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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Augmenting Naval Capabilities in Remote Locations

By

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December 2009

Approved for public release; distribution is unlimited

Prepared for: Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering

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ABSTRACT

The objective of this project was to apply a systems engineering approach to explore concepts for augmenting naval capabilities in remote sea locations using a standard Systems Engineering methodology coupled with Design for Lean Six Sigma tools. Because of increased challenges related to complexity, cost, and timing, our engineering approach focused on finding failure modes early and implementing effective countermeasures. Following requirements analysis and identification of needed functions, the project team synthesized candidate solutions that introduced new concepts and also exploited known programs of record within the Navy, the Coast Guard, and the Marine Corps. These included Unmanned Air Vehicles (UAVs), Unmanned Surface Vehicles (USVs), the aerostat Multi-Function Phased Array Radar, automation, and a Remote Sea Station. Results from analysis and simulations showed that an Automated Super-Highway Concept (ASHC) addressed the immediate need. The proposed approach combines the capabilities of the systems above to control the battle space in an effort to divert or destroy all non-friendly entities in the areas of interest. This approach also allows for persistent presence and analysis of the enemy movement while reducing the naval task force already assigned to patrol these areas.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The U.S. Naval force paradigm has been changing over the last few decades in order to combat emerging threats of the times. Currently, the naval force paradigm is once again shifting to a new capability that can combat smaller threats. In a recent article in the Naval War College Review, *The Navy's Changing Force Paradigm,* the author Professor Robert C. Rubel describes a force paradigm with four segments: access generation, power projection, maritime security, and a series of Maritime Operations Centers (MOCs). Although our Navy is unmatched in global dominance, a "Maritime Security" force is the paradigm segment whose capabilities are not meeting the goals of the mission of maritime security in area of coverage and in response time.

This capstone project focused on providing a recommendation for augmenting naval assets in remote locations in order to prevent piracy, illegal drug trafficking, and provide more security within ports, waterways, and coastal areas. The team applied systems engineering techniques integrated with Lean Six Sigma techniques to explore options for augmenting naval assets. The concept was developed using a combination of DCOV (Define, Characterize, Optimize, and Validate) and DMEDI (Define, Modify, Explore, Design, and Implement). Requirements were generated by looking at the SIPOC methodology (Supplier, Input, Process, Output, and Customer), as well as through the use of the Quality Function Deployment (QFD) process. Once the requirements were known, a Work Breakdown Structure was formed to meet customer expectations. Once an application specific design was chosen, it was modeled and analyzed. The modeling and analysis part of the project identified which components of the design would work well and where more work would be needed to meet the requirements.

The analysis considered the needed system's three major sub-functions which were detect, control, and engage. To complement this analysis of functions, the project team developed a concept of operations for how the system could provide an effective maritime security force near the coast of Somalia. The outcome of the study revealed four critical success factors: persistent presence, response time, area of coverage, and maritime awareness. The combination of functions and factors helped develop the

concept which the team called the Automated Super-Highway Concept or ASHC. After completing the analysis, the results indicated that a system of systems which included using unmanned vehicles would address the piracy problem.

The ASHC features one or more unmanned Remote Sea Stations (RSS) that act as a home base for the semi-autonomous operation of multiple unmanned vehicles; usually Unmanned Air Vehicles (UAVs) and Unmanned Surface Vehicles (USVs). The ASHC includes high altitude airships (aerostats) that provide the exchange networks and operations coordination framework that will be used by the system, either at a shore facility or aboard a ship. This is necessary to perform Intelligence, Surveillance and Reconnaissance to enhance Maritime Domain Awareness (MDA) and provide the ability to react to hostile pirates, terrorists, or other adversaries when the need arises. The RSS will enable the real-time sharing of data and live video, and refinement of joint procedures pertaining to the operation of relatively inexpensive multiple semi-autonomous airborne and surface vehicles across a specific region. At the present time, this can only be accomplished by manned aircraft and surface combatant ships.

The ASHC will build upon previous intelligent unmanned system investments identified on the unmanned system roadmap for the DoD to provide extended MDA information and threat detection response information for a region to a centralized control station. As a part of the ASHC implementation, interfaces to these existing systems must be developed to enable them to share data and video with each other, and the Maritime Operations Center (MOC).

As envisioned, the ASHC will utilize the capabilities of unmanned surface vessels (USVs) for surface warfare by extending the MDA defensive envelope of ships and other command stations. The ASHC system can be implemented through integration of persistent long term remotely deployed threat detection sensors and engagement systems onto unmanned platforms and potential manned platforms.

The ASHC provides flexible control and distributed assets that may be used to form a robust and scalable system of sentries to find, control, and deter/destroy threats. The proposed RSS architecture has a capability to store, maintain, launch and recover UAVs/USVs, and to provide self protection and communications for the sea station and

Navy unmanned vehicles. To support maintenance and servicing of UAVs and USVs, each station will house automated robots similar to those found on a modern production line.

Each RSS is responsible for an area of coverage that is a 200-nm by 200-nm box. When multiple RSSs are placed in a line, they provide a continuous defended area for a sea lane. For example, ten sea stations can provide sea lane protection along a stretch of 2,000 nm with a 200-nm width. An aerostat located at every third or fourth RSS provides multi-function phased array radar capability for all of the unmanned assets, the mother-ship or land-based control center, and the MOC. The aerostat also provides high speed communications for command and control and near real time video from each of the UAVs and USVs and the RSS. Using space links, all communications and video between the mother-ship and the RSS can be observed and followed at the MOC.

In summary, if implemented, the Automated Super-Highway Concept will prove to be beneficial to the Navy and the world's commercial shipping fleet. By confining shipping to a defended area that is only 8 percent of the currently affected zone of pirate operations, it greatly reduces opportunities for pirate attacks. In addition, the ASHC could perform the equivalent functions of a naval task force estimated to require 29 ships and 8,030 naval personnel to perform the same mission along the Somalia coast.

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I. INTRODUCTION

A. PROBLEM STATEMENT

As the U.S. Navy steams ahead into the 21st Century, it becomes apparent that it faces two potential problems. The first problem is the changing roles and missions that the Navy is being tasked with. These new roles and tasks will require a force structure change that will significantly impact the composition of the future Navy. Today's Navy is a power projection force equipped to do battle on the open ocean. The future Navy must evolve from "blue water" fighting to littoral combat with smaller aggressors [Rubel 2009]. Although the concept of littoral combat is still being defined, good examples of this include current missions such as anti-piracy and drug enforcement. The second problem that the Navy faces is a low number of ships available to make operational commitments. This translates to a lack of U.S. Naval presence in areas such as the Horn of Africa. The increase in pirate activity in this area has put a taxing toll on the existing force structure of the Navy through the requirement for a constant presence. Overall, these two problems present a unique set of challenges for the future Navy. It is clear that innovative solutions are needed to relieve the pressure off the current force structure and to provide the presence needed to respond to conflict in a timely manner. This project investigates potential solutions to the problems mentioned above.

B. DEFINING THE PARADIGM

In the 2009 article from the Naval War College Review titled *The Navy's Changing Force Paradigm,* the author, Professor Robert C. Rubel states, "A naval force paradigm is a theory of how various types of ships and weapons available to a navy should be organized for warfare. The paradigm is governed by the characteristics of the principal naval weapons of the day and by the maritime strategy a nation pursues." He further states, "The recently issued *Cooperative Strategy for 21st Century Sea Power* reflects an institutional response to America's changed strategic circumstances and embodies a logic that suggests a significant change to the Navy's force structure paradigm" [Rubel 2009].

The new force paradigm suggested by Professor Rubel provides the basis for the research presented in this report

C. BACKGROUND

1. The Changing Paradigm

Professor Rubel's paper outlines the argument that the Navy needs a new force paradigm. The Navy started out with small frigates carrying cannons, which could operate independently or in small squadrons to protect merchant ships. Upon entering into the twentieth century, the United States wanted to become more of a strategic player in the world scene. This caused a shift in the Navy's paradigm to that of a battleship centered fleet with the principal weapon being the large caliber naval gun. World War II brought yet another shift to the paradigm following the Japanese attack on Pearl Harbor. In this new change, the fast aircraft carrier became the center of a circular formation of ships. The formation was made up of specialized ships to perform certain duties such as convoy escort or amphibious operations. All of these paradigms were based on a central ship type that supported the primary weapon. By using this concept, it made it easy for the Navy to submit additional budget requests to Congress. The Navy could easily justify each ship type, along with the number and characteristics needed based on its role in the existing force paradigm.

Currently the Navy is in the initial stages of another paradigm shift. This shift is different from those seen in the past such as going from a battleship-centered force to an aircraft carrier-centered force. With the increasing lethality of anti-aircraft defenses and the effectiveness of newer anti-ship missiles, one must consider making the shift from the status quo to a more distributed concept, one oriented on missile firing platforms, such as submarines and surface combatants.

With the end of the Cold War and the collapse of the Soviet Union, the competition for supremacy of the seas disappeared and with that, much of the justification for maintaining the Navy's current fleet assets. In the post Soviet Union Era, the United States was left alone as sovereign of the seas. This meant that the Navy could now deemphasize some of its warfare areas such as sea control and emphasize other areas such as projecting power ashore in joint operations. Over the course of the last fifteen years, the Navy made a realignment to power projection invoking the concept of Carrier Strike Groups (CSGs) and Expeditionary Strike Groups (ESGs) [Rubel 2009]. Since the aircraft carrier remained the center of the new paradigm, the transition was easier. The Navy could now focus on the geographic hot spots with ships deployed mainly in two regions.

The late 1990's saw an emerging emphasis on Network Centric Warfare (NCW) and Littoral Warfare. The result of this emphasis led to the emergence of the Littoral Combat Ship (LCS) concept. However, unforeseen events such as the development of a ballistic anti-ship missile; China becoming an economic power and able to build a credible navy; the terrorist attacks of 9/11 with the resulting two wars in Iraq and Afghanistan; and a resurgence in Russian military power made the Navy uncomfortable with the direction they were heading and emphasized the need for a new maritime strategy. In 2006, the Chief of Naval Operations (CNO), Admiral Michael Mullen, called for the development of a new strategy. This new strategy, unveiled in October 2007 called for combat forces concentrated around Northeast Asia and the Persian Gulf, globally distributed, mission tailored forces, and a maritime security network, to work together to prevent or limit regional conflict, offer disaster relief, and provide necessary services to foster and defend commerce and security [Rubel 2009].

Studies based on this new strategy conducted by the Naval War College have now suggested that the Navy adopt a different style of war fighting and that the Navy consider tailoring its forces by region and mission. Based on these studies, Professor Rubel continues his analysis by proposing a Force paradigm consisting of four segments:

- An "access generation" force
- A "power projection" force
- A "maritime security" force
- A series of Maritime Operations Centers (MOCs)

The first segment, "access generation", would focus on employing missiles. Opposing access denial forces will be the main targets for these missiles. Defending against modern missiles is difficult, and this force would use a highly dispersed and covert posture to prevent the enemy from targeting them. The constitution and operation doctrine of this force would not be the same for different regions of the world. This force will be centered mainly on submarines, especially Special Service Groups Navy submarines (SSGNs), and surface ships such as the *Arleigh Burke* class of guided missile destroyer and the Littoral Combat Ship.

The second segment, a "power projection" force, would look much the same as it does today. CSGs and ESGs are centered on big deck aviation ships. Instead of its current role, show of power, they would become a specialized role-playing force. This new power projection force would operate in permissive environments but could support the access generation force under certain circumstances.

The third force segment, the "maritime security" force would be supported quite often by elements of the first two segments. This force would have specialized units conducting patrols in search of terrorists and other criminals and help establish a global maritime security partnership. Professor Rubel recommends that a new and less expensive platform should be considered for global maritime partnership missions.

The fourth segment is a series of MOCs that are currently being established around the world. These would not just provide command and control for forces afloat, but will also provide various information operations critical to maritime security, power projection, and access generation forces.

2. Maritime Awareness

Although this paper will primarily focus on an approach to implement the "maritime security" segment proposed in Professor Rubel's strategy paper, *The Navy's Changing Force Paradigm,* other aspects will also be taken into account, specifically the response time of the present day Navy. Because of the size of the Navy today and the geographic extent of regions where forces may be needed, it becomes difficult to protect all U.S. interests in a timely manner. This is known by our enemies and allows for windows of opportunity to attack U.S. interests with little or no consequence. The vulnerability to terrorists and criminals has led to the creation of directives to be followed by U.S. agencies. One such document is the Homeland Security Presidential Directive 13 (HSPD-13), which directs the coordination of Maritime Security Policy through the creation of a *National Strategy for Maritime Security* issued in December 2004. HSPD-13 was developed to establish U.S. policy and implement actions to further reduce the vulnerability of the maritime domain. This is imperative because more than 80 percent of the world's trade travels in the maritime domain and maritime security has a high priority to national security. Maritime security is no easy task since there are about 30 mega ports/cities spread throughout North America, Asia, and Europe. To reach these mega ports, 75 percent of the maritime trade must travel through only a handful of straits and canals. Figure 1 show the most frequently traveled routes in the maritime domain that connect the major ports of the world.

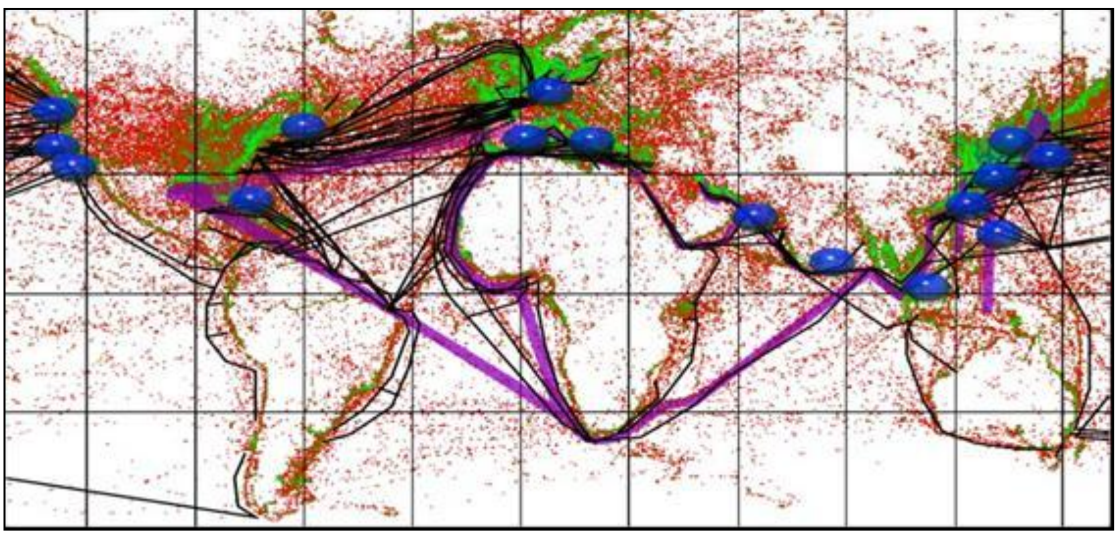


Figure 1. RF signature activity throughout the world.

This Figure provides a visual display of RF signals in the world indicated by the red dots. The sources from the ocean areas give an indication of ship and aircraft densities. The blue dots show major ports of commerce. The purple lines show major shipping lanes [21st Century Brief 2001].

Since the U.S. carries out approximately 90 percent of its commerce trade in this maritime domain, the U.S. Navy must protect the national interest of maritime security. As a solution to covering the vast distances involved, the U.S. has concentrated naval forces around Spain, Pakistan, and Japan. Figure 2 shows the movement capability of these forces after 24 hours, 48 hours, and 96 hours.

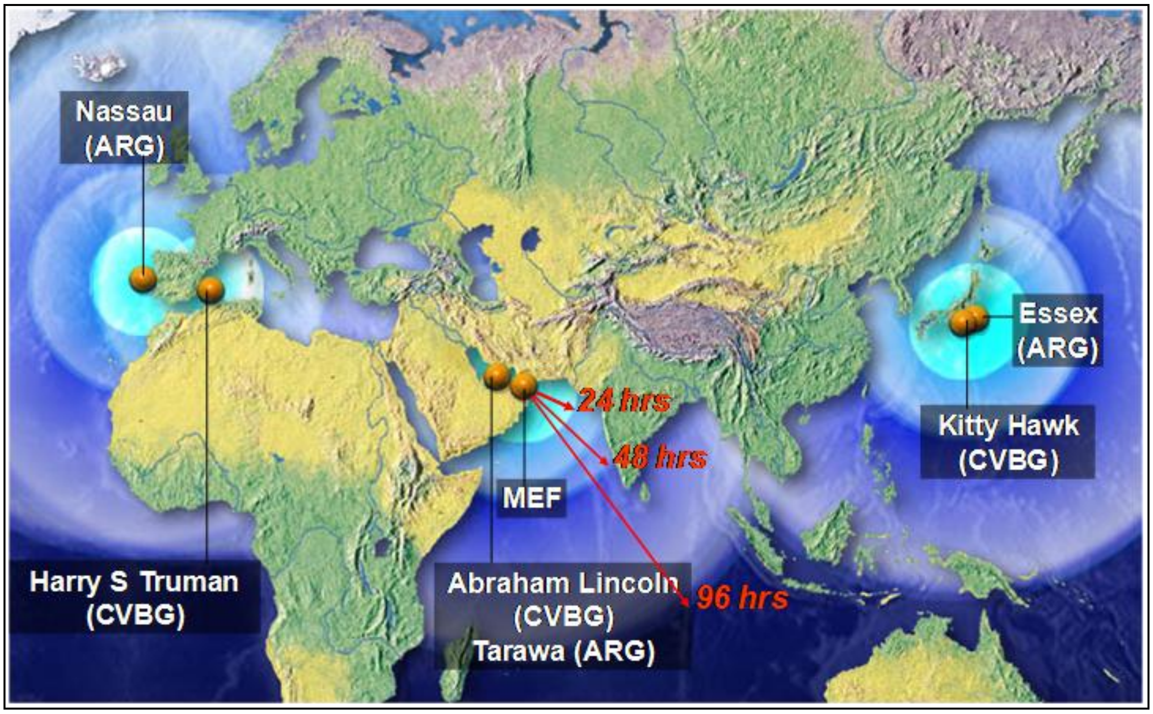


Figure 2. Movement Capabilities of Naval Forces.

The light blue circles show how far naval ships can travel in 24 hours; the next lighter ring is the amount of travel in 48 hours, and the larger ring shows projected movement at 96 hours [21st Century Brief 2001].

Reference to Figure 2 clearly shows that unless there is a naval vessel within close proximity it becomes difficult to respond quickly to an emergency in the majority of the oceans.

Another guiding directive is the Security and Accountability for Every Port Act of 2006 (or SAFE Port Act, Public Law 109-347). This act has required that the Secretary of Homeland Security develop a strategic plan to enhance the security of the international supply chain. July 2007 saw the completion of the Strategy to Enhance International Supply Chain Security, which establishes a framework for the secure flow of cargo through the supply chain by building on existing national strategies and programs [Department of Homeland Security 2007]. The protocols and guidance for resumption of trade following a transportation disruption or transportation security incident plays an important part of this strategy. The international supply chain, as defined in the strategy, "is the end-to-end process for shipping goods to or from the United States beginning at the point of origin (including manufacturer, supplier, or vendor) through a point of distribution, to the destination."

Enforcing the SAFE Port Act is becoming increasingly more difficult, especially around the Horn of Africa, where acts of piracy are on the rise (Figure 3). In this region pirates are operating in 1.2 million square nautical miles of ocean where there are only 30 warships from 14 nations on patrol to deter them. The lack of adequate protection by the warships is highlighted by the pirate attacks on the *Maersk Alabama* in April 2009. It took the USS *Bainbridge* three days of steaming to reach the site of the attack. The U.S. needs to increase its presence in order to protect its maritime interests.

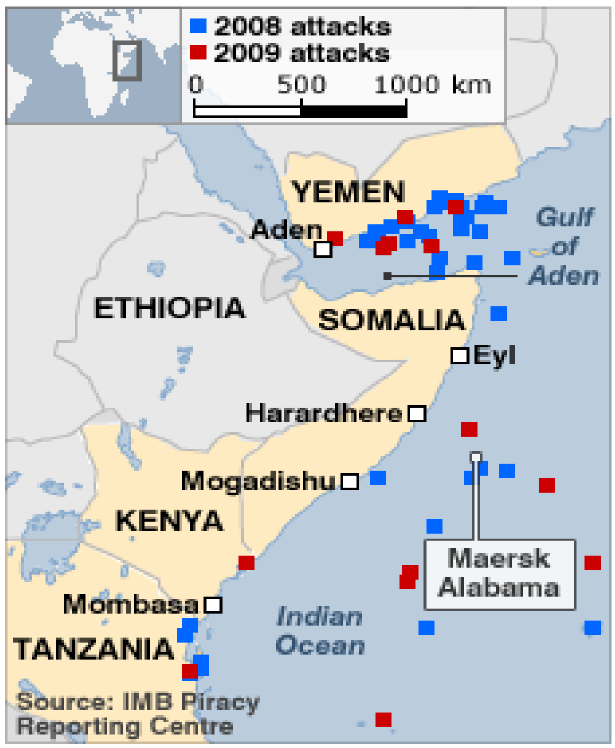


Figure 3. 2008/2009 Attacks.

A map showing Somalia and the surrounding area and a number of reported pirate attacks in 2008 and 2009 [British Broadcasting Company 2009].

One of the last reports mentions that since February 2009 pirates have attacked 78 ships near Somalia, hijacked 19 of them, and held 16 vessels with 300 plus hostages from more than a dozen countries [Kennedy 2009]. The pirates held these hostages and ships for ransom, which can affect all with higher consumer prices. Piracy has had a severe impact on maritime commerce going around the coast of Somalia and has required additional security forces for the protection of shipping, a cost that gets passed on to the consumer.

3. Power Projection Issues

The majority of the U.S. surface fleet is geared toward combating blue ocean threats from large nation states. While this is a vestige of the Cold War maritime strategy, the Navy of the People's Republic of China is an example of a potential blue ocean threat for the future. According to the 2009 Annual Report to Congress from the Office of the Secretary of Defense, "China has expanded its arsenal of anti-access and area-denial weapons, presenting and projecting increasingly credible, layered offensive combat power across its borders and into the Western Pacific. China has or is acquiring the ability to: 1) hold large surface ships, including aircraft carriers, at risk (via quiet submarines, advanced Anti-Ship Cruise Missiles (ASCMs), wire-guided and wake-homing torpedoes, or anti-ship ballistic missiles); 2) deny use of shore-based airfields, secure bastions and regional logistics hubs (via conventional ballistic missiles with greater ranges and accuracy, and land attack cruise missiles); and, 3) hold aircraft at risk over or near Chinese territory or forces (via imported and domestic fourth generation aircraft, advanced long-range surface-to-air missiles systems, air surveillance systems, and ship-borne air defenses). Advances in China's space-based reconnaissance and positioning, navigation, and timing as well as survivable terrestrial over-the horizon targeting, are closing gaps in the creation of a precision-strike capability".

Even with the Cold War over, there is a potential for a new battle for sea supremacy. To retain its current advantage, the U.S. still needs to have large warships available to deter potential threats. This in turn limits the ability to provide adequate protection in other areas of the globe to combat new threats such as piracy. This becomes especially true today since defense budgets are being cut, forcing the U.S. to find other alternatives for its dwindling navy.

4. Problems at Home

Not only is the U.S. Navy struggling with the piracy battle in Somalia, there is also evidence that our maritime forces face an equally challenging battle in our own coastal waters. Daily news reports about how often illegal drugs make it into the U.S. every year provide a good example of how we are losing this challenge. In addition, U.S. ports are open to a terrorist attack. If a large ship were sunk in the middle of one of the mega ports it would shut it down.

There is also a need for more surveillance of the pleasure craft that operate in the coastal waters of the U.S. Many times these small craft get into trouble and the Coast Guard does not have a vessel in the vicinity to assist if there needs to be an ocean rescue. There is piracy going on even in our own waters. These pirates will seize a yacht, kill the people on board, and use the vessel to run drugs into the U.S. Piracy is nothing more than high-seas criminal activity, which cannot be addressed by Harpoon missiles or five-inch guns from warships.

The Navy and Coast Guard are unable to protect these areas with current assets. This leads to a requirement for systems that could provide a way whereby the maritime forces can have a more persistent presence, providing better protection for commerce and recreation vessels operating in the coastal waters of the U.S. and in important shipping lanes around the world.

D. SUMMARY

The Navy's future conflicts will occur on a much smaller scale. These evolving missions require the Navy to prepare itself for expeditionary operations from blue water operations to inland operations.

At the same time, it is clear that the Navy must be prepared to handle large-scale threats. The Mission of the U.S. Navy, in addition to winning wars and deterring aggression, is maintaining freedom of the seas. Today's Navy does not have the means to battle small maritime threats or deter potential terrorist attacks on seagoing vessels in an efficient and cost effective manner. This shortcoming is the motivating influence for the Capstone Project described in this report.

The paper consists of five major chapters. In the first chapter, analysis of the problem introduced four critical factors that need to be considered for the design of a maritime security force near Somalia. Chapter II consists of the Analysis of Alternatives. In that chapter, several alternatives for solving the problem are evaluated. Chapter III describes the project team's technical approach and how the systems engineering approach was integrated with Lean Six Sigma techniques. Chapter IV discusses the modeling and analysis efforts, and Chapter V presents the team's conclusions.

II. TECHNICAL APPROACH

The approach selected for this project combined the standard systems engineering "Vee" process model of Figure 4 with Design for Lean Six Sigma (DFLSS) tool methods to accelerate architectural and engineering development. The DFLSS methodology used in this paper is shown in greater detail in Appendix L. The advantage of this approach is that use of the DFLSS tool set can facilitate the selection of available concepts and technologies and accelerate the development of a viable system solution to the problem at hand. Several of these tools were introduced in the previous section; e.g., Affinity Diagram and QFD. This section will expand upon and refine the outcome of the analysis of alternatives.

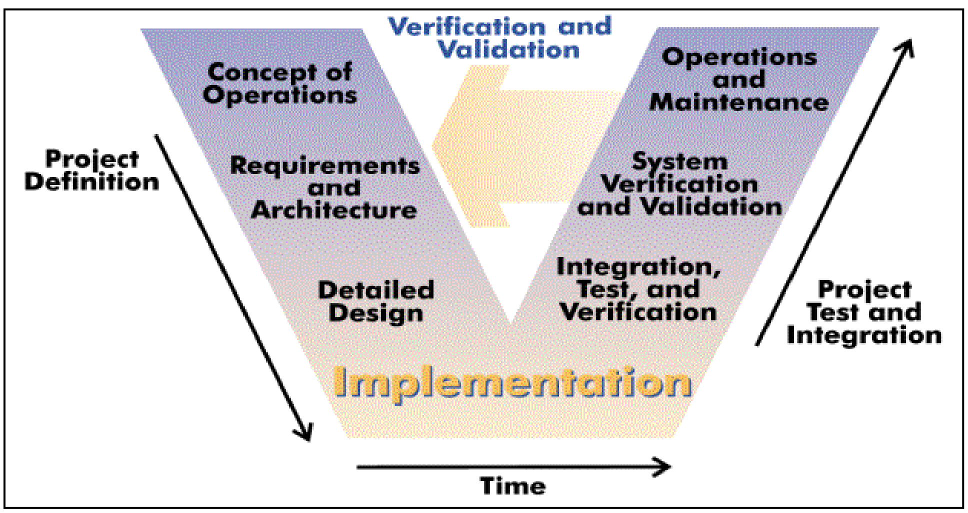


Figure 4. "Vee" Model Diagram.

The project team followed the Systems Engineering "Vee" Diagram up through the Requirements and Architecture phase and stopped at the Detailed Design phase [Osborne 2005].

The starting point for the next phase of analysis was a recent evaluation of the missions of the U.S. Coast Guard. Design for Six Sigma (DFSS) tools was applied to link strategic goals, operating areas, mission programs, and operational resources into one model [Stefanko 2008]. The Coast Guard is a military, multi-mission maritime service within the Department of Homeland Security with 11 statutory mandated areas that outline its role of protecting the public, the environment, and U.S. economic and security interests in any maritime region in which those interests may be at risk [Six Sigma Forum 2009]. Figure 5 is the resulting model.

Because of the limited time available for this project, the focus was on the maritime security threats: piracy off the coast of Somalia; Other-law Enforcement; and Ports, Waterways, and Coastal Security.

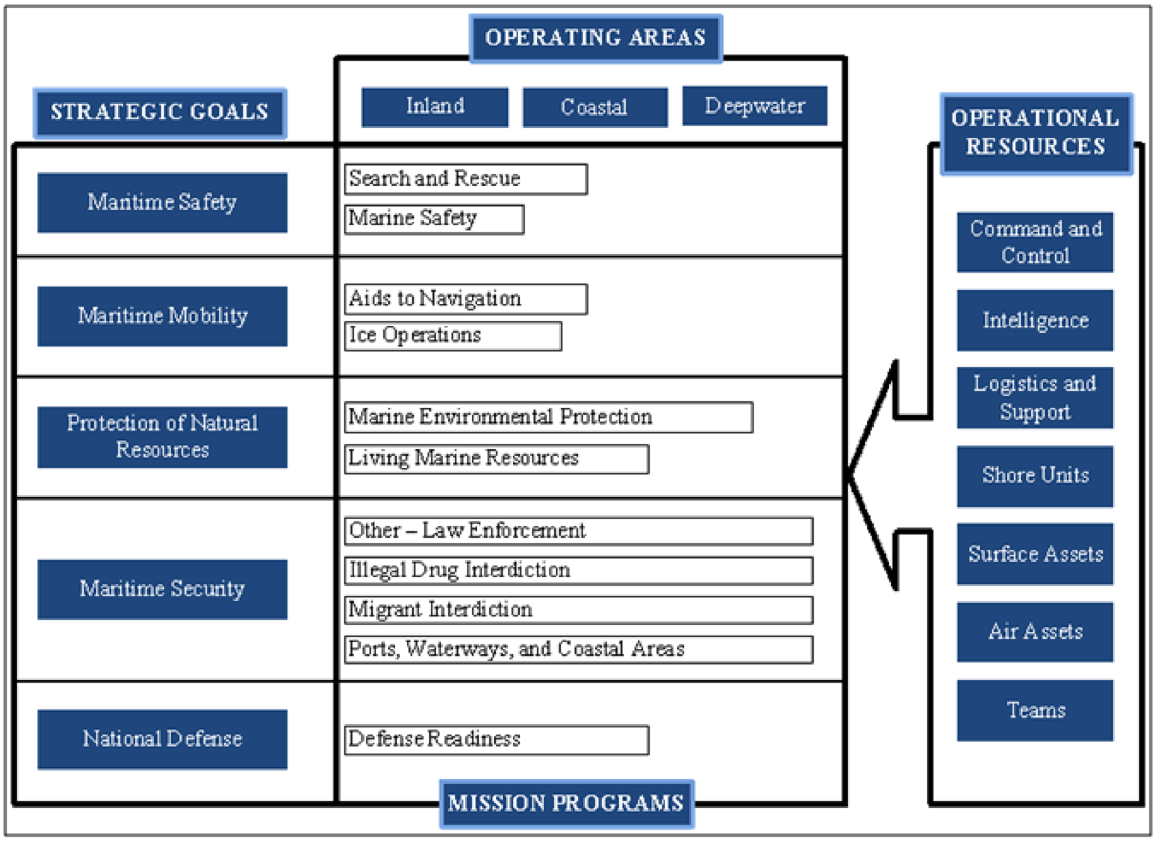


Figure 5. Simplified version of the Coast Guard Strategy.

The above diagram shows a simplified version of the latest Coast Guard Strategy Plan. This plan is also very similar to that of the U.S. Navy Strategy Plan. [Stefanko 2008]

Using DFLSS tools linked strategic initiatives to process improvement. Further, it facilitated the integrating of project goals with strategic initiatives already in place. This link can serve to accelerate concept development and acceptance. Critical to this linkage is a bounded set of assumptions that limit the scope of the project to the resources and time available. This set of assumptions also helped determine if the solution can be developed within the constraints of existing technology strategies or if a new solution is needed.

The Technology assumptions were derived using the theory of constraints (TOC). "The strength of a chain is dictated by its weakest link" is analogous to understanding that the performance of any value chain is dictated by its constraints. TOC is a five step process that maximizes the performance of a value chain.

1. Identify constraints
2. Decide how to exploit the constraints
3. Subordinate and synchronize everything else to the above decisions
4. Elevate the performance of the constraints
5. If any of the above constraints have shifted, go back to step 1

The above steps are called the *5 Steps of TOC* and provide the foundation for many generic solutions, which include the management of processes, inventory, supply chains, product development and projects (single and multiple), personnel, and decision-making (Figure 6). For this reason, theory of constraints was chosen for dealing with the piracy in Somalia. The fundamental objectives of Maritime Awareness are cost and operational effectiveness. Operational effectiveness is achieved through area of coverage, presence, maritime security force, and response time. The value chain in this project can be simplified to the challenge of ensuring availability of the right assets at the right place at the right time while maintaining high-tempo operations. The TOC Supply Chain concept can enable the Navy to achieve the fundamental objectives of maritime awareness: rapid response to demands, improved on-time performance, reduced need to utilize and expedite multiple expensive assets, and better utilize capacity to meet customer expectations. [Bahadir 2006-2007]

TOC when combined with Lean Six Sigma tools provided improved performance in the defined supply chain through the elimination of variation, waste, and overload.

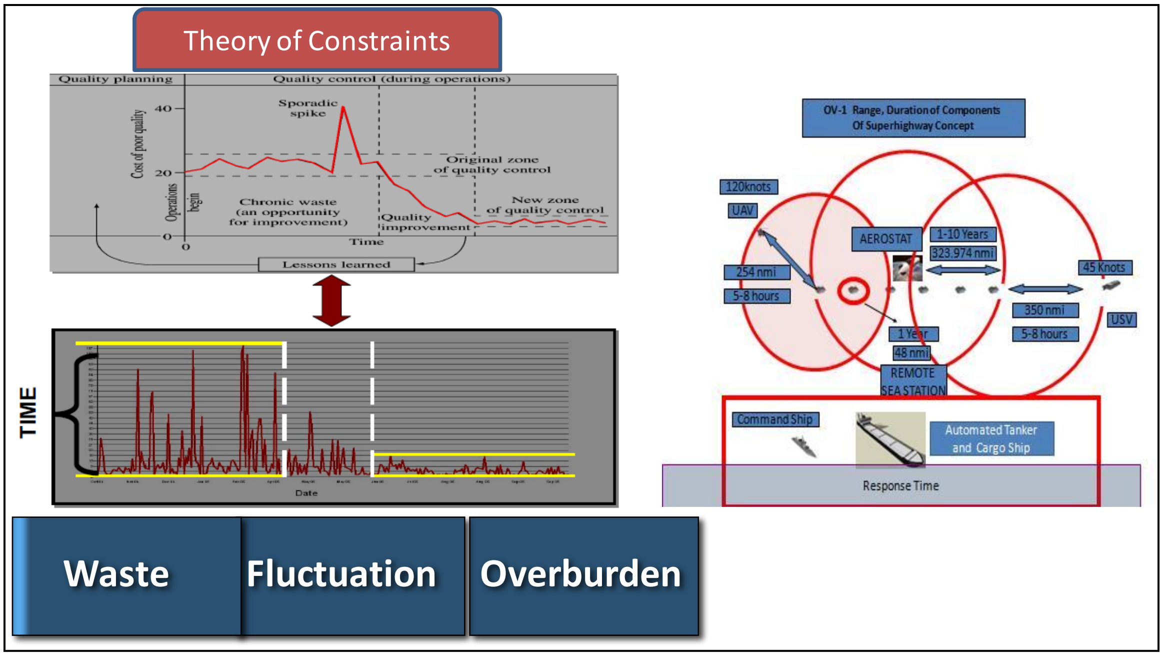


Figure 6. Theory of Constraints.

Theory of constraints is utilized to eliminate process variation. In lean, this process variation is associated with overburden, fluctuation, and waste. The principle of theory of constraints was utilized in the analysis of range with respect to the different components selected for the ASHC system. Reduced process fluctuation, overburdened equipment and waste leads to effective control.

A. SYSTEMS ENGINEERING ROADMAP

During the "define" stage of the systems engineering study, the team developed a systems engineering roadmap. This roadmap provided team responsibilities and a step-by-step process to follow. The system engineering roadmap developed is shown in Figure 7. The systems engineering roadmap utilizes many tools of Lean Six Sigma (Appendix L), which facilitated the gathering of large amounts of information in a short period of time. The complexity of the system under study, with only a 30 week period for the study, required acceleration of information gathering using techniques presented in the Naval Postgraduate School systems engineering curriculum, many of which correspond to Lean Six Sigma methods being deployed by Department of Defense (DoD). Four of the six team members are certified as Green Belt in Lean Six Sigma.

During the define stage of a Lean Six Sigma study, strategic roadmaps were carefully studied. These studies enabled critical decisions that accelerated concept development.

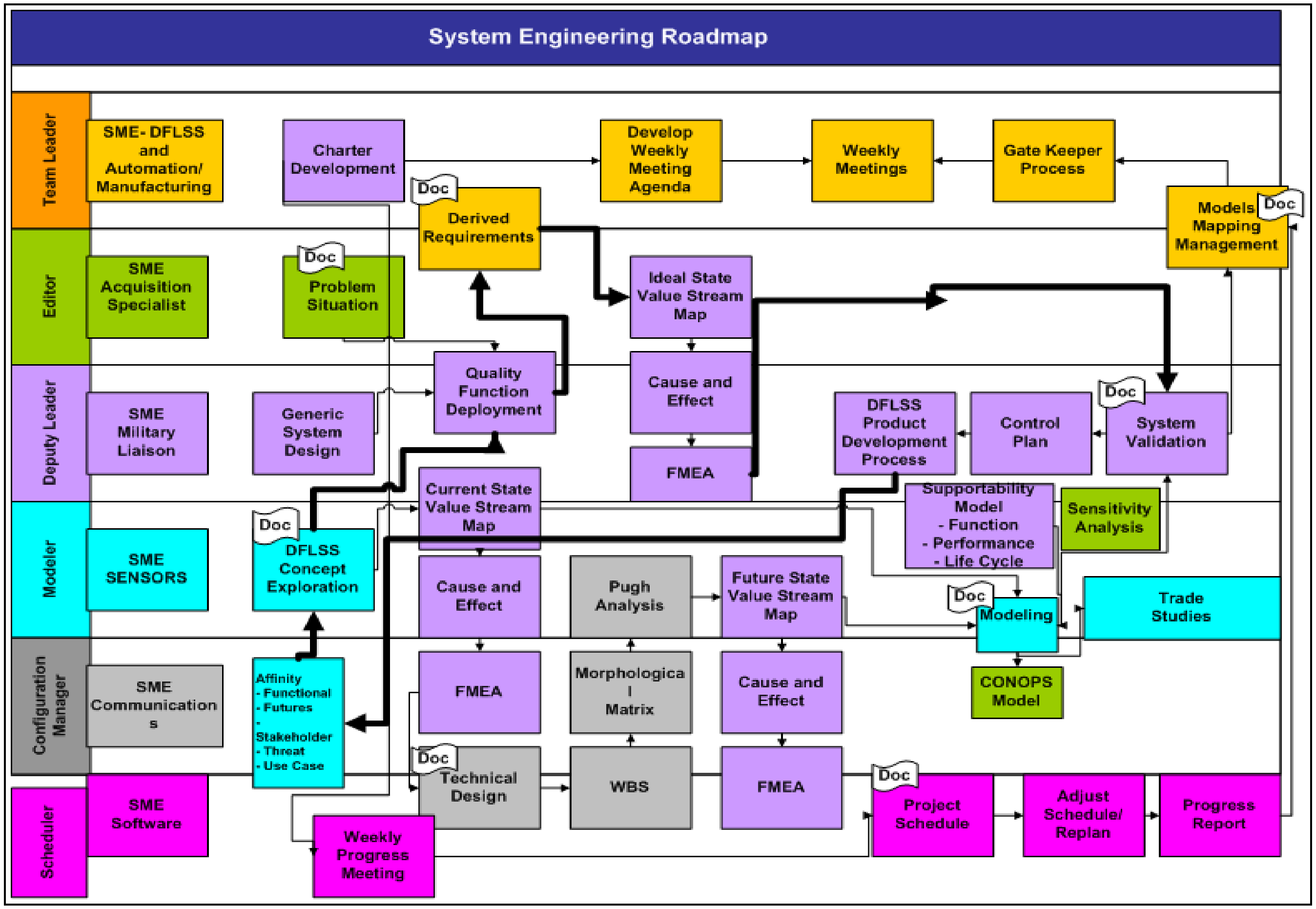


Figure 7. Team Roadmap.

The team roadmap represents a plan to execute a tailored systems engineering approach. Each color code corresponds to the team role and concurrent technical role. Each team role possesses a swim lane. Within each team role, related process blocks exist in assigned swim lanes. Team interaction between members occurs in swim lanes, between swim lanes, and by color code. Deliverables and enablers are included in the defined process blocks.

B. TEAM ORGANIZATION

The organization of the project team was critical for implementing the systems engineering approach. The team organization incorporated the concepts of a learning organization and innovative product development environment in which both concepts contribute to accelerate product development. The organization fostered a learning environment, which emphasized mentorship and guidance in the form of our professors from the Naval Postgraduate School. The learning organization utilized the technical resources of hull design, sensor development, and unmanned system development. The resulting team structure is shown in Figure 8.

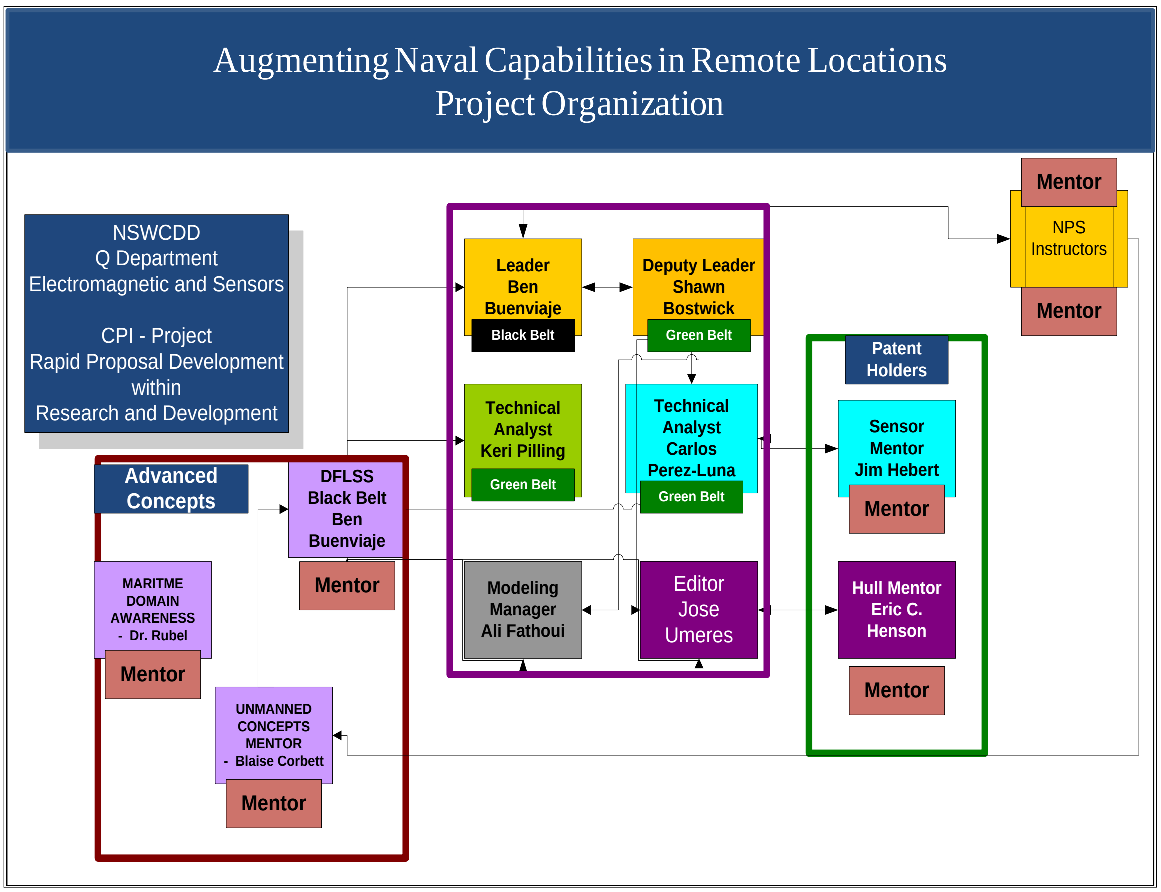


Figure 8. Development of the learning organization embedded the stakeholders in the process.

Acceleration of the systems engineering process occurs when the majority of the team understands Lean Six Sigma methodology. The Learning Organization mentors team members in advanced hull design, and strategic initiatives.

C. STAKEHOLDER ANALYSIS

A critical first step was stakeholder selection. Once the stakeholders were selected, current processes were examined. This led to a current state map, which established a common point of view. After the current state map was developed, a cause and effect diagram was developed that examined all causes in relation to the effect in detail. The data gathered from the current state map and from the cause and effect diagram were taken under consideration as the team developed the SIPOC (Suppliers, Input, Process, Output, & Customers) diagram. The SIPOC model considers first the high-level and then the low-level characteristics of the relationship y=f(x) which is a transfer function that helps evaluate the critical parameters of the process. The intent of the SIPOC model is to achieve an understanding of what is critical to the customer. The main functional blocks of the SIPOC analysis are listed in Figure 9. Figure 10 shows the relationship between the high level and low level characteristics of the SIPOC. Once the low level characteristics are determined, the customer's needs are placed into a House of Quality (HOQ) that compares those needs to measures of Critical- to-Quality (CTQ) parameters. Three additional HOQs are needed to determine the customer's requirements.

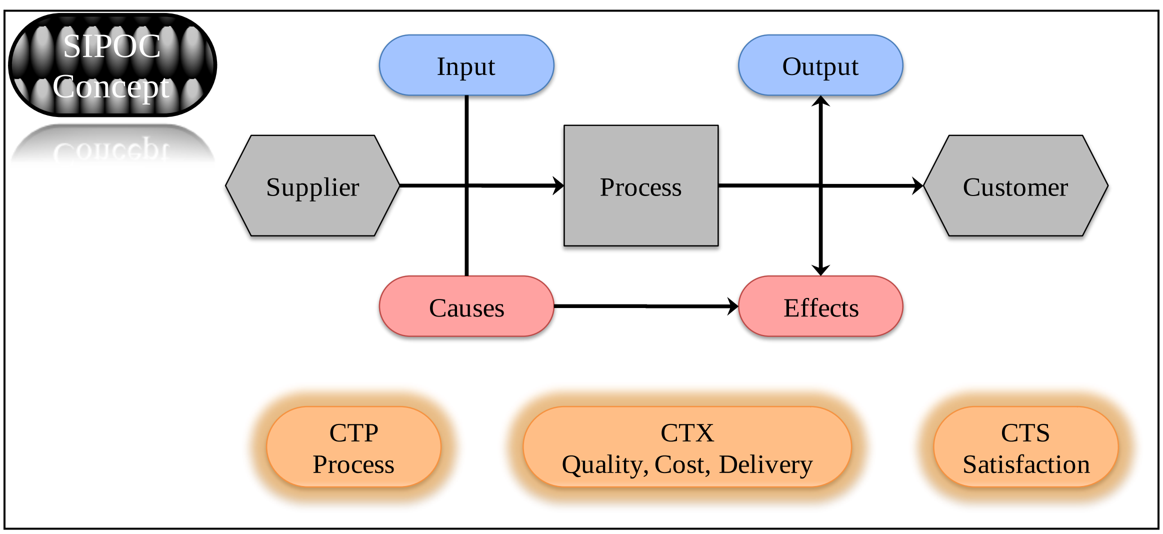


Figure 9. SIPOC Flowchart.

The SIPOC is a process that is used to obtain the Voice of the Customer. By understanding the voice of the customer, the systems engineering team focused the analysis in the area that is critical to the customer and critical to the process. The acronym, SIPOC, represents the supplier, the input, the process, the output, and the customer.

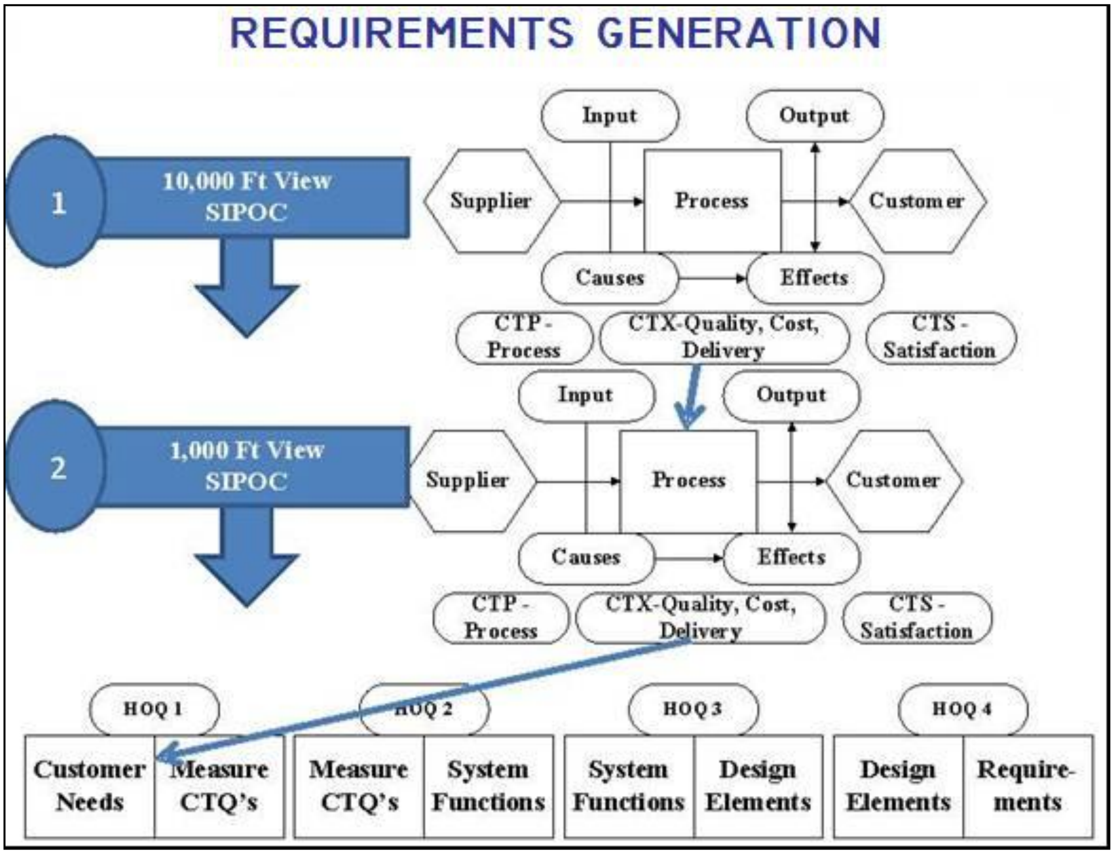


Figure 10. Voice of the Customer and Requirements Generation: Concept Design Phase.

