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SYSTEMS ANALYSIS OF ALTERNATIVE ARCHITECTURES FOR RIVERINE WARFARE IN 2010

by

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December 2006

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13. ABSTRACT

This thesis analyzed the Navy's proposed Riverine Force (RF) structure and capabilities of 2006. Systems Engineering and Analysis cohort 10 (SEA10) developed a cost-effective system of systems which increased battlespace awareness and situational responsiveness for 2010. Riverine missions were decomposed into their functional, physical, and operational architectures using the detect-to-engage sequence. This analysis determined critical RF functions. Critical functions detect and engage were then physically represented by feasible force package alternatives that augmented the baseline RF. SEA10 analyzed these alternatives using agent based models to identify baseline RF capability gaps and provide insights into possible solutions.

Reduction of modeling data indicated the baseline force was as effective as some upgraded force packages depending on the measure of performance (MOP) or scenario structure under scrutiny. Sensor augmentation demonstrated significant improvements to baseline performance by increasing battlespace awareness. Weapon augmentation alone did not significantly improve baseline performance by increasing situational responsiveness. Combined sensor-weapon augmentation performed well across all MOP and scenarios. The Unmanned Surface Vehicle (USV) was the most cost-effective alternative. Dedicated helicopter support demonstrated the best performance overall, but was the most costly alternative.

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THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user. Furthermore, every attempt was made to collect the most accurate cost estimation figures, but these values should not be viewed as verified or validated, and should be thoroughly investigated before given consideration in actual acquisition decisions.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

Acronyms Used:

AAV	Amphibious Assault Vehicle
ABS	Agent Based Simulation
ACE	Air Combat Element
AO	Area of Operations
ATFP	Anti-Terrorism Force Protection
ATGL	Advanced Tactical Grenade Launcher
BFT	Blue Force Tracker
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAPT	Captain
CAS	Combined Air Support
CENSECFOR	Center for Security Forces
CFFC	Commander Fleet Forces Command
CNA	Center for Naval Analysis
CNO	Chief of Naval Operations
COASTS	Coalition Operating Area Surveillance and Targeting System
COLMAR	Colombian Marines
COLNAV	Colombian Navy
COMMS	Communications
CONOPS	Concept of Operations
DoD	Department of Defense
ECRC	Expeditionary Combat Readiness Center
EOD	Explosive Ordinance Disposal
ESF	Expeditionary Security Force
ETT	Expeditionary Training Team
FAC	Forward Area Controller

FARC	Fuerzas Armadas Revolutionarias de Colombia
FCS	Fire Control Solution
FFBD	Functional Flow Block Diagram
FFD	Functional Flow Diagram
FLIR	Forward Looking Infrared
FY	Fiscal Year
GCE	Ground Combat Element
GPS	Global Positioning System
GWOT	Global War on Terror
HUMINT	Human Intelligence
IED	Improvised Explosive Device
I/O	Input/Output
IR	Infrared
ISR	Intelligence, Surveillance and Reconnaissance
JFMCC	Joint Force Maritime Component Commander
JTRS	Joint Tactical Radio System
KAA	Khar Abd Allah
KM	Kilometers
LAN	Local Area Network
LAV	Light Armored Vehicle
LCDR	Lieutenant Commander
LCM	Landing Craft, Mechanized
LCU	Landing Craft, Utility
LOC	Lines of Communication
LOS	Line of Sight
LT	Lieutenant
MANA	Map-Aware Non-Uniform Automata
MAX	Maximum
MCAG	Maritime Civil Affairs Group
MCO	Major Combat Operations

MDSU	Mobile Diving and Salvage Unit
MEDEVAC	Medical Evacuation
MM	Millimeter
MOE	Measure of Effectiveness
MOP	Measure of Performance
MRF	Mobile Riverine Force
MTT	Mobile Training Team
NAVELSG	Port Handling/Expeditionary Logistics
NCD	Naval Construction Division
NCW	Naval Coastal Warfare
NECC	Naval Expeditionary Combat Command
NM	Nautical Miles
NMETL	Navy Mission Essential Task List
NPS	Naval Postgraduate School
NTO	Narcótica Terrorista Organizations
NWP	Naval Warfare Publication
OIC	Officer in Charge
OIF	OPERATION IRAQI FREEDOM
OP	Operations/Operational
OPTEMPO	Operational Tempo
OTH	Over the Horizon
PBR	Patrol Boat, Riverine
PCF	Patrol Craft, Fast
POE	Projected Operational Environment
POL	Combat Logistics Support
PRR	Personal Role Radio
QRF	Quick Reaction Force
RADM	Rear Admiral
RAS	Riverine Assault Squadron
RF	Riverine Force

RGB	Red, Green and Blue
RHIB	Rigid Hull Inflatable Boat
RIVGRU ONE	Riverine Group One
RIVRON	Riverine Squadron
ROC	Required Operational Capabilities
ROE	Rules of Engagement
RPG	Rocket Propelled Grenade
RTT	Riverine Training Teams
SA	Situational Awareness
SAR	Synthetic Aperture Radar
SBU	Small Boat Unit
SEA-10	Systems Engineering and Analysis cohort 10
SEABEES	Naval Construction Battalion
SCCo	Small Craft Company
SF	Special Forces
SGT	Sergeant
SSGT	Staff Sergeant
SMTC	Special Missions Training Center
SOCOM	Special Operations Command
SOC-R	Special Operations Craft, Riverine
SURC	Small Unit Riverine Craft
TACSAT	Tactical Satellite
TF	Task Force
TNT	Tactical Network Topology
TOC	Tactical Operations Center
TRAC	Training Doctrine Command Analysis Center
TRSS	Tactical Remote Sensing Systems
TSC	Theater Security Operations
TTP	Tactics, Training and Procedures
UAV	Unmanned Aerial Vehicle

UGS	Unmanned Ground Sensor
UHF	Ultra High Frequency
USA	US Army
USCG	US Coast Guard
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
USMC	United States Marine Corps
USN	US Navy
VBSS	Visit, Board, Search and Seizure
VHF	Very High Frequency
YTB	Large Harbor Tug

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EXECUTIVE SUMMARY

Approximately 2.2 billion people live within 100 kilometers of coastline, and the highest population densities occur near major rivers and deltas[1]. Riverine environments are strategically important areas for commerce and transportation. Rivers are recognized battlegrounds in the Global War on Terror (GWOT) and can be used for shipment of illegal drugs, human trafficking, weapons, and contraband which may support terrorist operations. Systems Engineering and Analysis cohort 10 (SEA-10) was tasked to examine the structure of the Navy's riverine force (RF), identify capability gaps, investigate feasible alternative architectures and propose system of systems improvements for the RF in 2010. With the RF currently working to establish a command structure, train and equip its forces, and deploy to a combat zone all within the span of just over one year, SEA-10's choice of the 2010 timeframe narrowed the investigation to existing or nearly mature development efforts that would be worthy of inclusion as an RF augment as the RF looks toward potential future tasking.

SEA-10 was fortunate to have the opportunity to engage with RADM Don Bullard, Commander of the Naval Expeditionary Combat Command (NECC), Commodore Mike Jordan, Commander River Group ONE (RIVGRU ONE), and members of their staffs to help refine the problem. Two clear objectives emerged from these discussions: Where could the RF acquire the most useful combat capability for the least cost, i.e., what capability would return the "biggest bang for the buck," and What is needed to defeat the "bend in the river" ambush? These discussions were supplemented by in person interaction with other current riverine practitioners including Navy, Marine Corps, Special Forces, and riverine operators from other eras, as well as historical research of previous U.S. Navy riverine efforts. These efforts, along with continuing dialog with NECC and RIVGRU ONE, focused SEA-10 on the specific combat critical objectives of "improving battlespace awareness" (improving sensor detection capability) and "improving situational responsiveness" (improving engagement capability).

[1] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, 30 August 2006, Naval Amphibious Base, Little Creek, VA.

Eleven alternative force packages with the potential to increase the RF's detection and engagement capability were ultimately defined. Each of these alternatives was modeled around the most likely riverine scenario (waterway patrol) and the most severe (ambush – "the bend in the river"). Scenarios were modeled in MANA, an agent based simulation that accounted for terrain, line of sight, weapons characteristics, personality motivations, and communications capability. Alternative performance parameters were entered into MANA and modeled against a level II opposing force. Measures of performance such as time to first enemy detection and loss exchange ratio were collected from MANA. A detailed statistical analysis was conducted to compare the performance of competing alternative architectures. SEA-10 conducted an open source cost estimate for each alternative force package. Procurement and operating and support costs were considered for each alternative over a ten year period beginning in 2010. Each alternative's overall cost and performance was then combined to determine which alternative provided the RF with the biggest "bang for the buck." The most significant findings include:

- Addition of an Unmanned Surface Vehicle (USV) to the baseline force provided the greatest overall improvement system performance for the cost.
- Addition of dedicated helicopter support to the baseline force generated the best performance, but was the most costly alternative.
- In general, improved sensor capability had the greatest effect on overall system performance (versus improved engagement capability) for the associated cost.
- A single unmanned sensor option (USV, Unmanned Aerial Vehicle (UAV), or Unmanned Ground Sensor (UGS)) enhanced baseline force performance as well as networked sensor alternatives.
- Addition of a ground combat element produced a measurable improvement in percentage of no hit runs and loss exchange ratio, but when limited to two scenarios (patrol and ambush) it did not significantly improve overall system performance.

- Depending on the scenario and measure of performance all alternatives as modeled returned an improvement in battle space awareness or situational responsiveness over the baseline force. None of the alternatives, when compared with the 10 year operating cost of the baseline are cost prohibitive, and should be considered feasible.

Mobile sensor alternatives, the USV and UAV, increased battle space awareness and delivered the greatest increase in overall performance in simulated riverine missions. The low marginal cost of the USV allowed it to dominate all but the networked sensor and indirect fire alternatives. One alternative that was not modeled, but analysis showed as an interesting alternative worth further investigation, was the pairing of a single sensor detection augment to baseline force with an indirect fire augment (mortar team or mortar barge). Either of these alternatives has the potential to achieve parity or exceed the performance of the helicopter alternative for a much lower marginal cost.

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I. INTRODUCTION

A. BACKGROUND

Approximately one third, or 2.2 billion, of the estimated 6.5 billion world population in 2006[2] lived within 100 kilometers of a coastline. The highest population densities occurred near major rivers and deltas.[3] Riverine environments are strategically important areas for commerce and transportation. Rivers are battlegrounds in the Global War on Terror (GWOT) and can be used for shipment of illegal drugs, human trafficking, weapons, and contraband which may support terrorist operations. Systems Engineering and Analysis cohort 10 (SEA-10) was tasked to examine the structure of the Navy's riverine force (RF), identify capability gaps, and provide feasible alternatives for the RF. This thesis utilized agent based models to support a system of systems concept of operations (CONOPS), construct an operational architecture, and develop alternatives to identify capability gaps of the riverine force and provide potential feasible solutions.

This thesis was developed in parallel with the establishment of the Navy's RF. In early 2005, former Chief of Naval Operations (CNO), Admiral Vern Clark assembled a GWOT task force to develop ways the Navy could proactively participate in fighting terrorism. Chief of Naval Operations Strategic Studies Group 24 recommended expanding the Navy's green and brown water capability to rebalance the force so that the United States Navy can better combat today's green and brown water threats. In his speech to the Naval War College in August 2005, Chief of Naval Operations, Admiral Mike Mullen emphasized the need for a balanced Navy that is capable of fighting across the spectrum of the maritime domain. "I want a balanced force in every sense of the word…balanced to face the challenges of our age…balanced to operate in, and command, if need be, all things maritime…I believe our Navy is missing a great opportunity to influence events by not having a riverine force."[4]

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[2] U.S. Census Bureau, International Data Base. Table 001, Total Midyear Population. Retrieved 18 September 2006 from the World Wide Web at: http://www.census.gov/cgi-bin/ipc/idbagg.

[3] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, p. 30, Naval Amphibious Base, Little Creek, VA, 30 August 2006.

[4] Chief of Naval Operations remarks as delivered at the Naval War College, Newport, RI, 31 August 2005, Retrieved 12 September 2006 from the World Wide Web at http://www.navy.mil/navydata/leadership/mist.asp?x=5.

B. PROBLEM STATEMENT

Systems engineering is rooted in problem solving and seeks to apply an organized, analytical process to the development of solutions to complex problems. The process begins with the identification of a want or desire for something and is based on a real or perceived deficiency[5]. SEA-10 determined a primitive needs statement from the original tasking of "analyze riverine warfare" as:

"Define alternatives and recommend a cost-effective system of systems that enables United States Navy Riverine Forces to project power, conduct Intelligence, Surveillance and Reconnaissance (ISR), and defend the force within the riparian environment. The system will provide a tailorable, maneuverable, sustainable, organic force which is capable of integration with joint, coalition, and civilian agents up to 150 nautical miles (nm) from a forward operating base. The architecture will consist of systems that are currently in service or deliverable by 2010."

The formal problem statement is more detailed than a primitive need statement. It should be quantifiable to ensure enough detail can be extracted to proceed with the process and to assure the results reflect the true customer desires[6]. This problem statement was too broad and did not scope the topic of "riverine warfare" enough to enable detailed analysis or alternatives. It did serve as the starting point to decompose the functions of the global riverine system, begin functional analysis, and work towards a revised problem statement.

C. THE SYSTEMS ENGINEERING AND DESIGN PROCESS

SEA-10 utilized a combination of established systems engineering principles, architectures, and criteria to define, bound, and analyze riverine warfare in 2010. SEA-10 used Dennis M. Buede's approach as described in The Engineering Design of Systems to separate riverine warfare into functional, physical, and operational architectures to provide an overall framework for analysis[7]. These architectures enabled SEA-10 to examine riverine global functions, extract RF missions from these global functions,

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[5] B.S. Blanchard, & W.J. Fabrycky, *Systems Engineering and Analysis, 4th Ed*., pp. 55-56, Pearson Education Inc., 2006.

[6] Ibid

[7] D.M. Buede. *The Engineering Design of Systems: Models and Methods*, p. 245, John Wiley & Sons, Inc., 2000.

identify quantifiable measures of effectiveness (MOE) from RF missions, and finally develop alternatives that satisfy the RF revised problem statement.

D. PRIMARY SPONSOR (STAKEHOLDER)

In an effort to rebalance the force and contribute to the GWOT, the Naval Expeditionary Combat Command (NECC) was formally established on 13 January 2006. "NECC serves as a single Functional Command to centrally manage current/future readiness, resources, manning, training, and equipping of the Navy's Expeditionary Forces"[8]. The objective of NECC is to increase the Navy's capacity for conducting GWOT missions by "realigning expeditionary forces, improving war fighting effectiveness, and captures [sic] efficiencies and common synergies."[9] NECC brings the following commands under one common command structure: Explosive Ordinance Disposal (EOD), Mobile Diving and Salvage (MDSU), Construction Battalions (SEABEES), Naval Coastal Warfare (NCW), Port Handling/Expeditionary Logistics (NAVELSG), and Riverine Group One (RIVGRU ONE). NECC plans to "fill gaps in the long-term GWOT mission set…and to temporarily relieve stress on the Marine Corps and Army missions in Iraq and Afghanistan."[10]

The RF currently proposed by NECC consists of one riverine group composed of three squadrons. The riverine group is commanded by a Navy captain, and each squadron is commanded by a Navy commander. Each riverine squadron will be capable of forward deployed operations and complete self-sufficiency for up to two weeks without re-supply (not including fuel). The RF can operate from a sea base or a forward operating base, with ground or maritime forces, and is capable of operating with joint or

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[8] Naval Expeditionary Combat Command, Retrieved 27 September 2006 from the World Wide Web at http://www.necc.navy.mil/about.htm.

[9] Naval Expeditionary Combat Command, Retrieved 27 September 2006 from the World Wide Web at http://www.necc.navy.mil/about.htm.

[10] Naval Expeditionary Combat Command, *Missions and Objectives*, Retrieved 27 September 2006 from the World Wide Web at http://www.necc.navy.mil/about.htm.

coalition forces.[11] The first riverine squadron will become active and deploy to Iraq in February 2007 while the second and third riverine squadrons are not expected to become active until FY-09/FY-10.[12]

E. RECENT RIVERINE FORCE PERFORMANCE EVALUATION

Recent RF performance data is limited. United States Marine Corps (USMC) Small Craft Company (SCCo) was the only conventionally structured functional RF with recent operational experience outside of units in Special Operations Command (SOCOM). Army engineer bridge construction units patrolled areas surrounding critical infrastructure in OPERATION IRAQI FREEDOM (OIF), but this is not typical employment. SEA-10 relied on historical analysis, lessons learned, and contractor information for technical details to formulate the initial force baseline in 2007 and the expected force of 2010. Extensive historical analysis, SCCo lessons learned documents, discussions with stakeholders at NECC, and functional analysis led SEA-10 to the conclusion that the current RF will have limited organic detection and engagement capability beyond visual range. SEA-10 used the systems engineering process to develop architectures that provide the RF with increased ability to extend battle space awareness and engage the enemy with organic assets.

F. HISTORICAL ANALYSIS OF RIVERINE FUNCTIONS

1. Introduction

Riverine warfare is not a new mission for the U.S. Navy. It has had episodic importance since the inception of the United States. There are many examples of riverine warfare from the American Revolution to OPERATION IRAQI FREEDOM (OIF), and no two are the same. Basic RF functions remain the same throughout each historical example despite varying operational environments, technological developments, logistics support capabilities, and deployment timeframes. SEA-10 chose to analyze the Second Seminole War, the Vietnam War, and the war on drugs on the rivers of Colombia because all three conflicts required RF's to adapt to an ever changing enemy. RF's in all three

[11] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, p. 28 , Naval Amphibious Base, Little Creek, VA, 30 August 2006.

[12] Interview with Riverine Squadron personnel, Naval Amphibious Base, Little Creek, VA,16 August 2006.

conflicts adapted their tactics to increase communications and engagement abilities, and took the fight to the enemy on the green and brown waters.

2. Second Seminole War (1835-42)

In 1830 the Indian Relocation Act initiated the effort to move Indians to reservations west of the Mississippi. Although most of the tribes signed agreements to leave peacefully, some remained in Florida. The Indians continued to live in Florida in relative peace until 1835 when the Army was deployed to the region to forcefully relocate the remaining Indians.

Understandably, many of the Indians did not want to leave their ancestral homeland so they retreated deep into the Florida Everglades at the Southern tip of the Florida peninsula. This environment provided the Indians with protection because the colonizers were unable to pursue them into the shallow mangrove-ridden swamps. The Indians received their logistics support through Spanish-funded lines of communication from the Caribbean Islands to the Everglades that brought weapons and supplies to the Indian camps.

A first attempt at subduing the Indians was made by forming the Navy's West Indian squadron to intercept supply lines. The squadron was composed of blue water vessels that were not able to penetrate into the shallow waters of the Everglades. Although the blockade operations were considered relatively successful, they did not solve the problem of relocating the Indians who were still residing on the land. Troops had to be brought into the area to forcibly move the Indians. However, as the Army advanced into the swampy Everglades, it continually tried to impose Napoleonic-style warfare on the Indians by massing fires upon them. These tactics proved highly ineffective because the Indians would not engage in these scenarios and would, instead, retreat to the safety of the swamps. A change of tactics was needed to counter the guerilla style warfare that was brought upon the soldiers.

In an attempt to bring troops closer to the Indians, three schooners, *Flirt*, *Wave* and *Otsego*, with embarked Army troops operated at the mouths of the waterways. The draft of these ships prohibited access to the areas most populated by the Indians. In 1839, Lieutenant (LT) J.T. McLaughlin took the initiative to build up a force composed of flat bottomed boats and canoes that were capable of navigating the mangrove-ridden labyrinth of rivers and swamps[13]. Smaller vessels that could act independently gave the Navy riverine force the ability to penetrate deeper into enemy territory.

McLaughlin and his flat bottomed boats (mostly canoes) transported Army soldiers up and down the rivers to raid Indian villages and destroy their weapons caches and supply depots. Moving inland also gave the riverine force the capability to collect intelligence on enemy strength, encampments and logistics paths[14]. The raids had a devastating psychological effect on the Seminoles that left them demoralized. Over time and with repeated patrols of the same areas, McLaughlin and his 'Mosquito Fleet' ultimately gained control of the waterways. Without a reliable supply system and demoralized by the brutal attacks on their families, the Seminoles eventually surrendered to the soldiers.

a. Firepower

Firepower came in two varieties, specifically crew served weapons and naval gunfire. The latter was mostly ineffective because the deep draft of the ships prevented the Navy ships from moving within the effective range of their weapons. Several innovations were implemented to compensate for firepower inadequacies, such as affixing a gun capable of shooting 12 pound rounds on a barge or Mackinaw boat (flat bottomed) for inland missions.

Initially the riverine forces were dependent on the 'volley and charge' method of small arms fire. As the war progressed, weapons technology matured which enabled commanders to change their tactics. Advancement of the repeating shoulder weapon technology allowed the commander to "reduce the size of his unit without sacrificing the volume of fire…which prompted him to divide his riverine units into smaller independent task forces."[15] Table 1 summarizes the weaponry used during the Second Seminole War.

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[13] Navy Department Naval History Division, *Riverine Warfare: The U.S. Navy's Operations on Inland Waters*, p. 15, Washington: Government Printing Office, revised 1969.

[14] M. Freitas & B. W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla,* Naval Postgraduate School Masters Thesis, December 1994, p. 37.

[15] M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla,* Naval Postgraduate School Masters Thesis, December 1994, p. 36.

Weaponry of the Second Seminole War (1837-1845)				
Engagement	Weapon	Range	Number	Ammo
Small Arms	Model 1816, Caliber .69, flintlock smooth bore musket (1837)	100 yards	1 per man	3 rounds/min
	Paterson Colt Revolving Cylinder Percussion Carbine, Model 1836, Caliber .69, 32" barrel (1839)		1 per man	7 shot
	Paterson Colt Revolving Percussion Carbine, Model 1839, Caliber .47, 24.5" barrel (1839-1845)		1 per man	6 shot
Naval Gunfire (inland)	Gun barge	LOS	1-4 guns	4-12 pounders
	Mackinaw Boat (flat bottom)	LOS	1 gun	4 pounder
Naval Gunfire (coastal)	Sloop-of-War	LOS	18 guns	6-32 pounders
	Schooner	LOS	1-2 guns	6-24 pounders
	Steamer	LOS	1-2 guns	6-24 pounders

Table 1. Weaponry of the Second Seminole War[16].

b. Scouting

Riverine forces in the Everglades were unfamiliar with the territory and were, consequently, subject to ambush by Seminoles who were very familiar with the region. "A lack of maps placed a premium on an intimate knowledge of the countryside."[17] Riverine forces relied heavily on guides from local villages or their own canoe scouts to gain situational awareness of the battle space. Persistent patrol of the same areas was the most effective method for gaining an understanding of guerilla encampments. However, due to the immense size of the Everglades region, approximately 2,500,000 acres,[18] and the limited number of soldiers and sailors assigned to the mission (~500), the Indians would simply pick up and move their camps to avoid detection. Riverine forces were constantly subject to ambush and became increasingly frustrated by an enemy that was nearly impossible to detect.

[16] M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla*, Naval Postgraduate School Masters Thesis, December 1994, pp. 35-47.

[17] M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla*, Naval Postgraduate School Masters Thesis, December 1994, p. 37.

[18] J.C. White, *American Military Strategy in the Second Seminole War*, Retrieved 15 September 2006 from the World Wide Web at http://www.globalsecurity.org/military/library/report/1995/WJC.htm.

As the war matured, changes in command structure were initiated to bring a unity of effort between the riverine forces and the blue water forces. Under LT McLaughlin, the riverine commander was put in control of inland and coastal forces. Integration with the Navy's 'blue water forces' enabled faster dissemination of intelligence reports to inland forces about location Indian lines of communication (LOC) and supply caches. Riverine forces worked with blue water forces to intercept guerilla supplies that were arriving from the Caribbean.

3. Vietnam (1967-1975)

Riverine forces gained respect for their role in the Vietnam War. In 1965 a helicopter pilot conducting a MEDEVAC mission over the Southern Coast of Vietnam noticed the movement of a North Vietnamese vessel to a shore-based logistics facility. Upon further investigation, large weapon caches and supply depots were discovered alongside routes that were frequently used by the North Vietnamese to infiltrate South Vietnam. In response to this revelation, U.S. commanders established Task Force 115 to conduct coastal surveillance and to prevent the flow of supplies to the Vietcong from the Southern coast of Vietnam. Shallow draft boats were needed to penetrate the murky waters of the Mekong delta. After discovering that the inventory of small boats in the U.S. Navy was minuscule, Patrol Craft Fasts (PCF) were purchased from Sewart Seacraft, a manufacturer of water taxis used to service off shore oil rigs in the Gulf of Mexico[19]. PCF's, or Swift boats, worked with helicopter and Patrol Boat Riverine (PBR) units to intercept Viet Cong supplies from the coastal and inland waterways. Although the blockade remained throughout the war it was only partially effective in deterring the flow of supplies into South Vietnam. It was discovered that the Viet Cong were actually receiving a majority of their logistical and personnel support from roadways originating in Cambodia and through the waterways of the Mekong Delta. A plan was needed to prevent the transfer of supplies to the Viet Cong so Task Force 116 was established under the code name Game Warden.

Despite TF 116 efforts, the Viet Cong were still receiving enough supplies to wage a substantial guerilla campaign against South Vietnamese and American forces. A different strategy that involved penetrating deep into the Mekong Delta's rivers and

[19]Patrol Craft Fast, *Swift Boat Design Criteria*, Retrieved 21 November 2006 from the World Wide Web at: http://www.pcf45.com.

creeks was needed to further weaken Viet Cong forces. In 1966 the Mobile Riverine Force (MRF) was established with the mission to "seek and destroy Viet Cong main and local force units, their resources, and their infrastructure, and to open the waterways of the Mekong Delta to commerce."[20,21] The establishment of the MRF marked the first true riverine force of the Vietnam War. MRF forces were split into two groups, appropriately named Mobile Riverine Group A, which operated in the eastern delta, and Mobile Riverine Group B, which operated in the west. Each of the groups, were later renamed as Riverine Assault Squadrons (RAS). RAS composition is displayed in Table 2.

Riverine Assault Squadron Composition		
Platform	**Number**	**Mission**
LCM-6's	52	Armored troop Carriers
LCM-6's	5	Command and Control Boats
LCM-6's	10	Patrol
Assault Support Patrol Boats	32	Insertion/extraction
LCM-6's	2	Refueling
YTB's	2	Salvage
LCU	2	Salvage
100 ton barges	3	Floating dry docks

Table 2. Vietnam riverine assault squadron platforms[22].

The concept of the Mobile Riverine Force stated that the riverine force would conduct the following specific tasks:

1. "Secure U.S. base areas and lines of communication required for U.S. operations
2. Conduct offensive operations against Viet Cong forces and base areas that pose a threat to ….priority areas for rural construction...
3. Isolate the most heavily populated and key food-producing areas from Viet Cong base areas

[20] M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla,* Naval Postgraduate School Masters Thesis, December 1994, p. 54.

[21] W.C. Wells, Full Mission Profile. *Riverine Operations in Vietnam*, pp 41-42, Naval Special Warfare Publication, 1992.

[22] R.B. Dunnavent, *Brown Water Warfare: The US Navy in Riverine Warfare and the Emergence of a Tactical Doctrine 1775-1990,* Appendix A, University Press of Florida, 2003.

4. Interdict Viet Cong supply routes

5. Provide reserve and reaction forces in the IV Corps Tactical Zone in coordination with Vietnam armed forces"[23]

According to the concept of operations (CONOPS), the brigade was the smallest unit that the U.S. could provide to the delta with minimal risk to safety of personnel but fit within budget constraints.[24] The CONOPS also planned for the use of afloat mobile bases that provided a staging area for riverine operations. Troops conducted ground operations in 3-4 day intervals and then retreated to the mobile afloat bases to rest and repair equipment. Forces remained in an enemy controlled area for four to six weeks, or until the objectives were met, and then moved along the river to another enemy controlled area. Operational reach from the mobile bases was approximately 50 km. Combined water, land and air power of the Mobile Afloat Force was capable of conducting full scale combat operations while providing safety for the vulnerable afloat bases.

During the later years of the war the objective of the MRF was "to deny the enemy longitudinal and cross-waterway movement along numerous waterways surrounding and within the Kien Hoa province."[25] The operations in the Kien Hoa province presented special challenges to the MRF because of the significant limits on mobility due to the limited waterway network off the rivers. This lack of navigable waterways and anchorages for afloat bases of operations prevented the MRF from operating as it had in previous engagements. "According to intelligence reports, the enemy had formed special five-man teams in Kien Hoa to ambush the boats of the mobile riverine force…using rockets (RPG 2 and RPG 7, mostly), recoilless rifles, and small arms."[26] Countering the ambush threat required the joint effort of Army ground troops and Navy riverine craft. Army troops would engage enemy guerillas while the assault

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[23] W.B Fulton, Vietnam Studies: Riverine Operations 1966-1969, p. 32, Department of the Army, 1969.

[24] W.B. Fulton, *Vietnam Studies: Riverine Operations 1966-1969*, p. 35, Department of the Army, 1969.

M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla,* Naval Postgraduate School Masters Thesis, December 1994, p. 69

[26] W.B. Fulton, *Vietnam Studies: Riverine Operations 1966-1969*, pp. 170-172, Department of the Army, 1969.

craft blocked the enemy's escape routes. The Mobile Riverine Force combined with ground troops and helicopters used this strategy to "break up enemy underground organization, disrupt enemy plans, demoralize enemy forces, and aid in pacification."[27]

a. Firepower

Considerations had to be made when planning and executing operations that required firepower to be brought upon the enemy. The Vietnamese environment consists of thick foliage, high humidity, frequent rain, and hot weather. Due to the extreme environmental conditions, crew served weapons and small arms would frequently fire erratically, jam or fail to fire. Helicopters provided additional coverage to forces that were left unarmed due to equipment casualties. A confounding factor in massing firepower on the enemy was the large rural population along the rivers that were vulnerable to poorly aimed fire. Rules of Engagement (ROE) limited U.S. forces from engaging civilians. Despite ROE, it was not uncommon for non-combatants to come into the line of poorly aimed fire. Table 3 outlines many (though not all) of the different craft used during the Vietnam conflict and their contributions to firepower.

[27] W.B. Fulton, *Vietnam Studies: Riverine Operations 1966-1969*, pp. 170-173, Department of the Army, 1969.

Vietnam Riverine Force Firepower Baseline	
Riverine Platforms	**Armament**
PCF (Swift Boats)	Twin .50-caliber machine guns
	One .50-caliber machine gun
	One 81-mm mortar
	M-79 hand held grenade launcher
PBR (Patrol Boat River)	Twin .50-caliber machine guns (forward)
	One .50-caliber machine gun (aft)
	One 40-mm grenade launcher (side mount)
	One M60 machine guns (side mount)
	M-79 hand held grenade launcher
LCM-6 Conversion	One 81-mm mortar
	One 40-mm cannon
	One 20-mm cannon
	Two .50-caliber machine guns
	M60 Machine guns
Armored Support Patrol Boats	One 81-mm mortar
	One 20-mm cannon
	Two twin mounted .50-caliber machine guns
	Two or more Mk 18 grenade launchers
Artillery Barges	105mm howitzers (moved via helo)
Air Platforms	
UH-1 Iroquois (Seawolves)	2 2.75 rockets
	M-134 mini-guns
	Four M60C machine guns
	Small Arms
OV-10 Bronco	20 mm gun pod
	Four 7.62 mm M60C Machine Guns
	Four hardpoints for rockets, mini-guns or stores

Table 3. Riverine Platform Engagement Capabilities[28].

The riverine force imposed much of its lethality on the enemy using fires from air support platforms and artillery support. Air support from UH-1's or OV-10's could mass fires directed at enemy encampments, and could also provide intelligence to riverine commanders on optimal routes to engage enemy positions and troop concentrations. Supporting fires were also provided by Army artillery which brought significant firepower (with 105mm howitzers), but was less discriminating than close air

[28]R.B. Dunnavent, *Brown Water Warfare: The US Navy in Riverine Warfare and the Emergence of a Tactical Doctrine 1775-1990*, Appendix A, University Press of Florida, 2003.

support (CAS). In order to ensure its own survival, the riverine force had to overcome its inherent vulnerability to attack by increasing its rate of fire and survivability. "A tradeoff between protection, speed, draft, firepower, and armor, led to a composite force of riverine assault craft," and found that "rate of delivery and volume of superior firepower to destroy the enemy" provided the most significant payoff for riverine success[29].

When air support and direct artillery support were not available, the RF could not risk massing fires on the enemy. Instead, changes in tactics were instituted so that the force operated in smaller independent units that depended on stealth vice massed firepower. As a result, many of these units operated under the cover of darkness to ambush and surprise the enemy.

b. Scouting

Scouting was essential to the success of riverine operations. Small boat operators depended on intelligence gathered from reconnaissance missions that were conducted hours or sometimes, days before the mission. Intelligence on enemy strength, location, river characteristics, the local population and possible helicopter landing spots was gathered by helicopters, Navy assault group boats, and ground forces. Reconnaissance missions often yielded inaccurate information about the location of enemy bases and weapons caches. They were difficult to discern in photography because of the thick layers of foliage that covered river banks. The rapidly changing jungle environment caused much of this intelligence to quickly become outdated or unreliable so commanders did not place confidence in it when preparing missions. On the other hand, when reconnaissance missions were timely and informative, the riverine commander was directed to the exact location of the enemy where he could overwhelm him by surprise and massed firepower.

At night, scouting proved more of a challenge to the riverine force. Although night vision devices gave the RF a distinct advantage over the enemy, the technology was still new and suffered many of the bugs and kinks typical of new technologies. Electronic sensing devices provided bearings to enemy concentrations, but the RF needed a confirmed identity of the source of electronic transmission before it could engage the enemy. The most proven method for gaining intelligence on enemy

[29] M. Freitas, & B.W. Treadway, *Stygian Myth: US Riverine Operations Against the Guerilla,* Naval Postgraduate School Masters Thesis, December 1994, p. 72.

locations was through the use of guides. Guides were either anti-communist Vietnamese in support of the operation or members of American ground forces that had experience in a certain region. Guides came from the local population and usually provided the best information on enemy locations, movement, lines of communication (LOC), and other information that could be used to plan future operations. However, as with most human intelligence (HUMINT) sources, families of informants were vulnerable to intimidation by local Vietcong and many no longer chose to support U.S. forces. Although HUMINT provided the most accurate and up-to-date intelligence for the riverine force commanders, it could not always be relied upon.

The lack of sufficient means for identifying the enemy meant that riverine forces had to rely on ROE to justify using firepower. For example, during Game Warden the rules of engagement "explained that a nighttime curfew existed on the inland waterways of South Vietnam; this meant that all craft transiting canals or rivers after dark were considered enemy boats."[30] Once this ROE was established, the riverine forces had permission to search and seize boats that were operating after dark and worked under the assumption that the boats were enemy vessels. This method of assigning identification to unknown vessels was inefficient and had the potential to cause undue destruction to legitimate commerce. Vietnam riverine forces needed a way to identify enemy forces at night and in real time so they could direct their forces efficiently.

4. Colombia (1980-Present)

Colombia is a country scarred by a war that has been passed on through the generations. Since the early 1930's, Colombia maintained a democratic system of government (with a few years of military dictatorship in between) that led to prosperity for its citizens. In 1946, a vicious battle between the liberal and conservative parties eventually brought the country to civil war. The scope and intensity of the 20 year battle was so great than many Colombians termed it *La Volencia*. The liberal party assumed control of the land as fighting progressed which resulted in enormous economic disparity

[30] R.B. Dunnavent, *Brown Water Warfare: The US Navy in Riverine Warfare and the Emergence of a Tactical Doctrine, 1775-1970*, p. 130, University Press of Florida, 2003.

between the two groups.[31] Over time, the economic imbalance and lack of government intervention took its toll on the disadvantaged groups.

As a new generation began to emerge, underground markets for weapons, drugs, and other contraband items became well established avenues for economic trade. Wealth gained from these markets provided the money for poor peasants to fund their own educational, military and governmental institutions. The Fuerzas Armadas Revolutionarias de Colombia (FARC) was born as a result of the economic disparities between the social classes in Colombia and was monetarily supported by these underground markets. The FARC was just one of several insurgent organizations that emerged during *La Volencia.* The FARC still functions in Colombia as a medium for drug and weapon sales because of its energetic sympathizers and plentiful funding. The local populace supplies the FARC with shelter, recruits, food, money from drug sales, and money paid for protection from the drug lords.[32] Therefore, when the United States deemed it necessary to fight the War on Drugs, it used Colombia as one of its major battlegrounds.

Rivers in Colombia are a main mode of transportation between villages. Approximately 18,140 km of waterways within the country are navigable by river boats. The boats remain the most common form of transportation between towns in rural Colombia. Waterways are also key enablers for the passage of illegal goods within and to the borders of the country. In 1989, former President Bush established the Andean Ridge Initiative which established a RF, with the assistance of the Colombian military, to help fulfill the United States' counter drug policy in Colombia.

The Colombian river program was implemented in 1990 with the Untied States Marine Corps taking the lead for the mission. US Marines worked closely with the Columbian Marine Force to confiscate drugs and imprison those involved with the production and distribution of narcotics.

Not long after the Marines assumed the riverine mission in Columbia, it became clear that the Corps did not have the "capability to teach or implement the operational art

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[31] P.F. Wiley, The Art of Riverine Warfare from an Asymmetrical Approach, Naval Postgraduate School Masters Thesis, March 2004, p. 29.

[32] P.F. Wiley, The Art of Riverine Warfare from an Asymmetrical Approach, Naval Postgraduate School Masters Thesis, March 2004, p. 30

of riverine warfare."[33] Naval Special Warfare assumed the counter-narcotics mission in Colombia by continuing the Mobile Training Teams (MTTs) which educated the Columbian Marines (COLMAR), a subset of the Colombian Navy (COLNAV), on the art of riverine warfare, particularly as it applies to defeating an insurgency. Over time, the COLMAR developed a robust riverine program with the following mission:

> *to increase, recover, and maintain the control of the maritime, riverine, and land spaces under responsibility of the COLNAV, and to neutralize the NTOs that act in those areas; and to contribute to restore the democratic security for the people of Columbia.*[34]

The overarching goal of the COLNAV is to protect the citizens and resources of the nation of Colombia, to combat the illegal movement of drugs, weapons, and contraband, and to destroy the logistics structure of the Narco-terrorists In order to do this, the COLNAV must gain control of its area of operation and prohibit the movement of Narco Terrorist Organizations (NTO) along the coast, across seas and on the rivers.[35] This strategy, called "Closing the Gap," is a combined initiative that closes trade routes used by NTOs to transport narcotics and precursor chemicals required to produce drugs. It is understood that the government of Colombia (with the backing of the U.S.) will provide the funding necessary for carrying out the "Gap" strategy.

a. Firepower

Colombian riverine forces operate on 15,774 kilometers of the country's waterways. Five battalions are responsible for their respective areas of operation on the waterways. No one force structure is adequate for all operations in Colombia due to the differences in terrain, climate, and waterways within the country. The COLNAV does not have, nor does it use, advanced technology to fight the FARC. They rely on conventional weapons, knowledge of the operational environment, a semi-constant presence, and tactics that best utilize their resources to carry out their missions.

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[33] P.F. Wiley, The Art of Riverine Warfare from an Asymmetrical Approach, Naval Postgraduate School Masters Thesis, March 2004, p. 35.

[34] Armada Nacional Republica de Colombia, *The Columbian Navy in the Fight against Narco-Terrorism*, Retrieved 29 September 2006 from the World Wide Web at http://www.armada.mil.co/index.php?idcategoria=30009&.

[35] Armada Nacional Republica de Colombia, *The Columbian Navy in the Fight against Narco-Terrorism*, Retrieved 29 September 2006 from the World Wide Web at http://www.armada.mil.co/index.php?idcategoria=30009&.

b. Scouting

The jungle environment in Colombia is not conducive to systems that rely on unobstructed line of sight communications. Foliage is very thick, can limit visibility to less than 50 meters,[36] and can provide concealment to enemy forces. The use of helicopters, or other air assets, is of little use because the jungle canopy obstructs the view from the air, even with powerful infrared (IR) cameras. Therefore, the COLNAV must rely on HUMINT to detect the FARC and their logistics routes.

Scouting takes a different form in the Narco-Terrorism mission in the Colombian jungles. Instead of searching for a high-cost technological solution to the sensor problem, COLMAR maintained a constant presence on the waterways to gain intelligence on the FARC. Constant presence enabled the government to earn the trust of the people because, unlike 20 years ago, the people could now navigate the waterways without fear of extortion. Over time, the constant presence of COLMAR on the rivers showed the people that the government actually does care for its people.[37] As the COLNAV forces extended their presence in the region, they began to establish close ties with the members of the local population. As the relationships began to build, the locals saw the benefit of having COLNAV in their region and provided HUMINT to the COLNAV on the locations and troop strength of the FARC. This form of scouting continues to provide the intelligence needed for rooting out the FARC and waging the war on drugs in Columbia.

5. Historical Summary

Historical analysis was conducted and potential functions were validated for relevance and feasibility to modern riverine operators. SEA-10 contacted stakeholders and riverine operators with a list of historically feasible and verifiable riverine functions, and asked them to prioritize these functions. Generic missions typically associated with the RF included conducting maritime security operations, control and denial of the riverine area, insertion and extraction of conventional forces, providing fire support and

[36] Department of the Army Headquarters, Field Manual 90-5 Jungle Operations, Washington, DC, 16 August 1982. Retrieved 29 September 2006 from the World Wide Web at http://www.globalsecurity.org/military/library/policy/army/fm/90-5/index.html

[37] P.F. Wiley, *The Art of Riverine Warfare from an Assymetrical Approach*, Naval Postgraduate School Masters Thesis, March 2004, p. 39

conducting theater security cooperation.[38] SEA-10 chose five functions that are common to all of these missions and presented themselves as traceable, measurable, and quantifiable. These functions were C4ISR, engage, move, sustain, and defend.

The RF must be able to:

- Detect, identify, and assess enemy movements, positions, and units in the riverine environment
- Engage enemy positions and units in the riverine environment
- Move the RF from theater to theater and within theaters
- Sustain the RF (provide supplies, combat logistics)
- Defend the RF tactical operations center (TOC) and non-combatant units

Detect (a sub function of conduct C4ISR operations) and engage were deemed most important and both present quantifiable measurable data points such as range, probability of detection, and probability of kill. Detect and engage were also judged as the two functions that would have the greatest effect on the RF of 2010.

[38] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, pp. 8-10, Naval Amphibious Base, Little Creek, VA. 30 August 2006.

II. FUNCTIONAL ARCHITECTURE

A. FUNCTIONAL ARCHITECTURE COMPONENTS AND PURPOSE

A functional architecture represents the functions, tasks, and activities that a system must accomplish to be successful and the interactions that exist between them. SEA-10's approach to generating a functional architecture was similar to Buede's model; however, an existing list of system activities and functions was not available. The RF of 2007 is not yet in the field, the mission set is malleable, and there are no concrete performance requirements. As described previously, SEA-10 conducted a historical analysis to better understand traditional riverine technologies, missions, and tactics, as well as to identify critical RF functions. Figure 1 depicts SEA-10's top down perspective of the functional architecture through a hierarchical model of the functions performed by the system, the flow of functions through the system, a revised problem statement for riverine warfare, and a tracing of system inputs and outputs to both functions and entities[39]. The elements of the functional architecture led to the formulation of system objectives and quantifiable measures of effectiveness.

Figure 1. SEA-10 Top-Down Approach to Functional Architecture Formulation.

[39] D.M. Buede, *The Engineering Design of Systems: Models and Methods*, p. 175, John Wiley & Sons, Inc., 2000.

B. SYSTEM DECOMPOSITION

Historical analysis provided knowledge of riverine missions and activities. This knowledge enabled detailed system decomposition. Decomposition of these functions and elements and analysis of their interrelationships provided SEA-10 with top down perspective of a generic RF by designating what the RF must do to accomplish a historically feasible mission. A top down perspective was critical in extracting a relevant, feasible, quantifiable problem from the amorphous topic of "riverine warfare."

SEA-10 examined system functions, components, and their interrelationships with respect to where they occur within the hierarchical structure of super systems, lateral systems, and sub systems. Examination of the riverine system hierarchical structure yielded system functions and likely components. A function is a definite purposeful action that a system must accomplish to achieve success.[40] Components such as input, process, and output are the moving parts of a system. Structural components are static, operating components perform system processing, and flow components are the material, energy, or information being altered.[41]

The states of the system are static snapshots of the system's capabilities to perform the system's functions at any certain time. The system progresses through a constantly changing series of states as time progresses. State variables define the condition of the system's state at a specific point in time. This list of state variables contains information needed to determine the system's ability to perform the systems functions at that point in time.[42]

Initial decomposition of the riverine force, based upon the Draft U.S. Navy Riverine Force Concept of Operations prepared by NECC for Commander Fleet Forces Command dated 18 May 2006, is found in Figure 2. SEA-10 decomposed the RF concept into four key elements: functions, components, hierarchal structure and states.

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[40] A.P. Sage, & J.E. Armstrong, *Introduction to Systems Engineering*, John Wiley & Sons, Inc., 2000.

[41] B.S. Blanchard, & W.J. Fabrycky, *Systems Engineering and Analysis*, 4th ed, Pearson Education, Inc., 2006.

[42] D.M. Buede, *The Engineering Design of Systems: Model and Methods,* John Wiley & Sons, Inc., 2000.

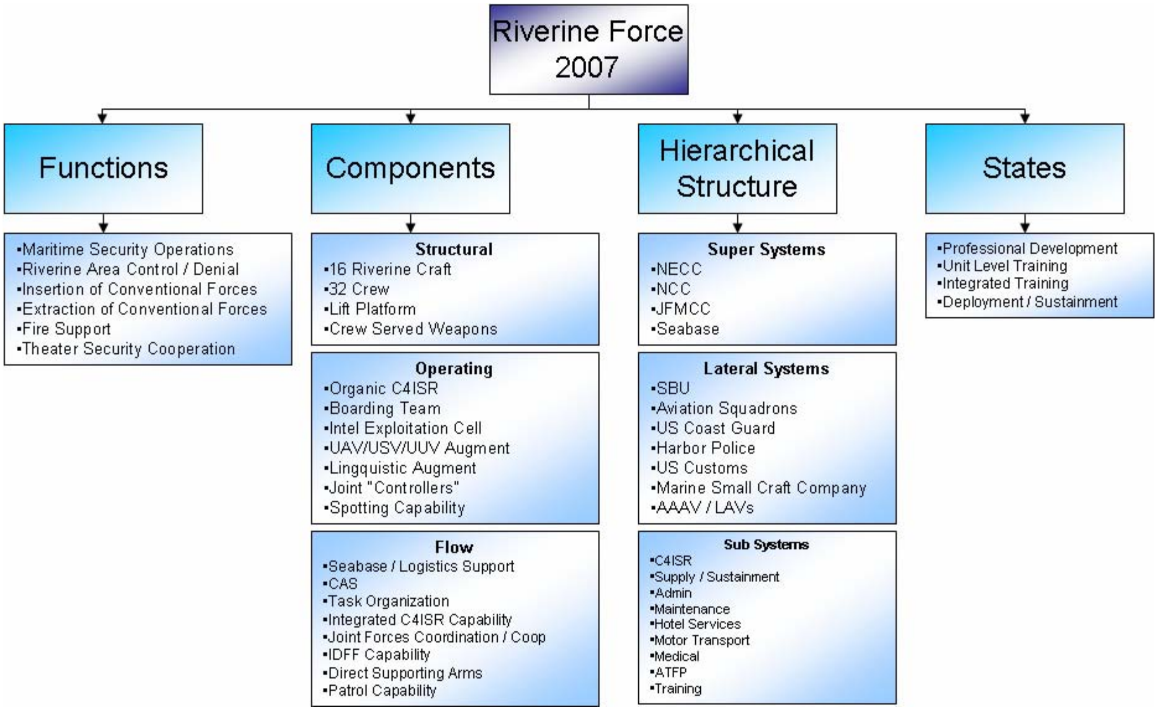

Figure 2. SEA-10 Initial Riverine System Decomposition[43].

1. Functions

Functions enabled the transformation process of input to output, and ask the question, "*What does the riverine system do?*" The functions listed in Figure 2 are the initial missions that NECC tasked the riverine force to perform. Functions/missions included: control and denial of the riverine area, conducting maritime security operations, insertion and extraction of conventional forces, providing fire support, and engaging in theater security operations[44].

2. Components

Components provide the physical breakdown of the RF and were separated into several component categories. Structural components comprise the physical aspect of the RF. Structural components that SEA-10 examined were: the number of riverine vessels NECC is willing to purchase and provide the RF (or the number inherited from the USMC), the number and the ratings of the sailors that will man the vessels, and the associated weapons issued to the crew or mounted on riverine vessels to provide

[43] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, pp. 8-10, Naval Amphibious Base, Little Creek, VA. 30 August 2006.

[44] Ibid.

offensive and defensive capabilities. Operating components encompass entities that are required for specific RF missions. Examples of operating components include the RF's Visit Board Search and Seizure (VBSS) teams, intelligence and exploitation teams, linguists, and organic C4ISR capabilities. Flow components enable the RF to interact with agencies outside its own force structure. Examples of flow components include sea basing and logistics support to the RF, integrated C4ISR capabilities that enable the RF to share information with other services, and Joint Forces coordination that allows the RF to call for fire.

3. Hierarchical Structure

Hierarchal Structure outlines the make up or the top to bottom organization that comprise the riverine force. The RF hierarchical structure has three levels. Super systems are top-level organizations and/or the Chain of Command that make up the riverine force. These are Naval Expeditionary Combat Command (NECC) who has overall responsibility for expeditionary combat and aligning the Navy's expeditionary capable elements so that the Navy is more capable, responsive and effective in the global war on terrorism (GWOT)[45], the Joint Force Maritime Component Commander (JFMCC), and the Sea Base Commander. Lateral systems are second tier organizations that support and make up the riverine force. Examples include Small Boat Units (SBUs), aviation squadrons that provide close air support, the US Coast Guard (USCG) who provides law enforcement detachment support for boarding, harbor police who aid in protecting and defending key operational areas, and US Customs who inspects cargo. These lateral sub-systems support and make up the riverine force indirectly with varying levels of interaction. Sub-systems are organizations and entities that support and make up the riverine force directly. Examples are supply and sustainment of the riverine force, support functions such as administrative, maintenance, medical, transportation and training support, Anti-Terrorism/Force Protection (ATFP), and hotel services.

4. States

States are the operational conditions that the RF progresses through during different phases of development and employment. States that apply to the RF:

- Professional development or school house training (initial phases of training)

[45] Naval Expeditionary Combat Command, Retrieved 27 September 2006 from the World Wide Web at http://www.necc.navy.mil/about.htm.

- Unit-level training where the team trains and qualifies in unit oriented missions (intermediate phases of training)
- Integrated training where the RF is evaluated on its ability to work with and employ other forces and assets available to them
- Deployment represents the final state where the RF executes a real-world operational mission

C. STAKEHOLDER ANALYSIS

System decomposition identified critical capabilities that a RF must have, and these capabilities were further categorized into functional blocks. SEA-10 determined core riverine missions from analysis of the RF CONOPS. Within each mission: Patrol and Interdiction, Theater Security Cooperation, Law Enforcement, Anti-Piracy and Maritime Security Operations, there are overlapping required riverine competencies. From these, SEA-10 derived the following critical global RF functions:

- Conduct Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) operations
- Move
- Defend
- Engage
- Sustain

Each function was defined using standard military definitions from Joint Pub 1-02[46]. These definitions enabled SEA-10 to derive questions about the baseline capability of the proposed RF. These questions served as a starting point with stakeholders and were designed to promote feedback and generate a collaborative atmosphere during research visits. Stakeholder feedback generated by these questions identified capability gaps of the proposed riverine force. Specifically named capability gaps helped identify the technologies, techniques, tactics, procedures (TTP's), and platforms SEA-10 should consider in creating RF physical and operational architectures.

Stakeholder analysis identifies the clients, analysts, resources, and users that will be affected by or contribute to the design process. Stakeholder input and guidance from

[46] *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms*, 12 April 2001.

core documents, individuals, and organizations influenced design efforts and ensured the end result, recommendations for improving the Navy's capability to conduct riverine operations, were relevant and applicable. Buede states that stakeholder feedback and input are critical during the development of the functional architecture because it validates function conceptualization and reduces the chance of focusing on unimportant functions as areas that require analysis[47].

Initial efforts focused on a literature review to identify core documents that provide a baseline of current and historical riverine operations (as discussed in the Historical Analysis section of this thesis), requirements, and challenges. SEA-10 identified the organizations and individuals that have conducted riverine missions in the past and looked for relevant lessons that can be applied to increase future Navy Riverine Force capabilities.

1. Primary Stakeholders

SEA-10's primary clients were Rear Admiral Bullard, the commander of Naval Expeditionary Combat Command (NECC), as well as Commodore Jordan, commander of River Group One (RIVGRU ONE), and the RIVGRU ONE staff. System users included river squadron operators and other NECC and Joint forces personnel who will work with composite river squadrons. Coalition partners are also affected by the Riverine Training Team (RTT) program. The operators at the Special Missions Training Center, small boat teams, and Coast Guard units may benefit from SEA-10's analysis of riverine warfare. Primary analysts for the design project are SEA-10, which consisted of two Naval Flight Officers and four Surface Warfare Officers. No member of SEA-10 had experience as a riverine operator. Collaborative efforts of Naval Postgraduate School (NPS) faculty and students provided insights gained from ongoing studies conducted by Tactical Network Topology (TNT) field experiments on tactical remote sensing systems (TRSS), and sensor networking for surveillance in collaboration with Coalition Operating Area Surveillance and Targeting System (COASTS) NPS.

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47 D.M. Buede, *The Engineering Design of Systems: Model and Methods,* John Wiley & Sons, Inc., 2000, p.129.

2. Core Documentation

Numerous core documents were used to gain a broad understanding of RF Required Operational Capabilities (ROC) and Projected Operational Environment (POE) in 2010. SEA-10 referenced three core documents during the initial research phase of the project. The first of these documents was the U.S. Navy Riverine Force Concept of Operations that was promulgated by RIVGRU ONE and NECC to define the current baseline and better understand the RF roles and missions proposed by NECC[48]. The Center for Naval Analyses' *Renewal of Navy's Riverine Force Capability: A Preliminary Examination of the Past Current and Future Capabilities* provided historical references and examined required capabilities along with potential gaps (see Figure 3). The most recent documentation on Riverine operations at the tactical level came from the Marine Corps Center for Lessons Learned in the document *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II: A summary of lessons and observations*[49]. SCCo's after action reports also provided excellent tactical detail and insights for modeling efforts.

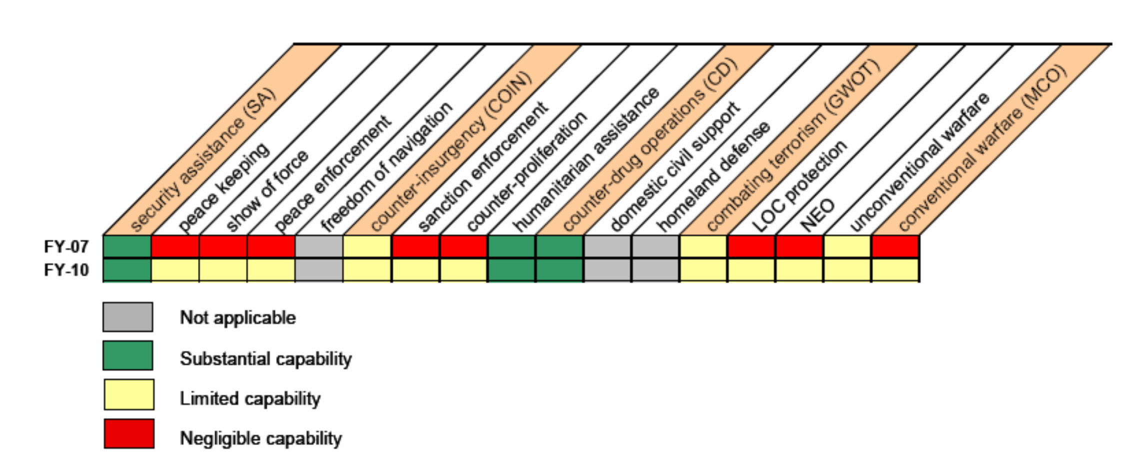

Figure 3. CNA Projected Riverine Capability[50].

[48] R. Benbow, P. Ensminger, S. Swartz, & D. Stimpson, Center for Naval Analysis Report, *Renewal of Riverine's Capability: A Preliminary Examination of Past, Current and Future Capabilities*, pp 85-100, January 2006.

[49] US Marine Corps Center for Lessons Learned, *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II (OIF II)*, 4 April 2006.

D. STAKEHOLDER INPUT

1. RADM Bullard, Commander NECC

In May of 2006, just after initial thesis topic assignment, SEA-10 was fortunate to have the Commander of NECC, Rear Admiral (RADM) Bullard, as a guest and presented him with an interim review and solicited his feedback. RADM Bullard told SEA-10 the project had immense potential for value and that he was looking for a "biggest bang for the buck" recommendation in terms of technology or force packages that returned the greatest improvement in mission performance. He also emphasized the need to understand the nature of engagements in the riverine environment and recommended SEA-10 study Vietnam air support and indirect fire methods. RADM Bullard was realistic about what could be accomplished during the course of SEA-10's thesis work and commented that a sound recommendation on a single piece of the riverine problem would be tremendously useful to him. He also pointed out that the RF should be examined as an extension of the battle group so there is an expectation of mutually supporting forces, and the realignment of the core expeditionary warfare competencies under NECC (see Figure 4) will facilitate that mutual support capability.

[50] R. Benbow, P. Ensminger, S. Swartz, & D. Stimpson, Center for Naval Analysis Report, *Renewal of Riverine's Capability: A Preliminary Examination of Past, Current and Future Capabilities*, p. 65, January 2006.

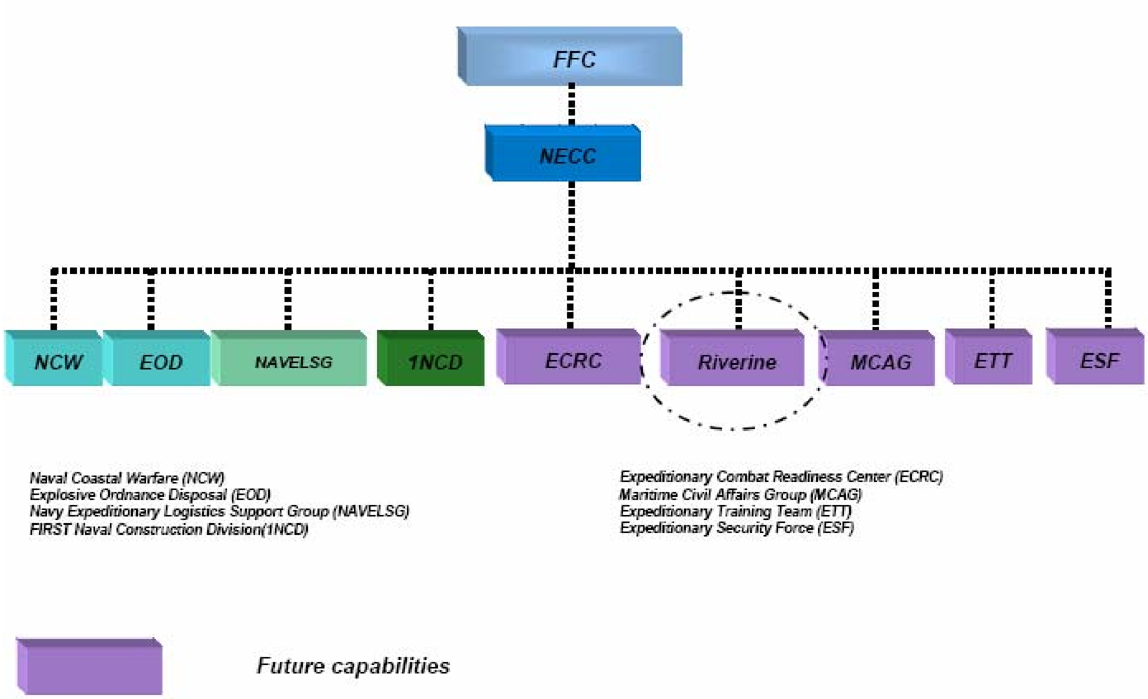

Figure 4. NECC Force Structure[51].

2. East Coast Stakeholder Meetings

SEA-10 felt face to face meetings were important to foster trust and solicit buy-in to the project. In early July, 2006 two SEA-10 team members traveled to meet with personnel at the Center for Security Forces (CENSECFOR) Naval Station in Chesapeake, Virginia, River Group One (RIVGRU ONE) at Little Creek Amphibious Base in Virginia, and finally the Special Missions Training Center (SMTC) at Camp Lejeune, North Carolina.

a. Center for Security Forces (CENSECFOR)

SEA-10 spoke to retired Marine Staff Sergeant (SSGT) Joshua Iversen at CENSECFOR. Mr. Iversen was a member of the Marine Small Craft Company (SCCo) and completed two deployments to Colombia as part of a Riverine Training Team (RTT) and two deployments to Iraq in support of Operation Iraqi Freedom. He was a boat captain for SCCo during his last tour in Iraq. He is a technical expert on the weapons, platforms, and tactics used by SCCo and was an invaluable source of information.

