						

Table 26 - Reliability Prediction and Comparison

For maintenance-facility-required prediction, there are three levels of maintenance facilities: unit, base and depot. Systems requiring only unit level maintenance facility would have a better maintainability compared to systems that require depot level maintenance.

Maintenance-organization-required prediction looks at the training of personnel that carry out the necessary corrective maintenance. There are three levels of maintenance organization: operator crew, maintenance team and manufacturer engineering team. Systems that require operator crew level maintenance would have a better maintainability compared to systems that require the manufacturer's engineering team.

Prediction based on the system's ability to record and process maintenance data/information, compares the system's ability to keep a record of usage data which would provide maintenance personnel with the system's information and usage pattern, thus facilitating corrective maintenance.

Using the above prediction techniques, the team compiled the necessary information and compared the relative maintainability of the various alternatives with reference to the baseline system. The relative scale is from one to nine. One demonstrates the lowest maintainability, five representing the baseline, and nine demonstrate the highest maintainability (shown in Table 27).

From the results obtained, it is noted that alternative 1 rated high in maintainability, followed by alternative 2, while alternative 3 and 4 had a poor rating. Depot level maintenance and the need for manufacturer engineering team were the main factors contributing to the poor maintainability rating for alternative 3 and 4.

Alternative	Components	Maintainability prediction based on spare parts and test & support equipment		Maintainability prediction based on maintenance facility required		Maintainability prediction based on maintenance organization required (personnel, training)		Maintainability prediction based on system capability to record and process maintenace data / information		Relative Nett Score
0	REMUS	Commercially available	5	Unit level	5	Maintenance team	5	Available	5	20
	EOD Diver	N.A		N.A		N.A		N.A		
1	REMUS	Commercially available	3	Unit level	4	Maintenance team	3	Available	5	15
	EOD Diver	N.A		N.A		N.A		N.A		
	AQS-20	LCS module - available only through Navy		Intermediate level		Maintenace team / manufacturer		Available		
	WLD-1	LCS module - available only through Navy		Intermediate level		Maintenace team / manufacturer		Available		
	Support Module	LCS module - available only through Navy		Intermediate level		Maintenace team / manufacturer		Available		
2	REMUS	Commercially available	4	Unit level	3	Maintenance team	3	Available	4	14
	EOD Diver	N.A		N.A		N.A		N.A		
	ALMDS	Widely available through Navy and some commercial		Intermediate level		Maintenace team		Available		
	AQS-20	LCS module - available only through Navy		Intermediate level		Maintenace team / manufacturer		Available		
	RAMICS	Widely available through Navy and some commercial		Intermediate level		Crew / maintenance team		Available		
	AMNS	Widely available through Navy and some commercial		Depot level		Manufacturer		Available		
	MH-60	Widely available through Navy and some commercial		Unit level		Crew		Not available		
3	Talisman M (c/w Archerfish, SeaArcher)	Available through Navy	4	Depot level	2	Manufacturer	2	Available	5	13
4	Improved REMUS	Commercially available		Unit level		Maintenance team		Available		
	Talisman M (c/w Archerfish, SeaArcher)	Available through Navy	4	Depot level	3	Manufacturer	1	Available	5	
	Benthos Modem Network	Commercially available		Intermediate level		Manufacturer		Available		13

Table 27 - Maintainability Prediction and Comparison

2.3 System Suitability

From the analysis of the various alternatives relative reliability and maintainability as compare to the baseline system, the team mapped the two factors together to determine the system availability and dependability. Table 28 illustrates the summary of the various alternatives' reliability and maintainability. The summary shows that alternative 1 had high reliability and maintainability and alternative 4 had low reliability and maintainability.

	Reliability	Maintainability
Alternative 1	High	High
Alternative 2	Low	Medium
Alternative 3	Medium	Low
Alternative 4	Low	Low

Table 28 - Summary of Various Alternatives Reliability and Maintainability

3. COST ANALYSIS

The life cycle cost (LCC) of each Alternative used to perform the identified system functions of *search*, *detect*, *classify*, *identify* and *neutralize* is analyzed to study the life cycle cost behavior from the perspective of a buyer.

Developing cost analysis tools allows for the evaluation of different alternatives based upon constant dollar amounts, assumption and best guesses while investigating the costs and benefits of each alternative. Each alternative was reviewed systematically to aid in the decision making process of which alternative is best for a given CONOPs. The following are elements in which this cost analysis was based:

a. Establishing and defining the objective desired

b. Searching out hypothetical alternatives for accomplishing the objective (describer in Chapter III)

c. Formulating appropriate assumptions

d. Determine the cost and benefits of each alternative

e. Comparing costs and benefits of all alternatives and ranking the alternatives[28]

Developing the Life Cycle Cost (LCC) was done to identify each element of the alternative's system components cost. Research Development & Test Evaluation (RD&TE), Acquisition, Operation & Support (O&S), Overhaul/Major Upgrades and Retirement & Disposal were the overarching categories used to develop the LCC. Each category was broken down further as listed in figure 45. Assumptions had to be made in order to generate cost dollars to perform this analysis.

For Alternatives 0, 1, 2 the estimated costs were determined using actual costs supplied from various sources based on current programs of record and budgets. By extrapolating the current program cost we were able to break down the cost of each system to develop an overall cost of the alternative. Alternative 3 and 4 include systems in which are still in the Research and Development phase and costs were estimated by analogy. Taking a single cost value form a single data point within a current system allowed us to estimate the cost of the system in the future.

3.1 Formulating Assumptions

Assumptions were made in order to scope the analysis down to the larger overall components of each alternative.

RD & TE for Alternative 0-2 were not included in the LCC because these systems are already developed and available for use. Alternative 3 has components in which are still in the RD & TE phase and educational/professional estimations were conducted to develop a cost range for each.

O & S takes into consideration attrition cost and operating personal costs. The attrition is defined as the reduction of the effectiveness of a system caused by loss of materiel and system degradation. Attrition was measured using an attrition rate, which is defined as "a factor, normally expressed as a percentage, reflecting the degree of losses of materiel and system degradations due to various causes with a specified period of time. "

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[28] Defense Economic Analysis Council ,Economic Analysis Handbook(Defense Resources Management Institute)Chapter 4.b

[29]Attrition rates were derived from data developed by a CNA study discussing the "Attrition of Future MCM Systems: Peacetime Attrition."

Number or personnel for each system component was extracted from professional knowledge and various personal conversations with subject matter experts and used as a means to calculate operating personnel costs. Individual personnel costs used only base pay, BAH and BAS to determine annual cost. Annual cost used average CONUS rates, no dependants and nominal year-in-rate[30].

Without any data on system overhaul and major upgrade, it was determined for cost estimation purposes that every five (5) years of service a major overhaul/ system upgrade was conducted. The cost was determined by using fifty percent of the initial acquisition cost of the system.

The economic life was determined to be ten (10) calendar years starting in 2009 for alternatives 0, 1, and 2. During this economic life, it is also assumed that ten years will also be the life expectancy of each alternative. It is expected that each alternative will perform its required mission for 10 calendar years while at the same time development of Alternatives 3 and 4 will require additional funding.

[29] Attrition of Future MCM Systems: Peacetime Attrition, Barry Reed, Kai Wang, The CNA Corporation, 2007

[30]Office of the SECDEF Military Compensation Calculator. http://www.dod.mil/cgi-bin/rmc.pl.

Cost Per Year	EOD	REMUS	WLD-1 RMS	AQS-20	ALMDS	RAMICS	AMNS	SH-60	Talisman M	Intgrated SAS	Archerfish EMNS	SeaArcher CMNS	Benthos Underwater LAN
Research and Development									$300,456,750	$172,456,750	$50,456,750	$50,456,750	
System life cycle management													
Tactic, Usages, Mission Planning									$456,750	$456,750	$456,750	$456,750	
Aqusition													
- Compnent Cost	$2,700,000	$300,000	$9,000,000	$7,400,000	$7,000,000	$5,000,000	$3,500,000	$28,378,781	$3,500,000	$3,500,000	$200,000	$200,000	$1,492,000
* Assumtion that RD&TE has been completed and componet cost is based as close as possible legitimate Per Unit Cost													
Operation & Support	$3,084,257	$644,774	$173,335	$219,639	$79,457	$88,335	$119,335	$1,379,462	$153,335	$141,457	$75,457	$75,457	$208,934
- Maintance	$2,700,000	$30,000	$90,000	$148,182	$8,000	$5,000	$36,000	$1,200,000	$70,000	$70,000	$4,000	$4,000	$29,840
- Operating personnel	$384,257	$614,774	$83,335	$71,457	$71,457	$83,335	$83,335	$179,462	$83,335	$71,457	$71,457	$71,457	$179,094
* Assumtion of rates used for operators/technitians. EOD & REMUS Plt are per EDVR rqmts	(1) OIC, (1) CPO, (3) E4, (2) E5, (2) E6	(1) OIC, (1) CPO, (5) E4, (4) E5, (3) E6	(2) E5	(2) E4	(2) E4	(2) E5	(2) E5	(1) O2, (1) O2, (1) E5	(2) E5	(2) E4	(2) E4	(2) E4	(1) E4, (3) E4-E6
Overhaul/ Major Upgrades	$2,892,128	$472,387	$4,586,667	$3,809,819	$3,539,729	$2,544,167	$1,809,667	$14,879,121	$1,826,668	$1,820,729	$137,729	$137,729	$115,691,940
* Assumtion, cost determined by using 50% of total aqusition and O&S													* 10 year cost for battery replacement
Retirement & Disposal	$54,000	$6,000	$180,000	$148,000	$140,000	$100,000	$70,000	$567,576	$70,000	$70,000	$4,000	$4,000	$29,840

Figure 45 - Life Cycle Cost Breakdown

3.2 Cost Analysis

3.2.1 Alternative 0

System cost estimates are based on FY08 dollars, initial costs to purchase one unit of the system and the operation/support costs for the first year. Figure 46 illustrates the estimated ten-year life cycle cost, which focused on the following:

a. Explosive Ordnance Disposal Mobile Unit

(1) OIC – O3

(1) CPO – E7

(7) Enlisted E3-E6

Support Equipment

Training

Travel

b. NOMWC UUV Platoon

(1) OIC –O3

(1) CPO – E7

(12) Enlisted E3-E6

(3) REMUS 100

Support Equipment

Training

Travel

YEAR	INITIAL COST	ANNUAL OP.COST	OVERHAUL	SCRAP VALUE	TOTAL CASH VALUE	DISCOUNTED CASH VALUE
2009	$6,729,031	$3,729,031			10,458,061	$10,458,061
2010		$3,729,031			3,729,031	$3,655,912
2011		$3,729,031			3,729,031	$3,584,228
2012		$3,729,031			3,729,031	$3,513,949
2013		$3,729,031			3,729,031	$3,445,048
2014		$3,729,031	$3,364,515.36		7,093,546	$6,424,843
2015		$3,729,031			3,729,031	$3,311,273
2016		$3,729,031			3,729,031	$3,246,346
2017		$3,729,031			3,729,031	$3,120,286
2018		$3,729,031		$54,000	3,729,031	$3,182,692
				NPV		**$43,942,638**
			DISCOUNTED	2.00%	CYCLE PERIOD	10

10 Year Life Cycle	Alt 0
Initial cost (in $millions)	$6,729,031
Annual cost	$3,729,031
One time overhaul	
(at 5 yr mark)	$3,364,515.36
Scrap value	$54,000
Ten Year Life Cycle Cost (FY09$)	$43,996,638

Figure 46 - Alternative 0 System Cost Estimate

3.2.2 *Alternative 1*

The Alternative 1 System cost estimates are built upon the baseline provided in Alternative 0 with the addition of the WLD-1 Remote Mine hunting System and the AQS-20. The system cost is calculated over a ten-year life cycle.