The requirements generation process starts with a 10,000-foot view SIPOC. Next, CTXs from the SIPOC provide input to the process blocks of the 1,000-foot view SIPOC. CTXs of the 1,000-foot SIPOC provide input to the customer needs block of the 100-foot view HOQ. The HOQ examines the different HOQ in which the final HOQ outputs are the requirements of the design. [NAVSEA Lean Six Sigma Green Belt Course 2005]

1. Stakeholder Selection

Professor Robert Rubel, Dean of Strategic Studies at the Naval War College, was selected to be included among the project's stakeholders. His paper, cited earlier, inspired the project team to develop a system that would augment naval assets in remote locations. Upon further study of unmanned system developments, the project team became aware of the opportunity to augment manpower in the battlefield by employing systems on the unmanned systems development road map sponsored by the Department of Defense.

Blaise Corbett was selected to be a stakeholder and mentor based on his one-year study of the application of autonomous unmanned systems at the Naval War College. Jim Hebert, from Dahlgren, Virginia was selected to be a stakeholder because of his research interest in remote sea basing and his background in sensors. Eric Henson, from Carderock, Maryland was selected as a stakeholder for his research interest in hull designs that are survivable under high sea state and his research interest in remote sea basing. Table 1 lists the stakeholders and their organization.

Table 1. Project Stakeholders.

This is a list of the identified stakeholders who were able to participate in the project. These stakeholders acted as advisors and provided input and guidance to the project team.

Name	Organization
James L. Hebert	Sensor Development and Integration Branch, Q41, Naval Surface Warfare Center (NSWC) Dahlgren Division
Dr. Emmett Maddry	Dahlgren Laboratory Chief Engineer, NSWC Dahlgren Division
Eric Hansen	Code 2350. Combattant Craft Division, NSWC Carderock Division
Blaise Corbett	Q51- E3 Systems Engineering and Technology Branch, NSWC Dahlgren Division
Professor Robert Rubel	Dean of Naval Warfare Studies, Naval War College

2. Performance Parameters

The analysis to determine performance requirements started with an Affinity analysis. The Affinity analysis produced the performance requirements shown in Table 2.

Table 2. Performance Requirements.

Performance Parameter	Development Threshold	Development Objective
Availability	24 x 7 for 90 Days, System deployment to operational area within 20 days	Same as Threshold
Coverage	Persistence coverage within 200 NM radius	400 nm +
Interoperability	Link 11, 12, & 16 compatibility, all military satellite, secure wireless. All systems JTIC certified	Interoperability with NATO, & Coalition, & ability to warn adversaries.
Lethality	Ability to disable/destroy, small-medium size targets (over one nautical mile standoff strike range)	A controlled disability/destruction capability synchronized with target discrimination.
Survivability	System shall operate up to Sea-State 5. System is capable of full operation in all operational areas, particularly tropics. System will defend against irregular forces. For example, such forces are small fast boats or small fast attack craft.	Ability to operate in all states the enemy is capable of operation.
Manning	Extensive use of automation to reduce personnel manning and to reduce logistical footprint	To minimize the systems footprint in proportion to the discriminated threat
C2	Ensure man in the loop (links to HQ), and prevent fratricide/civilian casualties (rules of engagement/CONOPS)	Full automatic and semi-automatic operation with man in loop at safe remote location
Reaction time	Arrive on area of interest within 30 minutes of notification.	Arrive on area of interest within 15 minutes of notification

Development of this table included a surface threat analysis. Pirates can unexpectedly attack commercial vessels at relatively short ranges. The tendency of pirates has been to attack soft targets with minimal defensive capabilities to ensure high probability of success. Several parameters were identified such as initial range, detection range, maximum and minimum intercept ranges, surface threat velocity, interceptor velocity, and process time for launch. These parameters were used to simulate the detection, and interception capabilities required to address this threat. Preliminary analysis indicated that deterrence through active presence in proximity to potential attack routes would be effective.

3. Operational Requirements

Because of the complexity of the problem and a need to group areas of importance, an Affinity Diagram approach was chosen to collect thoughts and ideas related to the initial problem statement (see Figure 11). The inputs were grouped into functional categories: Detect, Control, and Engage.

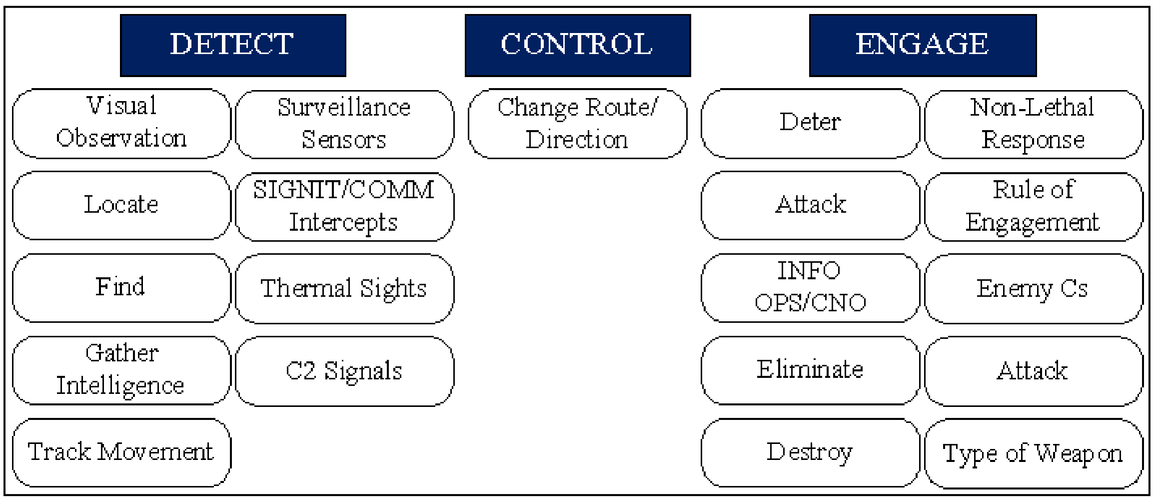


Figure 11. Affinity Diagram to Develop Functions to Prevent Delivery of Ordnance.

Affinity Analysis facilitates participative brainstorming. After the initial session, similar ideas are grouped together to develop common themes. Those common themes are Detect, Control, and Engage.

The headers of *detect* and *engage* both stood out as important elements for consideration in the system while seeking to fully understand the initial problem. The functional Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) area was chosen in the decomposition process because C4ISR functions will play a key role of exchanging information important to the problem set. Early detection is critical to maritime safety, and the assets must ensure responsive and continuous C4ISR procedures to shape a successful engagement of the enemy vessel.

The prevention system was subdivided into the elements of Function, Component, State, and Hierarchical Structure. Detecting an enemy vessel can be accomplished visually, though limited by Line of Sight (LOS) and through the use of signatures (e.g., electronic, thermal, and acoustic). Signatures help to extend visual detection to Beyond Line of Sight (BLOS) ranges. Improved BLOS ranges can be achieved through sensor elevation (e.g., higher terrain, an aerial platform, and a satellite) or by taking advantage of the adversary's platform signatures and physical features (e.g., engine, on board communications, reflective properties, existing surface areas, thermal properties, and platform movement).

The project team evaluated the three interoperating systems in combination with the four critical factors that the Naval War College studies focused on. The first factor is to establish a naval presence in remote locations so that naval forces have superior intelligence of enemies of maritime security. The second factor is the area of coverage. Being able to limit the area where the enemy of maritime security can engage our forces leads to more effective use of resources in remote locations. The third factor is response time during which the naval forces must be prepared to engage the enemy before the enemy of maritime security can become an undeterred threat. The fourth factor is the role of providing maritime security, which is our effective preparation for engagement of enemies of maritime security at a zero incidence level of a loss of a High Value Asset (HVA). An HVA is an asset determined by the enemies to be so valuable that the risk of death is a lower concern than obtaining the asset. The four critical factors support the concept of a maritime security force deployable around the world and around the coast line of the United States.

III. ANALYSIS

A. ANALYSIS OF CURRENT ALTERNATIVES

The Somalian piracy problem was chosen as the most stressing scenario for the analysis of current alternatives. It was assumed that other viable scenarios are a subset of the Somalia problem. A general approach was developed to analyze the Navy's available platforms and candidate new concepts that could be used to address the factors identified in Chapter I (maritime awareness, response time, area of coverage, and persistent presence).

1. Other Research

While piracy is not a new problem, the scale of the current threat presents a set of challenges that confound the traditional methods for combating this issue. A search of the existing literature documents the scope of the problem, but failed to reveal information on methods to contain the emerging threat outside of traditional naval force. As a result, the project team focused on evaluating existing platforms, both mobile and fixed to determine their effectiveness in combating the piracy problem in Somalia.

Currently, the problem in Somalia is being dealt with by using a traditional naval task force. This force, Combined Task Force 151, is a mobile naval force of 30 warships involving 9,000 personnel, 30 helicopters, and a smaller number of UAVs. With the battle space being 1.2 million square nautical miles, the area of coverage is too large for the existing number of warships to patrol effectively. This also means there is not a persistent presence. Along with the lack of being present, comes a decrease in response time because of the vast distances between patrolling warships. Maritime awareness is reduced because of all of these factors. Even though the number of ships increased from 20 to 30 ships in a six-month period, there were still about 146 reported attacks; indicating the problem still has not been resolved. This data shows the Navy is struggling with solving the piracy problem because the current force is deficient in the factors stated above.

Two possible solutions to combating the pirates in Somalia have been proposed by Northrop Grumman. However, they rely on the traditional naval task force concept. One concept involves 20 naval vessels, 6,900 personnel, and a combination of 20 SH-60 helicopters and a squadron of P-3s. The battle space covered by this concept is 480,000 square nautical miles and has an estimated cost of $7.2 million per day. The second concept approach involves 7 naval vessels, 14 Fire Scout, unmanned autonomous helicopters, 7 SH-60 helicopters, and one squadron of Broad Area Maritime surveillance (BAMS) unmanned aerial vehicles at a total cost of $1.7 million per day. This approach also has a battle space of 1.2 million nautical miles, comparable to that covered by Combined Task Force 151 [Newscast 2009].

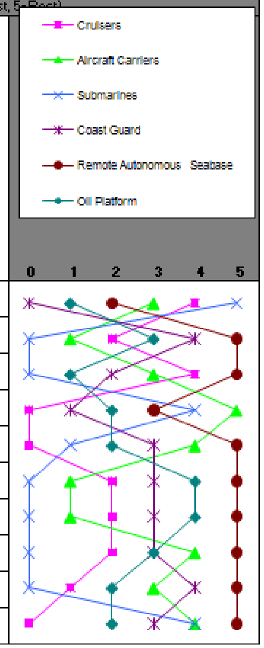
According to the analysis performed by Northrop Grumman, a traditional naval task force cannot cover the entire area. In reality, their analyzed battle space is less than one-half the area of concern; resulting in a deficiency in the area of coverage even more pronounced than identified in their results. This translates into a response time that is insufficient for most distress calls.

Clearly, this shows that a traditional task force is not the answer in solving the persistent presence problem, necessitating a look at other potential platforms. The examination of potential platforms is needed because the platform is the weakest link in the system. Solving the piracy problem is dependent on having a capable platform. That will provide; persistent presence, short response time, large area of coverage, and comprehensive maritime awareness.

2. Preliminary Problem Analysis

Quality Function Deployment (QFD) is an excellent method that can be used as a first step in matching platforms with mission requirements. The systems engineering team completed a House of Quality (HOQ) matrix that examined potential platforms that currently exist and some new concepts in the Navy and the Coast Guard. The HOQ is shown in Figure 12. The columns represent each platform (i.e., each potential solution). The rows represent the capability to react to common maritime security threats (the requirements). These threats where then given a numerical value (i.e., weighted value) based upon their criticality for being enforced. The strength of the relationship between the requirement and the platform was given a numerical score. The score for strength of the relationship and the weighted value of the requirement were multiplied. Each one of these numerical values was added and the sum corresponding to each platform was recorded. The platform with the greatest sum was ranked highest in satisfying the customer needs. Those needs are the missions of maritime security. The results of the QFD analysis gave an importance weight of 618.8 for the remote sea station concept. The remote sea station ranked the highest in importance weight. The remote sea station concept scored best in responding to 8 of the 10 common maritime security threats identified. In second place, the fixed oil rig produced a weighted importance score of 237.5. The fixed oil rig is a viable alternative although, not for Somalia's problem. The fixed oil platform is not a good alternative in Somalia because it does not have the mobility that is necessary in combating the pirates. This concept would be ideal for use as a port of entry, or where there are places where mobility is not necessary.

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Cruisers (22)	Aircraft Carriers (11)	Destoryers (58)	Submarines (54)	Frigates (30)	Littoral Combat Ships (2)	Patrol coastal Ships (9)	Guided Missile Submarines (4)	Amphibious Assault Ship(11)	Amphibious transport Docks (10)	Dock Landing Ships (12)	Mine Countermeasure Ships (14)	Coast Guard (Total Ships-42)	Remote autonomous sea station (0)	Oil Drill platform (0)	Cruisers	Aircraft Carriers	Submarines	Coast Guard	Remote Autonomous Seabase	Oil Platform
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)																					
1	9	6.3	4.0	DETECT FOREIGN SUBMARINES	O	O	O	Θ	O	▲	▲	Θ	▲	▲	▲	▲	▲	O	O	4	3	5	0	2	1
2	9	15.6	10.0	PREVENT TERRORISM AT MAJOR PORTS	▲	▲	▲	▲	▲	O	O	▲	▲	▲	▲	O	O	Θ	O	2	1	0	4	5	3
3	9	15.6	10.0	PREVENT PIRACY OF SEA LANES	O	O	O	O	O	O	O	▲	O	▲	▲	▲	O	Θ	O	4	3	0	2	5	1
4	3	15.6	10.0	ISOLATE GEOGRAPHICAL AREA	▲	O	▲	▲	▲	▲	▲	O	O	▲	▲	▲	▲	O	▲	0	5	4	1	3	2
5	9	15.6	10.0	PROTECT 100% OF THE COAST LINES	O	O	▲	O	▲	▲	▲	▲	▲	▲	▲	▲	O	Θ	▲	0	4	1	3	5	2
6	9	6.3	4.0	ELIMINATE DRUG TRAFFIKING BY SEA	O	▲	▲	▲	O	▲	▲	▲	▲	▲	▲	▲	O	Θ	O	2	1	0	3	5	4
7	3	6.3	4.0	ELIMINATE SEA TRANSFER OF ALIENS TO COAST	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	O	O	O	2	1	0	3	5	4
8	3	6.3	4.0	ELIMINATE AIR TRANSFER OF ALIENS TO COAST	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	O	O	O	2	4	0	3	5	3
9	3	6.3	4.0	ELIMINATE DRUG TRAFFIKING BY AIR	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	O	O	1	3	0	4	5	2
10	9	6.3	4.0	FIND SURFACE/UNDERWATER IED'S	▲	▲	▲	O	▲	▲	▲	O	▲	▲	▲	Θ	▲	O	O	0	4	4	3	5	2
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	3	3	3	9	3	3	3	9	3	1	1	9	3	9	3						
				Weight / Importance	187.5	206.3	143.8	225.0	156.3	162.5	162.5	193.8	162.5	100.0	100.0	181.3	231.3	618.8	237.5						
				Relative Weight	6.1	6.7	4.7	7.3	5.1	5.3	5.3	6.3	5.3	3.3	3.3	5.9	7.5	20.2	7.7						



Powered by QFD Online (http://www.QFDOnline.com)

Figure 12. Analysis of Existing Platform Alternatives.

The QFD method concludes that no existing platform can fulfill the mission requirements. With the cooperative analysis, our team concluded using the HOQ matrix, that the RSS rated highest 8 out 10 categories.

3. Needs Analysis

A needs analysis was performed to refine the initial problem statement into a set of effective needs. The Navy has already identified capability gaps in the maritime interdiction mission, and the threat posed by small boats particularly in the littoral environment.

a. Primitive Needs

The primitive needs analysis focused on ways to implement the "Maritime Security" segment proposed by Professor Rubel. As previously stated, it is difficult for the Navy to protect U.S. interests in a timely manner. In response to this problem, policy directives have been issued by the President and Congress, an example of which is Homeland Security Presidential Directive 13 (or HSPD-13), which directs the coordination of Maritime security policy through the creation of a *National Strategy for Maritime Security*. Another guiding directive is the Security and Accountability for Every Port Act of 2006 (or SAFE Port Act, Public Law 109-347).

The primitive needs statement is as follows:

Friendly forces require a rapid response capability to prevent smaller adversaries from attacking (delivering ordnance of any kind) against naval/ commercial vessels, or critical ports and off-shore installations.

The current emphasis on the LCS and the considerable investment of resources and active support from the Secretary of Defense provide additional evidence of this capability gap. This project's effective needs are supported by organized evidence as indicated in Chapter I, based on analyzing current and future trends. The Navy and DoD are focused on mitigating the threat from small and medium size boats and they are allocating considerable resources to alleviate the capability shortfall. Based on the analysis, the project team can infer that it may be possible to utilize available mature and proven technologies.

b. Capability Gaps

The Navy's established capability gaps, which resulted in the development of the LCS, are listed in Table 3.

Table 3. Mission Warfare Tasks and Related Capability Gaps.

Source: GAO from Navy Sources, March 2005.

Mission Task	Criteria to Measure Success	Capability gaps identified with current and programmed force structure
Surface Warfare: Escort ships through choke points	Neutralizing large sets of small boats in a single raid	Gaps exist in coverage areas in defeating 50 or more small boats, due to shortfall in the number of assets
Protect operating areas and ports	Neutralizing small sets of small boats in a single raid	Inadequate number of surface combatant assets and helicopters provide self defense capability only in port operating area
Mine Warfare: Establish and maintain mine cleared areas	Clearing transit lanes within 7 days	Inadequate number of mine counter-measure assets in the force to clear transit lanes within 7 days
Anit-submarine Warfare: Protect joint operating areas	Detecting submarines at 90% success rate	Inadequate number of assets and technology to detect submarines in shallow water 90% success rate

USS *Freedom* (LCS-1) is the first LCS operated by the Navy, and it has been undergoing sea trials since August 2008. A second LCS, USS *Independence*, completed sea trials in November 2009. Analysis indicates that the capability gaps will not be drastically changed by the current LCS availability schedule as it relates to the maritime interdiction mission in the next 10 years.

Under established plans, the first deployment of the USS *Freedom* was scheduled for 2012, however according to the Navy Times, CNO Roughead wanted to use the first LCS to patrol for pirates off the coast of Somalia prior to that date. The second LCS USS *Independence* is scheduled to be delivered in late 2009. According to the statistics posted on the official Status of the Navy Web site only 39 percent of the U.S. Navy ships are on deployment [NAVY.mil 2009]. If current LCS production rates are factored in with deployment schedules, the project team can conclude that very few (fewer than 5) LCSs will be deployable by 2015. The Navy's LCS vessels are tasked with the primary missions of mine, anti-submarine, and surface warfare. Therefore, it cannot be assumed that the total force will be available to support maritime interdiction missions. The LCS differs from existing types of Navy surface warships in fundamental ways since it will accomplish its primary missions through the use of helicopters, unmanned vehicles, and other systems that operate at a distance from the ship. The systems used to conduct each mission will be contained in mission modules to support the various warfare areas. The mission modules will be interchangeable, so that the LCS can be reconfigured depending upon its tasking. Although they are less expensive than larger vessels to build, maintain and operate, the LCS cost estimate is $370 million for the sea-frame and approximately $150 million for the mission packages (not including the cost of the MH-60 helicopter).

Another challenge that will hamper LCS global maritime interdiction operations is the logistics support required to meet the Navy's goal of changing LCS mission modules within four days of arriving at an appropriate facility. Limiting factors posing potential challenges include package storage location, how they are transported, and the proximity of LCS operating areas to ports when swapping of mission modules is required. LCS mission modules would not be changed in open waters, so the vessel will have to reach a friendly port before a different mission can be performed. These factors could increase the time required for a change in LCS mission modules, and impact its availability for maritime interdiction missions.

LCS is clearly a critical asset for the U.S. Navy. However, based on current shipbuilding schedules and operational tasks, LCS is not the most mission oriented and cost effective approach for performing the maritime interdiction missions.

B. CURRENT AND NEXT FUTURE STATE MAPS

Another key element of the analytic process is the current state map. This map communicates the present operating state of the system. A cause and effect diagram was derived next to determine the root causes of the problem. Once the causes were determined, recommendations for improvement in the system were examined. The recommendations were used with another voice of the customer tool, the SIPOC, which determined what was critical to the customer. With knowledge of what the customer wants and with input from the systems engineering team, development of the Quality Function Deployment (QFD) began. The QFD was used to look at suitable platforms that could be utilized to eliminate the root causes. Finally, the future state map was developed, based on the conclusions of these processes.

Stakeholder analysis and Lean Six Sigma, when combined, start with the development of a current state map. The purpose of the current state is to establish a common communication point with the stakeholders and the systems engineering team. After completion of the current state, the cause and effect diagram is developed. The current state of battling pirates off the coast of Somalia, shown in Figure 13, shows the team that a Mayday call is received before any action is taken. Once a call has been received, a response/acknowledge is sent and a helicopter or boarding party is launched to deter the pirates. Meanwhile, the warship is using its capabilities to search for the suspected pirates.

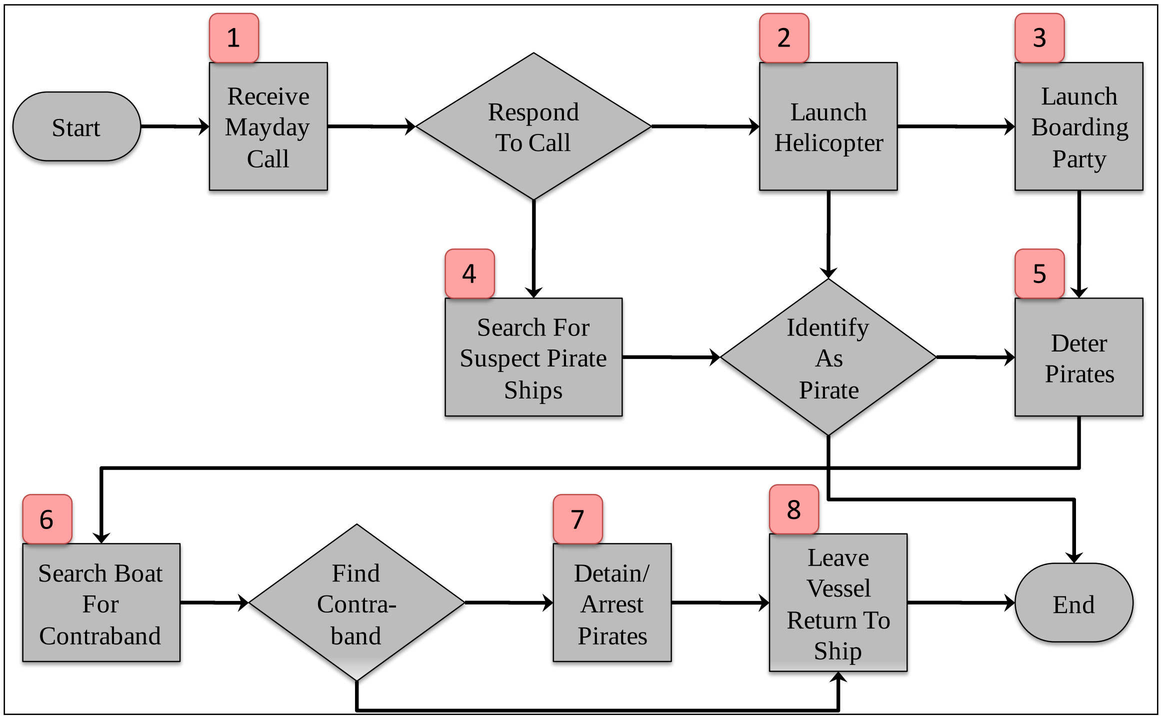


Figure 13. Current State Map.

The current state map consists of eight major steps which provided input to the SIPOC.

The current state map reflects the current process for handling pirates in Somalia. The project team looked through each process for unneeded steps. The analysis eliminated three out of eight steps. The overall intent of our study was to eliminate delivery of ordnance, which means the pirate cannot attack the HVA. Therefore, the project team eliminated the following three steps; launch boarding party, search boat for contraband, detain arrest pirates. Figure 14 represents the next future state, which does not have steps 3, 6, and 7.

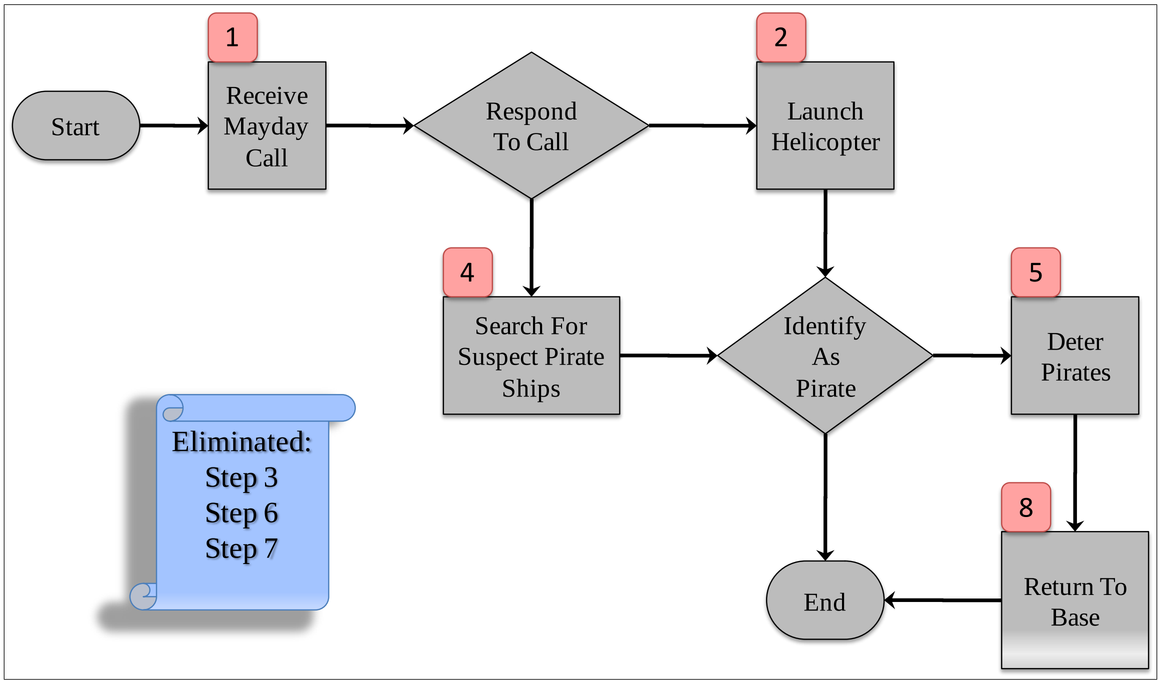


Figure 14. Future State Maps.

From a Lean Six Sigma perspective, the project team was trained to eliminate waste from the process. Based on the Cause and Effect analysis, Step 3 can be eliminated if the enemy is prevented from inflicting harm to the high value asset. Consequently, step 6 and step 7 can be eliminated if step 3 is eliminated. Eliminating these steps would reduce the future state map to five steps.

1. Cause and Effect Analysis

Previously, the project team developed a common process for handling the threat of pirates off the coast of Somalia. Next, the project team examined all the potential root causes that lead to the set of effects; i.e., kidnapped victims, hijacked ships, and lost income of maritime nations. Through the Cause and Effect diagram the project team identified the following five potential root causes which are elaborated on in Figure 15:

- Pirates adapting tactics to target large assets;
- The area to be defended is 1.2 million square nautical miles;
- Defender cannot reach the target of interest on time;
- Warships deployed in the region have an average range of coverage of 200 nautical miles; and
- Defender may not reach the victim for more than three days.

The root causes reveal that response time (Cycle Time) must be controlled before the enemy can reach the target, a HVA. The time to reach the target is a function of distance and velocity. The threat distance to the HVA could be controlled if the developed concept included control of the battle space. Therefore, the time to reach a target is minimized by selection of equipment with the speed needed to travel to the HVA before the enemy can attack.

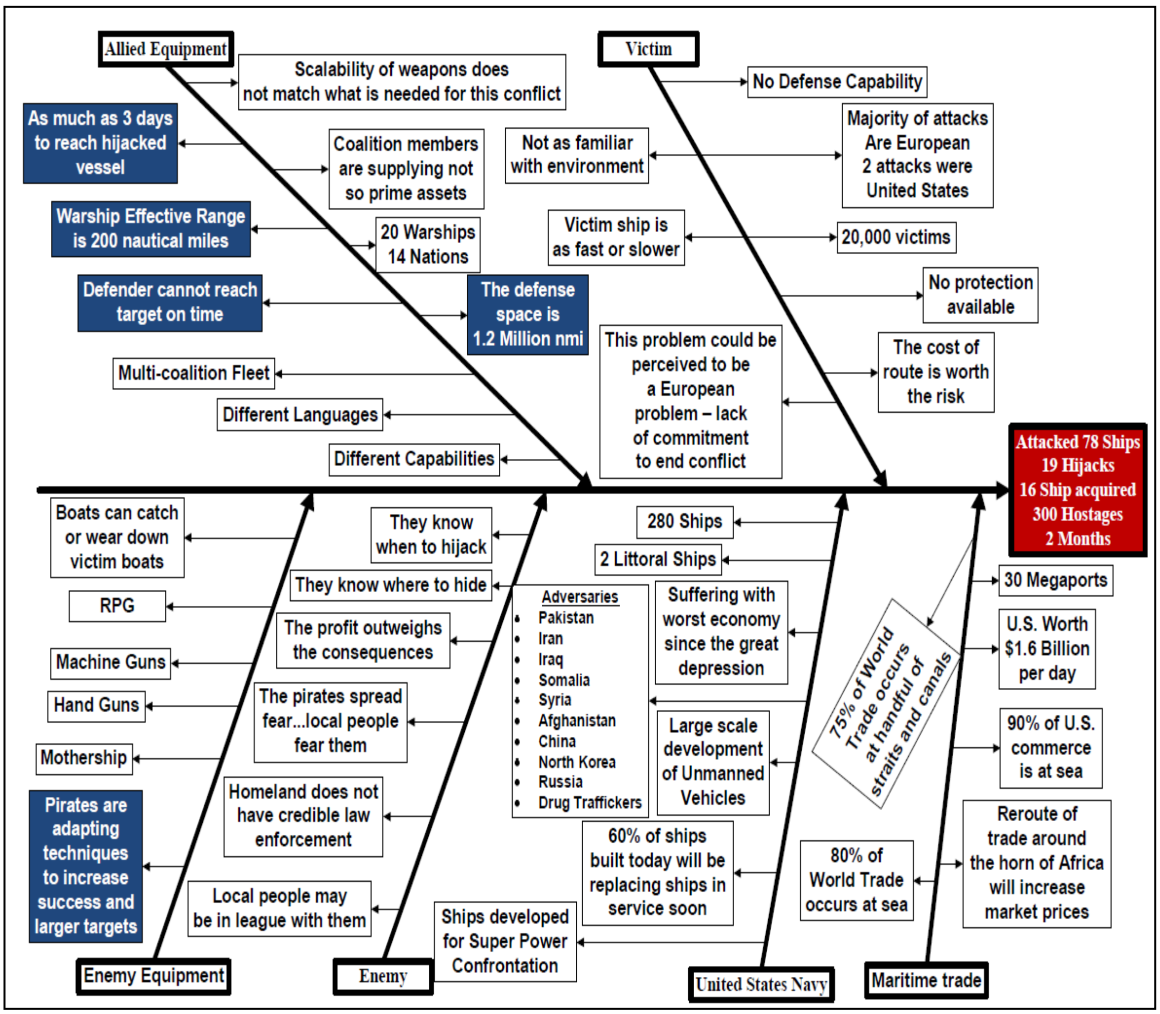


Figure 15. Cause and Effect Diagram of Pirate Actions and Responses from January - February 2009.

The Cause and Effect diagram examines the cause and effect of factors of the Somalia Piracy threat to Maritime Security. The analysis revealed root causes that include the fact that the defender does not have sufficient speed. Another root cause was that the battle space was too large to be defended with current assets.

In response to the Cause and Effect analysis, the following recommendations are made:

- **Root Cause: Pirates are adapting tactics to target large assets**
  Recommendation: Limit the types of tactics that the pirates can employ. The first of the four critical factors is to establish a naval presence in remote locations so that naval forces have superior intelligence of enemies of maritime security.
- **Root Cause: Defended space is 1.2 million square nautical miles**
  Recommendation: Limit the defended space so that a reasonable, affordable force can be effective. The second critical factor is limiting the area to be covered, because limiting where the enemy of maritime security engages our forces leads to effective use of limited resources in remote locations.
- **Root Cause: Defender cannot reach the target of interest on time & defender may not reach the victim for more than three days.**
  Recommendation: Minimize the response time so that assets can reach the target in time to be effective. The third critical factor is the response time within which our naval forces must reach and engage the enemy before the enemy of maritime security can become an undeterred threat.
- **Root Cause: Warships deployed in the region have an average range of coverage of 200 nautical miles.**
  Recommendation: Increase the range of sensors and the defender's combat radius. The fourth critical factor is range of sensors and the effective range of the assets embarked on the defender's warships.

The Cause and Effect diagram determined some underlying issues of the problem. The analysis revealed that the needs of the customer would be satisfied if the project team focused our study in these four issues.

2. SIPOC ANALYSIS

As noted before, the SIPOC analysis is another team consensus building process used to develop a chart of the complex interactions among functional blocks. The final product is used to develop Critical-to-X's (CTX) where the X in CTX, can be delivery, safety, cost, quality, morale, process, or customer. This form of analysis focuses on what is critical to the process and what is critical to the customer and it works well when the team first considers the High Level view point and then the Low Level view point. For this project, the High Level view represents the strategic point of view and the Low Level view represents the view point of the users in the field or the tactical view.

a. High Level SIPOC View

A critical item that came out of the High Level view analysis is the need for a Maritime Operations Center or a MOC. The MOC is critical for providing command and control of assets that can respond to the need for protection of HVAs. The MOC is also at the heart of the strategies described by Rubel [Rubel 2009]. Critical items are also known as Critical-to-the-Process (CTP). CTPs from the analysis are shown in Table 4.

The High Level SIPOC analysis provides inputs and outputs essential to the process. After the SIPOC form is completed, the "critical-to" trees are developed. The critical-to tree for this SIPOC examines what is Critical-to-the-Process (CTP) and what is Critical-to-the-Customer (CTC).

Critical-to-the-Process (CTP)

- CTP 1 – Need sensor with high resolution.
- CTP 2 – Need unmanned system with quick response.
- CTP 3 and CTP4 – Need hull that can withstand the environment and sea state of operation.
- CTP 5 – Need system with response time that allows interception wait time for the enemy.
- CTP 6 – Need Maritime Operation Center (MOC).

Critical-to-the-Customer (CTC)

- CTC1 – Must Protect High Value Assets.
- CTC2 – Must Protect Naval Forces in remote locations.

Table 4. High Level SIPOC View for Somalia.

S

Critical to Process

Sensor with High Resolution
Unmanned System with Quick Response
Hull that meshes with Environment
Hull that satisfies Sea States
System that has some wait time for response

P

Critical to Customer

Protection of High Value Assets
Protection of Naval Force in Remote Locatin

C

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
Unmanned System Roadmap	UAV/UUV/USV Limitations	Step 1: Receive Mayday Call	Plan for Area of Coverage	Dean Rubel - Changing Paradigm
AESOP - Naval Assets Listing	UAV/UUV/USV Missions	Step 2: Respond to Call	Plan for Naval Presence	Dean Rubel - Area of Coverage
Coast Guard - Strategic Plan	Exisiting Platform Analysis	Step 3: Launch Helicopter	Plan for Role of Maritime Security	Dean Rubel - Naval Presence
Naval Sea Power 21	Fishbone Analysis - Somalia	Step 4: Launch Boarding Party	Plan for Response Time	Dean Rubel - Role of Maritime Security
Changing Paradigm	Sensor Function Analysis	Step 5: Deter Pirates	Development of Sensor Plan	Emmet Maddry - Systems Engineering Approach
White Papers - UAV's and Automation	Generic System Design	Step 6: Search for Suspect Pirates	Development of CONOPS	Emmet Maddry - Technology Selected
ABB/Fanuc/Kawasaki	Application Specific Design	Step 7: Find Contraban	WBS	Jim Hebert - Sea Base Concept - Patent Pending
DARPA Research	Systems Engineering Roadmap	Step 8: Detain/Arrest Pirates	Simulation of ASHC	Eric Hensen - Sea Base Concept - Pantent Pending
Gerogia Research	Sensor Coverage Analysis	Step 9: Lean Vessel and Return	Simulation of Single UAV and Warship	OPNAV - Wargames for Maritime Domain Awareness
	QFD Analysis	MDA - Somalia	Simulation of Dual UAV and Warship	Dr. Rubel - Response Time
	Concept Development	MDA - Communications	Response Analysis in Crystal Ball	Navy - Limited Resources
	Lean Six Sigma	MDA - MOC	Requirements Generated	Navy - Ability to Respond
	Leanring Organization - Mentors		Work Structure Diagram	Blaise Corbett - Use of Unmanned Resources

b. Low Level SIPOC View

The Low Level SIPOC view, Table 5, examines the current state of the process in relation to the users of the process. Notice that in the future state, steps 3, 6, and 7 have been eliminated. Therefore, the Low Level SIPOC view reflects elimination of unneeded steps.

Table 5. Matrix of low level SIPOC.

This Table highlights the elimination of steps 3, 6, & 7 to reflect the outcome of the future state map.

Supplier	Input	Process Requirement	Process Step	Output	Customer
Maritime Nation	Response Capability	Speed of vessel	Step 1	Pursuit Capability	Maritime Nation Interests
Vessel	Communication Capability	Speed of Helicopter	Step 2	Pursuit and Response Capability	Victim
Vessel	Small vessel capability	Speed of small vessel transport	Step 3	Boarding capability	Victim
Vessel	Search Capability	Speed of vessel and quality of sensors	Step 4	Identification Capability	Vessel command
Vessel, Helicopter, Boarding Party	Pirate Attack on victim or vessel	Effective weapons	Step 5	Weapons Capability	Vessel and Victim
Victim, Vessel	Small arms	Effective weapons	Step 6	Protection or Attack Capability	Victim, Boarding Party
Victim, Vessel	Small arms	Effective weapons	Step 7	Protection or attack capability	Victim, Boarding Party
Vessel	Small transport capability	Speed of vessel	Step 8	Safe boarding capability	Boarding Party

What is critical to the process?

- CTP 2.1 = Speed
- CTP 2.2 = Effective Weapons

What is critical to the customer?

- CTC 2.1 = Vessel and Victim

c. Stakeholders Analysis Summary

The stakeholder analysis produced design elements for the project concept. Multiple analyses led to the conclusions that there were four critical factors necessary for combating Somalia pirates. The analyses described above prepared the team for systems integration with the generic design concept.

C. DEVELOPMENT OF DETAILED REQUIREMENTS

A QFD model was developed in the analysis of alternatives as a way to evaluate requirements. The following QFD analysis is a further refinement of that first step.

1. Quality Function Deployment

The research of platforms and unmanned systems was used as an input to the HOQ process. The HOQ of Figure 16 allowed the team to benchmark competitive systems and see the benefit of complementary actions or the harmful interaction of two or more proposed actions. The far left column has the list of customer wants along with weights for each "want". The top row below the ceiling of the house represents the "how" which satisfies the desired "what." The correlation between the "what" and the "how" was tabulated with a score indicating how well the "how" produced the "what." Each "how" was then linked to an action that would get the customer the "what" that is required. Each QFD level is known as a House of Quality (HOQ). There can be many levels of HOQs, for example:

- QFD House of Quality Level 1 – Mission Versus Platform
- QFD House of Quality Level 2 – Platform versus Measure CTQ
- QFD House of Quality Level 3 – Measure CTQ versus Function

- QFD House of Quality Level 4 – Design Elements versus Requirements

Appendix D contains the HOQs. The project team addressed customer needs by first analyzing the HOQ for mission versus platforms. Results from this analysis reinforced that either an oil platform or an autonomous sea station would fit the requirements. The analysis of the HOQ for platforms versus measured CTQs showed that the oil platform was less effective than the remote automated sea station. The analysis of the HOQ for measured CTQs versus system functions was influenced by the need to reach the target on time and the need to increase the coverage range. Finally, the analysis of the HOQ for design elements versus requirements led to two major requirements. The first requirement was that the defender needed the ability to stay stationary and the second requirement was that the defender needed to travel at speeds up to ten times the speed of the enemy pirates.

The HOQ analysis shown in Figure 16 concluded that no existing platform could fulfill the mission requirements. When compared to competitive options, it was concluded that the Remote Sea Station rated highest in 8 out of 10 categories and was the highest rated platform.

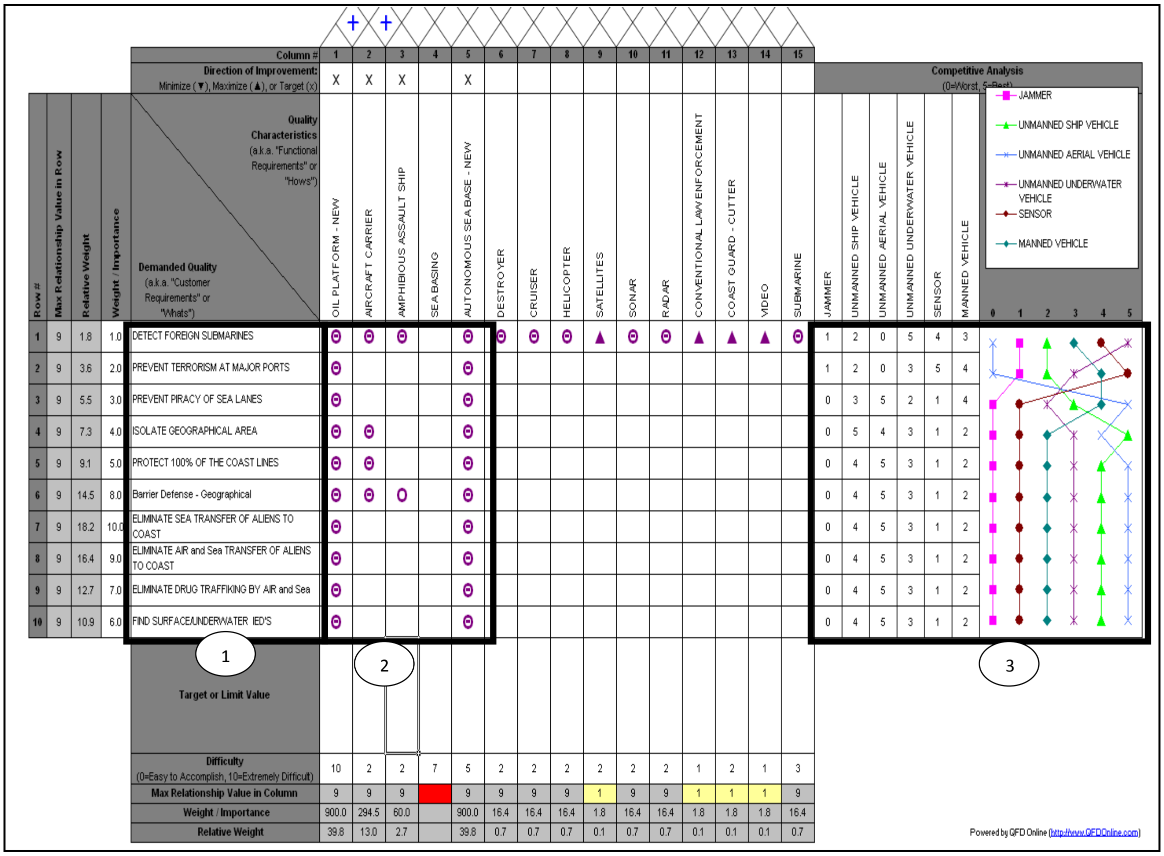


Figure 16. HOQ – Mission versus Platform.

Reference Item 1: This item shows missions of Maritime Security that our team has chosen to address.
Reference Item 2: The missions of Maritime Security that would apply suggest that an oil platform and a remote autonomous sea station would fit our need.
Reference Item 3: Indicates that the ability to meet mission requirements varies greatly among sensor and vehicle types. Detection of submarines, prevention of terrorism at ports, and interdiction of piracy each present distinct system needs. (This HOQ is one of a group of HOQ's located in Appendix D.)

2. Future State (Overview)

The Future State was developed based on the conclusions of the analysis conducted by the systems engineering team. The future state was analyzed with the simulation model shown in Figure 17.

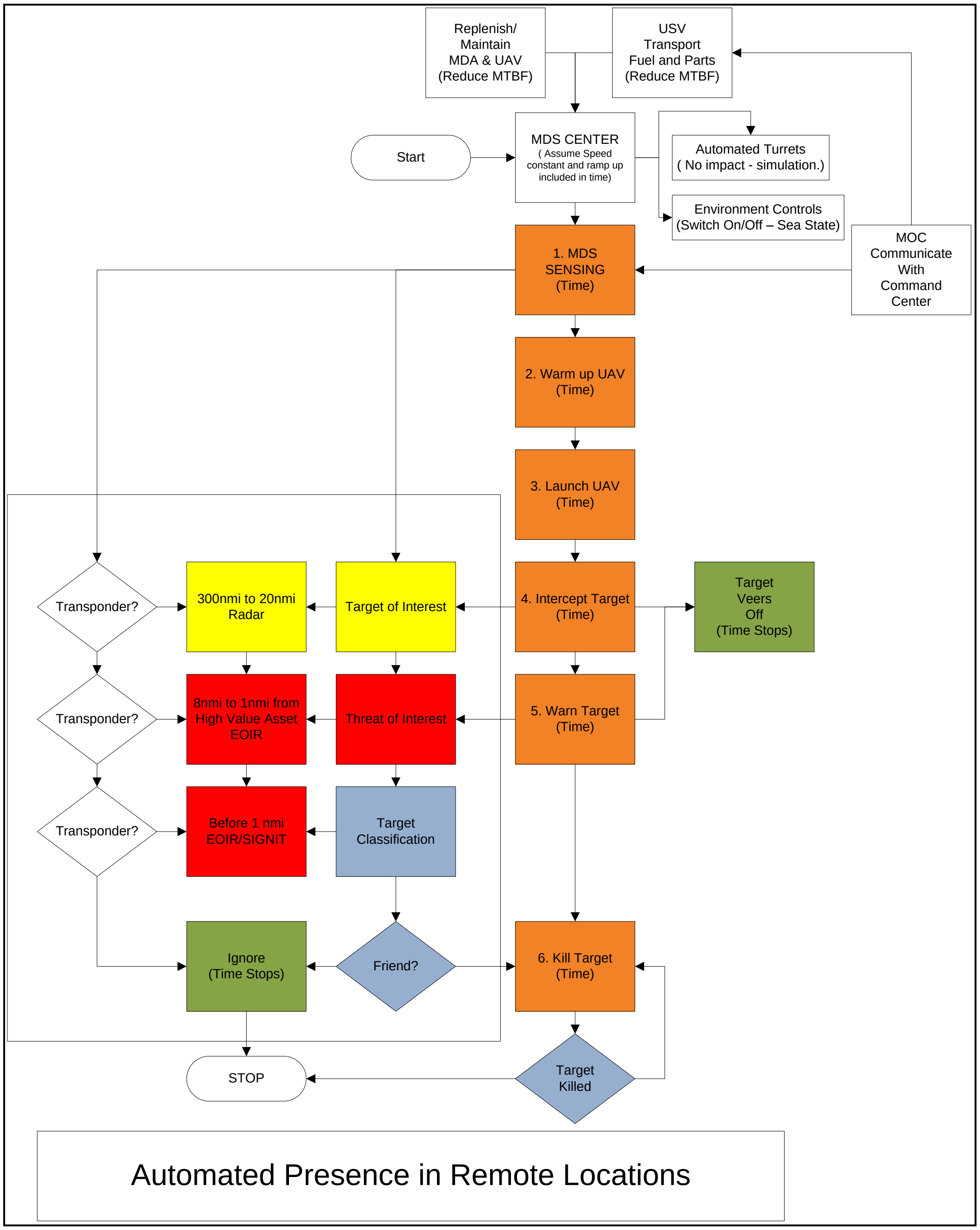


Figure 17. Simulation Model.

The future state is depicted in the simulation model in which the basic UAV functions are modeled. The future state is achieved with the help of UAV functions, sensor functions, and replenishment functions.

The simulation was used to compare the following alternatives: a warship housing a single UAV, a warship housing two UAVs, and a remote sea station housing two UAVs. The goal was to determine how well each alternative could handle a random variation of pirate activity. The simulation followed a sequence of steps:

1. Sense the target
2. Warm up the UAV
3. Launch the UAV
4. Intercept the Pirate
5. Warn the pirate to withdraw or be destroyed
6. Kill the pirate if he is not deterred

The pirates were given the capability to decide at random whether the pursuit of the high value asset (the target of interest) was to be continued. The simulation also gave the pirate the capability to withdraw when a UAV was deployed. Results indicate that a remote sea station is in a mode waiting for the pirate 100 percent of the time. The results also indicate that there is a possibility that the Warships would miss the pirates approximately eight percent of the time.

a. Future State: Automated Super-Highway Concept of Operations

The Future State is explained by describing the events that occur in the operational scenario and the supportability scenario.

i. Operational Scenario

In the operational scenario, a merchant ship is steaming along in the Indian Ocean off the coast of Somalia. The merchant ship approaches a controlled sea lane known as the Automated Super-Highway Concept (ASHC). The merchant ship will be designated as a HVA. A transponder that functions as a beacon and as a Mayday transmitting device would be given to the HVA prior to entering the ASHC to identify it as a platform of interest. The transponder signal is picked up by the aerostat and is transmitted back to the command ship.