[51] Naval Expeditionary Combat Command, *Riverine Force Concept of Operations Brief*, Naval Amphibious Base, Little Creek, VA, 3 March 2006.

Mr. Iversen explained that during Operation Iraqi Freedom SCCo was fully supported through the regional area of operations (AO) commander and able to support major combat operations (MCO). Areas where SCCo was supported included, but were not limited to, combat logistics (POL) support, combined supporting arms (Close Air Support (CAS), quick reaction force (QRF)), ground combat element (GCE), explosive ordinance disposal (EOD), linguists, and forward area controller (FAC) personnel as required by the mission profile (i.e., EOD for cache detection and destruction, Special Forces (SF) for High Value Target raids). Mr. Iversen presented the SCCo lessons learned brief covering SCCo platoon organization, TTPs, and his assessment of capabilities and deficiencies for SCCo including areas of concern for the Riverine squadrons (RIVRONs). A summary of the lessons learned included:

- The Small Unit Riverine Craft (SURC), the SCCo riverine platform, proved to be extremely robust and able to perform missions after taking battle damage.
- Dedicated air support and quick reaction force assets were essential in destroying defended riverbank positions.
- POL support proved to be critical in maintaining patrol tempo.
- Hydrographic and visual surveys of operational area were extremely important to preplan missions and ensure that units knew the river environment and locations of riverbank obstructions.
- There were no significant waterborne IED threats to date; therefore, doctrine has not been generated to combat waterborne IEDs.
- Linguists were useful only if they were trustworthy and could communicate to SCCo personnel effectively.
- The lead riverine vessel was always the target and detection usually occurred simultaneously with engagement.
- AO commanders must understand and trust RF capabilities if they are to be effectively integrated in the battle space.

b. River Group One (RIVGRU ONE)

SEA-10's focus at River Group One (RIVGRU ONE) was to determine the baseline capabilities of the proposed RF. At RIVGRU ONE, SEA-10 met with Commodore Jordan, Commander of RIVGRU ONE, and two of his civilian staff, both prior military, Mr. Russ Baker and Mr. Tom Lafferty. Mr. Baker is a former Navy small boat unit operator and Mr. Lafferty was an enlisted small boat unit operator and was later commissioned as a Surface Warfare Officer. Mr. Baker gave a brief overview of the types of technologies RIVGRU and NECC are interested in, including Unmanned Aerial Vehicles (UAV's), Unmanned Surface Vehicles (USV's), Unmanned Ground Sensors (UGS's), and platforms to augment the SURC's and crew served weapons that the river squadrons (RIVRONs) have inherited from Small Craft Company. Mr. Lafferty provided the RIVGRU training plan, draft Navy Mission Essential Task List (NMETL), doctrinal documentation including the latest draft of the NECC *Riverine Concept of Operations* and NWP 3-06M, along with lessons learned from SCCo in Iraq. Takeaways from RIVGRU ONE included:

- RF support (Logistics, CAS, Intel), in scenarios involving less than major combat operations conducted in remote environments, is not clearly defined (Theater Security Cooperation (TSC), Anti-Piracy).
- Use SCCo to determine the baseline platform, weapons, communications, and sensor capability for the US Navy's Riverine Force.

Mr. Lafferty also confirmed that the first RIVRON will inherit the SURC's from SCCo. Follow on squadrons will consist of six SURC, four Special Operations Craft Riverine (SOC-R), and two command and control craft (likely to be 11m RHIBs).

c. Special Missions Training Center (SMTC)

Former SCCo members SSGT Czernewski and SGT Philips hosted SEA-10 at SMTC. They provided excellent feedback on baseline capabilities and went over the list of stake holder questions. Key takeaways included:

- There are no waterborne IED's to date; therefore, no TTP was developed, but IEDs/waterborne mines are a likely area for concern.
- The typical SCCo communication package requires improvement. Units are using Blue Force Tracker (BFT), Very High Frequency (VHF) radios, Ultra High Frequency (UHF) radios, and Tactical Satellite communications (TACSAT). The RF used Global Positioning System (GPS) for position updates and communication with CAS units.

- Operators expressed a strong desire for Joint Tactical Radio System (JTRS), or a similar system, based on its projected ability to call for indirect fire support.
- Preventive and daily maintenance of SURC's and crew served weapons was not mission impacting. SURC crews maintained both platform and weapons with minimal contractor support.
- The SURC is a robust platform as proven by a battlefield example where a SURC sustained a direct RPG hit and was still able to return to the extraction point.
- Major SURC parts, engine, communication systems, and weapons, are "plug and play" for ease of use.
- All missions began with 3 days water and food ration.
- Boat captains must be equipped with Night Vision Goggles (NVG), and thermal imagers are necessary for night operations.
- Heavy Operational Tempo (OPTEMPO) necessitated multiple sets of equipment to be carried on board, despite original tasking. For example, night raiding equipment would be taken on early morning missions because time tables may change and returning to an extraction point or base may prove infeasible or impossible.
- SURC's require a fuel additive for use with JP-5/JP-8 versus diesel, and this could be a limiting factor for logistics/supply.
- Hydrographic data was critical to understand, identify, and avoid hazardous river obstacles and conditions.

3. Stakeholder Conclusions

Stakeholder feedback narrowed the focus of historical research and validated SEA-10's initial system decomposition. The flexibility of the RF to conduct operations effectively in multiple environments was a concern at all stakeholder levels. One of the primary concerns stakeholders had was RF vulnerability to attack from the riverbanks and its ability to detect and neutralize this type of threat. SEA-10 found this problem interesting, relevant, and feasible enough to make it the focus of the remaining systems architecting process. The RF has a need for increased ability to achieve battle space awareness beyond the visual range and a corresponding organic engagement capability. Achieving both are critical to fielding a survivable and effective RF.

E. INPUT-OUTPUT ANALYSIS

Input-output modeling is used to scope and bound a problem[52]. The input-output model defines the boundaries and boundary conditions of the system. It does so by analyzing inputs and focusing on what outputs are either intentionally or unintentionally generated by the system. SEA-10 examined the controllable and uncontrollable inputs to the global RF system and evaluated the potential for intended and unintended outputs from the system. Figure 5 illustrates the inputs and outputs considered by SEA-10. Consider a controllable input such as sensor coverage. In jungle environments, a likely riverine environment, increased sensor coverage could aid the RF to track potential hostile forces or remotely monitor sections of the riverine environment. This increase in sensor coverage could lead to increased situational awareness (SA). Conversely, it could lead the enemy to adapt tactics and change smuggling routes or force employment to offset the RF's increased SA. The ability to hypothesize and trace input flow and output effects adds great value to functional analysis.

[52] E.P. Paulo, *SI4001 Systems Engineering and Architecture Course Notes;Needs Analysis*, Naval Postgraduate School, Delivered 10 January 2006.

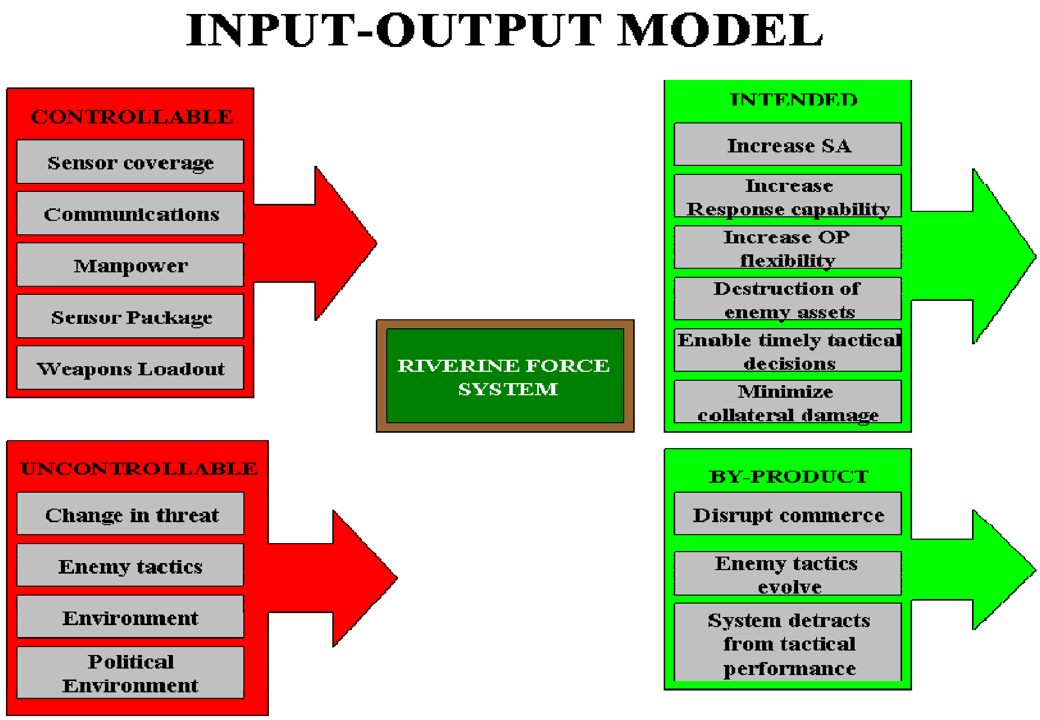

Figure 5. SEA-10 Riverine Input-Output Model.

F. FUNCTIONAL HIERARCHY

After system decomposition of the riverine problem, stakeholder feedback to validate ideas on global riverine system functions and components, and input output analysis, SEA-10 bound the riverine problem to the global functions which the RF must accomplish to succeed in missions assigned in the CONOPS. These missions include conducting maritime security operations, control and denial of the riverine area, insertion and extraction of conventional forces, providing fire support and conducting theater security cooperation. From these missions SEA-10 composed a functional hierarchy consisting of five global functions: conduct C4ISR operations, move, defend, engage, and sustain as shown in Figure 6. Identifying these global functions helped provide insight on whether the potential solution would involve the use of equipment, software, people, facilities, or data. Each function was defined using standard military definitions from Joint Pub 1-02.

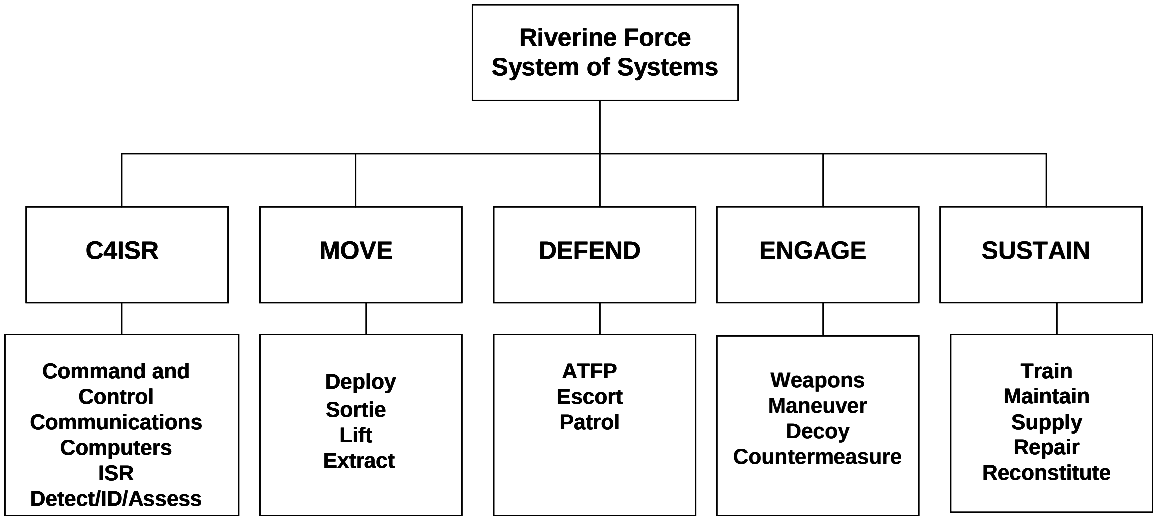

Figure 6. SEA-10 Primitive Riverine Functional Hierarchy.

1. Conduct C4ISR Operations

C4ISR operations include the authority and responsibility for effectively using available resources and for planning the employment of, organizing, directing, coordinating, and controlling military forces for the accomplishment of assigned missions. Sub-functions of C4ISR include:

Command and Control

- Deliver the commander's intent
- Exchange tactical data
- Direct supporting arms

Detect is the perception of an object of possible military interest[53]. Awareness and knowledge of identity are key elements of detect. Sub-functions of detect include:

- Exchange Intelligence, Surveillance and Reconnaissance (ISR)
- Search
- Find
- Identify Friend or Foe (IFF)

53 *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Term*, 12 April 2001.

2. Move

Move is to place ships, aircraft, or land forces in position of advantage over the enemy. It is the planning, routing, scheduling and control of personnel and cargo movements over lines of communications[54]. Sub-functions of move include:

- Sortie of the riverine force or deploy
- Lifting of troops and equipment
- Insertion and extraction of troops and vital personnel

3. Defend

To defend is to absorb or repulse attacks, progressively weaken an attack, prevent initial observations of the whole position by the enemy, and to allow the commander to maneuver the reserve[55]. Sub-functions of defend include:

- Provide AT/FP
- Escort units of interests
- Patrol areas of interests

4. Engage

Engage to bring the enemy under fire. It is a series of related military operations aimed at accomplishing a strategic or operational objective within a given time and space[56]. Sub-functions of engage include:

- Weapons employment
- Maneuver
- Decoy
- Countermeasures

5. Sustain

Sustain is the provision of personnel, logistics and other support required to maintain and prolong operations or combat until successful accomplishment or revision of the mission or the objective[57]. Sub-functions of sustain include:

- Training of the RF

[54] *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Term*, 12 April 2001.

[55] Ibid.

[56] Ibid.

[57] Ibid.

- Outfitting the RF
- Maintaining equipment
- Repairing equipment
- Combat supply of the RF

G. FOCUS ON DETECT AND ENGAGE FUNCTIONS

Interaction with stakeholders and needs analysis provided the necessary focus to reduce the number of functions and sub functions to investigate in the project. Stakeholder interaction specifically directed concern and emphasis toward study of defeating the "**bend in the river**" or ambush problem. The primary problem in the ambush scenario is to transform unidentified or hidden targets within the battlespace into neutralized targets while the RF avoids damage.

The RF's near term February 2007 Iraq deployment timeline motivated SEA-10 to focus on combat critical functions for this thesis. Even though the RF is deploying in 2007, stakeholder analysis focused on capabilities and budget funding that were available in the near term. Therefore, SEA-10's goal was to make recommendations to NECC and RIVGRU ONE on the needs of a RF in a sight constrained battlespace for 2010.

The basic need to improve the RF's ability to "see the enemy before they were seen," and to "kill the enemy before they were killed" became the focus of research after system decomposition and initial stakeholder feedback. With this need in mind, the functions of the riverine system were analyzed by looking at the kill chain functional hierarchy as shown in Figure 7[58]. Within this hierarchy SEA-10 chose to focus on the combat critical functions of detect and engage and sought to determine the mechanisms by which the RF system could be designed to affect overall system performance.

[58] The National Academies Press *"C4ISR For Future Naval Strike Groups"* Retrieved 05 September 2006 from the World Wide Web at [http://fermat.nap.edu/openbook.php?record_id=11605&page=R1]

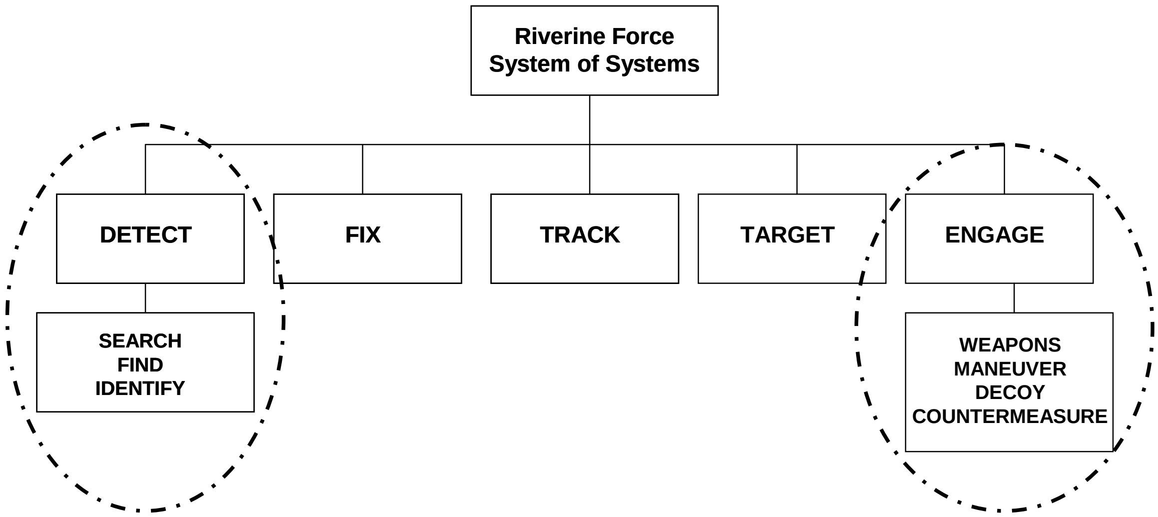

Figure 7. Refined Functional Hierarchy with the Detect-to-Engage Sequence.

H. FUNCTIONAL FLOW DIAGRAM AND CONTEXT MODEL

SEA-10 examined the system using a Functional Flow Diagram (FFD) and a corresponding Functional Flow Block Diagram (FFBD) that represents the kill chain. These diagrams illustrate how the functions interact to allow total system operations (Figure 8 and 9). Analysis further devolved top level functions into second level functions (1.1 and 5.1 series in Figure 9). Second level functions were broken down into third level functions (1.3.1 through 1.3.2 in Figure 9). From this level, sub functions were down to the level necessary to adequately describe the system and its various elements in functional terms, to show functional interrelationships, and to identify the resources needed for functional implementation. Block numbers are used to show sequential and parallel relationships and provide top-down traceability through functions. Later in the development of RF global physical architectures, these block numbers also demonstrate bottom-up traceability and justification of the physical resources necessary to accomplish detect and engage functions.

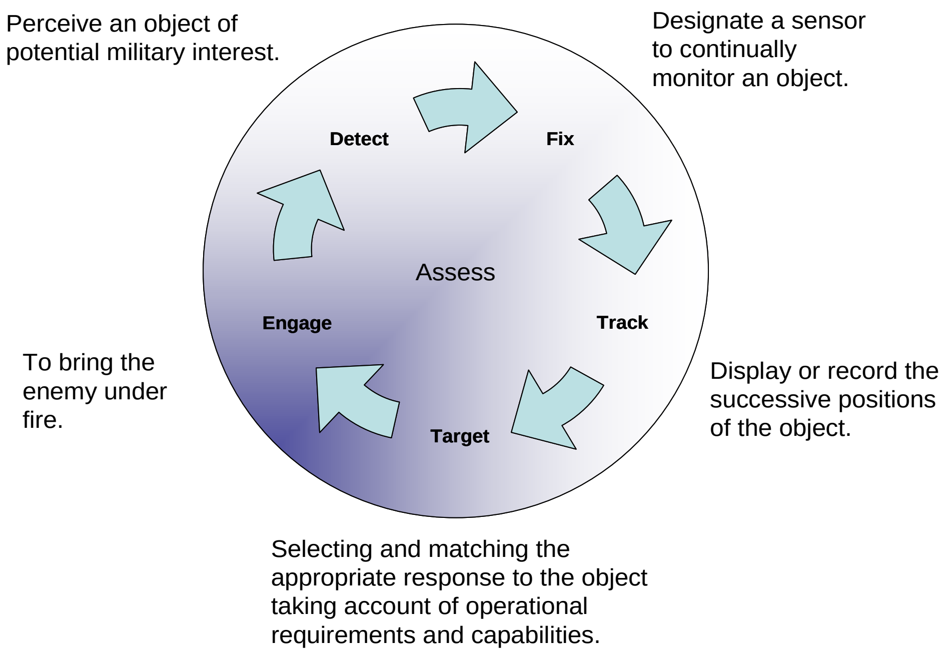

Figure 8. Functional Flow of the Kill Chain.

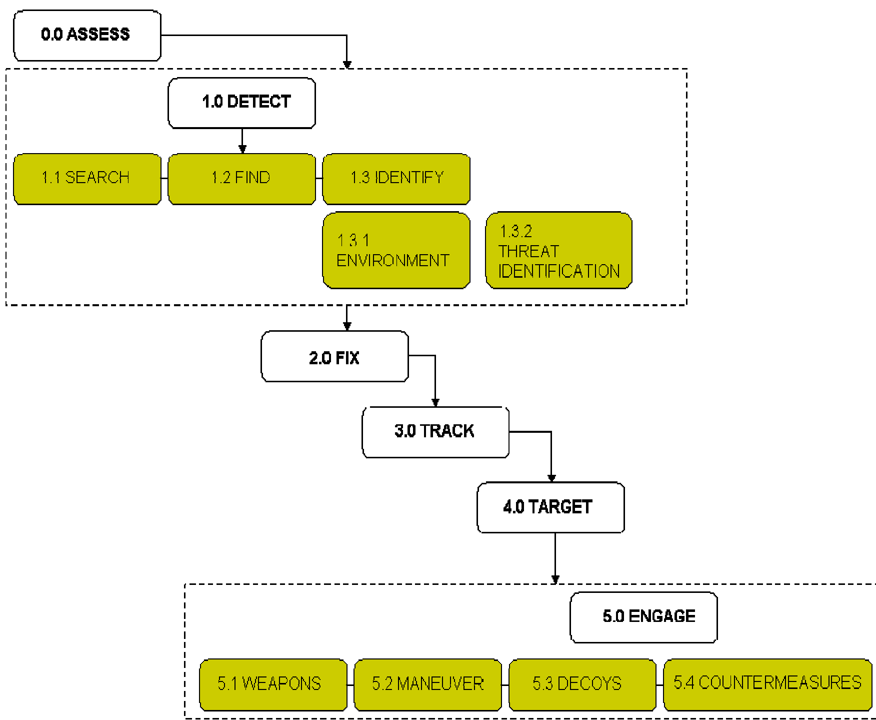

Figure 9. Function Hierarchical Block Diagram of the Kill Chain.

The final step in functional analysis was to build a context diagram that dissects the RF global detect and engage system into simpler parts and examines where interactions were taking place. Since SEA-10 was constrained by a timeline and modeling limitations, the choice was made to focus efforts on the relationships between the two functions in order to provide relevant insight. The two direct combat related functions of detect and engage were chosen on the basis that SEA-10 would be able to model each function during the time allotted with traceable measures of effectiveness and provide meaningful results to NECC and RIVGRU ONE in their consideration of alternatives for the 2010 RF. Each block in Figure 10 represents an operational function that must be performed for the system to accomplish its designated mission.

Each function (as shown in previous figures) was defined in terms of inputs, outputs, controls and/or constraints, and enabling mechanisms. Activities transform inputs into outputs. Inputs enter the left side of the box and are the information or material used to produce the activity's output. Mechanisms enter the bottom of the box and are the resources that perform processing or provide energy to the activity. Mechanisms lead to identification of physical resources necessary to accomplish the function, evolving from the "whats" to the "hows." For example, SEA-10 identified the detect mechanisms as sensors, computers and personnel while engagement mechanisms were identified as the employment of maneuver, decoys, weapons or countermeasures. Controls regulate an activity as it converts inputs to outputs. Outputs exit the box from the right and are the results of an activity.

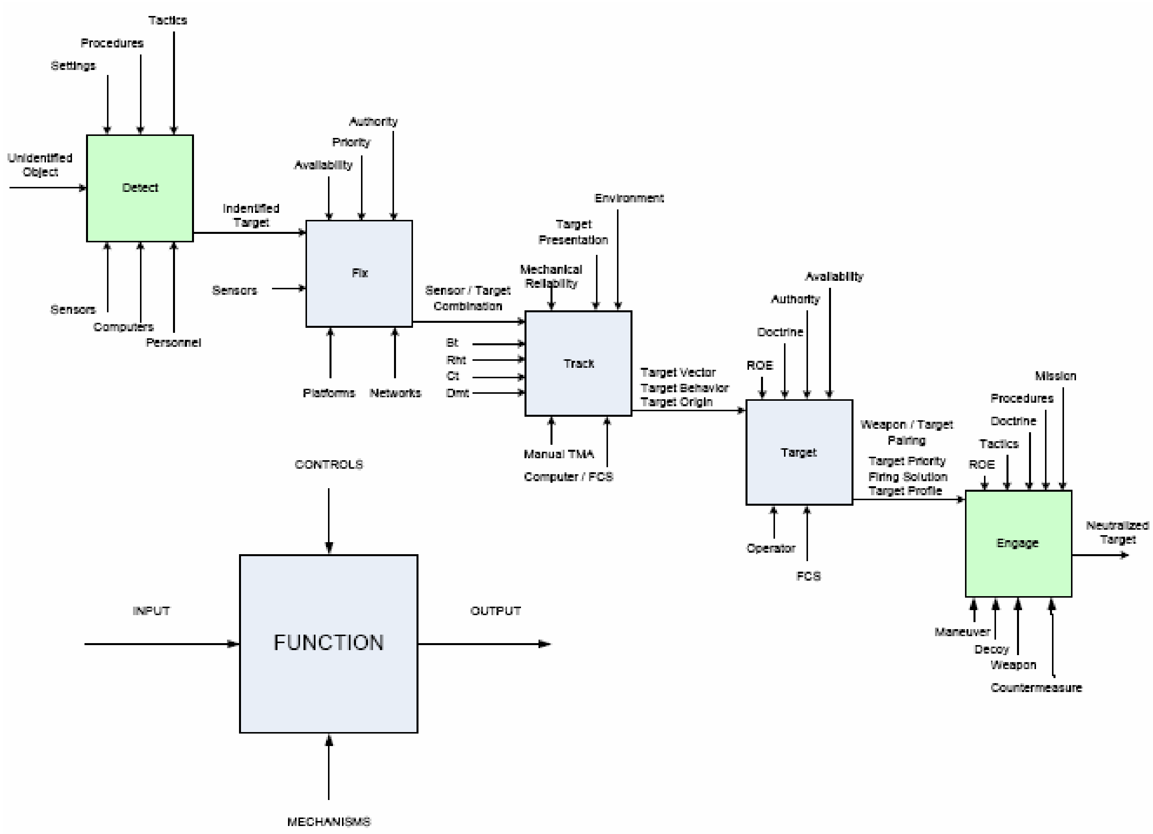

Figure 10. Riverine Context Diagram.

I. REVISED PROBLEM STATEMENT

The initial problem statement, stakeholder inputs, and functional analysis resulted in an improved definition of riverine warfare. SEA-10 used these elements of the functional architecture to generate the following revised problem statement:

> *"Define, analyze, and recommend a cost effective alternative from competing architectures that increases the US Navy's proposed riverine force's battle space awareness and situational responsiveness utilizing technologies currently in use or available for use by 2010."*

The critical function detect is best represented by the term battlespace awareness. Battlespace awareness encompasses sensor coverage and detection, communication ability, and the time a commander has to make a tactical decision. The critical function engage is best represented by the term situational responsiveness. Situational responsiveness encompasses the options available to a commander to bring weapons to bear upon enemy forces.

J. OBJECTIVES HIERARCHY

1. Introduction

An objectives hierarchy is defined by Buede as, "the hierarchy of objectives that are important to the system's stakeholders in a value sense; that is, the stakeholders would (should) be willing to pay to obtain increased performance (or decreased cost) in any one of these objectives.[59]" SEA-10 used the revised problem statement as the top level objective that must be achieved. This resulted in an easily understandable, non-redundant objectives hierarchy, supported by lower tier evaluation measures that adequately covered all evaluation concerns. Figure 11 illustrates the objectives hierarchy for this design problem. This section details the components, logic, and takeaways represented by the objective hierarchy.

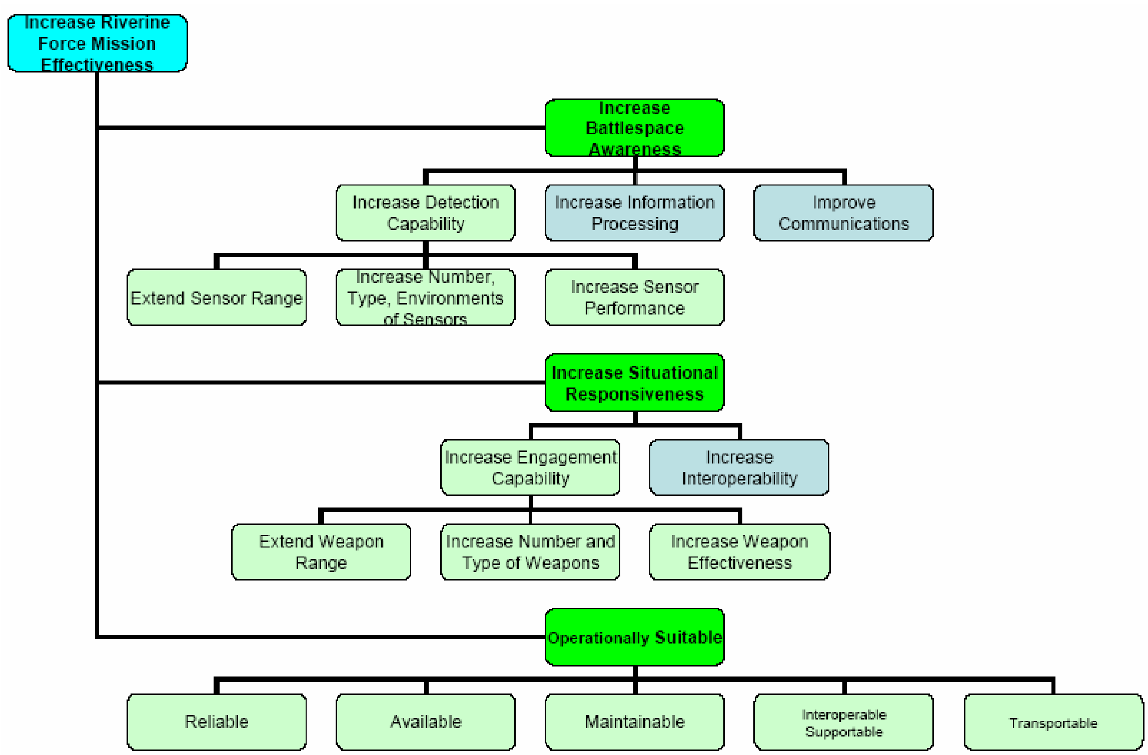

Figure 11. SEA-10 Riverine Objective Hierarchy.

[59] D.M. Buede, *The Engineering Design of Systems: Models and Methods*, p. 147, John Wiley & Sons, Inc., 2000.

2. Objectives Hierarchy Composition

The revised problem statement was decomposed into two separate objectives: increase situational awareness and increase situational responsiveness. These objectives were analyzed separately. The objectives hierarchy was limited to those portions determined to be most critical to the RF. This allowed the objectives hierarchy to be effectively communicated to stakeholders and used fewer resources to evaluate[60]

3. Increase Battlespace Awareness

SEA-10 determined that increased battlespace awareness can be accomplished by increased information processing, increased detection ability, and/or improved communications. SEA-10 chose to scope this objective down by only examining increased detection capability. Detection capability's importance was emphasized in both historical literature reviews and feedback from stakeholders. Detection technology is mature and could be implemented into the RF of 2010. Increased detection capability could be accomplished by increasing the number and types of sensors used, increasing sensor range, and increasing sensor performance as shown in Figure 12.

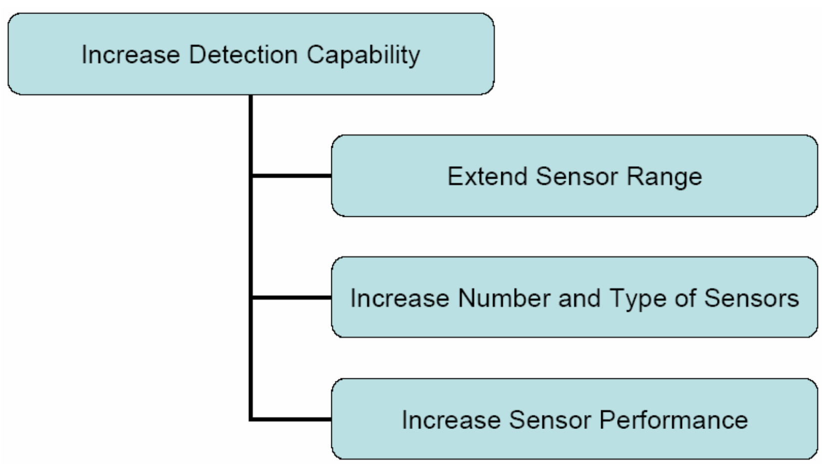

Figure 12. Increased Detection Capability Objective Breakdown.

4. Increase Response Capability

SEA-10 determined that increased response capability can be achieved by increased interoperability (of units and equipment) or by increased engagement

[60] E.P. Paulo, *SI4001 Systems Engineering and Architecture Course Notes, Value (or Objectives) Hierarchy: Functions, Attributes, and Metrics Brief*, Naval Postgraduate School, Monterey, CA, 23 January 2005.

capability. Increased engagement capability could be accomplished by increasing the number and types of weapons employed, increasing weapons range, and increasing the effectiveness or lethality of the weapons used as shown in Figure 13. Again, SEA-10 chose engagement over interoperability because engagement technologies are mature and fit the 2010 timeframe of this thesis. Engagement technologies also bypass the doctrinal and parochial issues that accompany interoperability. Engagement also pointed to distinct quantifiable measures of effectiveness.

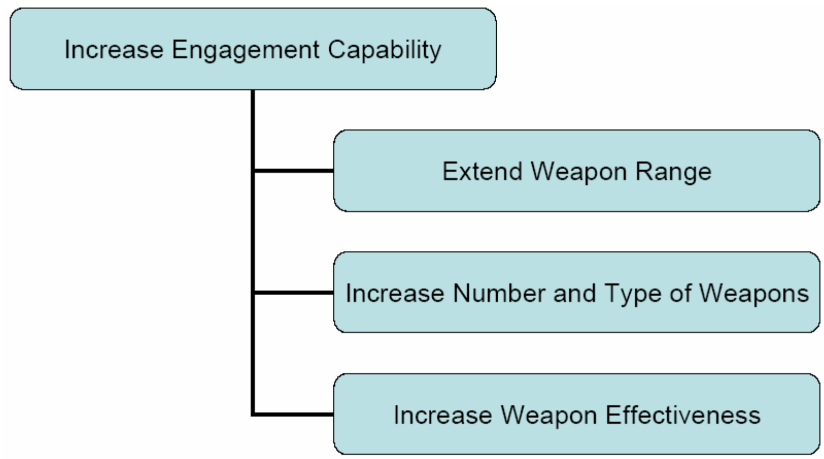

Figure 13. Increased Engagement Capability Objective Breakdown.

5 Operational Suitability

The third branch of the objectives hierarchy addressed operational suitability requirements shown in Figure 14. Operational suitability is another set of values that represent physical "ilities" that are critical to every system's efficiency. However, operational suitability was not considered for quantitative analysis in this thesis because SEA-10 did not want to limit the scope of the physical architecture by using any of the "ilities" as constraints. For example, SEA-10 did not want to constrain physical architecture alternatives by transportability because NECC's transport capability has not yet been defined. Limiting options by this constraint may result in a less effective analysis. SEA-10 did conduct a qualitative discussion of reliability (based on existing equipment) of the components of the various alternative force packages in chapter VII Riverine System Reliability.

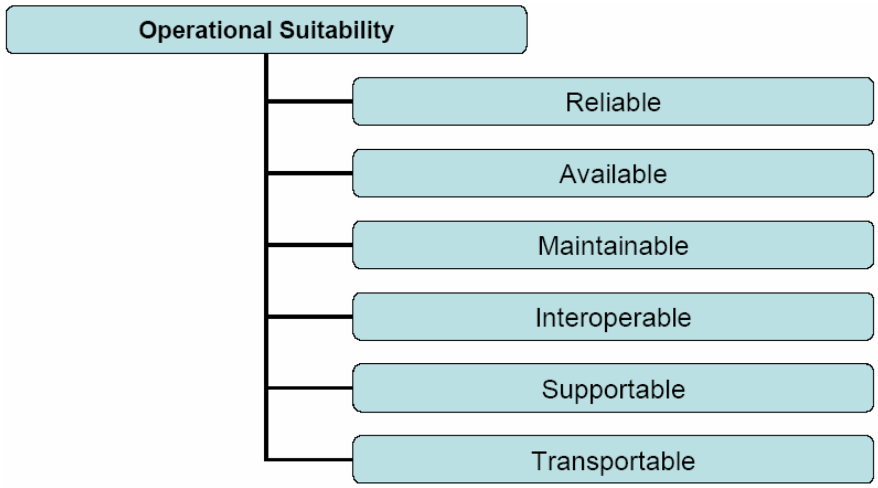

Figure 14. Operational Suitability Values.

K. MEASURES OF EFFECTIVENESS

The RF objectives hierarchy designated which objectives were measured and which design criteria were used to evaluate system designs[61]. A measure of effectiveness (MOE) expresses the extent to which a system accomplishes an operational objective[62]. MOE's also provide the decision maker with a way to measure the degree that one alternative is superior to the other alternatives. MOE's are recorded and analyzed in the modeling and analysis phase. MOE must be quantifiable, relevant to the problem, and feasible. In order to generate MOE that met these criteria, SEA-10 conducted stakeholder and Naval Postgraduate School (NPS) campus interviews with riverine operators to evaluate MOE suitability. The end goal was to generate MOE that present a clear indication of the alternative architecture's ability to achieve design objectives of improved battle space awareness and response capability.

1. MOE Collaboration

SEA-10 added credibility to the MOE listed in Figure 11 (MOE's are indicated by the light green boxes) by interviewing NPS students with past operational riverine experience (but were not experts on MOE). Five students replied to the request for information and provided insight on MOE feasibility and priority. The students had a

[61] A.P. Sage & J.E. Armstrong, *Introduction to Systems Engineering,* pp. 112-113, John Wiley & Sons, Inc., 2000.

[62] D.H. Wagner, W.C. Mylander, & T.J. Sanders, *Naval Operations Analysis*. 3rd Edition, p. 12, Naval Institute Press, 1999.

wealth of knowledge and came from different operational backgrounds. Table 4 summarizes each student's operational experience.

Service	Rank	Assignment	Mission
USN	O-4	Patrol Craft Commanding Officer	Patrol Iraqi rivers (KAA) in support of OIF
USMC	O-4	USMC Company Commander	Patrol Euphrates River with USMC boat company
USMC	O-3	Liaison officer with the Columbian Navy	Counter-narcotics on Columbian water ways
USN	O-3	Small boat team, 11m RHIB detachment OIC	Patrol Euphrates River in support OIF
USN	O-3	Navy Seal	Trained Philippine Naval forces in small boat tactics and counter insurgency

Table 4. NPS Riverine Operator Experience.

2. MOE Prioritization

Prioritization of MOE took place through an interview process with the student volunteers. Interviews of the students consisted of a one-on-one discussion with an SEA-10 member to record their professional opinions on how to prioritize a pre-determined list of MOE's. The students were then asked to prioritize a list of alternative force packages which were developed by SEA-10 members. Table 5 is the list of MOE given to the student participants.

Engagement MOE	Detection MOE	Other MOE
Accuracy (of weapons or systems designated)	Target Detection	Protection and security (unit or area)
Weapons Effectiveness	Target Recognition	Timeliness
	Target Classification	Mobility
		Robustness (how much damage can a unit sustain)
		Sustainability
		Interoperability

Table 5. Riverine MOE with Focus on Detect and Engage.

The following scenario was developed to place the MOE in context for the student volunteers, and based on scenarios that stakeholders reported were feasible RF missions.

> *You are the commander of the section of four SURC's and are on patrol in a river that is located in a populated region and whose banks are obstructed by foliage. Two of the SURC's are designated as the scout boats, the 3rd SURC is the command and control boat and the 4th SURC provides security for the C2 boat. You are in one of the lead scout boats and are going around a bend of the river where the enemy has recently carried out ambushes on riverine forces. What do you consider are the most important measures of effectiveness that will allow SEA-10 to adequately assess the best alternative for increasing detection and engagement capability of your section of SURC's in this scenario?*

Students were permitted to ask questions about the scenario and were then asked to prioritize the MOE's. Students were instructed to designate the most important MOE with #1. The students were also given the opportunity to ask questions about the meanings of the MOE's and were given the option to subjugate an MOE if they felt it should reside as a subset of another MOE. Table 6 lists the results of student operator MOE preferences. One of the student participants did not respond to SEA-10's request for MOE preferences.

Student/Preferred MOE	#1	#2	#3	#4	#5
USMC O-4	Combat Power (robustness)	Target Detection	Protection and security	Logistics (sustainability)	Patrol
USN O-3	Mobility	Target Detection	Target Recognition	Target Classification	Weapons Effectiveness
USN O-4	Situational Awareness	Target Detection/Recognition/	Accuracy, weapons	Robustness	(none mentioned, considered all others
USMC O-3	Protection and Security	Target Detection/Recognition/ Classification	Timeless of information	Interoperability	Weapons Effectiveness/Weapons accuracy

Table 6. NPS Riverine Operator MOE Preferences.

3. MOE Derivation

Analysis of the MOE lists indicated that having the ability to detect the target was a high priority for all of the students. Combat power and weapons accuracy also achieved a high priority among all four of the students. Most of the students mentioned mobility as a significant factor for mission success during the interviews, but they did not rank it as such. Due to the small sample size of participants, there was little point in conducting a robust statistical analysis of the results; however, SEA-10 felt that the interviews provided militarily significant information.

MOE displayed in Table 7 were derived from the RF objectives hierarchy and refined by student interviews. They are intended to scope the analysis and act as a basis for evaluation between competing alternatives. Measures of Performance (MOP) are listed with their corresponding MOE and are quantitative or qualitative measures of a system's performance[63]. MOE chosen for this thesis are in context with the scenarios and may not be adequate for all circumstances the RF may encounter.

Objective	Measure of Effectiveness	Measure of Performance
Increase Battlespace Awareness	Increase Detection Capability	Time of Detection
	Increase Sensor Range	Range of Detection
	Increase Sensor Performance	Proportion of enemies detected
	Increase number and types of Sensors	
Increase Situational Responsiveness	Increase Engagement Capability	Range at Engagement
	Increase Weapons Range	
	Increase Weapons Lethality	Time of Engagement
	Increase number and types of Weapons	
	Overall System Performance	Loss Exchange Ratio

Table 7. RF Objectives, Measures of Effectiveness, and Measures of Performance.

4. Conclusion

The objectives hierarchy provided the traceability and design guidance necessary to transition into the RF physical architecture. It described how the group chose to scope the problem and bounded the type of data needed to evaluate the alternative architectures and the ability of those architectures to achieve the stated objectives. SEA-10 focused its efforts in the combat critical skills of detect and engage to give the RF powerful high level insight into the types of architectures in which to invest.

63 D.H. Wagner, W.C. Mylander, & T.J. Sanders, *Naval Operations Analysis*. 3rd Edition, p. 12, Naval Institute Press, 1999.

III. PHYSICAL ARCHITECTURE

A. PHYSICAL ARCHITECTURE COMPONENTS AND PURPOSE

The physical architecture of a system is a hierarchical description of the resources that comprise the system[64]. The physical architecture provides resources for every function identified in the functional architecture[65]. The objectives hierarchy serves as a link between the functional and physical architectures by identifying physical entities that may satisfy needs identified in the functional architecture. The SEA-10 RF physical architecture consists of an analysis of the proposed NECC RF, and an analysis of SEA-10 generated alternatives of RF technologies and employment options. Each alternative was created with the overarching objectives of "increase battlespace awareness" and "increase situational responsiveness" in mind. MOE and MOP are traceable through each alternative to the overarching RF objectives.

B. NECC PROPOSED RF STRUCTURE AND EMPLOYMENT

1. NECC Proposed Riverine Force

The current U.S. Navy Riverine Force Concept of Operations specifies that the force will consist of three squadrons of 12 Small Unit Riverine Craft (SURC). The smaller force structure dictates that NECC RF elements be interoperable with other battle space assets in order to prosecute potential targets and maintain awareness. The proposed force's smaller size was one of the major reasons SEA-10 chose detect and engage as critical functions to study because of the limited number of organic combat assets available to the RF.

2. The Worthington Study

Analysis of RF size and hypothetical capability has been done before. In 1990, the Navy/Marine Corps Board commissioned the Worthington study on riverine warfare which explained the need for a RF and suggested a force layout[66]. The study examined potential missions for a RF and designed a brigade sized, joint Navy/Marine Corps force

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[64] D.M. Buede, *The Engineering Design of Systems: Models and Methods*, p. 216, John Wiley & Sons, Inc., 2000.

[65] D.M. Buede, *The Engineering Design of Systems: Models and Methods*, p. 217, John Wiley & Sons, Inc., 2000.

[66] R. Benbow, P. Ensminger, S. Swartz, & D. Stimpson, Center for Naval Analysis Report, *Renewal of Riverine's Capability: A Preliminary Examination of Past, Current and Future Capabilities*, January 2006.

that would be composed of approximately 3000 personnel, 75 riverine craft, and both rotary and fixed wing air assets. A similar force structure was utilized in Vietnam and found necessary in order to maintain battle space awareness in the riverine environment, mount a formidable assault, sustain the force for regular operations, and maintain riverine base security[67]. The Worthington Study differs significantly with the NECC proposed RF in that GCE, CAS, and other supporting elements are organic to the Worthington Study force, while all of these elements are alluded to as supporting forces in the NECC RF CONOPS. A full understanding of RF structure and employment capability was necessary to accurately develop a comprehensive physical architecture.

3. Conduct of Riverine Operations

The RF of 2007 is constructed around security missions on the Euphrates River and around Haditha Dam, a major source of hydroelectric power to central Iraq, approximately 140 miles northwest of Baghdad[68]. Even with the well understood immediate mission in Iraq, it was difficult to find an encompassing mission statement for the RF of 2007. Riverine operations in 2010 are more ambiguous and are subject to speculation on the future of world affairs. The River Squadron ONE (RIVRON ONE) website states that the mission of the riverine force is to "conduct Shaping and Stability Operations, to provide Maritime Security, train coalition partners in riverine operations, conduct intelligence, surveillance and reconnaissance and limited combined operations."[69] According to the Riverine CONOPS to Fleet Forces Command the focus of the riverine force "will be on conducting maritime security operations and theater security cooperation in a riverine area of operations or other suitable area."[70] The language used to describe the physical mission requirements, or the actual tasks that the RF would have to perform, was difficult to discern from these sources. Therefore, SEA-

[67] R. Benbow, P. Ensminger, S. Swartz, & D. Stimpson, Center for Naval Analysis Report, *Renewal of Riverine's Capability: A Preliminary Examination of Past, Current and Future Capabilities*, p. 18, January 2006.

[68] Global Security, Haditha. Retrieved 20 September 2006 from the World Wide Web at [www.globalsecurity.org/military/world/iraq/haditha.htm.].

[69] Naval Expeditionary Combat Command. Retrieved 5 October 2006 from the World Wide Web at http://www.necc.navy.mil/rivronone/index.htm.

[70] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (FINAL)*, Naval Amphibious Base, Little Creek, VA, 28 September 2006.

10 developed a 'long view'[71] of the RF's operating requirements and environment in 2010. SEA-10's interpretation of the RF's mission in 2010 is based on literature searches, interviews with stakeholders and educated judgment.

4. NECC Proposed Baseline Force

SEA-10 utilized the U.S. Navy Riverine Warfare Concept of Operations RF structure as the baseline for alternatives. This force structure will deploy to Iraq in the near term, a desert environment. SEA-10's scenarios are based in the Niger Delta, a jungle environment. SEA-10 chose this environment on the assumption that the RF will need to augment itself for missions in varying environments. The proposed RF is a single environment one dimensional force, shown in Table 8, while the force of 2010 will need to operate in multiple environments.

Platform	Crew Number	Weapons	Mobility Capability	Potential Augments
SURC X 4	2 X 7 man crews enabling 24 hour operations	1 X .50 caliber heavy machine gun	15 days projected sustainability (not including fuel)	Tactical USV/UUV/UAV teams
		1 X Mk 19 40mm automatic grenade launcher	Full Motor Transport Support (only limited by boat ramp availability)	Intelligence Exploitation Teams
		1 X GAU-17 7.62mm Gatling gun	Medical support by Navy Corpsmen	Civil affairs teams
		1 X M240G 7.62mm medium machine gun		Linguists
		1 X M-16 5.56mm assault rifle per crew member (7 total)		7 Man Visit Board Search and Seizure (VBSS) Team
Note: No organic Air Support or Ground Combat Element is planned for the NECC proposed RF. The NECC CONOPS states that these forces will support the RF.				

Table 8. Estimated NECC Baseline RF Capability[72],[73].

Substantiation of SEA-10's interpretation of the proposed baseline was critical to the overall credibility of alternatives and, ultimately, to the proposed system of systems. SEA-10's interpretation of the proposed baseline serves as the basis for comparison in analysis of alternatives because of the lack of operational data available for the proposed

[71] P. Schwartz, *The Art of the Long View: Planning for the Future in an Uncertain World*, Bantam Doubleday Dell Publishing Group, 1991.

[72] Naval Expeditionary Combat Command, Concept of Operations – US Navy Riverine Force (FINAL), Naval Amphibious Base, Little Creek, VA, 28 September 2006.

[73] US Marine Corps Center for Lessons Learned, *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II (OIF II)*, 4 April 2006.

RF. SEA-10's interpretation of the baseline force was endorsed by RIVGRU ONE, because it accurately represents the actual RF that will deploy to Iraq in February 2007[74].

C. ANALYSIS OF ALTERNATIVES

1. Analysis of Alternatives and the Physical Architecture

The purpose of analysis of alternatives is to develop an understanding of "how each alternative impacts the needs, constraints, alterables, and objectives that were specified as part of the issue formulation effort."[75] In plain terms, analysis of alternatives looks at all of the ways to accomplish a goal or complete a mission, and then chooses the most effective method to do so. A commander may think that he or she needs a bridge to cross a river, but a bridge may not actually be the most effective or efficient means of transporting people and equipment across. Instead of "needing a bridge", what the commander truly desires is "the best way to cross the river". Comprehensive analysis depends on two products of problem formulation: a detailed description of feasible alternatives and a set of criteria to evaluate the alternatives."[76] Evaluation criteria were generated in the functional architecture, while the generation of alternative physical system architectures substantiates the conceptual RF solutions generated in the functional architecture. This section examines the logic that SEA-10 used to develop objective criteria necessary for comparing alternative force packages, and which force packages were chosen for system modeling and analysis.

2. Need for Alternatives Generation

The Navy's proposed RF advertises itself as more capable than USMC Small Craft Company (SCCo) in that the Navy RF will act as an independent force capable of conducting boat operations 24 hours per day.[77] Analysis of previous riverine forces led SEA-10 to determine that the detection and engagement capability of the Navy's proposed RF may be less than that of SCCo. SCCo was supported by USMC Ground Combat Element (GCE) and Air Combat Element (ACE) units which enabled immediate deployable area control and integrated air support. Both GCE and ACE units trained

[74] Video Teleconference between RIVGRU ONE and SEA-10, Naval Postgraduate School Monterey, C.A., 6 October 2006.

[75] A.P. Sage & J.E. Armstrong, *Introduction to Systems Engineering*, John Wiley & Sons, Inc., 2000.

[76] A.P. Sage & J.E. Armstrong, *Introduction to Systems Engineering*, p. 179, John Wiley & Sons, Inc., 2000.

[77] Interview US Navy, RIVGRU ONE N2 and SEA-10, Camp Roberts C.A., 16 August 2006.

with and were familiar with SCCo operators and tactics. This level of combat integration is not present in the Navy's proposed RF as stated in the CONOPs. If the proposed RF is a "supported" force, fluidity of operations may be disjointed at times because of the lack of familiarity between joint forces. This analysis ultimately led to our revised problem statement that the proposed RF must have the capability to detect and engage enemy forces beyond visual range. Therefore SEA-10 chose alternatives that should enhance the detection and engagement capability of the proposed RF.

3. Alternative Generation Methodology

Alternatives must be feasible and significantly different from one another. Alternatives must also yield results that are quantifiable and may be assessed using measures of effectiveness that are traceable to the original problem statement. These criteria led SEA-10 to compose a set of alternatives that look at competing ways to increase detection and engagement capability for the RF of 2010 as compared to the baseline force of 2007.

Alternatives were the product of open group discussions that included stakeholders, past and current riverine operators, and technical experts in detection and engagement technologies. These discussions encompassed current and near term detection and engagement technology, as well as recently employed detection and engagement tactics. SEA-10 imposed the 2010 time constraint to add feasibility to this study in that only mature technology would be considered for alternative systems.

The lack of concrete RF performance requirements led to variability in the definition of mission "success" or "improvement" from one alternative to another. None of the current riverine source documents[78,79] state any definite performance standards that a force would have to meet for detection or engagement ranges and times. This issue was further confounded by the vast quantity of technological options available for both detection and engagement. This led to the development of a scaling process for select technological augments.

4. Proposed RF Mission for 2010

[78] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, Naval Amphibious Base, Little Creek, VA, 30 August 2006.

[79] US Marine Corps Center for Lessons Learned, *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II (OIF II)*, MCB Quantico, VA, 4 April 2006.

A succinct mission enables analysis of mission functions previously discussed in this thesis. Finding a specific mission statement for the RF was difficult because there is ambiguity among decision makers on the actual roles the RF will play in the future. SEA-10 developed plausible scenarios for future riverine operational environments to test alternative force packages.

SEA-10's mission for the Niger Delta RF of 2010 was based on scenarios that require the RF to patrol the Niger River over a 15 kilometer x 25 kilometer area, interdict contraband from rebel forces using the river as a means for transportation of illicit material, protect the lines of communication for the indigenous people, and defend against ambush. These scenarios are further explained in the RF operational architecture section.

5. Technologies Considered

Technologies considered for alternatives had to be feasible to the selected mission sets, technologically mature, obtainable, and employable by the United States. There are dozens of unmanned systems available to the defense department. SEA-10 examined these technologies from a broad standpoint of performance and chose systems that have been deployed or thoroughly field tested. Platforms were chosen based on the number and types of sensors they carried and the associated detection ranges of these sensors, whether or not they could provide targeting data rather than simply observation data, and overall physical and operational characteristics such as flight altitude, size, endurance, and controllability.

SEA-10 chose platform characteristics based on the average capability of platforms likely to be procured by NECC. For example, Predator or Global Hawk were not considered because of their cost. One Predator UAV system cost 24.4 million dollars (FY04$), and is not feasible for the budget of the RF.[80] UAV's like Dragoneye were also eliminated from consideration because of waterproofing, launch and retrieval problems, and lack of endurance.[81] UAV's with capabilities similar to Scan Eagle or Shadow 200 were chosen as the most likely platforms for wide area search. Spartan Scout, Sea Fox, and High Speed Surface Target all possessed characteristics that the RF may desire in a

[80] Office of the Secretary of Defense, *Unmanned Aircraft Systems Road Map 2005-2030*, p. 38, 2005.

[81] Office of the Secretary of Defense, *Unmanned Aircraft Systems Road Map 2005-2030*, p. 26, 2005.

USV. Tactical Remote Sensor System was chosen as a likely candidate for a UGS because of its maturity and field testing level.[82] SEA-10 chose unmanned sensor platforms that were not cost prohibitive to the RF, and that could produce a quantifiable gain in either detection or engagement capability. These sensor platforms were then integrated into five different force packages.

D. FORCE PACKAGES

Five individual force packages, other than the baseline force, were compared against each other using MOE and MOP to determine whether the force package adequately enhanced the detection and or engagement capability of the RF. The military significance of each force package is described below, as well as brief qualitative assessments of each force package's limitations and potential benefits. A summarization of how each alternative is significantly different from other alternatives is included for force package distinction, and to trace the logic of each alternative from functional objectives to physical employment options. Table 9, at the end of this section, summarizes the detection and engagement elements of all the force packages.

1. Baseline + Sensors

In the baseline + sensors alternative, a singular unmanned system (UAV, USV, or UGS) is paired with the previously described baseline force. Detect and engage elements of the baseline are augmented by the individual strengths of one unmanned system. Several assumptions accompany this alternative. The most critical assumption is that each unmanned system will be able to communicate with baseline forces via data link. Without data link capability, the information gathered by any of the unmanned systems would be useless to the RF. Unmanned system storage and maintenance are also assumed to integrate into baseline force elements. UGS would require accurate intelligence reports of target areas prior to distribution in order to monitor hostile forces. Random distribution of UGS over a wide unknown area is expected to produce few viable contacts. This alternative is limited by the robustness, baud rate, and penetration capability of the unmanned system data link. USV's are limited by fuel capacity and their ability to maintain station ahead of the baseline force. UAV's are limited by altitude

[82] Marine Corps Warfighting Publication (MCWP) 2-2.3, *Remote Sensor Operations,* p. 1-2, 17 April 1997.

required for stable flight, altitude required for visibility and detection of targets, weather, canopy cover, and recovery operations. Field of view is also a concern for UAV's and is a major limitation for employing a singular detection system for wide area search. Again, accurate intelligence of enemy force concentrations and movements would greatly increase UAV effectiveness. This alternative is significantly different from the baseline in that it has the potential to significantly extend the detection capability of the RF and enable the RF to bring its organic firepower to bear at maximum range.

2. Baseline + Engagement

RIVGRU ONE has expressed an interest in employing a ground combat element (GCE) for insertion and extraction operations. However, no GCE is currently assigned to the RF[83]. SEA-10 assumed that the GCE would be company strength and based the GCE on USA FM-3-21.11.[84] SEA-10 also assumed that the GCE would not have organic air support or major indirect fire support (artillery). The GCE will be able to employ mortars. Tactical insertion and extraction of the GCE will be similar to tactics used by SCCo. This alternative is limited by its detection capability in areas constrained by sharp river bends that create blind turns and dense canopy that prohibits a complete field of view. GCE soldiers embarked on SURC's are just as limited in their field of view as SURC crewmembers. Once disembarked, GCE members can spread out and increase the detection radius of the force, but also expose themselves to separate attacks. Data link between the GCE and SURC's are critical. Without communication between the two forces, the risk of fratricide exists, and combat accountability of forces would be extremely difficult. This alternative is significantly different from the baseline and other alternatives because it enables the RF to reconnoiter and attack targets from two directions. It also brings some remote fire support capability that extends the engage capability of the RF.

83 Video Teleconference between CAPT Jordan, US Navy and RIVGRU personnel and SEA-10, Naval Postgraduate School Monterey, C.A., 5 October 2006.

84 Global Security. *US Army Field Manual 3-21.11: The SBCT Rifle Company*. Retrieved from the World Wide Web on September 07, 2006 at: [http://www.globalsecurity.org/military/library/policy/army/fm/3-21.11/index.html].

3. Baseline + Networked Sensors

This alternative utilizes all three unmanned systems (UAV, USV, UGS) operating simultaneously with the baseline force. Again, data link capabilities are critical in this alternative's success. This alternative is significantly different from other alternatives in that it emphasizes the strengths of multiple semi-redundant unmanned sensors while reducing their weaknesses. The need for intelligence information of an unknown area decreases somewhat when multiple sensor systems work in conjunction with one another. The inefficiency of UAV's as wide area search platforms is minimized by the interaction with USV's and UGS. Potential targets detected by USV's or UGS can be relayed to UAV's and further evaluated. This depth of detection and classification ability does not exist in the other alternatives, and enables the baseline force to engage at the maximum range of their weapons.

4. Baseline + Networked Sensors + Indirect Fire

This alternative utilizes all three unmanned systems operating simultaneously with the baseline force and a separate indirect fire support system. This alternative is based on the same assumptions and limitations as the networked sensors alternative, except that it has a more robust engagement capability. Should the RF be unable to engage a detected target at maximum range, it can call in indirect fire support and safely engage the target from afar. Again, the importance of a reliable data link cannot be stressed enough. In this alternative, not only the baseline force needs to have an accurate picture of the battlespace, but the indirect fire support system needs an accurate picture as well.

5. Baseline + Dedicated Helicopter Support

This alternative forgoes unmanned systems in lieu of dedicated patrolling and on call helicopter support. This alternative assumes that helicopters supporting this mission will have fuel capacity, weapons, and range to adequately perform search, patrol, attack, and medical evacuation operations for the RF. This alternative is limited by the number of helicopters ready at any given time to support RF operations. However, unlike an unmanned system that requires man-in-the-loop target evaluation and classification (or special ROE), manned helicopters put a human on scene to evaluate and classify potential targets immediately. On the scene presence brings risk to helicopter pilots, but may be offset by the standoff engagement range that some helicopter launched weapons possess.