YEAR	INITIAL COST	ANNUAL OP.COST	OVERHAUL	SCRAP VALUE	TOTAL CASH VALUE	DISCOUNTED CASH VALUE
2009	$23,522,004	$4,122,004			27,644,009	$27,644,009
2010		$4,122,004			4,122,004	$4,041,181
2011		$4,122,004			4,122,004	$3,961,942
2012		$4,122,004			4,122,004	$3,884,257
2013		$4,122,004			4,122,004	$3,808,095
2014		$4,122,004	$11,761,002.19		15,883,007	$14,385,728
2015		$4,122,004			4,122,004	$3,660,222
2016		$4,122,004			4,122,004	$3,588,453
2017		$4,122,004			4,122,004	$4,122,004
2018		$4,122,004		$208,000	4,122,004	$3,518,091

	NPV			**$72,613,982**
DISCOUNTED		2.00%	CYCLE PERIOD	10

10 Year Life Cycle	Alt 1
Initial cost (in $millions)	$23,522,004
Annual cost	$4,122,004
One time overhaul	
(at 5 yr mark)	$11,761,002.19
Scrap value	$208,000
Ten Year Life Cycle Cost (FY09$)	$72,821,982

Figure 47 - Alternative 1 Cost Estimate

3.2.3 *Alternative 2*

The Alternative 2 System cost estimates are built upon the baseline provided in Alternative 0. Added to the baseline is the Airborne Laser Mine Detection System (ALMDS), Rapid Airborne, Mine Clearance System (RAMICS), AQS-20 and two SH-60. The system cost is calculated over a ten-year life cycle to include a onetime fifty percent overhaul/major upgrade cost at the five-year mark.

a. Alternative 2 includes:

EOD Mobile Unit

NOMWC UUV Platoon

(1) ALMDS

(1) RAMICS

(1) AQS-20

(2) SH-60

YEAR	INITIAL COST	ANNUAL OP.COST	OVERHAUL	SCRAP VALUE	TOTAL CASH VALUE	DISCOUNTED CASH VALUE
2009	$89,563,947	$5,615,258			$95,179,205	$95,179,205
2010		$5,615,258			$5,615,258	$5,505,155
2011		$5,615,258			$5,615,258	$5,397,211
2012		$5,615,258			$5,615,258	$5,291,383
2013		$5,615,258			$5,615,258	$5,187,631
2014		$5,615,258	$44,781,973.67		$50,397,232	$45,646,326
2015		$5,615,258			$5,615,258	$4,986,189
2016		$5,615,258			$5,615,258	$4,888,420
2017		$5,615,258			$5,615,258	$5,615,258
2018		$5,615,258		$1,833,151	$5,615,258	$4,792,569

	NPV		**$182,489,346**
DISCOUNTED	2.00%	CYCLE PERIOD	10

10 Year Life Cycle	Alt 2
Initial cost (in $millions)	$89,563,947
Annual cost	$5,615,258
One time overhaul	
(at 5 yr mark)	$44,781,973.67
Scrap value	$1,833,151
Ten Year Life Cycle Cost (FY09$)	$184,322,497

Figure 48 - Alternative 2 System Cost Estimate

3.2.4 Alternative 3

The Alternative 3 System costs estimates are not built upon from the baseline Alternative 0. This alternative includes new system technologies in which many of the components are still in the RD&TE phase. Cost data was not directly available and estimations were conducted using similar current year 2008 system cost data. Specifically, the Archerfish cost data was derived from using the cost data for the Expendable Mine neutralization System (EMNS).

The SeaArcher cost data was derived from using the cost data for the for the EMNS in combination to the ABS Countermine System.

a. Alternative 3 includes:

(1) Talisman with Integrated SAS

(2) SeaArcher EMNS

(2) ArcherFish CMNS

YEAR	INITIAL COST	ANNUAL OP.COST	OVERHAUL	SCRAP VALUE	TOTAL CASH VALUE	DISCOUNTE D CASH VALUE
0	$7,845,706	$445,706			$8,291,412	$8,291,412
1		$445,706			$445,706	$436,967
2		$445,706			$445,706	$428,399
3		$445,706			$445,706	$419,999
4		$445,706			$445,706	$411,763
5		$445,706	$3,922,853.00		$4,368,559	$3,956,738
6		$445,706			$445,706	$395,774
7		$445,706			$445,706	$388,014
8		$445,706			$445,706	$380,406
9		$445,706		$156,000	$445,706	$372,947

	NPV		**$15,482,419**
DISCOUNTED	2.00%	CYCLE PERIOD	10

10 Year Life Cycle	Alt 3
Initial cost (in $millions)	$7,845,706
Annual cost	$445,706
One time overhaul	
(at 5 yr mark)	$3,922,853.00
Scrap value	$156,000
Ten Year Life Cycle Cost (FY09$)	$15,638,419

Figure 49 - Alternative 3 System Cost Estimate

3.2.5 Alternative 4

The Alternative 4 System Cost estimates build from Alternative 3 and add the Benthos Underwater LAN systems, which utilizes the JAUS system. Like Alternative 3, this system has not been tested nor funding requirements established. The cost was estimated by analogy with current proven systems.

a. Alternative 4 includes:

(4) Advanced REMUS UUV

(1) Talisman M

Benthos Underwater LAN

(1) Gateway Buoy

(14) Network Nodes

(2) Archerfish EMNS

(2) SeaArcher CMNS

(1) Shore Station

YEAR	INITIAL COST	ANNUAL OP.COST	OVERHAUL	SCRAP VALUE	TOTAL CASH VALUE	DISCOUNTED CASH VALUE
2009	$10,097,554	$805,554			$10,903,108	$10,903,108
2010		$805,554			$805,554	$789,759
2011		$805,554			$805,554	$774,274
2012		$805,554			$805,554	$759,092
2013		$805,554			$805,554	$744,208
2014		$805,554	$62,894,747.12		$63,700,301	$57,695,326
2015		$805,554			$805,554	$715,309
2016		$805,554			$805,554	$701,283
2017		$805,554			$805,554	$805,554
2018		$805,554		$185,840	$805,554	$687,533

	NPV		74,575,445.60
DISCOUNTED	2.00%	CYCLE PERIOD	10

10 Year Life Cycle	Alt 4
Initial cost (in $millions)	$10,097,554
Annual cost	$805,554
One time overhaul	
(at 5 yr mark)	$62,894,747.12
Scrap value	$185,840
Ten Year Life Cycle Cost (FY09$)	$74,761,286

Figure 50 - Alternative 4 System Cost Estimate

10 Year Life Cycle	Alt - 0	Alt - 1	Alt - 2	Alt - 3	Alt - 4
Initial cost	6,729,031	23,522,004	89,563,947	7,845,706	10,097,554
Annual cost	3,729,031	4,122,004	5,615,258	445,706	805,554
One time overhaul	3,364,515	11,761,002	44,781,974	3,922,853	62,894,747
Scrap value	54,000	208,000	1,833,151	156,000	185,840
Total	**43,996,638**	**72,821,982**	**184,322,497**	**15,638,419**	**74,761,286**

Figure 51 - 10-year life cycle cost

3.2.6 Summation

Over a ten-year life cycle Alternative 2 is nearly double the cost of Alternatives 1 and 4. Major consideration for this is that Alternative 2 requires the use of two SH-60 helicopters to perform its mission. If the cost of the helicopters were removed and assumed that if a credible threat was made a request for services would be issued and the navy would provide then the cost is reduced to $85 million. This figure is more in line with the other Alternatives and will require performance and risk based analysis to determine which of the Alternatives lends itself to being the most cost effective.

4. RISK ANALYSIS

A risk is defined as the measure of the inability to achieve program objectives within cost and schedule constraints. Risk management is as an organized, systematic decision making process that effectively identifies, assesses, monitors, controls and documents risks that are associated with a program. Risk Management is a cyclic process that is executed continuously throughout a program's lifecycle. The risk management process used by the MIED Program is an established risk management process.

Risks that impact either the MIED program or successful completion of the MSSE Capstone Project were identified. Risks were identified using such techniques as: best judgment, lessons learned, negative trends, forecasting etc.

Every risk event has both a likelihood of occurring and a potential adverse consequence. These attributes were assessed and analyzed in order to quantify each risk identified. The likelihood that the risk event would occur is rated on a scale from 'A' to 'E'. A level 'A' rating indicates a remote possibility that the event will occur. A level 'E' rating indicates a near certainty that the event will occur. The consequence of the event occurring is rated on a scale from '1' to '5'. A level '1' rating indicates a minimal or no impact to the program. A level '5' rating indicates a catastrophic impact to the program.

Risks were then plotted on a risk matrix. A risk matrix is a pictorial representation of risk that clearly displays risk priority based on the likelihood and consequence of each risk. The green, yellow and red sections of the risk matrix denote low, medium and high priority risks, respectively. A sample risk matrix is provided in

Figure 52.

Low priority risks may cause minimal program impact. Minimal oversight is needed to ensure risk remains low. Medium priority risks may cause some program disruption. Mitigation plans are required and may need to be executed. High priority risks may cause major program disruption. Mitigation plans are required and must be executed. Mitigation plans were constructed for all risks and were implemented based on risk priority.

Program risks are dependent on the implementation of a specific alternative. Program risks will be evaluated to compare system alternatives regarding risk. Note that, since the Baseline System will be used in each system alternative the Baseline Risks apply to all system alternatives although they are only displayed once under 'Baseline System'.

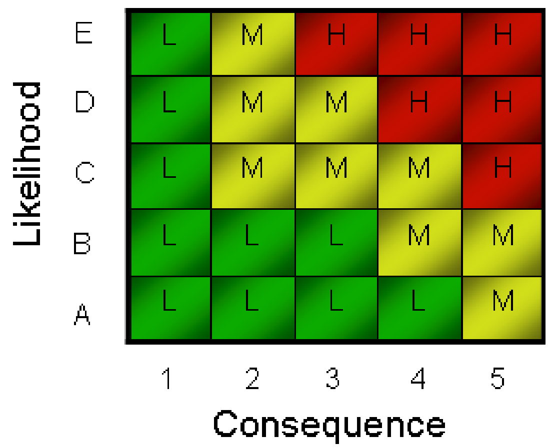

Figure 52 - Representative Risk Matrix

Four risk categories were considered for each system alternative: Development Based Risks, Cost Based Risks, Schedule Based Risks, and Organizational Based Risks. Program risks are provided by category in the following figures and described in the respective tables.