The ASHC is a system of systems comprised of ten essential elements with supporting assets and materials that will be described shortly. The system maintains situational awareness and provides protection of HVAs inside the sea lane.

As the ship moves through the ASCH, the sensing process detects a target of interest approaching the outer perimeter of the ASHC. Initially, the sensing system does not know if the target of interest is friendly or unfriendly. Since the target of interest is not carrying a transponder, the sensing system knows that it is not part of the group of ships being defended or an element of the ASHC. Once the target of interest breaches the ASHC boundary, the sensing system will evaluate how far the target of interest is from all HVAs within a 20 nautical mile radius. If any HVA is within 20 nm of the target of interest, the closest Remote Sea Station (RSS) will launch a UAV to intercept the target of interest. Each UAV has a warm up time. This warm up time is included in the calculation that determines if a UAV can reach the target and that determines when to launch the UAV from the RSS. The objective of the UAV is to reach the target of interest before it reaches a point 8 nm away from the HVA. The reason for this objective is that the Electro Optical or Infra Red (EOIR) system on board the UAV will need time to classify the target as friend or foe. Once this determination is made, the UAV will do one of two things. The UAV will either follow the target to see its intentions or the UAV will deter the target if it performs any hostile activities. A friendly target will be allowed in the zone; however, the friendly unit's path will be monitored. An unknown, an enemy unit, or a foe will be intercepted. Once intercepted, the UAV will initially transmit a warning. The enemy unit will be allowed to leave the ASHC zone if the enemy decides to withdraw. If the enemy decides to continue pursuit of a HVA unit or travels to within 8 nm of the HVA, the command ship will transmit a firing command to the UAV. The UAV will use some means of deterrent to stop the enemy. The UAV will return to the RSS after the enemy is successfully deterred. The HVA will continue travelling through the ASHC zone until it reaches the transponder drop off zone. Once the transponder is returned, the HVA is no longer tracked.

ii. Supportability Scenario

The above process describes a typical transit for a HVA. Once the UAV has completed its mission, the UAV will travel back to the RSS. The supportability scenario describes the replenishment and the maintenance process. The processes described are technically complex, so the project team will explain in more detail as required. The UAV and RSS will have sensors that track fuel usage, fuel inventory, armament usage, armament inventory, system status, condition based maintenance logs, maintenance supplies such as critical parts, and lubrication status. After completing the mission of deterrence, the UAV will approach the RSS. The RSS will have situational awareness of the UAV and will open its landing bay in advance of the UAV's arrival. The landing bay will open a water tight hatch door. A positioner will move the landing bay to a locked location. The UAV will be guided in to the landing zone. Once the landing bay has received the UAV, the positioner moves back to the home position. The hatch door closes. The system log will have information on armament used, fuel used, and maintenance history in terms of hours of operation. A graphical user interface will have a Central Processing Unit (CPU) that controls Programmable Logic Controllers (PLCs). The PLC will activate programs on the robots that will run maintenance and replenishment programs.

The first replenishment program is the home position. After describing the home position, it is important to discuss the properties of the robots and their safety systems. The robots will position themselves to the home position. The home position is a safe position in which no other entities will be in harm's way. The robots will have a total of seven axes of movement. The robots will be electrically driven and explosion proof.

The robots will work in groups of four. The four robot configuration will provide for full capability in case of the loss of two robots out of four robots. If a third robot fails, the system will operate at 60 percent efficiency. If all four robots fail, the system will place the RSS in bypass until the system faults are cleared. Because the system will utilize swarm methodology, when a RSS unit is down, the adjacent two RSS units will protect the downed system with no loss of availability for coverage or response time.

Each robot will have the ability to move to an applicator station. An applicator is the tooling at the end of the robot's arm. The end-of-arm tooling will consist of a variety of applicators. Examples of some of the applicators are grip and fluid applicators. The grip mechanism will function to move the UAV to a fixed known position. The fixed known position will allow for less complex tracking of movement. The reduction in complexity will reduce the need for motion sensing capability. Another function of the grip occurs when a robot faults out and the robot servos lose power. The servo brakes will engage. The CPU will activate a set of subroutines. The command ship will be monitoring the functions and will manually over-ride operation when necessary. The CPU will tell the other robots to hold the failed robot. A second robot will move the robot back to its home. Movement of the downed robot will commence when the first robot holds the robot in position. The servo brakes will then be disabled. Once the brakes are disabled, the robots can move the failed robot to a safe home position. The CPU will place the robot in bypass mode. Bypass mode allows the other robots to go to home and function with one less robot during the next cycle instruction.

Resuming the description of replenishment, a robot will be able to refuel the UAV, the USV, and the RSS. One robot can perform the task; however, under normal conditions, two robots will perform the task. One or two USVs will be sitting in fixed positions inside the four-bay RSS. At least one of the USVs will carry internal tanks (industrial 550-gallon totes) like a pickup truck. One robot will approach the 550-gallon tote nozzle opening. When the robot touches the nozzle cap on the tote, pneumatic controls on the fluid activator will activate the nozzle cap opening. Inside the robot is a solvent resistant fluid line that will reach to a second robot. The second robot will approach the Fire Scout UAV gas cap. The same process will occur with the second robot. Once both robots are in position, a fluid pump connected to the line near the robot will pump the fuel from the USV to the UAV. Level controls will tell the system to stop the refueling process. Inventory will be recorded on the CPU. The robots will go back to the home position. If the next task is different from refueling, the robots will move to the applicator station and change to the appropriate applicator. Automation will be described in further detail in the technology overview.

The exploration of operational and supportability scenarios helped the team mentally visualize the future state concept. The simulation provided the opportunity to observe what happened when a battle space is controlled. The team explored whether a mobile platform or fixed platform was feasible and could be used to launch unmanned systems that protect high value assets from any threats. An analysis of the different platforms concluded that the remote sea station would fit in the ASHC system of systems. The simulation, explored in detail later in the report, supports the initial assessment.

3. FMEA Analysis

Throughout the analytic process Failure Mode and Effects Analysis (FMEA) was employed to capture the present risks and suggest actions for improvement. This analysis uses a risk prioritization number (RPN) which is the product of the severity of the design issues, the probability of occurrence, and the probability of detection. The present state RPN was calculated to be 8,266 as compared to the future state RPN of 125. Details of the analysis are found in Appendix E.

D. INTERACTION DIAGRAM AND WORK STRUCTURE DIAGRAMS

The application of the systems engineering methodology led to a generic system design as the concept was being developed. This provided the ability to capture those components considered essential to the operational concept. Figure 18 communicates the hierarchal value system of the components of the Automated Super-Highway Concept. It links the critical success factors to the primary components. Level 2 of the Work Breakdown Structure (WBS) located in Appendix F lists the primary components. The interaction diagram (Appendix H), depicts how the primary components work together as a system of systems. These essential components, shown in Figure 19, were combined to form an overall work structure diagram providing a pictorial representation of the interfaces. The overview work structure diagram is divided into five additional diagrams in Appendix G. The primary components from Figure 20 are discussed in the technology overview.

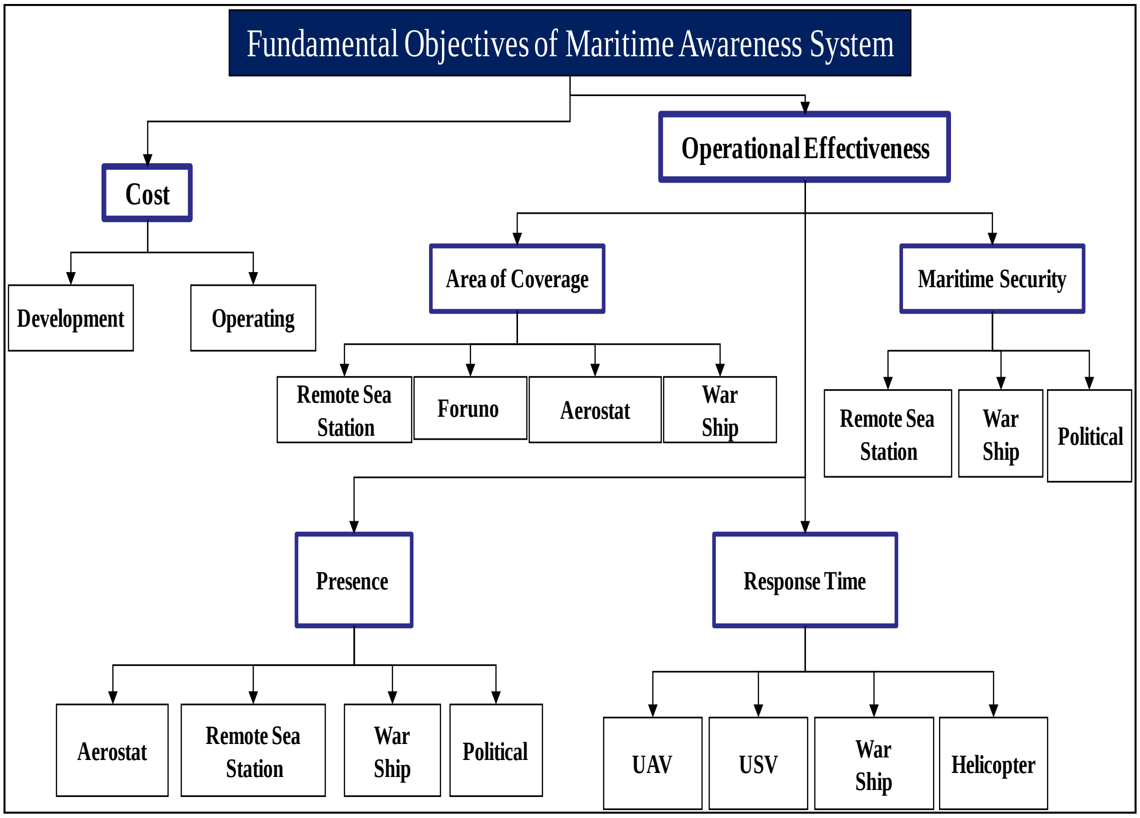


Figure 18. Fundamental Objectives of Maritime Awareness System.

The above diagram is a hierarchical breakdown of the fundamental functions that are involved with the maritime awareness. Under the Operational Effectiveness level are the four main issues, Area of Coverage, Maritime Security, Presence, and Response time. These relate to the issues put forth in the problem statement.

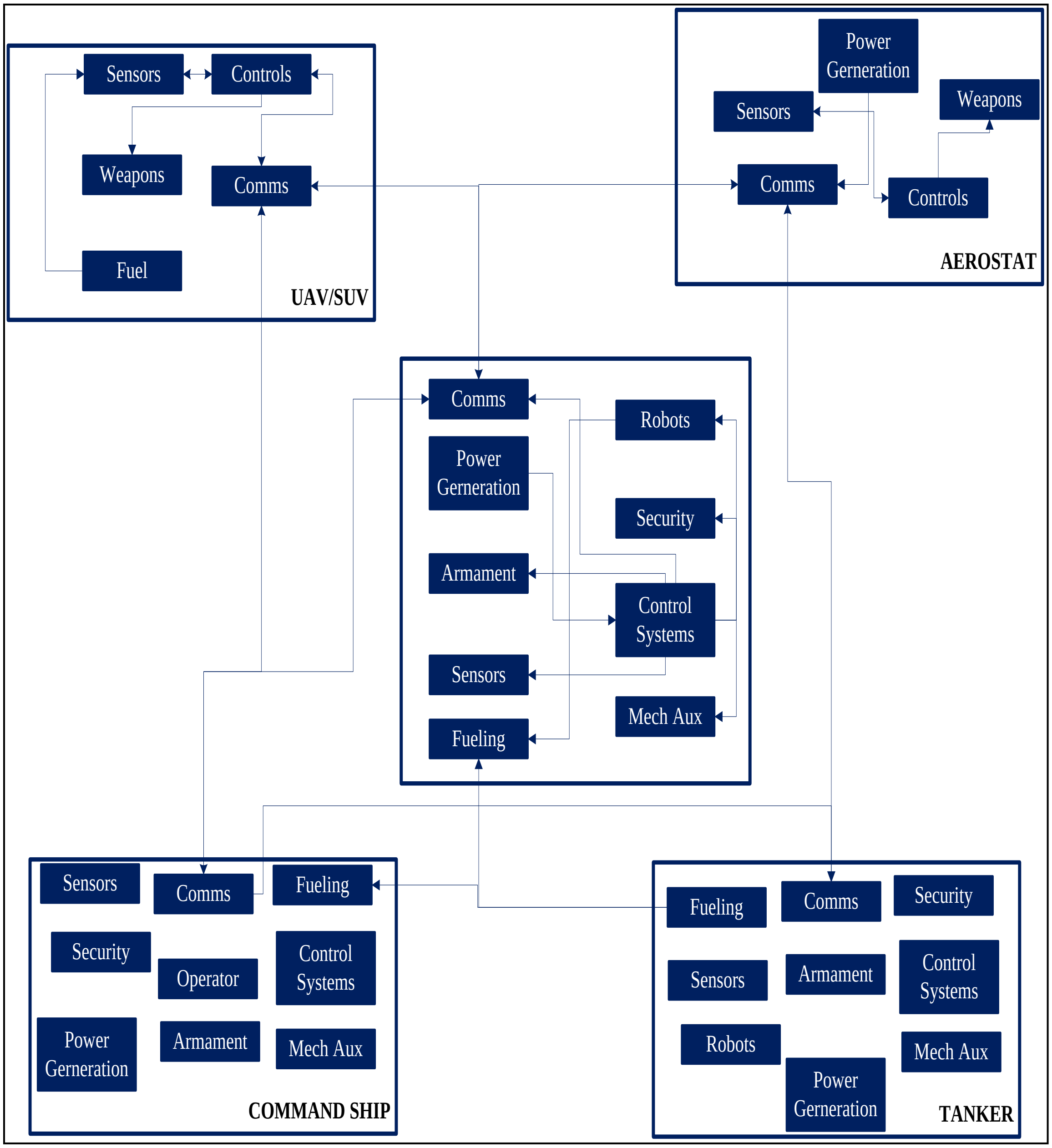


Figure 19. Work Structure Overview Diagram.

This diagram shows the major sub systems within each individual system. The individual systems are then interconnected to complete the Maritime Awareness System.

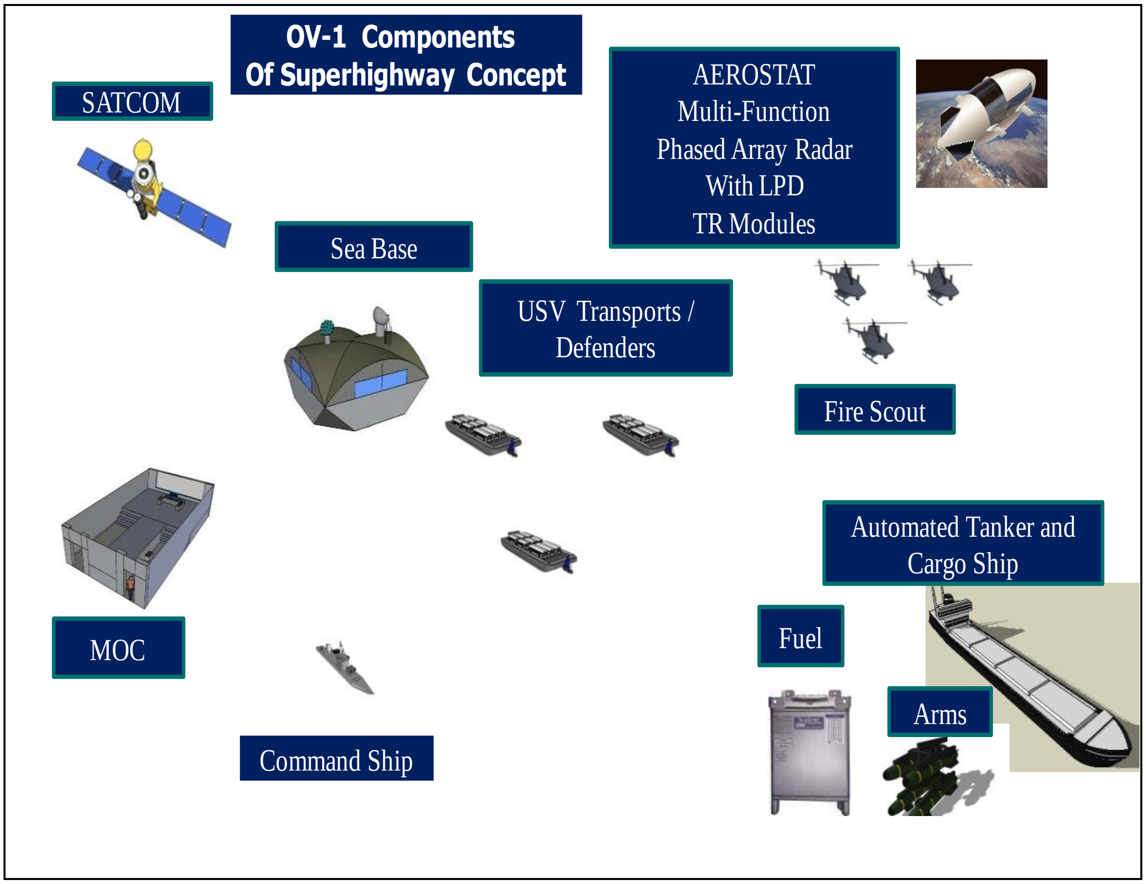


Figure 20. Key components of Super-Highway concept.

The above diagram shows an overview of the key components that make up the Super-Highway concept.

E. TECHNOLOGY OVERVIEW

The system concept was developed to meet requirements generated in the analysis. This section will present the relevant technologies that flesh out the proposed concept.

1. A Review of Requirements

a. Highlights of System

The proposed system utilizes preventative maintenance to maintain operations before failures occur. The maintenance schedule of these systems will be predetermined by an FMEA agreement between the supplier and the owner. Minor and medium overhaul capability for the unmanned systems will be available on the command ship and the supply ship. Spare parts inventory will be tracked on each RSS and on the command and supply ships.

b. Highlight of UAV, USV, and RSSs

The concept of automating lower level controls reduces the complexity of controlling multiple unmanned vehicles, as shown in the hierarchy of controls diagram in Figure 21.

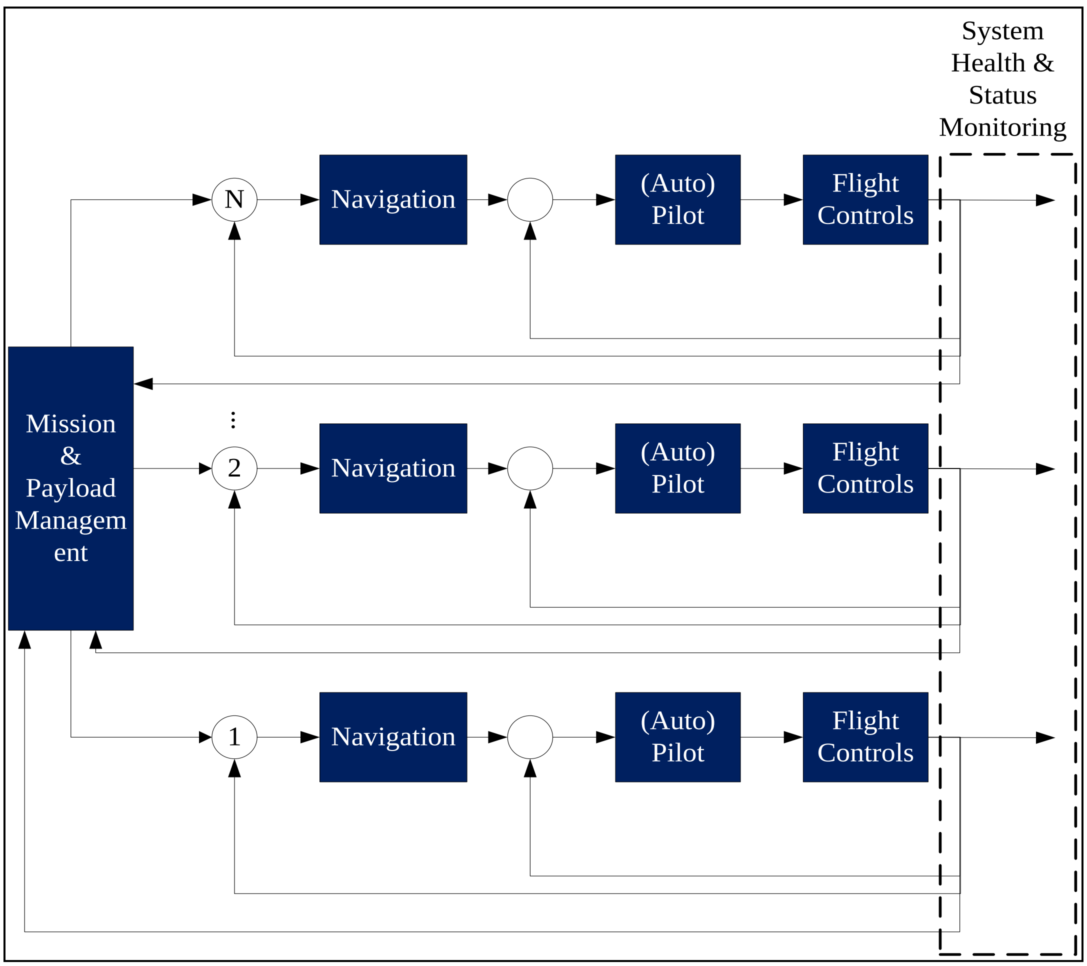


Figure 21. Hierarchical Control for Multiple Unmanned Vehicles.

This block diagram shows the general control scheme for multiple unmanned vehicles. This control method is important in order to perform a swarm strategy [Cummings 2007].

By reducing the complexity of control larger groups of unmanned vehicles, known as swarms, can be formed. A swarm control system allows the UAV, USV, and RSS to work together or alone. Swarm control techniques enable graceful degradation of performance. The advantage of graceful degradation is that the system of systems can continue to operate effectively when a percentage of unmanned systems are down. The capability to operate this way enables a higher probability of operational availability of the system. Swarm behavior would be implemented in teams of five.

c. Unmanned Systems Roadmap

The project team focused on capabilities available at the present time. Those capabilities were evaluated based on their own strengths and weaknesses (see Figure 22). This study did not consider the use of Underwater Unmanned Vehicles (UUVs). The treatment of this subject would require time beyond the 30 weeks allocated for this project.

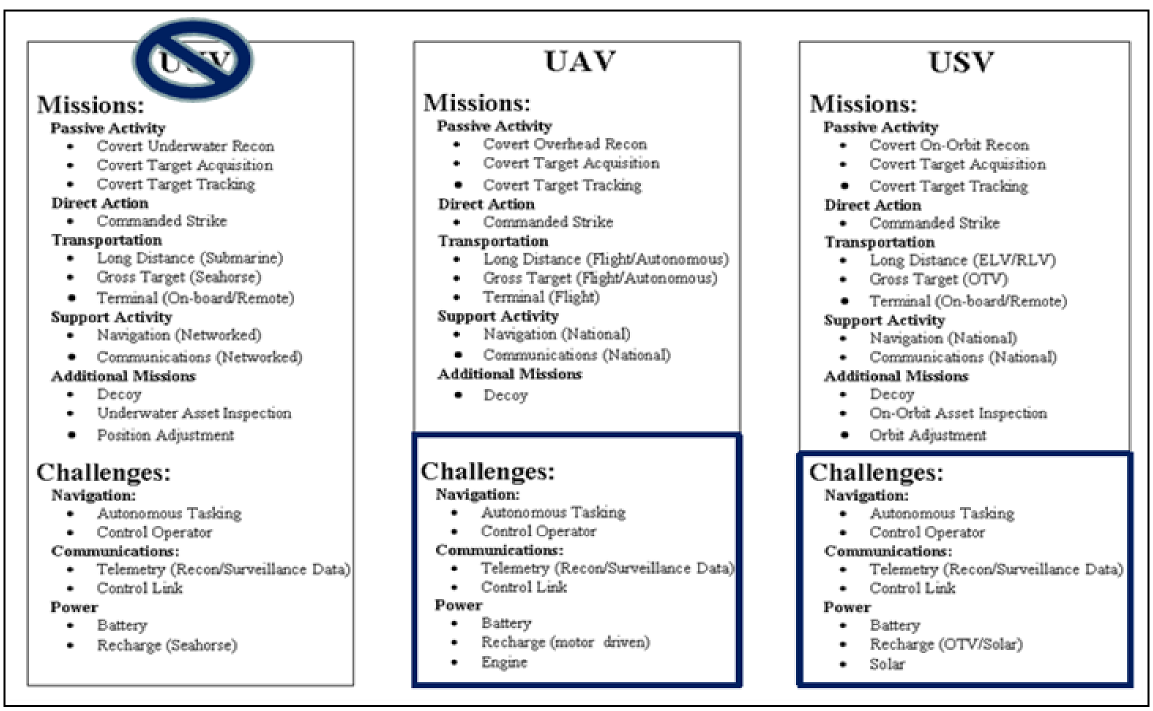


Figure 22. Platform Deficiencies.

Selection of technologies must overcome deficiencies such as power, communications, and navigation.

d. UAV Roadmap Selection

Understanding the Navy's development road map enabled the selection of readily available technology needed for our system. In reviewing the current state map of the Somalia Pirate process, the project team utilized an unmanned system that closely mimics the helicopter. A helicopter is a vertical takeoff system that is traditionally used for these missions. When compared with conventional larger helicopters, smaller vertical takeoff systems decreased the footprint of the platform needed to support a number of these aircraft. The UAV roadmap (Figure 23) communicates the DoD's development program for each of the armed forces. The Navy portion of the roadmap highlighted in black has one vertical takeoff system under development, the Fire Scout.

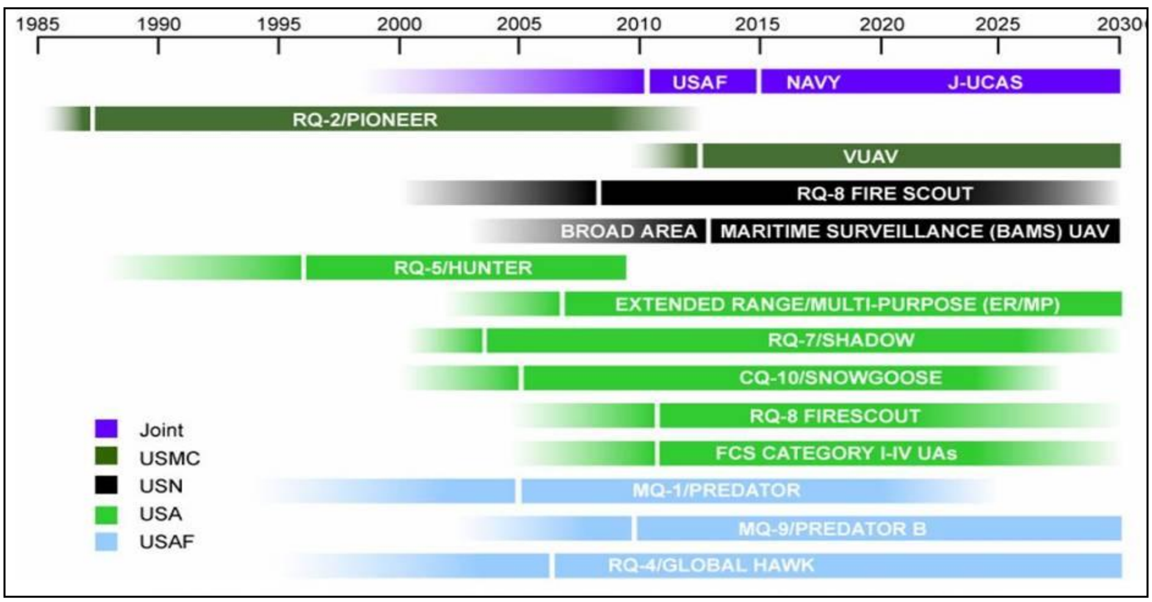


Figure 23. Existing UAV Platforms.

This figure shows some of the current UAV projects that are under development and could be used.

e. USV Roadmap Selection

By understanding the USV development table (Table 6), which compares a number of USVs under development by the Navy, the project team was able to select a fleet class (11M or 11 meters in length) USV, which is the largest USV available. The larger size is required to replenish systems and to defend HVA and U.S. Naval assets.

Table 6. Comparison Chart of USVs

The table below shows a comparison of different types of USVs that are available for consideration as possible assets to be deployed on the RSS. [Navy.mil 2007]

USV MP Priority	Joint Capability Area	Sea power Pillar	USV Mission	X-Class (small)	Harbor Class (7M)	Snorkeler Class (7M SS)	Fleet Class (11M)
1	Battle Space Awareness (BSA) / Access/ Littoral Control	Sea Shield	Mine Counter-measures (MCM)		MCM Delivery, Search / Neutralization	MCM Search, Towed, Deliver, Neutralization	MCM Sweep, Delivery, Neutralization
2	BSA / Access/ Littoral Control	Sea Shield	Anti-Submarine Warfare (ASW)			Maritime Shield	Protected Passage and Maritime Shield
3	BSA, HLD, Non-Trad Ops, 7 Others	FORCEnet	Maritime Security		ISR / Gun Payloads		7 M Payloads
4	BSA / Access / Littoral Control	Sea Shield	Surface Warfare (SUW)		SUW, Gun	SUW (Torpedo), Option	SUW, Gun, & Torpedo
5	BSA / Access / Littoral Control / Non-Trad Ops	Sea Strike	Special Operation Forces (SOF)	SOF Support	SOF Support		Other Delivery
6	BSA< C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control	Sea Strike	Electronic Warfare		Other IO	High Power EW	High Power EW
7	BSA, Stability, Non-Trad Ops, Littoral Control	Sea Shield	Maritime Interdiction Operations (MIO) Support	MIO USV for 11M L&R	ISR / Gun Payloads		

Primary Missions Supported by			
X-Class	Harbor Class	Snorkeler Class	Fleet Class
Secondary Mission of each class that are possible			

f. Highlights of Robot System

Three modes of robot operation were proposed: wait, automatic, and semi-automatic. During sea state 4 and above the system will be placed in wait mode. Wait mode is a mode where the UAVs and up to two USVs are parked inside the RSS. No other systems will bring supplies to the RSS during wait mode. The second mode is automatic mode. The system will replenish itself automatically. The system will detect and respond to intercept potential targets. Once a threat is identified, a series of steps will be activated that will deter the enemy or destroy the enemy. Man-in-the-loop control will be used to make the decision to kill. The third mode is a semi-automatic mode where overhaul maintenance may be performed along with replenishment of fuel and armaments. USVs with diesel fuel totes will park inside the RSS. The robots will attach to the totes and transfer the fuel to the UAV, the USV, and the RSS. (Shown in Figure 24 is a typical explosion proof robot that is used in industry.)

Figure 24. Explosion Proof Robot.

This photo shows an explosion proof robot. This type of robot is can be used in areas where refueling of vehicles is necessary [Sandia National Laboratories 2003].

The robots are more advantageous than fixed automation systems because of the advancement of robotic systems development and the training and support services robotics companies offer. In many cases, robotics firms and the customer sign up for modular build and an FMEA agreement that specifies the number of hours of operation required. “Modular Build” is a pre-installation test process whereby the entire system is assembled for operation in the factory, debugged, and run for an agreed amount of time under all proposed conditions without causing damage to the system. After the modular build is approved, the system is installed in the field. The system is run repeatedly for an agreed amount of time. Similar FMEA agreements used in industry help garner free robotics support and improvements utilizing FRACAS techniques. FRACAS stands for failure reporting and corrective action system. This process improves the product over time and holds the robot supplier accountable for operational goals. There are many other replenishment and maintenance processes that can be handled by robots; however, the refueling process serves to illustrate the possibilities. Because, the RSS is autonomous, the project team can design a smaller footprint system without needing accommodations for humans such as bathrooms, wash rooms, kitchens, and living quarters.

Although the RSS has a smaller footprint, it must still be able defend itself. The RSS needs a radar system capable of 48 nm of coverage radius. The system will be designed to be compliant with man-in-the-loop operation. The UAVs will provide protection when available. If not available a weaponized USV will provide protection. If the range to the RSS is too far for defense by the UAV or USV, the RSS will have automatic machine gun turrets that will be activated by the man in the loop stationed on the command ship. If the automatic turret has malfunctioned, the system will have anti tamper capabilities inside the RSS.

g. Highlights of Sensor System

The primary sensor selected will be an aerostat based multifunction phased array radar (MFR) with persistent coverage. The aerostat Mean Time Between Failure (MTBF) is to be ten years. The aerostat has a significantly lower energy signature due to the use of low power density transmit-receive modules embedded in the skin of the aerostat. Figure 25 shows a comparison of surveillance craft.

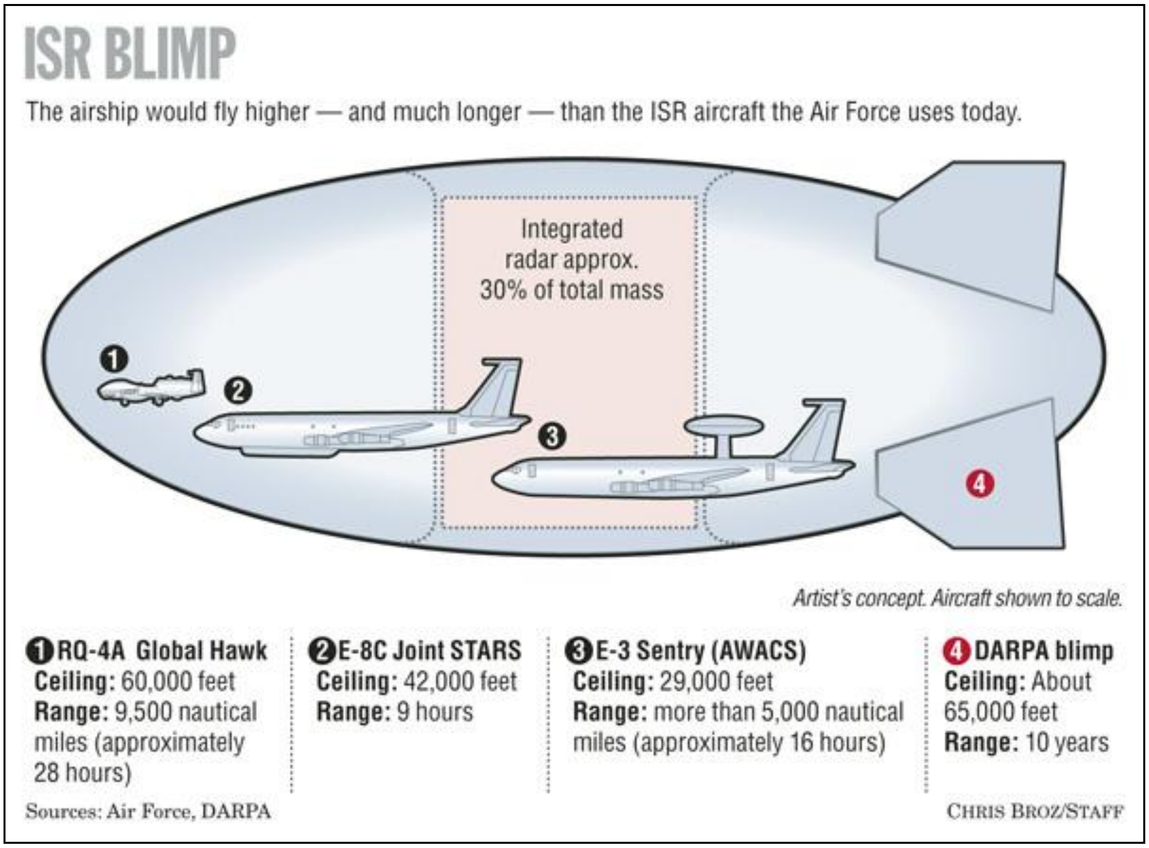
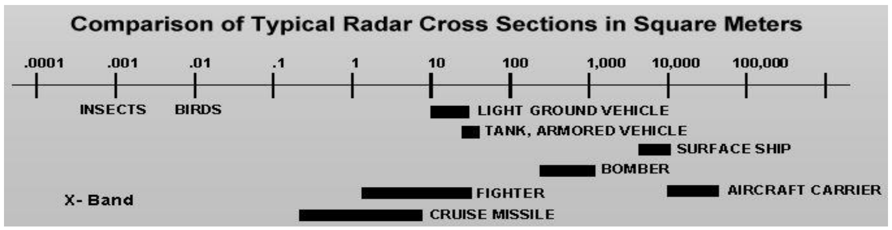


Figure 25. Conceptual Drawing of ISR Blimp.

The above drawing compares surveillance craft being used today to the new conceptual ISR Blimp. The new blimp design by DARPA could have reliability sufficient for the blimp to last up to 10 years on station.

The MFR is capable of near video resolution imaging of targets of interest. In Figure 26 the Radar Cross Sections (RCS) of small maritime targets are displayed. The aerostat MFR is based on Lightfoot technology (shown in Figure 27) which is far more energy efficient than radars with traditional transmit/receive modules. Figure 28 shows the aerostat to have the lowest risk and it is thus the best choice as a sensor platform.



Target Type	GRT	Length ft	Median RCS m^2
Unmanned dinghy		14	0.01 to 0.1
Large lit buoy			10
Container	26,436	695	10^4 to 10^5
Tanker	35,000	824	10^4 to 10^6

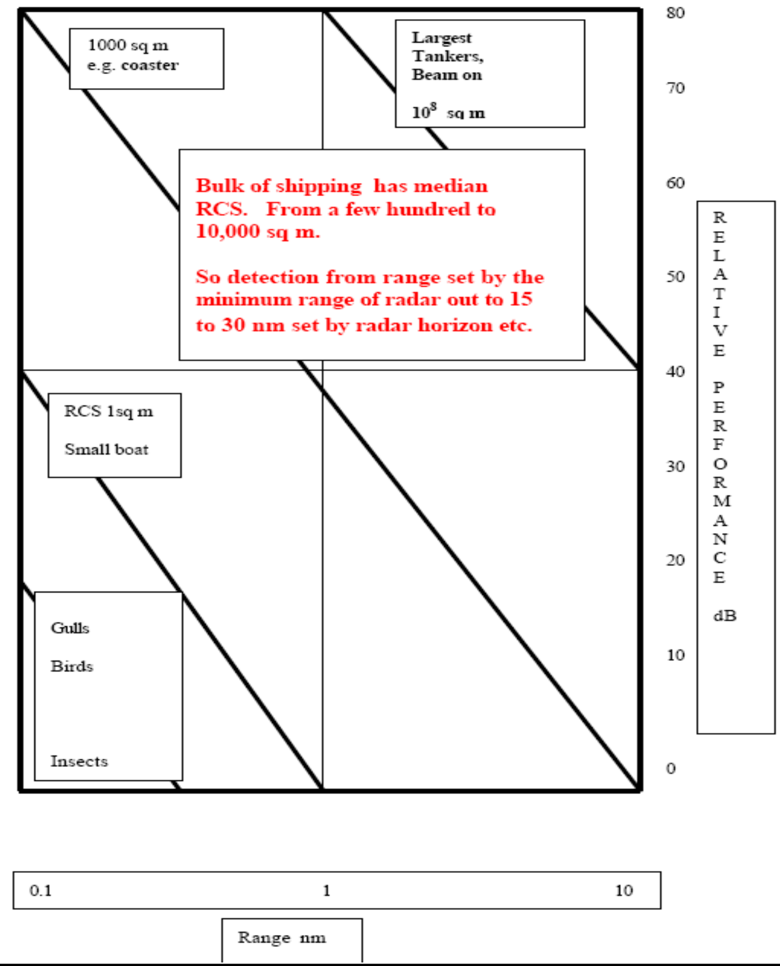


Figure 26. Typical Radar Cross Section (RCS) values.

The aerostat has a significantly lower energy signature due to the use of low power density transmit-receive modules embedded in the skin of the aerostat.

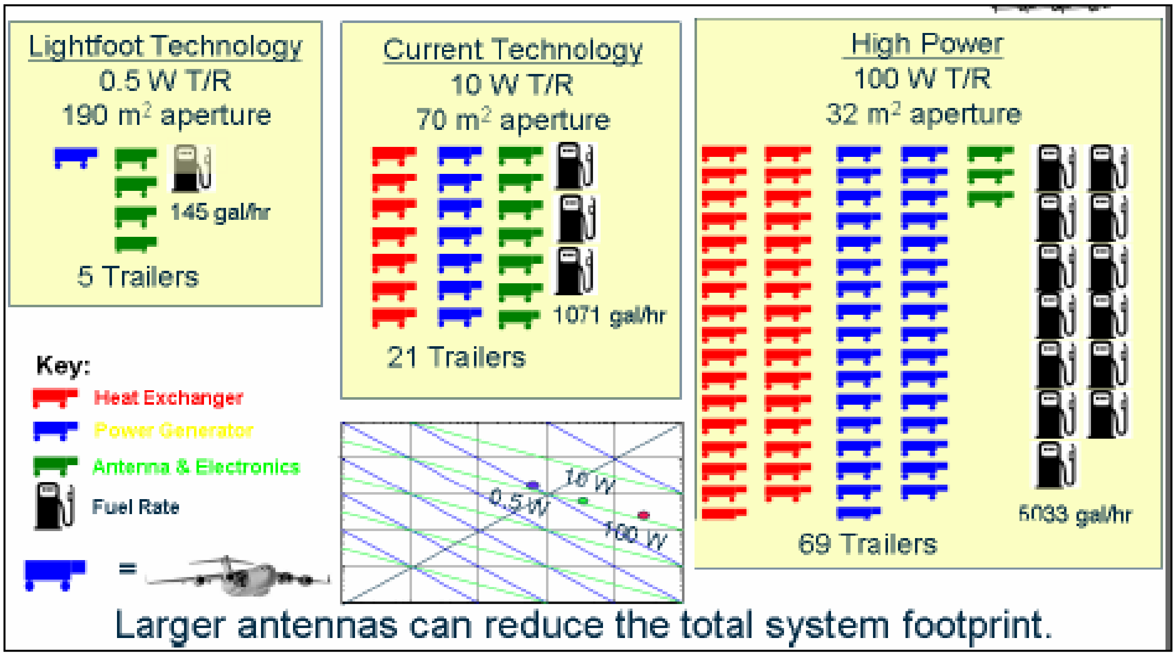
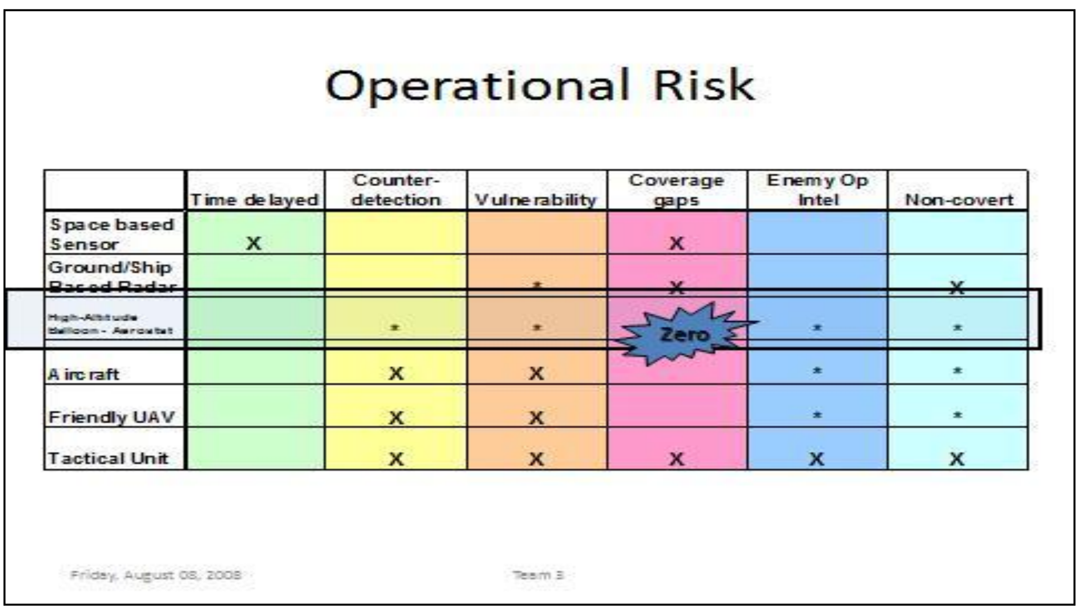


Figure 27. Power Consumption of different Radar technology.

This shows what it takes to power various radar systems. The new Lightfoot Technology has very low power consumption and a large aperture which allows for a larger area of coverage.



Operational Risk

	Time delayed	Counter-detection	Vulnerability	Coverage gaps	Enemy Op Intel	Non-covert
Space based Sensor	X			X		
Ground/Ship Based Radar			*	X		X
High-Altitude Balloon - Aerostat		*	*	Zero	*	*
Aircraft		X	X		*	*
Friendly UAV		X	X		*	*
Tactical Unit		X	X	X	X	X

Friday, August 08, 2008

Team 3

Figure 28. Operational Risk.

The chart shows the operational risks involved with several different platforms that have detection sensors placed on them. The high altitude balloon – aerostat – is the only available platform that has no gaps in coverage.

Sensors will be attached to the UAV, USV, RSS, and aerostat. A diagram of coverage is given Figure 29. A radar system will be attached to the RSS and the USV. All systems will be able to access information from the aerostat. Speed and range coverage for each system are provided below.

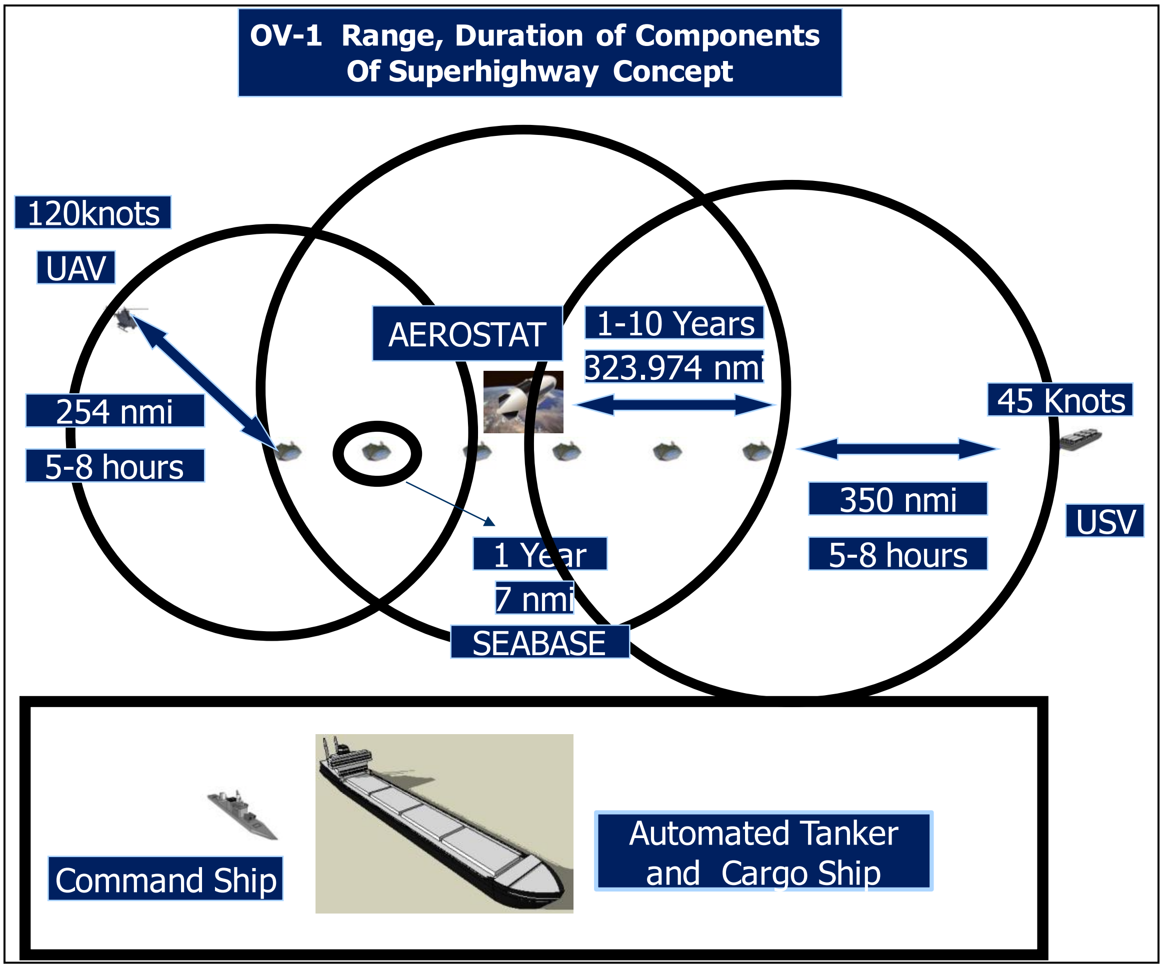


Figure 29. OV-1 Range, Duration of Components of Super-Highway Concept.

This Figure depicts the range which the components of the Super-Highway concept will be able to cover as well as the times that the individual components are able to stay on station.

The system will be divided into 200-nm square boxes of coverage. The system will be comprised of ten units providing a defended sea lane of 2,000 nm by 200 nm with persistent coverage. By confining shipping to a defended area that is only 8 percent of the currently affected zone of pirate operations, it greatly reduces opportunities for pirate attacks. Based on a Google earth map (Figure 30) of the Somalia Coast line, ten RSS units will be required to cover the sea lanes off the coast of Somalia.

A typical zone in the Super-Highway will look like the picture shown in Figure 31.