Alternative	Detection Platform(s)	Engagement Platform(s)
Baseline *1 weapon per SURC	Human vision Inland navigation radar Night vision goggles	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member
Baseline + Sensors **sensors are used individually, not simultaneously	Medium UAV** ***or*** Medium USV** ***or*** UGS Fields** ***or*** Human vision Inland navigation radar Night vision goggles	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member
Baseline + Engagement	Human vision Inland navigation radar Night vision goggles Human vision Inland navigation radar Night vision goggles	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member 2 x 12 man squads of infantry soldiers 2 x M-249 Squad Automatic Weapon (1 per squad)
Baseline + Networked Sensors ***all sensors used simultaneously	Medium UAV*** ***and*** Medium USV*** ***and*** UGS Fields*** Human vision Inland navigation radar Night vision goggles	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member
Baseline + Networked Sensors + Indirect Fire ***all sensors used simultaneously	Medium UAV*** ***and*** Medium USV*** ***and*** UGS Fields*** Human vision Inland navigation radar Night vision goggles	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member 2 x 81mm mortars
Baseline + Dedicated Helicopter Support	Human vision Inland navigation radar Night vision goggles FLIR APS-124 radar	M-240G medium machine gun* GAU-17 Gatling gun* Mk-19 40mm grenade launcher* .50 caliber machine gun* 1 x M-16 assault rifle per crew member 1 x GAU-50 machine gun per helicopter 4 x Hellfire missiles per helicopter

Table 9. Force Package Detect and Engage Components.

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IV. OPERATIONAL ARCHITECTURE

A. OPERATIONAL ARCHITECTURE COMPONENTS AND PURPOSE

The operational architecture integrates the system decomposition with the functional and physical architectures[85]. The operational architecture facilitates modeling, analysis, estimates system performance, and enables trade-off decisions[86]. Objectives derived in the functional architecture must be assigned to entities identified in the physical architecture to operationalize the RF system. In plain terms, SEA-10's mission essential objectives: increase battlespace awareness (key function detect) and increase situational responsiveness (key function engage); need to be directly associated with entities encompassed within the force packages described in the physical architecture. SEA-10 used two scenarios to present the force packages described in the physical architecture in situations that test each force package's detect and engage capability. Further analysis of operational feasibility was conducted through modeling and analysis. SEA-10 utilized agent based models to simulate each force package in the two scenarios, generate performance data, and analyze the results to make a performance based recommendation on which force package best satisfies SEA-10's RF objectives. SEA-10 also conducted cost estimation for the force packages described in the physical architecture. This cost estimation was compared with risk analysis for each force package to determine which would most benefit the RF of 2010.

B. RIVERINE SCENARIOS

Scenarios provide a structured avenue for operators to share operational experience and insights. Scenarios also provide a physical link to substantiate functions in a tactical real world environment. They examine physical features that may have been overlooked in functional analysis. Feasible operational scenarios were required to pare broad RF missions into succinct situations which test SEA-10's RF objectives of increase battlespace awareness and increase situational responsiveness. NECC promulgated scenarios of surveillance, barrier patrol, assault preparations, and assault in the Niger

[85] D.M. Buede, *The Engineering Design of Systems: Models and Methods*, p. 245, John Wiley & Sons, Inc., 2000.

[86] Ibid

River Delta[87]. SEA-10 felt these scenarios too broad for extraction of quantifiable effects, and composed two specific scenarios. SEA-10 chose scenarios that represented the most likely or frequently occurring situation (patrol), and the potential worst case situation (ambush) for study. Scenario specific parameters were derived from historical references and riverine operator experience[88]. Both scenarios operationalize SEA-10 RF objectives and enable evaluation of the force packages generated in the physical architecture.

Each scenario must have a relevant feasible operational setting. Through interaction with stakeholders and riverine operators, SEA-10 determined that any riverine system should be evaluated in a jungle environment. A jungle or heavy deciduous forest is both the most likely and worst case operational setting for RF operations because of the line of sight and concealment challenges that it imposes.

SEA-10 developed scenarios in the Niger River delta. A resource rich region in Western Africa, the rivers of Niger River delta have often been referred to as "Oil Rivers" because of the vast amount of petroleum and date oil found there. Disputes over the rights to the natural resources have caused political instability and economic hardship[89] for the indigenous people. As a result, militant groups continue to terrorize this region by kidnapping oil workers for ransom and causing damage to oil facilities. It is reasonable to believe that the political landscape of 2010 will result in competition for resources. Therefore, this region appeared to be a likely candidate for future RF employment. The terrain modeled is an area of the Niger Delta region, and is further elaborated upon in the modeling and analysis section of this thesis.

1. Scenario Operational Setting

The RF is operating in support of maritime security operations in Nigeria. The RF conducts routine daytime patrols on the Niger River looking for contraband smugglers. Weather (wind, rain, fog) was not an included variable in the scenarios. The Niger River Delta region is densely populated with approximately 200,000 people of

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[87] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, pg 49-51, Naval Amphibious Base, Little Creek, VA. 30 August 2006.

[88] See Chapter 2, Functional Architecture p. 42-44.

[89] D. Mahtani & S. Inskeep, *"Militant Group Targets Oil Producers in Nigeria,"* Retrieved, 11 November 2006 from the World Wide Web at: [http://www.npr.org/templates/story/story.php?storyId=5162952].

whom only 47% live in cities.[90] The Niger River has a length of 4350 km from head waters to the mouth of the delta[91] and has significant variation in width (from 1 kilometer to 150 meters) and depth (from 12 meters to less than 0.5 meters). Average line of sight on the Niger River is 150 meters, but can be as little as 50 meters because of low hanging jungle canopy, mangroves and brackish water.

2. Red Force Composition

Insurgent forces challenging the legitimate Nigerian government are present in the Niger River Delta region. Insurgent forces are known to smuggle opiates on the Niger River to support their insurgency. Insurgent forces operate at near company strength and utilize automatic weapons, sampan type small boats, rocket propelled grenades, and vehicle mounted crew served weapons. Insurgent groups have mortars, artillery, and recoilless weapons from national army formations which have been defeated in previous conflicts or disbanded. External powers have previously backed factions by supplying arms, ammunition, and equipment. However, insurgents mainly subsist by acquiring food and supplies from the countryside. Insurgent forces have mounted complex ambushes against Nigerian forces in the past and are likely to do so along the entire length of the Niger River.

3. Blue Force Composition

An entire riverine squadron is deployed to Nigeria in support of maritime security operations in accordance with NECC's Riverine Warfare CONOPS. The RF consists of 12 Small Unit River Craft (SURC) and approximately 230 operators and support personnel[92]. SURC's are armed with crew served weapons, detailed previously in Table 8, and each can be loaded with armed boarding teams or ground combat elements of up to sixteen personnel. There are no blue force air assets available, nor is there any inorganic fire support available. SURC's do have communications with the Tactical Operations Center (TOC), but real time unit and personnel tracking are not yet available.

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[90] Microsoft Encarta Online Encyclopedia, *Nigeria*, Retrieved 11 October 2006 from the World Wide Web at http://encarta.msn.com/encyclopedia_761557915_3/Nigeria.html.

[91] R. Benbow, P. Ensminger, S. Swartz, & D. Stimpson, Center for Naval Analysis Report, *Renewal of Riverine's Capability: A Preliminary Examination of Past, Current and Future Capabilities*, p. 157, January 2006.

[92] Internal source document, Naval Expeditionary Combat Command, supplied by Tom Lafferty.

4. Neutral Forces

Today's military operations must not only neutralize hostile forces, but also minimize civilian casualties. Neutral agents were included in RF models to simulate the civilian population of the Niger River Delta. Neutral agents degrade the detection and classification ability of both Red and Blue forces, and add realism to the scenarios and later simulations. The number of neutral agents was determined by examining the relationship between total population and Manpower Fit for Military Duty[93]. SEA-10 divided the total population of each country bordering the Niger River by the number of men fit for military duty in each country. The average of these ratios was taken and determined that 8 neutral agents would exist in the scenarios for every Red agent. Therefore SEA-10 entered 8 neutral agents into the model for every hostile agent to represent the proportion of background personnel in the region. Neutral agents were limited in their ability to maneuver in the terrain of the riverine environment. Unlike Red and Blue agents, neutral agents were not given any hostile characteristics, traits, or tendencies that favor either Red or Blue. Table 10 illustrates the populations of the countries considered and their respective neutral to hostile ratios.

Country	Total Population	Men Fit For Military Duty	Ratio
Ghana	22409572	3011081	7.44:1
Togo	5548702	696933	7.96:1
Benin	7862944	749774	10.48:1
Nigeria	131859731	15052914	8.75:1
Cameroon	17340702	1946767	8.90:1
		Mean	8.7:1
		Reduced Mean	8:1

Table 10. Neutral-to-Hostile Force Ratio Determination for Riverine Scenarios.

C. SCENARIO SUMMARIES

1. Scenario One: Patrol

You are the commander of a four SURC section and are on patrol in a populated region of the Niger River. Both river banks are at least partially obstructed by foliage. Two SURC's are designated as scouts.

93 The CIA World Factbook, *Nigeria*, Retrieved 11 October 2006 from the World Wide Web at https://www.cia.gov/cia/publications/factbook/index.html.

One SURC is the command and control boat and the remaining SURC provides supporting fires and security for the C2 boat[94]*. The river is wide and relatively straight but there are numerous civilian water craft and high foot traffic along the shore. Insurgent forces frequently operate among the civilian populace for cover and concealment.*

2. Scenario Two: Ambush

You are the commander of a four SURC section and are on patrol in a populated region of the Niger River. Both river banks are at least partially obstructed by foliage. Two SURC's are designated as scouts. One SURC is the command and control boat and the remaining SURC provides supporting fires and security for the C2 boat[95]*. The river is wide and relatively straight but there are numerous civilian water craft and high foot traffic along the shore. You are in one of the lead scouts and are going around a bend of the Niger River where the enemy has recently carried out ambushes on riverine forces.*

[94] US Marine Corps Center for Lessons Learned, *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II (OIF II),* MCB Quantico, VA, 4 April 2006.

[95] US Marine Corps Center for Lessons Learned, *Small Craft Company's Deployment in Support of Operation Iraqi Freedom II (OIF II),* MCB Quantico, VA, 4 April 2006.

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V. MODELING OVERVIEW

A. MODELING: PURPOSE AND COMPONENTS

Modeling provided SEA-10 with the capacity to test the baseline force and selected alternative force packages against the previously described operational scenarios. Modeling provides the data from which a quantitative analysis of how each physical architecture or force package performs to achieve the objectives set forth in the functional architecture. This section details the model setup, outputs, and software processes chosen to compare the proposed operational architectures.

B. SOFTWARE: MAP-AWARE NON-UNIFORM AUTOMATA (MANA)

While the Department of Defense (DoD) favors high-resolution, complex and resource intensive modeling techniques and procedures to support decision makers, SEA-10 chose the low-resolution agent based simulation (ABS) Map-Aware Non-Uniform Automata (MANA). MANA was recommended to SEA-10 by the U.S. Army Training and Doctrine Command Analysis Center (TRAC-Monterey).

High resolution modeling is data and time intensive. Time constraints limited the extent of data entry and MOE extraction. MANA provides useful results, requires a small learning curve, and is capable of rigorous iterations. MANA was the solution to time limitations and resource intensive data input requirements of physics-based models. MANA was scaleable to a geographic size that enabled detailed extraction of MOP such as range and time of engagement. Larger physics based programs did not offer the small scale granularity of MANA.

ABS, like MANA, contain entities that are controlled by decision-making algorithms. ABS combat models contain entities representing military units that make their own decisions, as opposed to the modeller explicitly programming and determining their behavior in advance. MANA and similar programs are often called complex adaptive systems (CAS) because of the way the entities within them react to their surroundings. Properties of MANA and CAS combat models are:

- The “global” behavior of the system “emerges” as the result of many local interactions.

- CAS is an example of a process of feedback that is not present in "reductionist", top-down models.
- CAS cannot be analysed by decomposition into simple independent parts.
- Agents interact with each other in non-linear ways, and "adapt" to their local environment.

The MANA model is an attempt to create a complex adaptive system for important real-world factors of combat such as:

- Spontaneous change of plans due to the evolving battle conditions.
- The influence of situational awareness on units when deciding on a course of action.
- The importance of sensors and how to use them to best advantage[96]

MANA allows agents at individual and squad level to be aware of and respond to the geographic characteristics of their surroundings. The agents respond independently to events determined by individual or squad predetermined behavior tendencies. Agents may react differently from modeling run to modeling run because of the variable stimulus of motivations programmed into the modeled environment. MANA models personalities, communication links, sensor and weapon characteristics, and engagements at an individual and squad level. The individual traits, data entry, and justification are discussed in more detail in the following sections.

C. MANA MODELING SETUP

SEA-10 could not model all the scenarios that the RF could possibly encounter and, instead, chose scenarios based on two criteria discussed previously: severity and likelihood. The ambush scenario is the most severe scenario that the RF will likely encounter. The patrol scenario is the most likely scenario that the RF will likely encounter. These scenarios operationalized the competing physical architectures, or force packages, to determine which provides the most significant increase in detection and engagement capabilities.

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[96] D. Galligan, et al.,"MANA (Map Aware Non-uniform Automata) Compressed Help File." Version 3.0.39. Operations Analysis Section, Defense Technology Agency, New Zealand, April 2005.

A comprehensive and detail oriented data entry process provided the backbone of the simulation and provided insights to increase the RF's battlespace awareness and situational responsiveness. All data was gathered and analyzed from unclassified sources. The RF will not deploy until February 2007. Therefore, baseline force structure, weapons, and sensor capability were hypothetically modeled since no performance data existed at the time of this thesis. SEA-10 developed MOE and MOP to determine the impact of the varying physical architectures on the objectives of increased battlespace awareness and increased situational responsiveness. The digital battlefield had to be established, and squad properties had to be assigned before MOE and MOP data was gathered and objectives could be evaluated.

1. Battlefield

SEA-10 chose a random area of the Niger River (Figure 15) that reflects the environment in which the RF may operate in 2010. MANA allows for a portrayal of terrain effects on detection and line of sight. The scenario portrayed in MANA was built by the design team and was intended to represent actual terrain and foliage of the Niger River.

Figure 15. SEA-10 Niger River Scenario Map[97].

[97] Google Earth. Retrieved 18 September 2006 from the World Wide Web at http://earth.google.com.

The map dimensions were scaled from miles to grids for MANA to process. The 24 X 15 mile sample map was converted into a 38.64 by 36.60 meters per grid box using the following conversion factor. The MANA modeling screen is 1000 grids long and 660 grids wide. Equation 1 and 2 outline the steps to convert the 24 mile length into meters per grid.

$$24 \text{ mi x } \frac{1.61 \text{ km}}{1 \text{ mi}} = 38.64 \text{ km}$$

Equation 1. 24 Mile to Kilometer Conversion.

$$\frac{38.64 \text{ km}}{1000 \text{ grids}} \times \frac{1000 \text{ m}}{1 \text{ km}} = \frac{38.64 \text{ m}}{1 \text{ grid}}$$

Equation 2. Converts Meters to MANA Grids in X Direction.

Equations 3 and 4 outline the steps to convert the 15 mile length into meters per grid.

$$15 \text{ mi} * \frac{1.61 \text{ km}}{1 \text{ mi}} = 24.15 \text{ km}$$

Equation 3. 15 Mile to Kilometer Conversion.

$$\frac{24.15 \text{ km}}{660 \text{ grids}} \times \frac{1000 \text{ m}}{1 \text{ km}} = \frac{36.60 \text{ m}}{1 \text{ grid}}$$

Equation 4. Converts Meters to MANA Grids in Y Direction.

The original riverine scenario map represented by Figure 15, was modified and palletized into an 8-bit color scheme as shown in Figure 16. 8-bit palletization not only allowed MANA to process the map, but also provided realism by incorporating detailed landscape characteristics of the actual area such as terrain, foliage, infrastructure, and waterways.

Figure 16. 8-bit Palletized Version of SEA-10 Niger River Scenario Map[98].

The Red-Green-Blue (RGB) values were sampled from Figure 16 and translated into MANA-recognizable terrain. This image is not simply an image of the area. Each grid may be assigned a value for cover, concealment, and movement impact based upon the RGB value of the individual grid. Hills, rivers, and roads were assigned different ratings in MANA's scenario map editor. The concealment factor affects the probability of detection and of being detected. When an agent lies in a grid-square with a non-zero concealment value, the terrain concealment factor for that square is combined with the agent's personal concealment factor in determining whether the agent is seen.[99]

MANA recognizes line of sight as a battlefield constraint. Cover affects whether or not a unit is exposed and therefore visible to another agent's line of sight. Foliage was broken down into three levels that reflects real world jungle landscape: Light canopy (Light Bush), Medium canopy (Medium Bush), and Heavy canopy (Dense Bush) to simulate different forest or jungle canopy characteristics. This serves two purposes. First, it allows forces given increased cover and concealment properties to favor usage of heavier covered forest areas when traversing or engaging. Second, it provides realism to

[98] Google Earth. Retrieved 18 September 2006 from the World Wide Web at http://earth.google.com.

[99] D, Galligan, et al.,"MANA (Map Aware Non-uniform Automata) Compressed Help File." Version 3.0.39. Operations Analysis Section, Defense Technology Agency, New Zealand, April 2005.

the detection capabilities of forces by restricting detection capabilities in heavier covered areas or hills as shown in Figure 17. The Red agents are not within Blue force detection arcs because of terrain that blocks the detection sensor. Cover and concealment also affect detection capability.

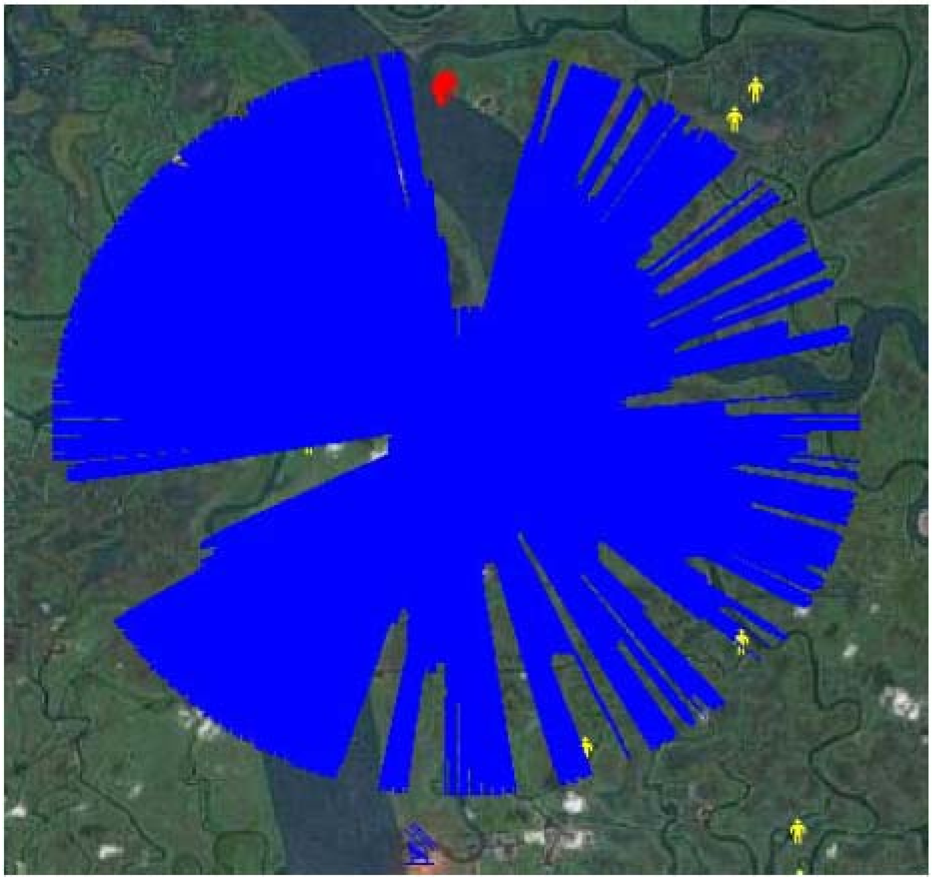

Figure 17. Terrain Effects on MANA Detection Ranges.

For example, in the palletized map, terrain was scored for the amount of cover it could offer. Hilltops and Light Bush provide only minimal cover yielding a cover value of .10. Medium Bush and Dense Bush provide increasingly higher coverage (.20 and .30 respectively) The Wall provided the highest Cover value at 1.0, yielding a complete block to line of sight. Roads and rivers provided the least resistance to movement while Dense Bush provided the most. Figure 18 outlines the different landscape parameters entered into the terrain properties menu. Hills (Hilltop) show differences in elevation and when possible, allowed individual forces to avoid or choose hills while traversing.

	Going	Cover	Conceal	Red	Green	Blue
BilliardTable	1.00	0.00	0.00	0	0	0
Wall	0.00	1.00	1.00	178	178	178
Hilltop	0.90	0.10	0.95	46	46	25
Road	1.00	0.00	0.00	255	255	0
LightBush	0.75	0.10	0.30	102	102	51
DenseBush	0.20	0.30	0.90	51	95	96
MediumBush	0.43	0.20	0.60	53	94	53
River	1.00	0.00	0.00	50	50	105

Figure 18. MANA Terrain Characteristics.

2. Platform Properties

SEA-10 modeled 12 distinct agent platforms within MANA. Each of the platforms' squad settings are discussed in the following section and specific situational awareness and range settings are available in Appendix A.

a. Tactical Operations Center (TOC)

The TOC provided no offensive or defensive capability. It served as the hub for network communications. All units capable of network operations relayed messages through the TOC when not in direct communication with each other.

b. Small Unit Riverine Craft (SURC)

The SURC is designed to provide tactical waterborne lift in support of military operations in a riverine environment (MORE). The primary function of the SURC is to provide tactical mobility and serve as a waterborne weapons platform. The SURC provides the mobility, speed, endurance, firepower, payload, survivability, and command and control capabilities to support sustained operations in riverine environments. Specific capabilities include:

- SURC can accelerate from motionless to 25 knots in 15 seconds.
- Maintains an average speed of 30 knots (threshold), 35 knots (objective).

- SURC has ballistic protection around the engine compartment.
- SURC has a combat radius of 250 nautical miles.
- SURC C2 systems integrate with Global Positioning Systems (GPS) for location information.
- Integrates with currently fielded and future Combat Net Radio Systems (CNR) systems.
- Is interoperable with current and future universal weapon mounts and pintle adapters for tactical vehicles.
- Is capable of beaching bow first on unobstructed shorelines with mud, sand, silt, and gravel surfaces (threshold) at one-quarter cruising speed (objective).
- SURC remains afloat as a survival platform when filled with water.
- SURC has a hull and propulsion system with a draft of 24 inches or less when operationally loaded in a stationary position.
- Transports 13 combat loaded soldiers or Marines plus 2 crew (threshold) and 18 combat loaded soldiers or Marines with 2 crew (objective).
- Has an organic heavy machinegun (threshold) mount(s) to integrate both organic medium and heavy machineguns (objective).
- Capable of external tactical lift by a CH-53D (threshold) and MV-22 (objective).[100]

c. Visit Board Search and Seizure (VBSS)

The VBSS agent is the fourth unit of the SURC section which hosts a 7 man boarding team. It is modeled similar to the SURC with the exception of an increased ability to sustain damage due to increased crew size.

d. Tactical Remote Sensor System (TRSS)

The Tactical Remote Sensor System provides continuous monitoring of activity within its area of operation and all weather location information. It provides a graphic depiction of MASINT (Measurement and Signals Intelligence) derived from targets' composite seismic, magnetic, infrared, thermal, and graphic images. TRSS may

[100] Global Security. *Small Unit Riverine Craft,* Retrieved 07 October 2006 from the World Wide Web at: http://www.globalsecurity.org/military/systems/ship/surc.htm.

provide direction, location, relative speed, quantity, length of column, and classification type through hand emplaced or air delivered sensors.

e. Unmanned Aerial Vehicles (UAV)

This agent was modeled after the Shadow 200 Tactical Unmanned Aerial Vehicle (TUAV) system. It is designed as a ground commander's primary day or night reconnaissance, surveillance, target acquisition, and battle damage assessment system. Shadow 200 is more robust than the procured system of the RF (SilverFox). However, the model was constructed around Shadow 200 parameters because performance is similar and data was available for analysis.

The Shadow 200 is a small, lightweight, tactical UAV system. The system is composed of airframes, modular mission payloads, ground control stations, launch and recovery equipment, and communications equipment. It will carry enough supplies and spares for an initial 72 hours of operation. It will be transportable in two high mobility multi-purpose wheeled vehicles (HMMWVs) with shelters, and two additional HMMWVs with trailers as troop carriers.

The airframe is constructed of composite materials, with a wingspan of 12.3 feet, and length of 11.2 feet. Power is provided by a commercial 38-horsepower rotary engine that uses motor gasoline (MOGAS). The payload has a commercially available electro-optic and infrared camera, and communications equipment for command and control and imagery dissemination. Onboard global positioning system instrumentation provides navigation information.

Shadow 200 is intended to provide coverage of a brigade area of interest for up to seven hours, at 65 kilometers from the launch and recovery site. The maximum range is 125 kilometers (limited by data link capability), and operations are generally conducted from 8,000 to 10,000 feet above ground level during the day and 6,000 to 8,000 feet above ground level at night. Operations may even occur as low as 1,000 feet. The air vehicle uses a pneumatic launcher and is recovered by a tactical automatic landing system without pilot intervention on the runway. The air vehicle is recovered using an arresting hook and cable system.[101]

[101] Global Security, *RQ-7 Shadow Tactical UAV*, Retrieved 07 October 2006 from the World Wide Web at http://www.globalsecurity.org/intell/systems/shadow.htm

f. Unmanned Surface Vehicles (USV)

The MANA modeled USV is an amalgam of existing USV platforms based mostly on SeaFox. The modeled system is an integrated, remotely controlled combat system which provides detection and identification support in barrier or focused area searches. Fast and highly maneuverable, this unmanned vehicle identifies its targets through a multi-sensor, electro-optical (EO) system with day and night targeting capabilities. MANA can discriminate and portray daytime or nighttime vision capabilities. The EO camera's zoom capability was quantified in MANA grids, input into MANA as a USV performance parameter, and served as its maximum detection range. The USV also hosts navigation radar. Potentially a highly accurate stabilized weapon station, a USV could provide immediate engagement capability and powerful lethality at stand-off ranges. A weapon bearing USV was not used in our model. The USV must be able to conduct sustained operations with parameters similar to the SURC.

g. Ground Combat Element (GCE)

The mission of the GCE is to close with the enemy and defeat, capture, or repel assault by fire, close combat, or counterattack. The fire squad is organized into 4-man fire teams consisting of a team leader, a grenadier, and an automatic rifleman. The fourth member within each fire team is either the squad's antitank specialist or the squad's designated marksman. The two weapons squads each consist of a squad leader and two 3-man machine gun teams. The weapons squad provides the primary base of fire for the maneuver of the GCE squads with highly accurate short- and long-range, direct, and small-arms fires against enemy personnel and equipment. The two machine gun teams consist of the gunner, assistant gunner, and ammunition bearer. Each team is equipped with the M240B 7.62-mm medium machine gun.

h. Mortar Team

The primary role of the riverine mortar team is to provide immediate responsive indirect fires that support the maneuver of the RF and that reinforce direct fires during close combat. The MANA modeled team consists of two 81 millimeter mortars. Each mortar team consists of four infantry indirect fire specialists. The 81-mm mortar systems enable the mortar team to provide dismounted mortar support to the RF patrol during assault and infiltration operations. SURC's improve the survivability of the mortar team and equipment by providing increased flexibility, responsiveness, mobility, and protected transportation. The TOC controls and directs the mortar team's maneuver and fires. Specifically, the mortar team provides the commander the ability to support the RF's close fight with indirect fires that[102]:

- Shape the conditions for maneuver.
- Provide close supporting fires for assaulting forces in restricted and severely restricted terrain.
- Destroy, neutralize, suppress, degrade, or disrupt enemy forces and force armored vehicles to button up.
- Break up enemy troop concentrations (mounted and dismounted) and destroy the enemy's synchronization.
- Fix enemy forces or reduce the enemy's mobility and canalize his assault forces into engagement areas.
- Deny the enemy the advantage of defile terrain and force him into areas covered by direct fire weapons.
- Provide standoff fires against light armored vehicles.
- Optimize indirect fires in urban terrain.
- Significantly improve the dismounted infantry's lethality and survivability against a close dismounted assault.
- SEA -10 limited the model to use only HE rounds.

i. Mortar Barge

The specifications for a modern and compact unmanned turret mortar system derived from New Efficient Mortar System (NEMO). NEMO is adaptable to light high speed vessels due to its low weight. In addition to indirect fire support NEMO has the capability of direct and Multiple Rounds Simultaneous Impact (MRSI) fire. The NEMO system is compatible with all standard 120mm smoothbore mortar ammunition as well as smart guided ammunition. MANA is currently modeled using only an 81mm mortar for standardization of forces between the waterborne vessel and the deployable

[102] Global Security.Org; *Fire Support Planning and Coordination*, Retrieved 17 October 2006 from the World Wide Web at http://www.globalsecurity.org/military/library/policy/army/fm/7-90/Ch3.htm#s2pl

mortar team. The hull was modeled after a 14.1m WATERCAT M-12 high speed amphibious troop carrier, with the turret mounted on the forecastle in lieu of the troop compartment.[103]

j. *HH-60 Armed Helicopter*

The HH-60H armed helicopter is a variant of the SH-60F, specifically designed for combat search and rescue (CSAR) and naval special warfare support. It can operate from aircraft carriers, and a variety of other naval and merchant vessels, as well as land bases. The HH-60H retains the same basic airframe, core avionics, inherent sea-basing capability of the SH-60F, and incorporates many of the ballistic tolerance attributes of the Army UH-60, which are ideally suited for the CSAR mission.

The largely empty cabin area of the HH-60H allows room for rescued personnel, SEAL teams in support of special operations, or potentially a GCE. HH-60H aircrews employ high-tech devices such as Night Vision Devices (NVD's) for increased detection capability. In addition, the HH-60H has recently been outfitted with Forward Looking InfraRed (FLIR) technology, and the capability to fire Hellfire missiles. The FLIR incorporates an integrated laser designator which is used to assist with classification of targets at long ranges, and provide laser guidance for Hellfire missiles. Additionally, they are armed with M-240 or GAU-17 machine guns used to suppress enemy fire during a rescue, or during a special operations troop insertion. It is capable of carrying M60 or M240 machine guns, a GCAL-50 machine gun, 2.75 inch Zuni rockets, Stinger, Maverick, or Hellfire missiles.[104]

k. *Red Rifle and RPG-22*

Scenarios are based upon a smaller-scale contingency (SSC) which is an operation, limited in terms of duration and geography, which is short of a major theater war (MTW). Left unchecked, an SSC can quickly escalate into an MTW. The political situation in the operational area may be uncertain, with varying levels of acceptance among local populations and a range of participation by coalition, interagency, and

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[103] Patria, *New Efficient Mortar System*, Retrieved 13 November 2006 as found on the World Wide Web at [www.partria.fi/modules/NEMO]

[104] Global Security; *HH-60H Sea Hawk Helicopter*, Retrieved 13 November 2006 as found on the World Wide Web at [http://www.globalsecurity.org/military/systems/aircraft/hh-60h.htm]

nongovernmental organizations partners.[105] SEA-10 modeled enemy forces as middle to low-end industrial-age forces based predominately on motorized infantry. Guerrillas, terrorists, paramilitary units, special purpose forces, special police, and local militias will be present in the environment. These forces are primarily equipped with rocket propelled grenades, mortars, machine guns, and explosives. These forces are expected to have robust communications using conventional military devices augmented by commercial equipment such as cell phones. These forces are not capable of long term, sustained, high tempo combat operations. They are capable of conducting long term, sustained, unconventional terrorist and guerrilla operations.

l. Neutral Agents

Neutral forces representing an indigenous population were placed within the model to provide a real world limitation specifically hampering target acquisition and the ability of ranged fires. No specific offensive or defensive capabilities were granted to the neutral forces. They were programmed with a desire to seek ease of movement which would create a desire to seek out roadways, rivers, and population centers.

3. Squad Properties

a. General

MANA offers a multitude of choices in programming squad behavior. Behavior areas are separated into tabs. The following sections review tab contents and how they are important to model performance. General settings permitted assignment of squad names, number of agents per squad, the icon representing an agent, and fuel. Fuel was not constrained within our model.

b. Map

Each agent was assigned a home point to establish the spawning location or starting point in the model. Waypoints could also be used to establish a movement pattern consistent with scenario objectives. Waypoints served as guides for agents and added realism to patrol routes. For example, waypoints prevented SURC's from patrolling over land.

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105 Global Security; *Chapter 1: Overview of the Styker Brigade Combat Team*; Retrieved 02 November 2006 as found on the World Wide Web at [http://www.globalsecurity.org/military/library/policy/army/fm/3-21-31/c01.htm#1_13]

c. Personality

Red force agent properties are loosely modeled after rifle platoon characteristics from United States Army (USA) Field Manuals 3-21.9 Infantry Rifle Platoon and Squad and 3-21.11 Infantry Rifle Company. SEA-10 was uncertain about the training and force structure of potential insurgent forces that the RF may face, but found that enemy forces in the delta region operate at near platoon level strength while sometimes approaching company level strength[106]. Since no enemy field manuals were available, SEA-10 chose agent parameters from USA sources so Red agents would simulate realistic units. SEA-10 referred to these documents to outline Red force structure as well as capabilities and limitations in organic communications and weapons. Red and Blue agent detection and engagement capabilities were affected by terrain, time, and velocity restrictions imposed by MANA.

Each agent was assigned a specific set of traits that defined its character and motivations within the scenario. SEA-10 claims that these settings are best applied after mathematically determining the other parameter settings for each squad's sensor, detection, communication, and weapon capabilities. A thorough understanding of an agent's capabilities and accurate entry of these capabilities into MANA enables the program to make decisions regarding the agent's ability to engage weaker, equivalent, or superior threats. Agent capabilities are compared against requirements for cover, concealment, ease of movement, and the desire to follow an intended route. Agent motivation is determined by setting behavior values from -100 to 100. For example, by setting an agent's waypoint value to greater than zero MANA simulates the agent's tactical decision to maintain a designated February route. An increased value of the agent's desire to go towards the enemy simulates the agent's tactical decision to engage the enemy. Negative values have the reverse effect upon each agent.

Examples of key traits that SEA-10 chose MANA to influence are:

- A Red force agent is assigned an increased concealment value to allow it to seek out areas of higher concealment (DenseBush) and avoid detection while transiting from one area to another.

[106] C. Timburg. "*In Fight Over Oil-Rich Delta, Firepower Grows Sophisticated*" Retrieved 11 November 2006 from the World Wide Web at [http://www.washingtonpost.com/wp-dyn/content/article/2006/03/05/AR2006030500961.html]

- A Red force agent has no motivation (given a zero value) to remain near injured or dead Red units.
- A Blue force agent is motivated (given an increased value) to remain within or near the center of the river while on patrol.
- A Blue force agent is not motivated (given a zero value) to engage neutrals.
- UAV/USV's were given increased data network capability to illustrate their ability to provide near instantaneous battlefield data to Blue force agents.
- Red and Blue force agents were motivated (given a greater than zero value) to travel in close formation.
- Red and Blue force agents were not motivated (given lesser than zero value) to run from an engagement.

These traits allowed SEA-10 to create agents that exhibit historically feasible real world behavior. Appendix A contains a detailed description of individual and specific trait inputs used to affect agent actions. SEA-10 attempted to simulate each individual agent's personality, traits, and behaviors to reflect those of real world operators and players. Each Red or Blue Force agent personality varied depending on the operational scenarios modeled. Agent personalities were modified in two ways. Natural modifications simulated the most likely reaction that the Red or Blue Force agent would exhibit given a certain motivation entered into MANA. Artificial modifications were used in order to force the Red or Blue Force agent to mimic the natural reaction. Examples of natural modifications were:

- The "Enemies" value would motivate Red and Blue agents to seek out and engage opposing forces.
- Friendly, enemy, and unknown situational awareness would increase an agent's ability to prioritize and act based upon the source of contact information.

- Cover and concealment enabled transiting or engaging agents to find cover and concealment. Neutral agents were not assigned a value for cover and concealment. Red and Blue agents were given cover and concealment values to reflect real world tendencies.
- UGS, UAV's, and USV's were given values to provide situational awareness on friendly, enemy, and unknown agents.

Examples of artificial modifications were:

- Agents programmed to protect an injured friendly unit would not engage the enemy and further expose themselves to damage. Initial modeling and analysis determined that assigning value to this piece prohibited the Blue Forces from engaging the enemy and prevented SEA-10 from gathering data that would answer MOP's and MOE's. Real world Blue forces would stay near injured forces while still engaging the enemy.
- Agents were programmed to go to the next waypoint, stay near the center of the waypoint route (line center), or find the easiest route to travel. SURC's stayed in one area especially if given a high cover and concealment value. They tended to look for a high covered and concealed area and remain there without patrolling. Therefore SURC agents were given high waypoint values in order to force them to patrol.

d. Time

Model range inputs directed sensor range, movement speed, fuel rate, concealment, threat levels, icons and other interaction parameters. Each MANA run was scaled to represent a 24 hour period depicting a 24 hour RF mission[107]. SEA-10 determined that one MANA time step needed to equal one minute for model accuracy and to enable enough granularities for MOE/MOP extraction. There are 1440 time steps in a MANA 24 hour time period. This conversion was critical to run the model since MANA uses the time set as the basic factor for determining all velocity data. Equation 5 outlines the steps to convert a 24 hour period into time steps.

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[107] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (FINAL)*, 28 September 2006, Naval Amphibious Base, Little Creek, VA, p. 27.

$$\frac{24 \text{ hours}}{} \times \frac{60 \text{ min}}{1 \text{ hour}} \times \frac{1 \text{ time step}}{1 \text{ min}} = 1440 \text{ time steps}$$

Equation 5. MANA Time Step Conversion.

e. Range

Each platform or agent in the RF scenarios was assigned a detection and classification range. Detection range is the radius in cells that an agent can see targets around it. Detection does not imply classification or identification and contacts are recorded as unknown on the situational awareness maps if they are recorded in an area where the detection range extends beyond the classification range. Classification range is the radius in cells that an agent can detect and classify targets around it. SEA-10 used the horizon equation[108] to determine each unit or platform's straight line visual detection and classification range. Equation 6, a sample calculation for a human (height of sensor 2 meters), is worked out below.

$$1.14 * \sqrt{\text{sensor height (2 meters)}} = \text{nautical miles} * 2000 \text{ yards} * \frac{3 \text{ feet/yard}}{3.24 \text{ meters}} = \frac{2985.56 \text{ meters}}{38.31 \text{ meters/grid}} = 78 \text{ grids}$$

Equation 6. Horizon Equation.

SEA-10 determined the maximum detection range is twice the distance to the horizon if both sensors are of equal height. The maximum detection range is twice the distance to the horizon, or 156 grids as shown in Figure 19.

[108] T. DiGiulian & L.D. Morris, *Distance to the Horizon*. Retrieved 20 September 2006 from the World Wide Web at http://www.navweaps.com/index_tech/tech-011.htm.

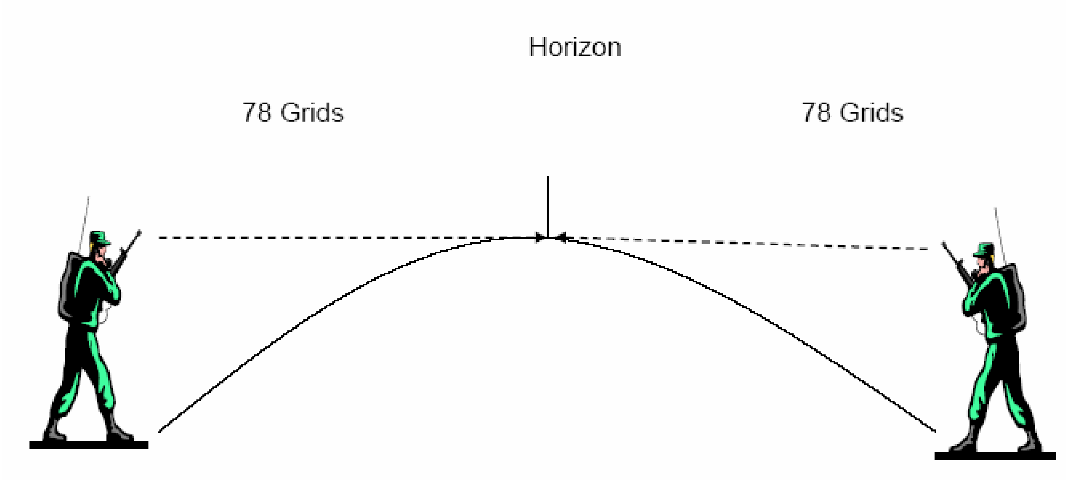

Figure 19. SEA-10 Model Horizon Interpretation.

However, based on operational experience under typical conditions SEA-10 determined that the maximum classification range is one eighth the maximum detection range. For example, the maximum classification range of a human 2 meters tall is 1/8 its maximum detection range or about 20 grids. Non-visual detection and classification ranges were derived from platform specifications.

f. Speed

Transiting personnel move slower than a patrol boat in a real-world environment, and to capture this relationship it was necessary to identify the speed of each agent. Different forces move specific distances within a given time period. The major entities modeled were personnel, SURC, helicopters, UAV's, and USV's. MANA uses a ratio for the probability that a unit will cross 1 grid in 1 time step. USA Field Manual 90-5 Jungle Operations stated that a typical US Army soldier given his physical condition, carried load, danger of enemy contact, and type of jungle growth will travel at a rate of 1 km per hour through a tropical forest during daylight.[109] This translates to a MANA velocity of .43 grids per time step. Equation 7 outlines the steps to convert a common foot soldier transiting at 1 kilometer per hour into MANA speed.

[109] Global Security. *Department of the Army Headquarters, Field Manual 90-5 Jungle Operations,* Washington, DC, 16 August 1982. Retrieved 29 September 2006 from the World Wide Web at http://www.globalsecurity.org/military/library/policy/army/fm/90-5/index.html

$$\frac{1\text{ Km}}{1\text{ hour}}\times\frac{1\text{ hour}}{60\text{ min}}\times\frac{1\text{ min}}{1\text{ time step}}\times\frac{1000\text{ grids}}{38.64\text{ Km}}=\frac{.43\text{ grids}}{\text{time step}}$$

Equation 7. Velocity to MANA Speed Conversion.

Therefore, in the model personnel will travel .43 grids per time step or approximately 16.6 meters per minute.

Helicopters and UAV's usually travel at a greater velocity than a common foot soldier. Both air assets were assigned a velocity 100km/hr based on medium capacity UAV flight characteristics and HH-60 fuel conservation cruising speeds. Unfortunately, MANA's operating manual specifically states that the velocity ratio must not exceed 1000 grids per 100 time steps or random side effects may skew model results. The simulation was restricted in that it could not have any vehicle moving at speeds greater than 22km per hour, and therefore any vehicle, airborne or waterborne, is limited to a maximum movement ratio of 9.53 grids per time step. All vehicles traveling greater than 9.53 grids per time step were rounded to 10 grids per time step. The following process outlines the Helicopter and UAV velocity conversion:

$$\frac{100\text{ Km}}{1\text{ hour}}\times\frac{1\text{ hour}}{60\text{ min}}\times\frac{1\text{ min}}{1\text{ time step}}\times\frac{1000\text{ grids}}{38.64\text{ Km}}=\frac{43\text{ grids}}{\text{time step}}$$

Equation 8. Helicopter and UAV MANA Velocity Conversion.

A SURC capable of 40 knots was restricted to 10 grids per time step. Equation 9 outlines the unit conversion for knots per hour to MANA speed:

$$\frac{1\text{ knot}}{1\text{ hour}}\times\frac{1.852\text{ Km}}{1\text{ knot}}\times\frac{1\text{ hour}}{60\text{ min}}\times\frac{1\text{ min}}{1\text{ timestep}}\times\frac{1000\text{ grids}}{38.64\text{ Km}}=\frac{.81\text{ grids}}{\text{timestep}}$$

Equation 9. Knots to MANA Speed Conversion.

Equation 10 outlines the SURC velocity conversion:

$$\frac{40\text{ knot}}{1\text{ hour}}\times\frac{1.852\text{ Km}}{1\text{ knot}}\times\frac{1\text{ hour}}{60\text{ min}}\times\frac{1\text{ min}}{1\text{ timestep}}\times\frac{1000\text{ grids}}{38.64\text{ Km}}=\frac{31.95\text{ grids}}{\text{timestep}}$$

Equation 10. MANA SURC Velocity Conversion.

4. Weapons

a. Kinetic Weapons

MANA captured several important quantifiable weapons characteristics. MANA differentiates between kinetic or projectile weapons and explosive or area weapons. The ranges, rate of fire, and armor penetration capability for kinetic weapons are detailed in Table 11 below[110]. Ranges were converted from meters to MANA grids using the conversion equation explained previously. Rate of fire was converted into time steps, and each agent was limited in the amount of ammunition they could carry for a particular weapon. Red and Blue agent detection and engagement capabilities were affected by terrain, time, and velocity restrictions imposed by the MANA program.

	Meters			Grids							
Kinetic (Solid Projectile) Weapon	Min	Effective	Max	Min	Effective	Max	Rate of Fire/Min	Max Targets / Step (MANA)	Max Rate of Fire / min	Carried Rounds	Penetration (mm)
AK-47/AKM 7.62mm Assault Rifle	0	300	2500	0	8	65	40	1000	600	120	0
AK-74 5.45mm Assault Rifle	0	500	800	0	13	21	40	1000	600	300	0
RPK-74 5.45mm Light Machine Gun	0	800	1000	0	21	26	50	1000	600	320	0
SVD 7.62mm Sniper Rifle	0	1300	3800	0	34	99	30	1000	30	40	10
PKM 7.62 mm Light Machine Gun	0	1000	3800	0	26	99	250	1000	650	600	8
NSV 12.7mm Heavy Machine Gun	0	2000	7850	0	52	205	100	1000	680	300	20
M-16A2/A3 7.62mm Assault Rifle	0	550	3600	0	14	94	45	1000	800	1250	0
M240B 7.62mm Heavy Machine Gun	0	800	3725	0	21	97	100	1000	200	1200	0
M249 5.56mm Heavy Machine Gun	0	1000	3600	0	26	94	100	1000	750	1000	0
M60 7.62mm Heavy Machine Gun	0	800	3725	0	21	97	100	1000	550	900	8
GAU-17/A 7.62mm Mini Gun	0	400	1000	0	10	26	2000	1000	4000	5000	0
M2 12.7mm .50 cal Machine Gun	0	2400	6770	0	63	177	200	1000	550	600	11

Table 11. Kinetic Weapons Characteristics for Red and Blue Forces.

b. Explosive Weapons

MANA also modeled explosive or area weapons. These weapons inflicted damage over an area, and this area had to be converted into MANA grids. A summary of the explosive weapons used, their ranges, shot radius, rates of fire, amount of ammunition carried, and armor penetration capability is detailed in Table 12.

110 Threat Support Directorate, World Wide Equipment Guide, 21 January 1999, Ft. Leavenworth, KS.

	Meters			Grids								
Explosive Weapons	Min	Eff.	Max	Min	Eff.	Max	Shot Radius (m)	Shot Radius (grids)	Rate of Fire/ min	{High Rate of Fire / min}	Carried Rounds	Penetration (mm)
RPG-7 40mm ATGL	0	500	800	0	13	21	5	0	6	6	5	330
RPG-22 72mm Disposable ATGL	0	150	250	0	4	7	5	0	1	1	1	390
SA-16 Manportable SAM	600	3500	5000	16	91	131	5	0	1	1	2	0
82mm Mortar 40mm ATGL	1000	4000	4000	26	104	104	15	0	4	65	10	0
GP-30 40mm Grenade Launcher	40	400	400	1	10	10	6	0	4	5	10	0
M203 40mm Grenade Launcher	31	350	400	1	9	10	5	0	5	7	36	330
M-72 66mm Disposable ATGL	10	200	1000	0	5	26	5	0	1	1	1	300
M224 62mm Mortar	44	1930	1930	1	50	50	4	0	8	30	20	0
M252 82mm Mortar	83	5608	5608	2	146	146	40	1	15	30	60	0
AGM-114K Hellfire Missile	500	5000	8000	13	131	209	10	0	4	4	4	500
MK19 40mm Grenade MG	18	1500	2550	0	39	67	15	0	40	60	164	51

Table 12. Explosive Weapons Characteristics for Red and Blue Forces.

5. Weapons Selection, Assignment, and Summary

SEA-10 simulated likely Red force weapon employment based on number of agents in the field, weight considerations (how much weight historically an infantry soldier or insurgent can carry for a day), and movement constraints (how fast the agent needed to traverse terrain for a given mission). MANA permits each Red or Blue squad multiple types of weapons. Red forces were limited to rifles and rocket propelled grenades (RPG). For example, a ten agent Red rifle company was modeled with ten AK-47's and three RPG-22's. Weapon types are selectable in MANA, as shown by the red outline in Figure 20. This MANA capability permitted agents to carry and employ weapons in a manner that reflects real world tactics. Each agent was assigned a specific role within a squad and MANA was programmed to determine the primary and secondary use of each weapon based on their specific capabilities (probability of hit, range, number of rounds). For example, an RPG team imbedded in a squad used RPG first (the primary weapon), before using assault rifles (the secondary weapon) weapons during an engagement. The green outline in Figure 20 highlights the weapons designation feature.

The blue outline in Figure 20 highlights the agent protect contact feature. This feature permits weapon specific ROE to minimize the damage to friendly, neutral, or unidentified forces, especially when using indirect fire weapons. Red forces were granted a more permissive ROE while Blue forces were constrained to minimize civilian casualties and fratricide.

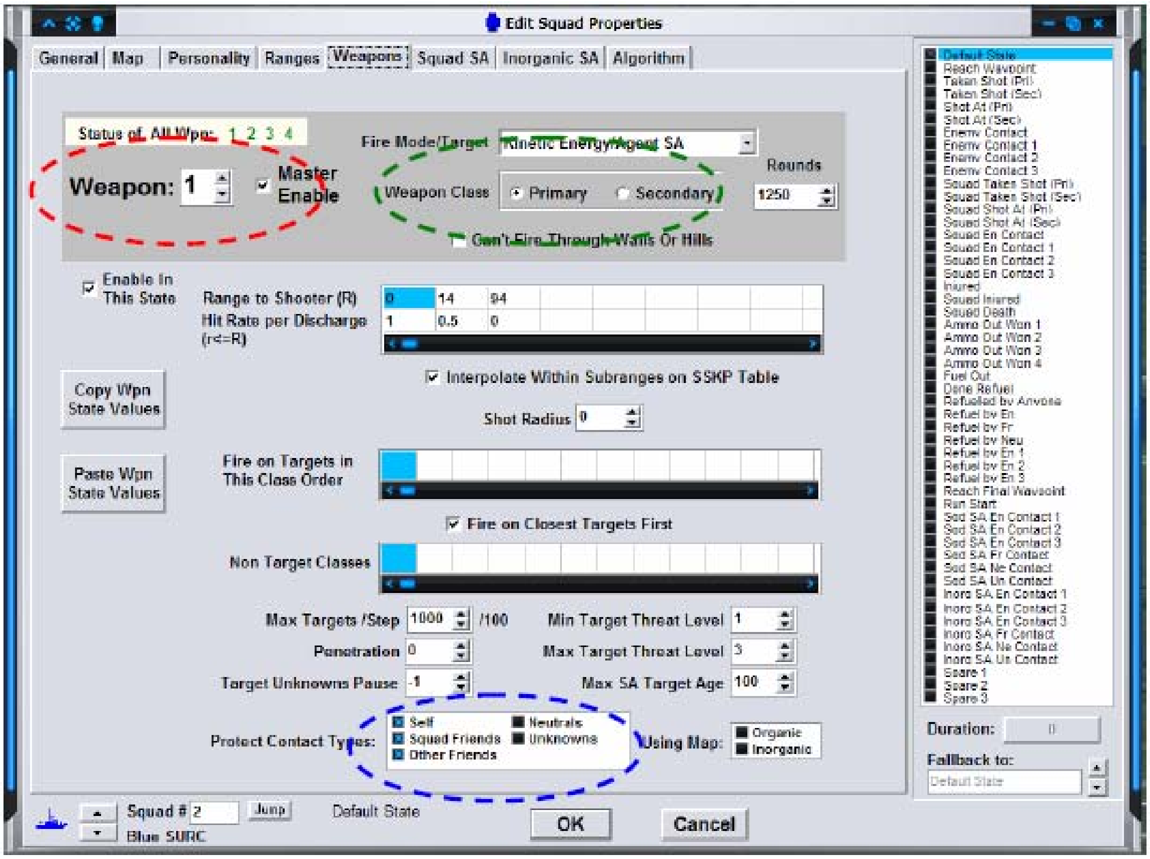

Figure 20. Weapons Selection Fields in MANA.

Individual weapons have specific capabilities that are not common to all available weapons. An M-16 assault rifle can be more effective than an AK-47 assault rifle because MANA allows modification of individual weapon effectiveness. Key parameters required for feasible weapons data entry were the minimum, effective, and maximum ranges of each weapon, the weapon's rate of fire, and the number of rounds carried by the agent. Minimum range is the shortest distance which an agent can safely fire the weapon without risking damage to itself. Effective range is the maximum distance at which a weapon may be expected to be accurate and achieve the desired result. It is the distance from a weapon system at which a 50 percent probability of target hit is expected, or the tracer burnout range. Maximum range is the greatest distance a weapon can fire without consideration of dispersion[111]. Minimum, effective, and maximum ranges provide a probability of hit matrix and more realism for the simulation. SEA-10 chose to enter minimum, effective, and maximum ranges and their associated probability of hit into the highlighted "Hit Rate Per Discharge" section of Figure 21. The minimum range of zero was assigned a value of 1 or 100% probability of hit. A value of .5 or 50% probability of hit was assigned at the weapon's effective range, and a zero value was assigned for probability of hit at maximum range. SEA-10 programmed MANA to interpolate the values between the minimum, effective, and maximum ranges. Appendix A contains all the individual weapon traits used in MANA.

[111] Global Security. *Department of the Army Headquarters, Field Manual 101-5-1 Operational Terms and Graphics*, Washington, DC, 30 September 1997. Retrieved 29 September 2006 from the World Wide Web at http://www.globalsecurity.org/military/library/policy/army/fm/101-5-1/index.html.

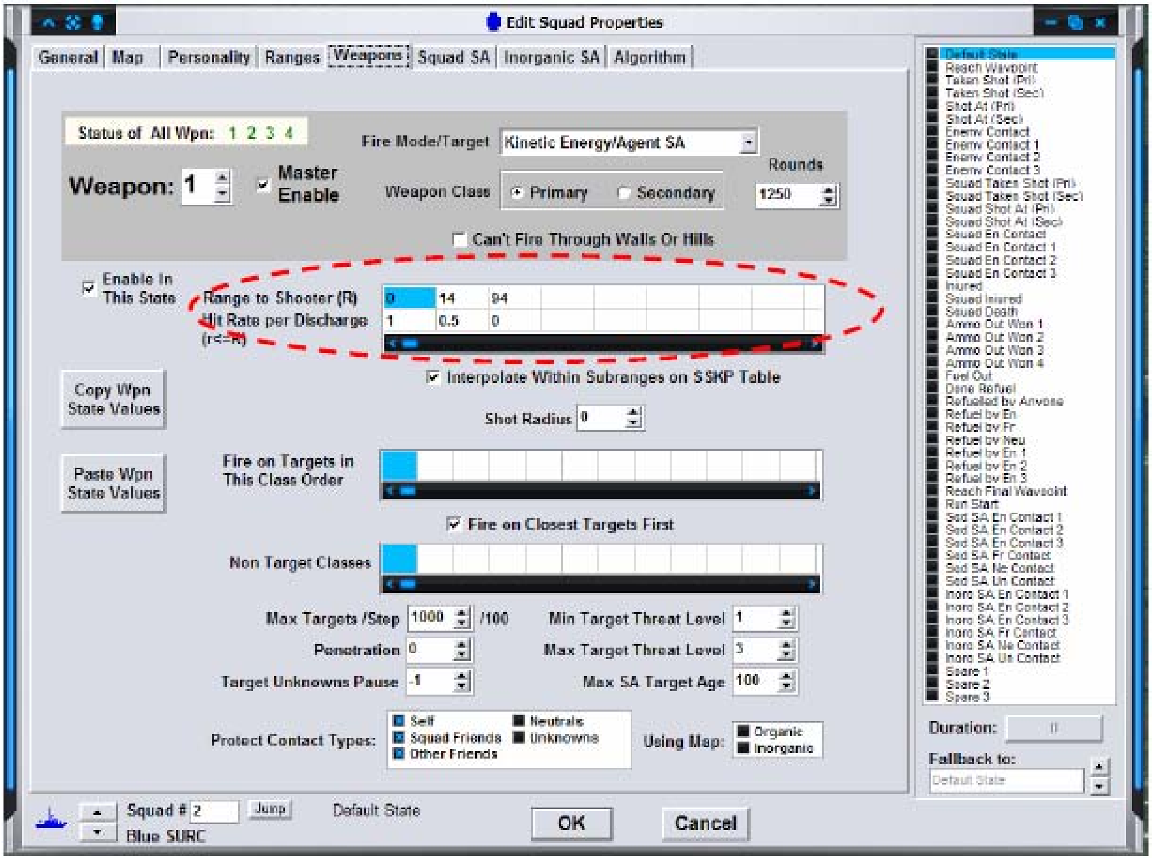

Figure 21. Hit Rate Per Discharge for Individual Weapons in MANA.

6. Communications and Situational Awareness within MANA

MANA permits control of the flow of situational awareness between squads using communications links as carriers of information. Outbound communications may be given specific settings for Range, Capacity, Buffer, Latency, Self, Reliability, Accuracy, Maximum Age, Rank Filter, Include, and Delivery.

a. Range

Range: Range is defined as the maximum range between the center of the transmitting and receiving squads. Messages are queued if this range is exceeded and the "Guaranteed Delivery" option is selected – otherwise they disappear (i.e., fail to transmit), just as in real world systems.

b. Capacity

Capacity: The number of messages that can be sent through the link per time step.

c. Buffer

Buffer: The buffer represents maximum queue size. While at maximum buffer capacity, new messages are discarded. The default value for this parameter is -1, which means no size limit is imposed. (Buffer≥-1)

d. Latency

Latency: The number of time steps taken for each message to reach the receiving squad.

e. Self

Self: The number of time steps between transmitted position messages for each of the members of the transmitting squad. Only used when the "Pass Self" option is checked.

f. Reliability

Reliability: The likelihood that a given message will be successfully sent on the link per transmission attempt. Unsuccessfully transmitted messages will be resent until they are successfully transmitted. (0%–100%)

g. Accuracy

Accuracy: This parameter sets the probability that a contact's identity (friendly, hostile, neutral) will be passed correctly. When a link is inaccurate an incorrect classification may be sent for the contact. An accuracy of 0% means always send as incorrect contact type and 100% means always send as correct contact type. The accuracy parameter is particularly useful for studies on friendly fire prevention and occurrence. (0%–100%)

h. Max Age

Max Age: This setting defines the maximum age or time that a contact can remain in the link queue. Age is measured from the time of initial organic sensor detection and not from arrival at the transmission queue. This parameter allows the user to prevent stale information from curtailing the flow of newer information in the first in first out (FIFO) queue. The default of value of -1 designates that there is no age limit on messages. The queue is processed at each step of the model, and any stale messages are eliminated. (MaxAge≥-1)

i. Link Reported Contact Types

Table 13 displays the contact types that are passed between agents as messages detection and classification identities on the link.

Message Prefix	Contact Information Sent
S	Share positions of own agents
F	Share details of friendly contacts
U	Share details of unclassified contacts
N	Share details of neutral contacts
E	Share details of enemy contacts
T	Share Squad's Local Situational Awareness
C	Share Inorganic Situational Awareness

Table 13 . MANA Contact Messages[112].

j. Delivery

Delivery: Guaranteed Delivery causes messages to be queued when the receiving squad is out of communications range. In such cases messages are lost if Fire-N-Forget is enabled. The following communications equipment was considered as viable riverine equipment.

- Cell phone or equivalent VHF Limited Reliability
- Basic Radio or equivalent UHF LOS
- Personal Role Radio (PRR) or equivalent UHF Intra-Team Communications
- PRC 148 or equivalent VHF/UHF Platoon – Squad – Team C2 - CAS Control
- JTRS Cluster (8 channel) or equivalent Digital Future Internet Networked Protocol System
- JTRS Cluster (4 channel) or equivalent Digital Future Internet Networked Protocol System
- JTRS Cluster 5 SFF-D-E-G or equivalent Digital Future Internet Networked Protocol System
- PRC 117 or equivalent VHF / UHF / Satellite Communications
- Squad – Plat – HHQ CAS/Fires Control (OTH - Digital)

[112] D. Galligan et al.,"MANA (Map Aware Non-uniform Automata) Compressed Help File." Version 3.0.39. Operations Analysis Section, Defense Technology Agency, New Zealand, April 2005

The RF was primarily modeled using JTRS, PRC 117 or equivalent, and cellular phones as the basic tools to maintain situational awareness between units. Specific settings are detailed in Appendix A.

7. Stop Conditions

An individual model run was terminated upon the defeat of all RED forces, the defeat of all BLUE forces, or the termination of 1440 time steps (24 hours).

D. DATA OUTPUTS

SEA-10 conducted 30 simulation runs for each of the 11 alternatives set within the two scenarios of ambush and patrol. The following output data files were recorded.