Developmental risk is the possibility that any combination of the individual components in an adaptive force package has integration, technology, or budgeting conflicts that could lead to a degradation of the capability or development of the system.

Cost risk is the possibility that the specified allocated budget will be exceeded, to include, cost over-runs and budgeted cost for the entire system life cycle.

Schedule risk is the possibility that the program will fail to meet the scheduled milestones and be delivered in time to be integrated into the Adaptive Force Package. Schedule failures can be influenced by delays in dependent technology, parts, decision, and hardware or by estimation errors.

Organizational risk is the possibility of competing or conflicting interests among customers, users, and stakeholders that could adversely affect the budgeting, acquisition, operation, or maintenance of the adaptive force package.

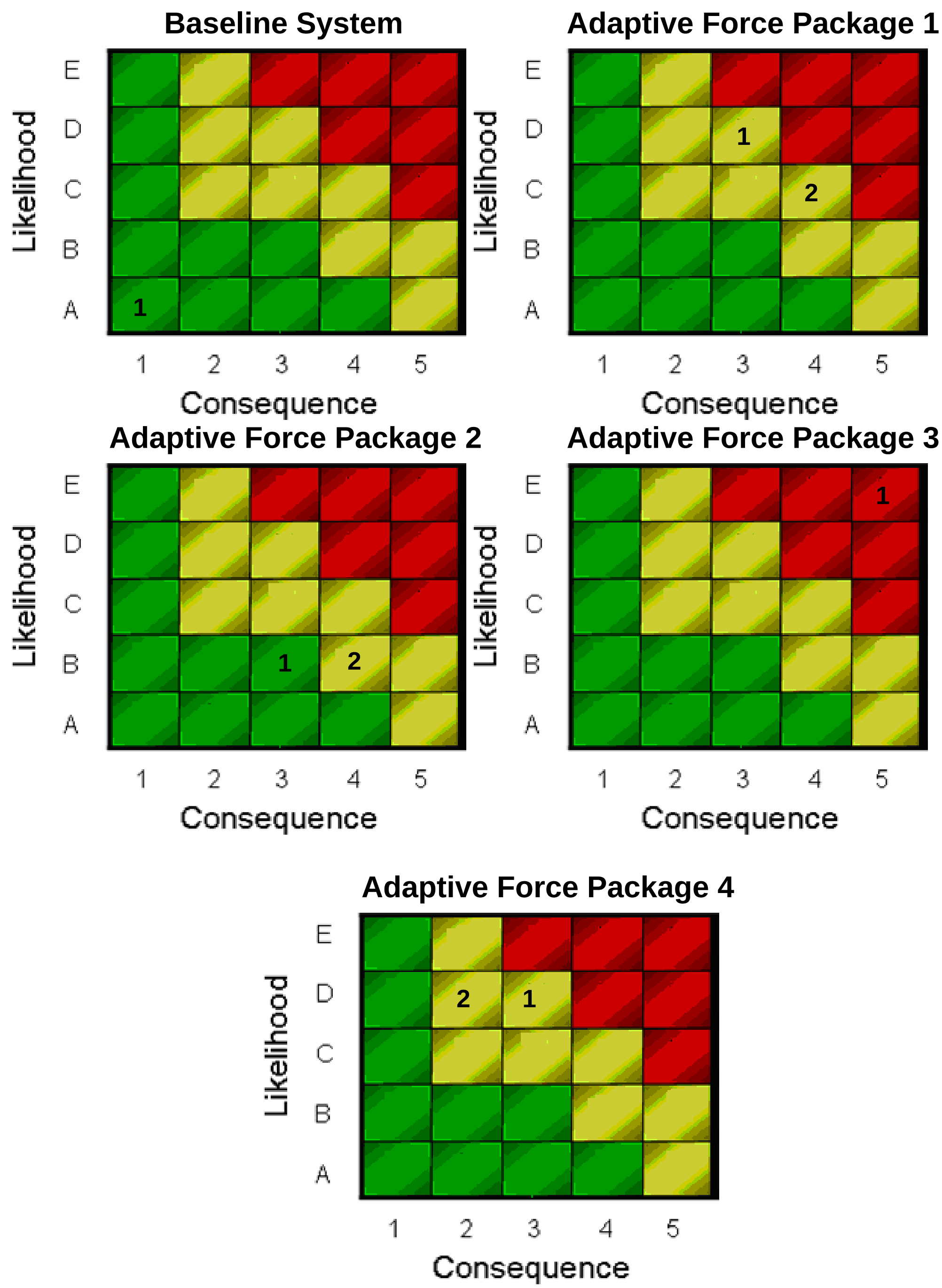

Figure 53 - Development Based Program Risks

Identification	Analysis	Mitigation Plan
Baseline System Risk 1	Low or no risk associated. The system has already gone through a number of years of satisfactory testing and operational use. This is assessed at A1.	
Adaptive Force Package 1 Alternative Risk 1	Risk that a MPCE production delayed may cause system degradation. This is assessed at D3. Currently, the LCS mission modules are tied to production of LCS ships, meaning ship delays are module delays.	Use baseline systems. Allocate more resources to R&D and production.
Adaptive Force Package 1 Alternative Risk 2	Risk of supportability issues with WLD-1. This is assessed at C4.	Use baseline systems; investigate other UUV alternatives.
Adaptive Force Package 2 Alternative Risk 1	Risk of integration incompatibility between hardware commonality systems ALMDS and RAMICS. This is assessed at B3. Currently, there is a 20% incompatibility issue between the two components.	Continue with current OPEVAL; allocate resources to development
Adaptive Force Package 2 Alternative Risk 2	Risk that there may be a delay in resolution of CSTR interface issues. This is assessed at B4.	Use baseline systems; continue with current OPEVAL, and allocate more resources to production and development.
Adaptive Force Package 3 Alternative Risk 1	Risk of difficulties with development and integration of the system. This is assessed at E5. There are currently no system requirements for the program. If requirements are established the risk will be substantially reduced.	Use baseline systems; Transition to partial capabilities that may be ready. Create system requirement.
Adaptive Force Package 4 Alternative Risk 1	Risk of difficulties with development and integration of the system. This is assessed at D3. The technology necessary for the inter-communication component of the system may cause degradation in mission capability.	Use baseline systems; Transition to partial capabilities that may be ready. Create system requirement.
Adaptive Force Package 4 Alternative Risk 2	Risk that Advanced REMUS productions delay may cause system degradation. This is assessed at D2.	Use baseline systems. Allocate more resources to R&D and production.

Table 29 - Development Based Risks

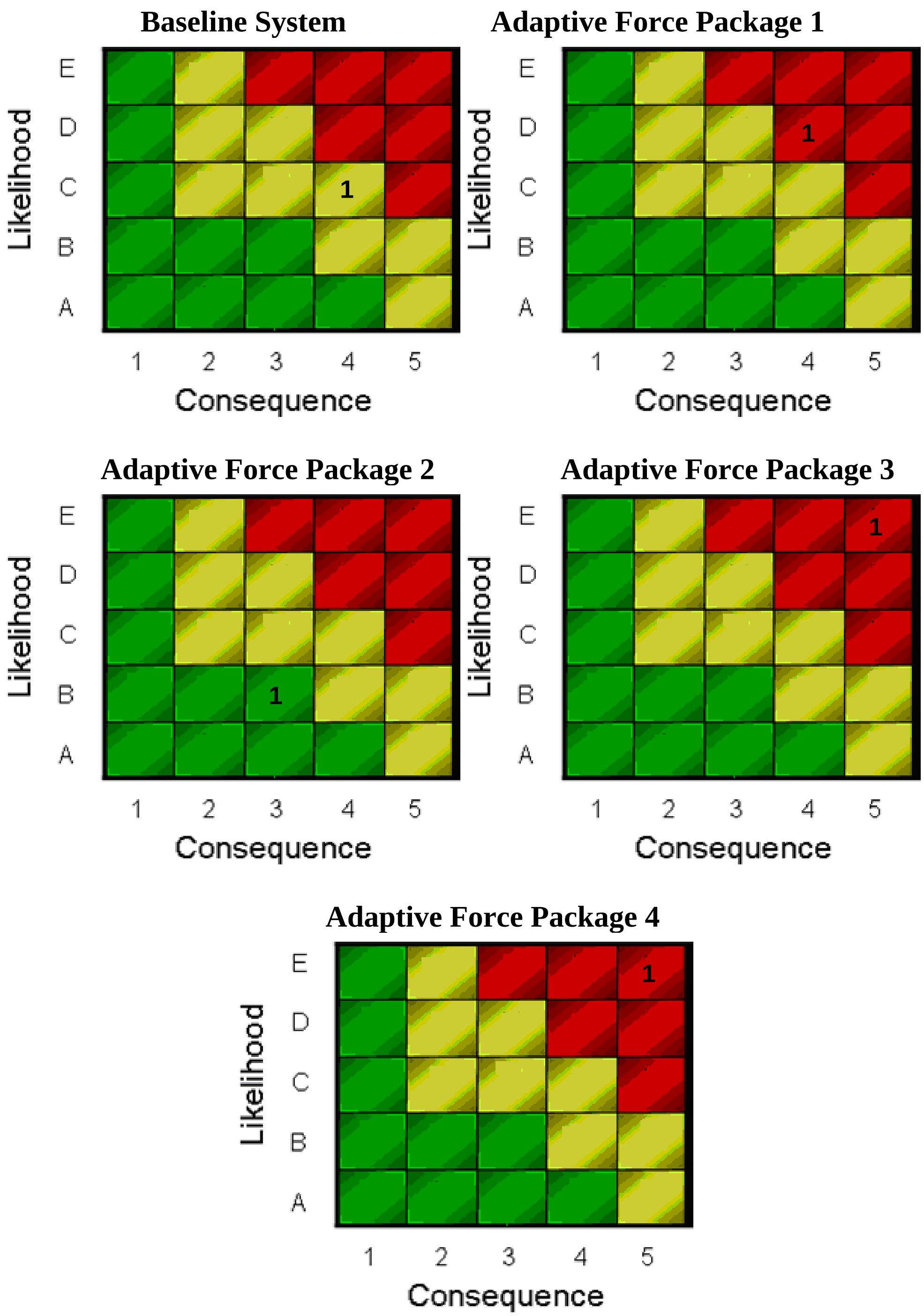

Figure 54 - Cost Based Program Risks

Identification	Analysis	Mitigation Plan
Baseline System Risk 1	Risk that a continuous funding stream is not available to support maintenance and training. *This is assessed at C4*	Assign roles and responsibilities to the appropriate agencies to be determined by higher level officials.
Adaptive Force Package 1 Alternative Risk 1	Risk that AFP 1 will not be funded adequately to achieve the required performance when it is needed. *This is assessed at D4.*	Assign financial roles and responsibilities to the appropriate agency to be determined by higher level officials
Adaptive Force Package 2 Alternative Risk 1	Risk of increased H-60 helicopter parts failure due to increased use. *This is assessed at B3.*	Account for additional maintenance requirements.
Adaptive Force Package 3 Alternative Risk 1	Risk of manufacturing and design problems that could cause some tasks for production labor to be rescheduled and not accomplished within scope of project timeline. *This is assessed at E5.* There are currently no system requirements for the program. If requirements are established the risk will be substantially reduced.	Use baseline systems. Allocate resources towards R&D. Create system requirement.
Adaptive Force Package 4 Alternative Risk 1	Risk of manufacturing and design problems that could cause some tasks for production labor to be rescheduled and not accomplished within scope of project timeline. *This is assessed at E5.* There are currently no system requirements for the program. If requirements are established the risk will be substantially reduced.	Use baseline systems. Allocate resources towards R&D. Create system requirement