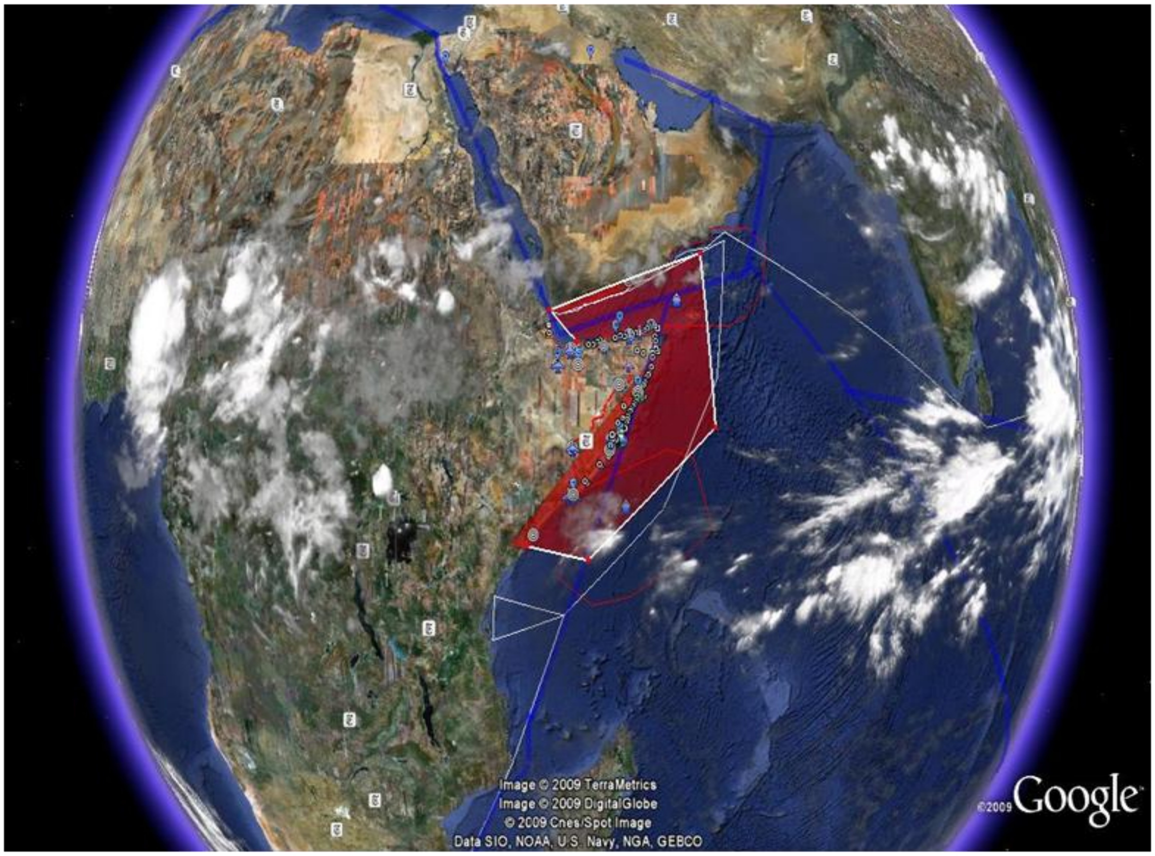


Figure 30. Area of Operation of the Somalia Pirates.

The area in red shows where the pirates operate. This operational area of the pirates covers an estimated 1.2 million square nautical miles. An area that large makes it difficult to provide adequate protection to vessels transiting through this zone.

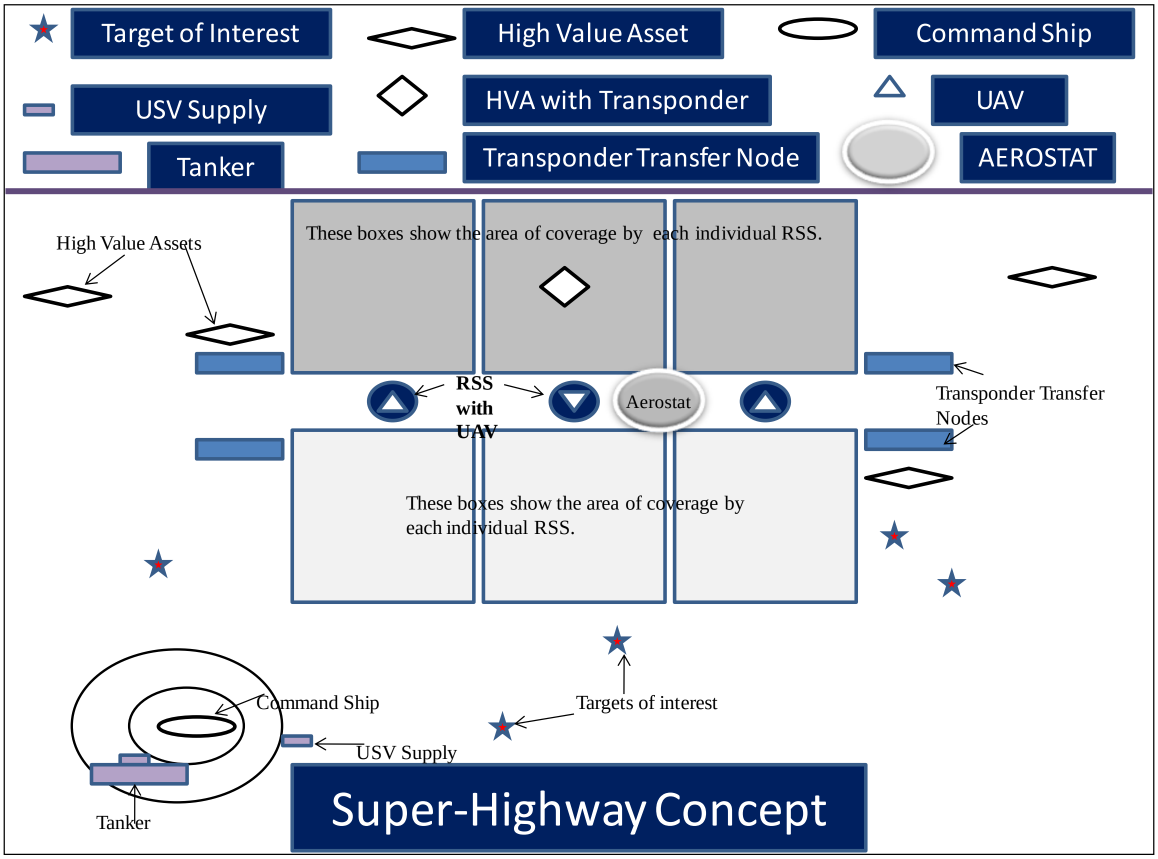


Figure 31. Super-Highway Concept.

The concept of the Super-Highway is to have a high value asset transverse a corridor that is 100 nm on either side of a RSS. By staying in this protection zone the high value asset will be able to receive assistance from a UAV in a timely manner if it were attacked by pirates.

h. Assumptions

The Super -Highway concept is a virtual space where no entity may enter without the system's knowledge. A transponder will allow the MOC to monitor each ship. The transponder, given to each ship at a check-in point, will allow the MOC to monitor the progress of the ship through the super-highway. The transponder is returned at a check-out point. Its purpose is for positive identification of the ship given permission to travel the super-highway. Another reason for issuing the transponder is for it to act as a distress signal if the ship is attacked by pirates. A USV transports the transponders according to a predetermined schedule.

F. DEVELOPMENT OF MODEL FOR SIMULATION

1. Analysis of Range

This analysis was done to determine if it is possible for a potential threat to be intercepted and deterred or neutralized by a boat launched from an RSS if it is detected 100 nm away from an RSS. Three scenarios were analyzed:

1. Potential threat moving toward a stationary HVA with an RSS being on the other side of the HVA and 100 nm from the point of detection of the potential threat (Figure 32).
2. Potential threat moving in the same direction as a HVA and toward the RSS (Figure 33).
3. Potential threat located 100 nm away from a RSS and 60 nm away from a stationary HVA (Figure 35).

Appendix J is a matrix of the time to intercept given various ranges and speeds.

a. Scenario 1

A cargo ship carrying multiple shipping containers is located between a potential threat, in this case a small speedboat with pirates, and an RSS, seen in Figure 32. The threat is detected when it is 100 nm away from the RSS and only 20 nm from the HVA. The RSS is initially located 80 nm away from the HVA.

The speedboat is moving toward the cargo ship at 30 kts, while the RSS launches an Unmanned Surface Vehicle (USV) which moves at 40 kts toward the HVA and hence the threat. Using Appendix J it can be seen that the pirates in the speedboat will take approximately 40 minutes to reach the stationary HVA, while the USV will take approximately 120 minutes to reach the HVA. In this scenario, the RSS is determined to be too far away from the HVA when it detected a potential threat.

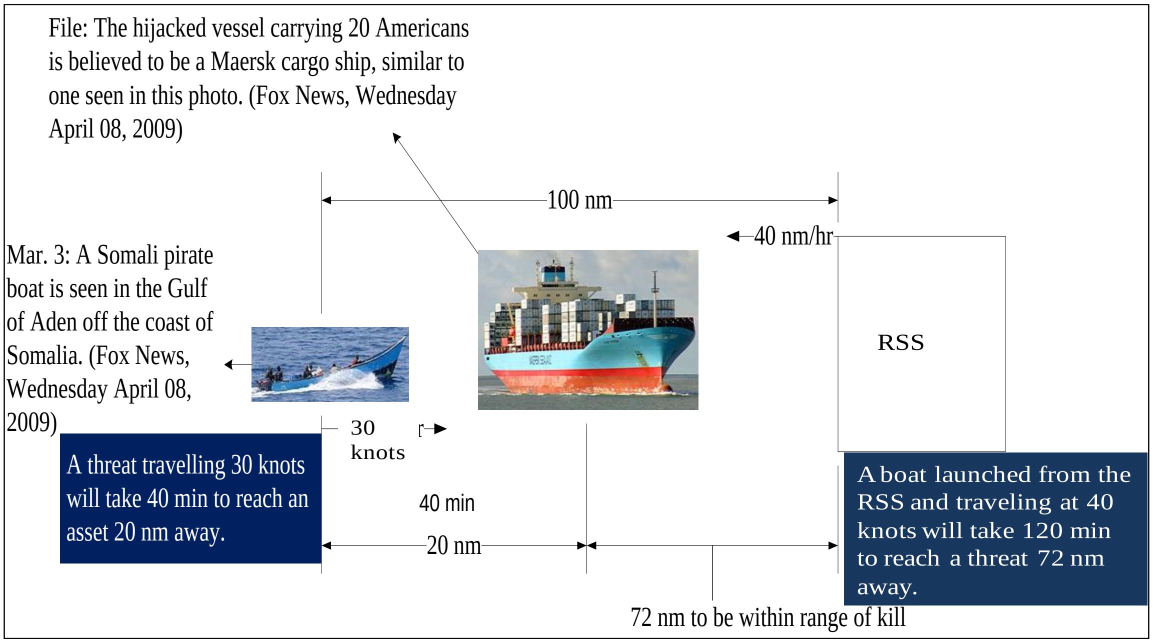


Figure 32. Simple Analysis of Time to Intercept.

This Figure shows the time for a threat to intercept its target and the time it takes for a boat launched from the RSS to intercept the threat. The threat, the boat on the left, is moving to the right at 30 knots towards a stationary asset and the RSS is located 100 nm from the threat. Once a boat is detected by RSS, it dispatches a boat to assess and intercept the detected boat. This boat travels to the left at 40 knots.

b. Scenario 2

In this case a cargo ship is moving toward an RSS while a potential threat, a small speedboat with pirates, is heading toward the cargo ship. The RSS detects the speedboat when it is 100 nm away (20 nm from the HVA) and launches a USV to intercept it. Figure 33 shows the velocity vectors of the threat, HVA, and the RSS being 30 kts to the right, 20 kts to the right, and 40 kts to the left, respectively. Since the HVA is moving, relative velocities are calculated and used to determine the times to intercept.

The relative velocity of the threat to the asset is 10 kts, while the relative velocity of the boat launched from the RSS to the asset is 60 kts. This means that the threat will take 120 minutes to reach the asset and the boat launched from the RSS will only take 80 minutes to reach the asset. In this scenario, the boat launched from the RSS will have enough time to reach and protect the asset from the threat.

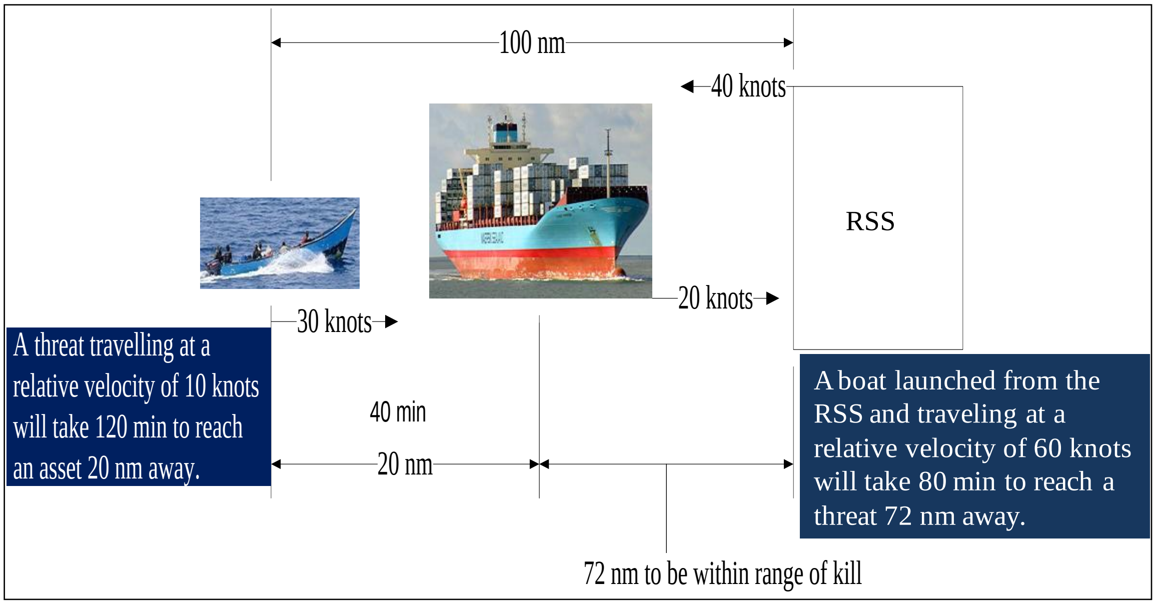


Figure 33. Time to Intercept a Moving Asset.

This Figure shows the time for a threat to intercept its target and the time it takes for a boat launched from the RSS to intercept the threat. The threat, the boat on the left, is moving to the right at 30 knots towards a moving asset and the RSS is located 100 nm from the threat. Once a boat is detected by RSS, it dispatches a boat to assess and intercept the detected boat. This boat travels to the left at 40 knots.

c. Scenarios 1 and 2 Results

For a stationary asset, an RSS located 80 nm away from the asset, and a threat detected 20 nm on the far side of the asset, the asset will not be able to be protected from attack (see Figure 32). This means that the RSS needs to be located within 27 nm of the asset to provide adequate protection from a threat on the far side of the asset. If the asset is not stationary, but moving towards an RSS, then an initial range of 80 nm may be close enough to provide adequate protection from a threat on the far side of the asset.

If a threat is approaching an asset that is moving away from an RSS, the initial range of 80 nm of the asset from the RSS will not provide adequate protection from the threat. In this case, multiple RSS systems or a faster interceptor vehicle are recommended in order to provide the coverage needed to protect the asset.

Figure 34, shows ranges from an asset that a potential threat should be detected, identified, and neutralized. The earlier a threat is detected and intercepted, the higher the probability of neutralizing it. The outer circle represents the outer edge of the range (100 nm) from an asset to a RSS. Ideally, the RSS will be within the 100 nm range. Once a potential threat it detected, identification as friendly or hostile should happen as soon as possible. If a potential threat crosses the 40 nm range (first inner circle), a boat (or UAV) shall be sent out to warn and intercept if needed. If the potential threat continues on its course after being warned, it will be considered hostile and will be engaged. Engagement can be either non-lethal or lethal. Once a threat reaches the 20 nm range, and consequently the red zone, there is a higher probability of the asset being damaged.

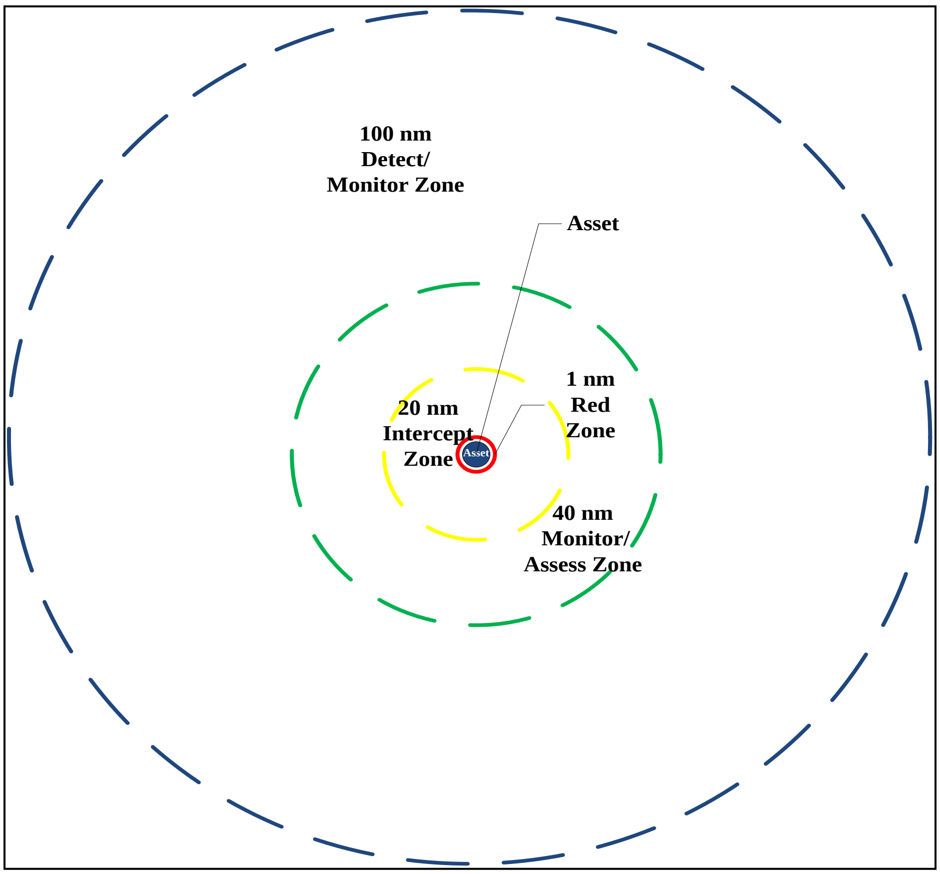


Figure 34. Ranges from an Asset.

This Figure depicts the ranges from an asset, within which, a threat needs to be detected (outer circle), monitored (all circles), identified as friendly or hostile (first inner circle), intercepted (second inner circle), and the threat must be neutralized before it reaches the third inner circle.

d. Scenario 3

A potential threat located 100 nm away from a RSS and 60 nm away from a stationary HVA. Figure 35 shows four steps for the threat to reach the HVA. At the first step, the threat is located at the radial intersection of 100 nm from the RSS and 60 nm from the HVA. It is moving toward the HVA at 40 kts, which means that at this rate it will take 90 min for the threat to reach the HVA. Step two is shown when the threat is 40 nm away from the HVA and a UAV is launched from the RSS to intercept and deter or neutralize the threat. Step three shows the UAV moving at a rate of 100 kts. At this time, it is located 44 nm from the threat, which is 20 nm away from the HVA. Step four shows the UAV intercepting the threat before it reaches the 1 nm critical range from the HVA.

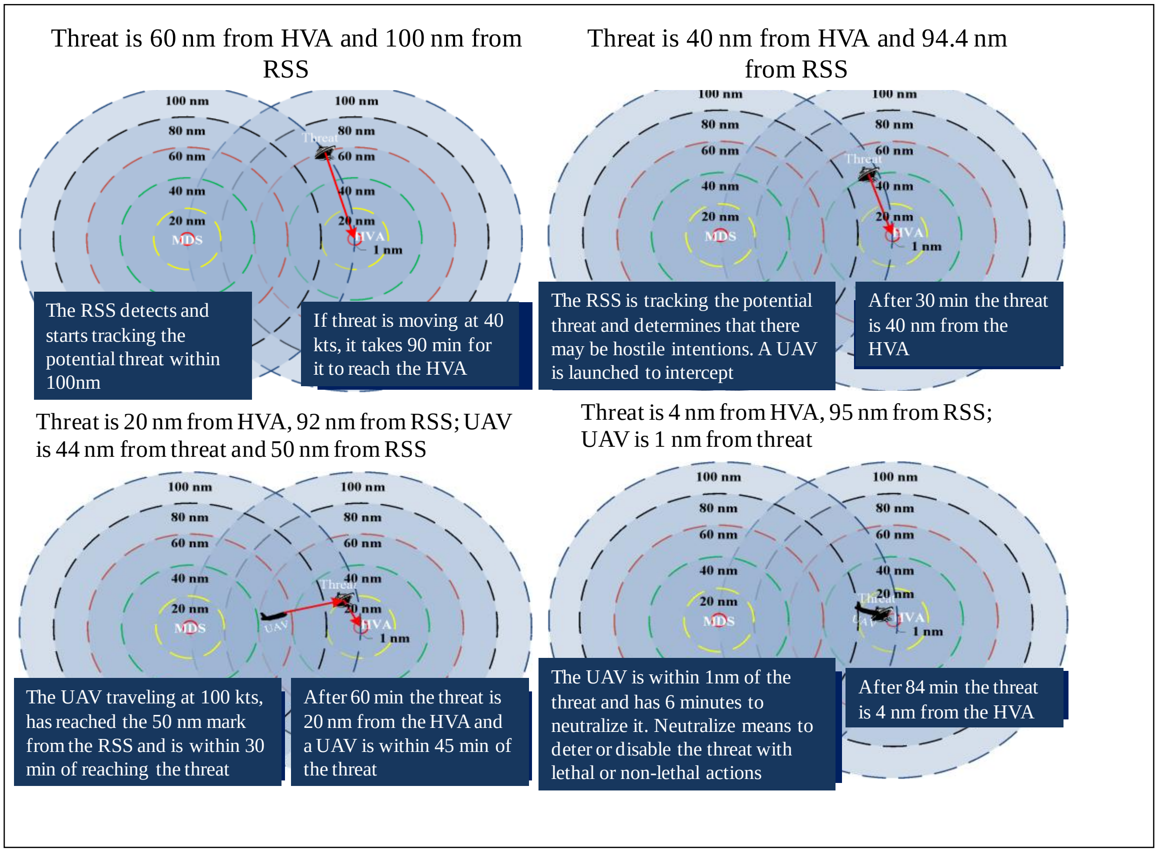


Figure 35. Analysis of Time to Intercept a Potential Threat.

This figure shows a four step process that the RSS goes through when a threat, which is 100 nm from a RSS and 60 nm from a stationary HVA, decides to go after the HVA.

2. Modeling and Simulation

During the simulation process, a model was created and various simulations were performed by varying inputs in a functional and systematic method for each alternative. Modeling and simulation provide the data needed to be used in the analysis of alternatives to provide stakeholders with recommendations for selecting the best alternative.

a. Process

The modeling and simulation process, shown in Figure 36, involved seven steps: generating scenarios, selecting the modeling tool, choosing evaluation measures, making assumptions, building the models, running the simulations, and analyzing the results. The seven steps are discussed in more detail in the following sections.

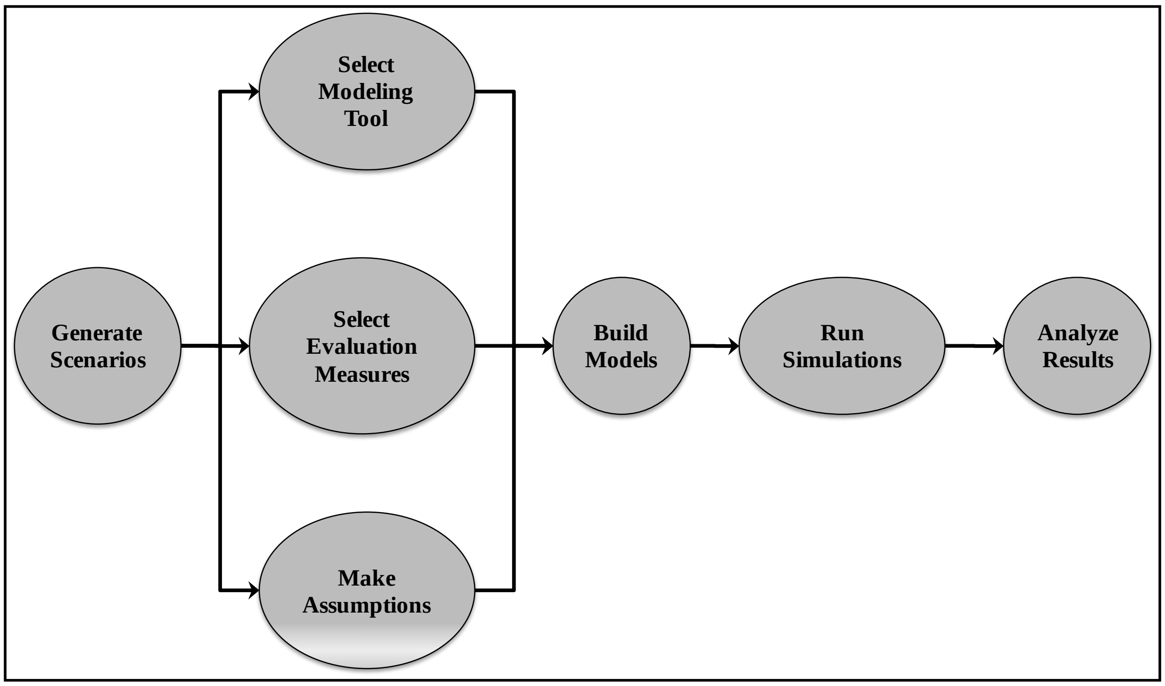


Figure 36. Modeling and Simulation Process.

This Figure shows the seven steps in the modeling and simulation process. The final result from this process is used in the analysis of alternatives to provide the stakeholders with a recommendation for accepting the best alternative studied.

b. Scenario Overview

Figure 37 and Figure 38 are based on the current state and future state maps presented earlier. The earlier Figure 13 and Figure 14 were used in a Lean process to show areas where waste could be eliminated in the process. Here, they provide the basis for the scenario used in the analysis. The current state scenario is based on possible operations that are occurring around the Horn of Africa in the prevention of pirate attacks on merchant vessels. In this area of operation, there are warships that are on patrol searching for possible threats to merchant vessels or Mayday calls for help. Once a potential threat is observed or a Mayday call is received, the warship will launch a helicopter, change heading to intercept threat, and launch the boarding craft with armed personnel. This is all dependent upon the distance that the warship is from the threat. If the threat is too far away, only the helicopter will be used to intercept the threat. When the threat can be reached by a boarding party craft before it reaches the merchant vessel, the boarding parties will perform a search and seizure of the suspected pirate vessel.

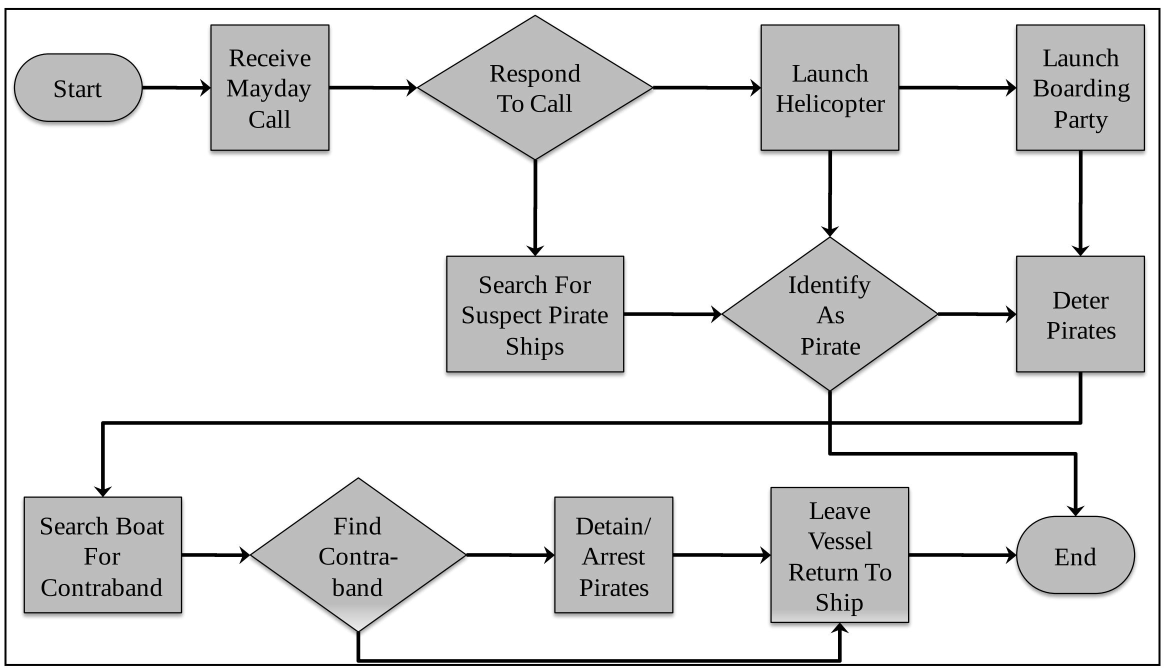


Figure 37. Current State Map.

This is the current state map of operations for the warships on patrol around the Horn of Africa and the basis of one simulation scenario that can be compared to the future state scenario.

The second scenario is a variation of the first scenario. This scenario incorporates two UAVs that can be launched from the patrolling warship. By performing this variation of the scenario the project team was able to get a better comparison between the warship and the sea station concept.

The third scenario was developed based on the future state map (Figure 38). The future state map is based on the RSS and operations similar to those of the warships presently patrolling around the Horn of Africa. The big difference in this scenario is that the project team condensed the battle space by offering a two hundred nautical mile wide safe zone shipping lane. Any vessel that wishes to transverse this shipping lane is under the protection of the ASHC, consisting of a series of individual RSSs, which carry three UAVs each. In this scenario, a merchant vessel enters the protected shipping lane and if there is any adversary that attempts to attack the merchant vessel, a UAV is launched from the RSS. The UAV then proceeds to intercept and stop the adversary from any aggressive actions against the merchant vessel. Simulation of this scenario can contribute to the identification of factors that may affect the RSSs ability to protect merchant vessels off the coast of Somalia.

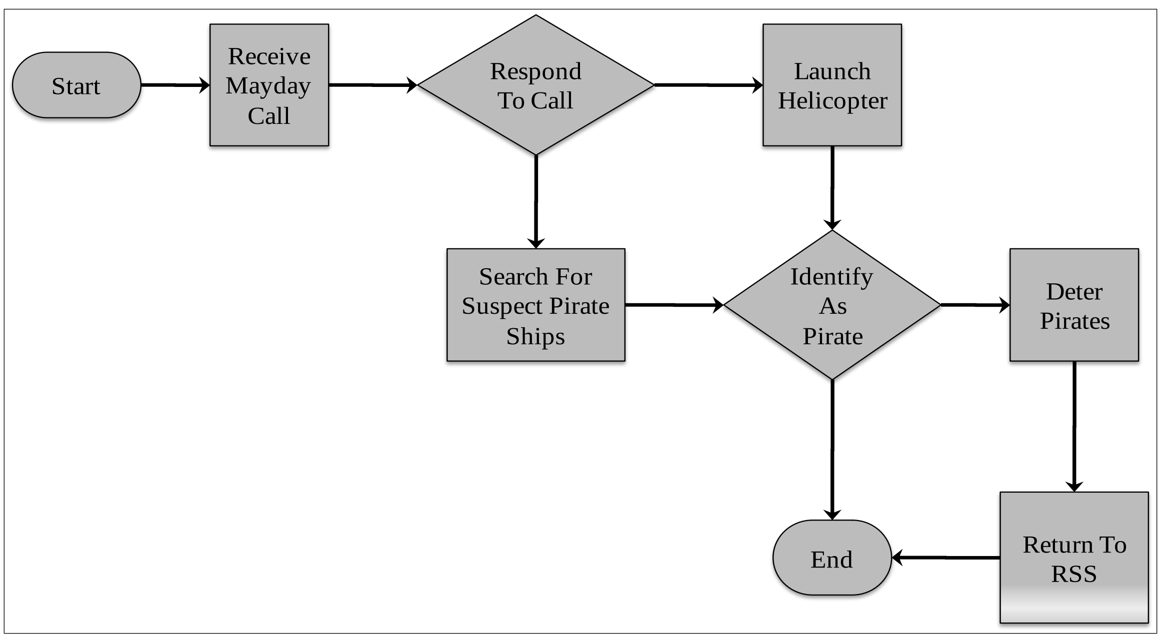


Figure 38. Future State Map.

The future state map shows the operations of the RSS. Compared to the current state map, the future state map has three fewer steps. Three steps have been eliminated as a result of the autonomous operations of the RSS.

c. *Tool Selection*

Selection of the right modeling and simulation tool is critical to the outcome of data needed for analysis. Each modeling and simulation tool has its advantages, disadvantages, and limitations. Another consideration that was taken into account was learning how to use the new tool. Therefore, since the project team was already familiar with the operations of ARENA and EXCEL, these two were under consideration to be used. The project team also looked at SIMIO, CRYSTAL BALL, MATLAB, and MINITAB. ARENA, SIMIO, and MATLAB, are able to model almost any system or process. Because MATLAB is matrix based, and most of the team members were not proficient using this tool the project team decided to eliminate it. Both ARENA and SIMIO are object-orientated and easier to use. Their dynamic modeling capabilities were able to be utilized to help answer questions on how an existing or a proposed system will perform. The project team decided to use SIMIO in preference to ARENA because SIMIO had better graphics and extended capabilities that were not available in ARENA. EXCEL, CRYSTAL BALL, and MINITAB were considered for the final analysis of the data that was collected from the simulations. EXCEL was eliminated because its statistical add-in package is not reliable in some statistical calculations, which in turn could lead to unreliable analysis of the data. In the end, the project team chose CRYSTAL BALL for the response analysis and MINITAB for the statistical analysis.

d. Evaluation Measures for Modeling and Simulation

The main focus of modeling and simulation was to evaluate the systems to protect a high value asset from unfriendly adversaries. For the system to be able to perform the main objective the system must be able to achieve the following: detect friendly and foe vessels in the area of coverage; have an asset available to intercept a foe; have the ability of the asset intercepting the foe; and have the ability for the asset to stop the foe. This emphasizes two major metrics: distance of the asset to the target and the relative speed between the target and asset.

Since the scenario for each of the alternatives was unchanged and only the platforms were changed, the project team was able to use the same metrics to measure the performance of each individual platform. This allowed the project team to collect similar data in each of the simulations and compare data obtained from several runs of the simulation. Once this data was collected, statistical analysis was performed and the results were used in the analysis of alternatives step.

e. Assumptions

It is assumed that the available assets, helicopters and UAVs, will be able to engage the enemy out to a 100 nm radius from any platform carrying these types of assets. The detection of all vessels in the area is equal to or greater than the 100 nm radius from the platform. The earlier a hostile threat is determined, the higher the probability of a neutralizing it. Radar will be monitoring and tracking all vessels in the area. All tactical information is being seen at the MOCs. All systems are using C4I capabilities such as LINK-16 and satellite communications.

Key modeling and simulation objectives were to determine the number of successful aggressive adversaries that were intercepted and either deterred or neutralized, thus preventing an attack on a high value asset, i.e. merchant vessel.

3. Generic Model Description

The decision making process in the model was built on the basis of a kill chain. This kill chain consists of three components: detect, control, and engage. The kill chain was adopted to establish a clear set of functions that the system of systems must perform. The purpose of the model was to demonstrate and quantify how effectively the candidate architectures performed the kill chain throughout the detect/control/engage sequence for each alternative.

a. Detect

The first phase of the kill chain is detection. In all models, which were developed in SIMIO, it was assumed that all vessels were detectable and that there was a random probability that some of these vessels would chase a HVA. These vessels would then be monitored to determine if they were vectoring towards the high value asset. If it was deemed that the craft was bearing down on the high value asset and crossed a 20 nm zone nearing the high value asset, then the closest platform will launch a helicopter or UAV (depending on whether it is a warship or an RSS). The generic detection section of the model is shown in Figure 39.

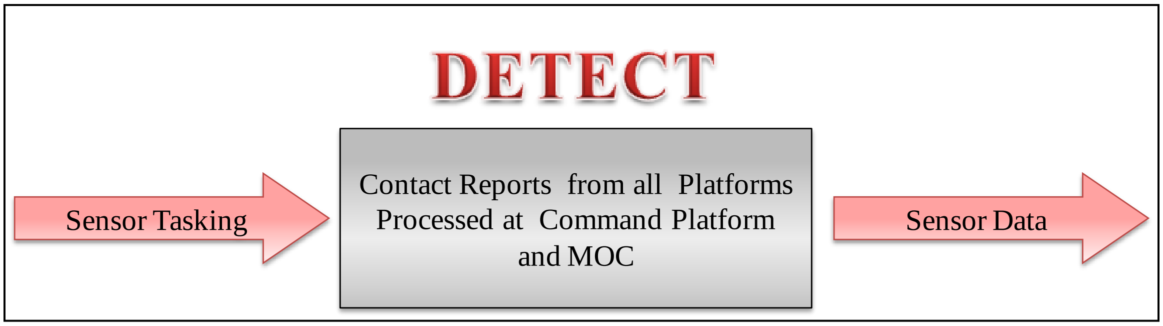


Figure 39. Detect Section of Model (Generic).

This Figure shows the generic detection concept used in the model. The inputs and outputs vary depending on the systems being used and the platforms that are deployed.

b. Control

As indicated earlier, the baseline model was developed in SIMIO and only slight changes were made to this baseline in order to depict different scenarios. In the control phase of the kill chain, a probability value was selected to determine whether the interception of the aggressor was successful or not. This is the part of control in which the helicopter or UAV intercepts the aggressor and determines the intent of the aggressor. At this point there are two likely outcomes from this encounter. The first is that the aggressor does not take the risk and will disengage from its hostile behavior. If this occurs, the interceptor will loiter in the area to ensure the aggressor does not reengage the HVA. The second outcome is that the aggressor continues on its course to attack the HVA. When this takes place, the intercept asset will switch to the engage mode. Figure 40 illustrates a generic control model.

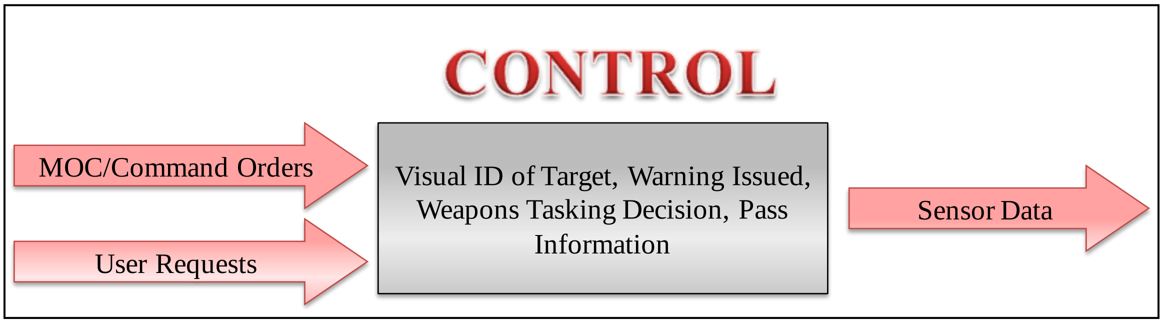


Figure 40. Control Section of Model (Generic).

This is a generic representation of the control element once a hostile aggressor is intercepted by either a helicopter or UAV via man in the loop. The interceptor determines the intent of the target and issues a warning of engagement if aggressive behavior is continued.

c. Engagement

The engagement phase of the model simulates how a typical weapon engagement is executed and provides outputs to the rest of the kill chain. Steps in the weapon engagement phase were: receive weapons tasking, launch a weapon, guide weapon to target, provide weapons inventory, and provide a kill evaluation of the target track. The project team simplified this to make the system model less complicated. The project team also assumed that the weapon engagement could be either non-lethal or lethal. Some examples of non-lethal weapons that could be used are acoustic, radio frequency, and microwave radiation. Once a "weapons free" command has been given, the interceptor would have the ability to neutralize the hostile aggressor by whatever means available. This means that either the aggressor would disengage from the attack on the high value asset or the aggressor would be eliminated. After the aggressor was neutralized, the interceptor would loiter in the area and provide visual feedback to the MOC confirming that the aggressor was stopped its pursuit of the HVA. The project team was only concerned with neutralization of the target (threat to HVA) in order to keep the modeling within the scope of the project. The inputs and outputs of the engagement portion are shown in Figure 41.

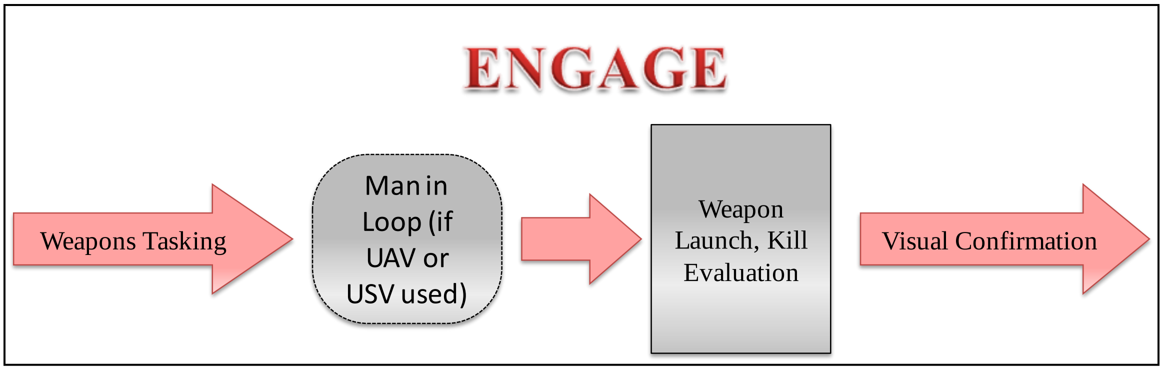


Figure 41. Engage Section of Model (Generic).

This Figure shows the simplified input and output of the engagement phase. The weapons tasking is received from the control platform. The tasks are interpreted and weapon engagement is commenced, followed by visual confirmation of kill or no kill.

The weapon type to be used was chosen based on the target's intent and the perceived aggressiveness of the target. The preferred weapon selected depends on the complement of weapons available on the defending platform. The orders of the MOC and rules of engagement must be followed. Lastly, there must be a confirmation of the neutralization of the target and evidence of a kill or no kill.

4. Modeling Alternatives

All three alternatives used the same baseline model so that all of the alternatives could be rated under the same criteria. The alternatives differed from each other in terms of platform distances to the HVA, speed, and availability of helicopters or UAVs. Furthermore, for the model to represent a realistic environment, random normal distribution generators were inserted into the simulation for: the number of high value assets, the number of hostile aggressors (pirates) attacking high value assets, and the number of successful intercepts and kills.

a. SIMIO Analysis

Modeling and Simulation (M&S) contributed to the development of the Concepts of Operation (CONOPS). Essentially, M&S allowed operational performance to be assessed while analyzing performance parameters. M&S also allowed the project team to conduct tradeoffs, and evaluate potential system changes and improvements.

Furthermore, the project team was able to predict the target area of coverage, and the required response times.

Figure 42 (page 78) represents one run of the SIMIO model with the HVA defended with a warship with one UAV. The numbers next to each block represent the number of entities that depart from the block. (Actual screen shots of the SIMIO simulation are in Appendix I)

The radar is able to 'ignore' friendly targets, and only track potential threats. The friendly assets move to the Ignore block, while the potential threats move to the Loiter 1 block where they are paired with an asset. This pairing allows the model to represent the potential threat locking in on an asset and pursuing it. Once the potential threat determines it wants to continue pursuing the asset, the pair moves to either Separator 3, where the asset is determined not be of value to the potential threat, or to Range 20 nm, where the threat determines the asset to be a HVA. When the threat starts pursuing an asset, the warship receives a signal, which in turn causes it to prepare the UAV for launch. The UAV is sent to meet the enemy at Loiter 3 and the sequence of deterring the threat has begun.

i. Scenario 1: Warship with one UAV

In this run of the scenario, 152 potential threats combined with an asset and moved through the Enemy Chasing HVA block. Seventy-eight threats were determined not to be of interest and 74 threats were determined to be HVA. Out of the 74 cases with enemies pursuing a HVA, only 69 could be met by a UAV. This means that in approximately 7 percent of the cases, a HVA could be attacked before the UAV could get there to intercept and deter the enemy. Once the threat was met by the UAV, it was able to be deterred 92.7 percent of the time and was destroyed the other 7.3 percent of the time.

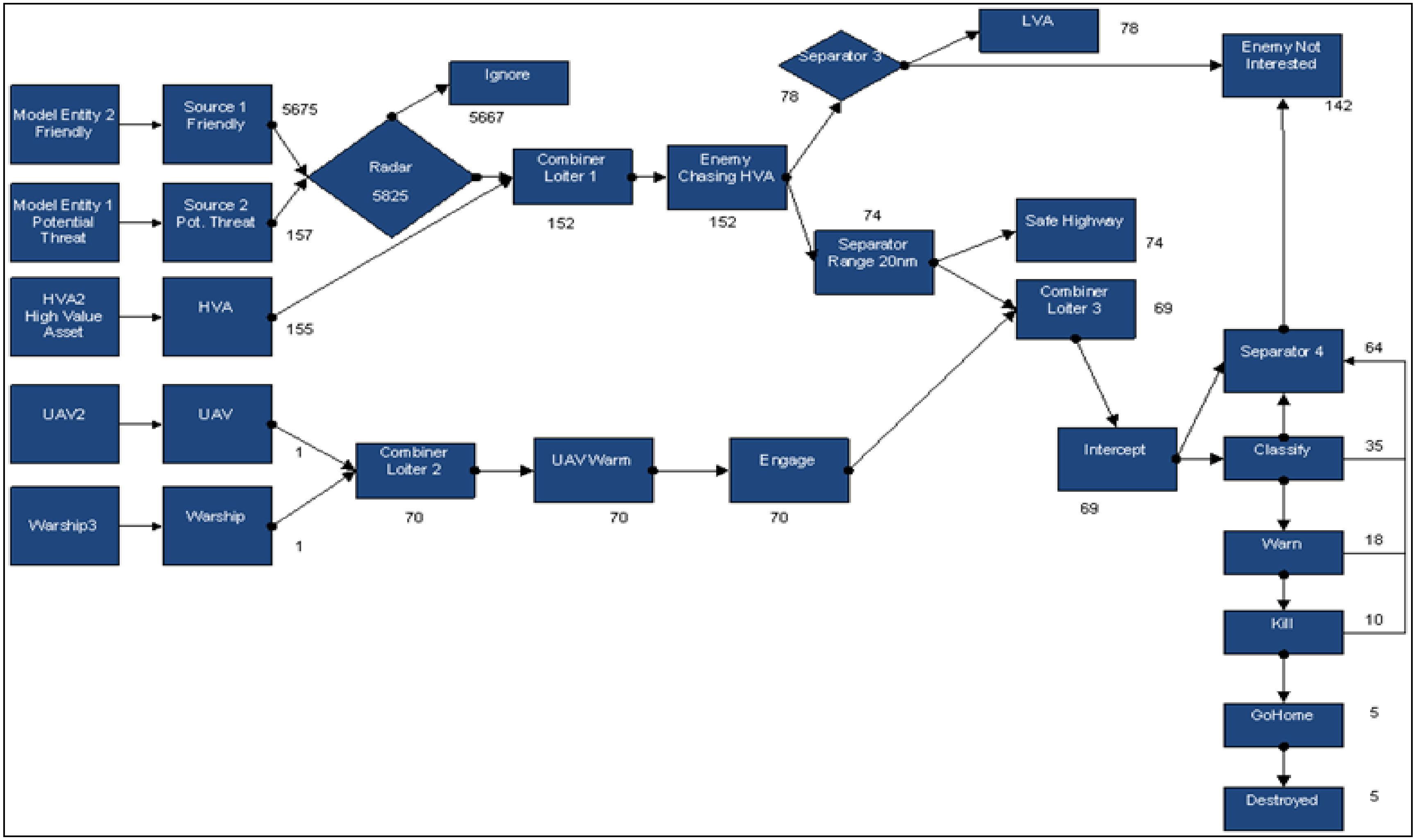


Figure 42. SIMIO Model - Warship with one UAV.

This figure represents one run of the model simulating an HVA defended by a warship with one UAV.

ii. Scenario 2: Warship with two UAVs

Scenario 2, seen in Figure 43 (page 80), has two UAVs able to be launched when a potential threat is detected pursuing an asset. One hundred twenty-six potential threats are combined with an asset and move on to the Enemy Chasing UAV block. From here, 54 are determined to be of little interest and 72 are pursued further. Out of the 72 threats pursuing an asset, 68 are able to be met by a UAV. While there is a slightly higher probability of an UAV intercepting the threat than scenario 1, there are still enemies that can attack an asset before help is able to arrive. Out of the threats that are intercepted, 92.6 percent are able to be deterred while 7.4 percent are destroyed.

iii. Scenario 3: RSS with two UAVs

The scenario with the two UAVs and a RSS shown in Figure 44 (page 81) is much like the two UAVs with a warship; however, the UAVs are able to return to the RSS and be prepared for re-launch faster than on the warship. The difference between the two scenarios is a controlled battle space where the RSS operates within design capabilities. One hundred thirty-eight potential threats are combined with assets and move on to the Enemy Chasing HVA block. Out of the 138 assets, 75 are determined to be of interest. The Loiter 3 block shows 75 enemies combined with UAVs departing to the intercept block. This means that a UAV is able to reach every threat that continues pursuing an asset. Out of the threats that are intercepted, 96 percent are able to be deterred while 4 percent are destroyed.