- **Step by Step Data**. This option saves a separate result file for each run containing step-by-step casualties, enemy contacts, and situational awareness activity.
- **Casualty Location Data**. This option saves a separate result file for each run containing the x and y coordinates and time step of each casualty.
- **Agent State Data**. This option saves a separate result file for each run containing data on each agent's state at the end of that run. Each row is an output for a separate agent.
- **Detections**. This option saves a separate result file for each run containing data for detections that occur on situational awareness maps.
- **Multi-Contact Detections**. This option saves a separate result file for each run containing data on detections that occur on situational awareness maps.
- **Red Detections per Step**. This option saves a separate result file for each run containing data on number of unique Red units detected each time step in each run of a multi-run.
- **First Enemy Detections**. This option records the time of first enemy detection on either of the situational awareness maps of each of the squads in the scenario.

E. SOFTWARE PROCESSES, ASSUMPTIONS AND LIMITATIONS

MANA processes interactions between agents and squads of agents at each modelled time step. In some cases, there is a systematic order of processing and in other cases the order is randomised to prevent bias. It is important for the modeller to understand which scheme is being used as it may affect the way they parameterise their scenario. The following tasks were carried out in strict order at each time-step throughout the entirety of the modelling process.

- All squads update their situational awareness maps to remove expired contacts. Agent ordering occurs by squad number.
- Agents are selected (one agent per time step) randomly from the pool of all agents present on the battlefield. A selected agent carries out the following tasks during its turn:
- It registers any contacts present within sensor range. It adds these contacts to the situational awareness map and onto any appropriate outgoing communications messages. Every agent on the battlefield is probed to see if it is within sensor range, the order of this probing is random to ensure that there is no systematic ordering of contacts arriving at communications links queues.
- The agent fires its weapons upon any valid targets. Enabled weapons are fired in order of weapon priority and number.
- It refuels any agents for which refuelling is specified and that are within range. Agents are refuelled in order of agent identification number.
- The agent moves.
- Each squad is selected once in random order to process its communications queues. [113]

F. MANA SYSTEM LIMITATIONS

SEA-10 had to make assumptions on system characteristics to capture the nature of the scenario and provide realism to the models. Every attempt was made to minimize MANA limitations. Key limitations dealt with during model development are described in the following section.

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[113] D. Galligan et al.,"MANA (Map Aware Non-uniform Automata) Compressed Help File." Version 3.0.39. Operations Analysis Section, Defense Technology Agency, New Zealand, April 2005

1. LIMITATION: Disembarkation of Forces

The GCE and the various unmanned systems used in the models presented programming challenges. MANA cannot debark the GCE from a SURC, and a compromise solution was required. To simulate the baseline + engagement force package, the GCE had to be artificially placed ahead of the SURC and placed into an inactive state until refueled. The SURC had to locate and "refuel" the GCE agents in order to simulate disembarking GCE agents and perform the mission.

2. LIMITATION: Erratic UAV/USV Movement

Unmanned systems patrolled irregular patterns and were of little value in initial models. UAV's and USV's were given waypoints similar to SURC in order to simulate the UAV/USV patrolling the riverine environment under operator guidance and prevent random behavior.

3. LIMITATION: SURC Damage Mitigation

The robustness of the SURC was difficult to capture with MANA. A SURC can absorb more than one bullet, but when modeled as an individual agent in MANA, it could not. In order to capture the SURC's durability and simulate individual agents onboard the SURC, SEA-10 increased SURC No. Hits to Kill by a factor that included the number of crew available, a sixty percent multiplier of exposed crew profile representing the additional armor hit capability. This prevented a single shot from destroying a SURC. Equation 11 was used to generate the value given to increase SURC armor.

$$\frac{\text{4 crew (exposed)}}{\text{7 crew (total)}} \times (7 crew) + \text{7 crew (total) = 11 Hits to Kill}$$

Equation 11. SURC Armor Augment Calculation.

SURC without the VBSS team embarked onboard received 11 Hits to Kill. SURC with the VBSS team embarked onboard received 22 Hits to Kill (to account for more personnel onboard). The VBSS SURC has a total of 14 crewmembers embarked. Again, the 0.6 multiplier represents the percentage of a body that is not covered by SURC armor for each person manning a weapon or standing in the SURC.

$$14 \text{ crew} + (14 \text{ crew} * .6) = 22 \text{ Hits to Kill}$$

Equation 12. SURC Damage Capacity Equation.

Although the method of adding extra damage mitigation to the SURC seemed rudimentary, the method was consistent, and provided the SURC with an increased armor value that stayed consistent throughout modeling runs.

4. LIMITATION: Modeling Velocity

The model was limited by the scaling capabilities of MANA. Real world velocity could not be processed by MANA due to scale. Vehicles which traveled at a rate of greater than 10 grids per time step (22 km per hour) had to travel at 10 grids per time step.

VI. COST ESTIMATION

A. COST ESTIMATE PURPOSE AND COMPONENTS

This cost estimation was conducted to describe the potential procurement and operating and support costs of the alternative force packages derived from SEA-10's functional and physical architectures. Individual technologies that compose the force packages were examined in detail and then combined as necessary for each complete force package estimate. The purpose of this cost estimate is to assist the decision maker in determining which alternative provides the best capability for the most acceptable cost. It is ultimately up to the decision maker to weight the importance of each capability as a function of the cost. This section is designed to provide insight into the potential life cycle cost of each force package.

B. COST ESTIMATES OF TECHNOLOGIES CONSIDERED

Cost was a critical factor in considering alternative force packages for the RF of 2010. Cost was not the sole variable for choosing one alternative over the others, but it was factored into SEA-10's recommendations for a preferred operational architecture. Procurement costs and operations and support costs were estimated over a 10 year period (2010-2020). All costs were derived from open source documents and, to the best of SEA-10's knowledge, are representative of actual contractor costs. No proprietary or for official use only documentation was used in the cost estimation in effort to make this thesis widely available.

C. UNMANNED AERIAL VEHICLES

Since the late 1980's, UAV programs received funding from the Department of Defense. UAV's have evolved to become viable agents of the DoD as a result of advances in microprocessor speed and light weight composite material. These advancements enabled UAV's to assume combat roles that were previously impossible for an unmanned system. Evidence of DoD's interest in UAV's is shown by increase in funding for UAV programs since the late 1980's. Until the late-1990's, DoD spent less than $500 M per year on UAV development while the aforementioned technologies matured, as shown in Figure 22. In 2001, annual funding for UAV's began to increase significantly, largely because of the United States involvement in Afghanistan and Iraq.

As technology evolves and the United States continues in the GWOT, it is highly probable that DoD will continue to invest money into RDT&E, procurement, and operations and support of UAV's.

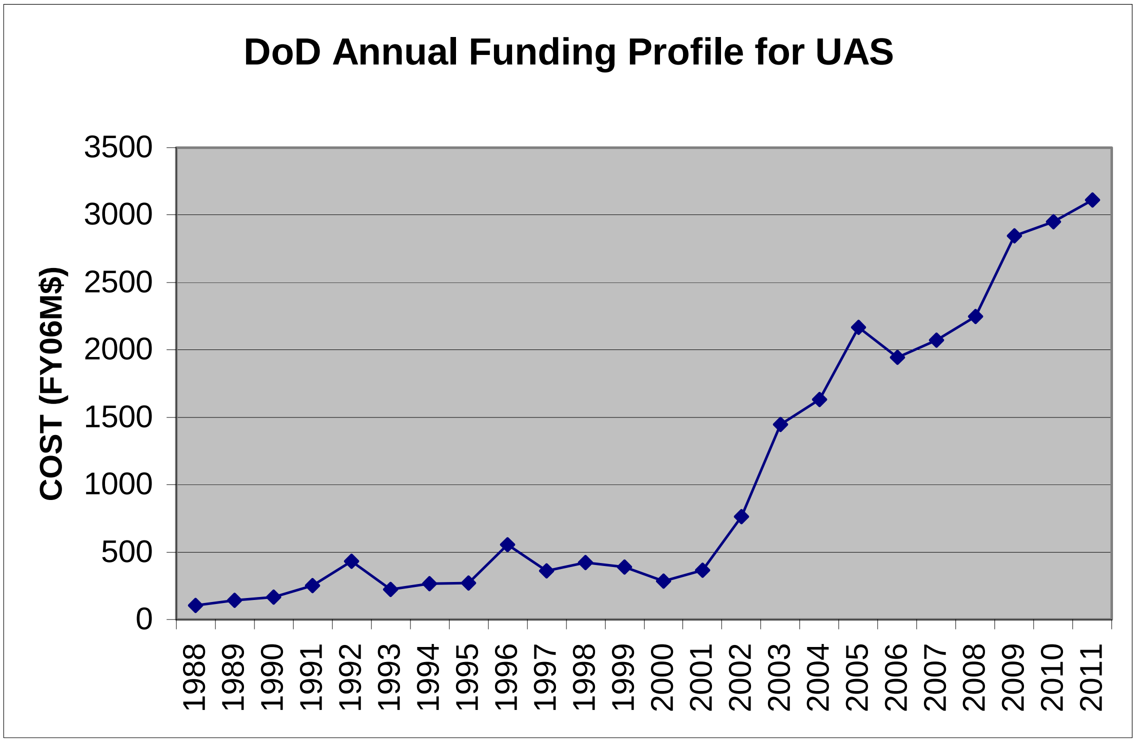

Figure 22. Department of Defense Unmanned Aerial Vehicle Funding 1988-2011[114].

1. UAV Categorization

SEA-10 separated UAV's into three categories:

- Small UAV- weigh less than10 lbs with an airspeed less than 100 knots (Dragon Eye, Raven)
- Tactical UAV- weight less than 500lbs with airspeed less than120 knots (Scan Eagle, Shadow)[115]
- Theater level- large body airframe capable of 24 hour plus mission endurance (Global Hawk, Predator)

SEA-10 assumed that theater level UAV's would not be directly attached to the RF because of cost limitations, but RF data link systems must be interoperable with these

[114] Office of Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030*, p 37, 2005.

[115] Ibid.

platforms as they may provide intelligence in a supporting role or may be operating in the area of operations with RF. Small UAV's were excluded from estimates because of their short endurance, fragility, and non-waterproof systems. Only tactical UAV's were considered in the evaluation of alternatives. Tactical UAV's have the characteristics required for search and detection of enemy forces. SEA-10 modeled the RF in operation for a full 24 hour period, of which the UAV can provide detection support for the entire duration of operations. Tactical UAV's have a service ceiling of 16,000 feet and a nominal cruise speed of 80 knots. SEA-10 assumed that UAV's will be launched and recovered from the TOC (this assumption also excludes small UAV's and theater level UAV's). As of February 2006, 224 tactical UAV's were in the DoD's inventory. The following breakdown of tactical UAV's is outlined in Table 14.[116]

UAV	Sponsor Organization	Number in Service
Pioneer	USN/USMC	34
Shadow 200	Army	140
Neptune	SOCOM	14
Tern	SOCOM	15
Mako	SOCOM	15
Tigershark	SOCOM	6

Table 14. Tactical UAV Sponsor Organizations and Number in Service[117].

2. Shadow 200

In 1999 the U.S. Army acquired the RQ-7/Shadow 200 system to support brigade level commanders. In 2003 Shadow went initial operatinal capability (IOC) with an expected delivery of 88 systems[118] and was "the first UAV in recent history to pass its Milestone III (full rate production) decision on 25 September 2002."[119] As of 2002, 20 Shadow 200 UAV systems (four airframes each) are assigned to operational units. The RQ-7B Shadow 200 system consists of four airframes, a rail launcher, recovery system, a ground control unit, a remote ground data terminal, and truck transport. Shadow is a rail

[116] Government Accountability Office, *GAO Report 06-610T Unmanned Aircraft Systems: Improved Planning and Acquisition Strategies*, p. 6, April 2006.

[117] Ibid.

[118] Office of Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030*, p 37, 2005.

[119] Office of Secretary of Defense, *Unmanned Aerial Vehicle Reliability Study*, p.50, February 2002.

launched tactical UAV with 7 hours of endurance and an operational radius of 69 nm. Equipped with a gimbaled electro optical (EO) infrared (IR) sensor it is capable of real time video via C-band line of sight data link. Table 15 is a breakdown of Shadow capabilities. Due to increasing operational requirements, procurement of Shadow UAV has grown to 35 systems and the FY2006 supplemental budget requested 9 additional Shadow systems for use in Iraq[120].

Shadow 200 Performance Characteristics			
Manufacturer	AAI	Fuel	MOGAS
Primary User	U.S. Army	Nominal Altitude (feet)	15,000
Weight (lbs)	216	Cruise Speed (knots)	60-100
Payload Capacity (lbs)	60	Operational Radius (nm)	69
Endurance (hrs)	7	Number of airframes per system	4

Table 15. Shadow 200 performance characteristics[121].

Shadow UAV would be used as a detection capability for the RF. Once launched from the Tactical Operations Center (TOC) the Shadow is controlled by two operators: an AVO (Aerial Vehicle Operator) and a MPO (Mission Payload Operator), who are in charge of the UAV navigation, and tactical control (searching for targets and system monitoring)[122]. The UAV can be flown to pre-designated waypoints or by direct control. UAV data relays to the TOC via IP based networks that must be established prior to riverine operations. The speed of data transmission is only limited by the availability of bandwidth. Shadow cannot operate for an entire 24 hour mission, but multiple airframes can relieve on station and cover the duration of the RF patrol. From an operating altitude of 3,000 feet, assuming a 30 degree field of view, Shadow will have a search sweep path of 2000 feet[123]. Shadow is a detection only platform, and does not have an engagement capability.

120 Office of the Secretary of Defense, Defense Budget Materials "*Department of Defense FY2006 Supplemental Request for Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF)*" Retrived 01 November 2006 on the World Wide Web at [http://www.dod.mil/comptroller/defbudget/fy2007/index.html]

121 Office of Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030*, p 8, 2005.

122 M.L Cummings, C.E. Nehme, & J. Crandall, "*Predicting Operator Capacity for Supervisory Control of Multiple UAVS*," Unpublished, Humans and Automation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts. 2006.

123 Department of the Navy, Office of the Chief of Naval Operations, *Integration of Unmanned Vehicles into Maritime Missions*, TM 3-22-5-SW, pp. 35-36.

3. Shadow 200 Research Developmental Testing Evaluation and Procurement Costs

The estimated cost for a Shadow UAV for FY10 is $320,000 per airframe and $18.0M (FY06) per system, to include the launcher, recovery unit, ground control system, remote ground data terminal and truck transport and maintenance support facility[124]. SEA-10 assumed that the RF would procure and operate two Shadow UAV systems. Increases in requirements[125] led to an 18% (3% with each procurement) increase to the cost of Shadow procurement over the 10 year period. Figure 23 was derived from information in the Army's budget request for 2007[126]. Lack of procurement funding in FY07 and FY08 is due to the need to refit the propulsion systems of existing systems to meet the payload requirements.

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[124] Office of Secretary of Defense, Defense Budget Materials "*Department of the Army Procurement Programs, Other Procurement February 2006*"Retrived 08 November 2006 on the World Wide Web at []http://www.asafm.army.mil/budget/fybm/FY07/pforms/opa2.pdf.], p 236.

[125] Office of Secretary of Defense, *Unmanned Aerial Vehicle Reliability Study*, pp.50-51, February 2002.

[126] Office of Secretary of Defense, Defense Budget Materials "*Department of the Army Procurement Programs, Other Procurement February 2006*"Retrived 08 November 2006 on the World Wide Web at []http://www.asafm.army.mil/budget/fybm/FY07/pforms/opa2.pdf.]], p 236.

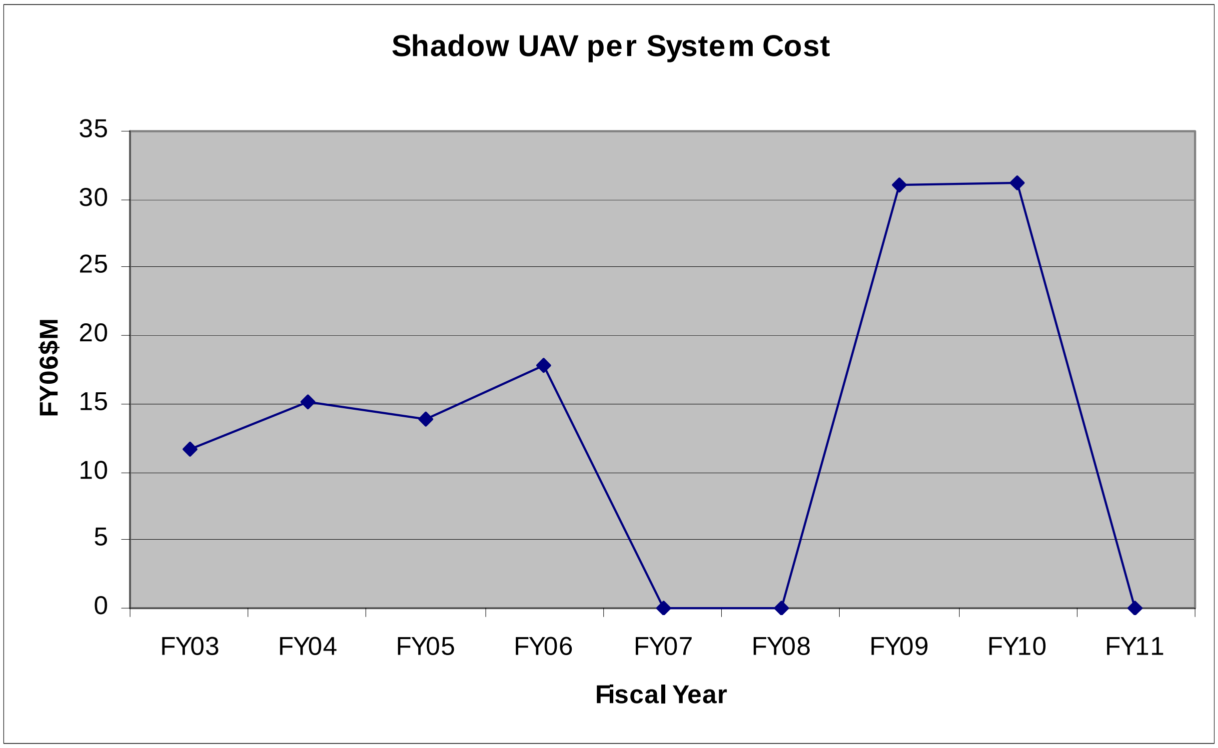

Figure 23. Shadow Procurement Costs FY2003 - FY2011[127].

SEA-10 assumed that the RF is not responsible for any RDT&E of the Shadow 200 system, and procured two Shadow 200 systems in 2010.

4. Shadow 200 Operating and Support Costs

Estimates of operating and support costs were derived primarily from the cost to train and deploy UAV operators. Yearly salaries were prorated for instructors based off of course length while students and operators entire yearly salaries were included. The USA owns and operates the Unmanned Aerial System Training Base (USATB)[128], therefore overhead costs, simulators, text books, and supplies were not factored into the training costs. Maintenance, technical support, and spare parts were estimated between 5% and 10% of procurement costs because much of this information was considered operationally and proprietarily sensitive and was not releasable from the program office to SEA-10. Estimates for Shadow 200 UAV operating and support costs were taken

[127] Office of Secretary of Defense, Defense Budget Materials "*Department of the Army Procurement Programs, Other Procurement February 2006*"Retrived 08 November 2006 on the World Wide Web at []http://www.asafm.army.mil/budget/fybm/FY07/pforms/opa2.pdf.], p 236.

[128] Office of Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030*, p 63, 2005.

from the President's budget for 2006[129]. Total yearly operating and support costs for two Shadow UAV systems range from $2.8 - $3.8M. Operating and Support costs over a 10 year period for Shadow UAV were $36.6 M.

D. UNMANNED SURFACE SYSTEMS

The incorporation of an Unmanned Surface Vehicle/System (USV/USS) has the potential to:

- Increase battle space awareness.
- Increase the RF's engagement capabilities through increased ISR.
- Preserve the force by engaging in "dull, dirty, and dangerous" but important missions deemed too risky for manned systems.

The USS is the entire system, inclusive of the USV, that acts as a forward scout for the RF. The USV sub-system is the self propelled water vehicle that maneuvers forward of the force, conducts ISR, and relays data on the tactical picture via data link. The USS provides the RF with an unmanned alternative to investigate potentially hazardous situations. USV's could be used to probe potential weapons caches, investigate suspected improvised explosives devices (IEDs), and close with suspicious vessels on the waterway. A USS has the potential to increase the RF battlespace awareness. A USV can preserve the force by providing information on the area around a river bend. This would enable the RF to observe a potential ambush site without placing a boat crew inside enemy weapons range. The USS also provides increased engagement capability by allowing crews to examine a potentially hostile site from a safe distance and allowing the RF the opportunity to exploit indirect fire options or take advantage of crew served weapons with greater ranges.

Once the decision was made on what the system must do, the critical question became: what capabilities must the USV have in order to successfully increase battle space awareness and increase engagement capability? First, if the USV cannot keep pace with the supported force, it cannot contribute to local battlespace awareness. Second, the USV must be able to provide feedback to the operator on the environment. Lastly, the USV must have sufficient survivability to ensure it can complete its specified tasks.

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[129] Office of Secretary of Defense, Defense Budget Materials "*Department of the Army Procurement Programs, Other Procurement February 2006*"Retrived 08 November 2006 on the World Wide Web at []http://www.asafm.army.mil/budget/fybm/FY07/pforms/opa2.pdf.], p 236.

Other manned and unmanned systems can similarly contribute to increased battlespace awareness and increased engagement capability, but USS's offer complimentary benefits to other RF systems in that they operate in the same riverine environment as the SURC's and patrolling crews, and they are often controlled from the SURC itself.

The USV must have a robust sensor package to accomplish the mission. In order to provide ISR data in a variety of conditions and operational environments, the sensor suite should consist of laser and point listening devices, EO and IR optical imagers with high power zoom capability, and an eye safe laser rangefinder to give precise range and bearing information to an integrated navigation and targeting system. The sensor suite should also have a megaphone for safe distance communication with suspect vessels. The USV should also have several low-light television cameras and small navigation radar for safety of navigation and situational awareness.

1. USV Categorization

Selection of an existing or developmental USV platform for riverine missions should consider payload capacity and platform capabilities (payload weight, electrical power generation, and stability), mobility, (size, weight, speed, and endurance), transportation and towing (size, weight, unit transportability, ease of launch and recovery), as well as a number of other issues such as stealth, survivability, host platform storage space, automation, and data communication. A large USV can be a more capable sensor platform, but consumes a larger storage and transportation footprint. Smaller less costly USV's require less storage and transportation space, but provide a less capable sensor platform with lower speed and endurance capabilities. Several candidates stood out as potential RF USV platforms. For the purposes of determining which platform to use for this cost estimation SEA-10 categorized USV's into small, medium, and large platforms. The USV that best represents the technology modeled was the medium USV SeaFox built by Northwind Marine, and it is the primary platform considered in this cost estimate. Small and large USV's and their trade off capabilities are described below.

Jet-ski based platforms such as the RoboSki target towing drone are based on commercial 2-stroke gasoline powered composite fiberglass and plastic hull jet-skis. They offer a light weight, shallow draft, and low cost platform option. Jet-ski based platforms' speed and maneuverability capabilities are similar to the SURC. They present a low profile because of their small size, but this limits payload capacity. Limited payload and electrical load capabilities of the jet-ski based platform restrict range and sensor capabilities. The jet-ski may be able to support the previously outlined sensor system with some modifications. While the jet-ski is a relatively light weight platform, it is not man portable and requires transport via trailer, and therefore extends the launch and recovery time of the RF and increases its vulnerability. Also, the composite hull is unproven in field use or combat.

Other small platform options include ultra lightweight, man portable pontoon hull configurations with nearly silent electric drive (COTS, low speed, electric trolling motors). The small pontoon USV's offer excellent stealth but are very limited in their sensor capabilities. It is not likely that these systems could support the desired sensor suite without significant developmental lead time. While these platforms generally provided a low cost solution, they did not have the range or speed necessary to keep pace with the SURC. The crews were required to stop, deploy the USV and retrieve it after it completed surveillance. This placed an extra burden on the crews and increased their vulnerability which may negate the stealth advantages of the platform. Lastly, the small craft is not very survivable in field conditions in its current light weight non-armored form.

The advanced concept technology demonstrator (ACTD) Spartan Scout is a standard Navy 7 meter RHIB with a remote piloting package that enables it to operate as either a manned or unmanned vessel. The remote pilothouse can be applied to the SURC platform, and allows it to function as a manned SURC or a USV. A SURC with such an external piloting system can keep pace with other SURC's, and is able to support the desired sensor package. Logistic issues should be minimized as the SURC platform will only differ from the manned SURC's in its remote piloting equipment. Additionally, if a manned SURC is damaged, the USV could be converted to a manned platform instantly. Launching the additional SURC sized boat would lengthen the vulnerability of the RF during launch and recovery operations and stealth is sacrificed for ease of support.

2. SeaFox

The SeaFox is a 5 meter (16 foot length overall) rigid-hull inflatable boat (RHIB) designed and built by Northwind Marine. The SeaFox is a purpose-built medium USV platform with an aluminum hull and a 220 horsepower heavy fuel (diesel or JP-5) engine powering a water jet propulsion system. The SeaFox is built for durability and heavy use. It has speed, maneuverability, and range comparable to the SURC. The larger size of the SeaFox requires transport via trailer and extends the RF vulnerability window of the launch and recovery phases. It is not as stealthy as the small USV platform. However, its low profile and quiet operation at low speeds offer better stealth than the SURC. The SeaFox is also able to support all elements of the desired sensor package. SeaFox can also employ additional systems to enhance its capabilities.

Another medium USV platform is the high speed mobile surface target (HSMST) which is a derivative of the Navy's standard 7 meter RHIB. The HSMST has capabilities and limitations similar to SeaFox. Both are small to medium sized RHIBs with powerful water jet propulsion systems.[130] However, HSMST is gasoline powered and requires modification to operate on heavy fuels and be logistically compatible with the SURC. HSMST is larger than SeaFox which increases the detection signature and logistical footprint.

SeaFox is the best representation of the USV that SEA-10 chose to model and cost estimate in this thesis. There were two major factors that drove this decision. The first was that NECC and RIVGRU ONE have set a requirement for two SeaFox vehicles to be delivered to the RF by late 2006 or early 2007.[131] The second factor was that the performance parameters of the medium USV category take advantage of some stealth and ease of use benefits without sacrificing performance. Since USV's are relatively new to the operational scene, finding accurate information on the actual cost of training, maintenance, and support was challenging. The cost of RDT&E was factored into this cost estimate as part of the procurement cost. Since USV systems are not in full rate production, procurement costs may not be representative of actual costs.

[130] HSMSTs have the option of twin gasoline outboards, twin gasoline powered inboards or twin gasoline powered water jets.

[131] Government Supplemental Contract number: GS-07F-0416, program is administered by: Naval Sea Systems Command, Washington Navy Yard.

3. SeaFox RDT&E and Procurement Costs

Research and development costs of the basic SeaFox vehicle were paid by the Office of Naval Research[132]. Procurement cost of SeaFox is $300,000 per unit, and it was assumed that RF would need a total of three SeaFox units to support operations for a deployed squadron[133]. This cost estimate assumed three USV's will be purchased in 2010.

4. SeaFox Operations and Support Costs

Operations and support costs are broken down into personnel, maintenance, and support categories. Personnel O&S cost were estimated based on training for typical RHIB crews. Operator and maintenance personnel training requirements were the same for large and medium USV's but not small USV's. Little to no real world operations or data was available to support training and operating estimates. Therefore SEA-10 concluded from an extensive open source internet search and literature review[134] that two E-5 operators with a week of quarterly training and three dedicated maintainers are capable of maintaining the same operational availability from the USV that can be expected from the SURC. All personnel pay was increased by 2% per year. Maintenance O&S cost included POL, consumable, and repairable spare parts. POL consumption and cost were derived from fuel curves for a Cummins Mercruiser Diesel which is a standard engine for a RHIB. Total cost of operations for three USV's per squadron over 10 years is $3.76M. The yearly range is $.24M to $.28M (FYO6). The cost of operations and support for the proposed USV is presented in Appendix B.

E. UNMANNED GROUND SENSORS

> *Remote sensor operations expand the commander's view of the battlefield. Remote sensors provide a means to economically conduct continuous surveillance of vast areas, contributing key information to the intelligence collection effort. These operations decrease the number of personnel required for reconnaissance and surveillance operations and reduce the risk associated with these operations. A remote sensor system, consisting of individual sensors, communications relays, and monitoring devices,*

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[132] Government Supplemental Contract number: GS-07F-0416, program is administered by: Naval Sea Systems Command, Washington Navy Yard.

[133] Three USV's are desired for continual coverage during riverine operations. Since there are three boat divisions, one USV will be assigned to each division.

[134] CANTRAC Website. *Small Boat Instruction*. Retrieved 13 November 2006 from the World Wide Web at [https://cetarsweb.cnet.navy.mil/pls/cetars/main.action?V_LOC=home]

provides the capability to conduct remote sensor operations. Sensors, relays, and monitoring devices are employed in an integrated network, providing general surveillance, early warning, or target acquisition over selected areas of the battlefield. Key considerations in employing remote sensors are the nature of the target, characteristics of the area or operations, time and resources available for emplacing the sensor network, and the location and connectivity of the sensor monitoring sites[135].

The excerpt above is from Marine Corps Warfighting Publication 2-2.3 (MCWP 2-2.3) and describes a generic CONOPS for unmanned ground sensors (UGS). SEA-10 utilized the Marine Corps Tactical Remote Sensor System (TRSS) for modeling alternatives and this cost estimation. MCWP 2-2.3 describes training and operating requirements for the system as well as providing data for modeling parameters. The technology of TRSS is mature and completely feasible for SEA-10's timeframe of 2010.

1. Tactical Remote Sensor System (TRSS)

TRSS consists of sensors, communications data relays, and monitoring systems. TRSS uses a string of 24 individually placed sensors with a range per sensor of up to 100 meters for vehicle detection. The sensors used in TRSS are seismic, magnetic, and infrared.[136] They act as a tripwire and alert units to the presence of personnel and vehicles, but have limited capability for classification of contacts. These sensors are ideally suited for areas of expected enemy activity or for use in critical force protection areas around a forward operating base or TOC. Only one ground unit will be needed for riverine operations. The ground unit requires four people to set up and monitor the UGS during deployment. The average duration of operations for TRSS is 30 days per battery charge. The UGS team will be integrated into the logistics and support of the RF due to its small size. The TRSS UGS divided up into four man portable components: one ground sensor; one sensor monitoring system; one portable monitor; and one relay system. The total cost of TRSS is the sum of all four components. One UGS is purchased in 2010 and one will be purchased every five years thereafter. In the non-

[135] Marine Corps Warfighting Publication (MCWP) 2-2.3, *Remote Sensor Operations,* Chapter 1, 17 April 1997.

[136] Marine Corps Warfighting Publication (MCWP) 2-2.3, *Remote Sensor Operations,* Chapter 2, 17 April 1997.

procurement years, 1% of the cost of the UGS is used for maintenance and upgrades. TRSS required no RDT&E estimate because it is already a technology developed and procured for DoD.

The individually deployed sensors used by TRSS have the added advantage that, as sensor technology improves, the system can use its existing data communication and monitoring architecture while incorporating sensor advancements. The Marine Corps has established a firm doctrinal base in its MCWP and has laid a solid organizational foundation for continued advancement in the efficient use of unattended sensors that will help other military users like RIVGRU should they choose to invest in this technology.

2. TRSS Operations and Support Costs

Operations and support is accounted for in the cost of personnel. SEA-10 assumed that the cost of personnel is substantially greater than the cost of the maintenance of the system. The basic unit for fielding a TRSS is the Marine Corps sensor employment team (SET) which consists of four marines and is designed to support a Marine Expeditionary Unit (MEU) sized Marine Air Ground Task Force (MAGTF) of approximately 2200 Marines[137]. The SET is capable of monitoring a single site continuously while providing first echelon maintenance for the system. The additional operating and maintenance responsibilities for TRSS would require an augment to RIVRON TOC personnel as well as initial and periodic refresher training. All unit cost values were drawn from a FY05 supplemental request for funds and the 2006 military basic pay scales. Total operational cost of the system over a 10 year period is $8.03M. The annual cost is between $.356M and $0.404M.

F. GROUND COMBAT ELEMENT

The GCE increases the versatility of the RF. The RF can engage the enemy on land as well as on water with a GCE embarked. The GCE can also be used for gathering intelligence, insertion and extraction of units, and covert operations. SEA-10 modeled the GCE to enhance the engagement capability of the RF on land. SEA-10 modeled a light infantry platoon consisting of one 12 man team with one squad automatic weapon (SAW) and 12 M-16 assault rifles. The modified light infantry platoon consists of two rifle squads with one machine gun team. A machine gun team consists of a machine

[137] Global Security, *Marine Corps Expeditionary Unit*. Retrieved 02 November 2006 from the World Wide Web at [http://www.globalsecurity.org/military/agency/usmc/meu.htm]

gunner and an assistant machine gunner. The platoon headquarters element consists of a platoon commander, senior enlisted advisor and a radioman. All individuals carry the M-16 assault rifle and only one designated individual carried the additional SAW.

The cost estimate for the GCE consists of the cost of personnel, weapons, and equipment. In this cost estimation, the service of the GCE was not a factor. SEA-10 assumed that Army or Marine Corps personnel could fill the role as the riverine GCE, and this assumption is supported by the NECC CONOPS for Riverine Operations[138]. Cost for training the GCE to the riverine mission was included in this estimate as the normal salaries of the members of the GCE. However, instructor, schoolhouse, and supply cost of instruction was not included, because it is assumed that it will be undertaken by the parent force (USMC or USA).

1. GCE RDT&E and Procurement Costs

Research and development were not considered for inclusion in the GCE cost estimate. Procurement only included the purchase of weapons. Every five years one SAW and 16 M-16 assault rifles are purchased at a cost that increases by 5% from the prior procurement. Initial procurement of tents, field packs, medical supplies, food and other supplies were included because SEA-10 assumed that the RF would not inherit this material from the GCE's parent force. Information about the complete composition of GCE material was provided by RIVGRU ONE and listed in Appendix B.[139]

2. GCE Operations and Support Costs

Military pay was found on the official DoD military pay website and it is assumed that all pay increases by 2% per year[140]. Personnel costs were only for the time of work up training and deployment (total of one year) because it was assumed that the GCE was assigned from a parent service and are only temporarily assigned to the RF.

[138] Naval Expeditionary Combat Command, *Concept of Operations - US Navy Riverine Force (DRAFT)*, p. 37, Naval Amphibious Base, Little Creek, VA, 30 August 2006.

[139] Riverine Group Initial Cost Estimate, Unpublished, 26 August 2006, see also Appendix Cost Estimate.

[140] Interview between Dr. Daniel Nussbaum, Professor, Naval Postgraduate School, and the author, October 29, 2006.

Weapons costs were based on estimates found through open source websites[141]. Every five years 1 SAW and 12 M-16 assault rifles were purchased. A cost increase of 5% was added to each weapon that was purchased after 2010. Additionally, cost of upkeep and ammunition for the weapons was included as 50% of the purchase price of the weapons and was part of each yearly cost, during the years when weapons were not procured (i.e., the 2nd, 3rd and 4th years).

Cost of food, medical supplies, infantry equipment, and communications equipment was based on numbers from the initial cost estimate done by NECC for the RF[142]. SEA-10 assumed that costs for these materials will inflate by 1% per year over the next 10 years because of changing operational requirements. Total cost for employment of the GCE over a 10 year period is $8.03 M$ (FY06). The yearly range for ground combat operations is .730M-.746M (FY06$).

G. NETWORKED SENSORS

The networked sensor alternative consists of one UAV, one USV, and one UGS system that are able to communicate with each other to detect and classify targets. The concept hinges on interoperability between the sensors, TOC, and SURC'S for data transmission. Not all of the sensors are able to talk to one another directly. Some UAV's and USV's may have data link capability by 2010, but UGS's are unlikely to have data link capability because of their small size. Therefore, the networked sensor alternative will have man-in-the-loop oversight to ensure that data flows from the detecting sensor to corresponding classification sensors. SEA 10 does not foresee the necessary cultural and technological changes taking place by 2010 that would enable sensors to queue directly off one another without human interaction. SEA-10 chose the Joint Tactical Radio Set (JTRS) as the communications network of the 2010 RF. If continued program setbacks and budget overruns occur, then it is possible that JTRS would not be the communications network of choice in this alternative.

1. JTRS Cluster 5

JTRS is a DoD wide initiative to develop a common voice, data, and video communications network throughout the joint battlespace. The key element of JTRS is a

141 Federation of American Scientists, *M16A2 5.56mm Semiautomatic Rifle.* Retrieved 12 November 2006 from the World Wide Web at [www.fas.org/man/dod-101/sys/lcnd/m16.htm]

142 Riverine Group Initial Cost Estimate, Unpublished, 26 August 2006, see also Appendix C.

wideband network waveform that can provide mobile network connectivity across the battleground. JTRS is divided into five clusters. Cluster 1 will provide the warfighter with a multi-channel, software programmable, hardware configurable digital radio networking system. Nominal range for the wideband network waveform is approximately 6.2 km. JTRS was initially designed to provide a digital communications capability to the Army. The program has fallen behind schedule and experienced cost overruns. As an interim solution to Cluster 1, Cluster 2 was developed to provide Special Forces with an interoperable hand-held radio with GPS capability. The Army created JTRS Cluster 5 which utilizes handheld radios that are capable of receiving multiple waveforms because of an increasing need for interoperable communications and programmatic difficulty with Cluster 1. At $10,000 per radio, JTRS Cluster 5 program is a low cost alternative to Cluster 1 and 2 (Cluster 3 and 4 programs were disbanded).

The Cluster 5 program is managed by the Army and consists of several handheld radios shown in Figure 24 that are capable of multiple waveform transmission. JTRS waveform implementation consists of a Waveform Application Code, Radio Set Devices, and Radio System Applications. Originally, there were 32 JTRS waveforms which have since been reduced to the following nine:

- Wideband Networking Waveform (WNW)
- Soldier Radio Waveform (SRW)
- Joint Airborne Networking–Tactical Edge (JAN-TE)
- Mobile User Objective System (MUOS)
- SINCGARS
- Link-16
- EPLRS
- High Frequency (HF)
- UHF SATCOM "143"

[143] Space and Naval Warfare Systems Command, *Joint Tactical Radio System Cluster 5*, Retrieved 02 November 2006 as found on the World Wide Web at [http://enterprise.spawar.navy.mil/body.cfm?type=c&category=27&subcat=80].

Characteristics/Description:

	Size	Wt	Pwr	Range	**BW
• Handheld (HH)					
1 Channel	*40in^3	2.0lbs	*5W	5km	2Mb
2 Channel	*70in^3	3.0lbs	*5W	5km	2Mb
• Manpack (MP)					
2 Channel	400in^3	9.0lbs	*20W	*10km	2Mb
• Small Form Fit (SFF)					
1 Channel	40in^3	1.2lbs	N/A	15km^2 grid	2Mb
2 Channel	70in^3	2.2lbs	N/A	15km^2 grid	2Mb

*Not Specified in ORD, but by Specification
**BW is Pt to Pt Bandwidth available using SRW or WNW

Figure 24. JTRS Cluster 5 components.

2. JTRS Operations and Support Costs

Operations and support costs for the unmanned systems are estimated as the same for the individual systems. O & S support for the communications equipment and network backbone is dependent on the amount of lost equipment (i.e., handheld radio dropped overboard), damage and wear and tear due to operational use, software upgrades, and security upgrades. Data is not available for yearly operations and support cost of JTRS cluster 5. SEA-10 assumed that the operation and support costs of the system were 10% of the procurement cost. To estimate the cost of JTRS an analogy was drawn to existing communications equipment. A 60% increase in cost was applied to JTRS elements because open source literature reported the cost of one JTRS cluster 5 handheld as $10,000. It was also assumed that the multiple waveform capability of JTRS eliminated the need for the PRC 117, and that the man portable communications package would have an HF/SACTCOM capability. Figure 25 depicts the basis for the analogy.

Existing system	Existing System Cost	JTRS System	JTRS Cost
Handheld PRC 148	$6,000	JTRS Cluster 5 Hand Held, including marine band	$9,600.00
AN/PRC 148 Accessories	$12,000	None	None
VHF Marineband	$4,200	None	None
AN/PRC 150 HF Manpack Radio	$19,000	JTRS Manpack Radio	$30,400.00
AN/PRC 150 HF Manpack Radio Accessories	$5,000	JTRS Small Fit Form	$8,000.00
AN/PRC 117F UHF/VHF SATCOM Manpack Radio	$27,000	None	None
AN/PRC 117F UHF/VHF SATCOM Accessories	$7,000	None	None

Figure 25. JTRS Cluster 5 Cost Analogy Matrix.

3. JTRS System Cost

Total cost for the network sensors package is $82.0M (FY06) and includes the procurement and operating support costs for UAV, USV, UGS and JTRS cluster 5. Annual operating costs are estimated at $3M-$4.5M.

H. INDIRECT FIRE SUPPORT

1. New Efficient Mortar System (NEMO)

The New Efficient Mortar System (NEMO) provides rapid accurate indirect fire support from a riverine platform. NEMO is a light weight semi-automatic turreted mortar weapons system that uses a single gyro stabilized 120mm mortar cannon. NEMO was designed by the Finnish defense company, Patria, as a coastal patrol artillery unit. The hull is a 14.1 meter WATERCAT M-12 high speed amphibious troop carrier. The lightweight (1500 kilograms) NEMO turret can be mounted on the forecastle in lieu of the standard troop compartment. NEMO can maintain speed with the SURC's in the boat division and extends the engagement capability of the force to over 10 kilometers.[144] In

[144] Patria, *New Efficient Mortar System*, Retrieved 13 November 2006 as found on the World Wide Web at [www.partria.fi/modules/NEMO]

addition to the indirect fire capability, NEMO has the ability to support the force using both direct fire and Multiple Rounds Simultaneous Impact (MRSI) fire.

NEMO is built by Patria, a Finnish defense company; therefore exception would have to be made to put this system into use for American forces. Although the company has not looked at the possibility of installing the turret on the SURC platform, if this capability is desired, it could become an area of further research.

2. NEMO RDT&E and Procurement Costs

NEMO has not been sold to any country as of the writing of this thesis. However, estimates were made on the cost of the Watercat M12 hull, NEMO turret, modifications to the SURC hull, additional C2 gear, and stabilized EO/FLIR sites. Actual cost of NEMO was not available, due to the company confidentially policy. However, a similar system was built by ABU Dhabi Ship Building (ADSB), with the assistance of Sweedship, a Swedish boat design company, for the cost of $2.2M (FY03) per copy[145]. The Sweedship design was about 10m larger than the Watercat M12 with a significant command and control suite, but has a similar aluminum hull and jet propulsion system. Estimated cost for one Watercat M12 is approximately $1.0M(FY06). It is assumed that the RF will procure three NEMO Watercats, which will allow for one to operate with each boat division.

3. NEMO Operations and Support Costs

NEMO Watercat O&S cost estimates are based on 12 operators (4 per crew) that are trained to drive the SURC and operate the NEMO Watercat system. Although the turret is unmanned, the operators are responsible for reloading the turret if all of the mortars are fired. Operators are also needed to drive NEMO Watercat and provide force protection for the vessel. O & S costs for spare parts and POL are based on analogy to the riverine assault craft (RAC) platform. O&S costs for NEMO Watercat were estimated as 10% of the procurement costs (this may be a low estimate for a non-U.S. weapons system). R&D costs for installing and testing the NEMO system were not included in the cost estimate. Cost for the 120mm HE shells were found in FEDLOG; however, Patria sells the NEMO system and the associated ammunition, therefore the cost may vary depending on how the contract is authored. Estimated total cost for

[145] Gulfnews.com, *ADHB wins Dh100M contract*, Retrieved 07 November 2006 found on the World Wide Web at [http://archive.gulfnews.com/articles/02/01/23/38652.html].

operating three NEMO Watercats over a 10 year period is $5.8M (FY06). The estimated average yearly cost for three NEMO Watercats is $1.1M (FY06).

I. DEDICATED HELICOPTER SUPPORT

A three helicopter detachment can potentially provide 24 hour coverage (assuming a 24 hour mission) for the RF. HH-60R helicopters would increase the detection and engagement capability of the RF. The range of the HH-60 is approximately 445 nm without refueling. The HH-60R can be armed with two Hellfire missiles and two .50 cal machine guns[146].

The cost estimate for helicopter support operations consists of RDT&E and procurement, O&S for personnel, O&S for helicopter support, and O&S for equipment. The basis for this section of cost estimate stems from an informal study done at NECC on the required force structure size of a helicopter detachment assigned to support the riverine squadron. When considering equipment needed to support a helicopter detachment, it was assumed that the personnel would share the camp perimeter with the personnel at the TOC. Although the helicopter detachment is supplied with their own tents, generator, computers, and MRE's, they are not responsible for security measures, medical, and water supply.

1. Helicopter RDT&E and Procurement Costs

Procurement cost for the HH-60R is approximately $42.3M (FY06)[147]. SEA-10 assumed that 3 HH-60R helicopters will need to be purchased to support riverine operations based on reliability and operational availability requirements[148]. Although the CONOPS indicates that the helicopters will come from a standing squadron, the 10 year cost estimation time increment dictates that the cost of procurement of the helicopters be considered. SEA-10 modeled helicopters to increase the engagement capability of the RF through the use of Hellfire missiles and .50 caliber machine guns. The cost of Hellfire

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[146] Federation of American Scientists. *MH-60R*. Retrieved on 13 November 2006 from the World Wide Web at [http://www.fas.org/man/dod-101/sys/ac/sh-60.htm].

[147] The Library of Congress Thomas, Navy Aircraft. *MH-60 Multi-mission Helicopter*. Retrieved on 13 November 2006 from the World Wide Web at [http://thomas.loc.gov/cgi-bin/cpquery/?&sid=cp10823vD4&refer=&r_n=sr260.108&db_id=108&item=&sel=TOC_174886&]

[148] Riverine Group Initial Helicopter Study, Unpublished, 2006.

missiles was estimated from open source documents,[149] and SEA-10 assumed that each helicopter will carry two Hellfire missiles on each mission. Initially, 10 Hellfire II missiles were procured for RF operations, although SEA-10 recognizes that operations may require more than the initial load out. Only 10 Hellfire missiles were included for procurement to minimize the number of personnel needed for maintenance and support of the missiles.

2. Helicopter Operations and Support Costs

Operations and support costs were divided into three categories; O&S for operations, O&S for equipment and O&S for personnel. Operations and support costs for personnel include the number of people required to constitute the helicopter detachment according to the NECC study. Personnel costs include 12 pilots, 12 aircrew, and 15 maintenance support personnel. Training of personnel was not included in the cost estimate. Due to the large number of personnel, it was necessary to consider lodging, food, and workspace equipment as part of the operating and support cost for the helicopter detachments. Operations and support cost for helicopter specific operations were found on the VAMSOC website in the H-60 almanac[150]. Although the costs may not be exact for the HH-60 platform, they were suitable for this cost estimate. Operations and support cost for equipment were found in documents given to SEA-10 from NECC personnel. These documents were a draft of the original cost estimate for the RF and may not represent the exact equipment that was purchased for RIVRON ONE. Helicopter detachment personnel were supplied with outdoor equipment (tents, electrical generators, etc), computers for maintenance support and operations, and food. It is assumed that helicopter detachment personnel will be co-located with the TOC. The costs for water, electricity, security, sandbags and other equipage that could be shared with the TOC were not accounted for in this cost estimation.

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[149] Lockheed Press Release. *U.S. Army Awards Lockheed Martin $170 Million Contract for Hellfire II Missile Production*. Retrieved on 5 November 2006 from the World Wide Web at [http://www.missilesandfirecontrol.com/our_news/pressreleases/06pressrelease/Hellfire]

[150] Navy Visibility and Management of Operating and Support Costs, *HH-60 Alamanac*, Retrieved 05 November 2006 from the World Wide Web at [www.navyvamosc.com].

J. COST ESTIMATION SUMMARY AND RESULTS

This cost estimate was generated from open source information. It is not all inclusive and care should be taken to closely research the systems mentioned before any acquisition decisions are made. Care was taken to ensure that the alternative costs were inclusive of all equipment, platforms, and sensors that were modeled. Special attention was also paid toward the notional manpower required to support scenario patrol operations modeled.

The results in this section are derived only from cost. A more descriptive analysis of cost versus performance is described in the analysis section of this thesis. Decision makers should evaluate systems on their military application rather than solely on cost, because affordable systems do not necessarily have the greatest military application. Conversely, the most expensive force packages are not necessarily the best in terms of performance. Therefore, careful consideration must be taken before deciding or discarding a particular force package.

Average operating cost is the average cost of operating the system over 9 years (all non-procurement years). Table 16 is a summary of the baseline and alternative costs. Procurement cost is the total cost of procuring the system in 2010 (using FY06$), and is shown for each alternative as compared against the baseline in Figure 26. The total 10 year cost is the cost of procuring and operating the system, and is shown for each alternative as compared against the baseline in Figure 27. Detailed break down of these costs can be found in Appendix B.

Alternative	Description	Average Operating Cost per Year	Procurement Cost	Total 10 Year Cost
	Baseline	$16,305,235.33	$85,000,000.00	$263,540,834.07
I	UAV	$3,900,000.00	$36,000,000.00	$78,322,500.00
	USV	$262,648.96	$900,000.00	$3,765,300.42
	UGS	$379,883.49	$1,904,229.00	$7,958,908.25
II	Ground Combat Element	$735,832.79	$188,474.96	$8,033,641.23
III	Networked Sensor	$4,583,586.17	$45,013,784.24	$90,849,645.89
IV	Mortar Team	$103,240.20	$87,988.00	$1,204,532.83
V	Networked Mortar Team	$4,686,826.37	$45,101,772.24	$92,054,178.73
VI	NEMO	$1,145,538.09	$5,333,568.00	$17,311,600.67
VII	Networked NEMO	$5,729,124.26	$50,870,003.99	$108,161,246.57
VII	Helo	$3,892,040.96	$126,900,000.00	$169,712,450.52
	Helo without procurmeent	N/A	N/A	$42,812,450.52

Table 16. Procurement and Operating Costs for Baseline and Alternatives.

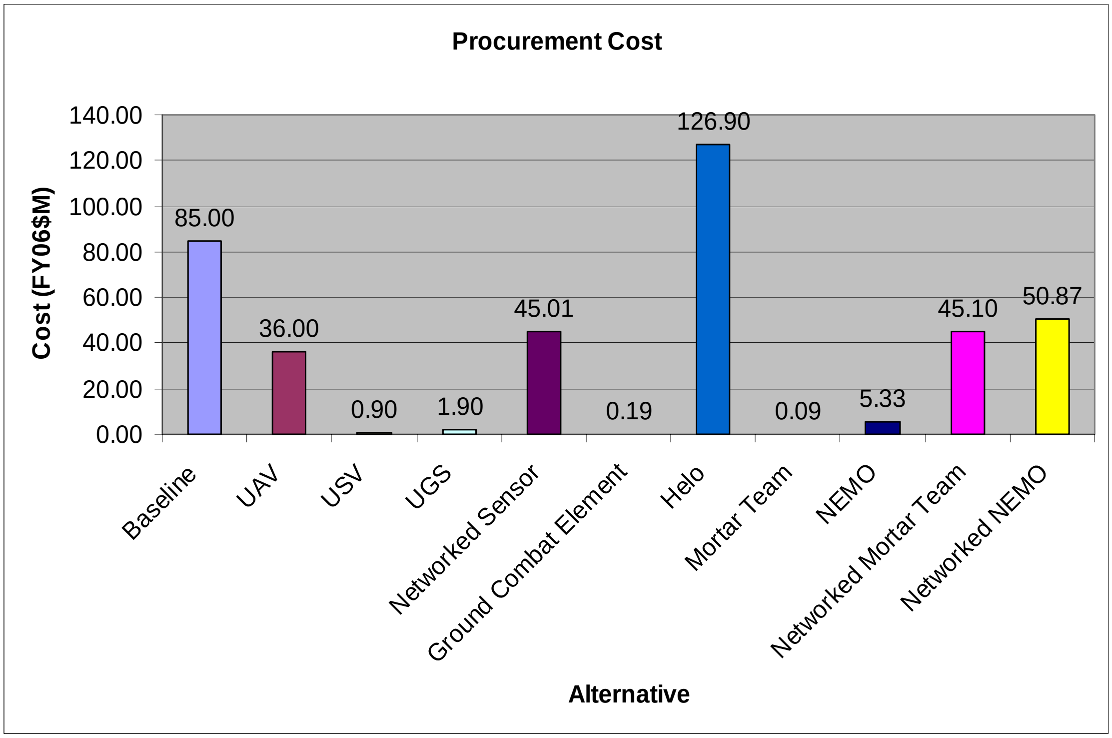

Figure 26. Procurement Costs of the Riverine Baseline and Alternatives.

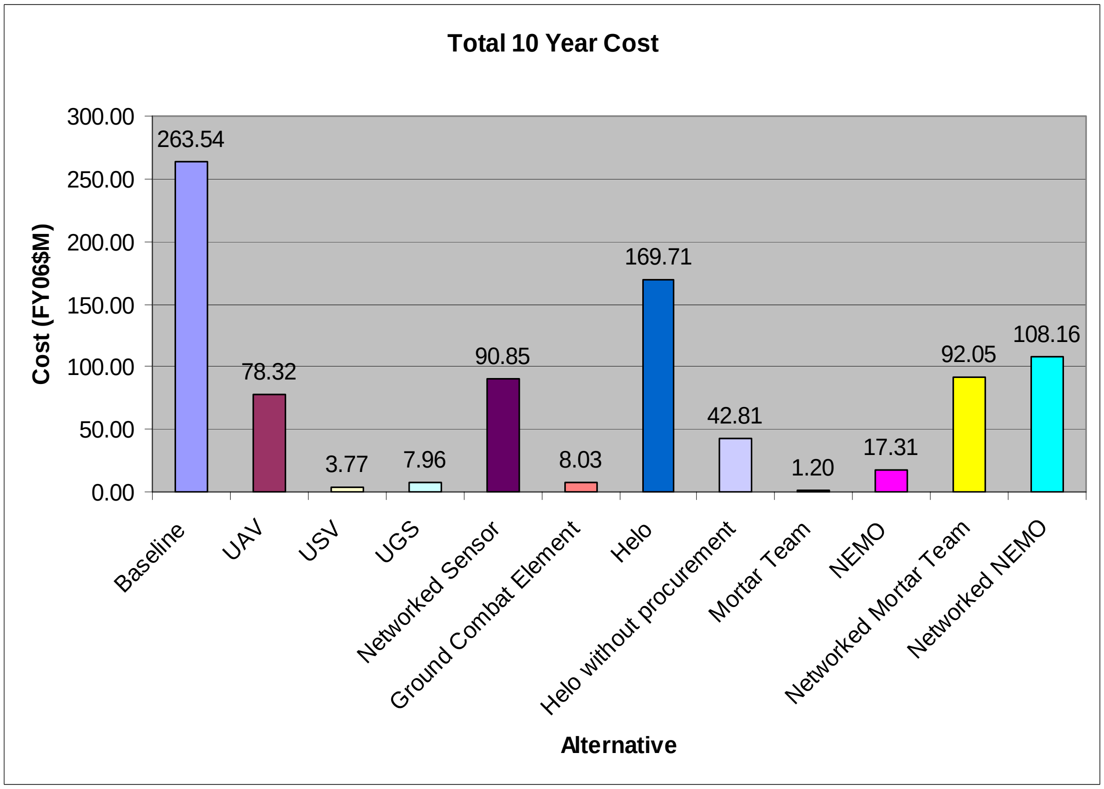

Figure 27. Total 10 Year Cost of Riverine Baseline and Alternatives.

The mortar team is the least expensive force package in terms of the procurement cost, annual operating cost and total cost. The most expensive force package alternative is the helicopter detachment in terms of total 10 year cost and procurement cost. The most expensive force package alternative in terms of annual operating cost is the networked mortar barge. Procurement cost is the driving factor in the total 10 year cost of the helicopter alternative. The helicopter 10 year operating cost is approximately 30% of the procurement cost which is inclusive of cost for personnel. If the helicopter is not procured then the networked mortar barge is the most expensive alternative in terms of total 10 year cost.

Figure 28 provides a further breakdown of the cost associated with networked sensors. Figure 29 includes the mortar team for the networked mortar team alternative. Figure 30 includes the cost of NEMO in the networked mortar barge alternative.

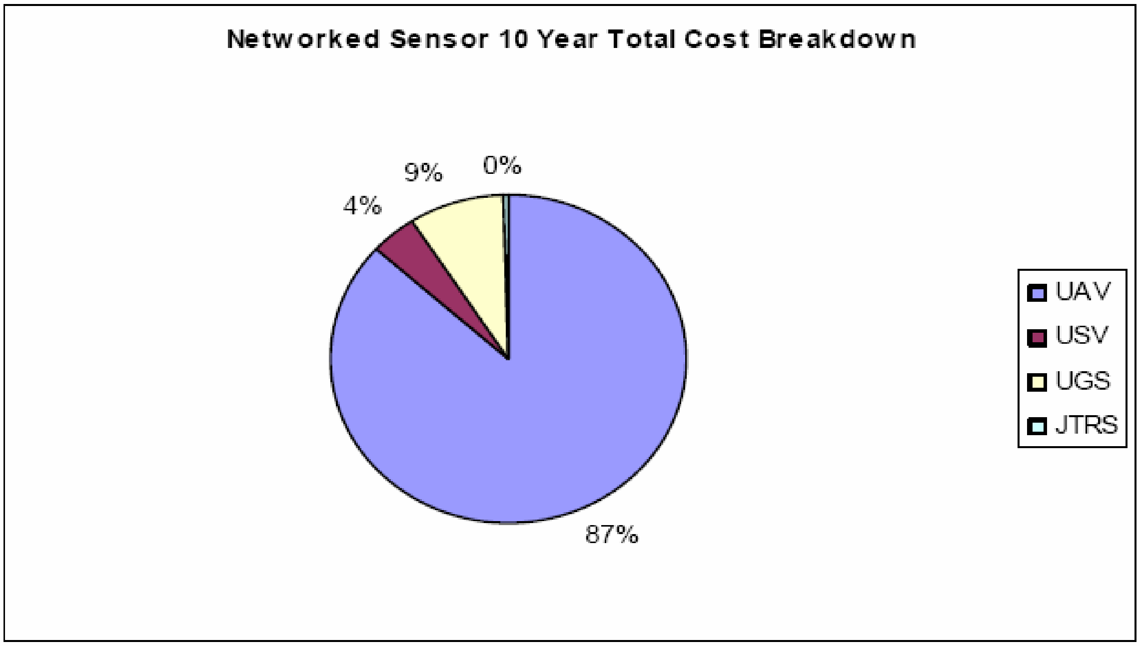

Figure 28. Networked Sensor 10 Year Cost Breakdown Per Sensor.

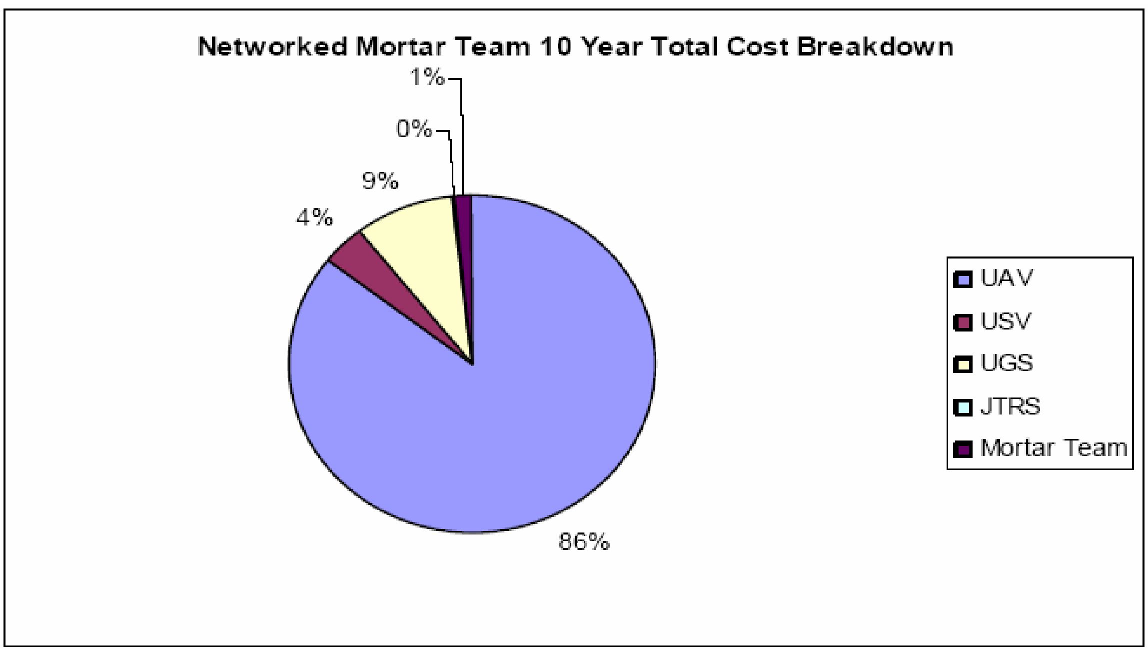

Figure 29. Networked Mortar Team Costs.