Table 30 - Cost Based Risks

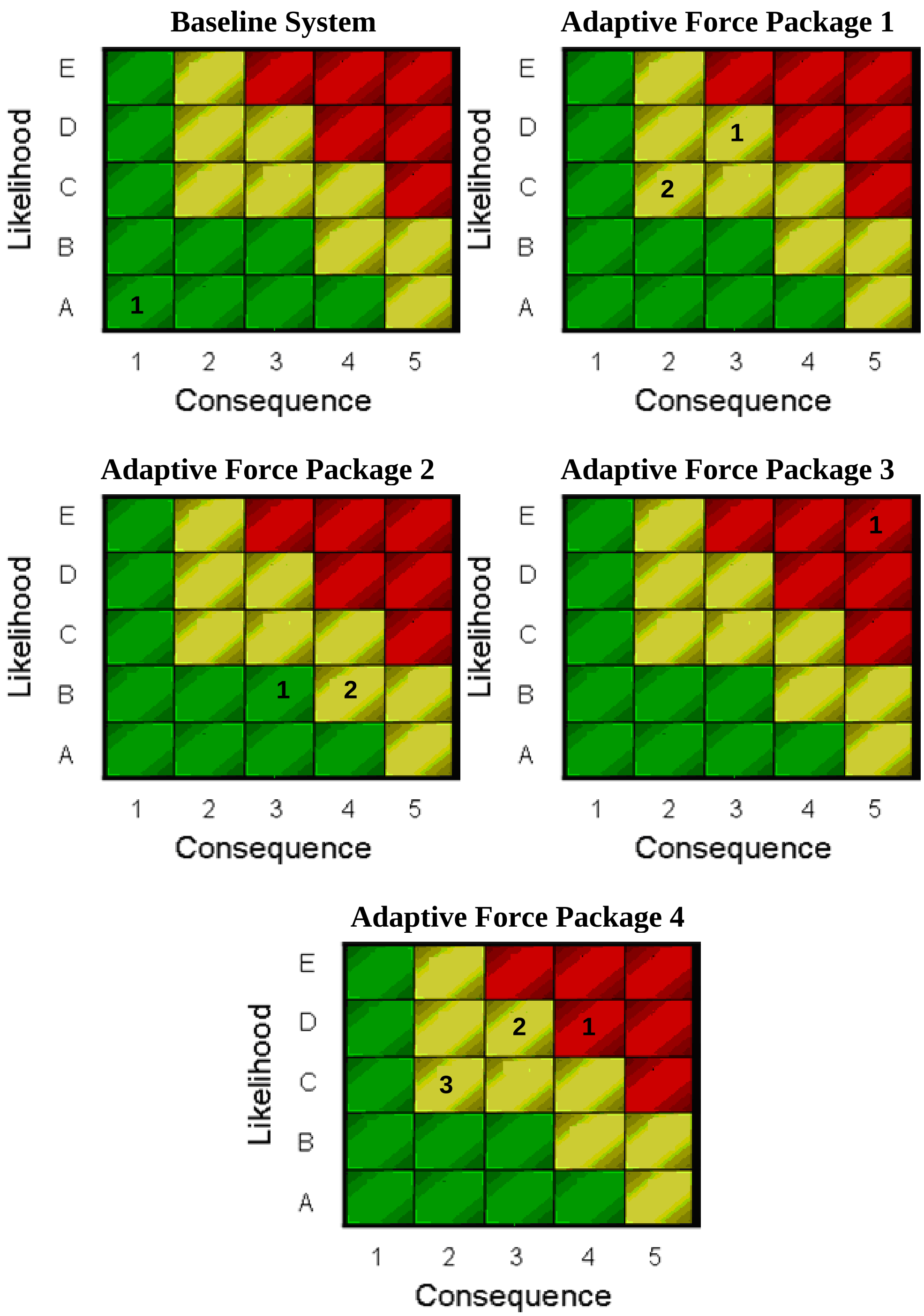

Figure 55 - Schedule Based Program Risks

Identification	Analysis	Mitigation Plan
Baseline System Risk 1	Low or no risk associated. The system is already an established program of record. *This is assessed at A1*.	
Adaptive Force Package 1 Alternative Risk 1	Risk of MPCE acquisition delay. *This is assessed at D3*.	Use baseline systems
Adaptive Force Package 1 Alternative Risk 2	Risk of MPCE schedule delay. *This is assessed at C2*.	Ensure that MPCE development is managed effectively to minimize schedule impact.
Adaptive Force Package 2 Alternative Risk 1	Risk of RAMICS schedule delays. *This is assessed at B3*.	Use baseline system; continue with OPEVAL and allocate resources towards R&D
Adaptive Force Package 2 Alternative Risk 2	Risk that there may be a delay in resolution of CSTR interface issues. *This is assessed at B4*.	Use baseline system; continue with OPEVAL and allocate resources towards R&D
Adaptive Force Package 3 Alternative Risk 1	Risk of manufacturing and design problems that could cause some tasks for production labor to be rescheduled and not accomplished within scope of project timeline. *This is assessed at E5*.	Use baseline system.
Adaptive Force Package 4 Alternative Risk 1	Risk of manufacturing and design problems that could cause some tasks for production labor to be rescheduled and not accomplished within scope of project timeline. *This is assessed at D4*. The technology necessary for the inter-communication component of the system may cause degradation in mission capability.	Use baseline systems. Allocate resources towards R&D.
Adaptive Force Package 4 Alternative Risk 2	Risk of Advanced REMUS acquisition delay. *This is assessed at D3*.	Use baseline systems. Allocate resources towards R&D.
Adaptive Force Package 4 Alternative Risk 3	Risk of Advanced REMUS schedule delay. *This is assessed at C2*.	Ensure that Advanced REMUS development is managed effectively to minimize schedule impact.

Table 31 - Schedule Based Risks

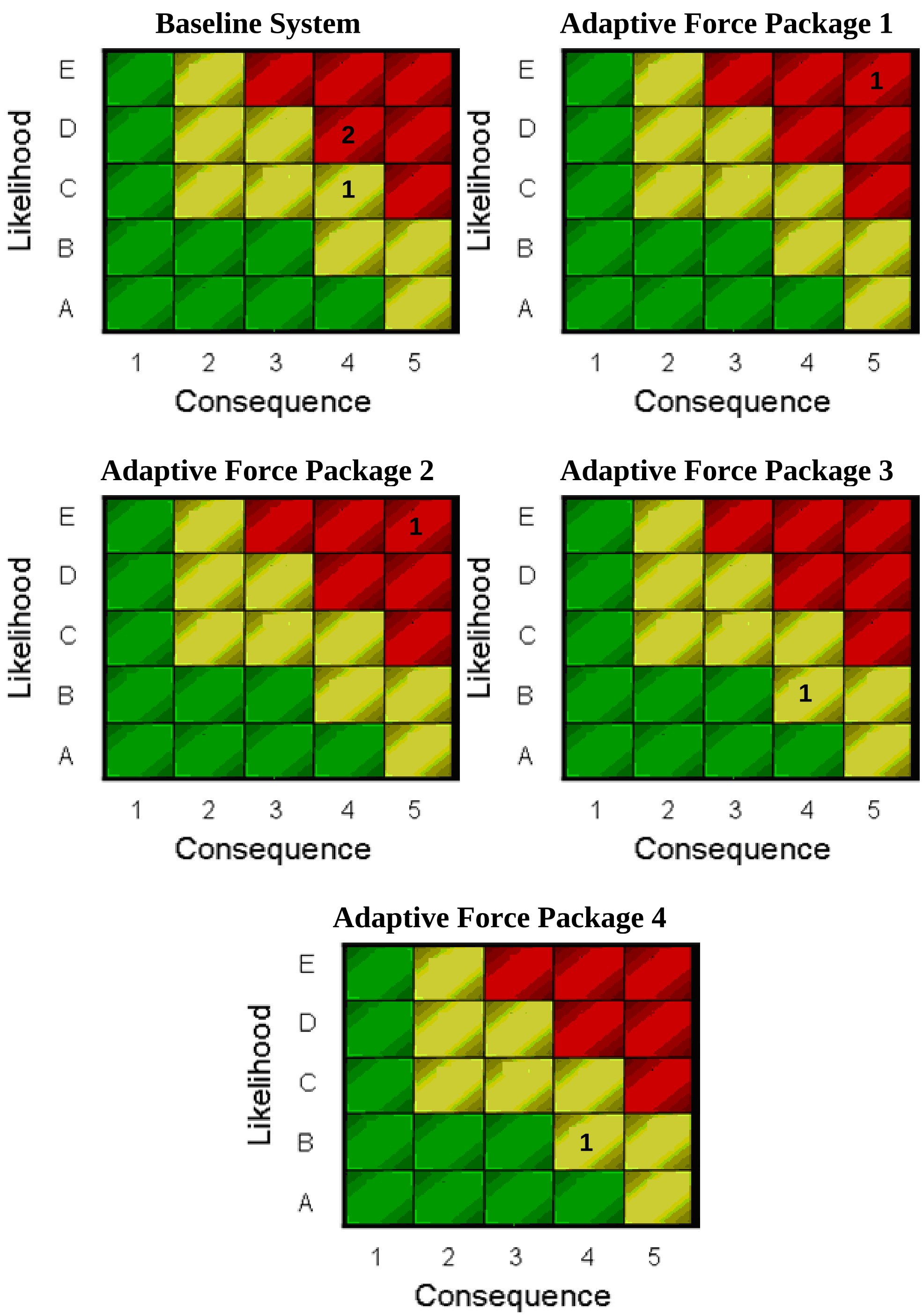

Figure 56 - Organizational Based Program Risks

Identification	Analysis	Mitigation Plan
Baseline System Risk 1	Risk of insufficient or ineffective command and control structure. *This is assessed at C4.*	Assign roles and responsibilities to the appropriate agencies to be determined by higher level officials
Baseline System Risk 2	Risk of failing to determine which of the agencies will fund the program. *This is assessed at D4.*	Assign roles and responsibilities to the appropriate agencies to be determined by higher level officials
Adaptive Force Package 1 Alternative Risk 1	Risk of conflicting asset availability. *This is assessed at E5*.	Allocate sufficient assets to the appropriate agencies.
Adaptive Force Package 2 Alternative Risk 1	Risk of conflicting asset availability. *This is assessed at E5*.	Allocate sufficient assets to the appropriate agencies.
Adaptive Force Package 3 Alternative Risk 1	Risk of conflicting asset availability. *This is assessed at B4.* This is assessed at a lower risk due to the minimal use of interagency assets.	Allocate sufficient assets to the appropriate agencies.
Adaptive Force Package 4 Alternative Risk 1	Risk of conflicting asset availability. *This is assessed at B4*. This is assessed at a lower risk due to the minimal use of interagency assets.	Allocate sufficient assets to the appropriate agencies.