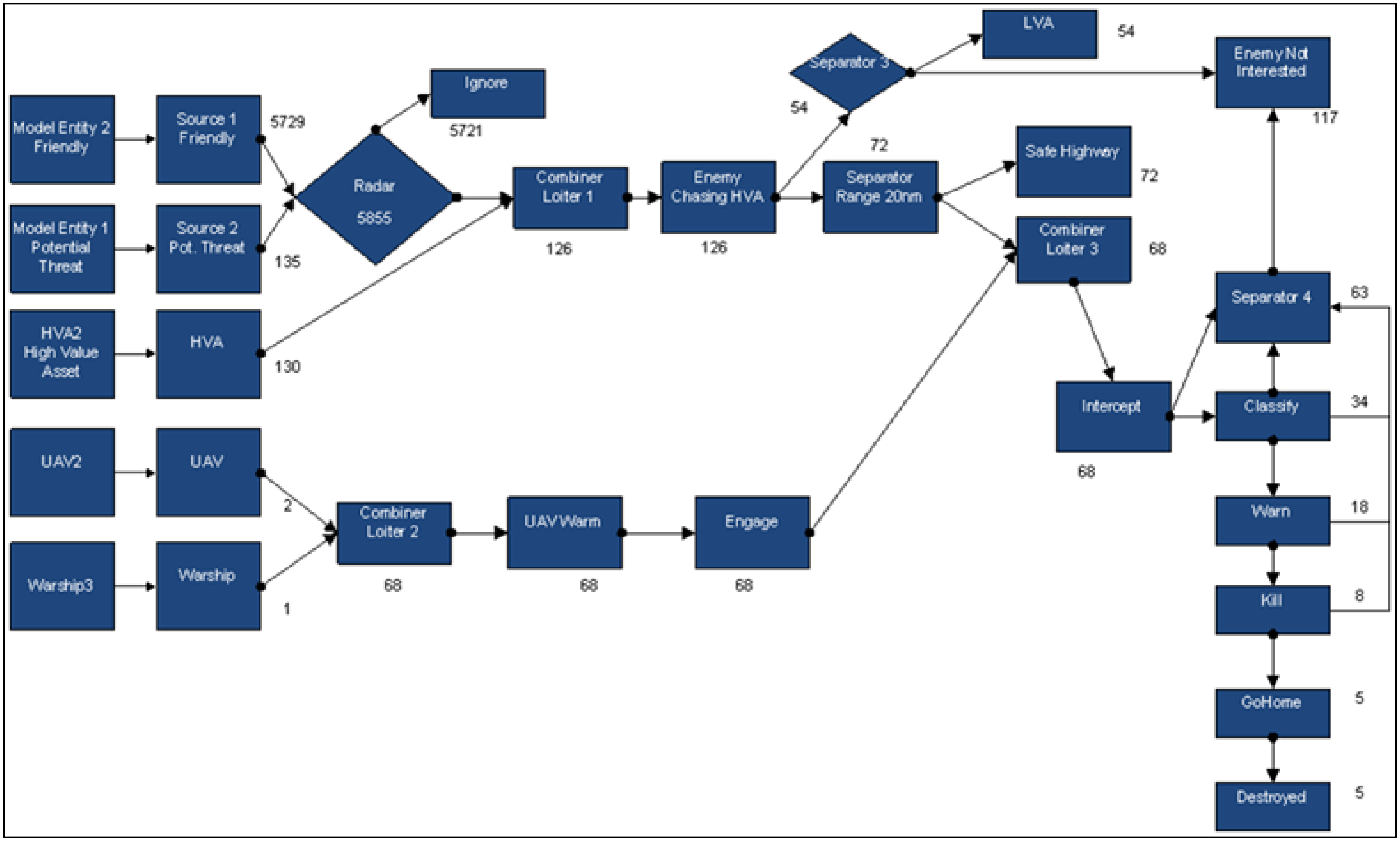


Figure 43. SIMIO Model - Warship with Two UAVs.

In this figure two UAVs are able to be launched when a potential threat is detected pursuing an asset.

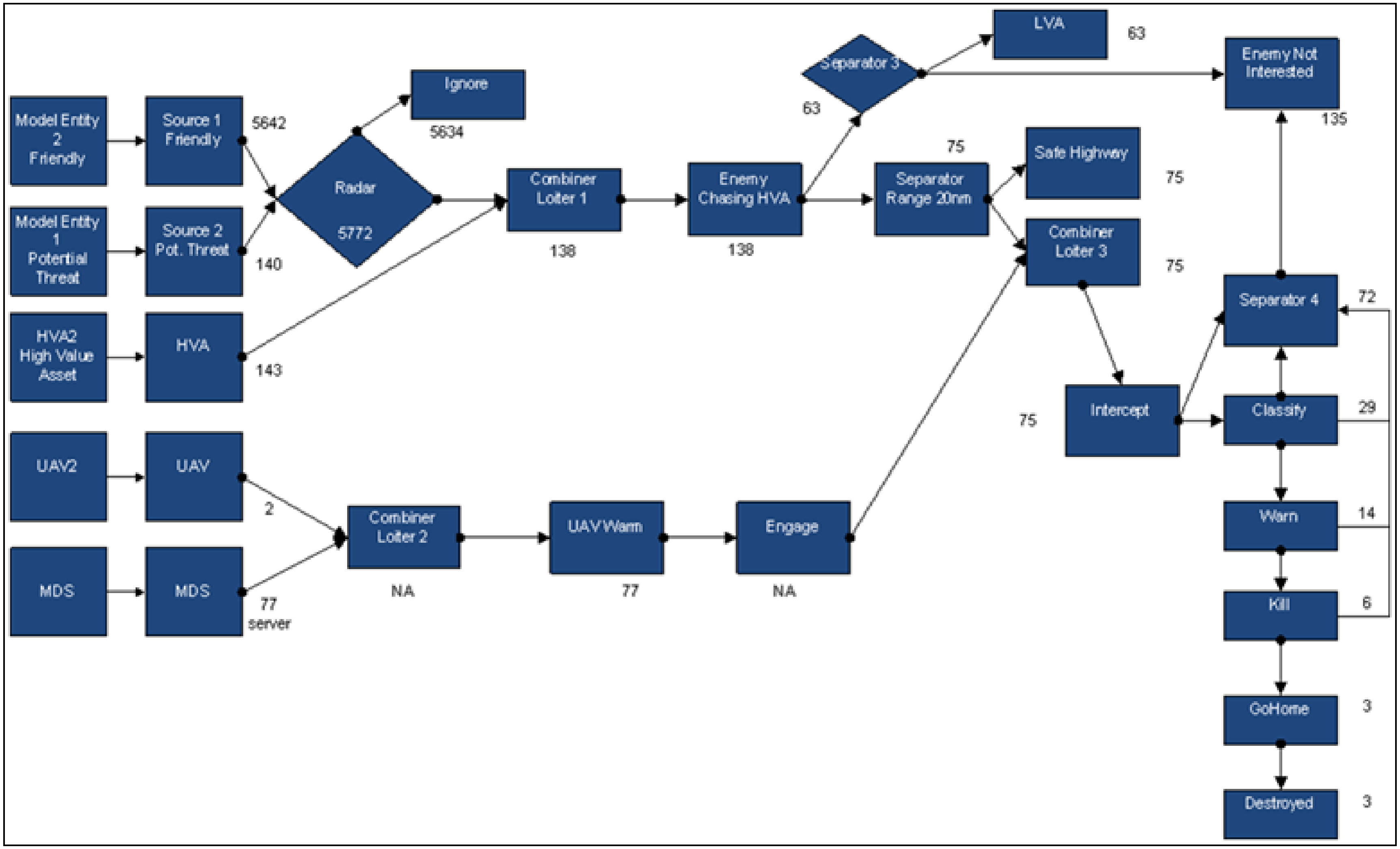


Figure 44. SIMIO model - RSS with Two UAVs.

In this figure UAVs are able to return and be prepared for re-launch faster than on the warship.

b. CRYSTAL BALL and MINITAB Analysis

The SIMIO simulation was able to visually show when the UAV could not intercept the enemy; however, the SIMIO software did not generate a distribution that could be evaluated in an ovelay chart or be used in a sensitivity analysis. CRYSTAL BALL software has overlay charts and sensitivity analysis charts built in. An overlay chart allows several distributions to be compared. For example, overlays of response time can show when two distributions overlap. This information can reveal when one response is better than another. The comparison leads to the selection of the best option. A sensitivity chart displays which process step affects the response the most. The sensitivity of an outcome to contributing factors can be easily interpreted when measures are presented in a Pareto chart (Appendix K). A step with a low magnitude means that the step has little effect on the process. A step with a large magnitude means that the step has a significant effect on the process. In summary, CRYSTAL BALL analysis allows the team to make conclusions quickly with less effort than SIMIO.

i. MINITAB Box Plot Analysis

CRYSTAL BALL was used to generate one thousand system response time outcomes for each scenario. The project team used triangular distributions to simulate the response time of the vessels and UAVs. The CRYSTAL BALL results were then imported into MINITAB. Next, a spreadsheet was developed to compare the response time for each platform. The first plots that the project team derived from the analysis were the Box Plots, shown in Figure 45.

These plots show that Warships had the worst response time. Response time for the warship and RSS means the time from detection of threat until a UAV, from either the warship or RSS, intercepts the threat. Enemy response time means time from detection of threat until it reaches the HVA. Response time for the HVA means time from detecting threat until threat over takes the HVA. The plots show very little overlap with the HVA and enemy elements, meaning the warship with either one UAV or two UAVs may not intercept the enemy in time. In other words, using a warship to patrol for pirates and protect a HVA is not very effective. In essence the warship is most likely to fail at its tasking. When the project team looked at the box plot for the RSS, it was clear that it was the lowest value of any result. This indicates that the RSS is most likely to provide adequate protection to all the HVAs while also being able to engage every enemy. The data shown here gives strong indication that the RSS system is more efficent with a higher probability at protecting the HVAs.

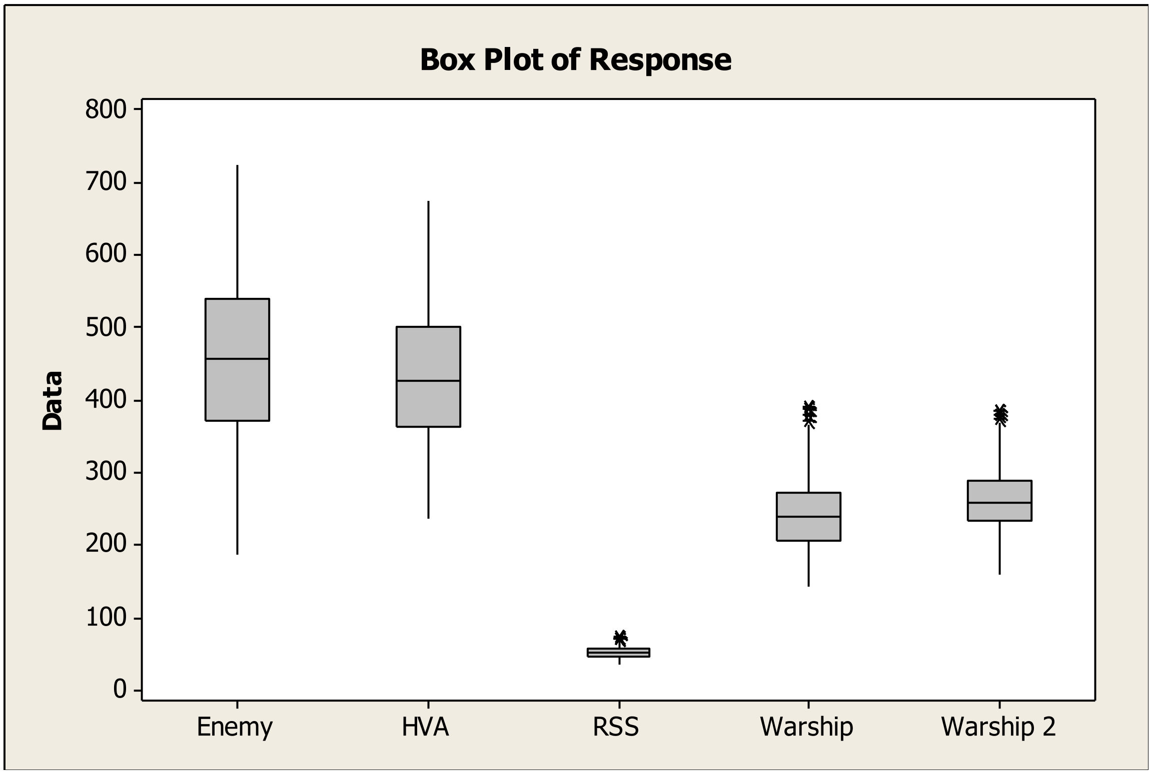


Figure 45. Box Plot from MINITAB.

This is the box plot from the MINITAB analysis. The Y axis represents minutes of response time. The X axis provides the names of the primary simulation elements. It shows how there is very little overlap with the warships and HVA and enemy. While the RSS has the lowest value of all, meaning that the RSS has the higher probability of protecting the HVAs. Enemy, HVA, RSS, Warship, and Warship 2 are all statistically different (see Appendix M). Therefore the intepretation for the Box Plots can be intepretated graphically.

ii. Confidence Interval Plot

Next the project team performed a 95-percent confidence interval analysis on the results obtained from the CRYSTAL BALL simulation runs. This analysis depicts the variation from the mean. Comparing this plot, shown in Figure 46 and the Box Plot Figure above, you will notice that the bigger the box in the box plot the wider the 95-percent confidence interval plot. This means that there is more consistancy in the performance of the RSS and once again emphasizing the fact that the RSS is more capable of protecting the HVA form the enemy or any aggressive adversary.

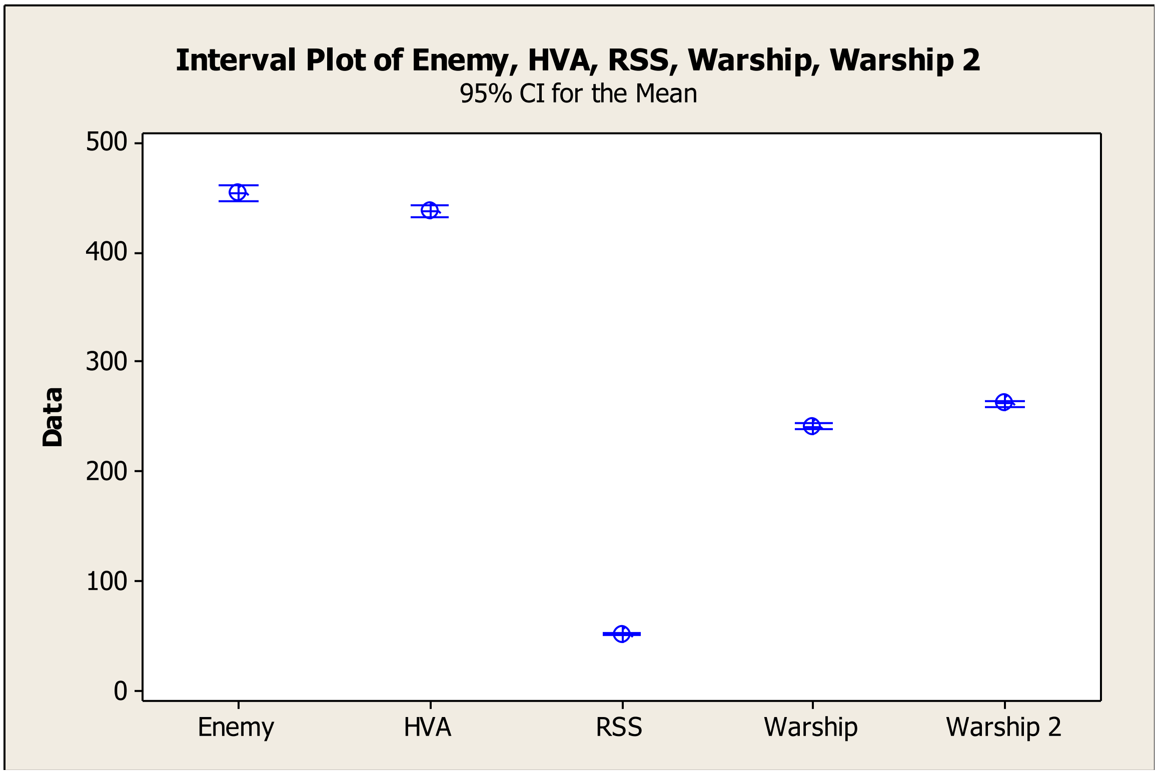


Figure 46. 95 Percent Confidence Interval Plot.

The above confidence interval plot shows the variation from the mean for each of the platfroms in the simulation. This once again shows how the warships have the largest variation from the mean, thus the least consistant performance of the platforms.

iii. Overlay Chart

The overlay chart shown in Figure 47 is a summary of the results obtained from running the CRYSTAL BALL simulation. This puts all the relevant information in an easy-to-see format for intepretation of the results. The results indicated that the warships have about a ten percent chance of missing the enemy. When looking at the HVA and enemy information one sees that the enemy will over take the HVA about thirty percent of the time. When the RSS stands alone and ahead of the HVA and enemy the RSS will be able to intercept the enemy 100 percent of the time.

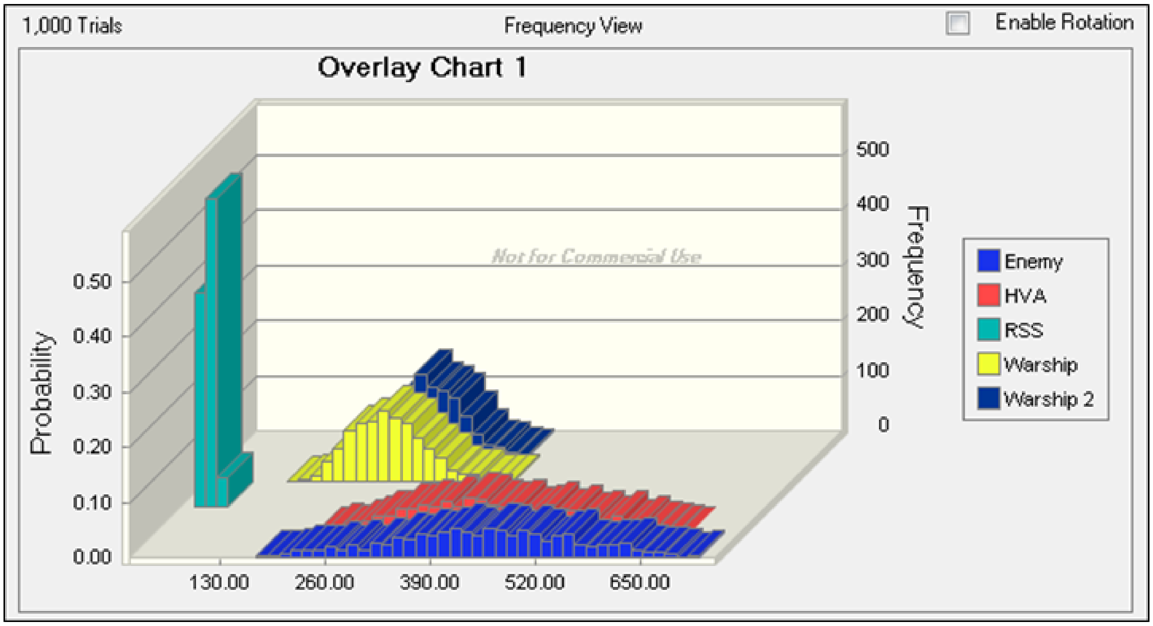


Figure 47. CRYSTAL BALL Overlay Chart (Response Time).

The overlay chart is a summary of the data results for a run of 1,000 trials. The X axis represents minutes and the Y axis represents relative frequency of event times. It shows that the RSS has the ability to intercept the enemy 100 percent of the time. Whereas the warships will only be able to intercept the enemy about 90 percent of the time, thus failing to protect the HVA adequately.

IV. CONCLUSION

Within a six-month period, pirate attacks have increased from 78 attacks to 146 attacks. Combined Task Force 151 has increased naval presence from 20 ships to 30 ships [Naval War College 2009]. Yet, it is clear that the piracy problem is not being solved by the conventional means being employed today.

This paper proposes a concept that utilizes one command ship with Remote Sea Stations (RSSs) and UAVs instead of the 30 ships making up Combined Task Force 151. In addition to reducing the number of ships, the number of personnel involved would also be dramatically reduced. A comparison of the concepts discussed in this report is shown in Table 7.

Table 7. Overview across Platforms.

	RSS Concept	UAV/Warship	Combined Task Force 151
Autonomous Sea base	10	0	0
UAV's / Helicopters	30	21	30
Resupply Needed	1	1	1
USV's	10	0	0
Naval Manpower	65	2100	9000
War Ships	1	7	30
Boarding Party	0	7	30
Aerostats	3	0	0
Effectiveness	Constant Presence	More Capable	Less Capable

The reduction in resources of manpower and number of ships to support the maritime security problem is a compelling reason to employ a system developed with an Automated Super-Highway Concept (ASHC). The Automated Super-Highway Concept approach is to control the battle space, which will limit the patrol area. Within the ASHC, the system would divert or destroy all non-friendly entities that do not belong in our defined battle space. The technology selected for the system allows for 100 percent availability when a single system or component fails. This system takes advantage of the graceful degradation provided by use of phased array technology. Graceful degradation is also applied to UAV swarm technology, which compensates for unavailable UAVs. The system employs a new concept for automated refuel, rearmament, and routine maintenance of unmanned systems by unmanned systems. Finally, a remote sea station is significantly less costly to build and maintain. The entire concept is depicted in the Operations View (OV-1) shown in Figure 48.

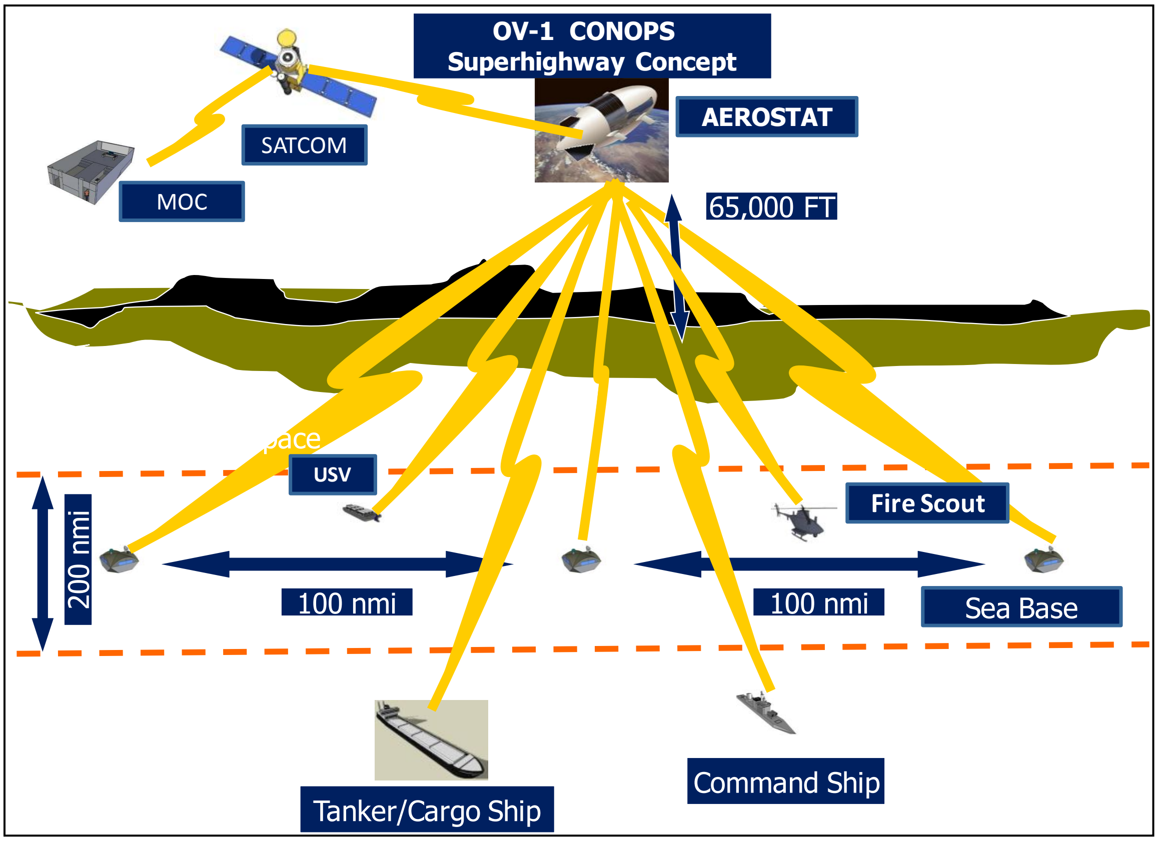


Figure 48. OV-1 of the Super-Highway Concept CONOPS.

This figure shows the CONOPS of the Super-Highway Concept which will allow for a safe area of operation for a vessel that chooses to travel via the controlled battle space. The controlled area will be monitored closely and if a possible threat wanders into the controlled area it will be intercepted by the UAVs.

The concept represents an architecture that provides a solution to the four critical success factors of the problem statement. The first factor required the establishment of a naval presence in remote locations so that naval forces have proximity to the areas needing improved maritime security and can gain superior intelligence of enemies. The second factor is area of coverage. Limiting the area within which the enemy of maritime security engages our forces leads to effective area coverage by limited resources in remote locations. The third factor is response time. Naval forces must be prepared to engage the enemy before the enemy of maritime security can become an undeterred threat. The fourth factor is the role of maritime security. Our forces and systems must be designed for effective engagement of enemies of maritime security.

Development of the ASHC and its related systems as presented in this paper could provide a viable solution to the problem. Analysis indicates that this solution was able to address and resolve all of the issues in the problem statement. Implementing this solution would allow larger warships to respond to threats elsewhere in the world, while the systems proposed in this paper still maintain a presence in remote areas.

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APPENDIX B – PROGRAM MANAGEMENT PLAN (PMP)

INTRODUCTION

Project Objective

The objective of the Team 3 capstone project is to apply a systems engineering approach to explore concepts for **Augmenting Naval Capabilities in Remote Sea Locations (ANCRSL)**. The goal of applying this approach is to build and strengthen each team member's ability to conduct high level engineering design, architecture, and analysis. The systems engineering approach will provide an analysis of multiple effective solutions with a goal to select the optimal solution or solutions that will augment naval assets in remote locations. Due to increasing challenges related to complexity, cost, and timing, the next generation of systems engineering practitioners must put more effort into finding failure modes early and implement effective counter measures. By utilizing sound systems engineering practices, we aim our efforts at providing valuable insight into the process of developing new technology. A secondary objective is that the capstone project may provide a solution to the problem, which may contribute to the performance of the Navy's mission.

Problem Overview

The nature of the enemy has changed dramatically since the end of the cold war. Navy planning efforts to secure the maritime domain are improving. However successful these efforts are, the efforts are not adequate for present maritime security needs. The Navy paradigm of once battling only large nation navies is shifting to combating the emerging maritime threats and the challenges posed by non-state groups engaged in unconventional attacks on maritime commerce. Two key issues in the headlines today are maritime domain awareness and piracy. The Navy's paradigm shift to respond to maritime domain awareness and piracy threats must include an equitable responsive scalable combat force.

The recently issued Cooperative Strategy for 21st Century Sea Power (Conway 2007) reflects an institutional response to the United States' changed strategic circumstances. Moreover, the document embodies a logic that suggests a significant change to the Navy force structure paradigm. A naval force paradigm is a theory of how to organize various ships and weapons available to the navy for warfare. Naval War College studies suggest that Navy forces should adopt a different style of war fighting for some scenarios. The new force paradigm communicates the need for a more spread out and more flowing war-fighter force. The needed force structure is different from the existing orientation of defensive bastions around sea bases of Carrier Strike Groups (CSGs) or Expeditionary Strike Groups (ESGs). Thus, the access-denial problem is fundamentally different in the Persian Gulf from what it is in Northeast Asia. These regions of fundamental differences suggest that the Navy should tailor its force by geographical region and mission area. Furthermore, studies suggest that the Navy does not necessarily need to design every ship for integration into a battle group (Rubel 2009).

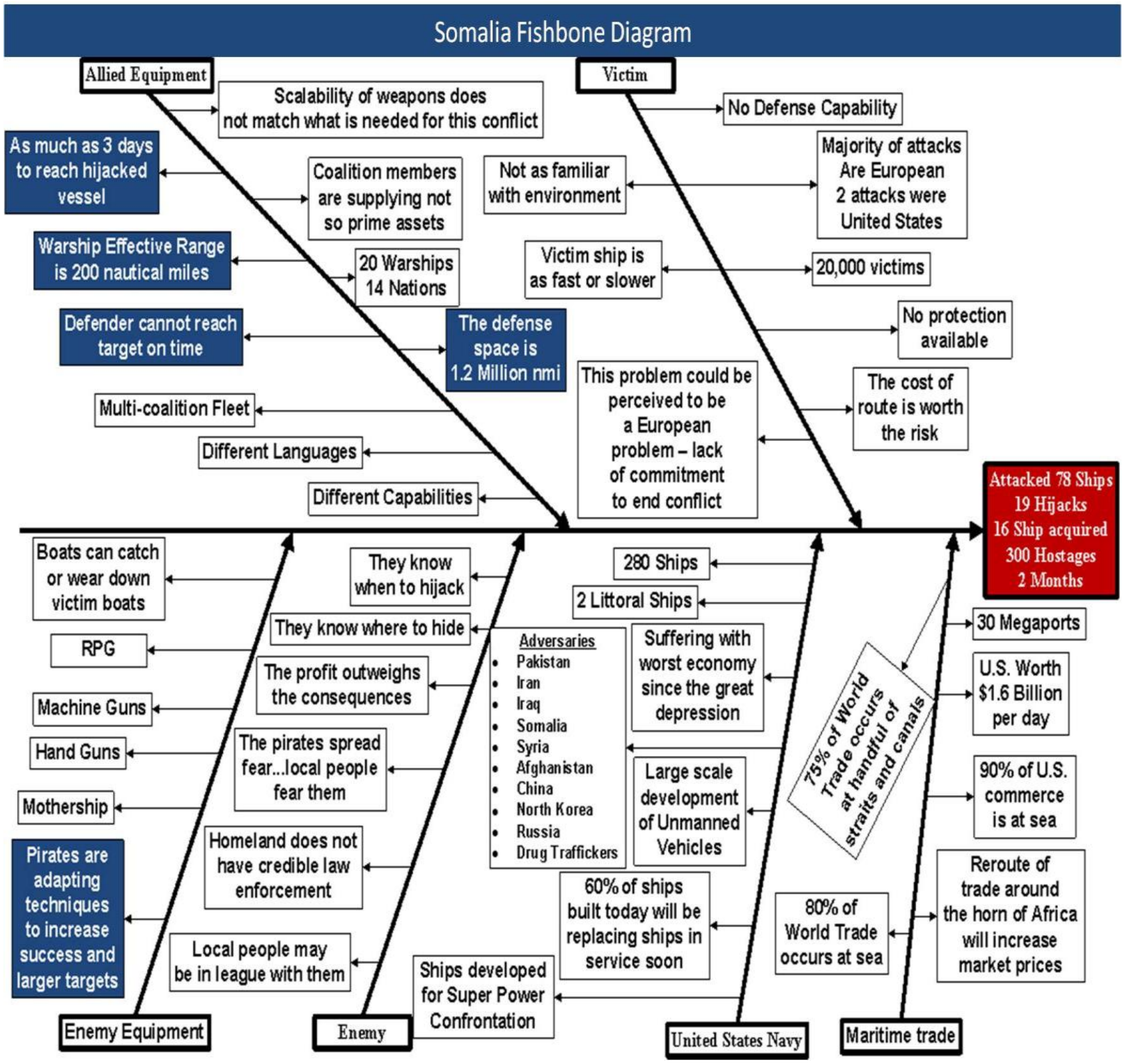


Figure 49. An Analysis of Pirate Actions and Responses from January - February 2009.

The fishbone analysis examines the reasons contributing to the Somalia Piracy threat to Maritime Security from the perspective of enemy equipment, the enemy, the United States Navy, maritime trade, allied equipment and the victims. The analysis reveals those reasons that contribute to the spread of piracy off the coast of Somalia.

In 2009, the broadcasts on CNN have amplified the existence of the changing paradigm in which small unlawful groups known as pirates have successfully impacted maritime security. In contrast, our response to the issue of piracy off the coast of Somalia is to form a multi-coalition naval force of the richest martime nations in the world. Despite the formation of a multi-coalition naval force, martime security is still threatened by Somalian pirate activities. An analysis of the root cause of the breach in martime security off the coast of Somalia is examined and the results are displayed in Figure 49. The fishbone diagram attempts to reveal the primary reasons for the existence of a thriving pirate operation resulting in 78 ship attacks, 19 hijacked ships, 16 acquired ships, and 300 hostages taken within a 60 day period (Kennedy 2009). The fishbone analysis reveals that the defender does not have the capability to cover the large remote area. Also, the fishbone analysis supports a conclusion that the pirate attacks were successful because the defender did not have the correct rate of response needed to reach the victim.

Problem Statement

As the US Navy steams ahead into the 21st century, it becomes apparent that it faces two potential problems. The first problem is the changing roles and missions that the navy is being tasked to do. These new roles and tasks will require a force structure change that will significantly impact the composition of the future navy. Today's navy is a power projection force equipped to do battle on the open ocean. The future navy must evolve from "blue water" fighting to littoral combat with smaller aggressors. Although the concept of littoral combat is still being defined, good examples of this include current missions such as anti-piracy and drug enforcement. Secondly, today's navy is at a low ebb with the number of ships in service. This translates to a lack of US Naval presence in areas such as the Horn of Africa. The increase in pirate activity in this area has put a taxing toll on the existing force structure of the navy. Overall, these two problems present a unique set of requirements for the future navy. It is clear that innovative solutions are needed to relieve the pressure off the current force structure, and which provide the presence needed to respond to conflict in a timely manner. This project will investigate potential solutions to the problems above.

Mission Needs Analysis

The scope and complexity of military missions must compete with the need to reduce development, deployment, and recurrent costs of supporting systems. As a result, systems engineers must perform multiple levels of mission analysis and develop associated concepts of operation to strengthen the value of systems used to support military missions. Mission needs analysis and the development of concepts of operation will bridge the gap between the user's operational needs and the technical specifications needed to provide the best solutions to the war fighter. As a basis in which to begin analysis of the problem we have defined, the team has developed a notional list of requirements for our problem listed in Table 8.

Table 8. Notional Requirements.

Performance Parameter	Development Threshold	Development Objective
Availability	24 x 7 for 90 Days, System deployment to operational area within 20 days	Same as Threshold
Coverage	Each Sea-Base provide persistence coverage within 200 NM radius	400 nm +
Interoperability	Link 11, 12, & 16 compatibility, + all military satellite, + secure wireless. All systems JTIC certified	Interoperability with NATO, & Coalition
Lethality	Ability to disable/destroy, small-medium size targets	A controlled disability/destruction capability synchronized with target discrimination.
Survivability	System will operate in Sea-State 5. System is capable of full operation in all operational areas particularly tropics). System will defend against irregular forces. For example, such forces are small fast boats or small fast attack craft.	Ability to operate in all states the enemy is capable of operation.
Manning	Extensive use of automation to reduce personnel manning & to reduce logistical footprint	To minimize the systems footprint in proportion to the discriminated threat
C2	Ensure man in the loop (links to HQ), and prevent fratricide/civilian casualties (rules of engagement/CONOPS)	Full automatic and semi-automatic operation with man in loop at safe remote location
Reaction time	Arrive on area of interest 15 minutes after notification.	Arrive on area of interest with 99% confidence interval of detection of hostile intent

To accomplish this needs analysis our team used the following tools and techniques to define the problem:

- System Decomposition
- Functional Analysis

- Futures Analysis

The needs statement is as follows:

Friendly forces require the rapid response capability to prevent smaller adversaries from attacking (delivering ordnance of any kind) against naval/ commercial vessels, critical ports, or offshore installations in remote locations.

This is our point of entry into our needs analysis. The following sections provide justification of our thought process on the design and development of a system to prevent enemies from delivering ordnance against friendly maritime assets/shore facilities. The focus of our effort was on the prevention of ordnance delivery specific to enemy small-medium size vessels/boats. Due to problem complexity, we used an Affinity Diagram approach, seen in Figure 50, to collect thoughts and ideas related to the initial problem statement. The inputs are in functional categories. The inputs in the center below may keep the forces safe but fail to prevent the actual delivery function of the ordnance.

The headers of *detect* and *engage* both jumped out as important elements for consideration in our system while seeking to fully understand the initial problem. Joint interoperability of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) equipment is the basis of the analysis of the initial problem. The team chose to include this functional C4ISR area in our decomposition process. C4ISR functions will play a key role to exchanging information important to our problem set. Likewise, we understand that before preventing an aggressive action, we need to detect the threat first. Early detection is critical to maritime safety, and our assets must ensure responsive and continuous C4ISR procedures to shape a successful engagement of the enemy vessel.

Figure 50. Affinity Diagram to develop functions to prevent delivery of ordnance.

Affinity Analysis facilitates participative brainstorming. After the initial session, similar ideas are grouped together to develop common themes. Those common themes are Detect, Control, and Engage.

Ways of detecting enemy vessels include line of sight (LOS) and using signatures. Signatures (e.g., electronic, thermal, acoustic, etc.) help to extend visual detection to beyond line of sight (BLOS) ranges. Improved BLOS ranges can be achieved through sensor elevation (e.g., higher terrain, aerial platform, satellite) or by taking advantage of the enemy's own platform signatures and physical features (e.g., engine, on board communications, reflective properties, existing surface areas, thermal properties, and platform movement).

In summary, the mission needs analysis investigates three interoperating system groups working together to address the problem. These include Detection, C4ISR, and Engagement systems (Detect, Control, and Engage).

Highlights of Systems Engineering Approach

Standard Systems Engineering Methodology coupled with a Design for Lean Six Sigma focus will define the approach executed by our team. Due to increasing challenges related to complexity, cost, and timing, our engineering approach will focus on finding failure modes early and implementing effective counter measures. Five possible failure modes are unintended function, intermittent function, over/under performance, and no function. The process for refining our design by eliminating failure modes is in the notional systems engineering road map below, in Figure 51.

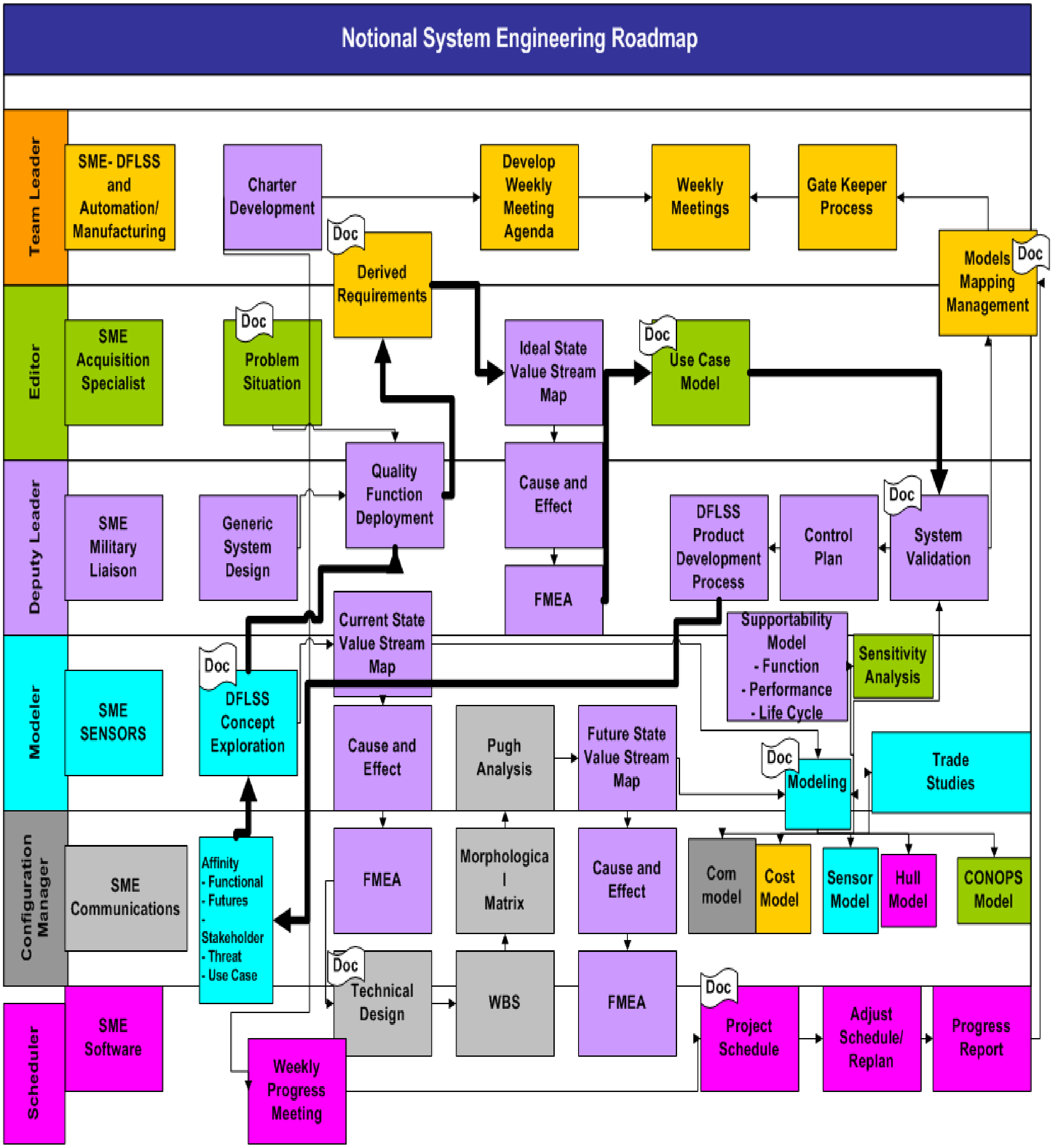


Figure 51. Notional Team Roadmap.

The notional team roadmap represents a plan to execute a tailored systems engineering approach. Each color code corresponds to the team role and concurrent technical role. Each team role possesses a swim lane. Within each team role, related process blocks exist in assigned swim lanes. Team interaction between members occurs in swim lanes, between swim lanes, and by color code. Deliverables and enablers are included in the defined process blocks.

Within the roadmap is the Design for Lean Six Sigma (DFLSS) tools concepts exploration function block. Concepts exploration involves examining the product development system consisting of a six step DFLSS tool process incorporated within three product development phases: Product Design and Definition, Manufacturing Process and Development, and Customer Deployment shown in Figure 52. This approach is similar to the spiral engineering process with each phase building upon the previous phase and repeating the process. In Figure 52, the hexagon labeled "A" refers to the DFLSS tool process repeated throughout each of the product development phases. Reference A is also the link between the "V" Diagram and the iterative product development systems engineering process.

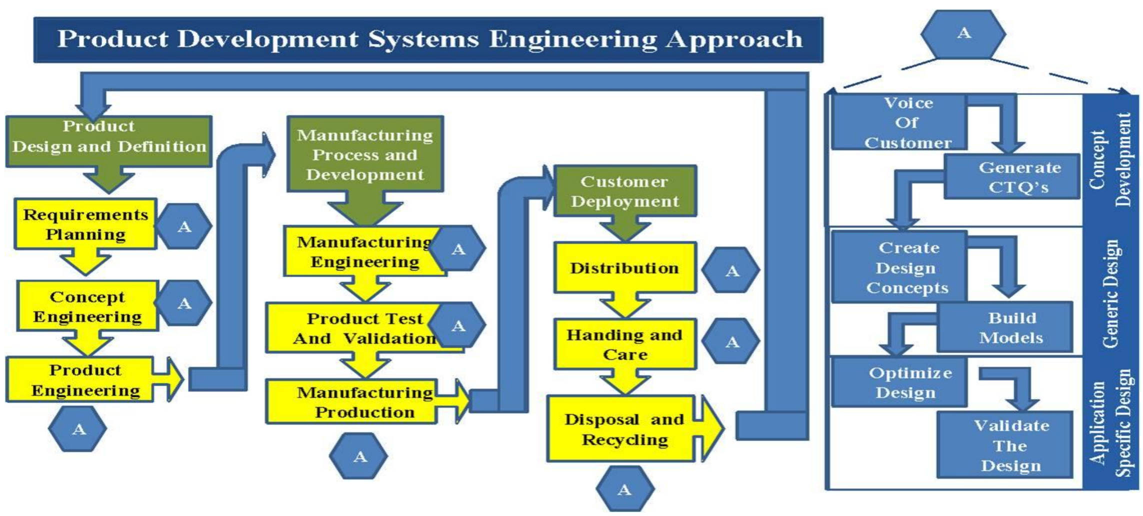


Figure 52. Product Development Systems Engineering Approach.

The product development systems engineering approach considers the entire life cycle of the product. Within each phase of product life cycle are three concern functions. Each function is analyzed using subroutine A. Subroutine A represents the development process in the "V" Diagram. The subroutine consists of concept development, generic design, and application specific design.

Concept Development

A DFLSS tools approach will complement the standard systems engineering approach. The DFLSS tools method presented at the Department of the Navy 2007 Continuous Process Improvement Symposium is an enabler for concept development. The concept development process is a combination of DCOV (Define, Characterize, Optimize, and Validate) and DMEDI (Define, Modify, Explore, Design, Implement)

DFLSS tools methods. The DFLSS tools process will apply many tools taught within the systems engineering program at the Naval Postgraduate School. One area where DFLSS tools will help is requirements generation. The Supplier, Input, Process, Output, and Customer (SIPOC) and the Quality Function Deployment (QFD) are tools that determine the voice of the customer.

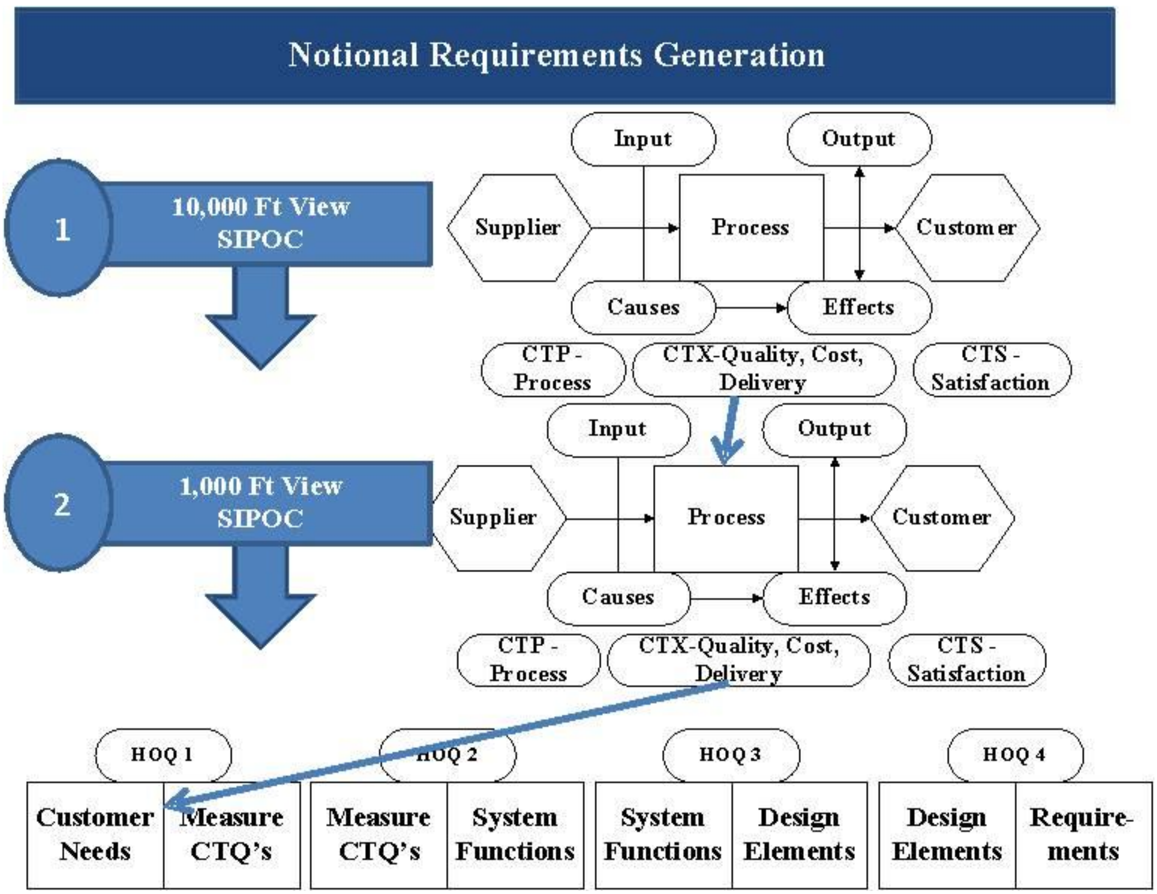


Figure 53. Voice of the Customer and Requirements Generation: Concept Design Phase

The requirements generation process starts with a 10,000-foot view SIPOC. Next, "Critical to X" characteristics (CTXs) from the SIPOC provide input to the process blocks of the 1000 ft view SIPOC. CTXs of the 1000 foot SIPOC provide input to the customer needs block of the 100-foot view QFD. The QFD examines the different houses of quality (HOQ) in which the final HOQ output is the requirements of the design.

Generic Design

A generic system design results from the development of a base-level functional flow system of standard capability. The functional structure extends the idea of boundary diagrams to capture functional flows between multiple functions/elements of an entire system or product. Functional structures add physical, architecture, and interface information beyond other methods. The properties of the functional structures include the ability to show a clear and specific relationship to customer use scenarios; the second property represents parallel and sequential functional relationships; the third property represents a clear system boundary; the fourth property describes a system in terms of input-output relationships independent of form. A functional flow structure shows the movement of materials, energies, and signals (information) through the boundaries of the product/system. Functional flow diagrams provide a concrete way to translate qualitative functions into quantitative transfer functions in complex systems.

Application Specific Design

Application specific design starts at the component level and progresses to the function level. The application specific design represents a new future state. Corresponding to each state is a Failure Mode and Effects Analysis (FMEA) analysis. The FMEA analysis calculates a risk prioritization number (RPN), a measurement of risk. Each future state possesses a calculated RPN number that we compare with the ideal state RPN number and the current state RPN number. The application specific design continues to improve on the RPN number until the customer and engineers agree on risk level performance.