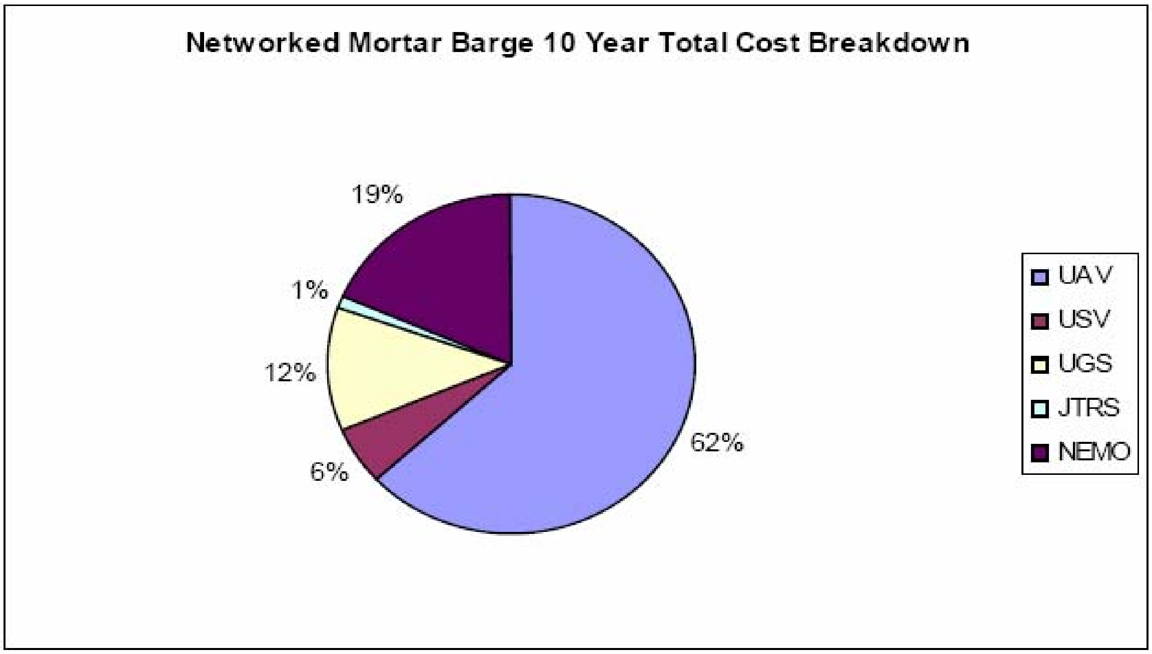

Figure 30. Networked Mortar Barge Costs.

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VII. RIVERINE SYSTEM RELIABILITY

A. SYSTEM RELIABILITY PURPOSE AND COMPONENTS

SEA-10 chose to evaluate the operational suitability component reliability from the RF system objective hierarchy. Reliability is critically important to the warfighter, yet not physically limiting like other elements of operational suitability such as transportability or supportability. SEA-10 conducted a qualitative analysis of RF component reliability because reliability on all components of the RF and proposed alternatives was not available at the time of this thesis. SEA-10 related reliability to availability and maintainability, other elements of operational suitability. Performance data on the alternatives generated in the physical architecture is limited, but hypothetical values and configurations shed insight into areas which may affect the RF of 2010. Further reliability study could be included in later quantitative analysis of RF performance.

1. Operational Availability

One of the primary functions of any military system is to go into harm's way and return man and machine intact and ready to fight again. Operational availability is the key component of combat readiness[151] and is the degree to which an item is in an operable state at the start of any given mission at any given time.[152] Operational availability is expressed as the expected value of system uptime divided by expected values of system uptime plus system down time, as shown in Equation 13.[153]

[151] **combat readiness —** Synonymous with operational readiness, with respect to missions or functions performed in combat. **operational readiness —** The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed. May be used in a general sense or to express a level or degree of readiness. *Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms*, Chairman, Joint Chiefs of Staff, 12 April 2001 (as amended through 14 April 2006).

[152] *Glossary of Defense Acquisition Acronyms and Terms*, 11th Edition, Defense Acquisition University Center for Program Management, Fort Belvoir, Virginia, 2003.

[153] Wikipedia. *Availability*. Retrieved 20 November 2006 from the World Wide Web at [http://en.wikipedia.org/wiki/Availability].

$$A_o = \frac{E[uptime]}{E[uptime] + E[downtime]}$$

Equation 13. Operational Availability

such that: E[uptime] = the expected value of system uptime

E[downtime] = the expected value of system downtime

SEA-10 reasoned that a system which performed well with respect to chosen MOE and MOP, but displayed poor operational availability, would be a poor choice from the standpoint of feasibility and cost versus performance. A system could contribute to the satisfaction of MOE and MOP if it was not available. Poor component or overall system availability required a large supply of components or systems as spares or replacements. A large supply of components and systems assured the minimum number of components required to complete the mission was available, but the system was overly expensive or required a large logistics support network.

Figure 31 demonstrates the connection between availability and maintaining the minimum number of “up” units for mission completion. If, in a hypothetical situation, SURC availability is 0.85 the probability of mission success increases as more SURC’s are available. This has serious implications for the RF. If a squadron deploys with 12 SURC, fielding a four SURC section is not an issue. However, as soon as two four SURC sections are required at the same time, availability becomes a much more serious consideration. This graph also did not account for any craft that may have been in a scheduled maintenance or overhaul period or in a maintenance status awaiting parts. It only accounted for the craft ready to go at the start of a patrol.

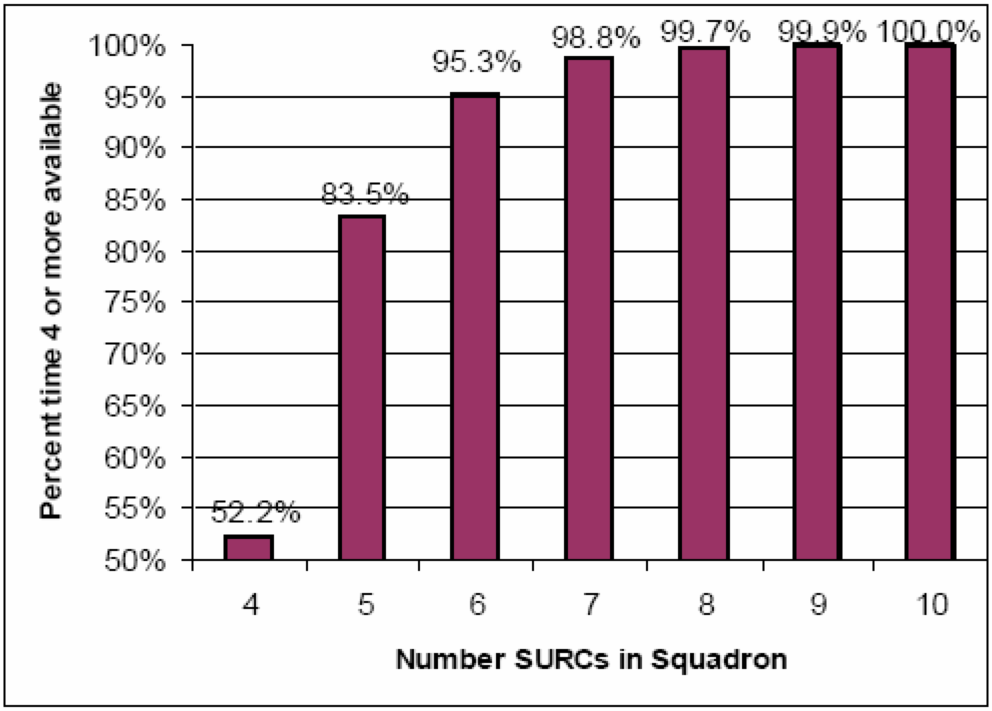

Figure 31. Effects of Number of Available SURC’s on Combat Readiness.

2. Maintainability

Maintenance is a critical component of availability. The ability of a unit to be maintained in, or restored to, a specified condition to enable operations is mission essential.[154] Mean Time to Repair (MTTR) is the total elapsed time for corrective maintenance divided by the total number of corrective maintenance actions during a given period of time. MTTR is a basic technical measure of maintainability.

3. Reliability

Another contributor to operational availability is reliability. Reliability is arguably more important to the warfighter because it is the most direct measure of system performance ability. Mean time between failures (MTBF) is the total time of system operation divided by the total number of failures during that time, as shown by Equation 14.[155]

[154] *Glossary of Defense Acquisition Acronyms and Terms*, 11th Edition, Defense Acquisition University Center for Program Management, Fort Belvoir, Virginia, 2003.

[155] Speaks, S. “*Reliability and MTBF Overview,*” Unpublished. Vicor Reliability Engineering, 2006.

$$\theta = \frac{T}{R}$$

Equation 14. Mean Time Between Failure.

such that : θ = MTBF

T = total time

R = number of failures

MTBF applies to time, rounds, miles, events, or other measures of unit life. Better system reliability translates into higher system availability, which can result in lower system costs and increased system performance.

4. System and Component Reliability

A system is only as strong as its weakest component. Cost versus performance trade offs occur during system design. These trade offs are often made to reduce weight, power requirements, and/or system cost, especially in unmanned systems. These decisions may affect the reliability of the components chosen and in turn overall system reliability. Incorrect trade off decisions are likely without a thorough understanding of how individual component reliability effects overall system reliability.

Technology advances and increasing operational requirements have caused systems to become more complex, and increased the number of individual components responsible for overall system operation. Series components rely on one another in a strict linear relationship. If one component fails, the system fails. Components arranged in series decrease the reliability of the system even if the individual components are highly reliable. A convenient shorthand method to describe highly reliable systems gives the number of "nines" in the reliability percentage. A component that experiences one failure in ten thousand cycles, time units, etc, has a 99.99% reliability or four nines reliability.[156] Table 17 demonstrates how individual component quality affects a series system.

[156] Unmanned Aerial Vehicle Study, Office of the Secretary of Defense, February 2003.

Individual Component Quality	Total Number of Series Components in the System	System Reliability
Four Nines (99.99%)	10	Three Nines (99.90%)
	100	Two Nines (99.00%)
	1000	One Nine (90.48%)
Five Nines (99.999%)	10	Four Nines (99.990%)
	100	Three Nines (99.900%)
	1000	Two Nines (99.005%)
Six Nines (99.9999%)	10	Five Nines (99.9990%)
	100	Four Nines (99.9900%)
	1000	Three Nines (99.9001%)

Table 17. Effect of Individual Component Quality on a Series System[157]

5. Mean Time Between Failure

As discussed above, the basic technical measure of reliability for most military systems is MTBF. MTBF was directly related to maintainability, operational availability, and therefore combat readiness and mission accomplishment as shown by Equation 15. Equation 15 was a restatement of equation 13 using MTBF as a surrogate for E[uptime] and MTTR as a surrogate for E[downtime].

$$A_o = \frac{MTBF}{MTBF + MTTR}$$

Equation 15. Operational Availability and MTBF.

such that : MTBF = mean time between failure

MTTR = mean time to repair

and the overall reliability of system or component over time (R(t)) is given by[158]:

$$R(t) = e^{(-t/MTBF)}$$

Equation 16. System Reliability Over Time.

such that: R(t) = reliability as a function of time

t = elapsed (mission) time

MTBF = mean time between failure

[157] Unmanned Aerial Vehicle Study, Office of the Secretary of Defense, February 2003.

[158] S. Speaks, "*Reliability and MTBF Overview,*" Unpublished. Vicor Reliability Engineering, 2006.

MTBF is a statistical measure of a population and is subject to the central limit theorem of statistics. As the sample size gets larger the sample mean approaches a normal distribution about the true population mean. Therefore, for a given MTBF, a single component or system will not necessarily fail 50% of the time at the given MTBF. Rather, the average failure time for the overall population, will occur at MTBF. The distinction is subtle, but important.

Figure 32 illustrates that for a typical RF mission of 10 hours, 90% reliability is achieved by an overall system MTBF of 100 hours. SEA-10 assumed that the probability of successful mission completion is equivalent to the system's reliability. The mission will succeed if there are no critical failures, and therefore system reliability becomes equivalent to the probability of mission success.

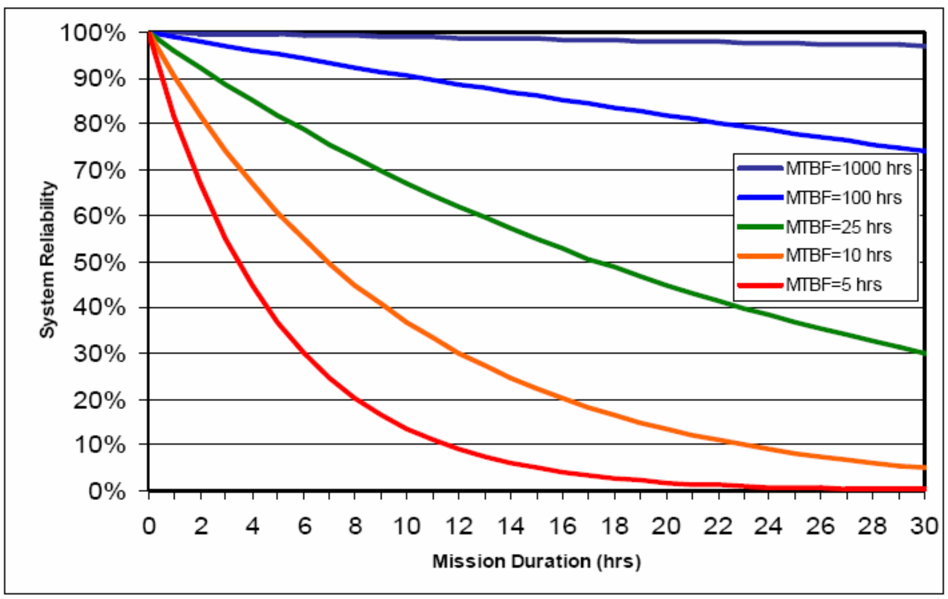

Figure 32. System Reliability Vs. Mission Duration for Selected MTBF.

When required, MTBF was determined for a given reliability by taking the natural logarithm of equation three, multiplying by "1/-t" and inverting both sides of the resulting equation to yield Equation 17.

$$MTBF = \frac{-t}{\ln(R(t))}$$

Equation 17. Mean Time Between Failure for a Given Reliability.

For example, if a mission success probability of 95% is desired and the system has a 95% reliability over a 10 hour mission, then the mean time between (critical system) failure must be 195 hours.

6. System Reliability Block Diagram

A system reliability block diagram is an excellent tool to model overall system reliability. The networked riverine system was modeled as a built-up-series/*k of n* parallel system. The block diagram is shown in Figure 33.

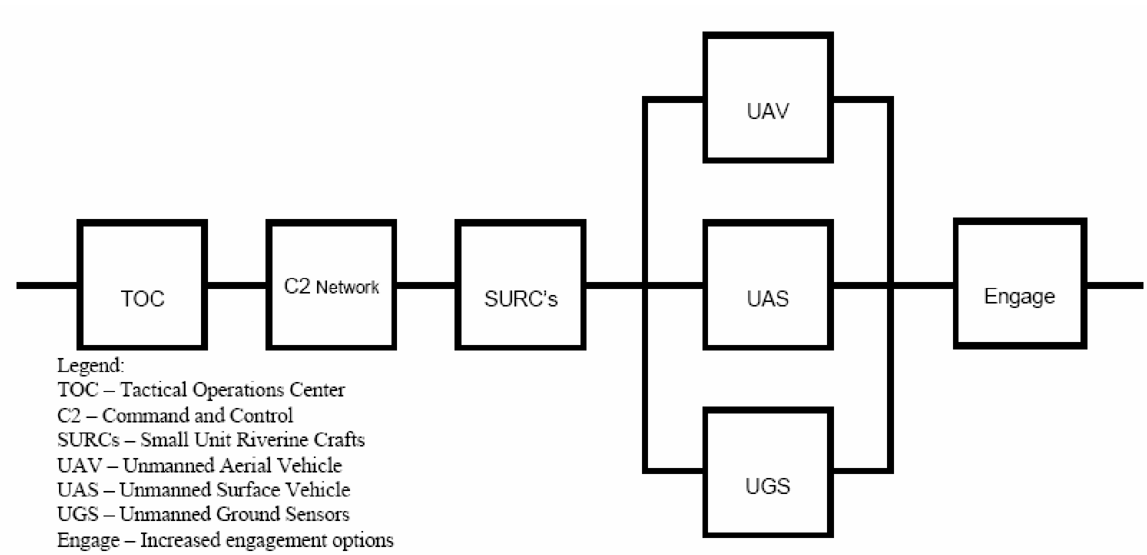

Figure 33. Networked Riverine System Reliability Block Diagram.

7. SURC Reliability

SEA-10 information searches and interviews with stakeholders indicate that the SURC is a reliable platform[159]. Actual reliability data for SURC combat performance was not available, but SEA-10 made an analogy from operational tests (OT) of the Naval Special Warfare (NSW) 11 meter rigid hull inflatable boat (RHIB). The 11 meter NSW RHIB is a high speed, diesel/water jet powered craft similar in size, capabilities, and equipment to the SURC. The 11 meter NSW RHIB showed 0.91 reliability in OT[160].

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159 Marine Corps Center for Lessons Learned. *Small Craft Company's Deployment in Support of OPERATION IRAQI FREEDOM II (OIF II). A summary of lessons and observations.* 4 April 2006.

160 Federation Of American Scientists. Rigid Hull Inflatable Boat (RIB). Retrieved form the World Wide Web 10 November, 2006. [http://www.fas.org/man/dod-101/sys/ship/rhib.htm]

SURC's were modeled as a 3 of 4 parallel system as shown in Figure 34. Reliability for SURC mission success was calculated through Equation 18.[161] SURC system reliability was calculated as 0.957.

$$R_s = \sum_{i=k}^{n} \binom{n}{i} R^{i} (1-R)^{n-i} (Binomial)$$

Equation 18. SURC Reliability

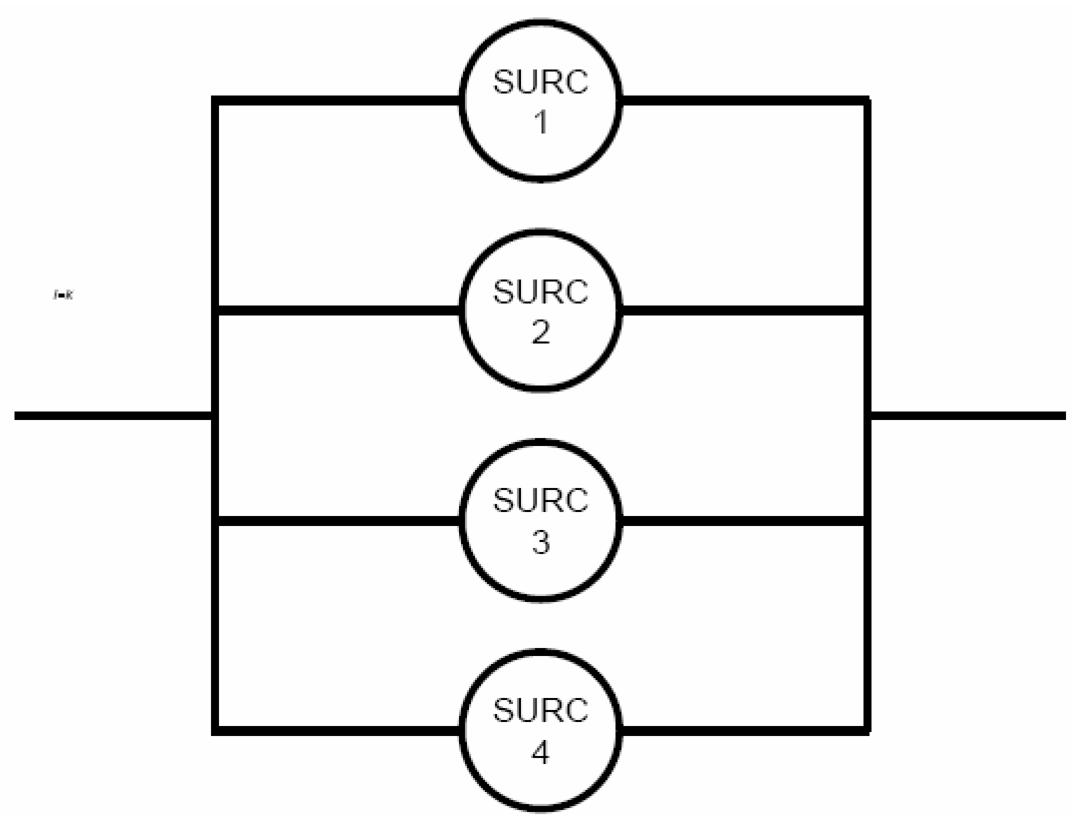

Figure 34. SURC Parallel 3 of 4 Reliability Block Diagram.

8. SEA-9 (MTR) Small Boat Availability Model Applied to SURC

Reliability and operational availability data for the SURC was analogous to the NSW 11-m RHIB. The estimated SURC operational data is listed in Table 18. SEA 9 developed an effective model using EXTEND for calculating reliability which SEA-10 modified for this study.

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[161] D. Schiffman, Commander, USN. *OS4580, Logistics Systmes Analysis class notes, Chapter 3, Reliability, Availability and Maintainability.* Naval Postgraduate School, October 2006.

Reliability	0.91
Availability	0.99
Range (nm)	250
Cruise Speed (knots)	35

Table 18. SURC Operational Data. [162]

Dividing cruise speed by the operational range at cruise speed yields an operational cruise time of approximately 7.14 hours. This is assumed to be the period over which reliability for the SURC is measured. Reliability is defined as: $R(t) = e^{(-t/\lambda)}$, where t is time in hours, λ is the number of failures per hour. Setting t = 7.14 hours and R(7.14) = .91 for the SURC, then solving for λ, yields .0132 failures per operational hour. The reciprocal of this (1/ λ) = 75.7 operating hours until failure (approximately).

$$R(t) = e^{(-t/\lambda)}$$
$$.91 = e^{(-7.14/\lambda)}$$
$$\lambda = \frac{-7.14}{\ln(.91)} = 0.0132$$
$$\frac{1}{\lambda} = 75.7$$

Equation 19. SURC Operational Time Until Failure (hours).

A rounded value of 76 was inputed into the Extend SURC Reliability Model as the expected amount of time a SURC operates until failure. This model can be viewed as Appendix D. The operational life of each SURC is unknown; some of the vessels will require repairs sooner than others. [163] A uniform distribution of SURC operational "life" was used to represent a generally random distribution, with no specific mean about which the SURCs lifetime would fall about a standard deviation. SURC's have an equal probability of failure anytime within a 76 hour period.

Once "broken," the SURC is removed from the pool of SURC's in use and returned to the TOC, or maintenance facility. A major potential limitation of the RF is the number of available depot level repair facilities. Although enough civilian small boat

[162] Federation of American Scientists, "Rigid-hull Inflatable Boat." [http://www.fas.org/man/dod-101/sys/ship/SURC.htm] 10 February 2000, accessed November 2006

[163] Operational life of a SURC refers to the age of the SURC's components in terms of requiring major service and/or replacement.

repair facilities may exist within the operational theater, they may or may not be available for repairs. A triangular distribution is used to determine the amount of time to repair and return the SURC to operation. Within the triangular distribution, a minimum value of 3 days, maximum value of 7 days, and most likely value of 5 days was used. These times include the time it would take to receive replacement parts at the relatively remote TOC, conduct repairs and maintenance, and return the SURC to an operational pool.

The model was iterated 100 times for 360 hours; representing 15 days within a deployment. SURC's were assumed to be operated in 4 man sections, rotating every 12 hours. Reliability was calculated using divisions of 12, 14, 16, 18 and 20 boats.

The current baseline concept of operations offers approximately a 75 percent chance of being able to field 4 operational SURC's after 360 hours. 16 SURC's, at a minimum, are required to achieve an operational availability greater than 90 percent as indicated in Figure 35.

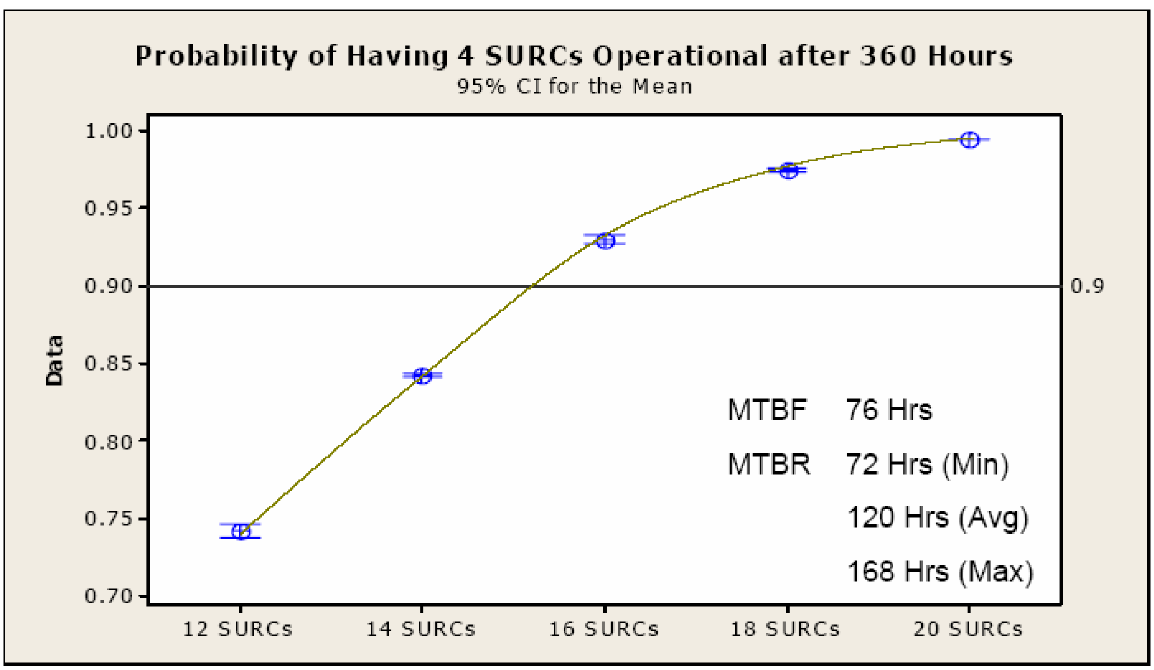

Figure 35. SURC Operational Probability after 360 Hours.

The model is heavily impacted by repair times, number of operationally required vessels, and reliability. A modification to any of these values would warrant further modeling. For instance; if the TOC could be given depot level resources to conduct repairs or if civilian repair facilities were readily available the probability would increase as it appears to have an inverse relationship to MTBR.

9. UAV, USV, and UGS Reliability

The UAV, USV and UGS reliability was modeled as a series system as shown in Figure 36. USV reliability was modeled identically to the UAV except that instead of an airframe, the USV has a hull.

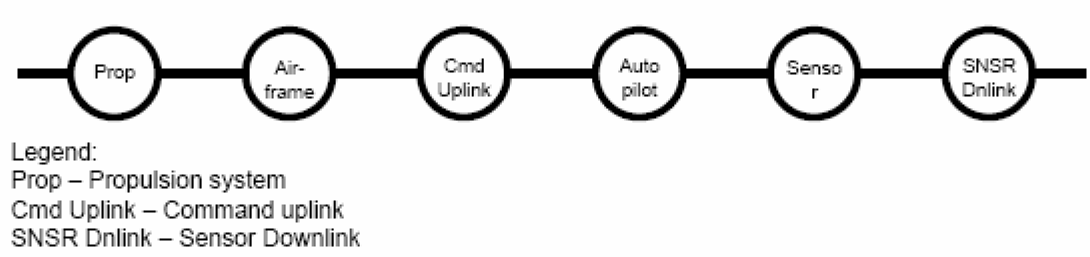

Figure 36. UAV Reliability Block Diagram.

> *The UAV systems project office at Redstone Arsenal, AL conducted a reliability, availability, and maintainability initial operational test assessment [of the RQ-7 Shadow UAV] based on two weeks of flights in an operational environment. The results from this limited flight test data indicate a Mean Time Between System Abort (MTBSA) of 26.9 hours.*[164].

SEA-10 assumed MTBSA was a system failure causing a mission failure and for the purposes of this thesis a surrogate for MTBF. SEA-10 used Equation 15 to determine Shadow reliability as 0.64. However, there will be at least three UAV airframes available at the TOC. If one failed another could be launched. Therefore, UAV reliability became a parallel system with 95.7% reliability.

Discussions with the manufacturer of the SeaFox USV yielded a potential 93% reliability based on limited data[165]. UGS is a mature and reliable system. The main reliability variable is placement. Improper placement could cause UGS units to malfunction or operate in a degraded capacity[166]. The reliability of the UGS was assumed to be 0.90, a slight improvement on the operational requirement of 0.88

[164] Unmanned Aerial Vehicle Study, Office of the Secretary of Defense, February 2003.

[165] Telephone Interview between Mr. Bruce Reagan, President of Northwind Marine Inc., and the author, October 10, 2006.

[166] Operational Requirements Document (ORD) for the Improved Remotely Monitored Battlefield Sensor System (IREMBASS), August 1999.

reliability for the older IREMBASS UGS.[167] Taken together as a two of three parallel system, the unmanned sensor system had a calculated reliability of 0.97 using Equation 18.

B. CONCLUSION

Reliability is a critical factor in achieving the expected performance of the force packages. All of the alternative force packages addressed in this thesis are complex systems that depend on all of their components to function when required. Failure of one of the components could lead to a complete failure of the system and degrade the operational robustness of the force. If the operator cannot depend on the system to work as it is designed or when it is needed, then the system will not be trusted and consequently will not be used by the war fighter. False confidence is another consequence of poor reliability. A commander may assume that the force has the systems' capabilities, but if the system is unreliable, it may fail at the critical moment of need. High system reliability increases the robustness of the force. A commander that has reliable systems will be able to conduct a larger variety of missions. In a riverine environment, the missions will continually change, and new problems will present themselves to the war fighters. Strong reliability of the systems will allow the commander to employ them in a variety of missions. In conclusion, without highly reliable systems, the alternative force packages will be of limited use to the war fighter and would increase the risk of the operations.

[167] Operational Requirements Document (ORD) for the Improved Remotely Monitored Battlefield Sensor System (IREMBASS), August 1999.

VIII. ANALYSIS, RESULTS, AND CONCLUSIONS

A. ANALYSIS PURPOSE AND COMPONENTS

SEA-10's goal for modeling and analysis was to answer the following questions:

- How does the Navy effectively perform riverine missions while minimizing risks to the force, i.e., what investments yield the "Most bang for the buck"?
- Which alternatives give the greatest capability increase to the baseline force?
- What is the effect of unmanned systems on detection and engagement?
- What is the effect of an organic indirect engagement capability?
- What is the effect of a dedicated ground combat element on detection and engagement capabilities?
- What are the effects of dedicated helicopter support?
- Which investment, increasing engagement or detection capability, has the greatest effect on overall system performance?

Modeling and analysis of the riverine system was based on comparisons between the baseline force and the baseline force augmented by previously described force package alternative architectures. Each alternative was formulated to satisfy RF objectives by increasing detection or engagement capability or both. Out of the five alternatives originally planned for analysis, there were three versions of the single unmanned sensor, non-networked versions of a mortar team and mortar barge, and versions for a networked mortar team and barge. These extra versions of the original five alternatives led to eleven distinct alternatives modeled over thirty runs (for each alternative) in two separate scenarios. Five measures of performance (MOP) were gathered from each run for a total of 3300 (11 alternatives X 2 two scenarios X 5 five MOP's X 30 modeling runs) data points for analysis. The analysis was limited by the number of alternatives and scenarios modeled, the number of MOP's captured, the number of runs per alternative/scenario combination, and the limitations of MANA.

SEA-10 conducted three different levels of data analysis. Initially, only the means were examined to evaluate alternative performance. Alternatives were analyzed for overall performance and cost in order to determine which provided the most "bang for the buck." Data was collected and normalized in order to weight and rank alternatives.

Weights were assigned to alternatives based on stakeholder feedback. Second, sensitivity analysis was conducted to determine the effects weighting the alternatives had on overall rankings. Analysis of variance (ANOVA) was used to determine if significant differences existed between alternatives. A non-parametric statistical tool, Kruskal-Wallis, was used in the event that the data assumed a non-normal distribution. MINITAB, a statistical analysis application, was used to conduct both mean comparison and Kruskal-Wallis tests.

B. REVISED MEASURES OF PERFORMANCE

Measures of Effectiveness (MOE) were derived from the objectives hierarchy and were a critical part of the riverine functional architecture. MOE were quantified by capturing measures of performance (MOP) for each MOEs. Table 19 represents the MOEs and MOPs that were initially chosen to fulfill the objectives hierarchy.

.

Objective	Measure of Effectiveness	Measure of Performance
Increase Battlespace Awareness	Increase Detection Capability	Time of Detection
	Increase Sensor Range	Range of Detection
	Increase Sensor Performance	Proportion of enemies detected
	Increase number and types of Sensors	
Increase Situational Responsiveness	Increase Engagement Capability	Range at Engagement
	Increase Weapons Range	
	Increase Weapons Lethality	Time of Engagement
	Increase number and types of Weapons	
	Overall System Performance	Loss Exchange Ratio

Table 19. RF Objectives, Measures of Effectiveness, and Measures of Performance.

Due to the capabilities and limitations of MANA, it became necessary to modify the initial MOP's because the data that best represented particular MOE's was unavailable, incomplete, or not applicable to the chosen scenarios. For example, information derived from loss exchange ratio was not truly indicative of each alternative's overall combat effectiveness because loss exchange ratio was only calculated when blue forces sustained damage. In runs where blue forces completely destroyed red forces, yet sustained no damage, loss exchange ratio numbers were skewed. Therefore, percentage of no hit runs was added to the value of loss exchange ratio to obtain a value more indicative of each alternative's battle space awareness and response capability. Detailed explanations of the equations used to derive MOP values are discussed later in this section.

Proportion of enemies detected was not an applicable MOP because of the agents' pre-programmed behavioral traits. Sensor search properties were arbitrarily programmed into MANA, and did not yield variable detection ranges. MANA only reported detection range as the range to the sensor, not to the entire force. Agents were motivated to seek each other out, and red agents were grouped in a common area in both scenarios, so once a single red agent was discovered, the remaining red forces were discovered nearby. Since neither of the two scenarios involved search algorithms, this MOP was not applicable.

Range at Engagement is a valid MOP that would have been of great value to this thesis. MANA, however, did not produce this data point as raw data, and SEA-10 was unable to devise an effective method to calculate it from other values. Instead, time from first detection to time of first engagement was added as an MOP to capture the time blue forces had to make decisions on how to engage red forces. If range at engagement had been captured, the misleading scores for the helicopter and networked mortar barge may have been averted.

Length of engagement was added as a measure of performance to assign values for weapons' lethality. In retrospect, this MOP contained a number of confounding factors that could not be attributed directly to weapons' effectiveness. Therefore, length of engagement was weighted lower than the other MOP's in the normalization and ranking of alternatives discussed later in this section. Table 20 illustrates the changes made to initial MOP's and the motivations behind the changes.

Origional MOP	New MOP	Reason
Loss Exchange Ratio	**Percentage of No Hit runs/Loss Exchange ratio**	More complete data
Maximum Classification Range	No Change	No Change
Proportion of Enemies Detected	No Change	Not applicable to scenarios
Range at Engagement	**Time from Detection to Engagement**	Modeling Limitation
Time of Engagement		
No Corresponding Origional MOP	**Length of Engagement**	Measure of Weapons' lethality
Time of First Detection	No Change	No Change

Table 20. Revised Measures of Performance.

1. Percentage of No Hit runs/Loss Exchange ratio

Percentage of no hit runs was the percentage of runs blue agents sustained no damage (out of all runs). Loss exchange ratio was calculated by dividing the total number of red agents killed by the total number of dead and injured blue agents. Injuries were scored as partial kills because SURC armor was modeled to absorb hits and that a blue agent had a 0.65 chance of being hit while on a SURC (based on SURC armor and cover/concealment discussed previously).[168] A high value in both of these responses is desirable and indicates a robust engagement capability. SEA-10's loss exchange ratio is shown in Equation 19:

$$\text{Loss Exchange Ratio} = R_{killed} / (\sum B_{killed} + (\sum B_{injured}).65)$$

Equation 20. Loss Exchange Ratio.

[168] As previously described on page 93.

2. Time to First Enemy Detection

Time to first enemy detection was calculated as the first time step that blue forces detected and identified red agents as enemy. SEA-10 used this measure to determine sensor range and performance. A smaller value in this response is desirable.

3. Time from Detection to Engagement

Time from detection to engagement is a measure of the time it takes an agent to engage after first detection and identification of the enemy. Comparison of this data point against the baseline and alternative force packages indicates which capabilities provide an increase in battle space awareness. A larger value in this response is desirable, except for alternatives that pair sensor and indirect fire weapons. Pairing remote detection and indirect engagement capabilities enabled nearly instantaneous engagement of enemy forces. Agents were programmed to engage one another as soon as classification occurred. MANA enabled both helicopter support and the networked mortar barge options to engage as soon as a classification took place due to the stand off range of their weapons. Their weapons were able to engage the enemy almost instantly from the same distance as enemy detection. Therefore, the smaller value for Detect to Engage time for the helicopter and indirect fire mortar barge is favorable. In reality, this stand off range would create time to evaluate the battlespace and decide upon the appropriate action. This value was calculated by subtracting first detection time from first enemy engagement.

4. Length of Engagement

The intent of measuring Length of Engagement was to relate the lethality or effectiveness of the weapons in an alternative. A short engagement time indicates that the opposing force was overwhelmed by fire. Length of engagement was calculated from the first shot fired by either red or blue agents until all red forces were killed, all blue forces were killed, or the simulation run time ended. Runs where all blue agents were killed were removed from the data since they do not represent blue force lethality or weapons effectiveness. Of the 660 runs there were only 3 runs (0.5%) where all blue agents were killed, and therefore they were not considered statistically significant. A low or high value could be desirable due to the differences in the alternatives modeled. For example, the powerful area weapon of the networked mortar barge had an extremely short length of engagement and resulted in all red agents killed. However, the GCE also killed all red agents with few blue agent losses, but the reduced lethality (as compared to the mortars) of blue force weapons lengthened the engagement.

5. Maximum Classification Range

Maximum classification range is the maximum range at which an agent may confirm another agent's identity. It does measure the range between the classifying agent and the main force. It is the maximum range an agent can identify another agent without combining multiple sensors. This response is used as a measure of sensor performance. It is important to note that this value was not the range at first enemy detection, but rather, it was the maximum range of detection and identification that an individual sensor was capable of during a given run. A larger value in this response is desirable.

C. DATA NORMALIZATION

A comparison of the responses was conducted by normalizing the raw data gathered from MANA output. Data had to be normalized to a common factor because of the difference in units among responses and because of the categorization of the responses by scenario. All responses, except for percentage of no hit runs and loss exchange ratio, were derived from more than a single data point. Once the values were normalized, the alternative force packages were ranked in order from highest to lowest and were compared against one another to determine the overall best alternative by response and scenario as shown in Table 21 and Table 22.

PATROL						
MOP Alternative	PERCENT OF NO HIT RUNS	LOSS EXCHANGE RATIO (RED/BLUE)	LENGTH OF ENGAGEMENT (IN MIN)	MAX CLASSIFICATION RANGE (GRIDS)	EARLIEST DETECTION TIME (IN MIN)	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT (IN MIN)
Baseline	3%	8.9	3.5	19.6	56.8	0.0
UAV	0%	12.1	21.5	17.9	26.0	20.0
USV	3%	9.6	22.2	126.3	23.8	18.4
UGS	0%	9.9	16.1	17.9	25.3	24.4
UAV+USV+UGS	0%	11.1	10.6	125.7	21.5	23.9
GCE	13%	10.7	4.3	19.9	50.6	0.0
HH60	97%	7.7	9.2	154.8	21.1	0.0
MORTAR TM	3%	8.4	2.2	19.3	41.1	0.0
MORTAR BARGE	7%	8.9	3.5	19.4	56.2	-0.2
NW MORTAR TM	3%	11.4	30.1	123.3	15.5	26.7
NW MORTAR BARGE	87%	11.8	12.7	123.1	23.6	1.9

Table 21. Patrol Scenario Raw Data Matrix.

AMBUSH						
MOP Alternative	PERCENT OF NO HIT RUNS	LOSS EXCHANGE RATIO	LENGTH OF ENGAGEMENT (IN MIN)	MAX CLASSIFICATION RANGE (GRIDS)	EARLIEST DETECTION TIME (IN MIN)	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT (IN MIN)
Baseline	0%	4.6	13.6	19.8	20.5	-0.3
UAV	0%	19.3	53.5	20.1	13.4	10.1
USV	0%	9.6	20.6	155.8	7.0	14.9
UGS	3%	5.3	11.4	20.0	19.6	0.7
UAV+USV+UGS	0%	6.8	21.0	156.0	7.1	13.0
GCE	0%	12.5	36.4	20.0	27.6	0.0
HH60	80%	26.0	23.2	153.9	4.0	1.6
MORTAR TM	0%	6.0	3.5	20.0	20.4	0.0
MORTAR BARGE	0%	6.0	5.0	20.0	20.5	0.0
NW MORTAR TM	0%	5.3	15.9	155.6	7.1	12.8
NW MORTAR BARGE	20%	22.7	16.2	155.8	7.1	1.9

Table 22. Ambush Scenario Raw Data Matrix.

Data was normalized to facilitate an even comparison of the alternative force packages against the baseline and each other. Once the scores for each response were calculated, the alternatives were ranked from highest to lowest. Within each response, the highest ranking score was assigned a value of 100 while the lowest ranking score was assigned a value of zero. Alternatives with scores between the high and low values were calculated by linear interpolation. Calculating the response value and then normalizing it depended on whether or not a high or low value was considered desirable. In responses where a high value was desirable (length of engagement and maximum classification range) Equation 20 was used.

$$\left(\frac{AlternativeData - MinDataValue}{MaxDataValue - MinDataValue}\right) \bullet 100$$

Equation 21. High Response Value Equation.

For responses where a low value was desirable (Earliest Detection Time and Time from First Detection to First Engagement) Equation 21 was used:

$$\left(\frac{MaxDataValue - AlternativeData}{MaxDataValue - MinDataValue}\right) \bullet 100$$

Equation 22. Low Response Value Equation.

Normalization for the percentage of no hit runs and loss exchange ratio responses was conducted by multiplying the scores of each response by a weighting factor and adding them together. Percentage of no hit runs was weighted at 75% of the total score while the weight for the loss exchange ratio was 25%, and is shown in Equation 22 as the value X.

$$X=(.75)\bullet\left[\left(PercentageOfNohitRuns\right)\bullet 100\right]+(.25)\bullet\left[\left(\frac{AlternativeData-MinDataValue}{MaxDataValue-MinDataValue}\right)\bullet 100\right]$$

Equation 23. Percentage of No Hit Runs and Loss Exchange Ratio Normalization Equation.

This weighting scheme emphasizes the significance placed on alternatives that allow blue forces to dominate the battle space. The best performance indicators of battle space awareness and response capability, regardless of scenario, were the ability to engage the enemy with no casualties and no hits.

1. Response Weighting

Once the values in the raw data matrix were normalized by scenario, as shown in Table 23 and 24, stakeholder input was used to determine the global weights, or relative importance, for each response. As discussed earlier, specific responses provided suspect data because of the modeling dynamics required to simulate certain functions such as mortar team deployment and ground combat element debarkation. As a result, responses such as maximum classification range and time from detection to engagement are not true measures of alternative architecture performance. For example, the maximum classification range response was recorded as the range from the classified agent to detecting agent. In the case of the UAV, maximum classification range was from the UAV to the red forces rather than from the red forces to the blue forces (in the boats). The same phenomena occurred with the USV, UGS and all of the networked sensor options. Consequently, the response of maximum classification range was removed from consideration in the overall performance scoring, because it did not truly represent overall system performance.

A second discrepancy with data collection was found in the response of Time from First Detection to Time of First Engagement. In this case, the detection capabilities of the helicopter and the networked mortar barge were equivalent to their engagement capability. Since the agents were designed to engage upon enemy detection, both alternatives engaged as soon as the red forces were detected. A true measure of decision time could not be derived in these two alternatives because of this pre-programmed agent behavior. Although detect to engage was not an accurate indicator of performance for the helicopter and networked mortar barge, it provided too much insight with respect to the remaining alternatives to discard.

PATROL	NORMALIZED				
MOP Alternative	PERCENT OF NO HIT RUNS/LOSS EXCHANGE RATIO (RED/BLUE)	LENGTH OF ENGAGEMENT	MAX CLASSIFICATION RANGE	EARLIEST DETECTION TIME	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT
Baseline	6	95	1	0	1
UAV	25	31	0	75	75
USV	11	28	79	80	69
UGS	10	50	0	76	92
UAV+USV+UGS	18	70	79	85	90
GCE	26	92	1	15	1
HH60	68	75	100	87	1
MORTAR TM	2	100	1	38	1
MORTAR BARGE	8	95	1	2	0
NW MORTAR TM	23	0	77	100	100
NW MORTAR BARGE	88	62	77	80	8

Table 23. Patrol Scenario Normalized Data Matrix.

AMBUSH	NORMALIZED				
MOP Alternative	PERCENT OF NO HIT RUNS/LOSS EXCHANGE RATIO (RED/BLUE)	LENGTH OF ENGAGEMENT	MAX CLASSIFICATION RANGE	EARLIEST DETECTION TIME	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT
Baseline	0	80	0	30	0
UAV	17	0	0	60	68
USV	6	66	100	87	100
UGS	3	84	0	34	7
UAV+USV+UGS	3	65	100	87	87
GCE	9	34	0	0	2
HH60	85	61	99	100	13
MORTAR TM	2	100	0	31	2
MORTAR BARGE	2	97	0	30	2
NW MORTAR TM	1	75	100	87	86
NW MORTAR BARGE	36	75	100	87	14

Table 24. Ambush Scenario Normalized Data Matrix.

The remaining responses were then weighted by importance to the stakeholder. Response weighting was based on interviews conducted with small boat operators, Marine Corps personnel with riverine experience in Colombia, and other NPS Students with river combat experience. Operators were presented with the opportunity to rank the following responses in order of importance to them:

- Loss Exchange Ratio
- Length of Engagement
- Earliest Detection Time
- Time from First Detection to First Engagement

All of the operators chose Earliest Detection Time as their top priority when placed in a combat scenario. In the operator comments of the survey, one operator stated that the ability to know the location of the enemy would enable him to get inside the enemy's decision loop and take the initiative in battle rather than having to remain on the defensive. The response of percentage of no hit runs/loss exchange ratio and time from detection to engagement ranked second and third, respectively. Both responses are worthy indicators of battle space awareness and combat capability. Length of engagement ranked last as a measure of performance by the operators. Operator comments for length of engagement indicated that variation in this response may be caused by multiple confounding factors. Therefore, attributing the value of this response solely to weapons effectiveness/lethality was not a very accurate method for representing weapon lethality. Averaging the weights assigned to the aforementioned responses resulted in the global weight assignments shown in Table 25.

PERCENTAGE OF NO HIT RUNS/LOSS EXCHANGE RATIO	0.3
LENGTH OF ENGAGEMENT	0.1
TIME TO FIRST ENEMY DETECTION	0.4
TIME FROM DETECTION TO ENGAGEMENT	0.2

Table 25. Assigned Global Weights by Response.

2. Normalized Decision Matrices

Once global weights were established three decision matrices were constructed. A normalized decision matrix for each scenario was generated, as well as an overall decision matrix that encompassed overall performance as shown in Tables 26, 27, and 28.

These matrices represent the modeling and simulation results that were normalized and weighted to determine a total utility score. A utility score acts as a common denominator by which all alternatives can be compared against one another. Each alternative's utility score was used to rank the alternative architecture within and across the scenarios.

PATROL					
MOP Alternative	PERCENT OF NO HIT RUNS/LOSS EXCHANGE RATIO	LENGTH OF ENGAGEMENT	EARLIEST DETECTION TIME	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT	SUM
Baseline	2	10	0	0	11
UAV	7	3	30	15	55
USV	3	3	32	14	52
UGS	3	5	31	18	57
UAV+USV+UGS	6	7	34	18	65
GCE	8	9	6	0	23
HH60	20	7	35	0	63
MORTAR TM	1	10	15	0	26
MORTAR BARGE	3	10	1	0	13
NW MORTAR TM	7	0	40	20	67
NW MORTAR BARGE	26	6	32	2	66

Table 26. Patrol Normalized Decision Matrix.

AMBUSH					
MOP Alternative	PERCENT OF NO HIT RUNS/LOSS EXCHANGE RATIO	LENGTH OF ENGAGEMENT	EARLIEST DETECTION TIME	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT	SUM
Baseline	0	8	12	0	20
UAV	5	0	24	14	43
USV	2	7	35	20	63
UGS	1	8	14	1	24
UAV+USV+UGS	1	7	35	17	60
GCE	3	3	0	0	7
HH60	26	6	40	3	74
MORTAR TM	0	10	12	0	23
MORTAR BARGE	1	10	12	0	23
NW MORTAR TM	0	8	35	17	60
NW MORTAR BARGE	11	7	35	3	56

Table 27. Ambush Normalized Decision Matrix.

OVERALL					
MOP Alternative	PERCENT OF NO HIT RUNS/LOSS EXCHANGE RATIO (RED/BLUE)	LENGTH OF ENGAGEMENT	EARLIEST DETECTION TIME	TIME OF FIRST DETECTION TO FIRST ENGAGEMENT	OVERALL UTILITY SCORE
Baseline	1	9	6	0	16
UAV	6	2	27	14	49
USV	3	5	33	17	58
UGS	2	7	22	10	41
UAV+USV+UGS	3	7	35	18	62
GCE	5	6	3	0	15
HH60	23	7	37	1	68
MORTAR TM	1	10	14	0	25
MORTAR BARGE	2	10	6	0	18
NW MORTAR TM	4	4	37	19	63
NW MORTAR BARGE	19	7	33	2	61

Table 28. Overall Normalized Decision Matrix.

3. Alternative Force Package Ranking

Ranking the alternative force packages was accomplished by summing scores across all responses to obtain a total utility score for each alternative. The results of the ranking by scenario are shown in Figures 36, 37, and 38.

In the patrol rankings, all single sensor upgraded alternatives ranked significantly higher than the baseline. Networked sensor options and the helicopter all performed equally as well and better than the single sensor options. The ground combat team and the mortar team ranked only marginally better than the baseline force.

In the ambush rankings, the helicopter alternative ranked highest. Networked sensor options and the USV were only fractionally less effective. All single sensor options ranked higher than the baseline. The USV was the highest ranked single sensor followed by the UAV and finally the UGS. The GCE ranked the lowest among all of the alternatives and the baseline. The mortar team was the only weapons-only upgrade that ranked marginally better than the baseline. In the overall rankings the helicopter alternative had a slightly higher utility score than the networked options.

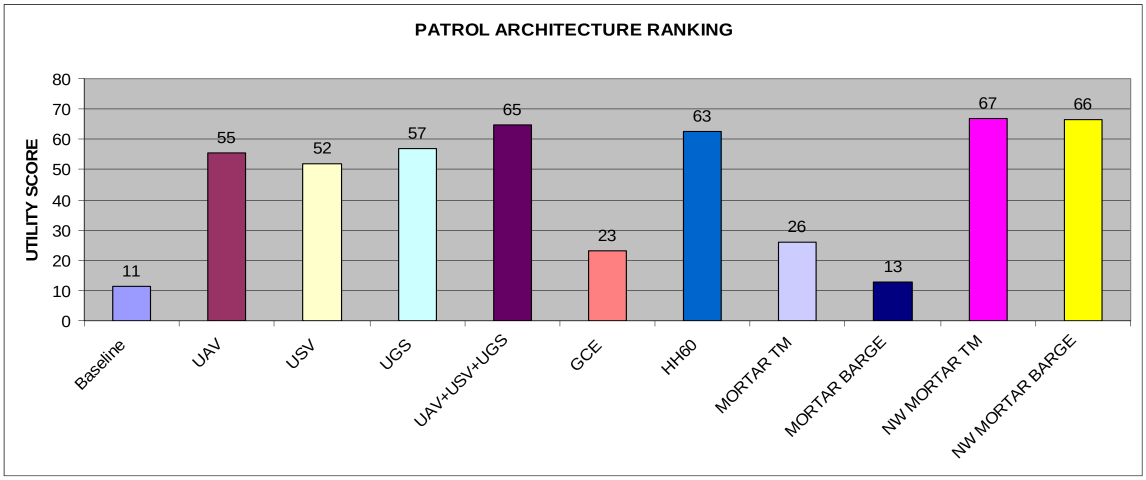

Figure 37. Patrol Scenario Alternative Architecture Ranking.

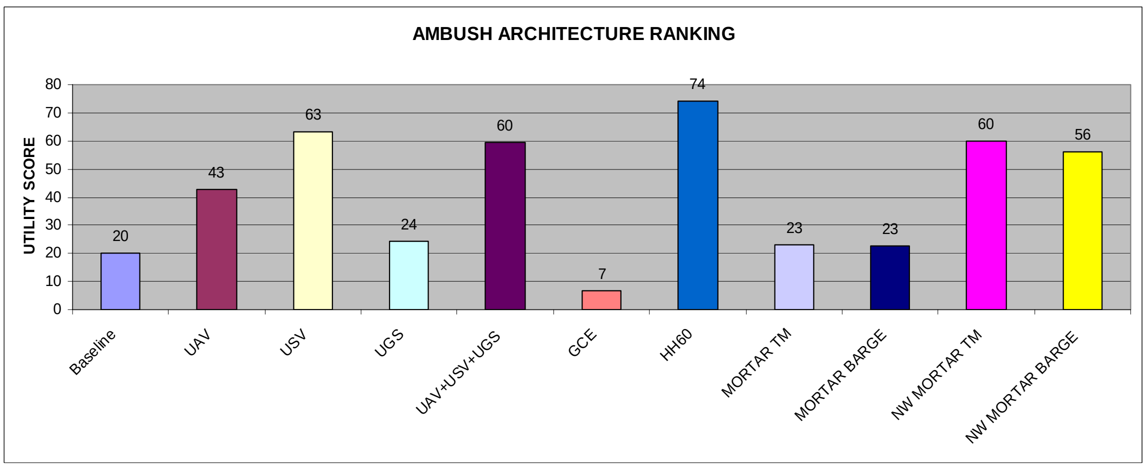

Figure 38. Ambush Scenario Alternative Architecture Ranking.

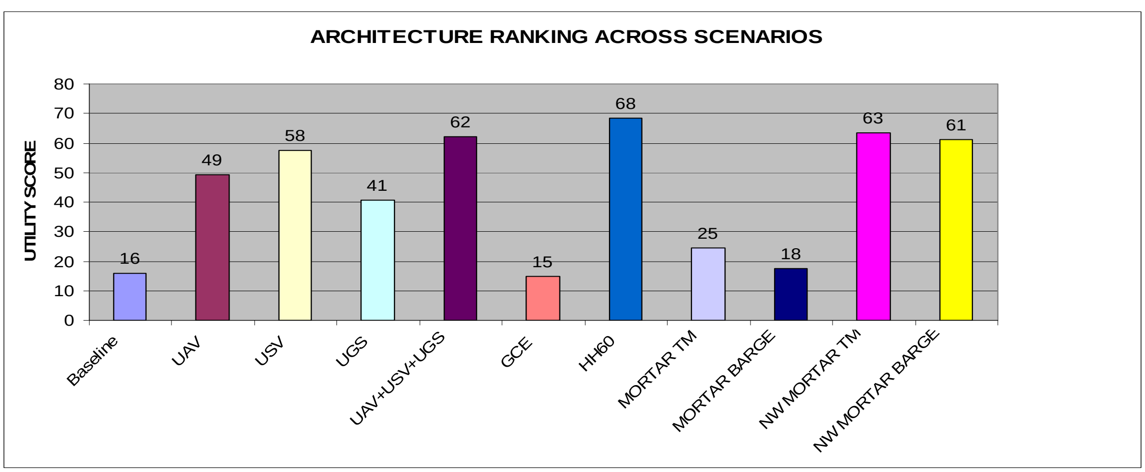

Figure 39. Overall Alternative Architecture Ranking Across Both Scenarios.

D. SENSITIVITY ANALYSIS

Sensitivity analysis focuses strictly on the extent to which the weighting of individual alternatives affects the outcome of overall alternative ranking. This analysis indicates how sensitive the architecture rankings are to changes in global weighting. Sensitivity analysis is designed to provide further insight for the decision maker should it be determined that the metrics or indicators of effectiveness have changed or do not match the global weight distribution assigned in this thesis. Table 29 is the original decision matrix in which weights from stakeholder interviews were assigned to each alternative force package.

Decision Matrix

Weight	Alternative / Evaluation Measure	Baseline	UAV	USV	UGS	NET	GCE	HH60	MORTAR TM	MORTAR BARGE	NW MORTAR TM	NW MORTAR BARGE
0.3	Percentage of no hit runs/Loss exchange ratio	3	21	8	7	10	18	76	2	5	12	62
0.1	Length of Engagement	88	15	47	67	67	63	68	100	96	38	68
0.4	Time to first enemy detection	15	67	84	55	86	8	93	34	16	94	84
0.2	Time from detection to Engagement	0	72	85	49	88	1	7	1	1	93	11
	WEIGHTED TOTAL	16	49	58	41	62	15	68	25	18	63	61

Table 29. SEA-10 Global Decision/Weighting Matrix.

1. Sensitivity Analysis Methodology

SEA-10 took the total utility score for each alternative (based on assigned weighting), and compared it with the total utility score that would be assigned to the alternative assuming 100% of the assigned weighting is based on the alternative's performance in a single response. The decision maker can evaluate how weighting one alternative affects the overall ranking of all the alternatives by repeating this process for each alternative

Alternatives' scores are plotted in order to determine if an alternative's performance is seriously impacted by raising or lowering weights. Plotted performance values are graphed as a line between two points. The resultant line indicates whether or not the individual alternative is sensitive to the weighting. The line also indicates how much of a shift in response weighting must occur for competing alternatives to achieve parity in performance. Parity is described as the point of intersection. If parity in performance can be achieved by varying weighting within a response by 10%, or less, then that response is considered "sensitive."[169] Sensitivity analysis was conducted for each of the four responses and the results are described in the following section.

2. Percentage of No Hit Runs/Loss Exchange Ratio

The helicopter and the networked sensor alternatives were the highest ranked in percentage of no hit runs/loss exchange ratio based on the assigned weights. Increased weighting in this response only marginally strengthened the helicopter and networked mortar barge rankings. Their utility scores remained fairly constant indicating that they were the only two alternatives that were insensitive to changes in weighting. All of the other alternatives benefit from decreased weight in this response, but suffer significantly with an increase in weighting as shown in Figure 40. Both networked mortar team and networked sensor alternatives' points of intersection were within ten percent at 0.227 and 0.224, respectively. This response was considered sensitive with original weighting assigned at 0.3. Should the decision maker choose to place less value on this measure of performance the outcome of the rankings would change, however, the family of alternatives at the top of the ranking would not change.

[169] E.P. Paulo, *SI4001 Introduction to Multi Objective Decision Analysis* Naval Postgraduate School, Monterey, CA, 05 January 2005.

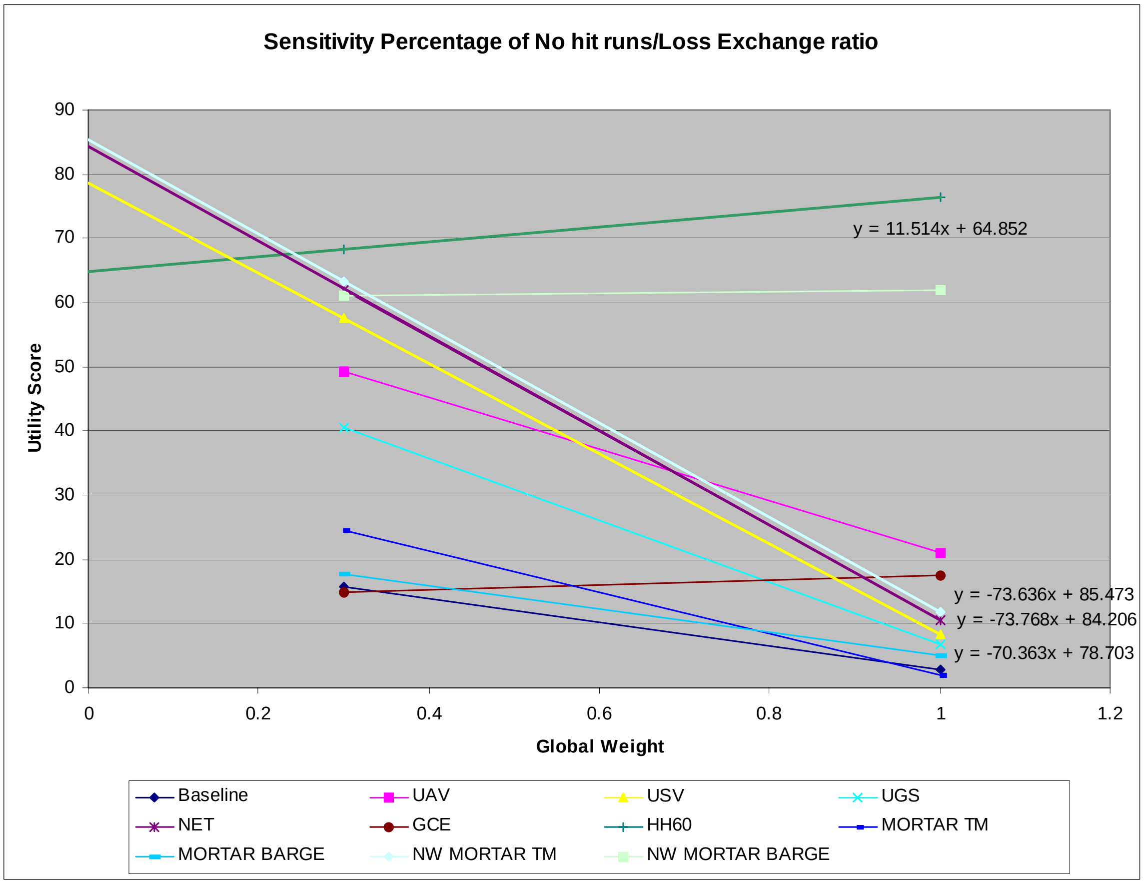

Figure 40. Sensitivity Curves for Percentage of No Hit Runs/Loss Exchange Ratio.