Table 32 – Organizational Based Risks

5. CRITICAL ANALYSIS

In order to properly assess the viability of each Adaptive Force Package, it is necessary to critically address each of the decision variables in order to make a final determination.

The most widely used decision analysis involves the comparison of performance data to expected costs, termed Cost-Benefit Analysis. Figure 57 shows a plot of the performance scores for each AFP compared to the expected lifecycle cost.

Compared to the Baseline, all alternatives show significant increases in overall performance, as the baseline is standardized to the 0 for the performance score. AFPs 2-4 have nearly indistinguishable performance scores, but have a broad range of cost associated with that performance. Notably, AFP 3 shows a significant improvement in overall performance at a similarly significant cost savings compared to the baseline system.

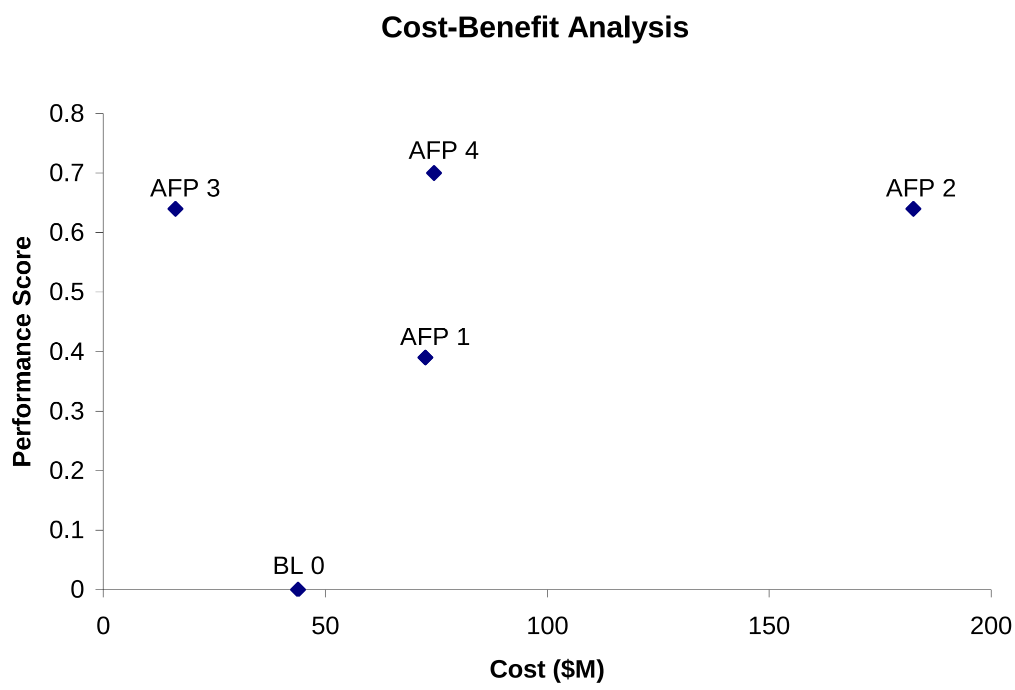

Figure 57 – Cost-Benefit Analysis

When risk is incorporated into the analysis, insights into the potential for cost overruns and performance degradation can be considered. Figure 58 shows the above plot modified to illustrate the level of overall risk associated with it.

Although AFP 3 and 4 attain high performance, the risk associated with their development is equally high due to the unproven concepts or technologies. A risk adverse decision maker may then decide to choose AFP 1 as it offers return on performance, is less costly than AFP 2, and involves less risk than AFP 3 or 4. However, a remarkably high increase in expected performance can be obtained by mitigating those risks early in the developmental stage and reduce the probability of cost overruns or performance degradation.

Despite AFP 3 containing a single body and therefore a search rate less that threshold, its performance score is still competitive with other AFPs that incorporate several bodies. Its relatively low cost would allow for the purchase and sustainment of three bodies that would make its cost and search rate comparable to the baseline and increase the overall performance score to 0.78, even higher than AFP 4.

Suitability of the alternatives should be considered in this critical analysis. As discussed previously, Figure 58 restates the overall maintainability and reliability predictions of each AFP.

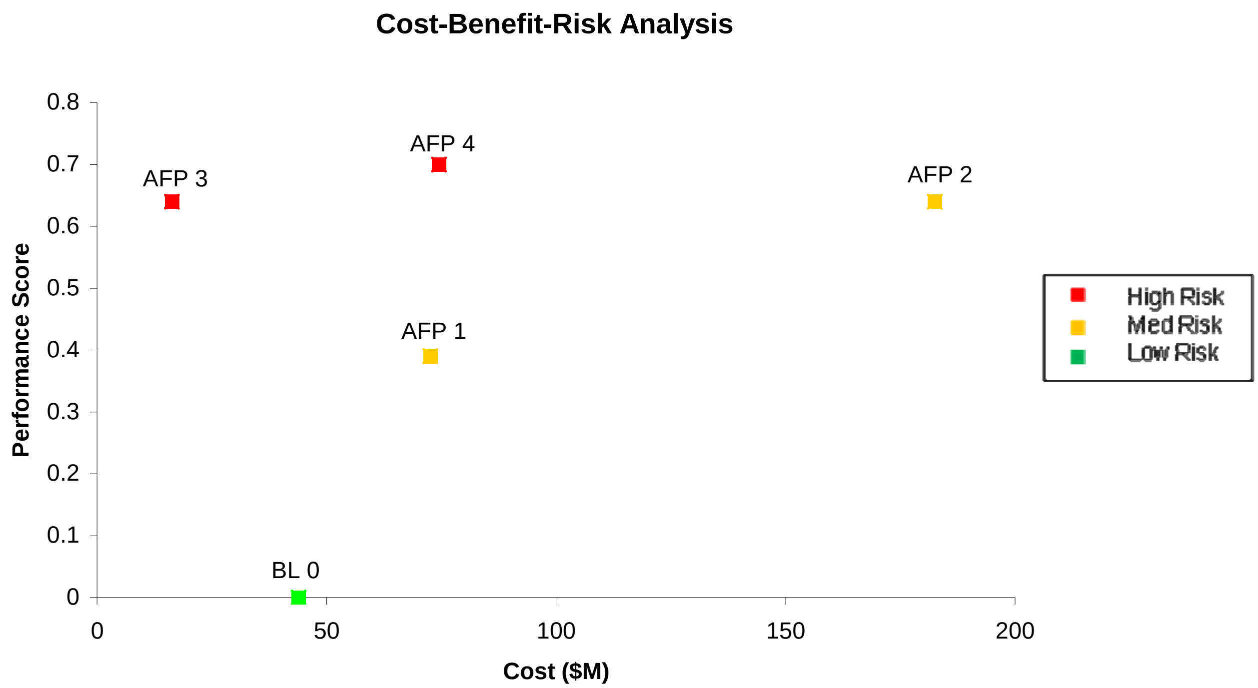

Figure 58 – Cost-Benefit-Risk Analysis

	Reliability	Maintainability
Alternative 1	High	High
Alternative 2	Low	Medium
Alternative 3	Medium	Low
Alternative 4	Low	Low

Figure 59 – Reliability and Maintainability Summary

To make the later AFPs viable, investments into suitability aspects would need to be made in order to improve their reliability and maintainability. The speculation with AFP 3 and 4 is largely due to the uncertainty of these as-yet undeveloped systems and employment. Operational testing at the component and system level may reveal more optimistic assessments of these suitability scores.

Overall, the layered approach of these AFPs, allowing for the implementation of certain components as they come online, is a suitable approach to build capability over the near to mid-term. AFP 3 and 4, while having the potential for high performance returns in the long run, must be supplemented with adequate resources in the near-term in order to reduce the risk and increase suitability scores to make them considerable for acquisition and operation.

VI. NATIONAL EMPLOYMENT

The selection of a definitive employment concept for the MIED problem could be the subject of its own study. Therefore this report will refrain from attempting to make a conclusive recommendation. However, over the course of this project much information regarding an appropriate employment concept has been brought to light, and as such the project team found it necessary to discuss those findings here. Below is our suggestion for the process of developing a national employment, followed by an example employment concept we have developed with supporting information.

Of note, the members of SEA-14 traveled around the country visiting many of our major ports for research, and observed many exercises relevant to our study. A major lesson learned from our observations is that there are many entities; government, DoD, and private, that are working on domestic port security and the MIED problem. However, there is a significant lack of continuity and cohesion at the national level, and high-level requirements for addressing the MIED problem have not been established.

For the purposes of employment development, some realities must be acknowledged. First and foremost, there is not an unlimited budget available to combat the MIED problem. As with any addressable threat, enough money could make the problem easier; but this just is not the case. A second reality is that the Navy does not currently have the assets to provide the proper coverage of ports necessary to fulfill this mission. Furthermore, the Navy is charged with defending the nation against threats abroad, while the subject of this study is the threat to domestic ports. Third, all ports are different, as will be discussed in detail below. Each port provides its own unique challenges to countering the MIED problem.

1 EMPLOYMENT DEVELOPMENT

The following is a suggested method for developing an established national employment concept. As mentioned above, the responsibility for defense against an MIED attack has not been established. The tasking of this responsibility is the first step that must take place.

1.1 Prioritize Ports

Due to the fact that the nation's ports vary largely in terms of capacity and capability, it is obvious an attack will have varying impact depending on the port. Therefore, an intermodal transportation body should be tasked to determine what ports in the Maritime Transportation System (MTS) are critical and to what degree each port requires preparation and protection from MIED attacks. A government body acting as a "Maritime Transportation System Security Council" should be established to take inputs from necessary stakeholders to determine where critical nodes are in the U.S. MTS. With the mindset of, "Where can terrorist attacks most likely achieve the economic impacts they desire?" the council should consider conducting network analysis, supply chain resiliency, tabletop discussions, input/output models, linear programming, etc. While the analysis should focus on the MTS, the counsel should take into account all intermodal aspects of the port. Furthermore, inland waterways such as the St. Lawrence Seaway and the Mississippi River should be considered as well.