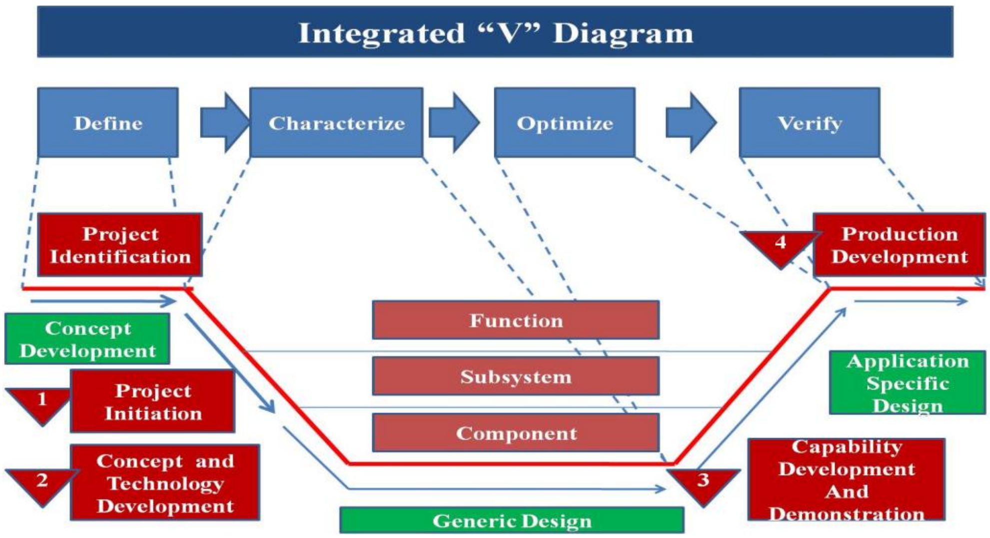


Figure 54. "V" process integrated with the gatekeeper process.

This figure shows the correlation between the Systems Engineering 'V' approach (green), the gatekeeper process (red), and the Design, Characterize, Optimize, Verify (DCOV) Lean Six Sigma process (blue). The Function, Subsystem, and Component blocks are the hierarchy levels.

Organization Structure

The organization of the team is critical to the implementation of the systems engineering approach. The team organization must incorporate the concepts of a learning organization and innovative product development environment in which both concepts contribute to accelerate product development. The organization must foster a learning environment, which will emphasize mentorship and guidance in the form of our professors from the Naval Postgraduate School. The learning organization will tap into the technical resources of hull design, sensor development, and unmanned development.

Knowing DFLSS tool applications will accelerate the learning organization, half the team took Lean Six Sigma Green belt training. Also important to the project is management buy-in. The learning organization obtains management buy-in through approval of calling the Capstone Project an organization sponsored lean project.

In Figure 56, the organization achieves level three, stage three standards to control innovative development. Next in Figure 58, the process includes a Gatekeeper process. The Gatekeeper Process is a self-validating process that allows project progression to continue when a set of milestone entrance and exit criteria are achieved. Figure 56 and Figure 58 represent some Lean Six Sigma concepts, which are part of our systems engineering approach. Another concept of Lean Six Sigma is the Kanban approach. The Kanban method allows momentary stoppages in the product development process when agreed to requirements are not satisfied. When the Kanban process receives information to stop the process, the team must resolve the design stoppage immediately. This action is a "Kaizen Blitz", which places emphasis on the ability to reflect carefully and act quickly. All three of these concepts must work together to be effective.

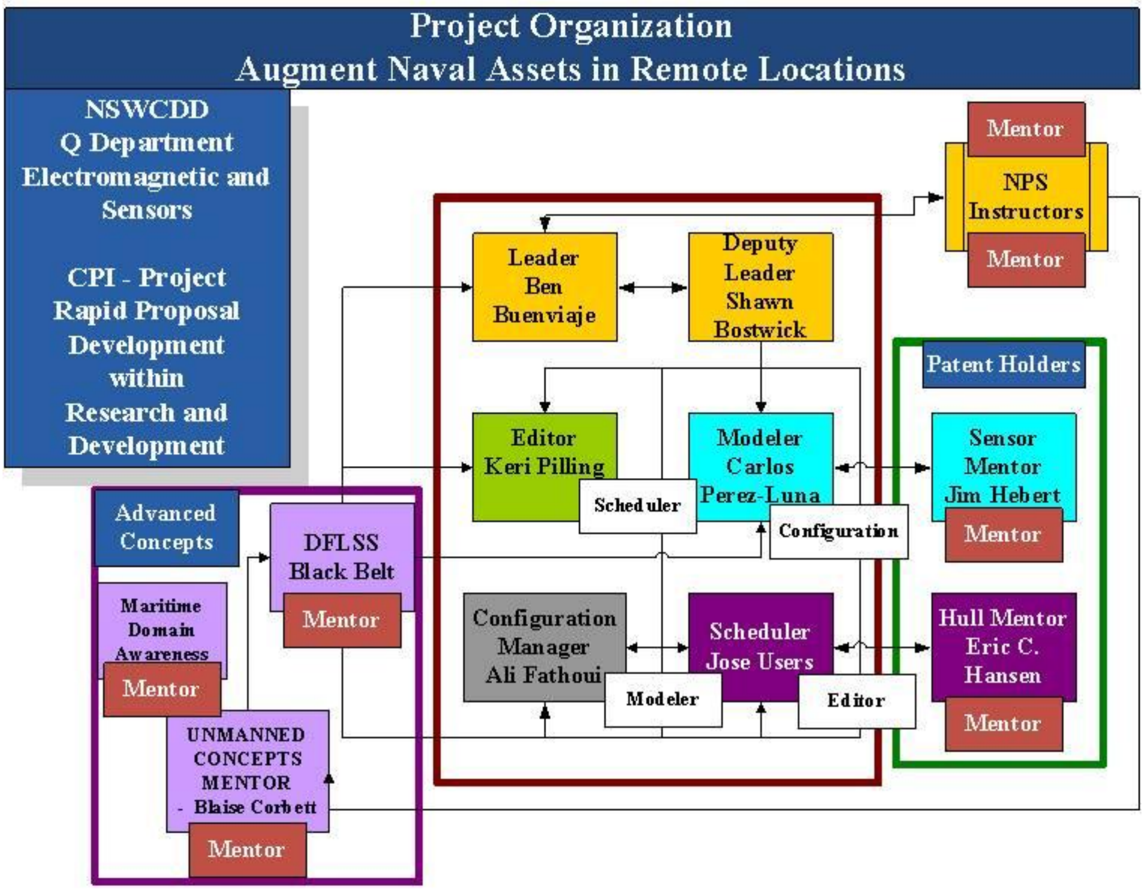
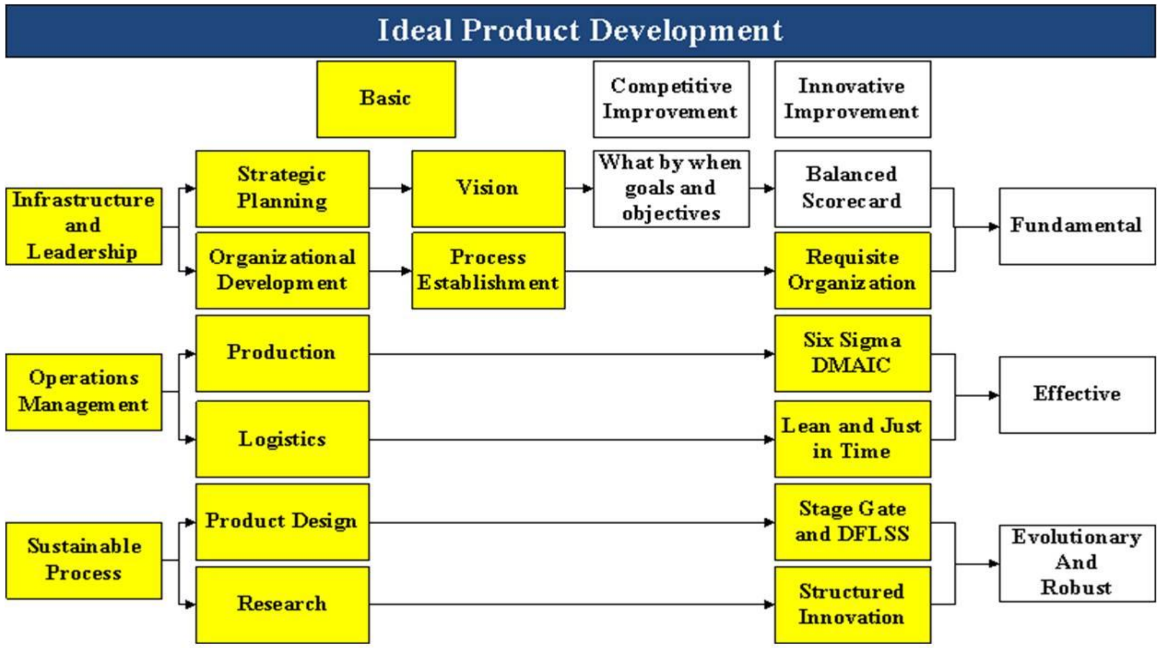


Figure 55. Project Organization.

Development of the learning organization will bind the stakeholders to the process. Acceleration of the systems engineering process occurs when the majority of the team understands Lean-Six Methodology. The Learning Organization mentors team members in Advanced Concepts in Unmanned Systems, Sensors, and Hull Design.



Rapid Team Development Strategy: 36 week period

Ideal Product Development can be measured
Level 1 – Basic
Level 2 – Competitive Level
Level 3 – Innovative Level

Stage 1: Infrastructure and Leadership	> Fundamental Goal
Stage 2: Operations Management	> Effective Goal
Stage 3: Sustainable Process	> Evolutionary and Robust Goal

Establish Infrastructure and Leadership
- Develop Strategic Plan – Week 1
- Provide Vision – Week 1
- Develop Organizational Structure – Week 1
- Develop Product Development Process – Week 1
  (What by When objectives – Charter)
  (Need Scorecard)

Establish Operations Management
- Focus on Production Methods – Comparison of FMEA to measure risk, establish process improvement through DMAIC (Define, measure, analyze, improve process)
- Focus on Logistics Methods – Rapid Prototyping, Rapid Manufacturing, Value Stream Analysis, Simulation, Statistical Analysis of State with 1000 trials to determine

Establish Sustainable Product Development Organization
- Focus on Product Design – Generic Design to Specific – Ideal State, Establishment of Gate Keeper Process
- Focus on Research – Structured Innovation – Present State to Future State, DFLSS Concept Generation, Generic System Engineering Approach

Figure 56. Innovative Team and Product Development.

Development of the innovative organization in the beginning instills an evolutionary and robust product focus in the early stages of the systems engineering approach. The yellow boxes indicate segments implemented by the team. Two concepts that need implementation yet are the “Balanced Scorecard” and “What by When Goals and Objectives” boxes.

Team Assignments

Each person on the team has a dual role. The dual role contains the team member's expertise and team assignment. The professional background of the team member determines their expertise role. The team leader determines the assignment. The assignments consist of a leader, a deputy leader, a scheduler, a librarian (configuration manager), and modeler.

Leader

The primary responsibility of the team leader is to facilitate the overall coordination of the project. This includes being the chair of team meetings, preparing the agenda, reviewing the schedule, getting collaboration on issues, reaching decisions, assigning action items with due dates, and managing the project risks.

Deputy Leader

The deputy leader will function as a general field manager enforcing policy set by the leader and perform the leader's function in his absence.

Scheduler

The scheduler will be responsible for developing project schedules and tracking group progress versus planned due dates. The scheduler will provide the status of group performance in meeting timelines.

Librarian (Configuration Manager)

The librarian will also be the configuration manager and responsible for keeping a complete audit trail of decisions, design modifications, and documented changes. This includes gathering and cataloguing all reference material provided by the team. The configuration manager will also be responsible for version control of all project documentation including the final report and briefing packages.

Editor

The editor shall be responsible for the editorial aspects of the report, which include reviewing, rewriting, and editing the work of teammates. Other responsibilities are formatting, spelling, grammar checking, and making the report a cohesive document. The editor will collect, merge, and render the final editorial decision on each submission.

The editor's job will also include verifying the correct format of all citations and references. Due to the complexity of the editorial process, it is imperative that the editor communicate directly with the author and the rest of the team.

Modeler

The modeler will be responsible for the development of a life cycle cost (LCC) model, a functional performance model, and an operational performance model. The modeler's main concern shall be to concentrate on the coordination of all models. The assigned team members will concentrate on the development of the needed models for coverage and response.

The LCC model will assess the affordability of the various alternatives. The functional performance model will evaluate, by means of simulation, the overall functionality of the system and sub-system. Simulation on the operational performance model will assess the impact to interoperability and overall mission effectiveness.

Notional Modeling Plan

The DFLSS tool Y = F(X), or transfer function, will accelerate Model Development planning. The transfer functions are the mathematical relationships that relate the output measure, denoted by Y, to input variables, collectively denoted X. It is usually denoted Y=f(X), with f( ) denoting the transfer function itself. The transfer function can be determined through the understanding of the physics and geometry of the system when the output measure is available, or it can be determined by empirical estimates through directed experiments or by the analysis of data that are already available.

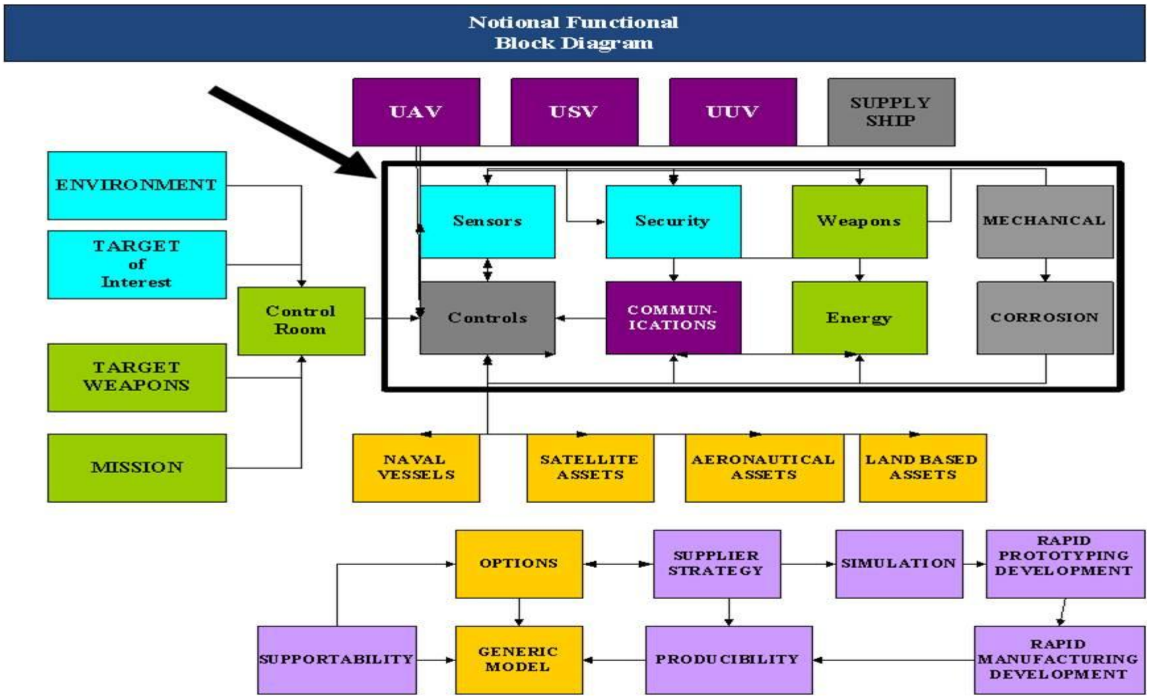


Figure 57. Notional Functional Block Diagram for Future Model WBS.

This notional block diagram is for illustration purposes only. The highlighted box in the diagram depicts the generic design concept. The generic design is comprised of functional blocks. These functional blocks may be included in the transfer function that would depict the desired output.

Systems Engineering Product Development Team Responsibilities

Engineering Enablers in the Road Map

Each team member should be aware of the engineering enablers built into the roadmap in Figure 51:

- Concept Generation is included in the morphological matrix.
- Risk Management is included in the current state, future state, and ideal state.
- Requirements Generation is included in the QFD and use case analysis.
- Structured Innovation is a method to detect problems, saving product development costs in rework.
- Rapid Prototype Development is the development of the future state.
- Baseline Design is the generic design concept in the "V" diagram.
- Statistical Significance helps eliminate doubt in design capabilities due to variation.

- The QFD captures the Voice of the Customer.

Sub-document Deliverables

The scroll-like objects, appearing in Figure 51, represent documents that are the deliverables listed below:

- The Problem Situation Document will include figures with analysis and conclusions.
- The Defined Requirements Document will capture all of the history of the decision making process for the selection of the requirement (such as the Kops).
- The Use Case Model Document will capture all requirements of the product.
- System Validation Document will reveal verification of design configuration to ideal conditions.
- Models and Mapping Management Document is an accumulated portfolio of all modeling and mapping documents.
- Technical Design Document is a log of all the technical design changes that happen throughout development.
- Project Schedule is a list of events and tasks assigned a duration and sequence in a logical order to complete a project.
- Modeling documents will include analysis and conclusion.

Alternatives Generation

After the generic system development is complete, an alternatives generation will take place. A morphological matrix will aid in the development of the alternative systems. A morphological matrix will aid in the development of the alternative systems.

Appropriate Analysis

Appropriate analysis is the analysis of the alternatives using methods appropriate to the problem/issue/situation. This can include modeling and simulation. The development of a present state model in comparison with a future state model will provide the basis for an analysis of alternatives. The designs may improve or degrade in comparison with the ideal model during multiple design iterations. The main point is that we can use modeling to provide a measure of the performance of each alternative.

Meeting Minutes

The main objective of the meeting minutes is to document the decisions reached and the actions taken by the team during meetings. A dedicated team member will take meeting minutes and then send them to the whole team upon completion of the meeting. This keeps everyone in the group informed of project progress. Furthermore, this same individual is responsible for keeping track of the status of all action items to ensure success of the project.

Stakeholders

The primary stakeholder for this project is Robert C. Rubel of the Naval War College. Other stakeholders include Blaise Corbett of the Naval Surface Warfare Center, Dahlgren Laboratory (NSWCDL); James Hebert (NSWCDL); and Eric C. Hansen Naval Surface Warfare Center, Carderock Division (NSWCCD). Blaise Corbett has six U.S. patents and is an expert in unmanned systems concepts. James Hebert and Eric C. Hansen are the patent holders for a remote sea station. They will provide mentoring for sensors and hull design, respectively. Lastly, author of an analytical paper, Robert C. Rubel's paper in the Naval War College Review is the basis of this paper's problem statement.

Risk Management

Risk management is comprised of tracking the FMEA and the Gatekeeper process.

- The team will fill out a FMEA matrix for the current state, the future state, and the ideal state. Each state will have a measure of severity of defect, ease of detection, and probability of occurrence. The product of all three parameters is the RPN number. Each transition from Current State to

Future State will be a storage point for a new RPN number. A plot of RPN numbers versus iteration will track risk improvement or degradation.

- A gated review process along with the application of FMEA will control the progression of issues and measure risk.

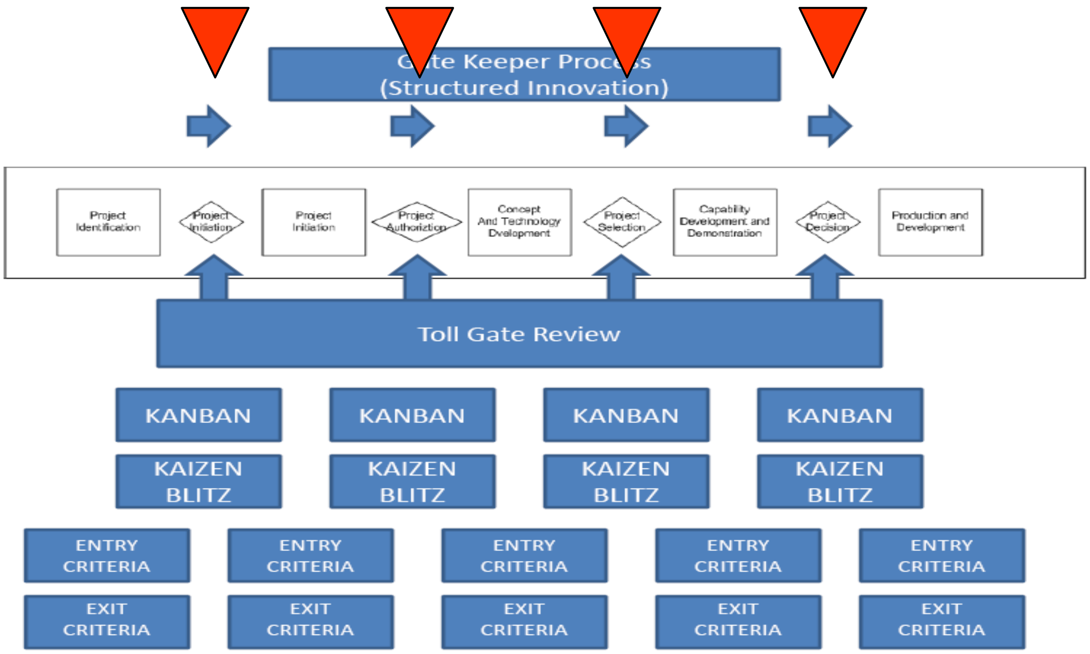


Figure 58. Gatekeeper Process with Kanban.

The gatekeeper process is in place to provide a structured innovative approach whereby the team can stop the process to focus on key problems rapidly. The concepts employ Kanban, Kaizen, and Entry/Exit Criteria. Each milestone review can correlate to a design review.

Milestones and Deliverables

Table 9. Deliverables Schedule.

Milestone	Description	Deliverable	Date
1	Project Management Plan Approval	Project Management Plan Draft	21 May 2009
2	Integrated Product Review - #1	Problem Definition Report (Effective Need; Problem Definition Statement)	12 June 2009
3	Integrated Product Review - #2	Modeling and Simulation	Summer Quarter
4	Final Report Submission	Best Alternative	Fall Quarter
5	Integrated Product Review - #3	Project Presentation and Final Report	Fall Quarter

Schedule

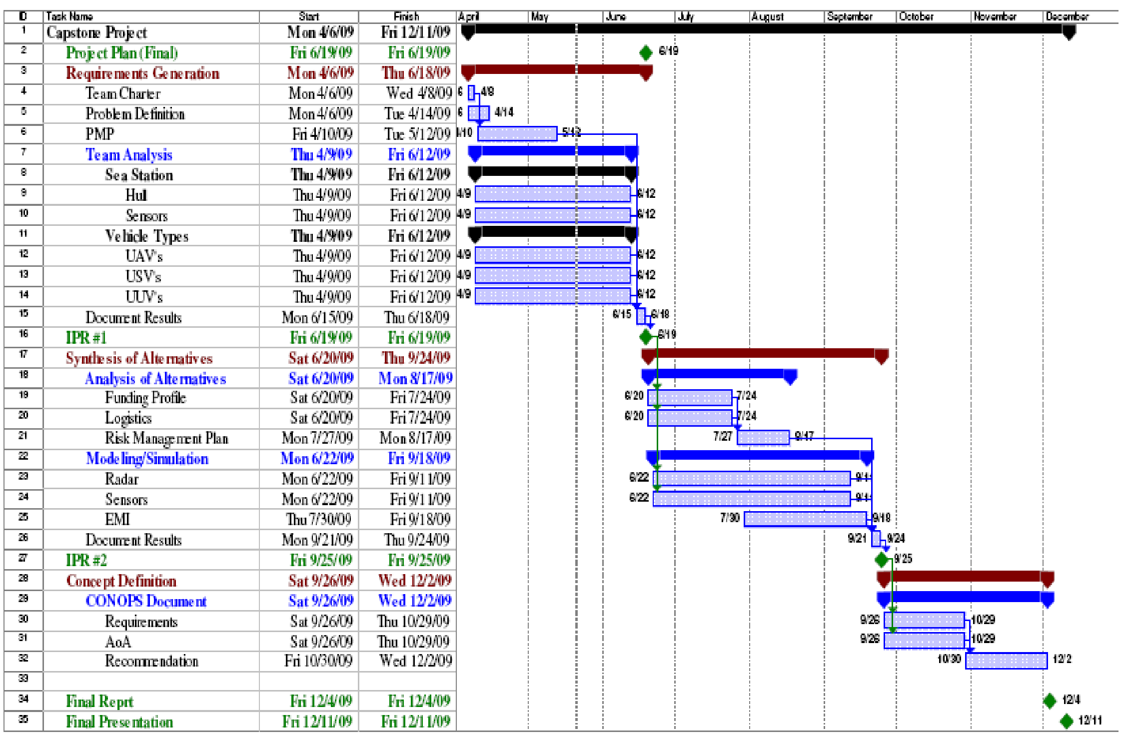


Figure 59. Program Management Schedule.

This was the schedule the project team followed to complete the paper.

Team Contact Information

Table 10. Team Member Information.

Role/Responsibility	Name	Phone Number	Email
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Team Advisor Contact Information

Table 11. Team Advisor Information.

Role	Name	Phone Number	Email
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Advisor	Professor David Hart (NPS)	831-656-3839	dahart@nps.edu

APPENDIX C – PIRACY ON THE HIGH SEAS

1.1 Introduction

Piracy has become a growing epidemic over the past several years especially off the coast of Somalia. Just recently there have been attacks aimed at U.S. cargo ships that were transiting the busy shipping lanes of the Indian Ocean and the Gulf of Aden. [Sky news 2009] These pirates that are from lawless Somalia are heavily armed with rocket propelled grenades and machine guns [Sky news 2009] and are no match for the unarmed crews of the merchant ships sailing in this area. Although some of the crews try to fight back or outrun the pirates, it is usually of no avail.

One of the most recent reports mentions that since February pirates have attacked 78 ships, hijacked 19 of them, and held 16 vessels with more than 300 hostages from more than a dozen countries [Kennedy 2009]. The pirates hold these hostages and ships for ransom. A recent outbreak in hijackings followed the U.S. Navy Seals' rescue of Captain Phillips from the *Maersk Alabama*, in which four more ships were seized along with another 60 hostages [Kennedy 2009]. "Our latest hijackings are meant to show that no-one can deter us from protecting our waters from the enemy because we believe in dying for our land," pirate Omar Dahir Idle told reporters by telephone. "Our guns do not fire water. I am sure we will avenge (those killed by the U.S. Special Forces)."[Sky news 2009] [Kennedy 2009]

1.2 Background

Somalia has a clan-based organization and a lack of central government. In Somalia's location at the Horn of Africa conditions were right for the growth of piracy in the 1990s. Boats illegally fishing in Somalia waters were a common sight and the pirates mainly wanted to secure the waters before businessmen came into the picture. In 2006, piracy declined due to the rise of the Islamic Courts Union. Then in December of 2006, pirate activity increased again because of an Ethiopian invasion into Somalia.

During the Siad Barre regime, Somalia was receiving money to help develop the fishing industry. Aid money helped improve the ships and supported maintenance facilities. Once the Barre regime fell out of power due to civil war, this caused the income from fishing to decrease. Some of the pirates are former fishermen who argue that foreign ships are threatening their livelihood by fishing in Somalia's waters. Seeing the profitability of piracy due to ransoms that were usually paid, warlords began to run the pirates' activities and split the profits with the pirates. In most of the hijackings, the pirates have not harmed the hostages and generally treat the prisoners well in anticipation of the large payoff. This goes as far as the pirates hiring caterers on the shores of Somalia to cook spaghetti, grilled fish, and roasted meat, while also having a large supply of cigarettes and drinks available.

Efforts were made to combat piracy by the Transitional Federal Government by allowing foreign naval vessels into Somalia territorial waters. More often than not, the chasing of the pirates by the naval vessels had to be broken off when the pirates entered into the territorial waters. The Puntland has made more progress in this struggle by interventions. In June 2008, the Transitional Federal Government asked the international community for help. The United Nations Security Council voted to pass a declaration authorizing nations and telling them that they have the permission of the Transitional Federal Government to enter Somalia territorial waters to deal with the pirates accordingly.

1.2.1 Pirates Profile

Most of the pirates range in age from 20 to 35 years old and come from the Puntland region of north-eastern Somalia where the East African Seafarers' Association estimates there are at least five pirate gangs for a total about 1,000 armed men. The BBC reports that the pirates can be divided into three main categories:

- Local fishermen – considered the brains of the operation due to their skill and knowledge of the sea
- Ex-militiamen – used as muscle and used to fight for the warlords
- Technical experts – operate high tech equipment such as GPS devices

The Web site globalsecurity.org suggests four main groups operate off the coast of Somalia. The National Volunteer Coast Guard (NVCG), commanded by Garaad Mohamed, who specializes in small boats and fishing vessels around the Kismayu on the southern coast. The Marka Group is made up of several less organized groups operating around the town of Marka and is led by Yusuf Indha'adde. The third group is made up of traditional fishermen operating around the Puntland and is called the Puntland Group. The last group is the Somali Marines, which are considered the most powerful and sophisticated group with a military structure having a fleet admiral, admiral, vice admiral, and a head of financial operations.

Figure 1. Map of Somalia

1.2.1.1 Life of a Pirate

Residents of the Puntland region, where most of the pirates come from, live a lavish life. "They have money; they have power and are getting stronger by the day," says Abdi Farah Juha who lives in the regional capital, Garowe. “They wed the most beautiful girls; they are building big houses; they have new cars; new guns,” he says. “Piracy in many ways is socially acceptable. They have become fashionable.” [Hunter 2009]

The rewards they receive are rich in a country that has been in conflict for the last 17 years and half the population needs food aid. Most of the captured vessels bring an average of $2 million, and this is why the hostages are well looked after [Hunter 2009]. As one can see, being a pirate in this country can be very appealing. This leads to more men wanting to become pirates.

1.2.2 Tactics

The pirates started out using small, slow boats called skiffs. These skiffs were too slow and rickety to catch anything other than slow unmaintained boats. The skiffs could only venture a few miles from the coast [Wired.com 2009].

Then the pirates innovated and began to capture trawlers and small freight ships. They used these as “mother-ships” to launch their attacks from. Today, the pirates will tow along two or three skiffs with these mother-ships and carry form 10 to 20 pirates. As a merchant ship approaches, they will send out the skiffs to engage the ships [Wired.com 2009].

2.0 Combating the Pirates

This often begins with a distress call form a merchant ship reporting an attack. Other times a patrol plane may spot a potential pirate mother-ship or skiff. This information is relayed to the naval commanders who sort through a list of the available warships in the area and determine who is the quickest to respond [Wired.com 2009].

When the warship is close enough, it will launch its helicopter to scout ahead and get confirmation that the hostiles are armed, while simultaneously preparing to lower the boarding team boats into the seas [Wired.com 2009]. All of this takes time and if a warship is not in the area, that gives more time for the pirates to hijack the vessel. Just the presence of the warship is usually deterrence enough so that pirates will not attack.

2.1 Show of Force

Deterring an attack on a vessel or avoiding a firefight first requires that a warship be in the area when the pirates strike [Wired.com 2009]. With the pirates operating hundreds of miles off shore and covering an area of about 1.1 million square miles, one can see that this is one large piece of real estate to cover [Kennedy 2009]. At present, there are only about 20 warships from 14 different countries operating in the Indian Ocean [Wired.com 2009].

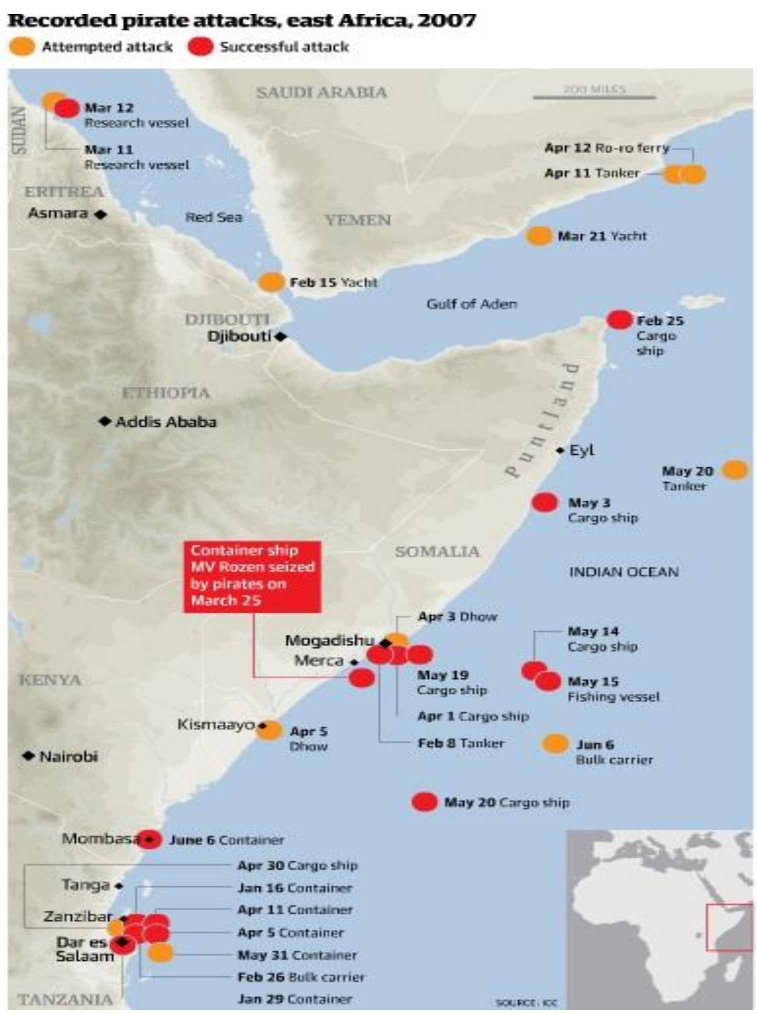

Fig. 2 Pirate attacks in 2007

It is nearly impossible for only 20 warships to have a positive effect of deterring pirating in this vast area of ocean. There needs to be a greater presence of deterrence. Naval forces have halted many attacks but the area is so vast that they cannot stop all of the hijackings [Kennedy 2009].

2.1.1 The Problem

The Gulf of Aden connects the Suez Canal and the Red Sea to the Indian Ocean, which happens to be the shortest route from Europe to Asia and has the busiest shipping lanes in the world. More than 20,000 ships traverse this route a year [Kennedy 2009]. The ratio is approximately 1,000 ships to 1 warship, so how can adequate protection be given to all of those vessels?

The answer may appear simple. Increase the number of warships in the area. However, the answer is not that easy to achieve, especially in today's world. Today the U.S. Navy is extremely small compared to what it once was and the cost of a new ship and crew to maintain that ship is escalating rapidly. So now, the question becomes how does one increase presence without increased manning and with something that is relatively cheap?

APPENDIX D – QUALITY FUNCTION DIAGRAM (QFD)

Row #	…lationship Value in Row	…e Weight	Weight / Importance	Quality Characteristics (a.k.a. "Hows") / Demanded Quality (a.k.a. "Whats")	Defender Cannot Reach Target on Time	Increase Effective Range of Defender from 200 Nautical Miles to….	Scalability of weapons to match or exceed capability of adversary without excessive cost or damage	Decrease the Defense space or Protection Barrier	Eliminate the desire to take the route that is infested with somalian Pirates	Eliminate the notion that the money reward of piracy is worth the consequences….even death	Somalia has no credible governement by law	Pirates have adapted techniques to reach larger range a	Pirates have adapted to using integrated teams to hijack	Uniform Defense Organization	Organized Approach	Understand the environment	knowthe locations of hidden pirates	Persistant Presence	Forward Presence
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	3	39.8	900.0	OIL PLATFORM - NEW		O	O												
2	[illegible]	3.0	294.5	AIRCRAFT CARRIER	Θ	O	Θ	O											
3	[illegible]	2.7	60.0	AMPHIBIOUS ASSAULT SHIP	O	Θ		O	▲										
4	1			SEA BASING	▲														
5	9	39.8	900.0	AUTONOMOUS SEA BASE - NEW	Θ	Θ	Θ	Θ											
6	3	0.7	16.4	DESTROYER	O														
7	3	0.7	16.4	CRUISER	O														
8	3	0.7	16.4	HELICOPTER	O														
9	9	0.1	1.8	SATELLITES	Θ	Θ													
10	1	0.7	16.4	SONAR	▲														
11	9	0.7	16.4	RADAR	O	Θ													
12	9	0.1	1.8	CONVENTIONAL LAW ENFORCEMENT	Θ														
13	3	0.1	1.8	COAST GUARD - CUTTER	O														
14	9	0.1	1.8	VIDEO	Θ														
15	1	0.7	16.4	SUBMARINE	▲														
				Target or Limit Value															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	4	1	1	1	10	2	1								
				Max Relationship Value in Column	9	9	9	9	1										
				Weight / Importance	496.2	548.1	595.2	405.5	2.7										
				Relative Weight	24.2	26.8	29.1	19.8	0.1										

Figure 60. House of Quality Analysis: Platforms vs. CTQs.

Reference Item 1 and Reference item 2: The oil platform is less effective than the remote automated sea station. Reference item 3: There is a lot of input to the defender not reaching the target on time. The next greatest input is to increase the range of the system. The third need is to have scalability of weapons to minimize cost. Reference item 4: High importance ranks in the following way: Increase range, Increase weapon scalability, and decrease the defense space

Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		Quality Characteristics (a.k.a. "Hows") / **Demanded Quality** (a.k.a. "Whats")	USV's	UUV's	UAV's - Helicopter	UAV - Plane	Weather Proof	Multifunction phased array radar	Lowenergy usage	Automatic weapons with man in loop	Netcentric communications	Fuel usage	video and audio Surveillence	Software - Coordinated Attack	weapon replenishment	Software - Acquire Targer	Software - Ssurveillence
24.2	496.2	Defender Cannot Reach Target on Time	Θ	Θ	Θ	Θ			Θ								
26.8	548.1	Increase Effective Range of Defender from 200 Nautical Miles to....	Θ	Θ	Θ	Θ			Θ								
[illegible]	[illegible]	Scalability of weapons to match or exceed capability of adversary without excessive cost or damage															
19.8	405.5	Decrease the Defense space or Protection Barrier															
0.1	2.7	Eliminate the desire to take the route that is infested with somalian Pirates		1													
		Eliminate the notion that the money reward of piracy is worth the consequences even death															
		Somalia has no credible governement by law															
		Pirates have adapted techniques to reach larger range a															
		Pirates have adapted to using integrated teams to hijack															
		Uniform Defense Organization															
		Organized Approach															
		Understand the environment															
		know the locations of hidden pirates															
		Persistant Presence															
		Forward Presence															
		Target or Limit Value															
		Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	4	4	5	3	9	1	3	4	1					
		Max Relationship Value in Column	9	9	9	9			9								
		Weight / Importance	459.0	459.0	459.0	459.0			459.0								
		Relative Weight	20.0	20.0	20.0	20.0			20.0								

Figure 61. House of Quality: CTQ vs. Functions.

Reference Item 1: The two CTQs that pop out are that we need to reach the target on time and we need to increase the coverage range.

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	X	X	▲	X	X	X	X								
				Quality Characteristics (a.k.a. "Hows") / **Demanded Quality** (a.k.a. "Whats")	Ability to Remain Stationary	Reach speeds 10 times faster than fastest pirate	Ability to see potential targets , tag the target, and classify the target	Ability to setup barriers where maritime vessels cannot cross and pirates cannot leave	Trade Embargo	Prevent the taking of hostages	Prevent the acquisition of victim ships	Prevent damage to victim ships	Prevent cost to world economy	Prevent the coordination of pirate teams	be able to withstand RPG, sub machine guns, hand guns, etc.	Be able to understand the language of the enemy	Track the pirate routes to find the home bases	Provide Brand Image for Pirates - They will fear the united states	Track all RF emmissions
1	9	20.0	459.0	USV's	⊖	⊖													
2	1	20.0	459.0	UUV's	▲	▲													
3	9	20.0	459.0	UAV's - Helicopter	⊖	⊖	⊖												
4	9	20.0	459.0	UAV - Plane	⊖	⊖	⊖												
5	9			Weather Proof	⊖														
6	9			Multifunction phased array radar															⊖
7	9	20.0	459.0	Low energy usage	⊖	⊖													
8				Automatic weapons with man in loop															
9				Netcentric communications															
10	3			Fuel usage	○														
11				Video and audio Surveillence															
12				Software - Coordinated Attack															
13				weapon replenishment															
14				Software - Acquire Targer															
15				Software - Ssurveillence															
				(1) **Target or Limit Value**															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	4	10	1	4	1	3								
				Max Relationship Value in Column	9	9	9												9
				Weight / Importance	740.0	740.0	360.0												
				Relative Weight	40.2	40.2	19.6												

Figure 62. Housse of Quality: Functions vs. Requirements.

Reference Item 1: Two major requirements: Speed to target and ability to be on standby.

APPENDIX E – FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

Table 12. Failure Mode Effects Analysis: Mission Warfare.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Gaps exist in coverage areas in defeating 50 or more small boats, due to shortfall in the numbers of assets.	Battle space is to large to be effective.	Unable to defend against multi-trajectory attacks.	10	No controls in place to define the battle space for the pirates	4	Task Force 151	2	80	Define the battle space and control it	Develop super highway concept	1	1	1	1
Inadequate number of surface combatant assets and Helicopters provide self defense capability only in port operating area.	Limited assets covering an increasing battlefield.	Unable to provide enough assets to cover the battle space.	10	No controls in place to define the battle space for the pirates	4	Task Force 151	2	80	Define the battle space and control it	Develop super highway concept	1	1	1	1
								160						2

Table 13. FMEA: SIPOC I.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
CTP 1 - Sensor with high resolution	Small Target RCS could be missed. Also, classification of targets for human in the loop is critical to timely response.	Target size could be missed. Targets beyond the radar horizon and during fade outs would increase probability of successful hijack or kidnapping.	10	If a small target is missed or if the forces to respond are overwhelmed with targets, the target will be free to deliver harm to merchants. Classification is critical to man in the loop litigation. Near video data stream is needed for intelligence.	4	Task Force 151	2	80	Analysis of RCS targets, Analysis of Ranges, Simulation of fixed assets versus moving assets, Analysis of different sensor sets, Selection of System for success.	Selection of AEROSTAT, Selecrtion of RSSS after analysis of all other assets was completed. Analysis of Furuno Radar. Selection of UAV and conops developed to protect high value asset.	1	1	1	1
CTP 2 - Unmanned system with quick response	Less than quick response will increase the probability of missing the target.	Speed achieved should place the interceptor within 8 nmi of classification of the target. Failure to achieve increases the proabaility of hitting a target that could be friendly. Speed of classification must be achieved before a firing solution can hit the enemy before the 1nmi red zone. The red zone is the area the enemy cannot breach.	10	Failure can be caused by an increasing growing battle space which quickly overwhlems forces. Failure can be due to multitrajectory attack with limited resources.	8	Task Force 151	2	160	Quick response is limited by distance and time. If the defense space is increasing and the UAV has a maximum speed, then response time will decrease. Selection of appropriate systems will improve response. Also, control of battle space will insure that maximum response time will not be lost.	Superhighway concept was developed to control the battle space.The controlled battle space limits enemy capability to deliver attacks. Transponder system insures that Friendly systems are identified all of the time. Communication, Detection, Classification, and ability for fast firing solution is key.	1	1	1	1

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
CTP - 3 and CTP - 4 hull that can withstand the environment and sea state of operation	The hull must survive sea state 5 and survive a TSUNAMI.	The system must be able to go to a wait mode at sea state three and survive sea state 5 such that operation is not degraded. When the system is in wait mode, the system should be able to survive weather conditions characterized as a TSUNAMI.	10	Failure is inherent to system design and to maintenance procedures.	2	Task Force 151	1	20	Naval presence can send a message to our enemies. Surivival of assets will continue that presence and send a message that we will not go away. Dean Rubel indicated that the mere sight of a grey Navy vessel sends fear to the enemy.	Carderock SME and Dahlgren SME were consulted on types of hulls . The hull will penetrate the water like a catamaran with very sharp edges on the bottom hull to achieve sea state 5. Corrosion will be incoprorated in all areas of design. Submersible pontoons will be incrementally added to acheive surivaval from TSUNAMI.	1	1	1	1
CTP 5 - System with response time that will allow interception	Response time is key to arriving in time to protect High value assets	The enemy must be intercepted between the 20nmi zone and the 8nmi zone, The 8nmi zone must be the minimal range of interception. EOIR will be used to classify target and determine a firing solution.	10	Failure is to miss the target of interest or fail to protect the high value asset within the conops specified.	7	Task Force 151	2	140	Careful design of battle space size and sensor capability in corrdination with UAV response time and resupply processes will be key to timely interception of enemy.	Controlling the battle space and understanding the speeds and ranges of the high value asset, enemy, and system will achieve a response where UAV waits for enemy to get	1	1	1	1

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
CTC 1 - Protection of High Value Assets	Protection of high value assets is the objective.	Protection of high value assets is important. An autonomous system must not kill unless a man in the loop makes the decision. The system must be able to be tamper proof and withstand a common range of ordnance.	1	Failure is to implement a system that cannot defend or deter those that would place asset in harm's way.	2	Task Force 151	2	4	Protection without killing when man in the loop is not present. Capability to kill when man in the loop makes the decision. Reduction of manned systems and increase of semi-autonomous systems.	A command ship and robust communications and sensing will protect high value assets. A transponder will identify the high value asset as needing to be monitored. Decisions will be automated at the lower level and high level decisions will require man-in-the-loop.	3	1	1	3
CTC 2 - Protection of Naval Forces in Remote Locations	Protection of Naval forces and Naval Assets are key to persistent presence.	Protection of Naval Forces is important because the system proposed will be moslty unmanned and a limited human crew will be available to maintain system only.	3	Failure is to withdraw from an area due to lack of Naval Presence. Failure is to engage the enemy without the selected UAV, USV, or RSSS.	2	Task Force 151	1	6	The ability to protect forces means to provide a means for autonomous operation and resupply capability. A system that accomplishes maintenance of unmanned systems is needed also.	Protection of systems will be incorporated on Command Ship, Supply ship, USV, UAV, RSSS, and AEROSTAT.	1	1	1	1
								410						8

Table 14. FMEA: SIPOC II.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
CTP 2.1 - Speed	Failure to intercept target on time places the high value asset at risk.	Large battle space is increasing. UAV and asset speeds are not changing to increasing space.	10	Uncontrolled groups of pirates familiar with the region can attack in multi trajectories earlier than the response of traditional deterrents.	6	Task Force 151	2	120	Superhighway concept will control battle space to within speed capaiblities of existing assets.	Develop superhighway concept.	1	1	1	1
CTP 2.2 - Effective Weapons	Effective weapons should be selected for effective operation and effective cost.	A 8 million dollar missile used to protect a high value asset from a RPG or Machine gun Fire does not seem like an equitable excahnge.	2	A warship is far more expensive than a stationary platform. 9000 men utiilized off the coast of somalia where 65 men could maintain a RSSS system.	8	Task Force 151	2	32	Utilization of a RSSS versus a group of warships is more economical and effective.	Develop superhighway concept.	1	1	1	1
CTC 2.1 - Vessel and Victim	The vessels and the victims need should not be affected by the pirate problem	Freedom of the seas should not affect the merchants that provide benefit to the world economy.	10	A maritime security force cannot cover 1.2 million nmi of batle space.	8	Task Force 151	2	160	Superhighway concept will control battle space such that high value assets are not aware of a threat.	Develop superhighway concept.	1	1	1	1
								312						3

Table 15. FMEA: Cause and Effect Analysis.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Root Cause 1 = Limit the types of tactics that the pirates can employ. Remember that the first principle is to establish a naval presence in remote locations so that Naval Forces have superior intelligence of enemies of maritime security	Multiple Trajectory Attacks on Merchant Vessels	Multiple Pirate Attacks	10	Area of Coverage is too large for existing assets	10	Task Force 151	10	1000	Superhighway concept limits battle space. Transponder for friendly targets will reduce monitoring.	Develop a graphical animiation for the superhighway concept. Develop a simulation of options for the superhighway concept versus standard methods.	1	1	1	1
Root Cause 2 = Limit the defense space so that a reasonable affordable force can be effective. Remember that the second principle is area of coverage because limiting how the enemy of maritime security engages our forces leads to effective use of limited resources in remote locations.	Unlimited access to the sea off the coast of Somalia has contirbuted to the large attack space the pirates enjoy.	Increasing Battle Space	10	The pirate has many options for attacking pirate vessels	10	Task Force 151	10	1000	Superhighway Concept will limit area of coverage.	Develop a graphical animiation for the superhighway concept. Develop a simulation of options for the superhighway concept versus standard methods.	1	1	1	1

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Root Cause 3 and Root Cause 5 = Minimize the velocity function so that assets can reach target within capability tolerance. Remember that the third principle is response time in which our naval forces must be prepared to engage the enemy before the enemy of maritime security can become an unaccountable threat.	The ratio of excessive distance to time leads to reduced response time.	Inasing speed requirement to reach high value assets	10	Larger distance equates to faster speed which lowers range of UAV.	10	Task Force 151	10	1000	Superhighway concept will reduce the maximum velocity needed to reach the victims.	Develop a graphical animiation for the superhighway concept. Develop a simulation of options for the superhighway concept versus standard methods.	1	1	1	1
Root Cause 4 = Increase the capability of sensors and response to reach target before the enemy. Remember that the fourth, final principle is the role of maritime security which is our effective preparation for engagement of enemies of maritime security at a zero incidence level.	Lack of control of maritime security leads to increased incidence of piracy.	Increase in incidences of hijackings, attacks, and kidnappings	10	Maritime Security Force does not show a constant presence	6	Task Force 151	1	60	A controlled battle space will eliminate the need to incarcerate pirates increasing attack response cycle time.	Develop a graphical animiation for the superhighway concept. Develop a simulation of options for the superhighway concept versus standard methods.	1	1	1	1
								3060						4

Table 16. FMEA: Rubel.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Naval Presence	Miss vital intelligence. Enemy has more confidence to attack. Native people will be less likely to report pirate activity.	Lack of superior intelligence will contribute to missed response to attacks. Lack of Naval Presence will give the enemy no imposed boundary curtailing impact to maritime security.	10	War vessels have limited range and are constanlty mobile. Lack of Naval presence provides the pirates with an attack space that is unlimited causing Task Force 151 to posess a 1,2 million sqaure nmi battle space.	8	Task Force 151	3	240	A series platforms stationed off the coast of Somalia to provide the message of a constant Naval presence.	QFD Analysis of all potential platforms. A sensor network for long term surveillence to trace pirate activity.	1	1	1	1
Area of Coverage	Miss helping high value asset when attacked. Difficult to cover 1.2 million nmi.	Missed opportunity to utilize limited resources in the fight against criminals off the coast of Somalia.	10	Uncontrolled maritime threat is increasing the battle space.	10	Task Force 151	3	300	Limiting the movement of pirates will reduce the area of coverage to a more manageable level.	A sueprhighway concept of coverage that would limit the battle space by 92%. A grid of vertical takeoff UAV's that could respond to a controlled area.	1	1	1	1

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Response Time	Ships hijacked. People kidnapped. Timed attacks when ship patrol not present.	Miss the opportunity to respond to the threat of maritime security before the threat becomes an uncontrolled threat,	10	The distance that the warships and helicopters have to travel is 1.2 million sqaure nmi. The process map of the current state involves incarceration which reduces the total cycle per pirate event.	8	Task Force 151	3	240	Selecting vertical takeoff UAV's to exist on the platforms would provide area of coverage if the quantity of platforms could be established.	Completion of ananlysis of speeds and distances of vessels of both pirates and merchants. Selection of a UAV that meets the analysis needs.	1	1	1	1
Role of Maritime Security	Protect US Interests around the Horn of Africa.	Fail to engage the threats to maritime security at zero incidence level.	10	The image of the united states as a world power is diluted by a lack of permanent mairimte security force	8	Task Force 151	4	320	A boundary of protection for law abiding merchants would satisfy the mitime security force need.	A controlled space or super highway cncept has been selected to limit the mult6itrajectory attack of the pirates.	1	1	1	1
								1100						4

Table 17. FMEA: Performance.