3. Length of Engagement

Again the helicopter and the networked sensor options ranked highest with the original weights. The mortar team, baseline, and mortar barge all benefited from increased weighting on this response as shown in Figure 41. The UAV, USV, and networked mortar had lower total utility scores with increased weighting on this response. The nearest point of intersection occurred with the mortar team at 0.617. Since the original weighting for length of engagement was 0.1, this response was deemed insensitive.

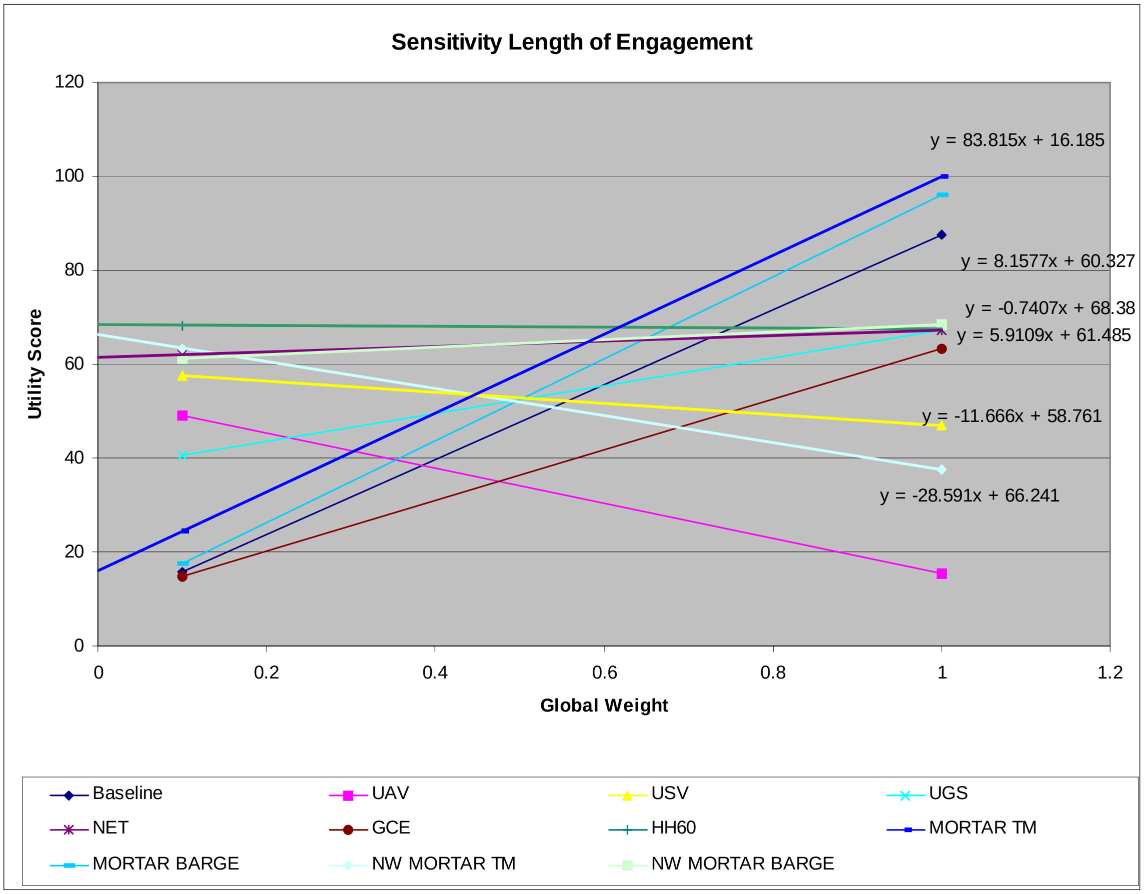

Figure 41. Sensitivity Curves for Length of Engagement.

4. Time to First Enemy Detection

As SEA-10 expected, all sensor upgraded alternatives benefited from an increase in weighting in this response as shown in Figure 42. The mortar team was the only alternative that did not have a sensor upgrade that ranked higher with an increase in this response. The networked mortar team achieved parity with the helicopter alternative at a value of 0.969. The original weight for this response was 0.4, and was therefore deemed insensitive.

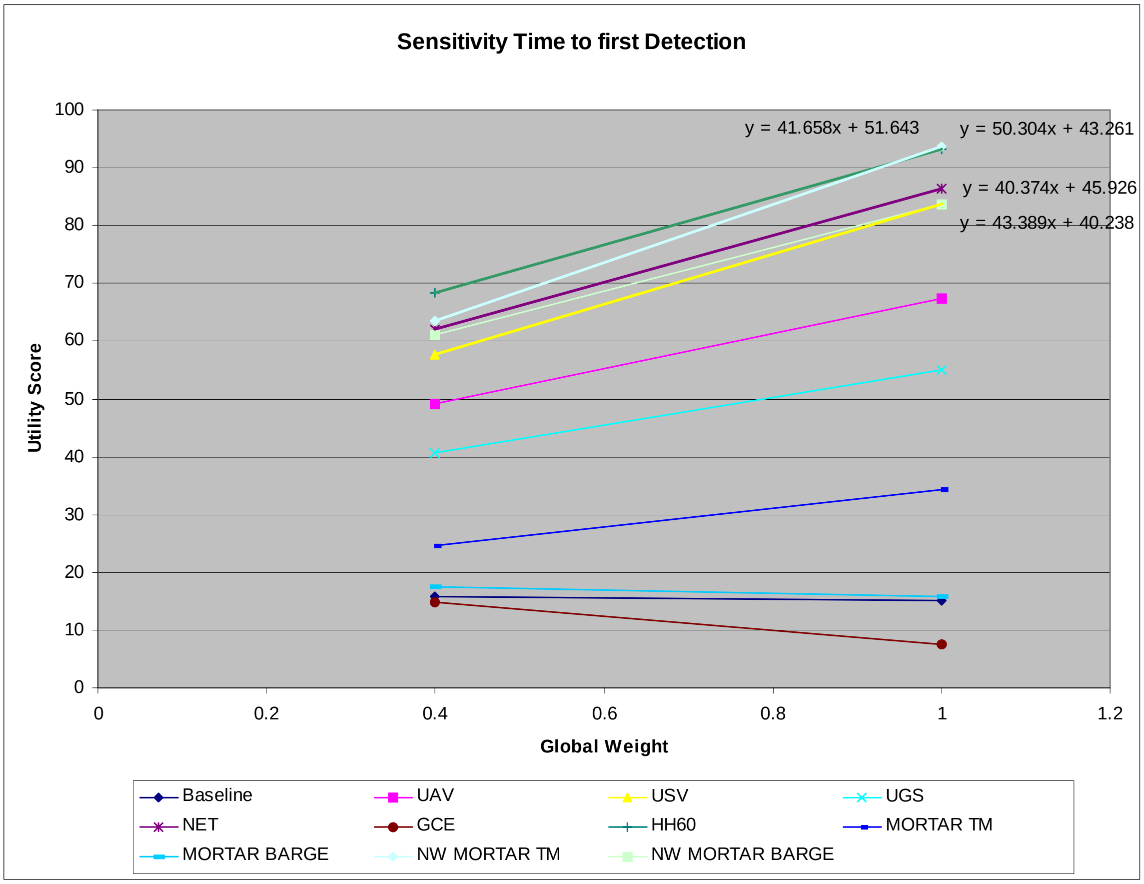

Figure 42. Sensitivity Curves for Time to First Detection.

5. Time from Detection to Engagement

With the exception of the helicopter and networked mortar barge, all sensor augmented alternatives benefit from increased weighting in this response as shown in Figure 43. All weapons only upgrades rank lower with increased weighting. The networked mortar team, the networked sensor, and the USV option point of intersections occur at 0.243, 0.257, and 0.298 respectively and the original weighting was set at 0.2. Increased weighting in this response would change the results of the architecture rankings because points of intersection indicate this response is sensitive to weight values. This response is not truly indicative of the performance of the helicopter and networked mortar barge. Pairing of weapons and sensors allowed the helicopter and networked mortar barge force packages to engage as soon as detection occurred. Change in the weighting of this response has the potential to misrepresent alternative capabilities.

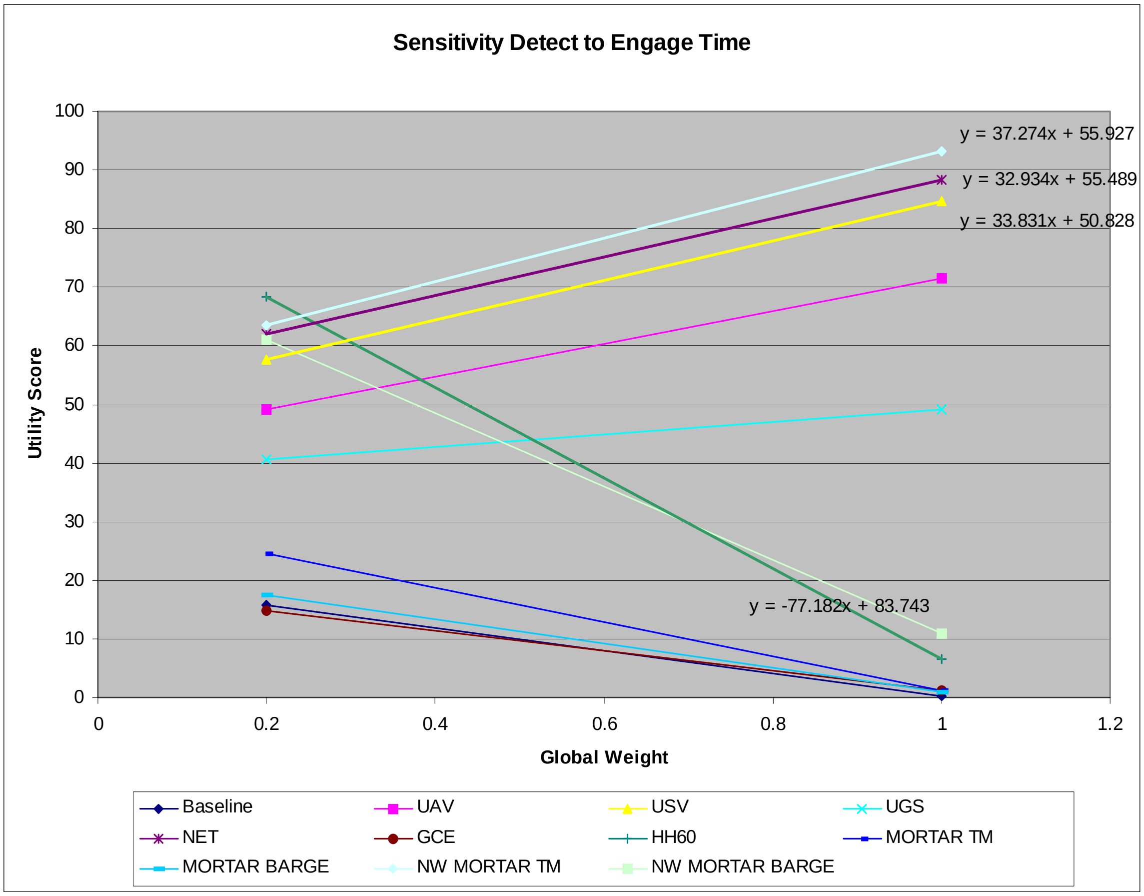

Figure 43. Sensitivity Curves for Time from Detection to Engagement.

6. Sensitivity Analysis Conclusion

Two of four responses were deemed sensitive, percentage of no hit runs/loss exchange ratio and time from detect to engage. Sensitivity in the time of first detection to engagement response is by-product of sensor weapon pairing. Increased weighting in this response could cause an inaccurate ranking of the helicopter and networked mortar barge alternatives. Percentage of no hit runs shows some sensitivity, but lowering the weight of this response would not significantly change the ranking of alternatives. The best performing alternatives in this response are closely ranked and therefore negate any positive effects of changing weight values.

E. DETAILED STATISTICAL ANALYSIS

1. Description of Patrol Runs

The patrol scenario was designed to represent the progression of blue agents north (toward the top of the page in Figure 44) following pre-planned waypoints. In all of the force packages, the SURC units begin at the Tactical Operations Center (TOC), which is approximately 300 grids (11.5 km) south of the red agents' location, and moved up the river along the pre-planned waypoints. The blue agents are designed to be highly aggressive toward red agents; therefore, the option of retreat or concealment was not desirable to them. The model required that the agents continually progress toward the next waypoint. Agents would only stop patrolling to either investigate neutral forces or engage red forces.

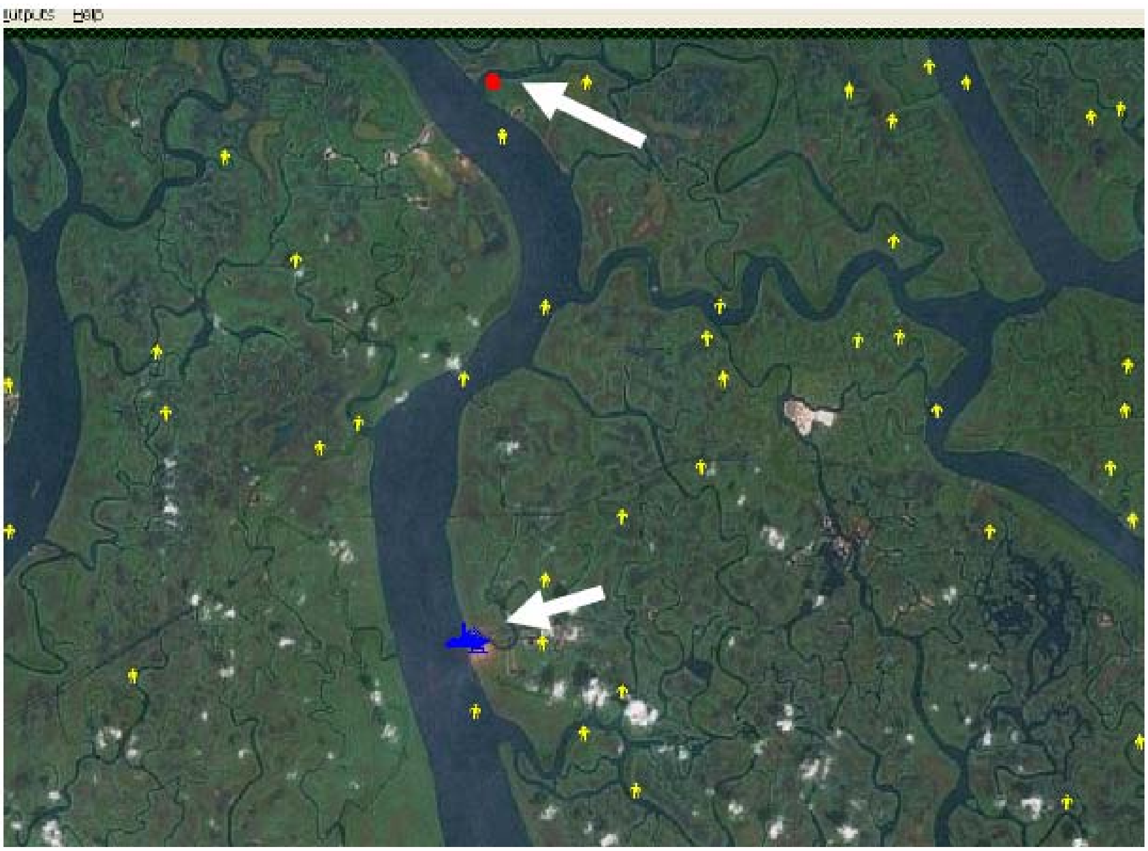

Figure 44. Patrol Modeling Overview.

2. Patrol Responses

a. Percent of No Hit Runs/Loss Exchange Ratio

Loss exchange ratio was not significantly different for any alternative as shown in Figure 45. However, when considered in combination with the percentage of no hit runs, the dedicated helicopter support and the networked mortar barge significantly outperformed all other alternatives as seen in Figure 46. The baseline force with the ground combat element was the only other alternative architecture that yielded any noticeable improvement for percentage of no hit runs. In terms of calculating loss exchange ratio, the helicopter and the networked mortar barge only yielded 4 and 1 data points, respectively, where a hit was taken by blue forces. Due to the small sample size and low confidence level, these instances they were not considered indicative of the alternatives' performance. Of the remaining alternatives UAV sensor addition had the best impact on loss exchange ratio.

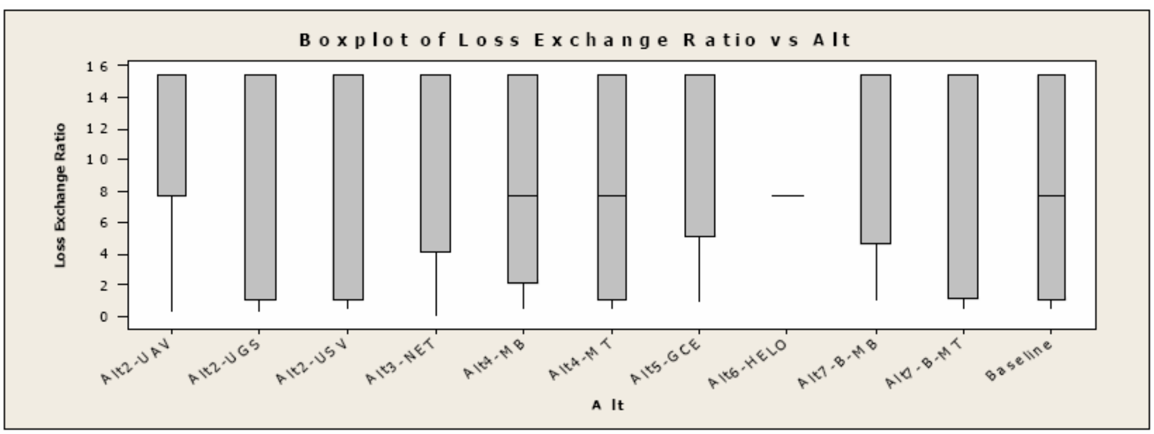

Figure 45. Box Plot of Patrol Loss Exchange Ratios.

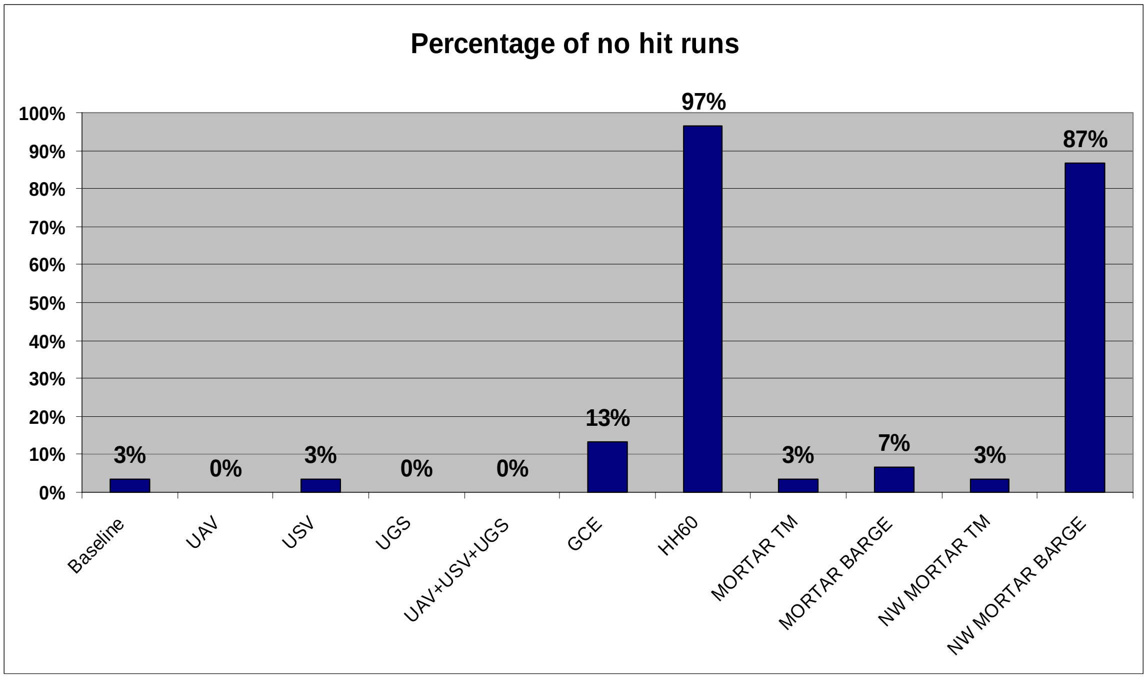

Figure 46. Percentage of No Hit Runs Per Alternative

b. Time to First Enemy Detection

All sensor alternatives had a significant improvement in time to first enemy detection and identification. Visual inspection of the box plot shows that the networked mortar team had the best time to first enemy detection and all sensor upgraded alternatives had an average of time to first detection that was 20 minutes faster than the baseline and weapons only augmented options as shown in Figure 47. A Kruskal-Wallis analysis (see Appendix C) of all alternatives with sensor upgrades confirmed that the networked mortar team afforded the earliest enemy classification with the helicopter alternative a close second. The Kruskal-Wallis analysis also revealed that the improved performance of the networked sensors alternatives was driven by the unmanned ground sensor system (UGS). UGS often acted as a queuing system for other unmanned systems. The communication network that existed between networked sensors enabled a contact to be located by UGS, and then verified and classified by a mobile unmanned system (either UAV or USV). A logical conclusion is that the UGS was also responsible for the improved performance of the networked mortar barge and the networked mortar team.

A plausible reason for the networked mortar team outperforming the other alternatives is likely due to an important modeling interaction. In order to simulate the debarkation of the mortar team from a SURC in MANA, the mortar team must be pre-staged as an inactive agent that has to be "refueled" and activated by the SURC.[170] This action forced the SURC's to come into proximity with red agents early in the modeling run and pass their situational awareness onto the mortar team.

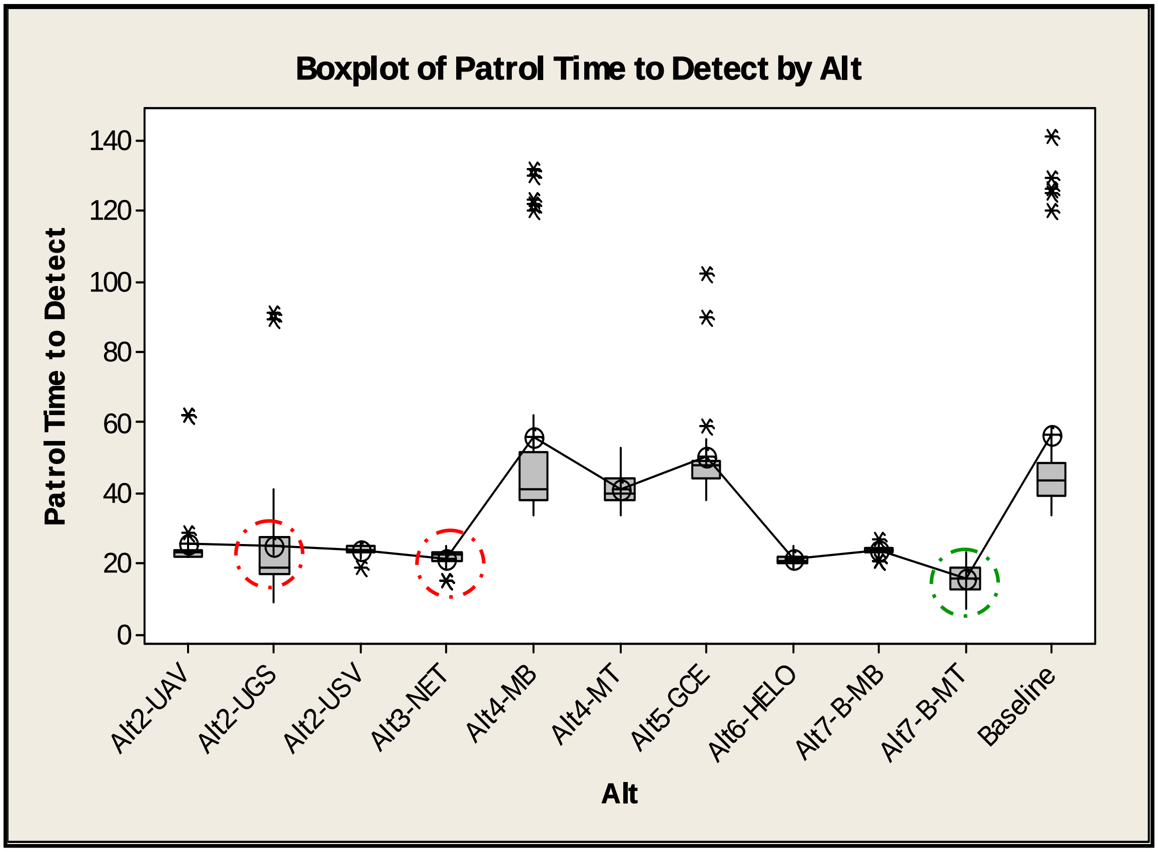

Figure 47. Box Plot of First Enemy Detection Per Alternative.

[170] As previously discussed on page 92, MANA Limitations: Debarkation of Forces.

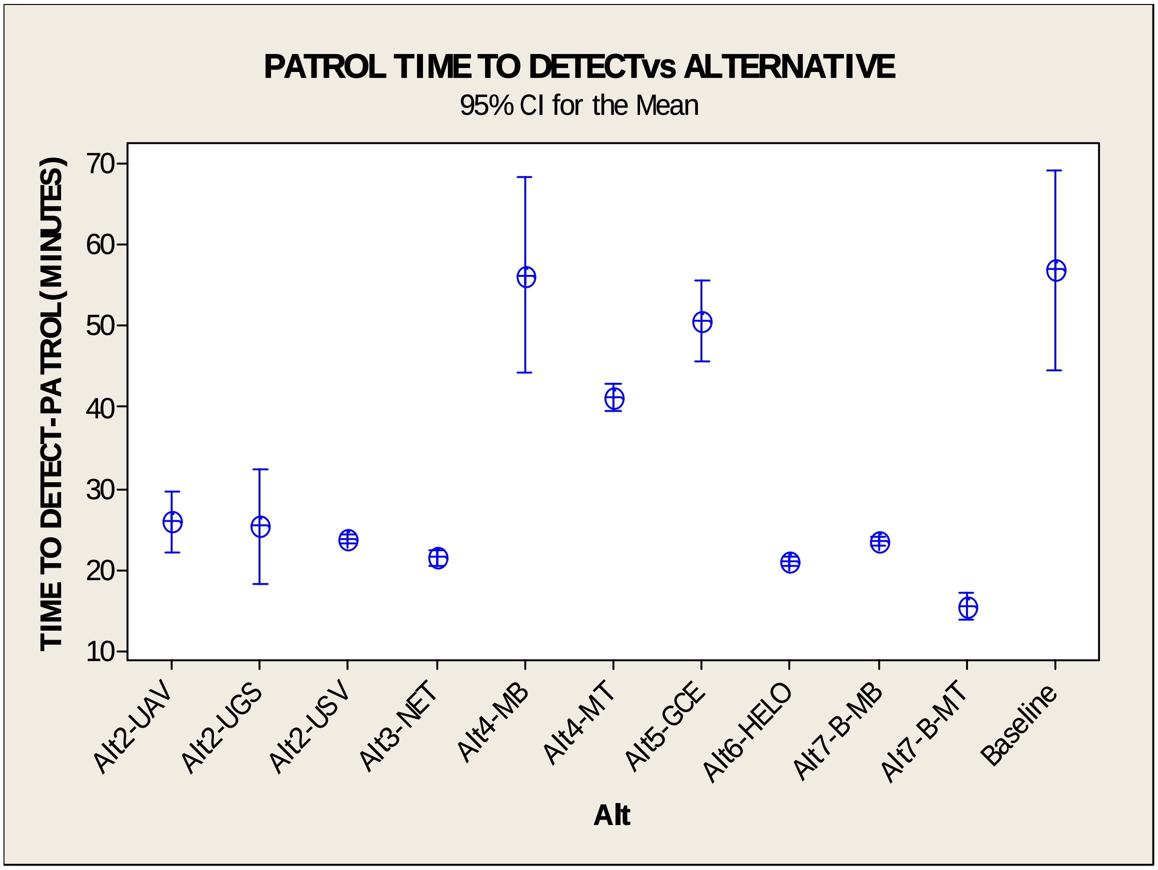

Figure 48. Time to First Enemy Detection Per Alternative for Patrol.

c. *Detect to Engage Time*

The alternatives with improved sensor systems provided the largest increase in time from first enemy detection to first engagement. Visual inspection of the box plot showed that there was a 20 minute increase in time between first enemy detection and engagement (see Figure 49). This is a critical measure of battle space awareness. UGS performed the best among unmanned systems and drove the performance of the networked sensor options.

The change in time from detection to engagement was negligible in alternatives where sensors were paired to weapons. The helicopter and networked mortar barge engaged immediately upon detection because their top priority of agent motivations was to engage enemy agents. Their extended engagement range and standoff ability enabled them to attack as soon as enemy agents were identified. Therefore, enemy agents were detected and engaged in the same time step, again because blue agents were motivated to engage the enemy once in weapons' range. These options are capable of providing greater lead time between first enemy detection and first engagement. There was no improvement over the baseline for any of the engagement augment only upgrades as shown in Figure 50. The networked mortar team does not have the same response as the mortar barge or helicopter because of the previously mentioned pre-staging/debarkation MANA work around. Hence, the networked mortar team performs only as well as the networked sensor option.

The baseline and engagement plus-up options have no advance warning of enemy attack. In four of the alternatives, the first notice of enemy presence did not occur until the red force fired first. In the case of the baseline plus mortar team and baseline plus mortar barge alternatives, they have indirect fire capability but no advance warning from sensors. Alternatives without the combination of both sensors and indirect fire capability have to wait on average an additional twenty minutes after classifying an enemy target before they can bring weapons to bear.

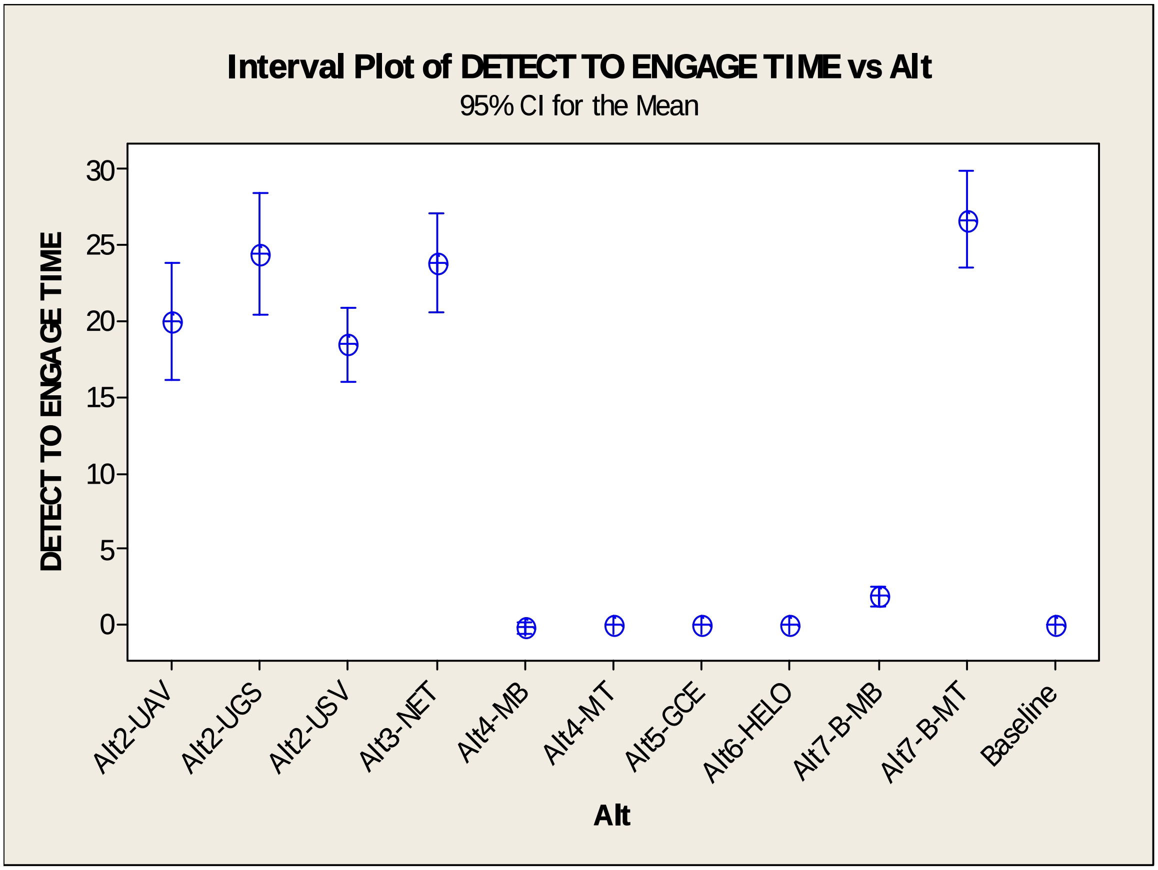

Figure 49. Detect to Engage Time Per Alternative.

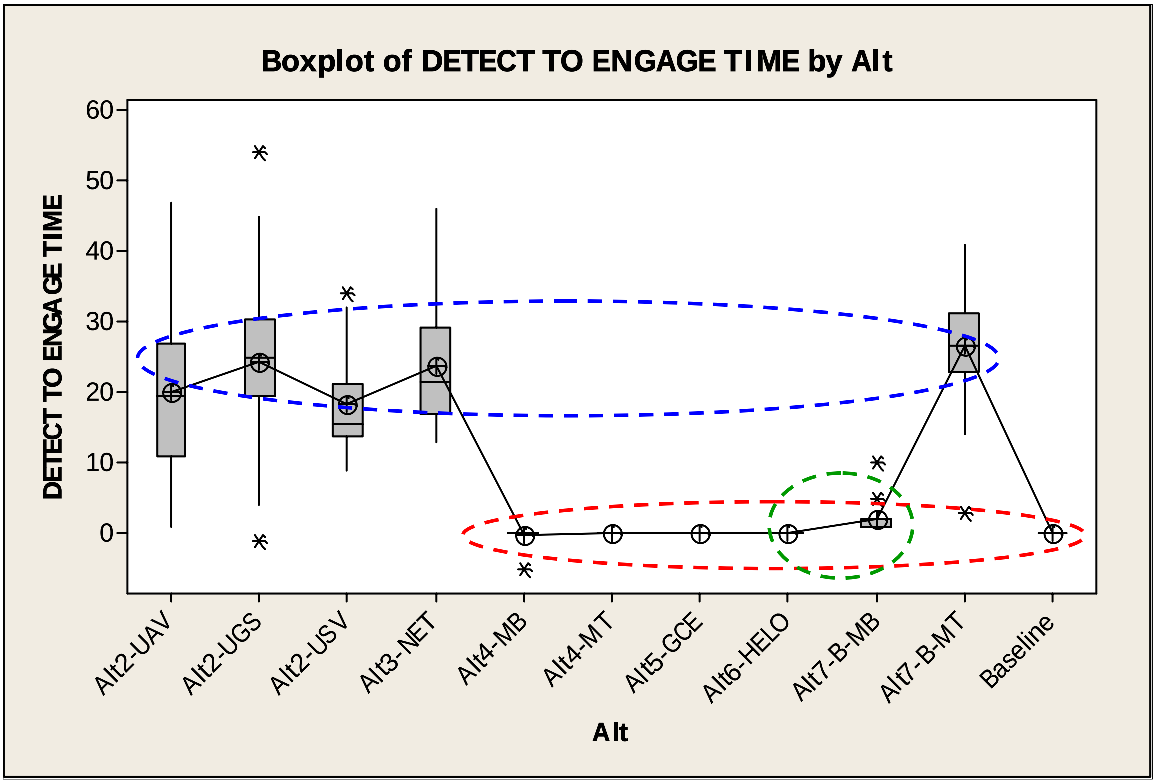

Figure 50. Box Plot of Detect to Engage Time Per Alternative.

d. Length of Engagement

SEA-10 expected that alternatives with weapons augments would have shorter length of engagement times than alternatives that did not have augments. Adding only weapons did not significantly improve performance over the baseline. However, analysis of the means showed that adding only sensors to the baseline extended engagement time as shown in Figure 51. SEA-10 interpreted the longer engagement time as potentially increased battlespace awareness for blue agents. The elongated engagement time may represent blue agent cautiousness because of situational awareness passed through the sensors. Alternatives with paired indirect fire and sensor augments also increased engagement time. Alternatives that use sensor and weapon augments have a longer time of engagement because of the increased range at which an enemy can be engaged. However, there were outliers in most of the sensor options as shown in Figure 52. Visual inspection of the box plot showed the distribution was not normal, and therefore Kruskal-Wallis analysis was determined to be more appropriate.

Kruskal-Wallis analysis revealed that the helicopter and networked mortar barge alternatives had significantly longer engagement time based on analysis of all alternatives' ranked median values. The baseline plus mortar team was the only alternative with a significantly shorter engagement time. The significantly shorter engagement time of the mortar team alternative is likely due to the modeling constraint associated with the pre-staged debarkation position of the mortar team that may put it within firing range of enemy forces.

There were only three runs out of all 660 runs (0.5%) for both ambush and patrol scenarios when red forces killed all blue forces. Those runs were not analyzed with respect to length of engagement because they did not have a relationship to blue force weapons effectiveness or lethality.

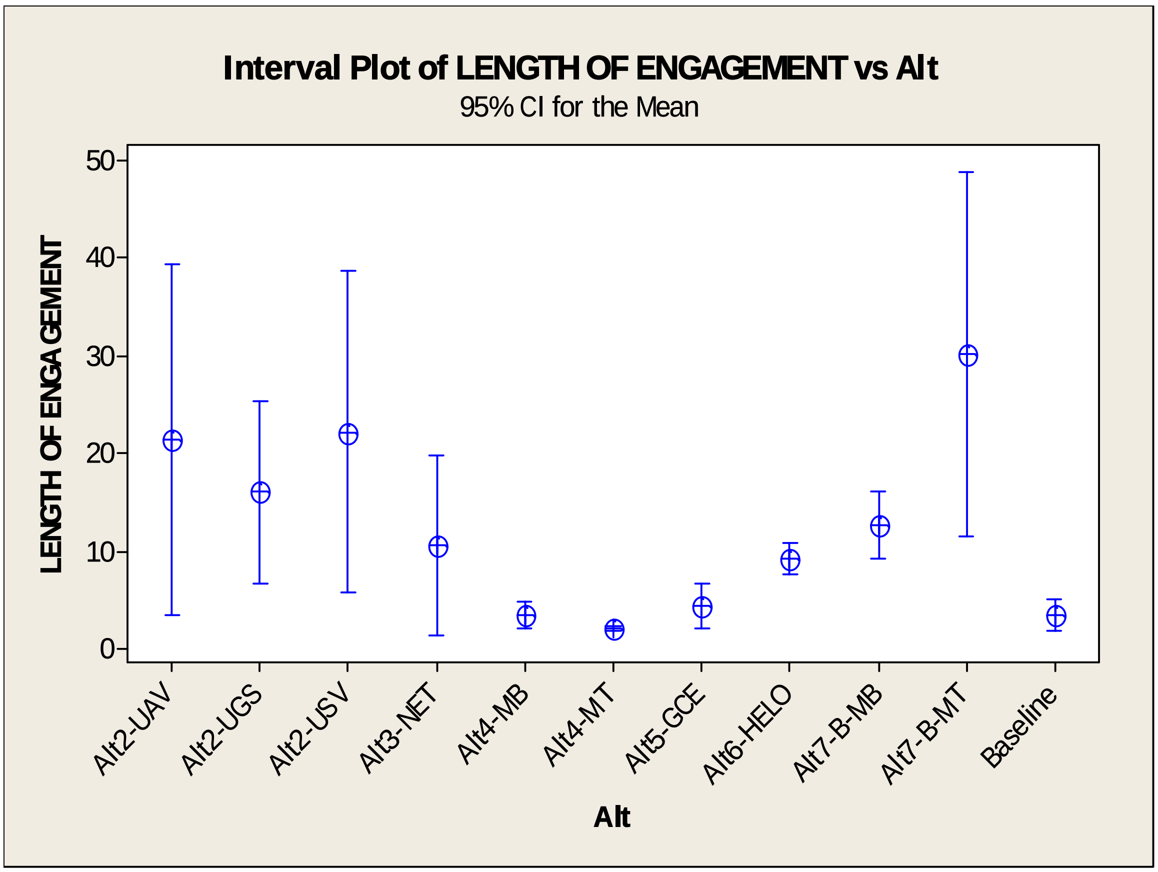

Figure 51. Length of Engagement Per Alternative.

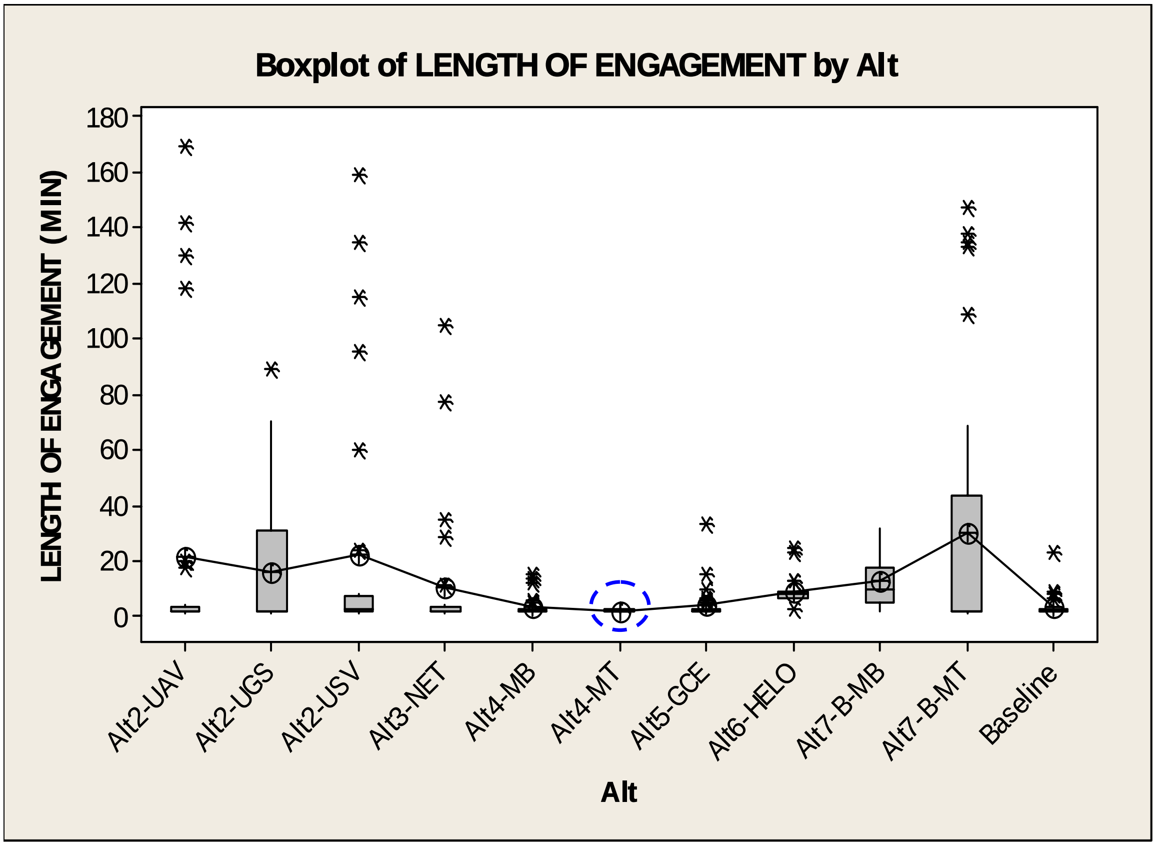

Figure 52. Box Plot of Length of Engagement Per Alternative.

e. Max Classification Range

Maximum classification range for alternatives was based on the parameters entered into the model. The networked sensor options mirrored the maximum classification range of the most capable individual sensor which was the USV as shown in Figure 53. It was not possible to capture the range from blue to red agents at the time of first detection due to modeling limitations of MANA. Only data for the range from the detecting agent to the detected agent could be collected. In other words if the UAV was 20 grids ahead of the blue agents and detected red agents 5 grids from its position MANA would record a 5 grid classification range instead of 25 grids. Data was collected to capture the most capable sensor capability for an alternative by taking the maximum range at which the blue agents were able to classify red agents during an entire run. It is worth noting that although the USV has a much greater maximum classification range in terms of detect to engage time, length of engagement, and loss exchange ratio it performed no better than the UAV or the UGS in the patrol scenario. The helicopter had the overall best maximum classification range.

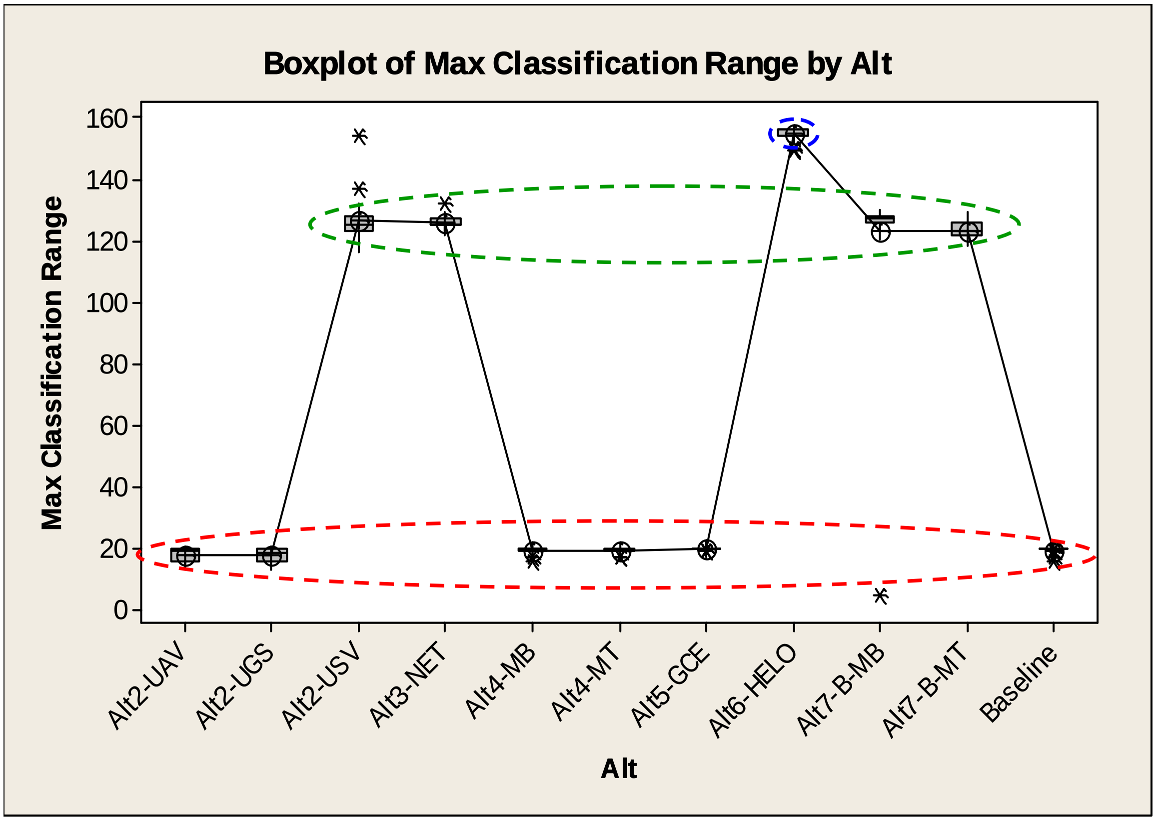

Figure 53. Box Plots of Maximum Classification Range Per Alternative.

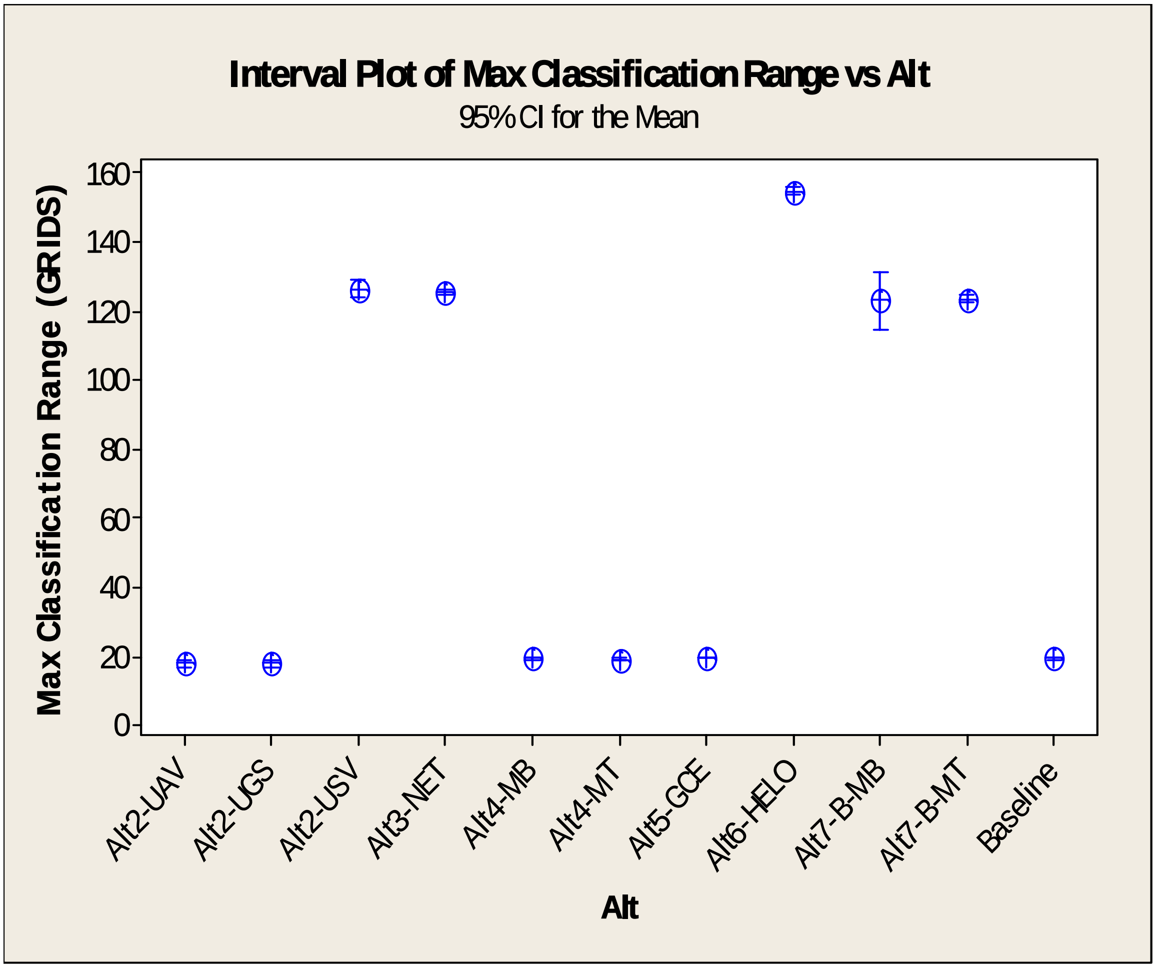

Figure 54. Maximum Classification Range Per Alternative.

3. Patrol Scenario Results

There was no statistically significant difference between a single unmanned sensor alternative and the networked unmanned sensor alternatives. The addition of sensors allowed blue agents more time between detection and engagement. Adding only weapons capability did not improve the alternative's performance in the patrol scenario. This is militarily significant, and it implies that the baseline force has significant weapons capability in a patrol scenario against a level II threat. The pairing of indirect fire weapons and sensors had, by far, the greatest performance improving effect.

Across all responses the baseline force performed as well as alternatives that had only engagement and no sensor upgrades. The ground combat element alternative produced a moderate improvement in percentage of no hit runs (13%) and a slight improvement in loss exchange ratio.

The baseline force with dedicated helicopter support had a 97% chance of killing all red agents while taking no damage. The networked mortar barge alternative had an 87% chance of killing all red agents without taking any damage. The helicopter and mortar barge results for loss exchange ratio, length of engagement, and detect to engage time must be interpreted differently due to the sensor weapons pairing.

The individual sensors performed as well as the networked sensor alternative which indicates that a single sensor can provides battlespace awareness that is roughly equivalent to a networked system of sensors. The UAV alternative had the best mean loss exchange ratio of the individual unmanned sensor systems, while the USV had the greatest maximum classification range. The combined network of unmanned system assumed the best attributes of each of the individual sensors.

4. Analysis of Ambush Runs

The ambush scenario is designed to test the response capability of the RF to a surprise enemy attack. In each run of the scenario blue agents begin at the TOC and proceed north along pre-planned waypoints as they would for a standard patrol. A red platoon is positioned on each bank of the river approximately 7.4 km north of the TOC. The enemy is located on a bend of the river, which gives them concealment and surprise. As in the patrol scenario, the blue agents are modeled as highly aggressive and do not have the option of retreat. Figure 55 represents the relative location of the forces in the initial ambush scenario.

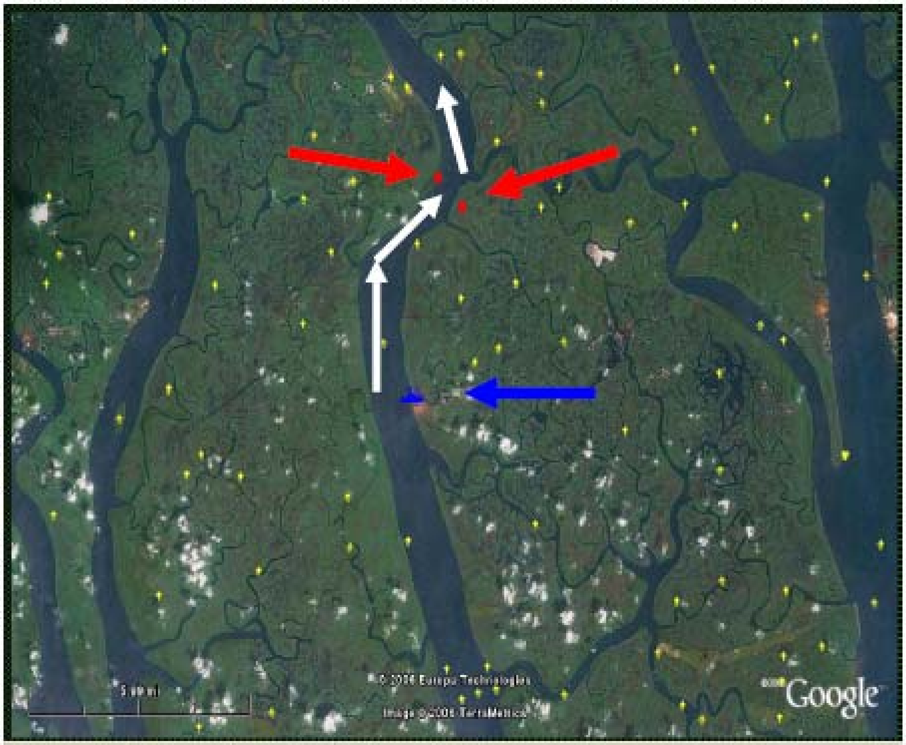

Figure 55. Ambush Scenario Overview.

a. Percent of No Hit Runs/Loss Exchange Ratio

In the ambush modeling runs the helicopter and networked mortar barge had the best percentage of no hit runs, and the helicopter was the overall best alternative. The mean loss exchange ratio for the helicopter alternative was the best of the all of the alternative force packages as shown in Figure 56. The loss exchange ratio for the helicopter was only calculated from six data points because of the helicopter alternative's high percentage of no hit runs. As a result of the small sample size, the recorded loss exchange ratio may not accurately represent the actual loss exchange ratio of the helicopter. Further runs would be needed to derive a fair representation of this data point.

A Kruskal-Wallis analysis of the medians showed the UAV and GCE alternative force packages had a significantly improved loss exchange ratio response over the baseline as shown in Figure 57. The networked mortar barge did not benefit from the paired sensor weapon upgrade because MANA artificially imposed that the mortar team had to "disembark" from the SURC prior to engaging the enemy. Also, the networked mortar barge did not experience the same success as in the patrol scenario in terms of percentage of no hit runs, but had approximately the same loss exchange ratio in both scenarios.

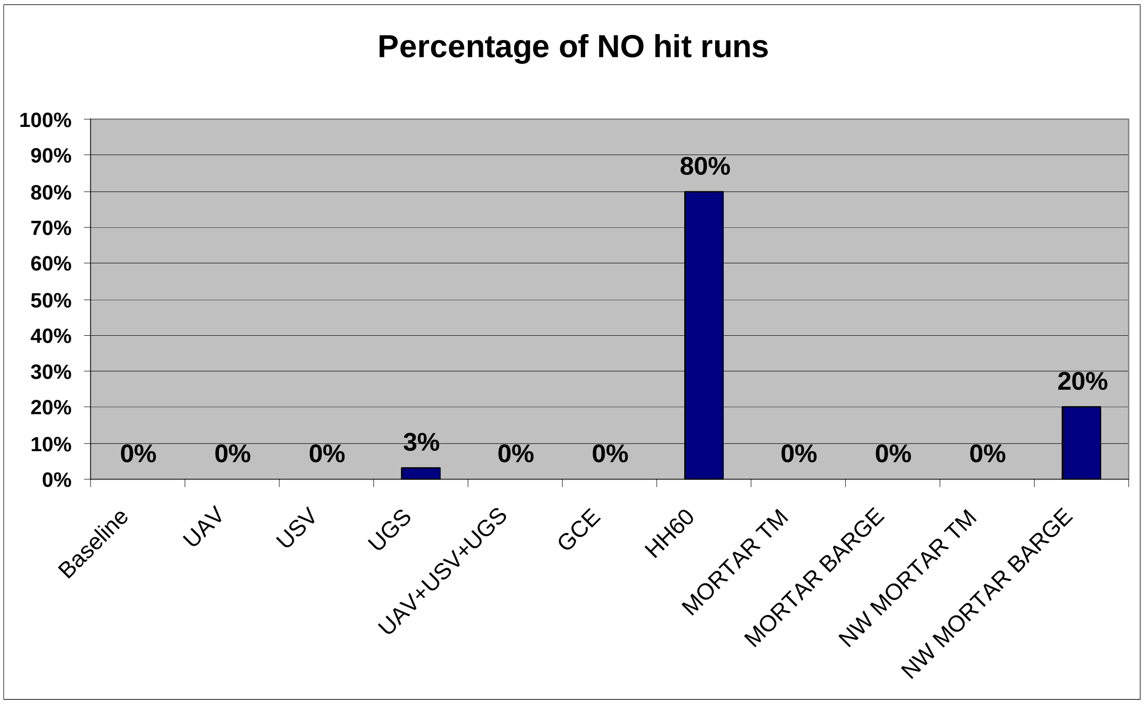

Figure 56. Percentage of No Hit Runs Per Alternative for the Ambush Scenario.

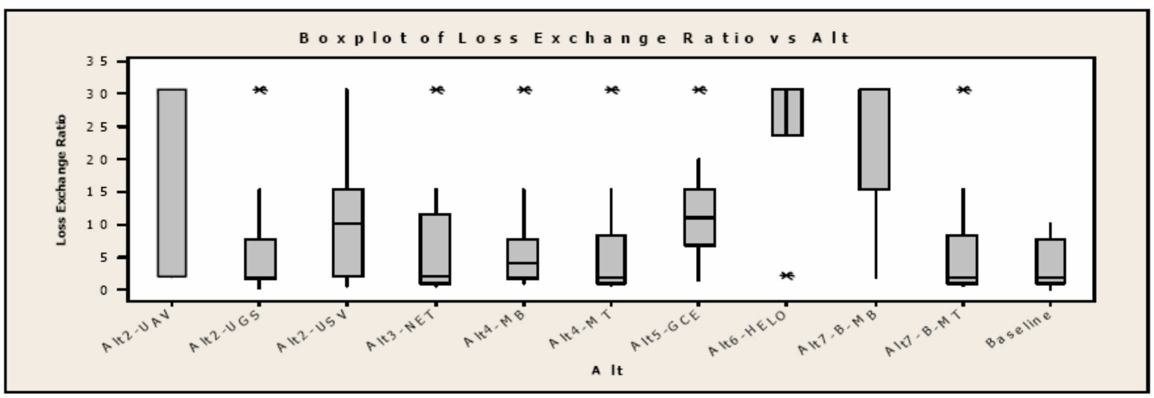

Figure 57. Box Plot of Ambush Loss Exchange Ratios.

b. Time to First Enemy Detection

All sensor upgrades improved the time of first detection, with the exception of the UGS. Among the alternative force packages, the helicopter required the least amount of time to detection followed by the USV and networked sensor options, and finally by the UAV (see Figure 58). The alternatives with no sensor upgrades showed no improvement over the baseline. Figure 59 displays the modal response of the alternative architectures with respect to the means (i.e., the programmed value was consistently returned in modeling, confidence intervals were very tight).