Many factors should be taken into account when criticality is being determined, and numerous stakeholders should be involved. Example factors that should be taken into consideration include; port capacity, port unique facilities and capabilities (such as Liquefied Natural Gas or heavy salvage capability, etc.), military or ammunition facilities, and how vital a port and its' cargo is to downstream users and industries. In order to accurately determine these factors, input should be taken from the Departments of Energy, Commerce, Transportation, Defense, and Homeland Security, as well as the U.S. Army Corps of Engineers, the Office of Naval Research, Center for Naval Analysis, and possibly even civilian think-tanks such as RAND or The Heritage Foundation.

1.2 Prepare for MCM Operations

The second step for national employment is to prepare ports for Mine Countermeasures (MCM) operations. After responsibility has been assigned and ports have been prioritized, the ports should prepare for MCM –type operations in accordance with their level of priority.

To conduct MCM operations, extensive knowledge of the environment is of paramount importance. The sensors involved in searching for MIEDs are all very sensitive and are easily affected by environmental conditions such as bottom type, clutter density, turbidity, tides, winds, and currents. All of these conditions are unique to each port. However, they can all also be determined well in advance of an attack. With this knowledge on hand in the event of an attack, the time required for personnel to prepare for and conduct a search is greatly improved.

Preparation should not only include the determination of environmental factors; the relationships of local agencies that will likely be called upon to assist in response and recovery operations after an attack are equally important. The standing Memorandum of Agreement (MOA) for use of services and assets to include Requests for Information (RFI) of sensitive information should be well established before an event in order to provide for efficient and effective crisis management. Organizations that should be included are; the Department of Defense (U.S. Navy and NORTHCOM under Defense Support of Civil Operations), Department of Justice (FBI), Department of Homeland Security (to include Customs and Border Patrol); local fire, police, and public works departments, utilities companies, and emergency medical response personnel. The establishment of a Joint Harbor Operations Center (JHOC) can be very effective in establishing the working relationships of entities involved, and is also useful in day-to-day operations.

1.3 Port Information

After responsibility is assigned, priority is established, and local environment conditions and personnel are identified, those personnel should work to "fingerprint" the port. As mentioned, every port is different, and may require different preparations. With the above relationships established, personnel can then work determine primary and secondary triage stations; prioritize berths, anchorages, and q-routes, and identify Critical Infrastructure and Key Resources (CI/KR). Examples of CI/KR could include underwater fiber optic cables, gas lines, seawater suction chests; bridges, geographic choke points, and locks and dams.

A suggestion that is being implemented in some ports across the country is the establishment of "port folders" in which the factors from this section were developed. Port folders should be standardized nationwide, and established via the above process.

1.4 Develop Response Timelines

Just as each port in the country has its standard and unique characteristics, they also have their own impacts to the country. The same council that prioritizes the ports should also delineate acceptable timelines for port opening, and at what capacity, to avoid catastrophic impacts. Only after these timelines are established will personnel then be able to determine the numbers and types of assets required to meet the timelines.

2 EMPLOYMENT EXAMPLE

Using the method outlined above, we have developed an example employment method that would significantly increase the national level of readiness against a terrorists attack. The basis for our example employment would involve the layered employment of Regional Pre-Crisis Data Collection (PCDC) teams feeding information to a National Post Mission Analysis (PMA) Center, which can then provide data to a National Neutralization Team.

After establishing a National Maritime Transportation System Security Council in order to delineate responsibility as mentioned above, priority is given to the ports. In our case, the project team decided on using the economic throughput of the ports to establish priority. The top twelve ports in the United States are responsible for over 64% of U.S. waterborne foreign commerce. The project team felt that prioritizing these twelve ports would notionally provide good coverage of economic throughput while still allowing for an acceptable number of prioritized ports.

After the selection of these twelve ports; Los Angeles, New York, Long Beach, Houston, Charleston, Hampton Roads (which consists of three ports), Baltimore, Seattle, Tacoma, and Savannah, it was noticed they fit discretely into five regions. Seattle and Tacoma would comprise the Northwest Region. Los Angeles and Long Beach would comprise the Southwest Region. Houston, TX would comprise the Gulf Coast Region. The Southeast Region would consist of Charleston and Savannah, with New York, Baltimore, and Hampton Roads comprising the Northeast Region.

The inclusion of U.S. Fleet and Forces Command's top twelve priority ports again fit nicely into these five regions. Bangor, Bremerton, and Everett would be included in the Northwest Region. San Diego would be included in the Southwest Region. Ingleside and Corpus Christi would be included in the Gulf Coast Region. Kingsbay and Mayport would join the Southwest Region. Finally, Norfolk, Little Creek, Newport News, and Groton would join the Northeast Region.

The primary purpose of the regions is Pre-Crisis Data Collection. As discussed above, the collection of data prior to an event is of paramount importance. The regions would maintain the assets required for this collection of data. The personnel and assets required for data collection would rotate through the ports in their region, enabling the near-continuous flow of data for significantly increased readiness. The nature of regional teams ensures a level of standardization and reduced cost over individual, port-specific teams, and increases survey frequency, asset availability, and organic knowledge over a national team.

After this raw data has been collected regionally, it will be submitted to a National Post-Mission Analysis Center. This center would be established by the MTSSC, possibly at NORTHCOM or a DHS facility. Staffed by dedicated, full-time PMA subject matter experts, this centralized PMA will again increase standardization, and significantly reduce the cost and complexity associated with PMA. After analysis, the results of the surveys would be returned to the port for inclusion into an ever-evolving port folder.

Finally, a national neutralization team consisting of Explosive Ordnance Disposal (EOD) personnel and a host of neutralization equipment would be established. This team would be capable of deploying anywhere in the country very quickly, and be capable of MIED neutralization via any known technique. This, again, allows for robust, thorough coverage while providing a cost-effective solution.

In the event of an MIED threat or attack, the regional search teams will deploy to the port under attack and begin the search, detect, classify, and identify functions of response. They will be able to do so quickly, with port familiarity, and be able to rely on the well-established port folders. The National PMA center will shift to dedicated support of the incident, able to provide rapid PMA for the effort. The national neutralization team will deploy rapidly to the scene, with all assets required for MIED Neutralization.

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VII. FINDINGS AND RECOMMENDATIONS

1 FINDINGS

The findings of this project offer insight into the technical issues encountered when dealing with the threat of MIEDs, but also highlighted observations about the tools of the SEDP and applications of this project to more general usages. This section discusses the general observations about these topics that were discovered during the course of this project.

1.1 System Components

This study demonstrates the need for the development of technical advances in unmanned systems, computer aided decision-making, underwater data networks, and non-explosive neutralization techniques. The use of unmanned systems, particularly in underwater environments, reduces the inherent risk to personnel while reducing the cost of personnel normally incurred in manned systems. This savings increases the likelihood of a system being employed in mass.

An improvement in operational timelines is noted when systems integrate CAD/CAC programs and underwater acoustic networks. By enabling search systems to capture selective data of interest to decision makers and equipping them to transmit that data without stopping the search process, the time it takes to clear a given search area is reduced by 50-75%. This savings is realized by not having to process search data after the sensor has completed its search, which recent exercises suggest takes up to three times as long.

Novel, non-explosive neutralization is key in domestic ports to protect infrastructure, prevent public distress, ensure safety of personnel, and provide more useable data for forensics collection and criminal prosecution. Systems modeled with this capability had a high performance score, largely due to the relatively high weight the neutralization MOP had on the score. This area is emerging as a concept that could provide huge benefits to defeating domestic MIEDs and warrants further research and development.

1.2 Wargame Use in HLD/HLS Scenarios

SEA 14's use of wargaming demonstrated the benefit of simulations such as JCATS to model HLD/HLS exercises in general, and MIED scenarios in particular. These programs are particularly useful in modeling a mixture of technical concepts, probabilistic models, and human factors. The scenarios, databases, and lessons learned offer a spring board to further studies that may develop and improve these tools to provide an even better representation of an MIED incident. Further developing conditional stochastic models to represent component-level performance and "soft" areas such as human factors and stationing times would improve the validation of this modeling tool.

However, the use of this complex tool requires trained users, supported by subject matter experts, and dedicated for a considerable amount of time to building scenarios, validating databases, and executing the program. SEA 14 was fortunate to have sponsorship by US JFCOM and JIEDDO, and supported by those organizations in addition to NPS faculty and staff, CAW, and the Port of Seattle. However the dedication of two people for the propensity of the project schedule was a significant strain on the work load of the project team. It is recommended that the use of wargaming be used by SEA and similar projects when there is sufficient time, manpower, and resources to ensure personnel are trained, support and funding is available, and will not cause a significant increase in work load.

1.3 Performance Modeling

The methodologies used to model performance may lead to potential variation in the results and need to be further studied in order to validate the performance claims of the project. AHP, used to determine the weighting scale of functions and measures of performance based on formal stakeholder input gathered from a survey, has been criticized as having flaws that may lead to assumed order where no order exists, rank reversals, or biased results depending on flaws in the verbal scale used in the survey. Alternate methods of multi-criteria decision analysis are available, but not practiced in this study due to time and resource constraints. These alternate means should be explored to validate or repudiate the project findings.

Similarly, a sensitivity analysis of the measures of performance weights and their effects on overall performance scores should be conducted, but was again omitted from this project due to time and resource constraints. The effects of varying MOP weights on system performance is not known, but given the range of raw performance data and the often complementary performance of one AFP over another, its probable that as particular MOPs are weighted more heavily, overall performance marks could shift dramatically. This study acknowledges this shortfall and recommends a sensitivity analysis of the MOPs as a follow-on project.

Lastly, the threshold and goal limits placed in the performance analysis introduce the possibility of systems with an extremely high or extremely low MOP score being unfairly judged, as extreme outliers with an improvement over 20% of threshold do not receive a higher score. Therefore, it is recommended that a series of utility curves for each MOP be developed to ensure outlier data does not unfairly affect overall performance scores.

1.4 Expeditionary Applications

Although not addressed specifically in this study, the use of these systems in expeditionary operations shows potential. However, the organizational problems coupled with a lack of reliable infrastructure compounds the problem, more so than in a domestic setting.

In an MIED threat in a foreign port that threatens U.S. commercial and military interests, there is likely a lack of command and control structure and multiagency plan that will assist in mitigation efforts. There are also concerns about what capabilities the host nation has available to resume port activities. The need for strategically significant commercial ports around the world to develop an incident response plan that addresses maritime homeland security, similar to the NIMS, needs to be implemented. Contingency planning and security measures need to be regulated and standardized in the largest commercial ports. One means of doing so includes the involvement of non-government organizations, such as the IMO or insurance companies, to pressure ports to train personnel, properly equip them, and exercise them in MIED scenarios.