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Availability	24 x 7 for 90 Days, System deployment to operational area within 20 days	Maintenance Failure at Sea, Replacement Parts, Logistics of Replacement Parts, Level of Technical Capability of Human Technicians	10	No Maintenance Plan in Place, No replacement parts available, skill level of technician lacking, no specialized shops available to perform technical work required for maintenance	5	None	10	500	Apply condition based maintenance to process. Develop specialized technical/fabrication shops on command ship, and supply ship, employ analysis of all machines, implement autonomous systems with maintainability design. Select AEROSTAT for primary sensor with MTBF = 10 Years.	1. Graceful degradation - Phased Array Radar, 2. Condition Based maintenance. 3. Swarm technology for UAVs 4. Extensive training of technicians with train the trainer program. 5. Specialized maintenance shops with self fabrication. 6. Autonomous systems with self lubrication and component replacement capability.	1	3	1	3
Coverage	Persistent coverage within 200 NM radius	Miss targets. Pirates able to attack high value assets.	10	Lack of coverage. Vessels too slow. Not enough assets in area.	8	Multi-nation Navy - 30 ships and Helicopters from 17 maritime nations.	3	240	1. Aerostat capability will provide 100% coverage with no fade out. Mimic Helicopter range and speed with Fire Scout. Develop range of speed analysis. Develop simulation of scenarios.	1. AEROSTAT Selected as primary sensor. 2. Vertical takeoff UAV, Fire Scout, selected. 3. Analysis of common speed selected. Simulation of coverage and response time completed. Selection made.	1	1	1	1

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Interoperability	Link 11, 12, & 16 compatibility, + all military satellite, + secure wireless. All systems JTIC certified	Non-communication will result in bad decisions or erros in detection, reaction,etc.	10	Interoperability not designed into system.	10	SATCOM, Media	3	300	1. Selection of AEROSTAT with low fadeout. 2. Man in the loop is onboard command ship. 3. Communication is communicated in work structure diagrams. 4. Communication with MOC through satcom. 5. Transponder installed on all HVA's passing through the superhighway concept.	1. Included. 2. Included. 3. Complete. 4. Included. 5. Included.	3	4	1	12
Lethality	Ability to disable/destroy, small-medium size targets (over one nautical mile standoff strike range)	1. High value asset is hijacked. 2. Occupants are killed or kidnapped. 3. Pirates able to attack again.	10	1. Weapons fired are not proportional to threat. 2. Helicopted or warship not able to reach high value asset on time.	4	Multi-nation Navy - 30 ships and Helicopters from 17 maritime nations.	3	120	1. Morphological matrix on turrets. 2. Morphological matrix on IR inserts for classification error proofing. 3. Morphological matrix on FURONO radar for RSSS.	1. In process. 2. In process. 3. In process.	8	2	1	16

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Survivability	System shall operate up to Sea-State 5. System is capable of full operation in all operational areas particularly tropics. System will defend against irregular forces. For example, such forces are small fast boats or small fast attack craft.	1. Communication failure. 2. Damage to system. 3. Inability to defend.	10	1. Fadeouts 2. System Failure	3	Multi-nation Navy - 30 ships and Helicopters from 17 maritime nations.	3	90	1. Incorporate designs from Carderock. 2. Design for environment and corrosion. 3. Superior maintenance processes. 4. Graceful degradation of systems. 5. Swarm Technology. 6. Automation redundancy.	1. Team includes Eric Henson for hull design. 2. Corrosion, environment design considerations included. 3. 100% availability design included.	8	1	1	8

Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Actions Taken	SEV	OCC	DET	RPN
Manning	Extensive use of automation to reduce personnel manning & to reduce logistical footprint	1. 9000 personnel tied up in present Naval Force	3	1. Robotic Failure 2. Communications Failure 3. High Technical capability needed. 4. Excessive resources	4	Multi-nation Navy - 30 ships and Helicopters from 17 maritime nations.	10	120	1. Autonomous systems such as robots to perform refuel, maintenance, rearmament 2. Highly qualified technicians and maintenance shops. 3. Superior communications. 4. High uptime of equipment. 5. Human Factor Analysis of Human Overload.	1. High availability design is included. 2. High maintainability design is included. 3. Command ship and supply vessel will need integration into autonomous operations. Sensors selected for superior perfomance. 4. Condition based maintenance along with support structure included in design.	2	4	1	8
C2	Ensure man in the loop (links to HQ), and prevent fratricide/civilian casualties (rules of engagement/CONOPS)	1. Legal implications for automation and manpower.	1	1. Legal problems. 2. Faults in kill chain.	1	Multi-nation Navy - 30 ships and Helicopters from 17 maritime nations.	2	2	1. Communication lines embedded in system design. 2. MOC, SATCOM, and AEROSTAT in loop.	1. Completed. 2. included.	1	1	1	1
								1372						49

APPENDIX F – WORK BREAKDOWN STRUCTURE (WBS)

Table 18. Work Breakdown Structure.

AUGMENTING NAVAL CAPABILITES IN REMOTE LOCATIONS
WORK BREAKDOWN STRUCTURE LEVELS (WBS)

WBS ELEMENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
01	SYSTEMS OF SYSTEMS			
01.01		AEROSTAT		
01.01.001			Multi-Function Acquistion Radar	
01.01.001.A				EW Radar
01.01.001.B				Target Tracking Radar
01.01.002			Multi-Function Engagement Radar	
01.01.002.A				Fire Control Radar
01.01.002.B				Fire Control Illumination Radar
01.01.002.C				Illumination Radar
01.01.003			Space Vehicle	
01.01.003.A				Structures and Mechanisms Subsystem
01.01.003.B				Thermal Control Subsystem
01.01.003.C				Electrical Power Subsystem
01.01.003.D				Attitude Control Subsystem
01.01.003.E				Propulsion Subsystem
01.01.003.F				Telemetry, Tracking, and Command Subsystem
01.01.003.G				Spacecraft Bus Flight Software
01.02		SEA BASE		
01.02.001			Hull Structure	
01.02.002			Electric Plant	
01.02.003			Command, Communication and Surveillance	
01.02.004			Auxiliary Systems	
01.02.005			Outfit and Furnishings	
01.02.006			Force Protection	
01.02.007			Total Integration/Engineering	
01.02.008			Assembly and Support Services	
01.02.009			Refueling System	
01.02.010			UAV Ground Support	
01.02.011			Automation Package	
01.02.012			Radar System	
01.02.013			USV ground Support	
01.03		SUPPLY SHIP		
01.03.001			Hull Structure	
01.03.002			Propulsion Plant	
01.03.003			Electric Plant	
01.03.004			Command, Communication and Surveillance	
01.03.005			Auxiliary Systems	
01.03.006			Outfit and Furnishings	
01.03.007			Re-armament System	
01.03.008			Total Ship Integration/Engineering	
01.03.009			Ship Assembly and Support Services	
01.03.010			Automation Package	
01.03.011			Refueling System	
01.04		COMMAND SHIP		
01.04.001			Hull Structure	
01.04.002			Propulsion Plant	
01.04.003			Electric Plant	
01.04.004			Command, Communication and Surveillance	
01.04.005			Auxiliary Systems	
01.04.006			Outfit and Furnishings	
01.04.007			Armament	
01.04.008			Total Ship Integration/Engineering	
01.04.009			Ship Assembly and Support Services	
01.04.010			Prime Mission Product	
01.04.010.A				PMP Applications Software
01.04.010.B				PMP System Software
01.04.010.C				Integration, Assembly, Test and Checkout

WBS ELEMENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
01.05		UAVs (Fire Scout)		
01.05.001			Air Vehicle	
01.05.001.A				Airframe
01.05.001.B				Propulsion
01.05.001.C				Communications/Identification
01.05.001.D				Navigation/Guidance
01.05.001.E				Central Computer
01.05.001.F				Auxiliary Equipment
01.05.001.G				Air Vehicle Application Software
01.05.001.H				Air Vehicle System Software
01.05.001.E				Integration, Assembly, Test and Checkout
01.05.001.F				Gracefull Degradation
01.05.002			Payload	
01.05.002.A				Survivability
01.05.002.B				Reconnaissance
01.05.002.C				Electronic Warfare
01.05.002.D				Armament
01.05.002.E				Weapons Delivery
01.05.002.F				Payload Application Software
01.05.002.G				Payload System Software
01.05.002.H				Integration, Assembly, Test and Checkout
01.05.003			Ground Segment	
01.05.003.A				Ground Control Systems
01.05.003.B				Command and Control Subsystem
01.05.003.C				Launch and Recovery Equipment
01.05.003.D				Transport Vehicles
01.05.003.E				Ground Segment Application Software
01.05.003.F				Ground Segment System Software
01.05.003.G				Integration, Assembly, Test and Checkout
01.06		USVs (Transport / Defenders)		
01.06.001			Sea Vehicle	
01.06.001.A				Hull Structure
01.06.001.B				Propulsion Plant
01.06.001.C				Electric Plant
01.06.001.D				Command, Communication and Surveillance
01.06.001.E				Auxiliary Systems
01.06.001.F				Total Ship Integration/Engineering
01.06.001.G				Ship Assembly and Support Services
01.06.002			Ground Segment	
01.06.002.A				Ground Control Systems
01.06.002.B				Command and Control Subsystem
01.06.002.B				Launch and Recovery Equipment
01.06.002.C				Transport Vehicles
01.06.002.D				Ground Segment Application Software
01.06.002.E				Ground Segment System Software
01.06.002.F				Integration, Assembly, Test and Checkout
01.06.002.G				Automated Fuel Delivery System
01.06.002.H				Automated Armament Delivery System
01.07		SATCOM		
01.07.001			SEIT/PM and Other Common Elements	
01.07.002			Spacecraft Bus	
01.07.002.A				SEIT/PM and Other Common Elements
01.07.002.B				Structures and Mechanisms Subsystem
01.07.002.C				Thermal Control Subsystem
01.07.002.D				Electrical Power Subsystem
01.07.002.F				Attitude Control Subsystem
01.07.002.G				Propulsion Subsystem
01.07.002.H				Telemetry, Tracking, and Command Subsystem
01.07.002.E				Spacecraft Bus Flight Software
01.07.003			Communication / Payload	
01.07.003.A				SEIT/PM and Other Common Elements
01.07.003.B				Communication
01.07.003.C				Payload (as required)
01.07.003.D				Communication/Payload Flight Software

WBS ELEMENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
01.07.004			Booster Adapter	
01.07.005			Space Vehicle Storage	
01.07.006			Launch Systems Integration	
01.07.007			Launch Operations & Mission Support	
01.08		**MOC**		
01.08.001			Observatory I&T Management	
01.08.002			Payload I&T & Environmental	
			Spacecraft I&T & Environmental Qualifications	
01.08.003				
01.08.004			Ground System Element I&T	
			Observatory I&T and Qualifications	
01.08.005				
01.08.006			Observatory & Launch Site GSE	
01.08.007			Launch Operations Support	
		* Items below are aplicable to each System		
01.XX.001			System Test and Evaluation	
01.XX.001.A				Development Test and Evaluation
01.XX.001.B				Operational Test and Evaluation
01.XX.001.C				Mock-ups/System Integration Labs (SILs)
01.XX.001.D				Test and Evaluation Support
01.XX.001.E				Test Facilities
01.XX.002			Training	
01.XX.002.A				Equipment
01.XX.002.B				Services
01.XX.002.C				Facilities
01.XX.003			Data	
01.XX.003.A				Technical Publications
01.XX.003.B				Engineering Data
01.XX.003.C				Management Data
01.XX.003.D				Support Data
01.XX.003.E				Data Depository
01.XX.004			Peculiar Support Equipment	
01.XX.004.A				Test and Measurement Equipment
01.XX.004.B				Support and Handling Equipment
01.XX.005			Common Support Equipment	
01.XX.005.A				Test and Measurement Equipment
01.XX.005.B				Support and Handling Equipment
01.XX.006			Operational/Site Activation	
01.XX.006.A				System Assembly, Installation and Checkout on Site
01.XX.006.B				Contractor Technical Support
01.XX.006.C				Site Construction
01.XX.006.D				Site/Ship/Vehicle Conversion
01.XX.007			Industrial Facilities	
01.XX.007.A				Construction/Conversion/Expansion
01.XX.007.B				Equipment Acquisition or Modernization
01.XX.007.C				Maintenance (Industrial Facilities)
01.XX.008			Initial Spares and Repair Parts	

APPENDIX G – WORK STRUCTURE DIAGRAMS

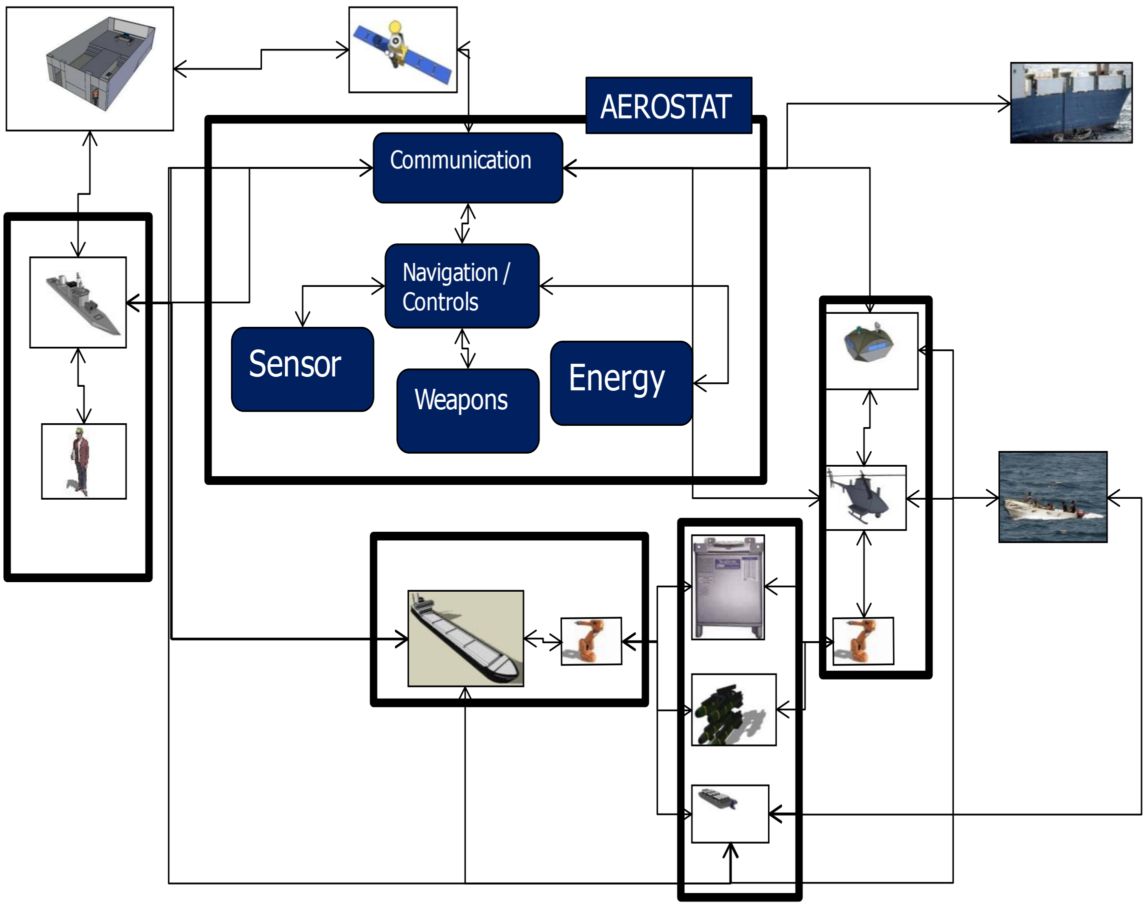

Figure 63. Function Structure Diagram: Aerostat.

This is a function structure diagram of the aerostat system. The diagram shows how the aerostat interacts with other systems of the ASHC.

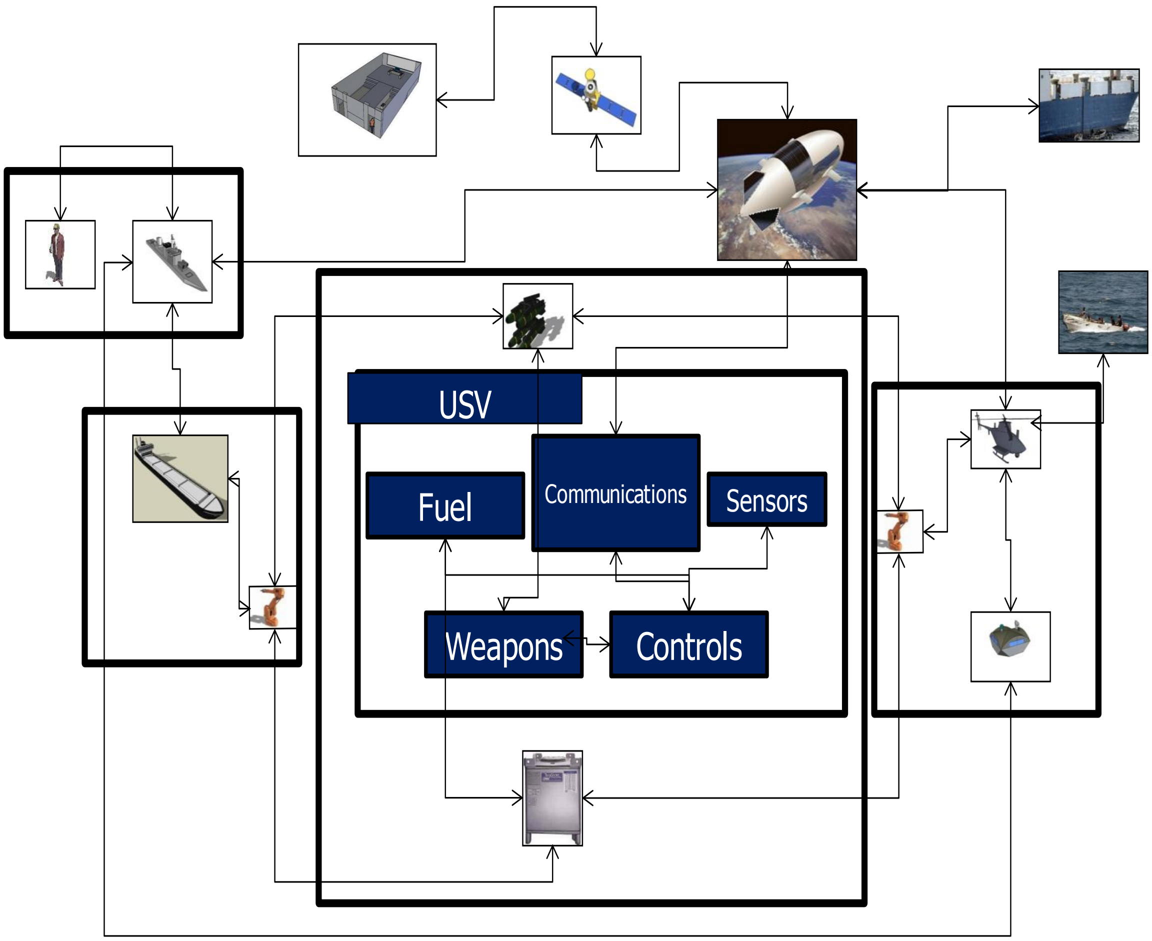

Figure 64. Function Structure Diagram: USV.

This is a function structure diagram of the USV system. The diagram shows how the USV interacts with other systems of the ASHC.

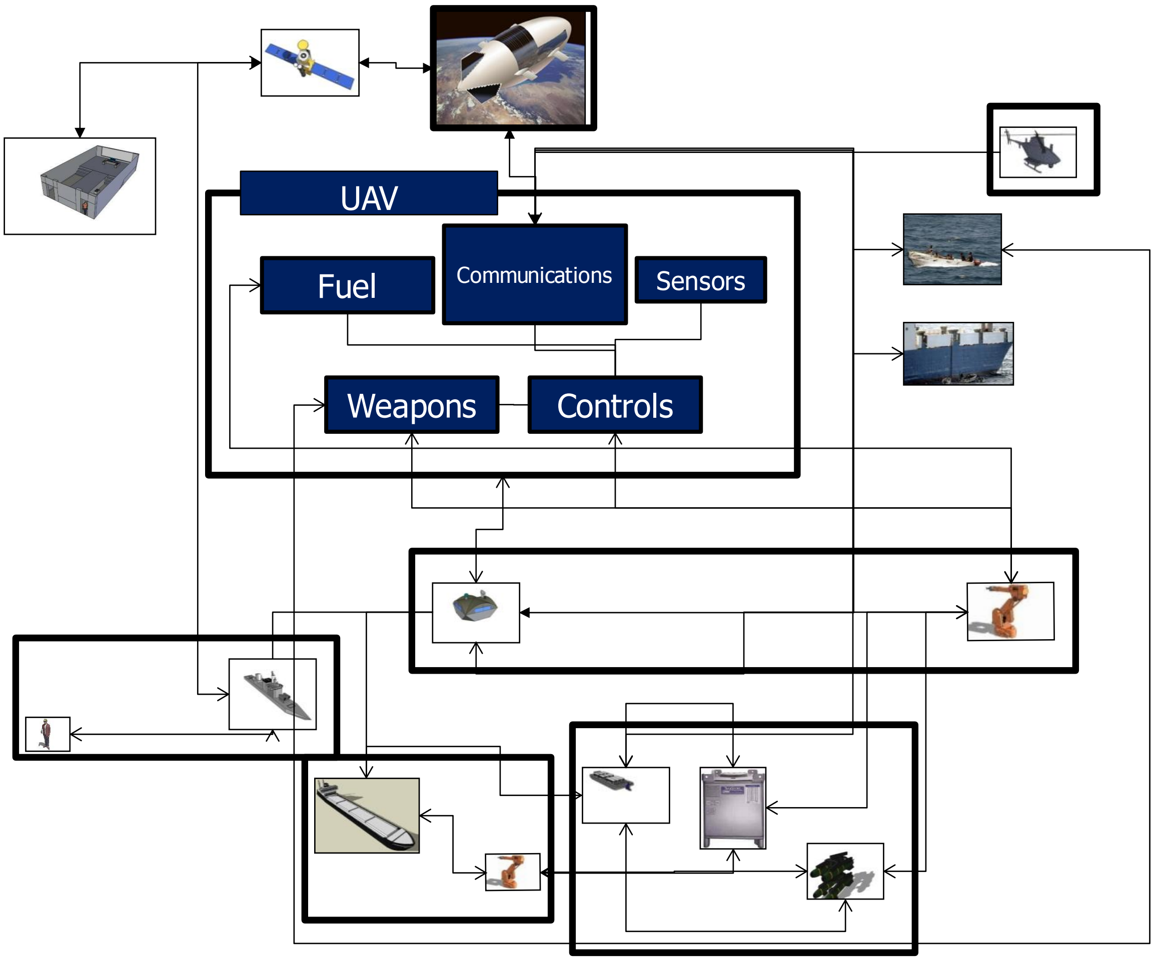

Figure 65. Function Structure Diagram: UAV.

This is a function structure diagram of the UAV system. The diagram shows how the UAV interacts with other systems of the ASHC.

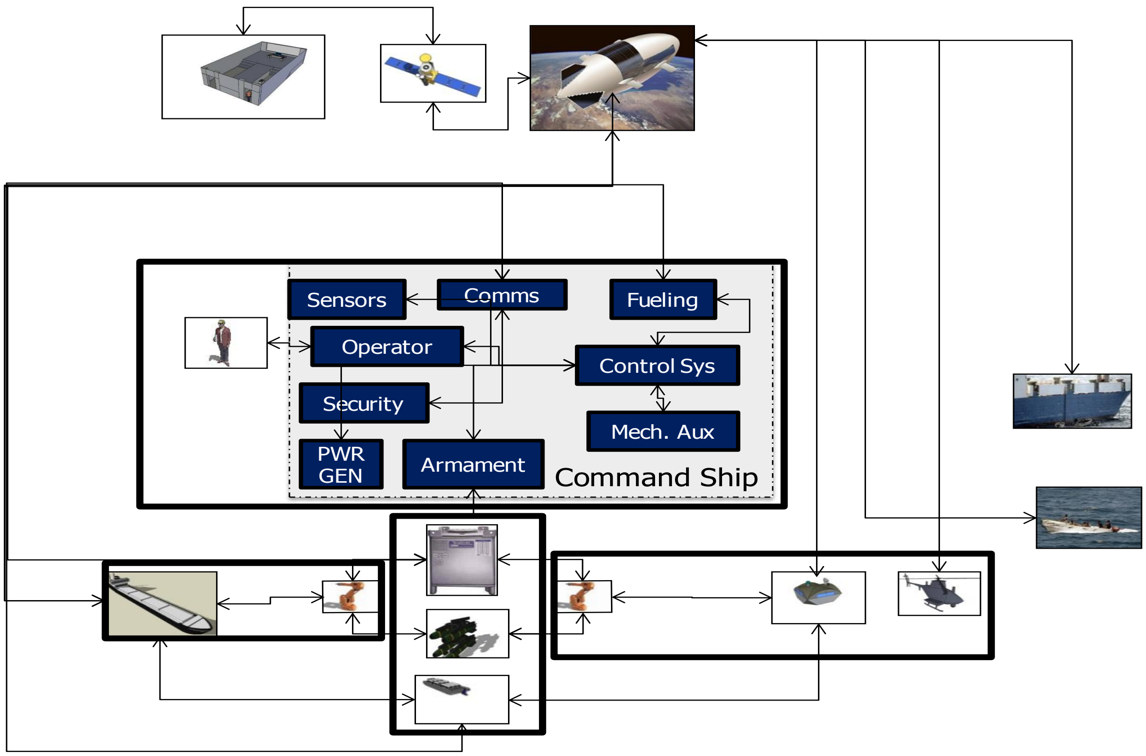

Figure 66. Function Structure Diagram: Command Ship.

This is a function structure diagram of the command ship system. The diagram shows how the command ship interacts with other systems of the ASHC.

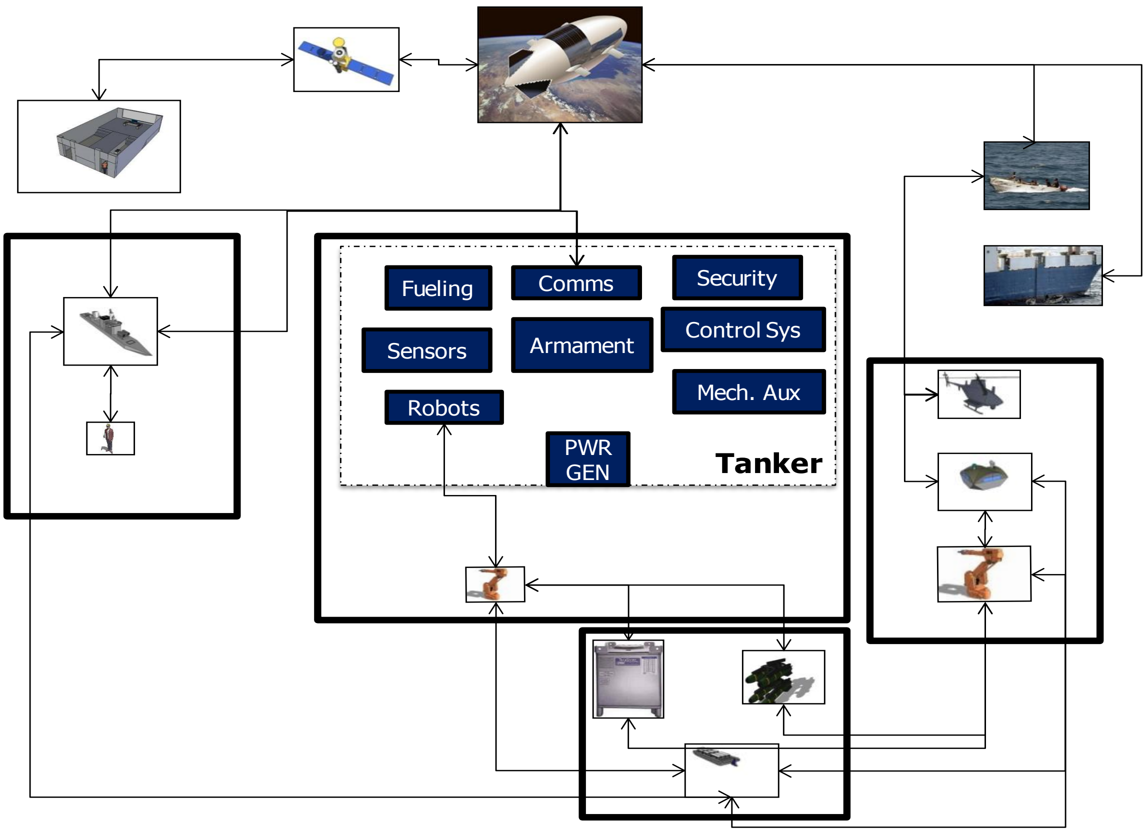

Figure 67. Function Structure Diagram: Tanker.

This is a function structure diagram of the tanker system. The diagram shows how the tanker interacts with other systems of the ASHC.

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APPENDIX H – INTERACTION DIAGRAM

Each cell gives its four values as printed in a 2 × 2 arrangement: top row (P E) / bottom row (I M).

		COMMAND SHIP	TANKER	USV	REMOTE SEA BASE	UAV WITH EOIR	AEROSTAT	SENSOR	ROBOT	EOIR	
Internal Sub_Systems of Radio	COMMAND SHIP		2 2 / 2 2	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0
	TANKER	2 2 / 2 2		2 2 / 2 2	0 0 / 2 0	0 0 / 0 0	0 0 / 1 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	USV	0 0 / 2 0	2 2 / 2 2	P E / I M	0 0 / 0 0	0 0 / 1 0	0 0 / 1 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0
	REMOTE SEA BASE	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0		2 2 / 2 2	0 0 / 1 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0
	UAV WITH EOIR	0 0 / 2 0	0 0 / 0 0	0 0 / 1 0	2 2 / 2 2		0 0 / 1 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0
	AEROSTAT	0 0 / 2 0	0 0 / 1 0	0 0 / 1 0	0 0 / 1 0	0 0 / 1 0		0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	SENSOR	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0		0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	ROBOT	0 0 / 2 0	0 0 / 0 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0		0 0 / 0 0	0 0 / 0 0
	EOIR	0 0 / 2 0	0 0 / 0 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 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 / 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	
Key environmental and External Sub_System Interfaces	MOC	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	SATCOM	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	FRIENDLY	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 2 / 2 0	0 0 / 0 0
	ENEMY	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	-1 0 / -1 0	0 0 / 0 0
	TARGET OF INTEREST	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	OTHER SEA BASES	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 1 0	0 0 / 0 0	0 0 / 0 0
	OTHER UAV'S	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0
	SEA STATE LEVEL <=3	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 2 0	0 2 / 0 0

	MOC	SATCOM	FRIENDLY	ENEMY	TARGET OF INTEREST	OTHER SEA BASES	OTHER UAVS	SEA STATE LEVEL <=3
COMMAND SHIP	0 0 / 2 0	0 0 / 2 0	0 0 / 1 0	0 -1 / 1 0	0 1 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
TANKER	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 -1 / 2 0	0 1 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
USV	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 -1 / 2 0	0 1 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
REMOTE SEA BASE	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 -1 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
UAV WITH EOIR	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 -1 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
AEROSTAT	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 2 / 2 0
SENSOR	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 2 0	0 0 / 2 0	0 0 / 2 0	0 0 / 0 0	0 2 / 2 0
ROBOT	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 0 / 1 0	0 0 / 0 0	0 2 / 2 0
EOIR	0 0 / 0 0	0 0 / 0 0	0 2 / 2 0	0 0 / 2 0	0 0 / 0 0	0 0 / 0 0	0 0 / 0 0	0 2 / 2 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 / 0 0	0 2 / 0 0
MOC								
SATCOM								
FRIENDLY								

P	E
I	M

P: Physically touching
I: Information exchange
E: Energy transfer
M: Material exchange

Required	2 Necessary for function
Desired	1 Beneficial, but not absolutely necessary for functionality
Indifferent	0 Does not affect functionality
Undesired	-1 Causes negative effects but does not prevent functionality
Detrimental	-2 Must be prevented to achieve functionality

Figure 68. Interaction Diagram.

The interaction diagram is a matrix that shows how various components of the ASHC interrelate with each other. Each square relates to physically touching, energy transfer, information exchange, and material exchange. The numbers in the square correspond to the need of the interrelationship with the other components.

APPENDIX I – SIMIO SCREEN SHOTS

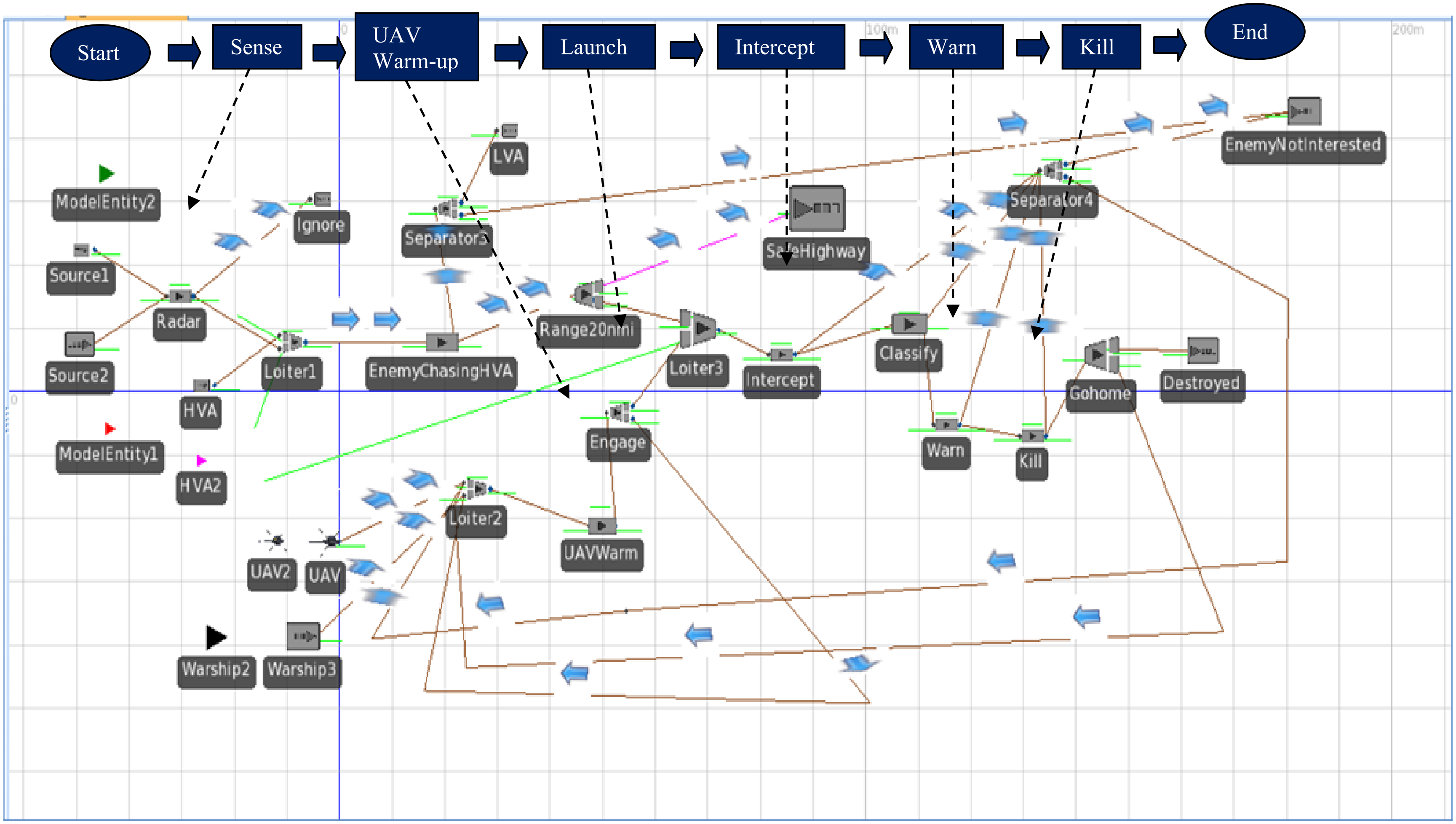

Figure 69. SIMIO Screen Shot: Warship with One UAV.

This figure is an actual screen shot of the SIMIO simulation of a warship with one UAV. At the top of the figure are the different phases and where they are located in the simulation.

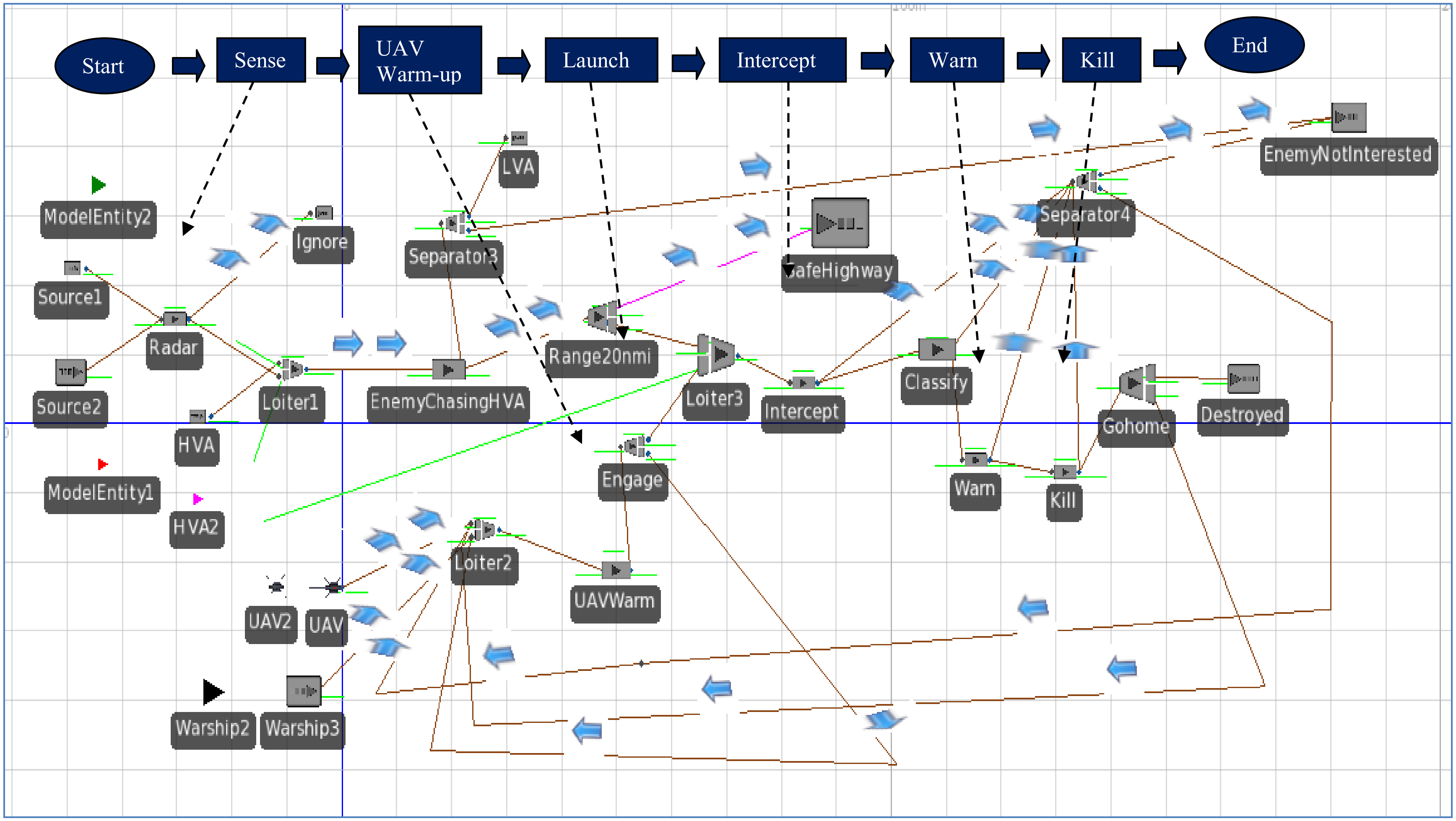

Figure 70. SIMIO Screen Shot: Warship with Two UAVs.

This figure is an actual screen shot of the SIMIO simulation of a warship with two UAVs. At the top of the figure are the different phases and where they are located in the simulation.

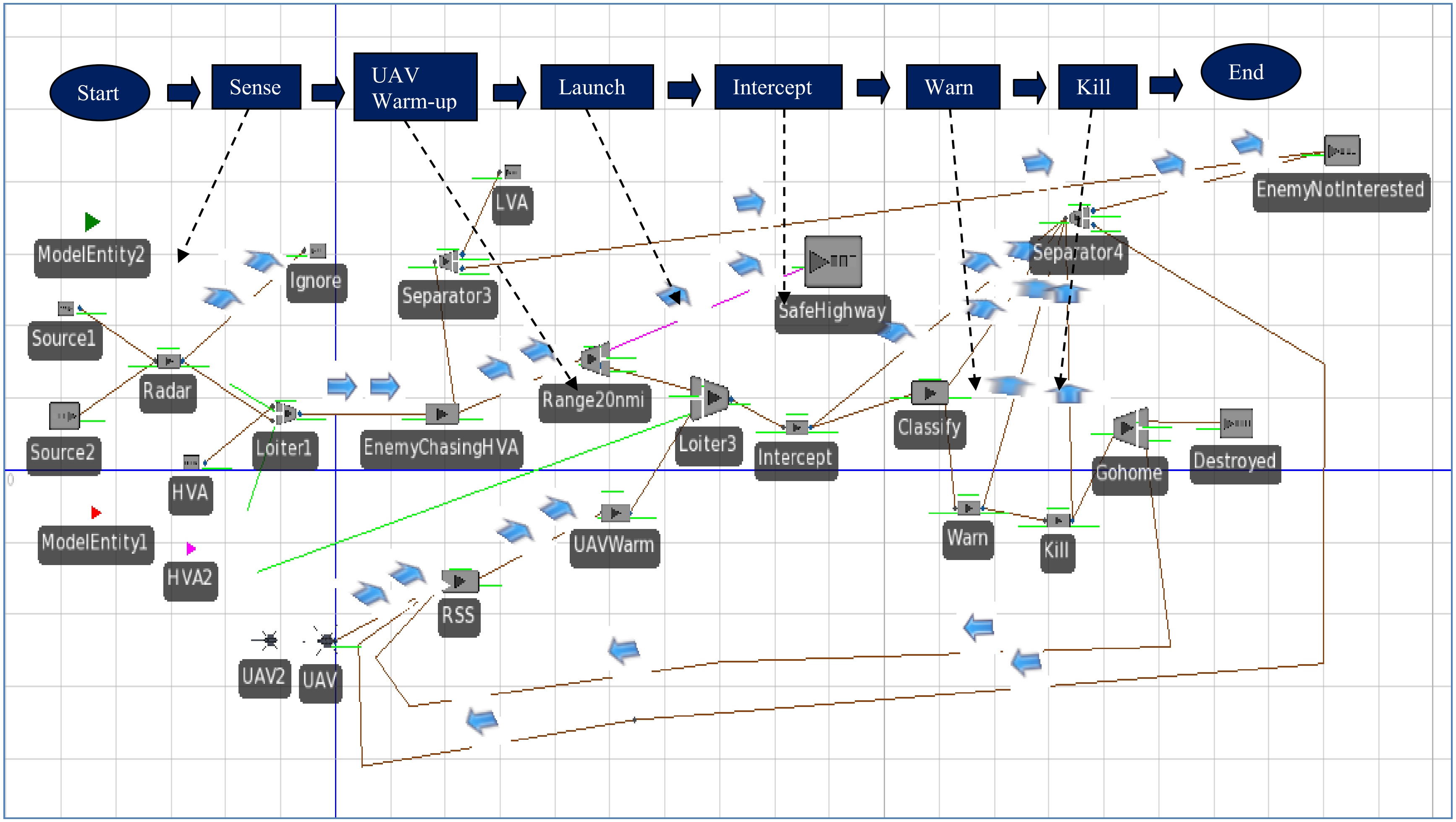

Figure 71. SIMIO Screen Shot: Remote Sea Station with Two UAVs.

This figure is an actual screen shot of the SIMIO simulation of a Remote Sea Station with two UAVs. At the top of the figure are the different phases and where they are located in the simulation.

APPENDIX J – SPEED VS DISTANCE MATRIX

Table 19. Time to Intercept: Speed vs. Range.

Distance (nm)	Speed 120	100	90	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
100	50	60	67	75	80	86	92	100	109	120	133	150	171	200	240	300	400	600	1200
94.4	47	57	63	71	76	81	87	94	103	113	126	142	162	189	227	283	378	566	1133
90	45	54	60	68	72	77	83	90	98	108	120	135	154	180	216	270	360	540	1080
80	40	48	53	60	64	69	74	80	87	96	107	120	137	160	192	240	320	480	960
72	36	43	48	54	58	62	66	72	79	86	96	108	123	144	173	216	288	432	864
60	30	36	40	45	48	51	55	60	65	72	80	90	103	120	144	180	240	360	720
55	28	33	37	41	44	47	51	55	60	66	73	83	94	110	132	165	220	330	660
50	25	30	33	38	40	43	46	50	55	60	67	75	86	100	120	150	200	300	600
45	23	27	30	34	36	39	42	45	49	54	60	68	77	90	108	135	180	270	540
44	22	26	29	33	35	38	41	44	48	53	59	66	75	88	106	132	176	264	528
40	20	24	27	30	32	34	37	40	44	48	53	60	69	80	96	120	160	240	480
35	18	21	23	26	28	30	32	35	38	42	47	53	60	70	84	105	140	210	420
30	15	18	20	23	24	26	28	30	33	36	40	45	51	60	72	90	120	180	360
29	15	17	19	22	23	25	27	29	32	35	39	44	50	58	70	87	116	174	348
27	14	16	18	20	22	23	25	27	29	32	36	41	46	54	65	81	108	162	324
26	13	16	17	20	21	22	24	26	28	31	35	39	45	52	62	78	104	156	312
25	13	15	17	19	20	21	23	25	27	30	33	38	43	50	60	75	100	150	300
24	12	14	16	18	19	21	22	24	26	29	32	36	41	48	58	72	96	144	288
23	12	14	15	17	18	20	21	23	25	28	31	35	39	46	55	69	92	138	276
22	11	13	15	17	18	19	20	22	24	26	29	33	38	44	53	66	88	132	264
21	11	13	14	16	17	18	19	21	23	25	28	32	36	42	50	63	84	126	252
20	10	12	13	15	16	17	18	20	22	24	27	30	34	40	48	60	80	120	240
19	10	11	13	14	15	16	18	19	21	23	25	29	33	38	46	57	76	114	228
18	9	11	12	14	14	15	17	18	20	22	24	27	31	36	43	54	72	108	216
17	9	10	11	13	14	15	16	17	19	20	23	26	29	34	41	51	68	102	204
16	8	10	11	12	13	14	15	16	17	19	21	24	27	32	38	48	64	96	192
15	8	9	10	11	12	13	14	15	16	18	20	23	26	30	36	45	60	90	180
14	7	8	9	11	11	12	13	14	15	17	19	21	24	28	34	42	56	84	168
13	7	8	9	10	10	11	12	13	14	16	17	20	22	26	31	39	52	78	156
12	6	7	8	9	10	10	11	12	13	14	16	18	21	24	29	36	48	72	144
11	6	7	7	8	9	9	10	11	12	13	15	17	19	22	26	33	44	66	132
10	5	6	7	8	8	9	9	10	11	12	13	15	17	20	24	30	40	60	120
9	5	5	6	7	7	8	8	9	10	11	12	14	15	18	22	27	36	54	108
8	4	5	5	6	6	7	7	8	9	10	11	12	14	16	19	24	32	48	96
7	4	4	5	5	6	6	6	7	8	8	9	11	12	14	17	21	28	42	84
6	3	4	4	5	5	5	6	6	7	7	8	9	10	12	14	18	24	36	72
5	3	3	3	4	4	4	5	5	5	6	7	8	9	10	12	15	20	30	60
4	2	2	3	3	3	3	4	4	4	5	5	6	7	8	10	12	16	24	48
3	2	2	2	2	2	3	3	3	3	4	4	5	5	6	7	9	12	18	36
2	1	1	1	2	2	2	2	2	2	2	3	3	3	4	5	6	8	12	24
1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	4	6	12

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APPENDIX K – SENSITIVITY PLOTS AND RESPONSE DISTRIBUTIONS

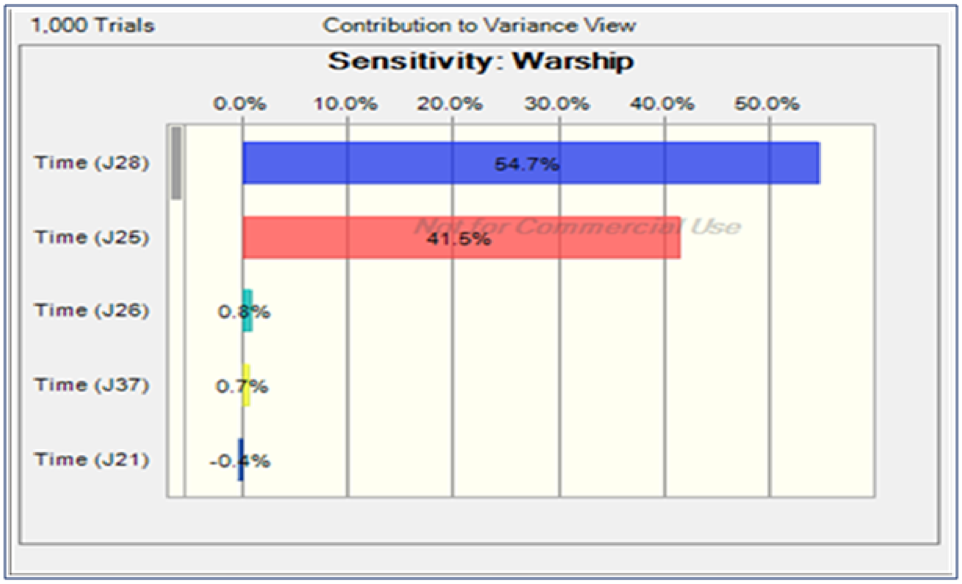

Figure 72. Sensitivity Analysis of Warship with One UAV.