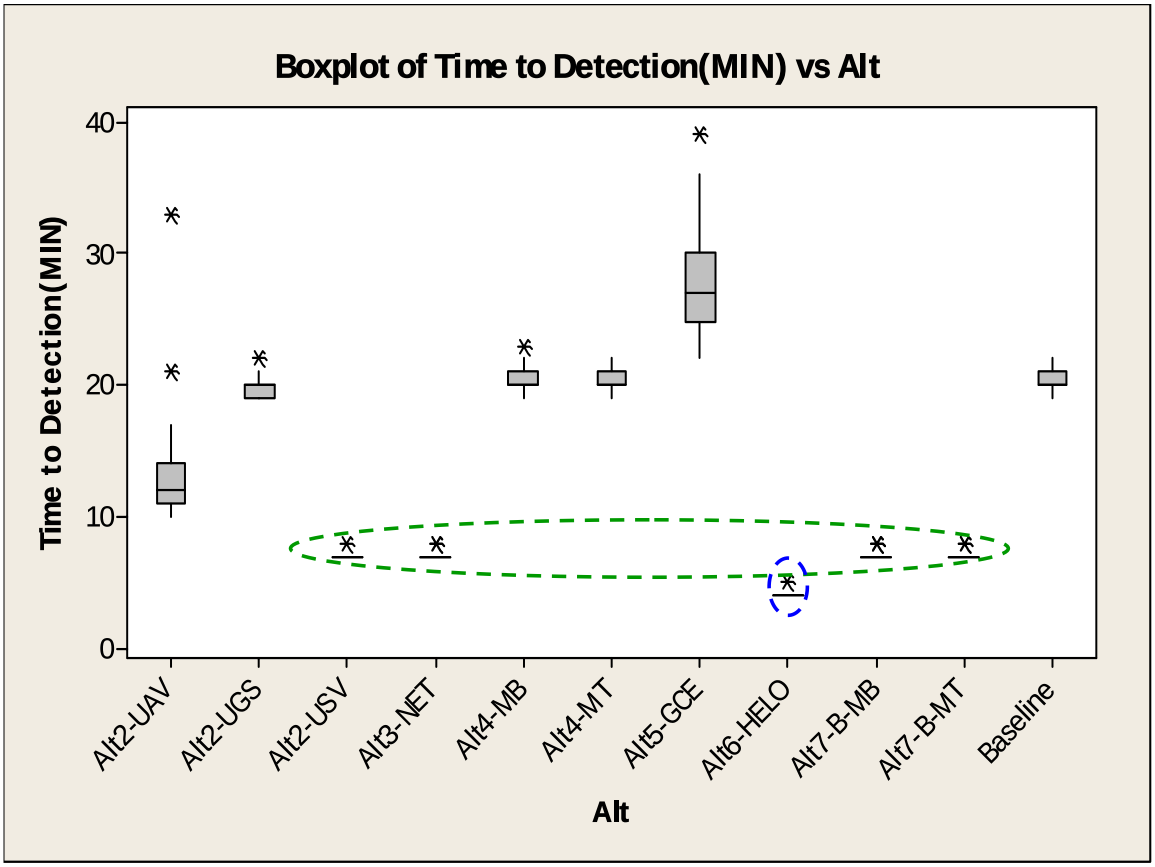

Figure 58. Box Plot of Time to Detection Per Alternative.

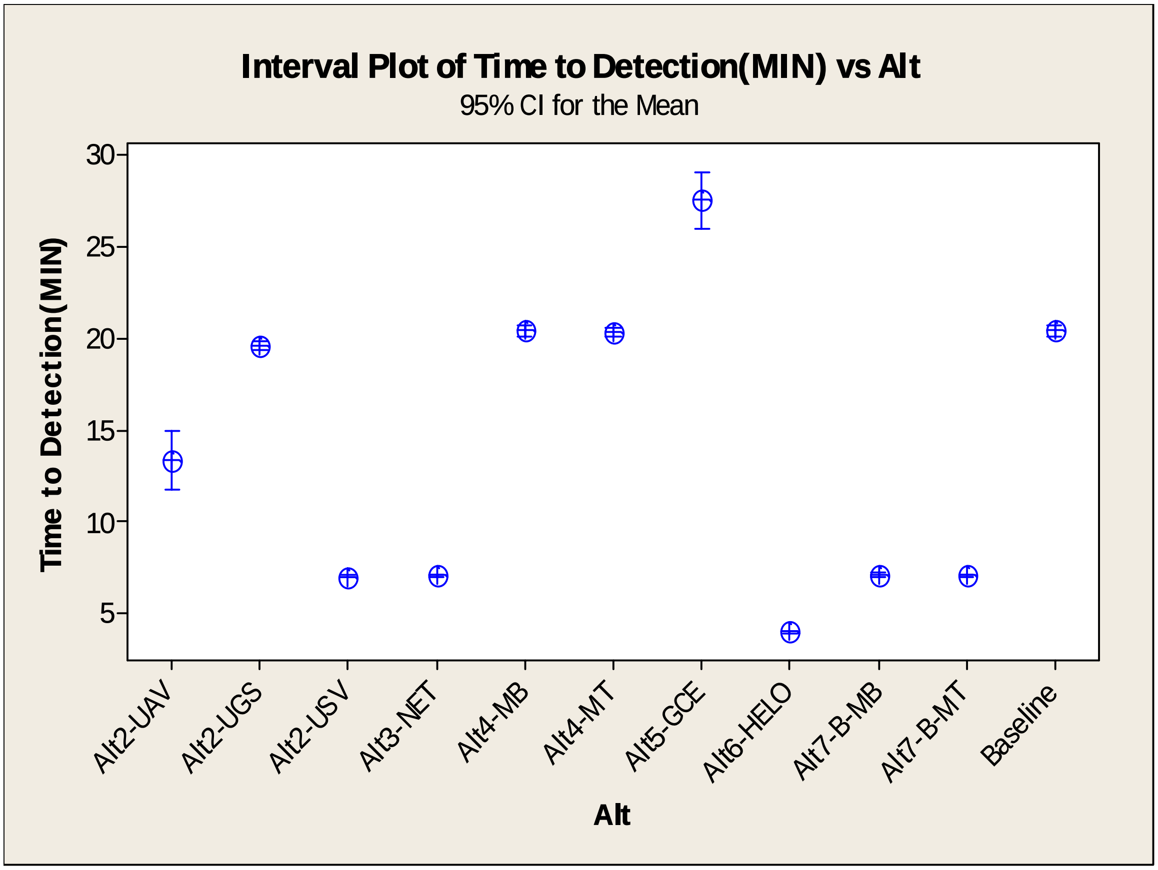

Figure 59. Time to Detection Per Alternative.

c. Time from Detection to Engagement

All sensor options, except UGS, significantly increased the length of time from enemy detection to engagement as shown in Figure 60. This response measures the time from first enemy detection to first engagement. A greater amount of time between these two events is desirable, because it implies that the war fighter will have additional time to make a decision on his next course of action.

The values of this response for the helicopter and networked mortar barge alternatives are zero because these force packages have a sensor range that matches their engagement range. By design of the model, the agents are motivated to engage the enemy as soon as the enemy is detected and is within engagement range. The agents in these two force packages engage in the same time step that the enemy is detected. Consequently, the values for the helicopter and the network mortar barge time from first detection to engagement appear low, but are actually favorable.

A Kruskal-Wallis analysis of medians (see Figure 61) shows that UAV, USV and networked options all preformed equally well in this response.

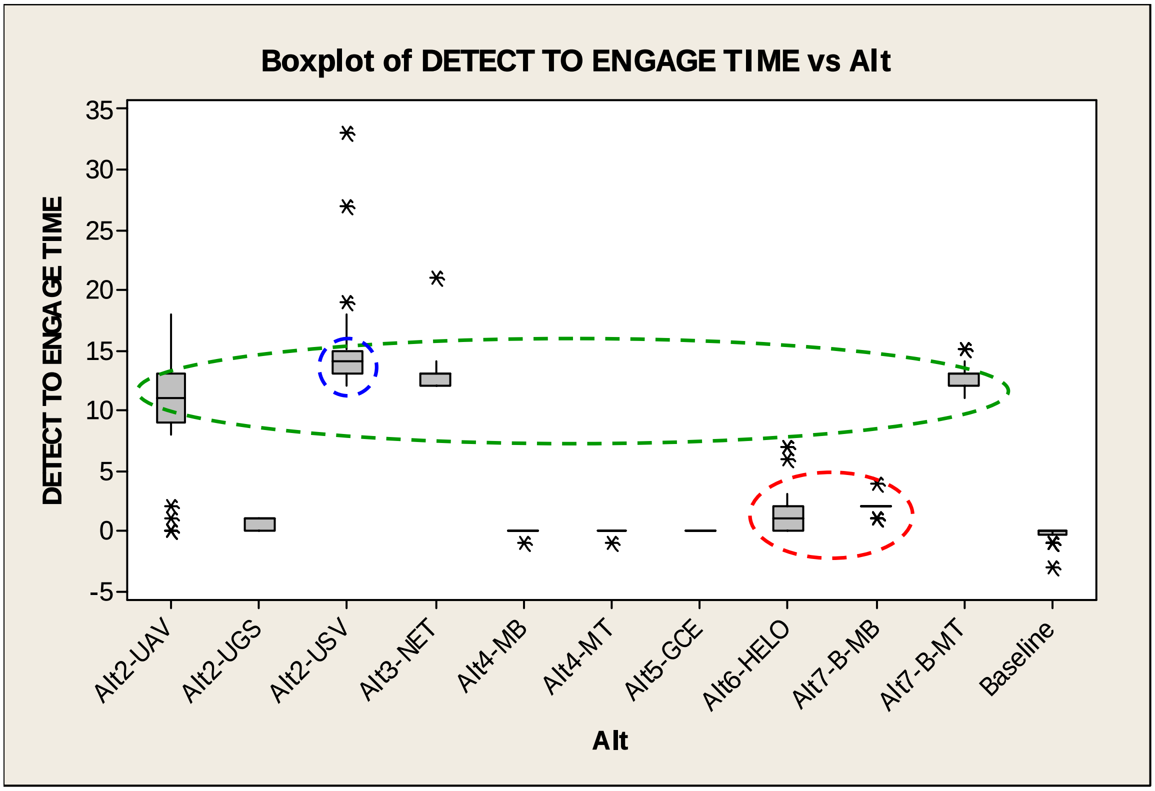

Figure 60. Box Plot of Detect to Engage Per Alternative.

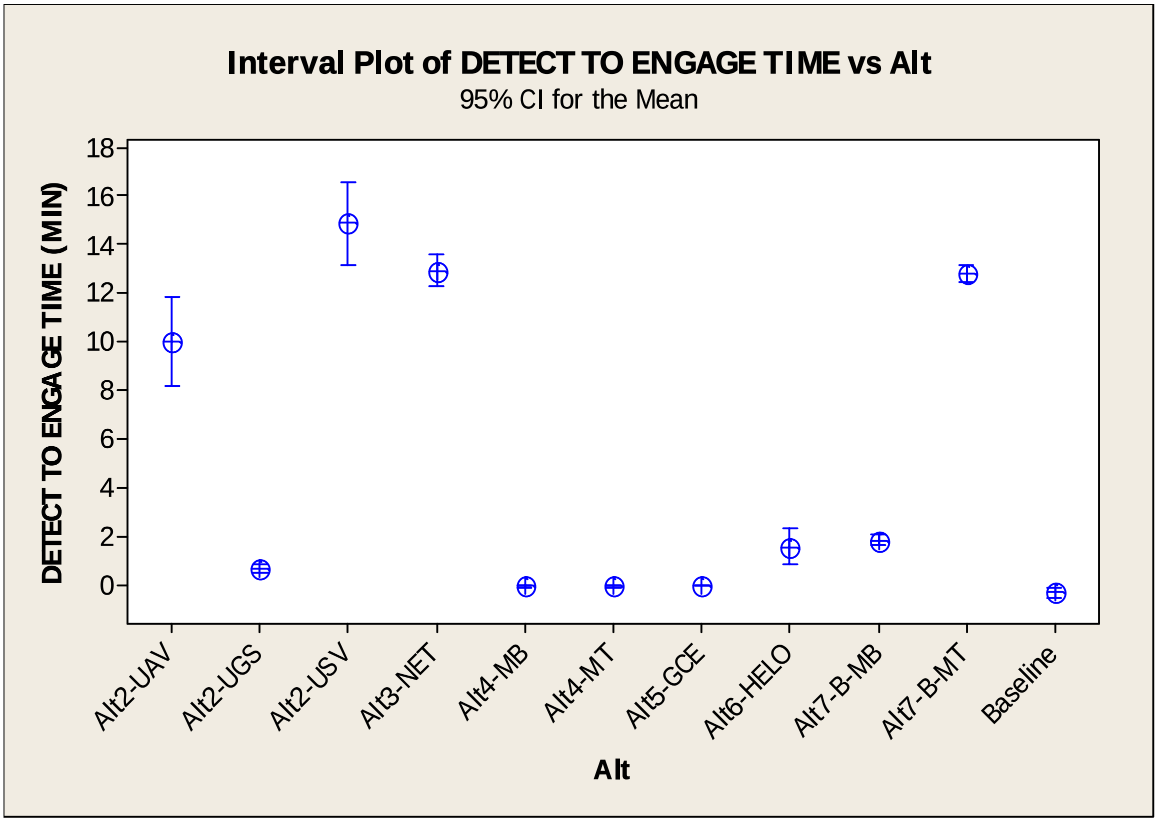

Figure 61. Interval Plot for Detect to Engage for Ambush.

d. Length of Engagement

In the ambush scenario, adding a mortar team or mortar barge reduced mean engagement time to half of the baseline engagement time as shown in Figure 62. This indicates that in this scenario there is potentially a benefit to adding weapons with larger blast radii. The helicopter, GCE, UAV, and USV alternatives' interaction with the model increased engagement length while the networked mortar barge and networked mortar team performed no better than the baseline (see Figure 63). This response reinforces that the baseline force has substantial weapons capability. It also demonstrates that there is benefit in increased firepower in an ambush scenario more so than in the patrol scenario.

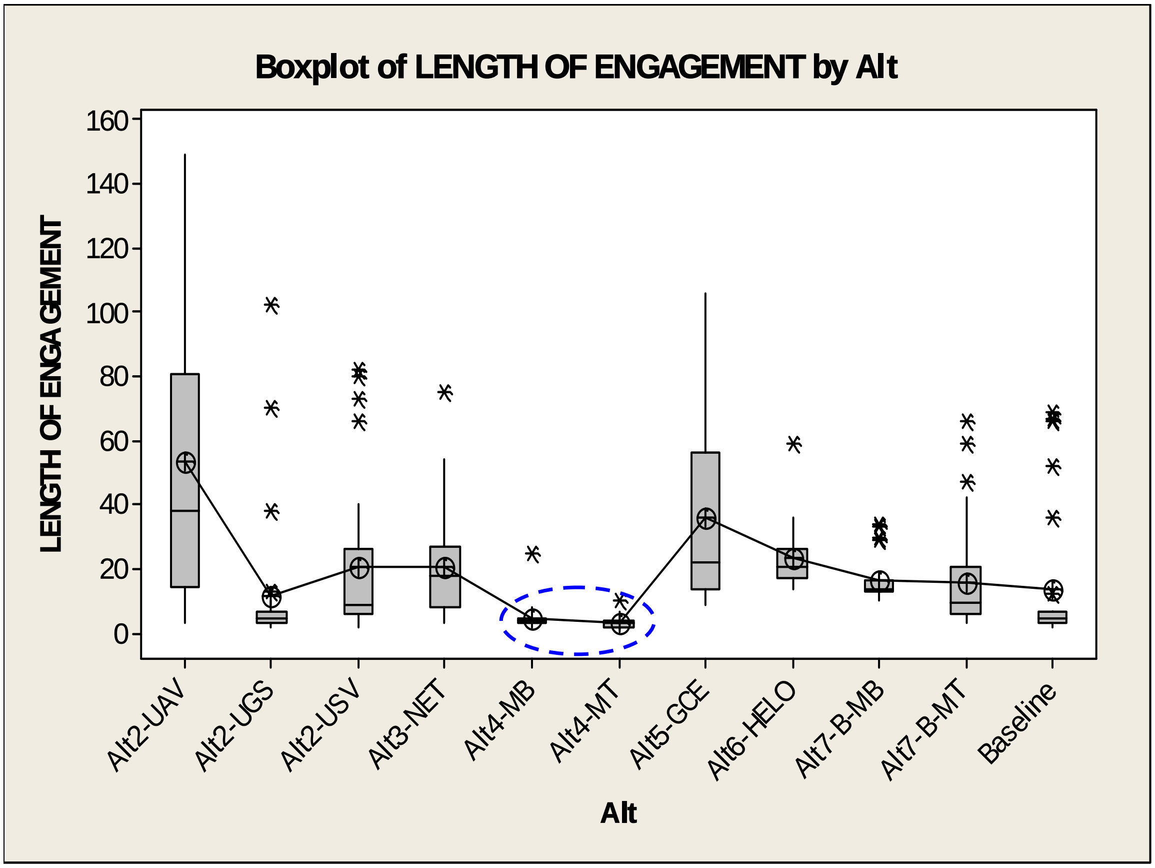

Figure 62. Box Plot of Length of Engagement Per Alternative.

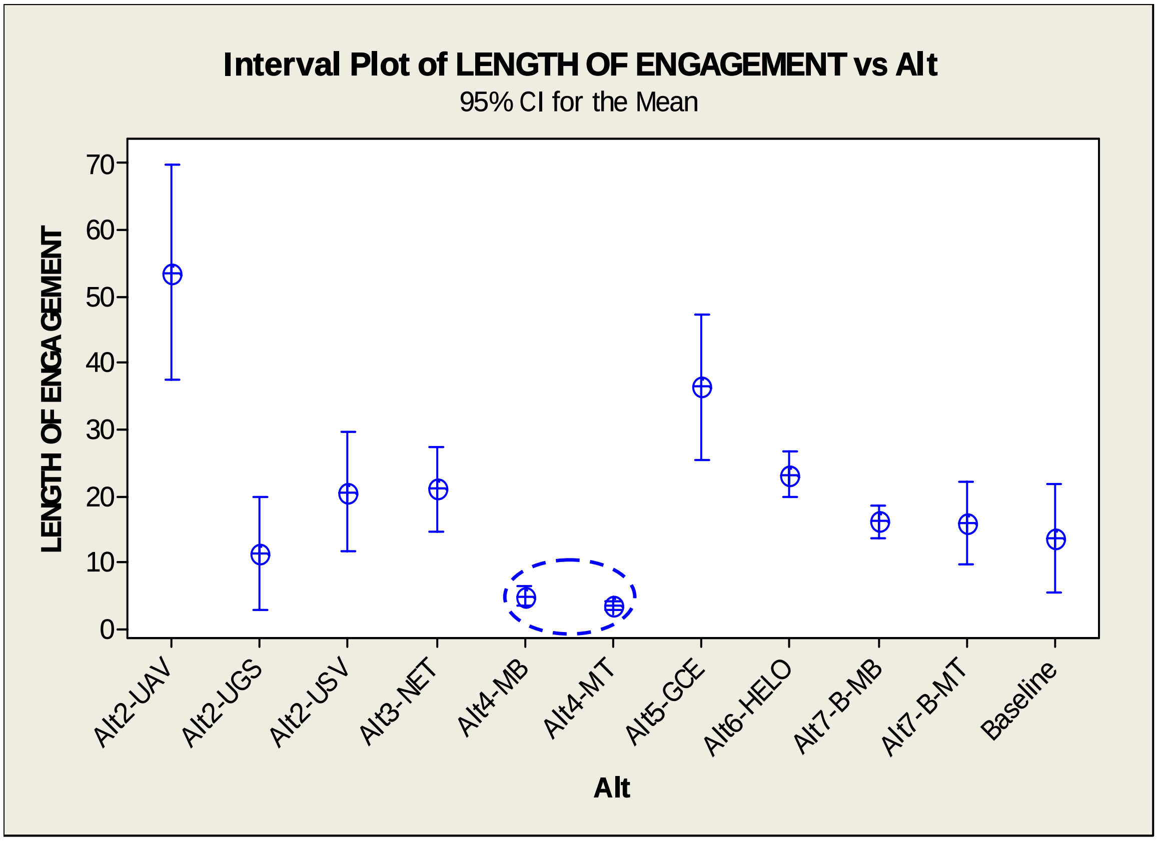

Figure 63. Length of Engagement Per Alternative.

e. Max Classification Range

The networked alternatives follow the performance of the most capable individual unmanned system. As seen in the patrol scenario, the USV and the helicopter options dominate the other alternatives (see Figure 64). Maximum classification range was gathered in a way that does not take into account the true distance from the classified enemy agent to the main blue force. Instead, it reflects the range from the sensor platform to the enemy classified agent. This response was bi-modal (see Figure 65), and did not reflect the range at first detection time. SEA-10 determined this measure of performance to be critically flawed as an overall measure of alternative performance and chose not to use it to calculate overall system performance.

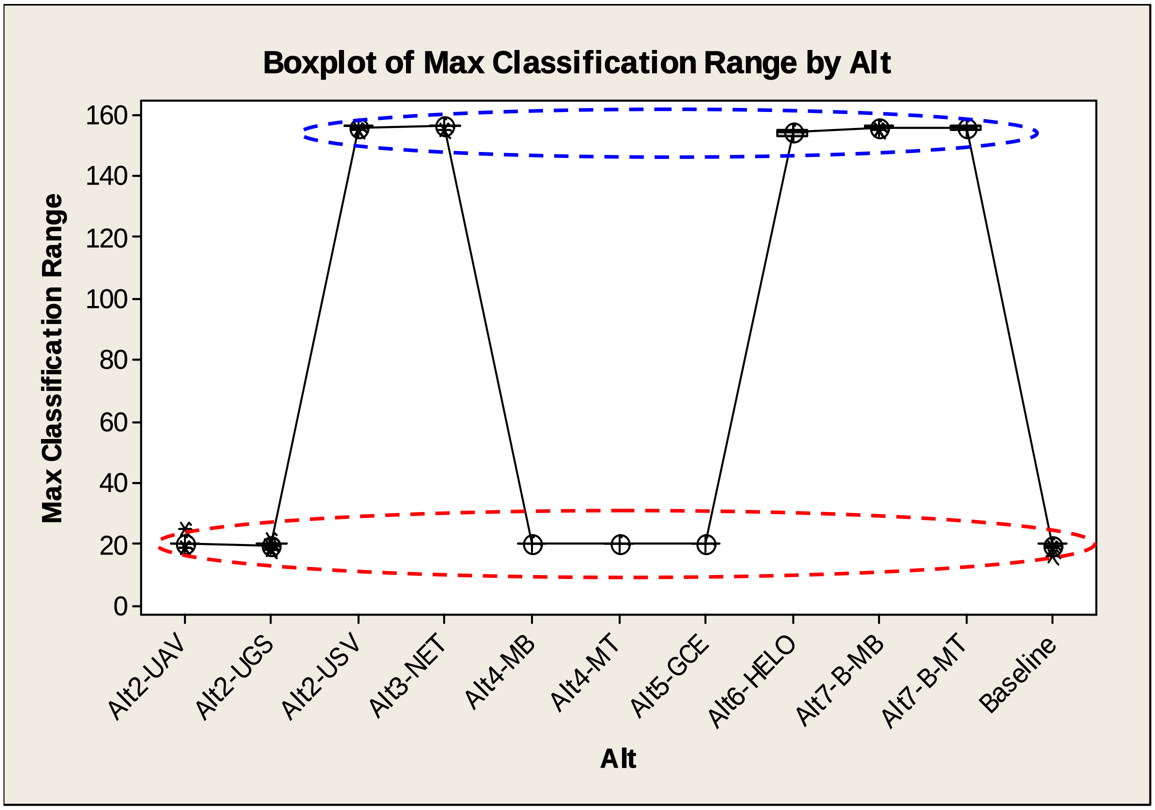

Figure 64. Box Plots of Maximum Classification Range Per Alternative.

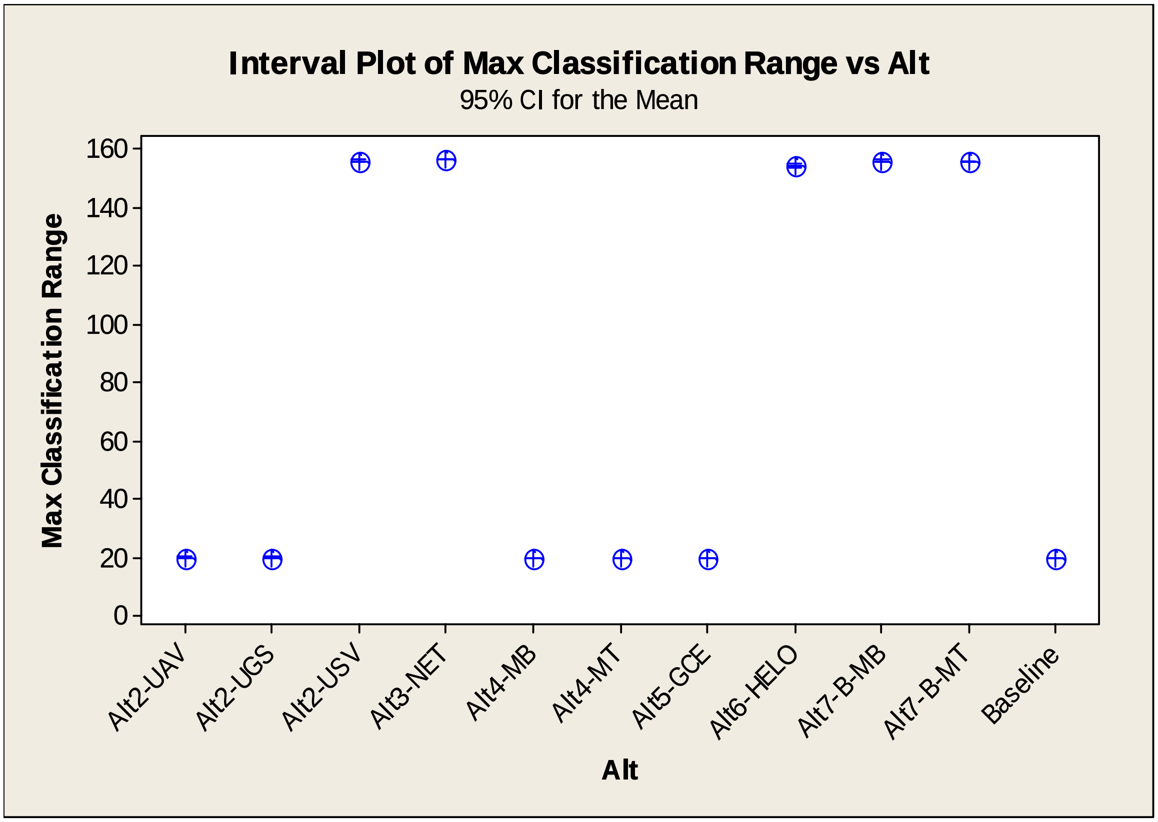

Figure 65. Maximum Classification Range Per Alternative.

5. Ambush Scenario Results

The ambush scenario produced distinct differences from the responses in the patrol scenario, but it also reinforced the patrol findings. The single USV or UAV performed equally well as the networked sensor alternative. The UAV alternative returned the most significant improvement in loss exchange ratio of the sensor only upgrades. The UGS proved ineffective in the ambush scenario due to the stationary nature of red agents and the sensor nodes and therefore resulted in no improvement over the baseline. The mortar team and mortar barge cut engagement time in half, but had no other performance enhancing effect over the baseline. The helicopter and networked mortar barge significantly improved the percentage of no hit runs while the combination of sensor and indirect fire alternatives had dramatic effects on the loss exchange ratio and percentage of no hit runs.

F. ALTERNATIVE ARCHITECTURE EFFICIENCY CURVES

Utility scores and architecture rankings tell an interesting story, but which architecture has the potential to give the RF the greatest improvement in overall capability for the best cost value, or the "Biggest Bang for the Buck?" SEA-10 combined resultant utility scores with cost data described in section VI to generate efficiency curves. The efficiency curve is a useful tool that plots the alternative cost along the X-axis and the alternative utility score along the Y-axis. The efficiency curve is created by moving from left to right and connecting the points of the highest utility scores. The resultant line is called an efficiency curve or frontier. The alternatives that lie to the right and below the curve are classified as "dominated alternatives" in that there is an alternative that outperforms it for a cheaper cost.

SEA-10 generated efficiency curves for each scenario, and an overall efficiency curve based on the calculated utility scores and cost estimation data. These efficiency curves have commonalities and distinct differences. All curves start at the baseline as the cheapest option. The baseline RF is the foundation of all of the alternatives. The mortar team alternative follows adding marginally improved performance for a small premium. The next point in all three curves is the USV single sensor alternative. It either doubles or triples the utility score depending on the scenario for approximately the same cost as the mortar team. At this point the curves diverge and warrant individual attention.

1. Patrol Scenario Efficiency Curve

In the patrol scenario (Figure 66) the UGS alternative provides additional performance for nearly the same cost as the USV. The next point on the curve is the networked mortar team at a considerable increase in cost and only a marginal increase in capability. All other alternatives are dominated by these points. It is significant to note that the UAV, the networked sensor, and the networked mortar barge alternatives have approximately the same cost and performance value.

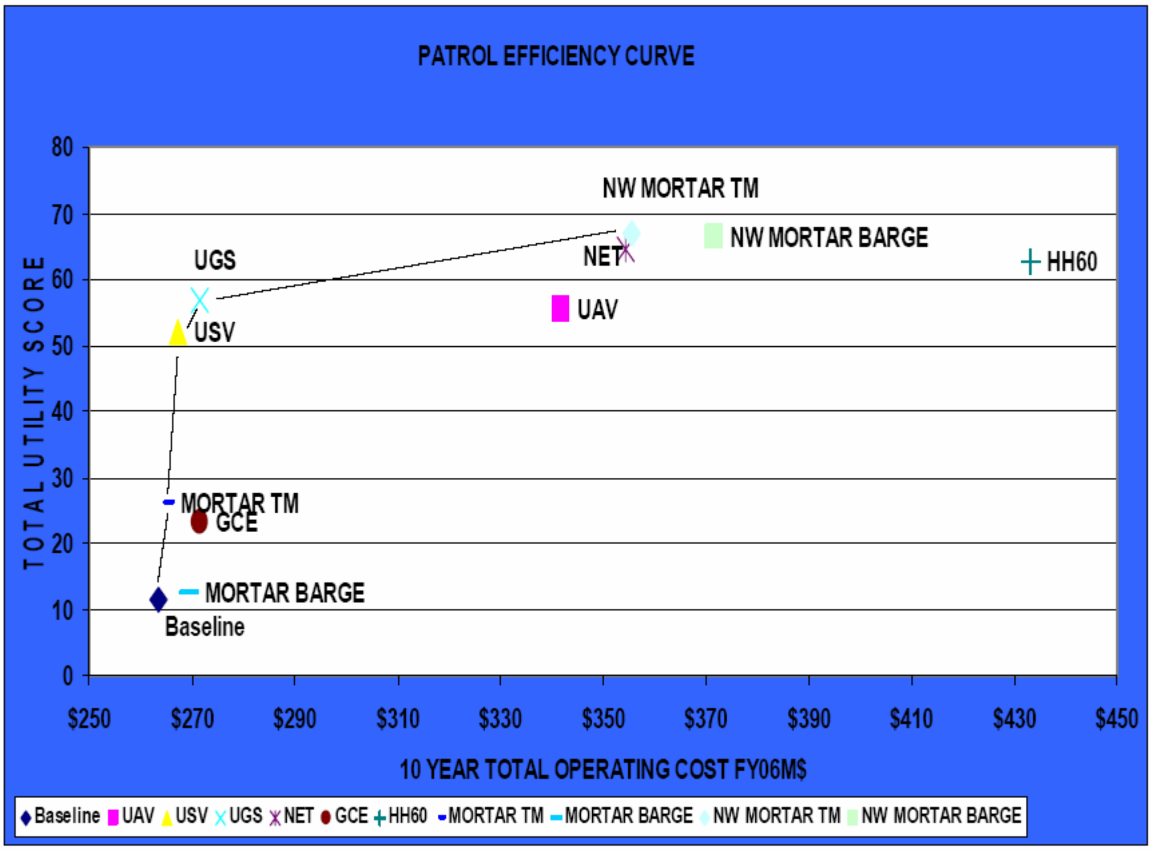

Figure 66. Patrol Scenario Efficiency Curve.

2. Ambush Scenario Efficiency Curve

In the ambush scenario (see Figure 67) the efficiency curve runs from the USV to the helicopter alternative. In the ambush the USV dominates all other alternatives except for the helicopter alternative which has a significantly increased utility score. The interaction of the helicopter against red forces in the scenario was notable, but the added performance resulted in a significant additional cost.

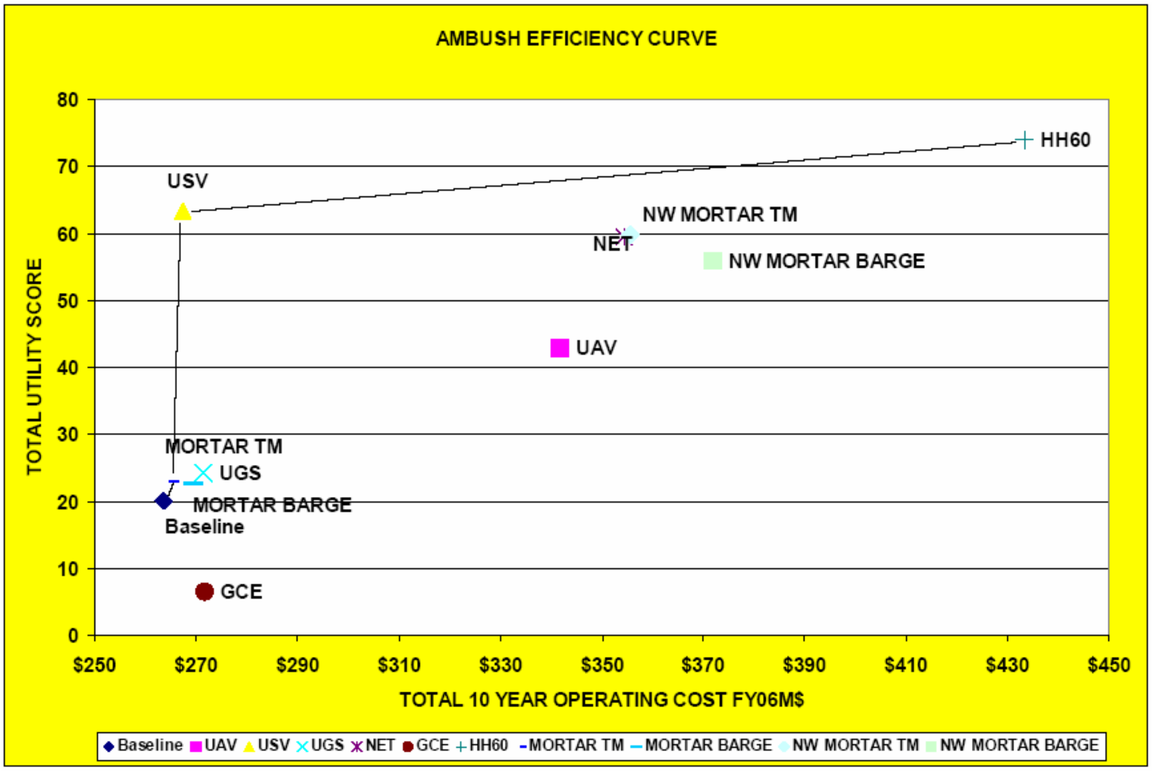

Figure 67. Ambush Scenario Efficiency Curve.

3. Overall Efficiency Curve

In the overall efficiency curve (see Figure 68) the line connects the USV alternative at the far left hand side to the networked mortar team in the middle and ends at the helicopter alternative on the far right hand side. The overall efficiency curve shows that within the single sensor options the USV is the best across both scenarios for the cost. All netted sensors options improve performance, but require some significant investment while the helicopter alternative adds only marginal performance for the increased cost.

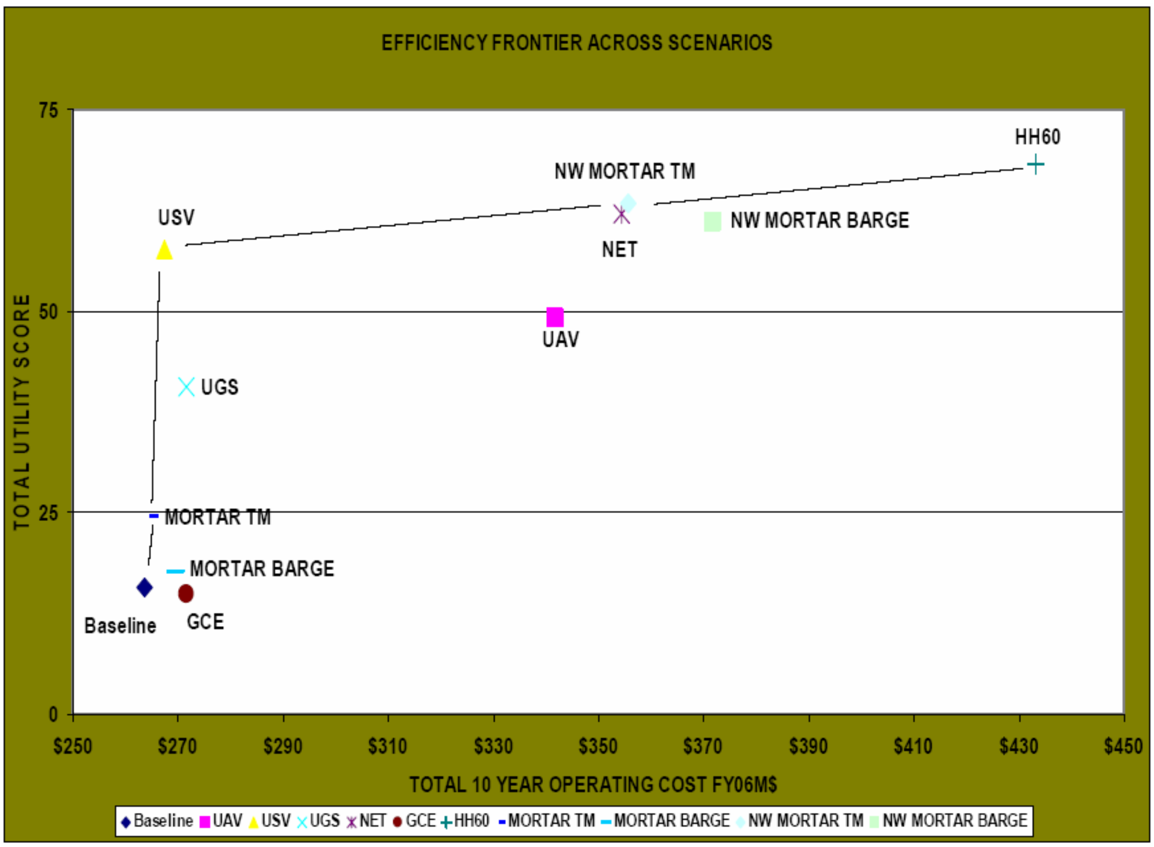

Figure 68. Overall Efficiency Curve.

G. CONCLUSIONS

There were four significant takeaways from initial data analysis.

- The baseline force is fairly robust and occasionally achieves parity in performance with upgraded alternatives depending on the response and scenario.

- A single robust sensor gives the baseline force almost all the benefits of networked sensors.
- In the ambush scenario, upgraded weapons have a significant effect in reducing the length of engagement.
- The combined indirect fire and sensor pairing of the networked mortar barge and the helicopter option dominated all other options across all responses except detect to engage time (only because of model dynamics described previously).

These takeaways were confirmed in detailed statistical analysis, and SEA-10 was now able to answer the initial research questions.

- **Which alternatives give the greatest capability increase to the baseline force?**

  Across both scenarios the helicopter and the indirect fire networked sensor mortar barge dominated engagement and detection responses.
- **What is the effect of unmanned systems on detection and engagement?**

  A single unmanned sensor option (USV, UAV, or UGS) performed as well as the networked senor option with the exception of the UGS in the ambush scenario due to the stationary red force positions.
- **What is the effect of an organic indirect engagement capability?**

  Except in the case of the mortar barge and mortar team cutting length of engagement by greater than half in the ambush scenario simply adding weapons to the baseline had no significant effect on system performance. The pairing of indirect fire and sensor upgrade found in the networked mortar barge and helicopter alternatives is the most potent option.
- **What is the effect of dedicated ground combat element on detection and engagement capabilities?**

  The addition of the GCE does produce a measurable improvement in percentage of no hit runs and loss exchange ratio, but when limited to SEA-10's two scenarios it did not significantly improve overall system performance.

- **What are the effects of dedicated helicopter support?**

  The dedicated helicopter support was by far the most performance enhancing of all the alternative architectures. The combination of extended enemy detection and engagement capability dominated all the other options.

- **Which investment, increasing engagement or detection capability, has the greatest effect on overall system performance?**

  Improving sensor capability had the greatest effect on overall system performance. This may be because the baseline force had adequate weapons capability for the modeled scenarios.

H. RECOMMENDATIONS

As described in the data normalization and detailed statistical analysis sections of this thesis, the helicopter and networked mortar barge detect to engage response scores do not accurately reflect their contribution to battle space awareness. The following conclusions are written with that in mind.

The USV returned the best bang for the buck with an overall utility score of 58 and a nominal cost of $900K (FY06). The USV maintained a high utility score in both the patrol and ambush scenarios. The single sensor option increased battle space awareness and had the necessary mobility that allowed for flexibility of missions in the riverine environment. As modeled, the USV had the ability to scout ahead of the other blue agents, find the enemy, and provide information on enemy locations to blue forces. With this information, blue force agents selected the correct weapons and engaged red forces prior to being ambushed. In reality, this information would give blue forces the opportunity to decide whether to pursue their designated course and if so, prepare for conflict, or to simply find an alternate route.

Given that the USV and UAV single sensor options performed about as well as the networked option SEA 10’s recommendation is to invest in a robust single sensor platform, likely a USV, rather than a complex and expensive networked system. Unfortunately, due to time and schedule constraints, it was not feasible to model all combinations of single sensor options with the increased engagement capability of a mortar team or barge. Further modeling efforts could determine the feasibility and affordability of pairing the USV with an inexpensive indirect fire weapon, potentially a mortar barge like NEMO, to obtain the maximum increase in battle space awareness and response capability for the RF of 2010.

It is also important to consider alternatives that should have had a significant utility value at a reasonable cost, but did not. Increased weapons alternatives did not significantly enhance performance, because the baseline force already has a considerable engagement capability without an additional weapons augment. The networked sensor option performed at parity with the combined indirect fire sensor alternatives but did not provide any added capability.

SEA-10 recommends looking into the feasibility of procuring USV's comparable to those modeled (SeaFox) to work in tandem with riverine boat divisions. The added performance capability of the system for the low cost makes this alternative a promising candidate to increase battlespace awareness and situational responsiveness.

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IX. AREAS FOR FURTHER STUDY

A. AREAS FOR FURTHER STUDY

The Navy's most recent version of the riverine force (RF) has presented many areas of study that should be addressed to help the war fighter. SEA-10 chose to address the detection and engagement capability of the RF, and how to enhance these capabilities to give the war fighter better situational awareness and responsiveness. Through the course of this study SEA-10 discovered many other areas of research beyond the scope of this thesis, but worthy of further study and research. SEA-10 categorized areas for further study as communications, energy, modeling and simulation, movement, force protection, mine countermeasures, sustainment, and policy.

1. Communications

All of the alternative force packages relied heavily on the use of reliable and robust communication and data networks. In the models, this reliability is assumed. However, in the real world, network reliability is a valid concern, particularly in environments in which the RF will be expected to operate. It was also assumed that the Joint Tactical Radio System (JTRS) would be available for use by 2010. Due to significant programmatic issues and budget constraints, it would be beneficial to conduct further research on available networking options. Potential areas for study include:

- Network reliability
- Network backbone alternatives to JTRS (i.e., ADNS, IP based mesh networks)
- Network efficiency among the different alternatives (what is the best way to set up the networks for speed of information and ease of interpretation)
- Foliage penetration of sensors and wireless networks

2. Energy

Competition for natural resources will become a common cause for military action in resource rich regions of the world as global supplies dwindle. The United States purchases a majority of its fossil fuels from abroad. As the effects of globalization increase, other countries will have the ability to compete economically with the United States, making it more expensive to protect vital national interests.

Logistics considerations should be made when applying alternative energy resources to riverine operations. Riverine forces may be required to operate in remote locations. Decreasing the need for fuel could greatly enhance the operational reach of the force and maintain the RF on station longer. The opportunity exists to build a military force using alternative energy which may set a trend for future uses of alternative fuels. Potential areas of study include:

- Use of alternative fuels on SURC or other small boat platform(diesel alternatives)
- Use of solar/wind and compost power for TOC
- Man portable photo-voltaic cells (solar panels) for SURC energy requirements
- Study of battery requirements for riverine operations (on SURC, in TOC)

3. Modeling and Simulation

There are almost countless alternative force packages to apply to the riverine model. As technology increases the number will continue to rise. SEA-10's originally proposed to model five force packages. Upon further evaluation, benefit was seen in adding six more alternative force packages. Modeling and analysis of other force packages in these scenarios would certainly be of benefit to the war fighters. However, in the interest of delivering a quality product within the established time constraint, SEA-10 had to refrain from conducting more modeling runs. The following suggestions could be areas of further study that use the model already established by SEA-10:

- Model ground combat element with a single sensor plus up (UAV, USV or UGS)
- Model the weapons plus-up (mortar team, mortar barge) with a single sensor (UAV, USV, UGS)
- Model the capabilities and limitations of various riverine platforms: Small Unit Riverine Craft (SURC); RAC, SOC-R; 11m RHIB; M12 Watercat (Finnish)
- Executing the architectures within more detailed models to include elevation, endurance restrictions, varied missions, more state levels (i.e., differing reactions other than aggression)
- Day vs. night modeling and how to model illumination effects on sensors

4. Movement

The RF will operate in a variety of environments. It is reasonable to assume that the RF will operate in the vicinity of an ocean or other large body of water that can sustain a seabase. Investigation of rivers where the RF may operate, show that this is not always the case. Therefore, careful consideration will have to be made on how to get the RF to its area of operation, and once there, how it will be sustained.

- What is the most cost effective means to move the RF into theater?
- How is the RF reconstituted after loss of equipment / personnel in remote regions?
- How will the RF get to the fight?

5. Force Protection

The RF is designed as a self sustained force that is required to provide its own force protection measures. In an environment where the host country does not have control of the people within its borders the RF will be at a greater risk than in a country where this is not the case.

- What are the RF force protection requirements?
- How do you defend the RF from an AT/FP standpoint?
- What technology can aid in implementing force protection measures?
- What non-lethal alternatives can be employed safely? What is the effectiveness of various non-lethal agents?
- Unmanned system swarm tactics

6. Mine Countermeasures

Mine countermeasures could be a subsection of force protection; however, as the RF continues to evolve so will the enemy. As seen with the IED problem in Iraq, it is only a matter of time before the enemy realizes the importance of the waterways to the success for the forces and begins to employ countermeasures to hinder operations. Historically, mines were used in almost all conflicts that involved sustained operations on rivers[171]. It would be dangerous to assume that the enemy would not employ mines

171 R.B. Dunnavent, *Brown Water Warfare: The US Navy in Riverine Warfare and the Emergence of a Tactical Doctrine 1775-1990*, Appendix A, University Press of Florida, 2003.

against RF forces. Steps should be taken now, before the mine threat exists, to train forces and design the force to counter this threat.

- How resilient is the SURC hull towards an exploding mine?
- What are the procedures for clearing mines in shallow water?
- What technology can be used to counter mine threats in a river way?
- What personnel should be employed with a RF when a mine threat is present (METOC, EOD, intelligence detachment, helicopter detachment)?

7. Sustainment

Riverine forces are unique to the conventional navy in that they must operate around the land. In the event that a Seabase is not established, the RF will be required to sustain itself from the land. This is a significant area of further study that will need to be addressed if the RF is going to be used in remote areas.

- What are the logistics requirements to move the RF into theater?
- What levels of sustainment are required to support the RF in theater?
- Where is a Seabase appropriate?
- How do you re-supply the RF under the 1000 ship navy paradigm?
- Fuel requirements of RF, including NEMO (see above recommendation)

8. Policy

History has shown that the composition of a riverine force depends on the environment in which that force is operating[172]. What works in Iraq will not necessarily work in Colombia or the Niger River Delta. The initial RF is being equipped to work in a semi-arid desert environment but is also looking at employing forces elsewhere in the world, where the environment is vastly different. Additionally, the RF will be in direct contact with a constantly evolving enemy that will continue to improve his weapons and tactics. A static force, in terms of procurement will not have a chance to adapt to the enemy and may be required to use systems that are not suitable for the operational environment.

An acquisition system similar to SOCOM would be desirable; however, it is understood that significant policy changes would have to take place for this to happen.

[172] R. Benbow, F. Ensminger, P. Swartz, S. Savitz, & D. Stimpson, Center for Naval Analysis, *Renewal of Navy's Riverine Capability: A Preliminary Examination of Past, Current and Future Capabilities*, January 2006.

SOCOM, unlike NECC, has Title 10 authority that permits the agency to purchase weapons and systems without being subject to the time intensive and cumbersome JCIDS process. An alternative that provides a rapid acquisition process for riverine needs should be investigated.

It would be advantageous that NECC use the ongoing low cost experimentation efforts such as COAST and TNT to field test desired capabilities.

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APPENDIX A. MANA MODELING INPUT METHODOLOGY

SEA-10 had to track levels of individual agent situational awareness, how much of the information the agent has gathered per turn, the amount of shared memory maintained by a squad, and the levels of information shared between squads over communication links. SEA-10 also recorded various agent ranges and specific settings based on the agent's state. Weapons settings, conversions, and communications were the last two remaining key matrices which may provide comparison for further study.

	Agent SA																		Squad SA							Inorganic SA					
AGENT and STATE	Enemies	Combat	Enemy Threat 1	EnemyThreat 2	EnemyThreat 3	Ideal Enemy	En. Class	Uninjured Friends	Injured Friends	Cluster	Neutrals	Next Waypoint	Advance	Alt. Waypoint	Easy Going	Cover	Concealment	Line Center	Enemy Threat 1	EnemyThreat 2	EnemyThreat 3	Squad Friends	Other Friends	Neutrals	Unknowns	Enemy Threat 1	EnemyThreat 2	EnemyThreat 3	Friends	Neutrals	Unknowns
TOC	100		100	75	50	100	0	100	50		0	0		0	10	100	10	0	100	75	50	100	50	0	0	75	50	15	50	0	0
SURC	100		100	75	50	100	0	0	0		0	75		0	10	10	10	10	100	100	50	30	0	0	0	100	100	50	0	0	0
VBSS	100		100	75	50	100	0	0	0		0	75		0	10	10	10	10	100	100	50	0	0	0	0	100	100	25	0	0	0
TRSS	100		0	0	0	0		0	0		0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UAV	100		100	100	100	0		0	0		0	20		0	0	0	0	0	100	100	100	0	0	0	100	100	100	100	0	0	100
USV	100		100	75	50	100	0	0	0		0	75		0	0	0	0	0	100	100	50	30	0	0	0	100	100	50	0	0	0
GCE Default	0		0	0	0	0		0	0		0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GCE Fuel Out	0		0	0	0	0		0	0		0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GCE Refuelled by Anyone	100		100	75	50	0		100	50		0	75		0	10	30	30	10	100	75	50	50	25	0	100	75	50	25	25	0	75
Mortar Team Default	0		0	0	0	0		0	0		0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mortar Team Fuel Out	0		0	0	0	0		0	0		0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mortar Team Refuelled by Anyone	100		100	75	50	0		100	50		0	0		0	10	30	30	10	100	75	50	30	0	0	0	75	50	25	25	0	100
Mortar Barge	100		100	75	50	100	0	0	0		0	75		0	10	10	10	10	100	100	50	30	0	0	0	100	100	50	0	0	0
HH-60	100		100	100	100	0		0	0		0	20		0	0	0	0	0	100	100	100	0	0	0	100	100	100	100	0	0	100
Red RifleRPG-22	100		100	75	50	100	0	100	50		0	50		0	10	30	30	10	100	75	50	25	0	0	100	75	50	25	15	0	75
Red RifleRPG-22 AMB Default	100		100	75	50	100	0	100	50		0	50		0	10	30	60	10	100	75	50	25	0	0	100	75	50	25	15	0	50
Red RifleRPG-22 AMB Squad EN Contact	100		100	100	50	100	0	100	50		0	50		0	10	30	30	10	100	100	100	50	25	0	20	75	50	25	15	0	50
Red RifleRPG-22 AMB IO SA Enemy Contact	100		100	75	50	100	0	100	50		0	50		0	10	30	30	10	100	75	50	50	25	0	100	75	50	25	15	0	50
NEUTRAL	-100		0	0	0	0		100	50		0	10		100	100	0	0	0	-100	-100	-100	0	0	0	0	-100	-100	-100	0	0	0

Table 30. MANA Agent Behavioral Settings.

AGENT and STATE	Icon	Allegiance	Threat	Agent Class	Movement Speed	No Hits to kill	Stealth	Armour Thickness	Waypoint Radius	Sensor Class Range	Sensor Detect Range	Sensor Height (m)	Fuel Usage Rate	Refuel Trigger Rate	Prob Refuel Enemy	Prob Refuel Friend	Prob Refuel Neutral	Notes
TOC	15	1	2	0	0	1	100	0	3	0	0	2	0	0	0	0	0	
SURC	11	1	3	1	1000	11	0	0	3	20	156	2	0	50	0	0	100	
VBSS	11	1	3	1	1000	22	0	0	3	20	156	2	0	0	0	0	0	
TRSS	14	1	3	1	0	1	100	0	3	5	5	2	0	0	0	0	0	
UAV	9	1	3	0	1000	1	0	1000	3	5	5	308	0	0	0	0	0	
USV	5	1	3	1	1000	5	0	1000	3	156	156	2	0	0	0	0	0	
GCE Default	78	0	2	1	0	1	0	0	3	0	0	2	1000	0	0	0	0	Initial state creates fuel need.
GCE Fuel Out	53	0	2	0	0	1	0	0	3	0	0	2	0	0	0	0	0	State requesting fuel
GCE Refuelled by Anyone	2	1	2	0	44	1	10	0	3	20	156	2	0	40	0	0	100	Refuelled, simulates deployment
Mortar Team Default	78	0	2	1	0	1	0	0	3	0	0	2	1000	0	0	0	0	Initial state creates fuel need.
Mortar Team Fuel Out	53	0	2	0	0	1	0	0	3	0	0	2	0	0	0	0	0	State requesting fuel
Mortar Team Refuelled by Anyone	2	1	3	1	44	1	0	0	3	20	156	2	0	40	0	0	100	Refuelled, simulates deployement
Mortar Barge	7	1	3	1	1000	7	0	0	3	20	156	2	0	0	0	0	0	
HH-60	8	1	3	0	1000	7	0	0	3	156	156	200	0	0	0	0	0	
Red RifleRPG-22	26	2	2	1	44	1	10	0	3	20	156	2	0	0	0	0	0	
Red RifleRPG-22 AMB Default	26	2	2	1	0	1	21	0	3	20	156	2	0	0	0	0	0	Awaiting Ambush
Red RifleRPG-22 AMB Squad EN Contact	26	2	2	1	44	1	10	0	3	20	156	2	0	0	0	0	0	Enemy Contact
Red RifleRPG-22 AMB IO SA Enemy Contact	26	2	2	1	44	1	10	0	3	20	156	2	0	0	0	0	0	Inorganic Enemy Contact
NEUTRAL	51	0	0	0	44	1	0	0	3	0	0	2	0	0	0	0	0	

Table 31. General MANA Agent Settings.

Kinetic	Meters			Grids										
Name	Min	Effective	Max	Min	Effective	Max	Shot Radius (m)	Shot Radius (grids)	Max Targets/ min	Max Targets / Step (MANA)	{High Rate of Fire / min}	Carried Rounds	Penetration (mm)	Notes
AK-47/AKM	0	300	2500	0	8	65	0	0	40	1000	600	120	0	7.62mm Assault Rifle
AK-74	0	500	800	0	13	21	0	0	40	1000	600	300	0	5.45mm Assault Rifle
RPK-74	0	800	1000	0	21	26	0	0	50	1000	600	320	0	5.45mm Light Machine Gun
SVD	0	1300	3800	0	34	99	0	0	30	1000	30	40	10	7.62mm Sniper Rifle
PKM	0	1000	3800	0	26	99	0	0	250	1000	650	600	8	7.62mm GPM
NSV	0	2000	7850	0	52	205	0	0	100	1000	680	300	20	12.7mm Heavy Machine Gun
M-16A2/A3	0	550	3600	0	14	94	0	0	45	1000	800	1250	0	7.62mm Assault Rifle
M240B	0	800	3725	0	21	97	0	0	100	1000	200	1200	0	7.62mm Heavy Machine Gun
M249	0	1000	3600	0	26	94	0	0	100	1000	750	1000	0	5.56mm Heavy Machine Gun
M60	0	800	3725	0	21	97	0	0	100	1000	550	900	8	7.62mm Heavy Machine Gun
GAU-17/A	0	400	1000	0	10	26	0	0	2000	1000	4000	5000	0	7.62mm Mini Gun
M2	0	2400	6770	0	63	177	0	0	200	1000	550	600	11	12.7mm .50 cal Machine Gun

Table 32. MANA Kinetic Weapons Settings.

High Explosive	Meters			Grids										
Name	Min	Effective	Max	Min	Effective	Max	Shot Radius (m)	Shot Radius (grids)	Max Targets/ min	Max Targets / Step (MANA)	{High Rate of Fire / min}	Carried Rounds	Penetration (mm)	Notes
RPG-7	0	500	800	0	13	21	5	0	6	600	6	5	330	40mm ATGL
RPG-22	0	150	250	0	4	7	5	0	1	100	1	1	390	72mm Disposable ATGL
SA-16	600	3500	5000	16	91	131	5	0	1	100	1	2	0	Manportable SAM
82mm Mortar	1000	4000	4000	26	104	104	15	0	4	400	65	10	0	40mm ATGL
GP-30	40	400	400	1	10	10	6	0	4	400	5	10	0	40mm Grenade Launcher
M203	31	350	400	1	9	10	5	0	5	500	7	36	330	40mm Grenade Launcher
M-72	10	200	1000	0	5	26	5	0	1	100	1	1	300	66mm Disposable ATGL
M224	44	1930	1930	1	50	50	4	0	8	800	30	20	0	62mm Mortar
M252	83	5608	5608	2	146	146	40	1	15	1000	30	60	0	82mm Mortar
AGM-114K	500		8000	13		209	10	0	4	4	4	4	500	Hellfire Missile
MK19	18	1500	2550	0	39	67	15	0	40	1000	60	164	51	40mm Grenade MG

Table 33. MANA Explosive Weapons Settings.

Item #	Device	Type	Notes	Range (meters)	range (grids)	Capacity (msgs/sec)	capacity (msgs/step)	Queue Buffer Size	Latency (sec)	latency (model)	Self	Reliab.	Accuracy	MxAge	Rank Filter	Include	Delivery (Guaranteed or F-N-F)
1	Cellphone or equivalent	VHF	Limited Reliability	2,000	52	1	60	2	10	0	2	70	100	-1	High	SETC	F-N-F
2	Basic Radio or equivalent	UHF	LOS	50	1	1	60	2	10	0	2	70	100	-1	High	SET	F-N-F
3	Personal Role Radio (PRR) or equivalent	UHF	Intra-Team Communications	500	13	1	60	2	10	0	2	93	100	-1	High	SNETC	F-N-F
4	PRC 148 or equivalent	VHF/UHF	Platoon – Squad – Team C2 - CAS Control	6,500	170	1	60	2	10	0	2	93	100	-1	High	SNETC	F-N-F
5	JTRS Cluster(8 channel) or equivalent	Digitial	Future Internet Networked Protocal System (Joint Tactical Radio System)	50,000	1,305	8	480	16	10	0	2	93	100	-1	High	SNETC	F-N-F
6	JTRS Cluster(4 channel) or equivalent	Digitial	Future Internet Networked Protocal System (Joint Tactical Radio System)	50,000	1,305	4	240	8	10	0	2	93	100	-1	High	SNETC	F-N-F
7	JTRS Cluster 5 SFF-D-E-G or equivalent	Digitial	Future Internet Networked Protocal System (Joint Tactical Radio System)	50,000	1,305	5	300	10	10	0	2	98	100	-1	High	SNETC	F-N-F
8	PRC 117 or equivalent	VHF / UHF / Satellite Communi cations	Squad – Plat – HHQ CAS/Fires Control (OTH - Digital)	11,500	300	1	60	2	10	0	2	93	100	-1	High	SNETC	F-N-F
			notes:					Call Waiting		Time to connect	every 2 min			Will wait indefinitly.			