Unlike in a U.S. port, information about the environment of a foreign port may not be accessed or obtained. However; it is critical that the U.S. Navy in conjunction with the port authorities and indigenous naval forces conduct port surveys in several of the strategic foreign ports that are routinely accessed by U.S. Naval ships. Senior Navy leadership needs to dictate the prioritization of ports that the Navy is willing to assist in conducting baseline level surveys on foreign shores, using a similar process used to designate priority domestic ports as outlined in Section V.

Many of the assets presented in this study can be applied toward clearing a foreign port. The use of unmanned submersibles, EOD personnel, small vessels and towed equipment would constitute the first line of defense against an MIED threat inside commercial waterways. One concern is that if the Navy were to take a significant role in addressing security in foreign ports, additional resources would be required. Several more EOD teams would be needed as well as submersibles and their support equipment. Also these teams would have to be ready to deploy at a moment's notice to ports around the world in the event of a crisis.

The sustainment and funding requirements in taking the MIED problem beyond the scope of domestic ports will be similar. The Navy does not have the funding or resources to conduct all of the surveys it needs to in domestic ports simultaneously with surveys done abroad. The Navy must seek partnerships with host nations, global maritime organizations, and the IMO to help fund the surveys and to ensure that the information in port folders is kept current.

The need for an international legal framework is essential to a rapid response. An agreement between the Navy, host nation port authorities, and maritime security partners is required in order to allow forces to be employed quickly without political and administrative pitfalls in the event of a crisis. The goal is to establish a memorandum of understanding so that the U.S. Navy can conduct or support counter-MIED operations in a host country during peace time.

Considering lessons learned during this project, there are measures that need to be addressed without delay on the domestic front as well as abroad regarding the MIED problem. The safety of equipment, economic interests, and personnel on foreign shores is of great importance, and an MIED attack is more likely to occur in a foreign country than in the U.S. International agreements need to be developed and contingency plans made allowing the use of naval assets in a foreign port. The Navy must acknowledge the significance of the vulnerability of ships from MIEDs when entering a foreign harbor. When it occurs, all eyes will be on the U.S. Navy for answers and it must be ready to meet the challenge and lead others in combating MIED terrorist attacks.

2 RECOMMENDATIONS

The lessons learned in this study are beyond the initial scope of the project and the SEDP, but offer insight into issues at the highest levels of the MIED problem. These recommendations are the product of the technical research that was conducted in support of this project, and the organizational issues that were highlighted along the way. This project makes four overarching recommendations, each with supporting points and enabling mechanisms.

2.1 Set Timelines for the Clearing of a Port

The first and arguably most important recommendation is the setting of timelines for the clearing of a port and how long it must take to restore to normal operations. This timeline must account for the importance of that port to the national economy and other effects that are more port specific. Such effects to consider include any specific commodities the port deals with, including natural gas, of which there are only five ports nationwide capable of receiving this import.

Only after the baseline timelines are established can the determination of mission requirements at the operational and tactical level occur. A designated coordinating agency can then develop the roles and responsibilities of first and second responders deployed to the scene of an MIED attack or threat.

These requirements must also justify adequate funding for sustained manning, training, and equipment. Although grants are useful for the rapid procurement of capability, the need for adequate funding for sustainment cannot be over-emphasized. Many ports have excellent security gear, purchased with grant money, sitting unused in storage due to the lack of funds to man and maintain the gear properly.

2.2 Set National and Local Priorities

Priorities must be set at the national and local level. The threat of an MIED attack, although a "low probability" event, must be acknowledged as having the potential for extremely high impact to commerce and industry. Therefore, it must become a national priority to establish defense against these attacks. Once that establishment has been made, it must be decided which US ports require coverage of the counter-MIED system, and as stated before, to what timetable is desired to mitigate long-term impact to the MTS.

At a local level, port leadership must decide which areas are of most importance to their port industry so that focused recovery operations can begin almost immediately after an attack. These decisions must be documented, trained to, and developed by all stakeholders that would be influenced by an underwater attack.

Figure 60 shows a map of the approaches to LA/Long Beach. This map shows two means of approach, the Queen's Gate and Angel's Gate. After a baseline survey was conducted in support of LEAD SHIELD III, it was discovered that the Queen's Gate approach offered a much better underwater picture with a third of the contacts. This fact could make this approach better suited for a rapid survey and clearance route. These types of discoveries can only be made if baseline surveys are completed and documented.

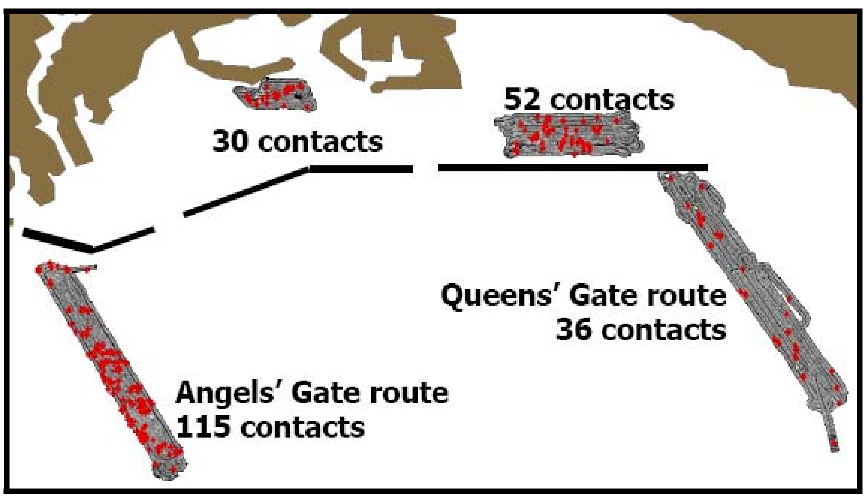

Figure 60 – Approaches to LA/Long Beach

2.3 Make Early Investments

Additionally, in order to enable the system concepts discussed to be brought to fruition, investments must be made in the near-term to develop these technologies and improve system performance. The need for safe, non-explosive neutralization techniques due to the unique environment of domestic ports must be emphasized. The use of underwater communications and CAD/CAC algorithms has the potential to greatly reduce the time it takes for operation completion and has potential for use in other warfare areas, highlighted by programs such as SeaWeb and UV Sentry, ongoing projects from ONR, NPS, NSWC, NUWC, and SPAWAR for applications in force protection and port surveillance.

The Navy is a leader in the usage of underwater sensors. However, these systems were often developed for deep, blue water purposes. The effects of port environments, geography, and hydrography have not been well studied. These effects must be better understood in order to develop sensing platforms optimized for near-shore employment.

Exercises must be developed that flex the true capability of systems and responsible players. Although MIED exercises have improved in quality and quantity since 9/11, true multiplayer exercises involving all required players flexing interagency coordination have not yet occurred. Often exercises have been conducted to test a particular concept or technology. A series of holistic exercises flexing the interagency coordination as a means of counter MIEDs in various ports is required to fully understand the complexities this threat poses and the capabilities that must be built and maintained to offer a credible, reliable counter-MIED capability.

2.4 Develop Force Multipliers

Finally, the development and implementation of force multipliers is vital to reducing operation timelines and improving efficiency.

For example, the use of port folders is a concept that could be utilized today by Captains of the Port and area maritime security councils. By cataloguing priority data, the location of CIKR, and MCM applicable environmental data, first responders have a wealth of timely data in which to begin operations.

These folders are tantamount to building a common underwater picture that can be used to reduce the timeline. Experiments have shown that by cataloguing underwater contacts before a crisis occurs, the number of contacts that require prosecution can be reduced by 50-90%. By simply comparing recorded imagery to surveys conducted after an incident has occurred, time that would normally have been spent investigating historical contacts can be reduced or even eliminated, allowing for assets to only engage newly discovered contacts. Only by conducting baseline surveys before a crisis and recording that data in a useable form can these time savings be realized.

In order for the data to be shared, this data must be standardized to allow for barrier-less data sharing. If the data collection and maintenance is standardized, data can be collected by several entities, ranging from national data collection teams to port authorities that want to lean forward in collecting underwater data.

The Limited Objective Experiment in Tampa Bay included a team from the Florida State University Underwater Crime Scene Investigation Team. The tools and procedures they use could provide early intelligence into the nature of underwater threats and their chemical composition and enable the collection and prosecution of forensics data for use in criminal investigation. The full potential of this capability has not been fully realized and requires exercises enabling the integration of UWCSI and MCM methods. Early coordination of forensic analysis is crucial. Surveying for data could potentially delay clearance operations, and therefore must be coordinated with the Incident Commander through the MCMC in order to ensure the IC's priorities are met.

All players involved in Maritime HLS/HLD should be familiar with the Incident Command System. ICS is a standardized, on-scene, all-hazard incident management concept that coordinates interagency response teams. This structure is used in all incidents ranging from wildfires to hurricane recovery and is the means by which multiple agencies communicate and coordinate response. The Navy in particular, that has had limited exposure to this structure, should train responding personnel to ICS standards in order to ensure a smooth integration of Navy capability into the command structure.

Since the potential for disaster was first realized in the wake of 9/11, the nation has made limited headway in taking preparations to protect our ports and seaways. Despite this, there is still much work to be done, starting with the acknowledgement of high-ranking government officials that a solution to this threat warrants development and employment. As Dr. Scott Truver, proponent of countermine and MIED programs stated in his Naval War College Review article, "…as we address America's "threat-rich" maritime security problems we must become mine and [MIED] conscious, if not "last week" then certainly *before* a terrorist's weapon ruins our day."

APPENDIX 1
TASKING ORDER, AS ISSUED

NAVAL POSTGRADUATE SCHOOL

30 Jan 2008

MEMORANDUM FOR SEA-14 STUDENTS

Subj: SEA-14 CAPSTONE PROJECT OBJECTIVES

Enclosures: Tab A: Background for Capstone Project Development
Tab B: Preliminary objectives for the Maritime IEDs, Mines, and Port Security Portion of the Project
Tab C: Preliminary objectives Interdependency in Organic Mine Warfare Programs Portion of the Project

1. The objective of this memorandum is to provide guidance for the conduct of the integrated project which is required as partial fulfillment for your degree. You will deliver your completed and approved project report and final briefing on or before 10 December 2008, in accordance with the following plan and milestones.

   (a) Develop a project proposal and a project management plan during the Spring Quarter 2008 for each project tasking. These proposals and plans will serve to focus your initial research and analysis. You should plan to review and update the plans frequently as you progress with your research.
   (b) Conduct project reviews approximately every six weeks, finishing with a final brief to be scheduled for the first week of December 2008.
   (c) Begin outlining and preparing your Project Reports as early as you can. Work with your faculty advisors, about every week, to prepare your Project Reports for their approval and signature. The edited final report is due on 15 December 2008.

2. Background information on the character and the project objectives is outlined in Tab A. The preliminary objectives statements for the two portions of the project are contained in Tab B and Tab C. It is suggested that your initial efforts be aimed refining these objectives statements, based on research of current guidance documents and subject to the approval of your faculty advisors. You should plan, at an appropriate time, with the concurrence of your advisors, to divide yourselves into two sub-teams, based on the Tabs B and C objectives. Your final report should address

the relationship of the two portions; the Tab C objectives study may be included as a portion of the overall report – it is not necessary for there to be two separate reports. You are expected to work as a team on the full scope of the problems outlined, with strong interaction between the two sub-teams.

3. You will be expected to identify and integrate students and faculty from across the campus -- and other resources from outside the school -- to participate directly in your project or to provide source documents, technical knowledge and insights, and knowledge of evolving requirements, capabilities, and systems. This participation could include students who would join your groups, students doing related individual thesis topics, faculty inside or outside NPS who have expertise related to your project, and appropriately engaged government agencies and industry developers. Current NPS research projects that have relevance to your project include OR thesis work related to side scan effectiveness and Port Security War Gaming by the Chair of Mine Warfare. It will be your responsibility to integrate the efforts of outside participants into your projects and your final report. Your faculty advisors will, of course, assist in these efforts.

3. You should employ the systems engineering and analytical methodology you have been learning in your class work and from your advisors. Your role in the campus-wide integrated project is that of the lead project systems engineering team. In this role you will complete the Project Concepts Exploration phase. This will require you to do a Stakeholder Analysis and Needs Analysis to determine operational requirements for the systems which will solve the problem the stakeholders have defined. You will have to define the functions and performances of your system. In executing these tasks you will be defining and understanding the overall project requirements (recognizing that this definition process is iterative and will evolve as the project progresses).

4. You will have to define the selected concepts for supporting systems (the components in your systems) and partition the overall system requirements to be addressed by supporting teams of students and faculty. Your role will include providing central guidance and requirements clarification and resolution, working with supporting teams, and completing your tasks according to your schedule. Ultimately, you will be responsible for integrating the work of supporting teams with your own to form a coherent, cohesive, finished report of the overall project.

5. Background research of the references listed in Tab A are only a beginning. You should also become familiar with related past SEA projects such as Maritime Security and other analytical studies concerning port security from RAND, IDA, CNA and other institutions and civilian industry.

6. The grades assigned to the participants in these projects will be pass/fail, and will be assigned by the lead faculty advisor. Although you will work as part of a team, your individual performance will be the basis for this evaluation. Successful completion and documentation of your project is a degree requirement.

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Distribution:
SEA-14 students
Profs Hughes, Papoulias, Paulo, Smith, Stevens, Solitario, Kline, Hoivik, Olwell, Eagle, Harney, Langford, Dean Boger, Dean Kays, Dean Purdue, Dean Ord, Dean Beck, Col Smarsh, CDR Burton, CDR Schiffman

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Tab A

Background for Capstone Project Development

Objective

- Provide educational content appropriate to future professional careers as senior leaders.
- Apply course content to execution of projects.

Character of Capstone Projects

- Address future security environments.
- Relate strategic objectives, systems concepts, operational concepts, and technologies.
- Tailor topics to group size and composition.

Guidelines for SEA-14 Capstone Project Development

- Establish homeland specific needs to counter a domestic mining threat in naval and civilian ports.
- Working together, the SEA-14 students will derive threat types and levels.
- Consider your Maritime Mine Port Security system to be capable of employing and supporting interagency forces.
- Develop other faculty and student roles for the cross campus integrated projects

Sources of guidance on current national maritime objectives

- NSPD-41/HSPD-11 “Maritime Security Policy”
- National Strategy for Maritime Security
- National Plans for Maritime Security
- Maritime Operational Response Plan

Related CNO guidance

- Maritime Strategy
- Navy Strategic Plan
- CNO Guidance for 2010 POM
- Naval Operational Concept

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Tab B

Port Security Systems to counter mine Objectives

Design a system of systems to employ a regional or port specific port security system to counter the threat of mines or MIEDs. The system should be capable of collecting and responding to maritime intelligence, surveying, and conducting timely response to open ports for maritime traffic. The system must operate in an interagency and joint environment. Consider current fleet structure and funded programs as the baseline system of systems to execute port security operations in developing these concept of operations, then develop alternative architectures for platforms, manning, command and control, communication, and operational procedures to evaluate against the current program.

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Tab C

Defining program interdependencies in the Organic Mine Countermeasure System

Describe the requirements and current system programs to employ the Organic Mine Countermeasure concept. Measure the level of inter-dependencies between component programs and identify critical key technologies in the current programmed system. Use this programmed system as a base case and design system enhancements to lessen technical and operational risk of achieving the Organic Mine Countermeasure concept, or identify areas of potential investment savings. Relate this project with the ability to respond to homeland defense requirements as well as world-wide requirements for organic mine countermeasures.

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APPENDIX 2
EXERCISE ANALYSES & POST-TRIP REPORTING NOTES

A.2.1.

PORT OF CHARLESTON (01 April – 04 April 2008)

Objectives: Visit Project SeaHawk in Charleston, SC to see how one of the nation's best Joint Harbor Operations Centers is preparing to the MIED threat.

Conclusions: Project SeaHawk is a congressionally funded pilot program that was developed in 2002, in large part by Senator Ernest F. Hollings, to create an interagency and joint operations control center to coordinate and integrate the efforts of multiple assets. SeaHawk was officially established by Congress in 2003. "Project SeaHawk is designed to demonstrate the value of interagency cooperation, joint operations, unity of command, and the sharing of intelligence and information to drive the risk-based allocation of homeland security/law enforcement resources across federal, state, and local jurisdictions. Project SeaHawk brings together the maritime and intermodal law enforcement operations, intelligence, and investigations of about 30 different federal, state, and local agencies with jurisdiction over one or more elements of the intermodal transportation system in South Carolina. Project SeaHawk is funded by DOJ and operates under the National Incident Management System/Incident Command System." (CAPT Beeson, USCG).

Although there is a high degree of interagency communication and a heightened Common Operational Picture (COP) there is no Common Underwater Picture (CUP). The port has a acquired a Klein 4000 Side Scan Sonar (SSS) for law enforcement personnel to use, there can be huge improvements in the capability to counter MIEDs.

A.2.2.

PORT OF SEATTLE (28 April – 01 May 2008)

Objective. Discuss Emergency Response Procedures (ERPs), research process of port security and relationships with CG and Local Authorities. Discuss authorities, equipments and capabilities and limitations of all entities during a casualty or threat.

Conclusion. The Port of Seattle, Sector Commander, CAPT Metruck will support SEA-14 to the fullest of their availability. They are interested in what we develop and will serve as a sounding board for ideas, concepts and future SEA-14 capstone developments. Ports are ill-equipped to prevent the emplacement of an MIED. They must wait until attacked, and then respond. From and equipment standpoint, ports have ample money through grants that may be used to purchase new equipment, but are not afforded any grant money to continue required maintenance and operation of such equipment.

A.2.3.

FRONTIER SENTINAL PORTSMOUTH EXERCISE (11 – 14 June 2008)

Objective. The purpose of the Frontier Sentinel series was to exercise a coordinated planning and response plan to maritime threats to North America. The scenario for this exercise involves an underwater mine explosion located near Portsmouth, N.H. It involves the coordinated detection, assessment and response to a maritime security threat to Canada and the U.S. Frontier Sentinel exercise's objective was to practice, evaluate, and recommend improvements for multi-agency responses to maritime security threats with a focus on underwater mine detection and countermeasures.

Conclusion. Intelligence is the primary factor that most-effects the ability of personnel to deter and respond to an MIED or threat of an MIED. The DOD is not capable of handling the MIEDs in commercial ports and must defer to DOHS/USCG. COTP should implement Pre-planned Responses (PPRs) and coordinate the efforts of all civilian agencies.

A.2.4.

HONOLULU HARBOR EXPERIMENT (19 July – 25 July 2008)

Objective: Honolulu Harbor Experiment was developed to complete baseline sonar surveys of Pearl Harbor and Honolulu Harbor, to exercise interoperability between USCG COPT and USN MCM forces, and exercise the CNMOC change detection methodology. Additional objectives are to discuss mine warfare threat indicators and response escalation, discuss the command and control structure, and discuss measures to secure harbor facilities and vessels in a mine threat situation and, what required preparations required for the arrival of an MCM force.

Conclusion: The baseline sonar survey was conducted in both Pearl Harbor and Honolulu Harbor. Priority search areas were identified by the COTP and additional searches were ordered. Change detection was made difficult that due to a large amount of clutter on ocean bottom. It was also determined that survey data may become obsolete after 12 months, requiring a new complete sonar survey. UUV operations witnessed which allowed for a deeper understanding of their capabilities and limitations.

A.2.5.
TAMPA BAY EXERCISE (21 August – 28 August 2008)

Objective: The Tampa Bay Experiment was conducted to determine the applicability and feasibility of deploying an Adaptive Force Package in support of civil authorities and in response to a MIED threat. Maritime operations were closely coordinated with the USCG Captain of the Port and include some operations initiated from the Coast Guard station. The essential elements of the experiment are detailed surveys of selected locations within Tampa Bay and tactical employment of sensors, following simulated terrorist actions, using exercise mine shapes and MIED. The primary experiment objective is the platform-independent employment of MIW Mission Modules, heretofore envisioned as deployed only from the Littoral Combat Ship (LCS).

Conclusion: SEA-14 witnessed the successful use and implementation of the LCS MIW Mission Module to search and detect exercise mines and mine-like objects, calling this applicability and feasibility an Adaptive Force Package.” This was the first time the LCS MIW Module was used separate an actual LCS hull. Additionally, the Incident Command Structure (ICS) was used and a C2 structure was implemented in way that has not been performed in previous harbor security exercises. In addition, a first, Florida State University's College of Criminology's underwater crime scene investigation dive team gathered forensic evidence, which was analyzed, on location by the National Forensic Science Technology Center's mobile crime lab.

A.2.6
NAVAL SURFACE WARFARE CENTER (9 September – 11 September 2008)

Objective. Establish a detailed knowledge of tactics, processes, legacy systems and systems under development. Discuss SEA-14 ideas with system and warfare experts.

Conclusion. Met with current project managers and engineers to discuss various project and observed demonstrations. Gathered detailed data, regarding capabilities and limitations, for various systems to be utilized during follow on JFCOM hosted war games. Further, other potential uses or modifications to currents systems were discussed as it relates to feasibility. Discussed TACMEMOs under development within the Tactics and Analysis Department, and lessons learned to be implemented. Compared notes with respect to lessons observed from the previous Tampa Bay exercise.

APPENDIX 3
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