Table 34. MANA Communication Settings.

APPENDIX B. COST ESTIMATION SPREADSHEETS

Cost estimation was conducted to describe costs associated with each of the alternative force packages. The purpose is to assist the decision maker in determining which alternative provides the best capability with the least cost. However, it is ultimately up to the decision maker to weight the importance of each capability as a function of the cost. This section is designed to define the cost of each individual force package based on its intended use in the scenarios. The overall cost estimated is presented first, followed by the individual alternative cost estimates.

Costs for each alternative are divided into three categories; procurement, operating and support for personnel, operating and support for equipment (including ammunition where applicable). Throughout the 10 year period several rules were instated in the interest of fairness for evaluating the cost. The following are the guidelines used for developing cost estimates.

- All numbers are in FY06$
- All pay is increased by 2% per year
- All procurement occurs in 2010
- All operating and support costs for equipment are estimated at 10% of procurement cost. Each year an additional 1% is added to this value to account for inflation
- All information is from open source documents.
- The vehicles/equipment chosen are not an endorsement for any one product over another, rather, they most closely met the requirements for the riverine force as seen by SEA 10.
- All systems currently are, or have plans to be programs of record by 2010[173].

[173] NEMO is one exception to this statement. Although the technology is available it is not a US system and would therefore be subject to further T&E.

Baseline	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total/Average
Alt 1 (UAV)												
RDT&E and Procurement	36,000,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
O&S (personnel)	469,496.55	478,886.48	488,464.21	497,854.14	507,811.22	517,201.16	527,545.18	536,935.11	547,673.81	557,063.74	568,205.02	
O&S (schools, maintenance, spare parts, equipment)	2,853,003.45	2,948,613.52	3,044,035.79	3,139,645.86	3,234,688.78	3,330,298.84	3,424,954.82	3,520,564.89	3,614,826.19	3,710,436.26	3,804,294.98	
Total	39,322,500.00	3,427,500.00	3,532,500.00	3,637,500.00	3,742,500.00	3,847,500.00	3,952,500.00	4,057,500.00	4,162,500.00	4,267,500.00	4,372,500.00	78,322,500.00 **HI 78.3 M, Lo 3.4M** 3,900,000.00
Alt 1 (USV)												
RDT&E and Procurement	900,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
O&S Personnel	$171,154.85	$174,577.95	$178,069.51	$181,630.90	$185,263.51	$188,968.78	$192,748.16	$196,603.12	$200,535.18	$204,545.89	$208,636.81	
O&S Maintenance	$67,656.00	$68,332.56	$69,015.89	$69,706.04	$70,403.10	$71,107.14	$71,818.21	$72,536.39	$73,261.75	$73,994.37	$74,734.31	
Total	1,138,810.85	242,910.51	247,085.39	251,336.94	255,666.62	260,075.92	264,566.37	269,139.51	273,796.94	278,540.26	283,371.12	3,765,300.42 **Hi 3.7M Lo .32M** 342,300.04
Alt 1 (UGS)												
RDT&E and Procurement	1,904,229.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
O&S Total	2,255,844.39	356,743.47	361,672.28	366,674.77	371,757.77	376,922.81	382,171.34	387,504.82	392,924.76	398,432.69	404,030.15	
Total	4,160,073.39	356,743.47	361,672.28	366,674.77	371,757.77	376,922.81	382,171.34	387,504.82	392,924.76	398,432.69	404,030.15	7,958,908.25 **Hi 2.0M Lo .161M** [illegible]

Table 35. Alternative 1 Unmanned Sensor Cost Estimates.

ALT 2
Ground Combat Element

Personnel	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40	671,510.40
Weapons	17,800.00	8,080.00	10,480.00	8,080.00	10,480.00	18,142.00	8,226.40	8,226.40	8,226.40	8,226.40	19,364.98
Equipment	170,674.96	51,202.49	51,714.51	52,231.66	52,753.97	53,281.51	53,814.33	54,352.47	54,896.00	55,444.96	55,999.41
Total	**859,985.36**	**730,792.89**	**733,704.91**	**731,822.06**	**734,744.37**	**742,933.91**	**733,551.13**	**734,089.27**	**734,632.80**	**735,181.76**	**746,874.79**

Hi .859
8,218,313.25 **Lo .7**
747,119.39

ALT 3

Network Sensor

Network	$392,400.00	$39,240.00	$39,632.40	$40,028.72	$40,429.01	$40,833.30	$41,241.63	$41,654.05	$42,070.59	$42,491.30	$42,916.21
Unmanned Systems	$42,247,658.69	$3,548,267.50	$3,652,793.46	$3,757,657.57	$3,862,113.16	$3,967,297.58	$4,071,692.53	$4,177,209.23	$4,281,547.89	$4,387,409.20	$4,491,696.25
Total	$42,640,058.69	$3,587,507.50	$3,692,425.86	$3,797,686.29	$3,902,542.18	$4,008,130.88	$4,112,934.16	$4,218,863.28	$4,323,618.48	$4,429,900.50	$4,534,612.46

Hi 24M
83,248,280.27 **Lo 5.5M**
83,248,280.27
$7,568,025.48

Alt 4
Indirect Fire (NEMO)

Procurement	4,800,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&S Personnel	522,651.75	533,104.78	543,747.77	554,584.51	565,618.88	576,854.83	588,296.39	599,947.67	611,812.87	623,896.27	636,202.23
O&S POL, spare parts, Ammo	533,568.00	538,368.01	543,751.69	548,648.18	554,134.66	559,129.57	564,720.87	569,816.17	575,514.34	580,712.06	586,519.18
Total	5,856,219.75	1,071,472.79	1,087,499.46	1,103,232.69	1,119,753.54	1,135,984.40	1,153,017.25	1,169,763.84	1,187,327.21	1,204,608.33	1,222,721.41

Hi 1.6 M
5,856,219.75 **Lo .69M**
1,145,538.09

Table 36. Alternative 2, 3, and 4 Cost Estimates.

ALT 5
Helicopter

Procurement	126,900,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Personnel	1,357,650.00	1,384,803.00	1,412,499.06	1,440,749.04	1,469,564.02	1,498,955.30	1,528,934.41	1,559,513.10	1,590,703.36	1,622,517.43	1,654,967.77		
Operations and Support (helo)	2104867.284	2125915.957	2126126.444	2147387.708	2126341.162	2147604.573	2126343.33	2147606.763	2126343.352	2147606.786	2126343.352		Information was available on VAMSOC
Operations and Support (equipment)	176700	53010	53010	53010	53010	53010	53010	53010	53010	53010	53010		
Weapons (procurment and O&S)	1930350	19303.5	19496.535	19691.50035	19888.41535	20087.29951	20288.1725	20491.05423	20695.96477	20902.92442	21111.95366		
Total	132,469,567.28	3,583,032.46	3,611,132.04	3,660,838.25	3,668,803.60	3,719,657.18	3,728,575.91	3,780,620.91	3,790,752.68	3,844,037.14	3,855,433.08	169,712,450.52	**Hi 35.2M Lo 3.4M**
												3,892,040.96	
										10 year without procurement		42,812,450.52	

Table 37. Alternative 5 Cost Estimate.

Unmanned Aerial Vehicle

The cost for Unmanned Aerial Vehicles (UAVs) is recorded in the following spreadsheet. All information is open source.

Procurement costs for Shadow UAV were estimated at $18.2M for each system. Based on phone interviews with personnel directly involved with the Shadow and Pioneer program it was found that typical deployments of UAV company's include two UAV systems[174]. Additionally, based on reliability data and phone interviews with operators, it became apparent that two Shadow UAV systems would be needed to provide 24 hour support to riverine forces.

The Shadow UAV operations and support cost includes the cost of training students and providing schoolhouse support. Personnel who are trained to operate the Shadow are the Aerial Vehicle Operators (AVO) and Mission Payload Operators (MPO). The average AVO and MPO is an E3 with two years of service and an E4 with 3 years of service, respectfully. The AVO's and MPO's attend school for 24 weeks and are then assigned to a Shadow company. Maintenance and technical support personnel also are assigned to the Shadow company. The maintenance personnel consist of 3 E-3s with 2 years of service and 3 E-4s with 3 years of service and attend school for 8 weeks prior to assignment in the Shadow company. Technical support for the Shadow company comes from a Shadow technician who is generally a Chief Warrant Officer with 10 years of service and who attends school for 9 weeks.

A Shadow company consists of one O-3 Company Commander, four O-1 platoon leaders, four CWO 1 technicians, one Senior NCO, three MPO's, three AVO's and six maintenance personnel. All cost associated with the Shadow company were derived from military pay charts for FY-06.

Operations and support cost for equipment was estimated between 10% o of the procurement cost from the President's budget for FY2006[175].

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[174] Phone interview with Shadow UAV S-3 10 October 2006 and email with Pioneer PMA representative

[175] Office of Secretary of Defense, Defense Budget Materials "*Department of the Army Procurement Programs, Other Procurement February 2006*"Retrived 08 November 2006 on the World Wide Web at []http://www.asafm.army.mil/budget/fybm/FY07/pforms/opa2.pdf.], p 236

Unmanned Aerial Vehicles													
Scan Eagle	Description	Service Contract											
Total System	440 K / 6 months	880000	880000	880000	880000	880000	880000	880000	880000	880000	880000	880000	9680000
		Agent pays Boeing/Insuit for Scan eagle service. For example, buy 10 or 12 hours of service per day										Sum Service	$ 9,680,000.00
		for a fixed amount of time (i.e. 6 months). Service contract includes aircraft, operators, maintenance										Sum Service for 70 systems	$ 677,600,000.00
		support, etc. Images are provided to agent for a fixed fee of life of the contract.										(only two craft per systems)	
Shadow	Description	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
Acquisition													
Shadow	President's Budget												
		2 systems		2 systems									
Total System	18 M per system, 2 systems every other year	$36,000,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$36,000,000.00
4 Birds	.39M											Total Procurment Cost	$36,000,000.00

Table 38. UAV Cost Estimation Calculations.

Personnel													
Training													
Operators (AVO/MPO)	24 Weeks (6 months)/ 480 per year (E-3 = 1595.70)	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$4,595,616.00	$50,551,776.00
Maintenance	8 weeks/80 per year/(E-3=1595.70)	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$255,312.00	$2,808,432.00
Technician	8 weeks/80 per year/ W1 w/ 10 years = 3243.90)	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$648,780.00	$7,136,580.00
School House Officers	12 Officers: 1 LT Col (w/16 years6630.60), 4 Major (w/ 12 years 5755.8), 7 O-3 (w/6 years 4503.00) Nominally**	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$734,097.60	$8,075,073.60
School House Enlisted	127 Enlisted (average E-6 w/ 12 years)	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$4,366,717.20	$48,033,889.20
		$5,489,708.00	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$10,600,522.80	$116,605,750.80
	Sum for Company	$65,554.95	$66,866.05	$68,203.37	$69,567.44	$70,958.79	$72,377.96	$73,825.52	$75,302.03	$76,808.07	$78,344.23	$79,911.12	

Table 39. UAV Cost Estimation Calculations.

Unmanned Surface Vehicle

Unmanned Surface Vehicle (USV) costs include procurement of the system and cost of operations and support of personnel and equipment.

Cost of procurement is 300K (FY06$) for one USV, and it is assumed that three USVs are procured to support each of the boat divisions.

Operations and Support cost for personnel includes the cost of training five students (all E-5's), once a quarter for five days. The personnel being trained include operators and maintainers for each USV. Cost of training also includes the cost of one instructor who is an E-7 with 14 years of service.

Operations and support cost for equipment includes the cost of fuel and spare parts. The cost of fuel was estimated using the fuel curves fro the Cummins Mercruiser Diesel engine, Model 2.8L ES200. It was assumed that 80% of the time the USV will operate at cruising speed, 8-12 knots (1200 RPM), and 20% of the time the USV will run at sprint speed, 30+ knots (3600-3800 RPM). On average, the USV would burn 3.4 gallons/hour and over a 10 hour patrol 34 gallons of petrol (DFM) would be burned at a nominal cost of $2.00 per gallon. Also included in POL cost is the cost of oil changes.

Operations and support cost for spare parts includes both repairable and consumable parts. Cost analogy was derived from the cost of the Riverine Assault Craft (RAC) for consumable and repairable spare parts.

	Unit Cost	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total	Total
Procurement	300,000.00	900,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	900,000.00	3,765,300.42
O&S Personnel														
Operators	2 E-5 with 10 years of service	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	639,302.40	
Training														
Instructor	1 Instructor (E-7 with 14 years of service)	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	38,995.20	428,947.20	
Class	5 students for 5 days, 4 times a year	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	15,922.85	175,151.34	
Maintainers	2 E-5 with 10 years of service	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	58,118.40	639,302.40	
	Personnel Total	171,154.85	174,577.95	178,069.51	181,630.90	185,263.51	188,968.78	192,748.16	196,603.12	200,535.18	204,545.89	208,636.81	2,082,734.65	
Operations and Maintenance														
POL	34 gal/patrol, Oil change every 50 hours	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	19,656.00	216,216.00	
Spare Parts														
Consumable	Oil Filter, spark plugs, hoses, battery	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	132,000.00	
Repairable	Patching hull, rebuilding engine	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	396,000.00	
	Maintenance Total	67,656.00	68,332.56	69,015.89	69,706.04	70,403.10	71,107.14	71,818.21	72,536.39	73,261.75	73,994.37	74,734.31	782,565.77	
USV	Procurement	900,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	900,000.00	
	O&S Total	238,810.85	242,910.51	247,085.39	251,336.94	255,666.62	260,075.92	264,566.37	269,139.51	273,796.94	278,540.26	283,371.12		
	Total	1,138,810.85	242,910.51	247,085.39	251,336.94	255,666.62	260,075.92	264,566.37	269,139.51	273,796.94	278,540.26	283,371.12		

Table 40. USV Cost Estimate.

Unmanned Ground Sensors

The cost for Unmanned Ground Sensors (UGS) is derived form the Marine Corps War fighting Publication (MCWP) 2-2.3. Procurement of the UGS systems includes the following:

- One unattended ground sensor (consisting of 24 nodes)
- One Sensor Mobile Monitoring System
- Four Portable Monitors
- Five Relay Assemblies

Operations and support cost for personnel includes the cost of the TRSS crew yearly pay and cost for training. The operational crew consists of one E-6, one E-5, two E-4's who also attend the TRSS five week class. Cost of personnel also includes the instructor cost of one E-7.

Operations and support cost for maintenance was estimated as 10% of the procurement cost.

Unit	Quantity	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
Sensors, Ground Unattended, AN/GSQ-257 (inclusive of 24 nodes)	1	867264	0	0	0	0	0	0	0	0	0	0
Sensor Mobile Monitorling System (SMMS), AN/MSC-77 (includes HMMWV)	1	657000										
Portable Monitor (PM), AN/USQ-121	4	112000										
Relay Assembly (RA), RE-1162/U	5	267965										
Procurement Total		$1,904,229.00	0	0	0	0	0	0	0	0	0	0
TRSS	Description	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
Crew	1 E-6 w/7, 1 E-5 w/5, 2 E-4 w/3	106848	108984.96	111164.6592	113387.9524	115655.7114	117968.8257	120328.2022	122734.7662	125189.4615	127693.2508	130247.1158
Instructor	1 instructor (E-7 with 14 years of service)	40204.8	41008.896	41829.07392	42665.6554	43518.96851	44389.34788	45277.13483	46182.67753	47106.33108	48048.4577	49009.42686
Training SET Class	1 crew to Remote Sensor operator 5-week course (MOS 8621) per year	14139.69231	14422.48615	14428.14203	14428.25515	14428.25741	14428.25746	14428.25746	14428.25746	14428.25746	14428.25746	14428.25746
Maintenance	10% of Procurment Cost	190422.9	192327.129	194250.4003	196192.9043	198154.8333	200136.3817	202137.7455	204159.1229	206200.7142	208262.7213	210345.3485
	O&S Total	351615.3923	356743.4712	361672.2754	366674.7672	371757.7707	376922.8127	382171.34	387504.8241	392924.7642	398432.6872	404030.1486
	Total	$2,255,844.39	$356,743.47	$361,672.28	$366,674.77	$371,757.77	$376,922.81	$382,171.34	$387,504.82	$392,924.76	$398,432.69	$404,030.15

Table 41. UGS Cost Estimate.

Ground Combat Element

The cost for the Ground Combat Element (GCE) is estimated from cost of procurement of weapons and ammunition, operations and support cost of personnel and equipment. Procurement costs include the cost for 2 Squad Automatic Weapons and 16 M-16's. Operations and support cost for personnel includes the cost of one year's salary for each of the following individuals. It is assumed that the parent organization (USA or USMC) will assume responsibility for initial training of the GCE. Additionally, although the nominal deployment for riverine force is six months, the GCE cost is estimated for one year, due to time allotted for pre-deployment training and post-deployment wrap-up. A ground combat element consists of 12 personnel

- One Platoon Commander (O-2 w/ 3 years of service)
- One Platoon Sergeant (E-7 w/ 18 years of service)
- One Platoon RATELO (E-3 w/ 3 years of service)
- One Squad Leader (E-6 w/ 10 years of service)
- Two Machine Gunners (E-5 w/ 6 years of service)
- Two Assistant Machine Gunners (E-4 w/ 4 years of service)
- Two Anti-Armor Gunners (E-5 w/ 6 years of service)
- 2 Assistant Anti-Armor Gunners (E-3 w/ 3 years of service)

Cost of operations and support for the GCE equipment is estimated at 40% of the procurement cost and includes the cost of ammunition. Cost of equipment to sustain the GCE such as: tents; radios; medical supplies, and food are also included in the O&S support

Deployed Personnel	Description	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
1 Platoon Commander	0-2 w/ 3 years of service 3651.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00	$43,812.00
Platoon SGT	E-7 w/ 18 years 3516.3	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60	$42,195.60
Platoon RATELO	E-3 w/ 3 years 1692	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00	$20,304.00
Weapons Squad A												
Squad Leader	E-6 w/ 10 years 2770.50	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00	$33,246.00
2 Machine Gunners	E-5 w/ 6 years 2273.50	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00
2 Assistant Machine Gunners	E-4 w/ 4 years 1935.90	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60
2 AntiArmor Gunners	E-5 w/ 6 years 2273.50	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00	$54,564.00
2 Assistant Anti Armor Gunners	E-3 w/3 years 1692.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00	$40,608.00
	Sum Deployed Personnel	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20	$335,755.20
	Personnel sum with 2% Cost increase	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**	**$671,510.40**
Weapons												
Squad Automatic Weapon	1 = 4100.00	8200	3280	3280	3280	3280	8446	3378.4	3378.4	3378.4	3378.4	8699.38
M-16	1 = 600	9600	4800	7200	4800	7200	9696	4848	4848	4848	4848	10665.6
	Sum Weapons	**17800**	**8080**	**10480**	**8080**	**10480**	**18142**	**8226.4**	**8226.4**	**8226.4**	**8226.4**	**19364.98**
	Sum Equipment	**$170,674.96**	**$51,202.49**	**$51,714.51**	**$52,231.66**	**$52,753.97**	**$53,281.51**	**$53,814.33**	**$54,352.47**	**$54,896.00**	**$55,444.96**	**$55,999.41**
	Total	**$859,985.36**	**$730,792.89**	**$733,704.91**	**$731,822.06**	**$734,744.37**	**$742,933.91**	**$733,551.13**	**$734,089.27**	**$734,632.80**	**$735,181.76**	**$746,874.79**

Table 42. GCE Cost Estimate Part 1.

Equipment	Required Qty/Unit	Cost/Unit	Total Cost
Infantry Equipment			
MSF Individual Infantry Equip f/1 person to include:	12	500	6000
Load Bearing Vest			
- Web Belt			
- Canteen (2 ea)			
- Canteen Cup			
- Canteen Cover (2 ea)			
- First Aid Kit			
- Field Pack / Medium / Soft / no frame			
M-16 Mag Pouch Blackhawk PN 541600 or equivalent (6 EA)			
Weapons Catch III Blackhawk PN 71CQD3 or equivalent (1 EA)			
Radio Pouch Blackhawk PN 37CL20 or equivalent (1 EA)			
Tac Light Holster Blackhawk PN 52SF04 or equivalent (1 EA)			
M203 Pouch Blackhawk PN 37CL23 or equivalent (1 EA)			
Duty Collapsible Bag Blackhawk PN 52 DB21 or equivalent (1 EA)			
Dual Mag Pouch Blackhawk PN 52PMK2 or equivalent (2 EA)			
Holster, 9MM (1 EA)			
Helmet, Kevlar/ Combat, Assy	12	152	1824
Body Armor, Lightweight Assault Vest	12	1549	18588
Mustang Flotation Collar	12	106	4664
Entrenching Tool	12	28	336
Entrenching Tool Case	12	2.5	30
Insect Head Net Nylon	12	5.15	4665
Flashlight	12	89	1068
Compass and Case Sunnto	12	37	444
Gerber Multi-tool(EN's /BM's)	12	44	4666
Camelback Drinking System	12	45	540
Kit Bag Flyer's	12	23.05	276.6
PPE - Goggles Wind/Sun/Dust(Boat Crew)	12	55	4667
PPE - Sunglasses (Wiley-X; ANSI Z87.1-2003 high velocity impact standard Ballistic Eye Protection - Polarized/Clear - Hard Case)	12	150	1800
Medical			
MOLLE Bag	1	800	800
Automatic External Defibrillator (primary AED)	1	1776	1776
First Aid Kit, Small Craft	4	241.09	964.36
Subsistence			
- MRE's required for 3 day duration (12 per box) consumable	18	87	1566
Communications			
AN/PRC 150 HF Manpack Radio	2	19000	38000
AN/PRC 150 HF Manpack Radio Accessories	2	5000	10000
AN/PRC 117F UHF/VHF SATCOM Manpack Radio	2	27000	54000
AN/PRC 117F UHF/VHF SATCOM Accessories	2	7000	14000
		Sum for Equipment, Medical, Subsistence, Communications	$170,674.96

Table 43. GCE Cost Estimate Part 2.

Networked Sensors

The cost of the Network Sensors option includes procurement, operations and support cost for personnel, and operations and support cost for equipment. Procurement of all of the systems occurs in 2010. Although it is possible that the RF could procure all three unmanned systems in the same FYDP, it is highly unlikely. This methodology standardizes procurement for comparison among alternatives vice an actual planning strategy for procurement. The cost of the Networked Sensors option includes the procurement and O&S cost for actual network hardware. In the model, SEA 10 made the assumption that the JTRS Cluster 5 system would be made available for use by the force in 2010. A cost analogy was made using current RF communications equipment to estimate the JTRS Cluster 5 system.

Each year after the procurement year, 10% of the cost of the network is allotted to operations and support cost for network upgrades and security installations. Operations and support cost for the unmanned sensors is based off open source documents whose references can be found within the actual chapter.

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
JTRS Procurement	$392,400.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
UAV	$36,000,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
USV	$900,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
UGS	$1,904,229.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operations and Support											
JTRS		$39,240.00	$39,632.40	$40,028.72	$40,429.01	$40,833.30	$41,241.63	$41,654.05	$42,070.59	$42,491.30	$42,916.21
UAV	$2,853,003.45	$2,948,613.52	$3,044,035.79	$3,139,645.86	$3,234,688.78	$3,330,298.84	$3,424,954.82	$3,520,564.89	$3,614,826.19	$3,710,436.26	$3,804,294.98
USV	$238,810.85	$242,910.51	$247,085.39	$251,336.94	$255,666.62	$260,075.92	$264,566.37	$269,139.51	$273,796.94	$278,540.26	$283,371.12
UGS	$351,615.39	$356,743.47	$361,672.28	$366,674.77	$371,757.77	$376,922.81	$382,171.34	$387,504.82	$392,924.76	$398,432.69	$404,030.15
	$392,400.00	$39,240.00	$39,632.40	$40,028.72	$40,429.01	$40,833.30	$41,241.63	$41,654.05	$42,070.59	$42,491.30	$42,916.21
Unmanned Systems	$42,247,658.69	$3,548,267.50	$3,652,793.46	$3,757,657.57	$3,862,113.16	$3,967,297.58	$4,071,692.53	$4,177,209.23	$4,281,547.89	$4,387,409.20	$4,491,696.25
Total	$42,640,058.69	$3,587,507.50	$3,692,425.86	$3,797,686.29	$3,902,542.18	$4,008,130.88	$4,112,934.16	$4,218,863.28	$4,323,618.48	$4,429,900.50	$4,534,612.46

Mortar Barge

It is important to note that the New Efficient MOrtar (NEMO) capability has not yet been openly explored for a U.S. small boat. NEMO is waterborne direct and indirect fire capability that is centered on a 120mm smoothbore mortar affixed to a land or waterborne vehicle. A Finnish company, Patria Systems, designed the NEMO turret to fit on the Finnish M12 Watercat hull, which is approximately the same size as the SURC. In the event a decision maker finds this alternative worth pursuing, he must be forewarned of the additional cost for test and evaluation of this foreign made system.

The cost for the Networked Mortar Barge includes the cost of procurement, operations and support of personnel and operations and support of equipment including ammunition. In order to support RF operations, it was estimated that three NEMOs would be procured. The approximate procurement cost is $1.0 M for a NEMO waterborne system. This cost was based off of an analogy to a small boat mortar system design by Swedeship, which was sold to UAE. Due to competition sensitivity of the NEMO, the company declined to present a cost estimate for the system.

The cost of operations and support for NEMO includes the cost for the crew of four personnel, a coxswain, a boat engineer and two people to shoot the mortar. Equipment O&S cost are analogous to the cost O&S of the RAC small boat for repairable and consumables. POL consumption was derived from the fuel estimates for 92.8 gallons of POL per patrol plus an oil change every 50 hours. Fuel estimates were found in the Cummins Mercruiser Diesel (Model 4.2L ES320) engine information packet and assumed 80% of the time was spent at cruise speed (~12 knots) while the remaining 20% of the time was spent at sprint speed (above 40 knots). All cost information for the 120mm mortar was found on FEDLOG.

MORTAR BARGE		
		FY10
NEMO	Unit Cost	
Total System	$ 1,600,000.00	$ 4,800,000.00
WATERCAT M12- based off of analogy to Swedeship sale to UAE	1000000	
NEMO Turret	250000	
Mods to hull	100000	
Add'l C2 Gear	150000	
Stabilized EO/FLIR sights	100000	

Table 44. Mortar Barge Procurement Cost.

Operating and Support Cost												
Personnel		FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
Training	12 E-5 with 10 years of service	$ 348,710.40	$ 355,684.61	$ 362,798.30	$ 370,054.27	$ 377,455.35	$ 385,004.46	$ 392,704.55	$ 400,558.64	$ 408,569.81	$ 416,741.21	$ 425,076.03
Instructor	1 instructor (E-7 with 14 years of service)	$ 38,995.20	$ 39,775.10	$ 40,570.61	$ 41,382.02	$ 42,209.66	$ 43,053.85	$ 43,914.93	$ 44,793.23	$ 45,689.09	$ 46,602.87	$ 47,534.93
Coxswains	5 students for 5 days, 4 times a year	$ 47,768.55	$ 48,723.92	$ 49,679.29	$ 50,634.66	$ 51,590.03	$ 52,545.40	$ 53,500.77	$ 54,456.14	$ 55,411.52	$ 56,366.89	$ 57,322.26
Maintainers (boat engineer)	3 E-5 with 10 years of service	$ 87,177.60	$ 88,921.15	$ 90,699.58	$ 92,513.57	$ 94,363.84	$ 96,251.11	$ 98,176.14	$ 100,139.66	$ 102,142.45	$ 104,185.30	$ 106,269.01

Table 45. Operations and Support Costs for Equipment.

Operations and Support		FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
POL	92.8 gal/patrol, Oil change every 50 hours	53,568	53,568	54,104	54,104	54,645	54,645	55,191	55,191	55,743	55,743	56,301
Spare Parts												
Consumable	Oil Filter, spark plugs, hoses, battery	36,000	36,360	36,724	37,091	37,462	37,836	38,215	38,597	38,983	39,373	39,766
Repairable	Patching hull, rebuilding engine, Mortar specifics (turret drive motors, barrels, etc)	444,000	448,440	452,924	457,454	462,028	466,648	471,315	476,028	480,788	485,596	490,452
Ammo	120mm HE shell	265,000	13,250	13,383	13,516	13,651	13,788	13,926	14,065	14,206	14,348	14,491
	O&S Personnel	522,652	533,105	543,748	554,585	565,619	576,855	588,296	599,948	611,813	623,896	636,202
	O&S Spare parts, POL, Ammo	533,568	538,368	543,752	548,648	554,135	559,130	564,721	569,816	575,514	580,712	586,519
	O&S Total	1,056,220	1,071,473	1,087,499	1,103,233	1,119,754	1,135,984	1,153,017	1,169,764	1,187,327	1,204,608	1,222,721
	Procurement Total	4,800,000	0	0	0	0	0	0	0	0	0	0
	Total	5,856,220	1,071,473	1,087,499	1,103,233	1,119,754	1,135,984	1,153,017	1,169,764	1,187,327	1,204,608	1,222,721

Table 46. Operations and Support Costs for Equipment II.

Mortar Team

Cost for the Mortar Team was derived from procurement cost for three 81mm mortars, O&S cost for personnel and O&S cost for equipment including ammunition. It was assumed that the mortar team would procure three 81mm mortar systems.

Operations and support cost for personnel includes the cost for mortar team personnel consisting of one E-4 team leader and 3 E-3 mortar team members. O&S cost for equipment includes the maintenance and repair of the mortar tubes at 10% of the procurement cost, each year. It was assumed that the Tactical Operations Center (TOC) would have the ability to store mortar cartridges and fuses. Therefore, in the initial procurement of ammunition, 500 rounds were purchased, and warehousing costs were not figured into the total cost estimate. All cost information for equipment and ammunition was found in FEDLOG.

81 mm Mortar Team												
Operating and Support Personnel	Description	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
Team Leader	E-4 w/ 4 years 1935.90	$23,230.80	$23,695.42	$24,169.32	$24,652.71	$25,145.77	$25,648.68	$26,161.65	$26,684.89	$27,218.58	$27,762.96	$28,318.22
Mortar Team Members	E-3 w/3 years 1692.00	$60,912.00	$62,130.24	$63,372.84	$64,640.30	$65,933.11	$67,251.77	$68,596.81	$69,968.74	$71,368.12	$72,795.48	$74,251.39

Table 47. Operations and Support Cost Personnel.

Procurement and Operating and Support Costs Equipment		FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
M29A1 Mortar, 81mm	3 systems (unit cost 8996.00) NSN: 1015-00-999-7794	$26,988.00	$2,698.80	$2,725.79	$2,753.05	$2,780.58	$2,808.38	$2,836.47	$2,864.83	$2,893.48	$2,922.41	$2,951.64
M-374 HE Cartridge, 81mm	NSN 1315-00-935-6002 Unit cost $122.00	$61,000.00	$6,100.00	$6,161.00	$6,222.61	$6,284.84	$6,347.68	$6,411.16	$6,475.27	$6,540.03	$6,605.43	$6,671.48
M524A2 Fuze, PD	NSN: 1390-00-892-4804 Per unit cost $11.09	$5,545.00	$55.45	$56.00	$56.56	$57.13	$57.70	$58.28	$58.86	$59.45	$60.04	$60.64
	O&S Personnel	$84,142.80	$85,825.66	$87,542.17	$89,293.01	$91,078.87	$92,900.45	$94,758.46	$96,653.63	$98,586.70	$100,558.43	$102,569.60
	Procurement	$87,988.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	O&S Equipment		$8,854.25	$8,942.79	$9,032.22	$9,122.54	$9,213.77	$9,305.91	$9,398.96	$9,492.95	$9,587.88	$9,683.76
	Total	$238,675.80	$100,835.36	$102,701.97	$104,604.41	$106,543.38	$108,519.60	$110,533.80	$112,586.73	$114,679.13	$116,811.79	$118,985.49

Table 48. Total Equipment Cost.

Networked Mortar Team

Cost for the Networked Mortar Team is broken out into procurement, O&S for personnel and O&S for equipment. Cost of procurement includes the cost for all unmanned sensors, the mortar team and the network. Operations and Support cost for personnel includes all cost for personnel who operate the Unmanned Systems and the individuals on the Mortar Team. Cost of all ammunition was found on FEDLOG. Cost references for the other individual systems can be found in their respective sections. For dollar reference see cost summary at the beginning of this appendix.

Networked NEMO

Cost for Networked Mortar Barge is broken out into procurement cost, O&S for personnel and O&S for equipment including ammunition. All procurement is assumed to take place in 2010. It is further assumed that all unmanned systems, the network and the mortar barge will be procured in the same year. O&S cost for personnel includes the cost for all personnel who operate the unmanned systems, and who are on the NEMO. For dollar reference see cost summary at the beginning of this appendix.

Helicopter

Cost for the helicopter detachment assumes a model with 3 MH-60Rs[176] helicopters with 12 pilots, 12 maintainers and 12 crewmen. Costs were divided up into procurement, operation and support for personnel and operations and support for equipment. The helicopter alternative is presented with a procurement and non-procurement option, since it is generally not typical for helicopters to be procured for one specific unit (other than a squadron). The procurement cost for the MH-60 was found on the world wide web[177]. Cost for O&S for the helicopter was found on the Navy VAMOSC website[178]

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[176] Riverine Group Initial Helicopter Study, Unpublished, 2006

[177] Federation of American Scientists. *MH-60R*. Retrieved on 13 November 2006 from the World Wide Web at [http://www.fas.org/man/dod-101/sys/ac/sh-60.htm].

[178] Navy Visibility and Management of Operating and Support Costs, *HH-60 Alamanac*, Retrieved 05 November 2006 from the World Wide Web at [www.navyvamosc.com].

Helo Alternative		FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
Pilots												
2 O-4	w/ 8 years of service 5131.80	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20	$123,163.20
8 O-3	w/ 6 years of service 4503.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00	$432,288.00
2 O-2	w/ 3 years of service 3651.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00	$87,624.00
Aircrew												
2 E-7	w/ 14 years of service 3350.40	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60	$80,409.60
3 E-6	w/ 12 years of service 2865.30	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80	$103,150.80
5 E-5	w/ 8 years of service 2402.10	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00	$144,126.00
2 E-4	w/ 4 years service 1935.90	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60	$46,461.60

Table 49. Helicopter Aircrew Costs.

Maintenance												
1 E-7	w/ 14 years of service 3350.40	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80	$40,204.80
2 E-6	w/ 12 years of service 2865.30	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20	$68,767.20
4 E-5	w/ 8 years of service 2402.10	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80	$115,300.80
5 E-4	w/ 4 years service 1935.90	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00	$116,154.00
	Personnel Sum	$1,357,650.00	$1,384,803.00	$1,412,499.06	$1,440,749.04	$1,469,564.02	$1,498,955.30	$1,528,934.41	$1,559,513.10	$1,590,703.36	$1,622,517.43	$1,654,967.77
O&S	VAMSOC	**$2,104,867.28**	**$2,125,915.96**	**$2,126,126.44**	**$2,147,387.71**	**$2,126,341.16**	**$2,147,604.57**	**$2,126,343.33**	**$2,147,606.76**	**$2,126,343.35**	**$2,147,606.79**	**$2,126,343.35**
Total O&S		**$3,462,517.28**	**$3,510,718.96**	**$3,538,625.50**	**$3,588,136.75**	**$3,595,905.18**	**$3,646,559.88**	**$3,655,277.74**	**$3,707,119.86**	**$3,717,046.71**	**$3,770,124.21**	**$3,781,311.13**

Table 50. Helicopter Maintenance Personnel Costs.

Procurement	**See Cost Estimation Paper for Ref**	126900000	0	0	0	0	0	0	0	0	0	0
Weapons Procurement and O&S	30 hellfire	1930350	19303.5	19496.535	19691.50035	19888.41535	20087.29951	20288.1725	20491.05423	20695.96477	20902.92442	21111.95366
Total		**$130,362,517.28**	**$3,510,718.96**	**$3,538,625.50**	**$3,588,136.75**	**$3,595,905.18**	**$3,646,559.88**	**$3,655,277.74**	**$3,707,119.86**	**$3,717,046.71**	**$3,770,124.21**	**$3,781,311.13**

Table 51. Helicopter Weapons Procurement Costs.

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APPENDIX C. ANOVA AND KRUSKAL-WALLIS CHARTS

This appendix contains the results of a one way ANOVA analysis of means and a Kruskal-Wallis analysis of medians conducted for each of the five original responses by scenario using MINITAB. These results augment the graphical depiction of the 95% confidence intervals and box plots contained in the text of the theses generated from the same data in MINITAB. References to Kruskal-Wallis in the body of the text refer to the ranking of the median of an alternative against the overall median for all data points for all alternatives for a particular response by scenario. The results are presented in the same order as that found in the detailed statistical analysis section for ease of reference.

PATROL

LOSS EXCHANGE RATIO

```
One-way ANOVA: Loss Exchange Ratio versus Alt

Source   DF       SS    MS     F      P
Alt      10    403.0  40.3  0.99  0.451
Error   254  10324.8  40.6
Total   264  10727.8

S = 6.376   R-Sq = 3.76%   R-Sq(adj) = 0.00%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level        N    Mean  StDev -------+---------+---------+---------+--
Alt2-UAV    30  12.094  5.767                      (--*---)
Alt2-UGS    30   9.892  6.876                   (--*--)
Alt2-USV    29   9.623  6.779                  (---*--)
Alt3-NET    30  11.114  6.364                     (--*--)
Alt4-MB     28   8.899  6.162                 (---*--)
Alt4-MT     29   8.395  6.053                 (--*--)
Alt5-GCE    26  10.747  5.867                    (--*---)
Alt6-HELO    1   7.692      * (-----------------*-----------------)
Alt7-B-MB    4  11.795  7.170                (--------*--------)
Alt7-B-MT   29  11.409  6.549                     (--*---)
Baseline    29   8.883  6.713                 (---*--)
                              -------+---------+---------+---------+--
                                   0.0       7.0      14.0      21.0

Pooled StDev = 6.376
```

Kruskal-Wallis Test: Loss Exchange Ratio versus Alt

Kruskal-Wallis Test on Loss Exchange Ratio

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	15.380	153.0	1.52
Alt2-UGS	30	15.380	128.2	-0.36
Alt2-USV	29	15.380	129.6	-0.25
Alt3-NET	30	15.380	142.6	0.73
Alt4-MB	28	7.690	118.2	-1.08
Alt4-MT	29	7.690	112.7	-1.51
Alt5-GCE	26	15.380	140.9	0.55
Alt6-HELO	1	7.692	112.0	-0.27
Alt7-B-MB	4	15.380	153.6	0.54
Alt7-B-MT	29	15.380	149.2	1.21
Baseline	29	7.690	119.9	-0.97
Overall	265		133.0	

H = 8.54 DF = 10 P = 0.576
H = 10.51 DF = 10 P = 0.397 (adjusted for ties)

* NOTE * One or more small samples

TIME TO FIRST ENEMY DETECTION

One-way ANOVA: Patrol Time to Detect versus Alt

```
Source   DF      SS    MS      F      P
Alt      10   70213  7021  27.61  0.000
Error   319   81118   254
Total   329  151331
S = 15.95   R-Sq = 46.40%   R-Sq(adj) = 44.72%
                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level       N   Mean  StDev  ---+---------+---------+---------+------
Alt2-UAV   30  25.97   9.93        (---*---)
Alt2-UGS   30  25.33  18.90        (---*---)
Alt2-USV   30  23.80   1.56       (---*---)
Alt3-NET   30  21.53   2.70      (--*---)
Alt4-MB    30  56.20  32.13                              (--*---)
Alt4-MT    30  41.13   4.39                    (--*---)
Alt5-GCE   30  50.57  13.23                          (---*---)
Alt6-HELO  30  21.07   1.62     (---*---)
Alt7-B-MB  30  23.63   1.40       (---*---)
Alt7-B-MT  30  15.53   4.33  (--*---)
Baseline   30  56.83  32.89                              (---*---)
                             ---+---------+---------+---------+------
                               15        30        45        60
Pooled StDev = 15.95
```

Kruskal-Wallis Test: Patrol Time to Detect versus Alt

Kruskal-Wallis Test on Patrol Time to Detect

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	23.00	143.8	-1.31
Alt2-UGS	**30**	**19.00**	**104.6**	**-3.67**
Alt2-USV	30	24.00	147.7	-1.07
Alt3-NET	**30**	**22.50**	**100.9**	**-3.89**
Alt4-MB	30	41.00	263.8	5.92
Alt4-MT	30	40.00	247.6	4.95
Alt5-GCE	30	48.00	286.4	7.28
Alt6-HELO	**30**	**21.00**	**80.5**	**-5.12**
Alt7-B-MB	30	24.00	144.1	-1.29
Alt7-B-MT	**30**	**16.00**	**32.9**	**-7.98**
Baseline	30	43.50	268.3	6.19
Overall	330		165.5	

H = 248.91 DF = 10 P = 0.000

H = 249.83 DF = 10 P = 0.000 (adjusted for ties)

DETECT TO ENGAGE TIME

One-way ANOVA: DETECT TO ENGAGE TIME versus Alt

Source	DF	SS	MS	F	P
Alt	10	42418.4	4241.8	111.10	0.000
Error	319	12179.7	38.2		
Total	329	54598.1			

S = 6.179   R-Sq = 77.69%   R-Sq(adj) = 76.99%

```
                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level       N    Mean   StDev   ---+---------+---------+---------+------
Alt2-UAV   30  19.967  10.424                         (--*--)
Alt2-UGS   30  24.400  10.836                               (-*--)
Alt2-USV   30  18.433   6.600                       (--*--)
Alt3-NET   30  23.867   8.641                              (--*--)
Alt4-MB    30  -0.167   0.913   (--*--)
Alt4-MT    30   0.000   0.000   (--*--)
Alt5-GCE   30   0.000   0.000   (--*--)
Alt6-HELO  30   0.000   0.000   (--*--)
Alt7-B-MB  30   1.933   1.780      (-*--)
Alt7-B-MT  30  26.667   8.466                                   (-*--)
Baseline   30   0.000   0.000   (--*--)
                                ---+---------+---------+---------+------
                                 0.0       8.0      16.0      24.0
Pooled StDev = 6.179
```

Kruskal-Wallis Test: DETECT TO ENGAGE TIME versus Alt

Kruskal-Wallis Test on DETECT TO ENGAGE TIME

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	1.95000E+01	242.6	4.64
Alt2-UGS	30	2.50000E+01	258.9	5.62
Alt2-USV	30	1.55000E+01	232.8	4.05
Alt3-NET	30	2.15000E+01	259.6	5.66
Alt4-MB	30	0.000000000	74.5	-5.48
Alt4-MT	30	0.000000000	77.0	-5.33
Alt5-GCE	30	0.000000000	77.0	-5.33
Alt6-HELO	**30**	**0.000000000**	**77.0**	**-5.33**
Alt7-B-MB	**30**	**1.000000000**	**167.9**	**0.14**
Alt7-B-MT	30	2.65000E+01	276.4	6.67
Baseline	30	0.000000000	77.0	-5.33
Overall	330		165.5	

H = 263.46 DF = 10 P = 0.000
H = 290.27 DF = 10 P = 0.000 (adjusted for ties)

LENGTH OF ENGAGEMENT

One-way ANOVA: LENGTH OF ENGAGEMENT versus Alt

```
Source   DF      SS    MS     F      P
Alt      10   25427  2543  3.48  0.000
Error   318  232316   731
Total   328  257742
S = 27.03   R-Sq = 9.87%   R-Sq(adj) = 7.03%
                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level       N   Mean  StDev  ------+---------+---------+---------+---
Alt2-UAV   30  21.50  47.89                  (-------*-------)
Alt2-UGS   30  16.07  25.04             (-------*-------)
Alt2-USV   30  22.20  43.75                  (--------*-------)
Alt3-NET   29  10.62  23.90         (-------*-------)
Alt4-MB    30   3.53   3.64   (-------*-------)
Alt4-MT    30   2.17   0.79  (-------*-------)
Alt5-GCE   30   4.33   6.13    (-------*-------)
Alt6-HELO  30   9.23   4.51        (-------*-------)
Alt7-B-MB  30  12.70   8.99          (--------*-------)
Alt7-B-MT  30  30.13  49.55                         (-------*-------)
Baseline   30   3.50   4.13   (-------*-------)
                             ------+---------+---------+---------+---
                                   0        12        24        36
Pooled StDev = 27.03
```

Kruskal-Wallis Test: LENGTH OF ENGAGEMENT versus Alt

Kruskal-Wallis Test on LENGTH OF ENGAGEMENT

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	2.000	141.9	-1.40
Alt2-UGS	30	2.000	158.0	-0.42
Alt2-USV	30	3.000	177.2	0.74
Alt3-NET	29	2.000	141.2	-1.41
Alt4-MB	30	2.000	137.1	-1.69
Alt4-MT	30	2.000	112.1	-3.20
Alt5-GCE	30	2.000	148.9	-0.97
Alt6-HELO	**30**	**8.000**	**249.7**	**5.12**
Alt7-B-MB	**30**	**10.000**	**247.9**	**5.01**
Alt7-B-MT	30	2.000	161.0	-0.24
Baseline	30	2.000	139.3	-1.55
Overall	329		165.0	

H = 65.79 DF = 10 P = 0.000
H = 69.58 DF = 10 P = 0.000 (adjusted for ties)

MAXIMUM CLASSIFICATION RANGE

One-way ANOVA: Max Classification Range versus Alt

```
Source   DF       SS      MS        F      P
Alt      10  1041930  104193  1994.48  0.000
Error   319    16665      52
Total   329  1058595
S = 7.228   R-Sq = 98.43%   R-Sq(adj) = 98.38%
                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level       N    Mean  StDev  ------+---------+---------+---------+---
Alt2-UAV   30   17.90   2.11  *)
Alt2-UGS   30   17.93   2.12  *)
Alt2-USV   30  126.33   6.84                           (*
Alt3-NET   30  125.73   2.05                           *)
Alt4-MB    30   19.40   1.00  (*
Alt4-MT    30   19.30   0.84  (*
Alt5-GCE   30   19.87   0.35  (*)
Alt6-HELO  30  154.77   2.03                                  (*
Alt7-B-MB  30  123.07  22.36                          (*
Alt7-B-MT  30  123.30   2.85                          (*
Baseline   30   19.60   0.93  (*)
                              ------+---------+---------+---------+---
                                   40        80       120       160
Pooled StDev = 7.23
```

Kruskal-Wallis Test: Max Classification Range versus Alt

Kruskal-Wallis Test on Max Classification Range

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	19.00	60.3	-6.34
Alt2-UGS	30	18.50	63.6	-6.14
Alt2-USV	**30**	**125.50**	**242.1**	**4.61**
Alt3-NET	**30**	**125.00**	**241.6**	**4.58**
Alt4-MB	30	20.00	100.9	-3.89
Alt4-MT	30	19.00	90.1	-4.54
Alt5-GCE	30	20.00	122.0	-2.62
Alt6-HELO	**30**	**156.00**	**315.3**	**9.02**
Alt7-B-MB	**30**	**127.00**	**254.9**	**5.38**
Alt7-B-MT	**30**	**123.00**	**217.6**	**3.14**
Baseline	30	20.00	112.2	-3.21
Overall	330		165.5	

H = 266.48 DF = 10 P = 0.000
H = 274.98 DF = 10 P = 0.000 (adjusted for ties)

AMBUSH

LOSS EXCHANGE RATIO

One-way ANOVA: Loss Exchange Ratio versus Alt

Source	DF	SS	MS	F	P
Alt	10	12220.8	1222.1	17.71	0.000
Error	288	19874.6	69.0		
Total	298	32095.4			

S = 8.307   R-Sq = 38.08%   R-Sq(adj) = 35.93%

Individual 95% CIs For Mean Based on Pooled StDev

```
Level        N    Mean   StDev  --------+---------+---------+---------+-
Alt2-UAV    30  19.250  13.118                    (---*---)
Alt2-UGS    29   5.292   6.368   (---*--)
Alt2-USV    30   9.649   8.934        (---*---)
Alt3-NET    30   6.756   8.477     (--*---)
Alt4-MB     30   6.046   6.065    (---*--)
Alt4-MT     30   5.306   7.210   (---*--)
Alt5-GCE    30  12.514   8.625           (---*--)
Alt6-HELO    6  26.012  11.655                       (--------*-------)
Alt7-B-MB   24  23.371   9.363                        (---*---)
Alt7-B-MT   30   5.306   7.210   (---*--)
Baseline    30   4.564   3.786  (---*--)
                                --------+---------+---------+---------+-
                                      8.0      16.0      24.0      32.0
```

Pooled StDev = 8.307

Kruskal-Wallis Test: Loss Exchange Ratio versus Alt

Kruskal-Wallis Test on Loss Exchange Ratio

Alt	N	Median	Ave Rank	Z
Alt2-UAV	**30**	**30.770**	**217.2**	**4.49**
Alt2-UGS	29	1.940	105.6	-2.91
Alt2-USV	30	10.260	171.4	1.43
Alt3-NET	30	2.070	122.5	-1.84
Alt4-MB	30	4.045	123.7	-1.76
Alt4-MT	30	1.940	108.9	-2.75
Alt5-GCE	**30**	**11.060**	**191.7**	**2.78**
Alt6-HELO	**6**	**30.770**	**252.2**	**2.92**
Alt7-B-MB	**24**	**30.770**	**248.0**	**5.79**
Alt7-B-MT	30	1.940	108.9	-2.75
Baseline	30	1.940	99.8	-3.36
Overall	299		150.0	

H = 103.32 DF = 10 P = 0.000
H = 104.45 DF = 10 P = 0.000 (adjusted for ties)

TIME TO FIRST ENEMY DETECTION

One-way ANOVA: Time to Detection(MIN) versus Alt

```
Source    DF        SS       MS       F      P
Alt       10  19010.85  1901.09  553.38  0.000
Error    319   1095.90     3.44
Total    329  20106.75
S = 1.853   R-Sq = 94.55%   R-Sq(adj) = 94.38%
                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level       N    Mean  StDev  -----+---------+---------+---------+----
Alt2-UAV   30  13.400  4.383               (*)
Alt2-UGS   30  19.633  0.718                        (*)
Alt2-USV   30   7.033  0.183      (*)
Alt3-NET   30   7.067  0.254      (*)
Alt4-MB    30  20.500  0.820                         (*)
Alt4-MT    30  20.400  0.724                         (*)
Alt5-GCE   30  27.600  3.997                                   (*)
Alt6-HELO  30   4.033  0.183  (*)
Alt7-B-MB  30   7.100  0.305      (*)
Alt7-B-MT  30   7.067  0.254      (*)
Baseline   30  20.467  0.776                         (*)
                              -----+---------+---------+---------+----
                                 7.0      14.0      21.0      28.0
Pooled StDev = 1.853
```

Kruskal-Wallis Test: Time to Detection(MIN) versus Alt

Kruskal-Wallis Test on Time to Detection(MIN)

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	12.000	173.6	0.49
Alt2-UGS	30	20.000	213.4	2.88
Alt2-USV	**30**	**7.000**	**88.5**	**-4.64**
Alt3-NET	**30**	**7.000**	**90.5**	**-4.52**
Alt4-MB	30	20.000	248.7	5.01
Alt4-MT	30	20.000	245.4	4.81
Alt5-GCE	30	27.000	314.4	8.96
Alt6-HELO	**30**	**4.000**	**15.5**	**-9.03**
Alt7-B-MB	**30**	**7.000**	**92.5**	**-4.40**
Alt7-B-MT	**30**	**7.000**	**90.5**	**-4.52**
Baseline	30	20.000	247.5	4.94
Overall	330		165.5	

H = 295.17 DF = 10 P = 0.000
H = 310.44 DF = 10 P = 0.000 (adjusted for ties)

DETECT TO ENGAGE TIME

One-way ANOVA: DETECT TO ENGAGE TIME versus Alt

```
Source   DF        SS       MS       F      P
Alt      10  11755.10  1175.51  246.95  0.000
Error   319   1518.47     4.76
Total   329  13273.56
S = 2.182   R-Sq = 88.56%   R-Sq(adj) = 88.20%
                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level       N    Mean  StDev  --+---------+---------+---------+-------
Alt2-UAV   30  10.067  4.870                     (*-)
Alt2-UGS   30   0.733  0.450    (*-)
Alt2-USV   30  14.900  4.483                              (-*)
Alt3-NET   30  12.967  1.671                          (-*-)
Alt4-MB    30  -0.033  0.183  (-*-)
Alt4-MT    30  -0.033  0.183  (-*-)
Alt5-GCE   30   0.000  0.000  (-*-)
Alt6-HELO  30   1.600  1.958      (*-)
Alt7-B-MB  30   1.867  0.571      (-*)
Alt7-B-MT  30  12.833  0.950                          (-*)
Baseline   30  -0.300  0.651  (*-)
                              --+---------+---------+---------+-------
                              0.0       5.0      10.0      15.0
Pooled StDev = 2.182
```

Kruskal-Wallis Test: DETECT TO ENGAGE TIME versus Alt

Kruskal-Wallis Test on DETECT TO ENGAGE TIME

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	1.10000E+01	230.6	3.92
Alt2-UGS	30	1.000000000	137.5	-1.69
Alt2-USV	30	1.40000E+01	293.3	7.69
Alt3-NET	30	1.30000E+01	270.2	6.31
Alt4-MB	30	0.000000000	73.2	-5.56
Alt4-MT	30	0.000000000	73.2	-5.56
Alt5-GCE	30	0.000000000	75.5	-5.42
Alt6-HELO	30	1.000000000	148.5	-1.02
Alt7-B-MB	30	2.000000000	187.8	1.34
Alt7-B-MT	**30**	**1.30000E+01**	**271.8**	**6.40**
Baseline	30	0.000000000	59.0	-6.41
Overall	330		165.5	

H = 266.58 DF = 10 P = 0.000
H = 286.30 DF = 10 P = 0.000 (adjusted for ties)

LENGTH OF ENGAGEMENT

One-way ANOVA: LENGTH OF ENGAGEMENT versus Alt

```
Source   DF      SS    MS      F      P
Alt      10   61176  6118  13.56  0.000
Error   317  143012   451
Total   327  204189
S = 21.24   R-Sq = 29.96%   R-Sq(adj) = 27.75%
                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level       N   Mean  StDev  --+---------+---------+---------+-------
Alt2-UAV   30  53.47  43.29                          (---*---)
Alt2-UGS   29  11.45  22.12      (---*---)
Alt2-USV   30  20.60  23.87          (---*---)
Alt3-NET   30  21.00  17.14           (--*---)
Alt4-MB    30   4.97   4.08   (--*---)
Alt4-MT    30   3.53   1.80  (---*---)
Alt5-GCE   30  36.37  29.28                 (---*---)
Alt6-HELO  30  23.23   9.26            (---*--)
Alt7-B-MB  30  16.20   6.39        (---*---)
Alt7-B-MT  30  15.87  16.60        (---*---)
Baseline   29  13.55  21.41       (---*---)
                             --+---------+---------+---------+-------
                               0        20        40        60
Pooled StDev = 21.24
```

Kruskal-Wallis Test: LENGTH OF ENGAGEMENT versus Alt

Kruskal-Wallis Test on LENGTH OF ENGAGEMENT

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	38.000	258.0	5.67
Alt2-UGS	**29**	**5.000**	**99.6**	**-3.86**
Alt2-USV	30	9.000	170.3	0.35
Alt3-NET	30	18.000	198.0	2.03
Alt4-MB	**30**	**4.000**	**79.1**	**-5.18**
Alt4-MT	**30**	**3.000**	**53.4**	**-6.73**
Alt5-GCE	30	22.000	240.2	4.59
Alt6-HELO	30	21.000	236.3	4.35
Alt7-B-MB	30	14.000	199.7	2.13
Alt7-B-MT	30	9.500	162.1	-0.15
Baseline	**29**	**5.000**	**108.8**	**-3.31**
Overall	328		164.5	

H = 162.60 DF = 10 P = 0.000
H = 163.05 DF = 10 P = 0.000 (adjusted for ties)

MAXIMUM CLASSIFICATION RANGE

One-way ANOVA: Max Classification Range versus Alt

```
Source   DF       SS      MS          F      P
Alt      10  1500834  150083  346931.95  0.000
Error   319      138       0
Total   329  1500972
S = 0.6577   R-Sq = 99.99%   R-Sq(adj) = 99.99%
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level       N     Mean  StDev  ----+---------+---------+---------+-----
Alt2-UAV   30   20.067  0.980  *
Alt2-UGS   30   19.967  0.556  *
Alt2-USV   30  155.800  0.407                                       (*
Alt3-NET   30  155.967  0.183                                       (*
Alt4-MB    30   20.000  0.000  *
Alt4-MT    30   20.000  0.000  *
Alt5-GCE   30   20.000  0.000  *
Alt6-HELO  30  153.933  1.484                                       *
Alt7-B-MB  30  155.767  0.430                                       (*
Alt7-B-MT  30  155.567  0.568                                       *)
Baseline   30   19.800  0.761  *
                               ----+---------+---------+---------+-----
                                  35        70       105       140
Pooled StDev = 0.658
```

Kruskal-Wallis Test: Max Classification Range versus Alt

Kruskal-Wallis Test on Max Classification Range

Alt	N	Median	Ave Rank	Z
Alt2-UAV	30	20.00	87.6	-4.69
Alt2-UGS	30	20.00	90.4	-4.52
Alt2-USV	**30**	**156.00**	**267.8**	**6.16**
Alt3-NET	**30**	**156.00**	**278.8**	**6.82**
Alt4-MB	30	20.00	93.5	-4.34
Alt4-MT	30	20.00	93.5	-4.34
Alt5-GCE	30	20.00	93.5	-4.34
Alt6-HELO	**30**	**154.00**	**211.3**	**2.76**
Alt7-B-MB	**30**	**156.00**	**265.6**	**6.03**
Alt7-B-MT	**30**	**156.00**	**254.0**	**5.33**
Baseline	30	20.00	84.6	-4.87
Overall	330		165.5	

H = 254.01 DF = 10 P = 0.000
H = 304.10 DF = 10 P = 0.000 (adjusted for ties)

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APPENDIX D. REVISED SEA-9 RELIABILITY MODEL

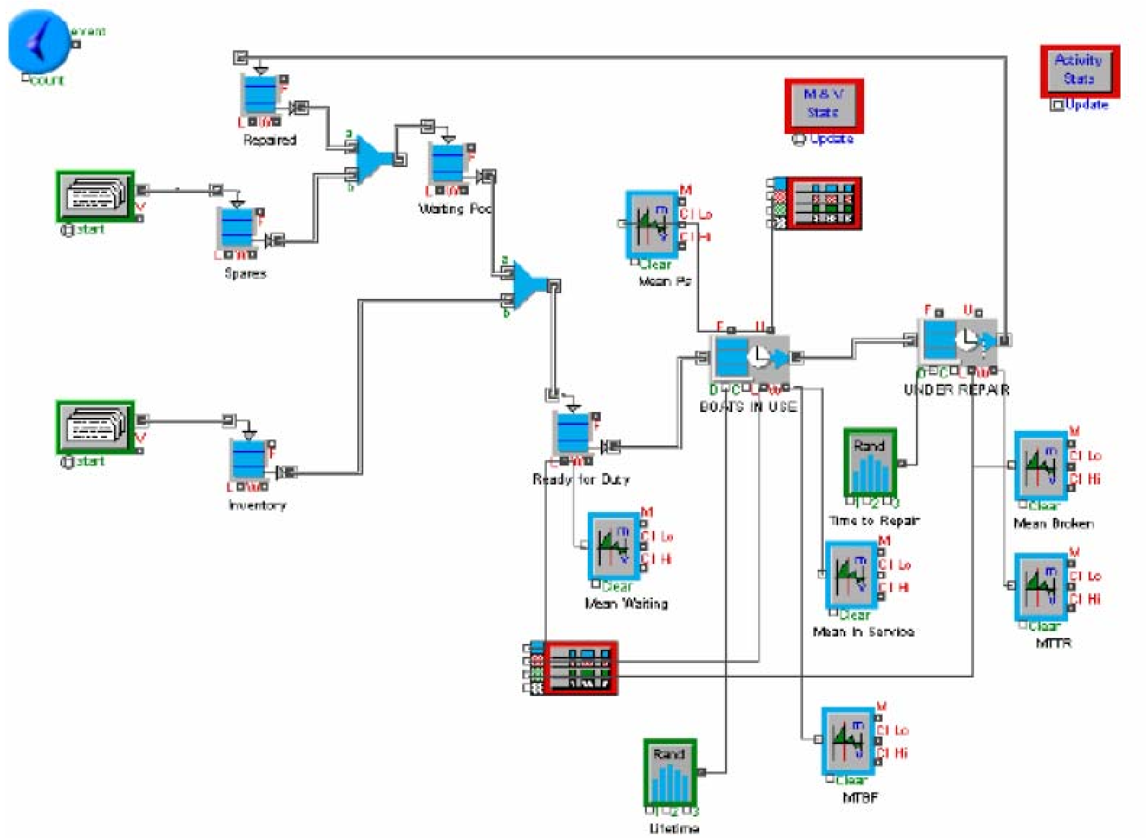

Figure 69. Revised SEA-9 Reliability Model.

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