The sensitivity plot shows the process that takes the most time during the Warship with One UAV simulation.

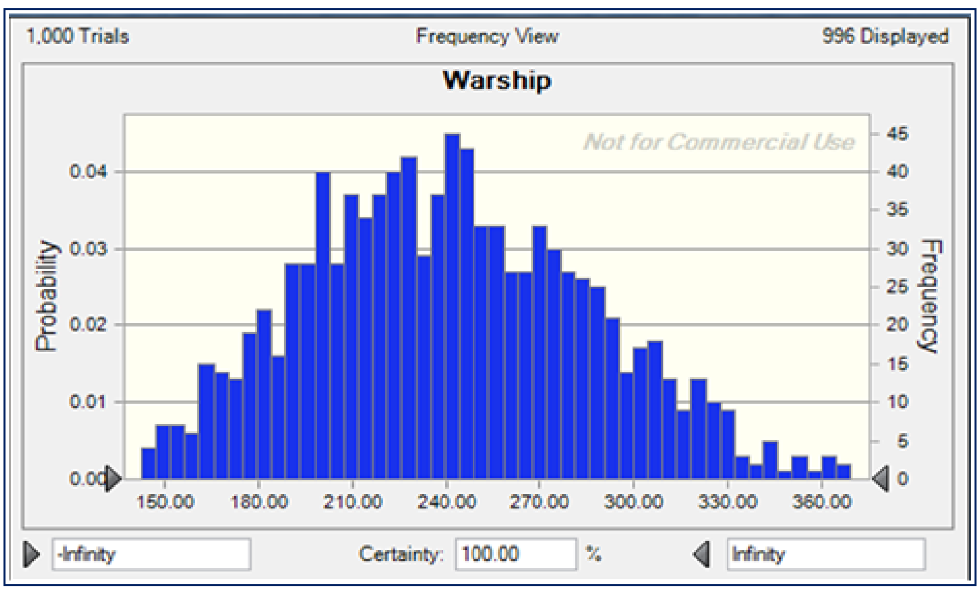

Figure 73. Frequency Analysis of Warship with One UAV.

The frequency analysis shows the different probabilities of the times that occurred during the Warship with One UAV simulation.

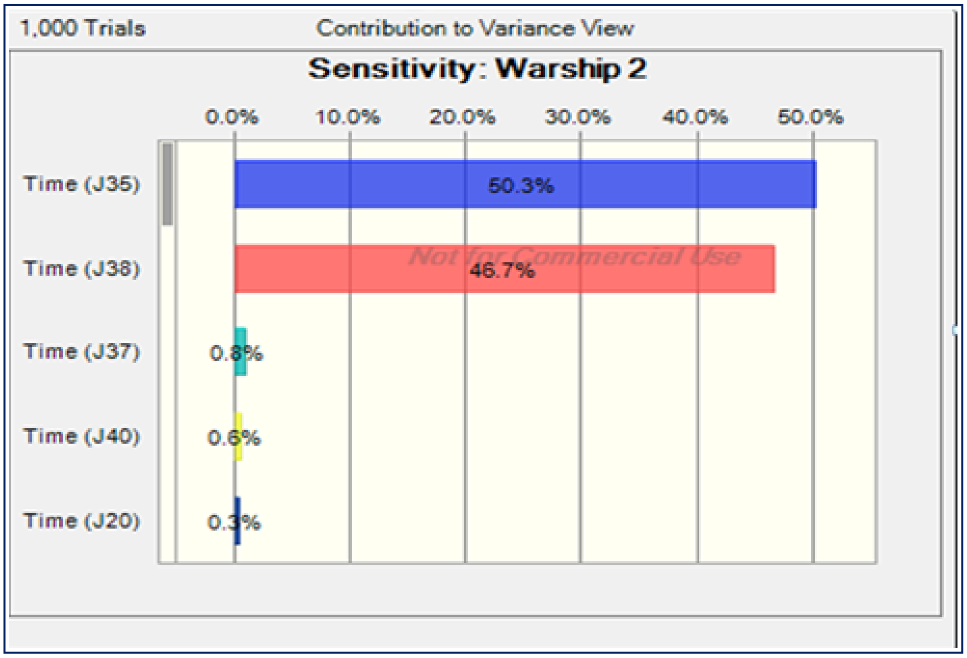

Figure 74. Sensitivity Analysis of Warship with Two UAVs.

The sensitivity plot shows the process that takes the most time during the Warship with Two UAVs simulation.

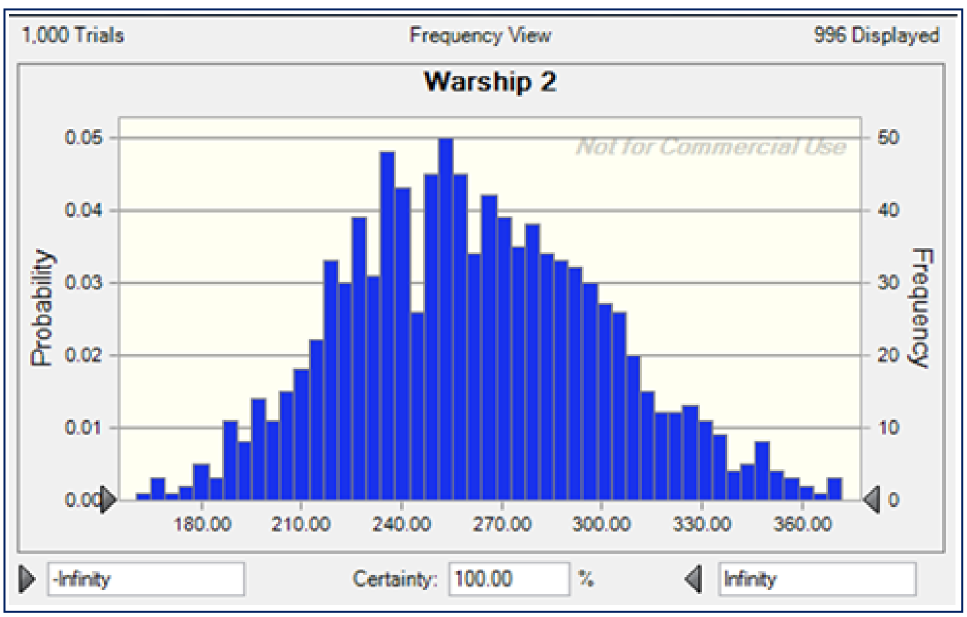

Figure 75. Frequency Analysis of Warship with Two UAVs.

The frequency analysis shows the different probabilities of the times that occurred during the Warship with Two UAVs simulation.

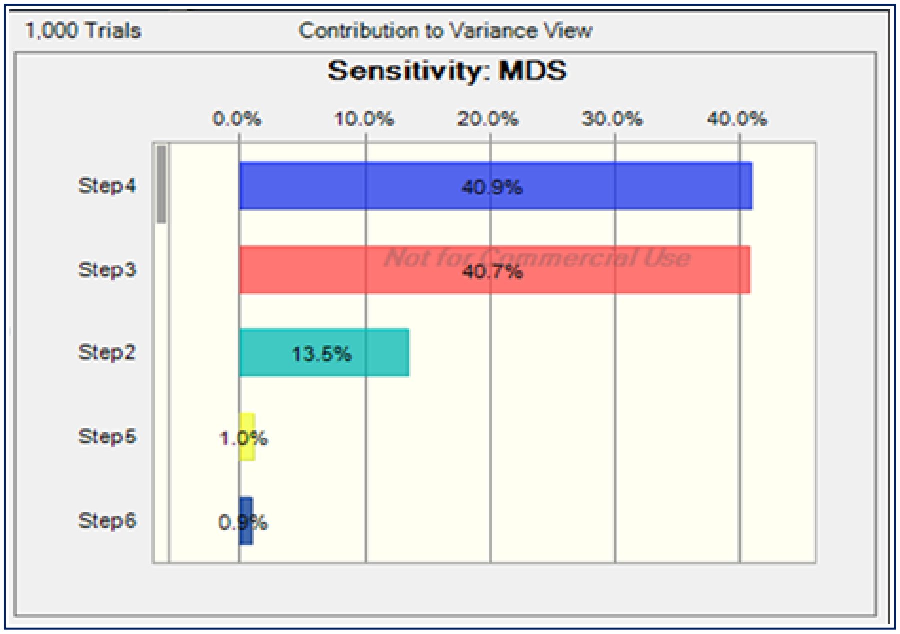

Figure 76. Sensitivity Analysis of Remote Sea Station (MDS shown here) with Two UAVs.

The sensitivity plot shows the process that takes the most time during the Remote Sea Station (MDS shown here) with Two UAVs simulation.

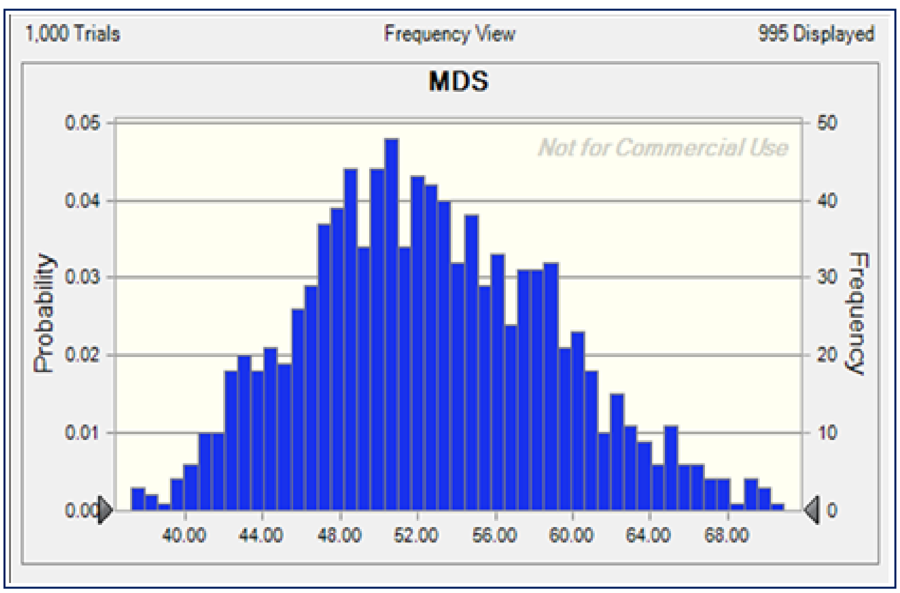

Figure 77. Frequency Analysis of Remote Sea Station (MDS shown here) with Two UAVs.

The frequency analysis shows the different probabilities of the times that occurred during the Remote Sea Station (MDS shown here) with Two UAVs simulation.

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APPENDIX L – SYSTEMS ENGINEERING ROADMAP DECOMPOSITION

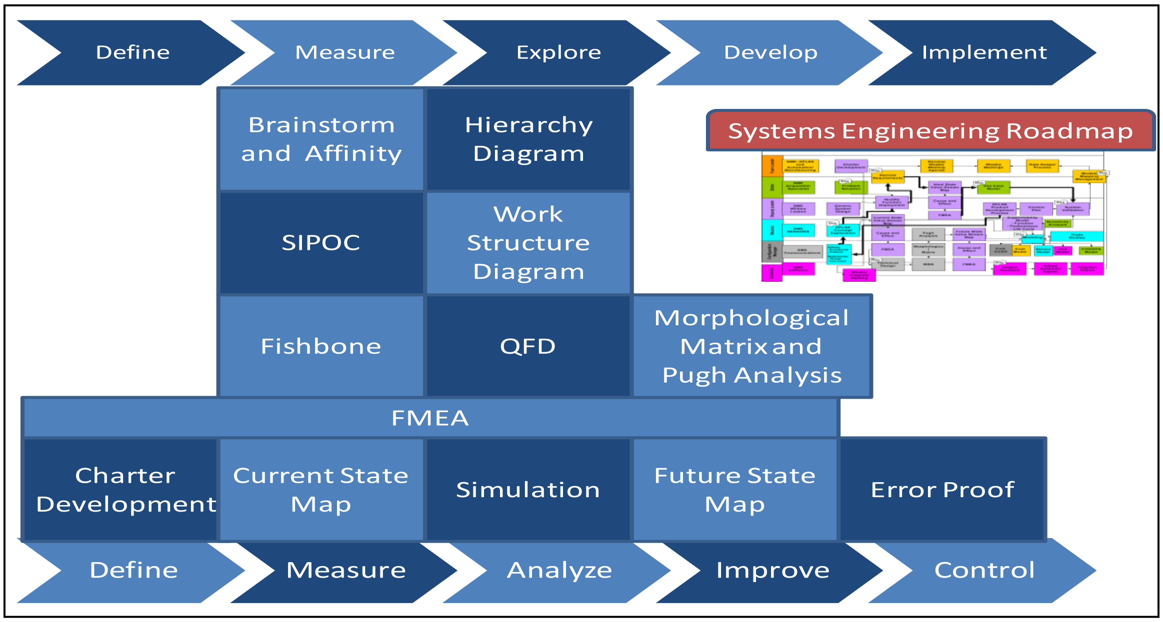


Figure 78. DoD Combined DMEDI/DMAIC Design for Lean Six Sigma Approach.

Developed for the Department of Defense in 2007, Design for Lean Six Sigma Tools from the DMEDI process were combined with Lean and DMAIC Six sigma Tools. The team divided these tasks into a Systems Engineering Roadmap. [U.S. DoD 2007]

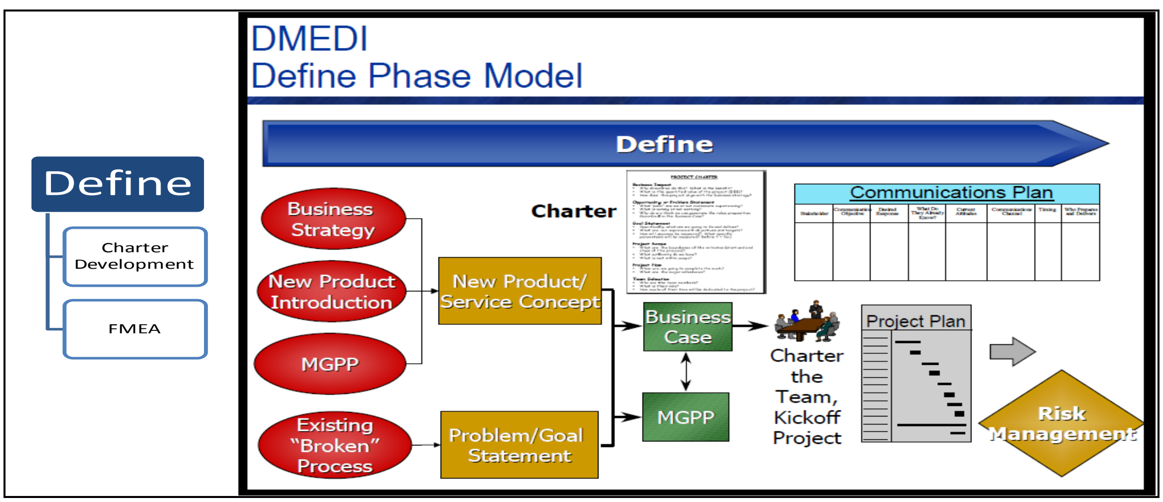


Figure 79. DMEDI Define Phase Model

The systems engineering roadmap utilized <u>Define</u> phase DMEDI tools: Charter and FMEA. [U.S. DoD 2007]

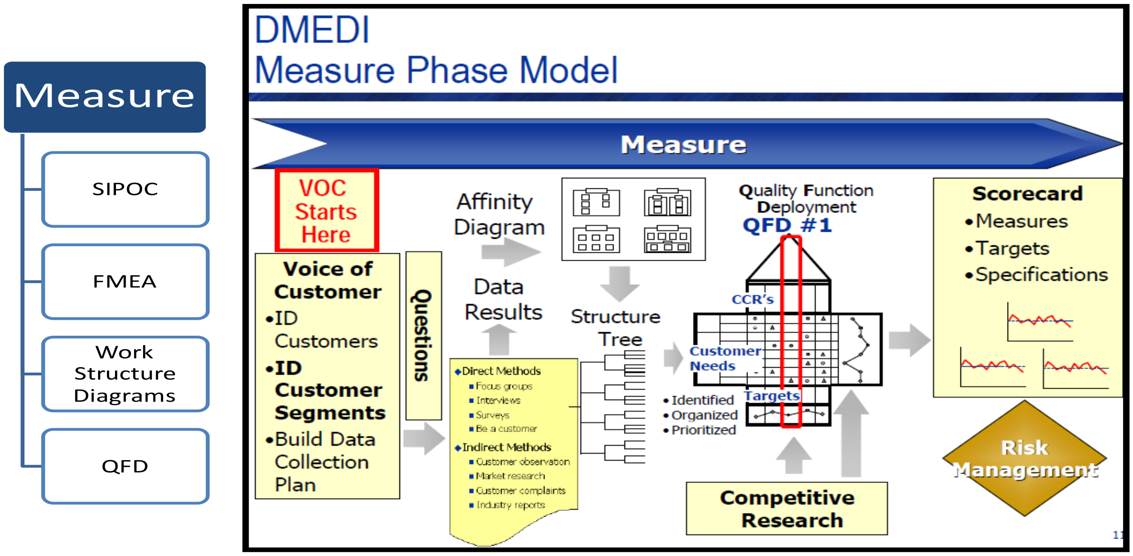


Figure 80. DMEDI Measure Phase Model

The Systems Engineering Roadmap utilized <u>Measure</u> phase DMEDI tools: SIPOC, FMEA, Work Structure Diagrams, and QFD. [U.S. DoD 2007]

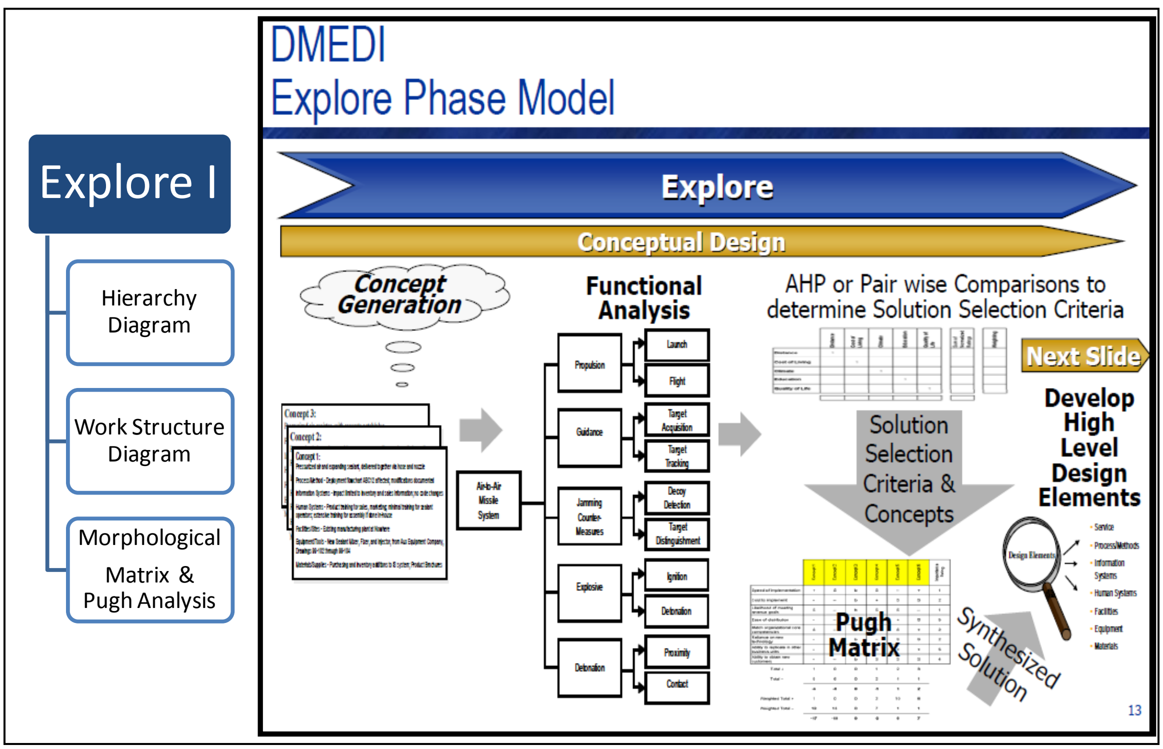


Figure 81. DMEDI Explore Phase Model.

The Systems Engineering Roadmap utilized <u>Explore</u> phase DMEDI tools: Hierarchy Diagram, Work Structure Diagram, Morphological Matrix and Pugh Matrix. [U.S. DoD 2007]

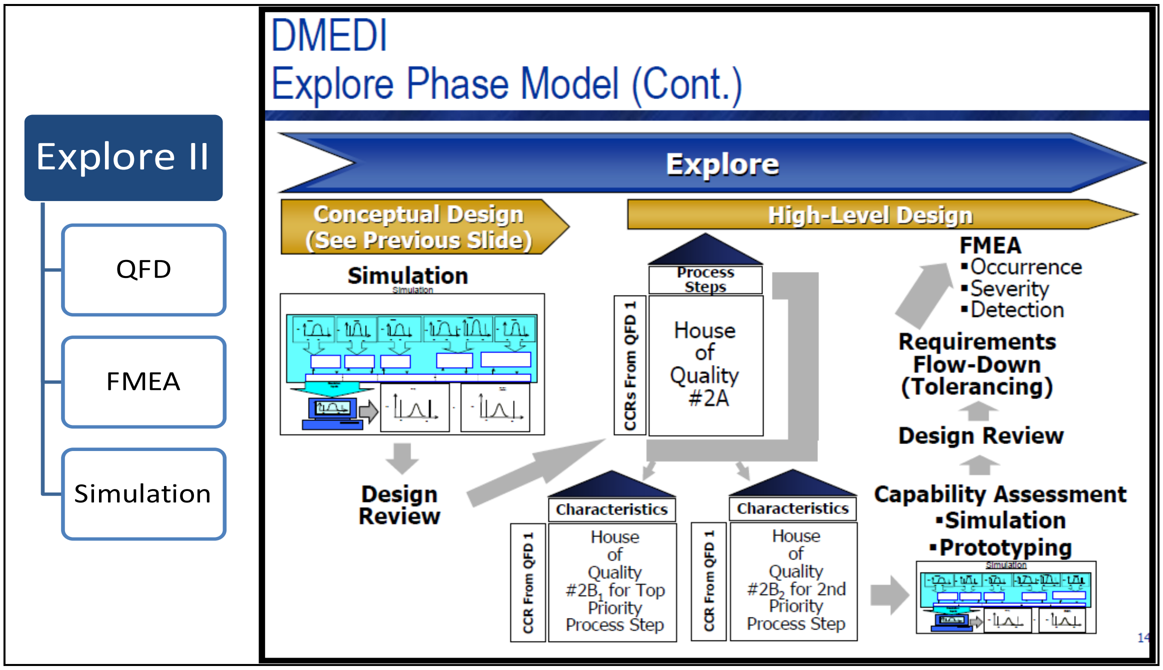


Figure 82. DMEDI Explore Phase Model (Cont.).

The Systems Engineering Roadmap utilized Explore phase DMEDI tools: QFD, FMEA, and Simulation. [U.S. DoD 2007]

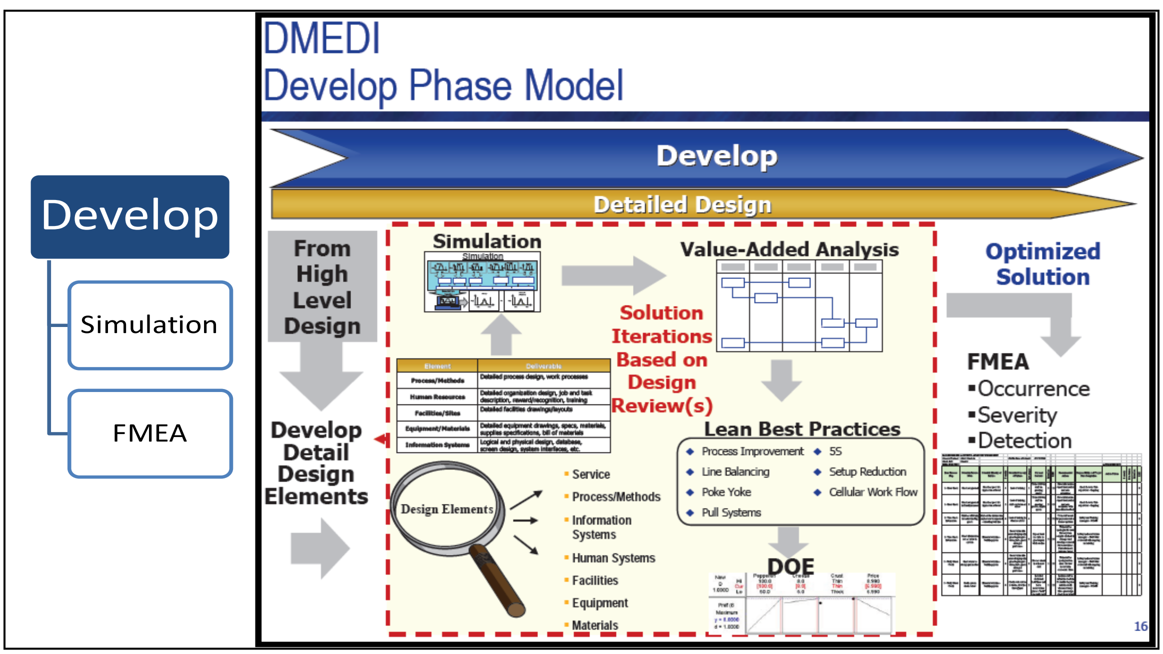


Figure 83. DMEDI Develop Phase Model.

The Systems Engineering Roadmap utilized Develop phase DMEDI tools: Simulation, FMEA, and other design elements. [U.S. DoD 2007]

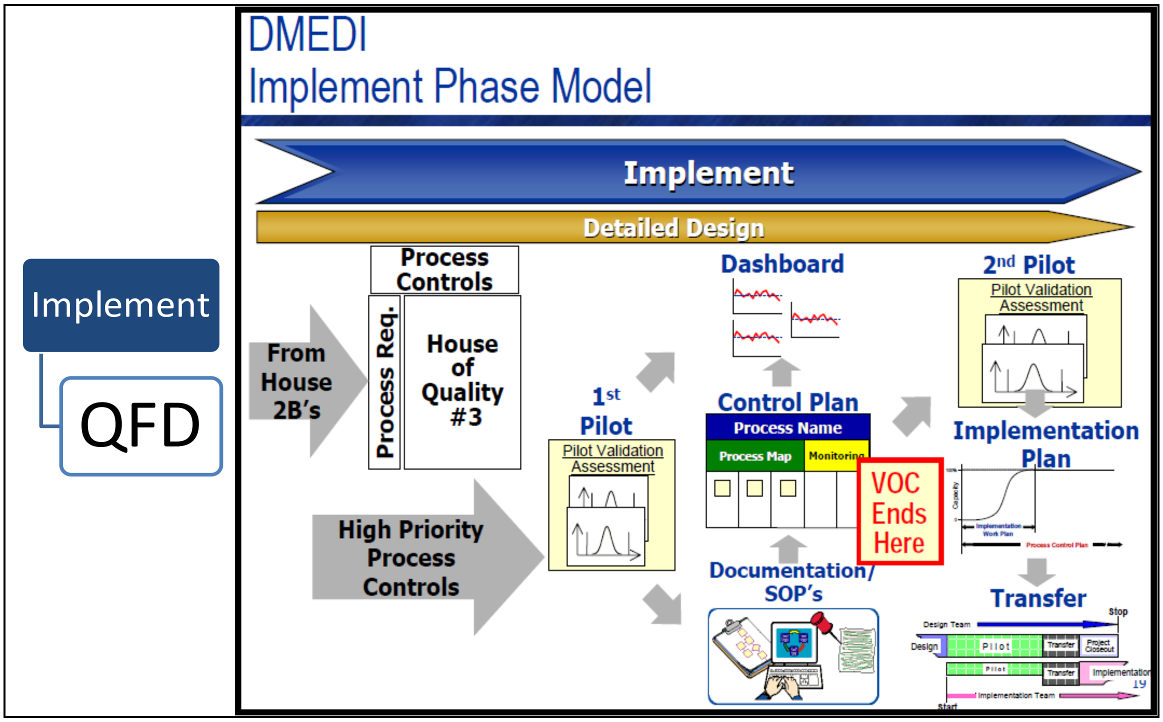


Figure 84. DMEDI Implement Phase Model.

The Systems Engineering Roadmap utilized Implement phase DMEDI tools: QFD. [U.S. DoD 2007]

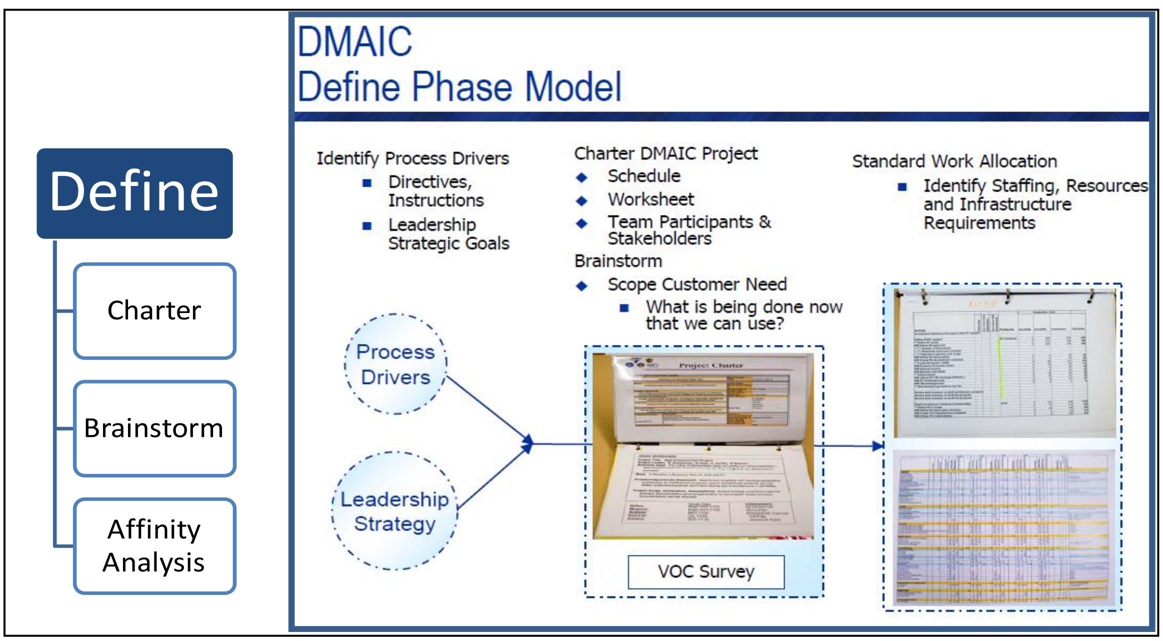


Figure 85. DMAIC Define Phase Model.

The Systems Engineering Roadmap utilized Define Phase Tools from DMAIC: Brainstorm, Charter, and Affinity Analysis. [U.S. DoD 2007]

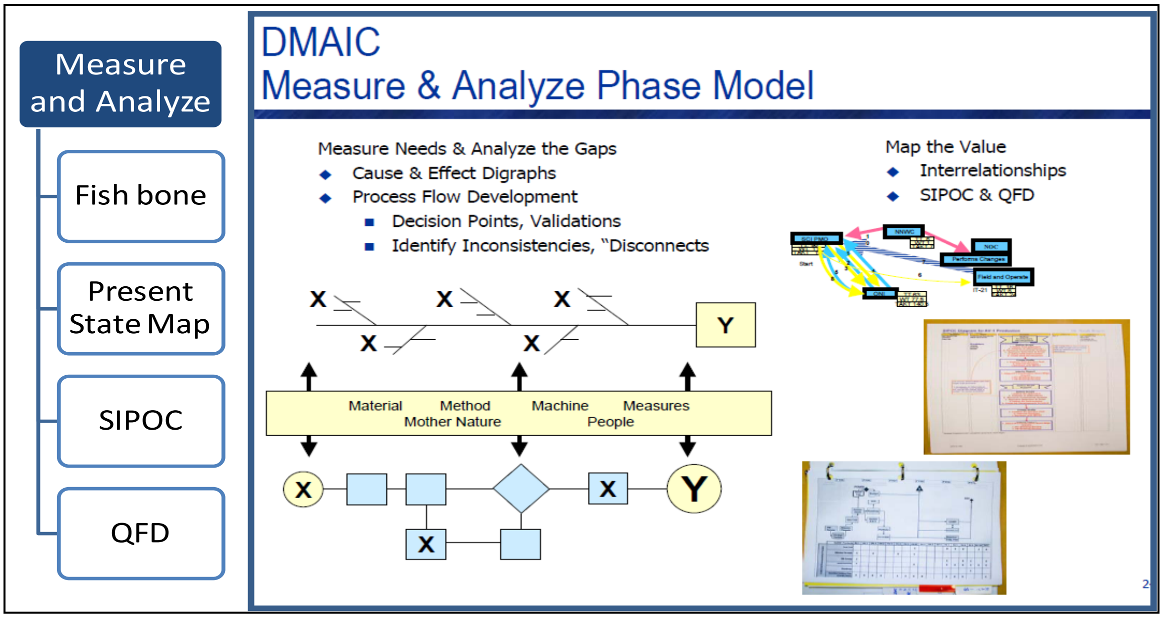


Figure 86. DMAIC Measure & Analyze Phase Model.

The Systems Engineering Roadmap utilized Measure and Analyze Phase DMAIC Tools from DMAIC: Fishbone, Present State Map, SIPOC, and QFD. [U.S. DoD 2007]

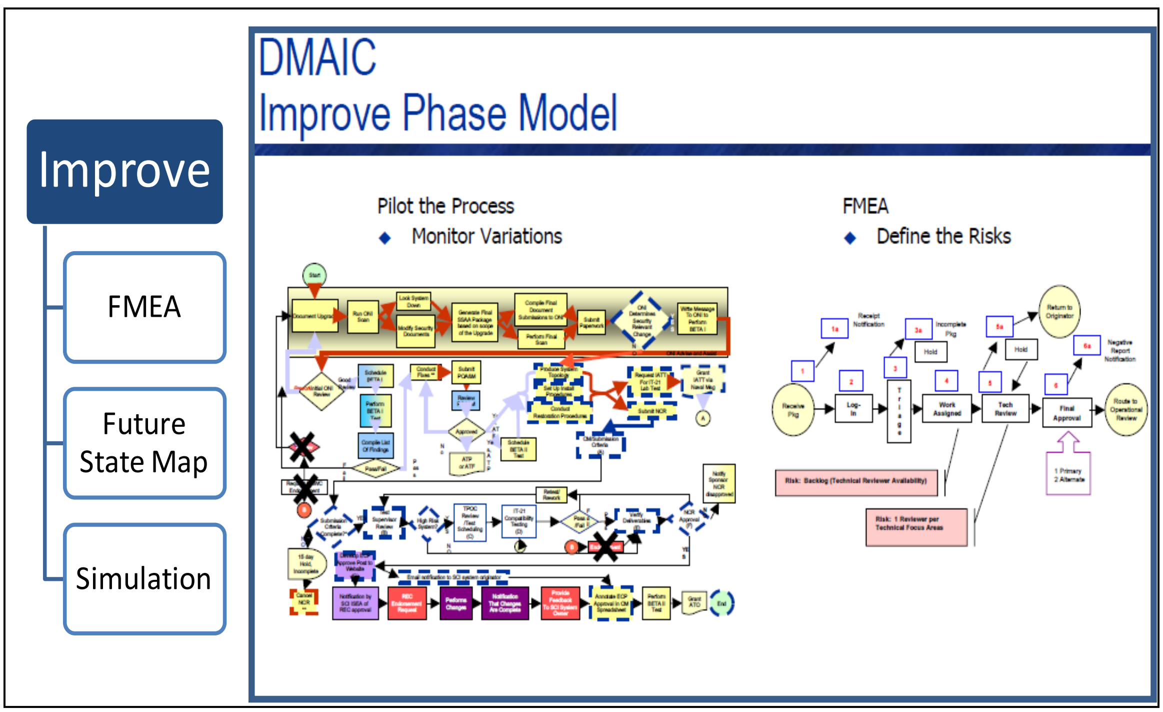


Figure 87. DMAIC Improve Phase Model.

The Systems Engineering Roadmap utilized Improve Phase DMAIC Tools: Future State Map, Simulation, and FMEA. [U.S. DoD 2007]

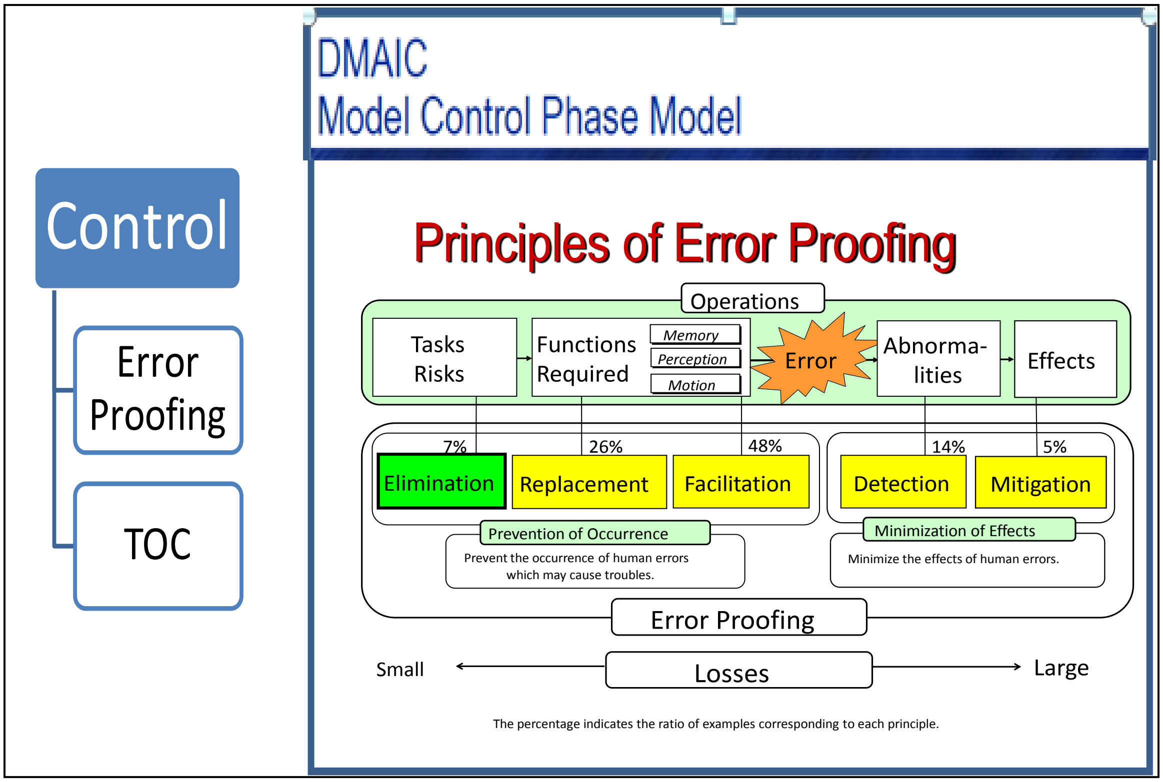


Figure 88. DMAIC Model Control Phase Model.

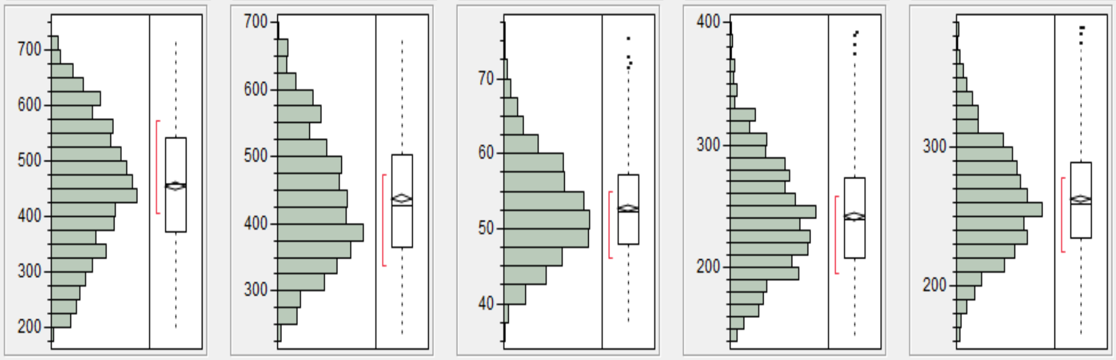
The Systems Engineering Roadmap utilized Control tools from Lean and DMAIC: Error Proofing and TOC. [U.S. DoD 2007]

APPENDIX M – STATISTICAL DATA

Table 20. Data Analysis

Distributions

Enemy | HVA | RSS | Warship 1 | Warship 2



Quantiles

		Enemy	HVA	RSS	Warship 1	Warship 2
100.0%	maximum	724.79	676.79	75.273	391.29	385.54
99.5%		702.04	663.90	70.960	365.82	369.75
97.5%		658.56	625.47	66.416	331.14	346.33
90.0%		608.03	573.92	61.104	304.05	313.09
75.0%	quartile	540.40	502.91	57.218	272.60	288.70
50.0%	median	457.04	427.33	52.144	239.14	259.09
25.0%	quartile	371.33	364.66	47.943	207.83	234.26
10.0%		291.84	319.99	44.456	182.33	213.21
2.5%		227.30	272.95	41.244	161.80	190.04
0.5%		205.72	249.95	38.601	147.97	170.15
0.0%	minimum	187.63	236.02	37.239	142.42	160.64

Moments

	Enemy	HVA	RSS	Warship 1	Warship 2
Mean	453.94618	436.90097	52.650488	241.23844	262.03383
Std Dev	116.10823	94.939018	6.5086349	45.68941	39.157905
Std Err Mean	3.6716648	3.0022354	0.2058211	1.444826	1.2382817
Upper 95% Mean	461.15124	442.79238	53.054379	244.07368	264.46376
Lower 95% Mean	446.74112	431.00955	52.246596	238.4032	259.6039
N	1000	1000	1000	1000	1000

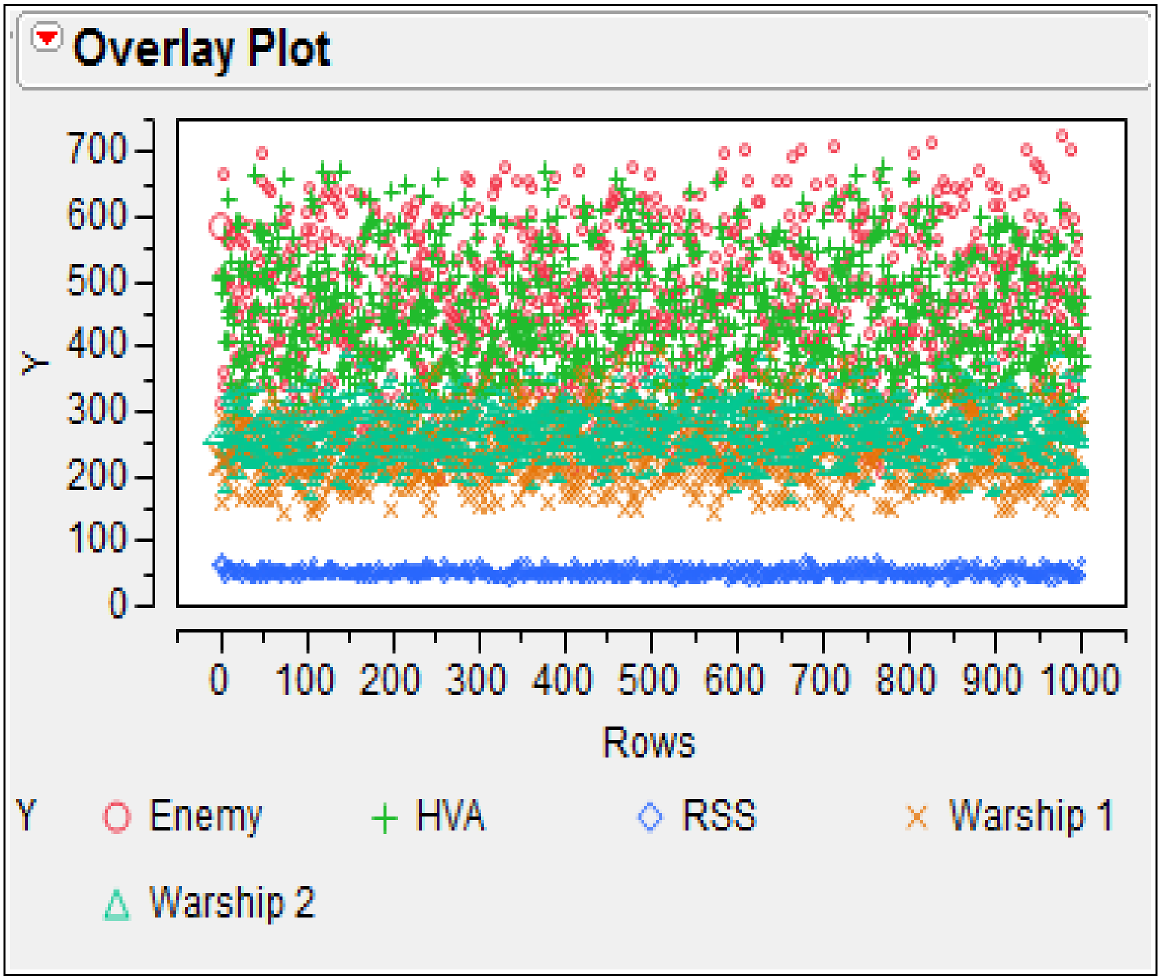


Figure 89. Overlay Chart.

Overlay Plot depicts the interaction between the enemy, HVA, RSS, Warship 1, and Warship 2.

Table 21. Two Sample T-Test Part 1.

Two-Sample T-Test and CI: RSS, Enemy

```
Two-sample T for RSS vs Enemy

         N   Mean  StDev  SE Mean
RSS    1000  52.65   6.51     0.21
Enemy  1000    454    116      3.7


Difference = mu (RSS) - mu (Enemy)
Estimate for difference:  -401.30
95% CI for difference:  (-408.51, -394.08)
T-Test of difference = 0 (vs not =): T-Value = -109.12  P-Value = 0.000  DF =
     1005
```

Remote Sea Station versus Enemy – P<alpha, reject null hypothesis = ““Statistically Different”

Two-Sample T-Test and CI: RSS, HVA

```
Two-sample T for RSS vs HVA

        N   Mean  StDev  SE Mean
RSS  1000  52.65   6.51     0.21
HVA  1000  436.9   94.9      3.0


Difference = mu (RSS) - mu (HVA)
Estimate for difference:  -384.25
95% CI for difference:  (-390.16, -378.35)
T-Test of difference = 0 (vs not =): T-Value = -127.69  P-Value = 0.000  DF =
     1008
```

Remote Sea Station versus High Value Asset – P<alpha, reject null hypothesis = ““Statistically Different”

Table 22. Two Sample T-Test Part 2.

Two-Sample T-Test and CI: RSS, Warship

```
Two-sample T for RSS vs Warship

           N   Mean  StDev  SE Mean
RSS      1000  52.65   6.51     0.21
Warship  1000  241.2   45.7      1.4


Difference = mu (RSS) - mu (Warship)
Estimate for difference:  -188.59
95% CI for difference:  (-191.45, -185.72)
T-Test of difference = 0 (vs not =): T-Value = -129.22  P-Value = 0.000  DF =
     1039
```

Remote Sea Station versus Warship 1 – P<alpha, reject null hypothesis = ""Statistically Different"

```
Two-sample T for Warship vs Warship 2

            N   Mean  StDev  SE Mean
Warship    1000  241.2   45.7      1.4
Warship 2  1000  262.0   39.2      1.2


Difference = mu (Warship) - mu (Warship 2)
Estimate for difference:  -20.80
95% CI for difference:  (-24.53, -17.06)
T-Test of difference = 0 (vs not =): T-Value = -10.93  P-Value = 0.000  DF =
     1952
```

Remote Sea Station versus Warship 2 – P<alpha, reject null hypothesis = ""Statistically Different"

Two-Sample T-Test and CI: RSS, Warship 2

```
Two-sample T for RSS vs Warship 2

            N   Mean  StDev  SE Mean
RSS        1000  52.65   6.51     0.21
Warship 2  1000  262.0   39.2      1.2


Difference = mu (RSS) - mu (Warship 2)
Estimate for difference:  -209.38
95% CI for difference:  (-211.85, -206.92)
T-Test of difference = 0 (vs not =): T-Value = -166.80  P-Value = 0.000  DF =
     1054
```

Warship versus Warship 2 – P<alpha, reject null hypothesis = ""Statistically Different"

APPENDIX N – ACRONYMS LIST

Acronym	Term
4 M's	Machinery, Mother Nature (environment), Method, Manpower
ASCMs	Advanced Anti-ship Cruise Missiles
ASHC	Automated Super-Highway Concept
ASW	Anti-Submarine Warfare
BAMS	Broad Area Maritime Surveillance System
BLOS	Beyond Line of Sight
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance
CM	Configuration Management
CNO	Chief of Naval Operations
CONOPS	Concept of Operations
CPI	Continuous Process Improvement
CPU	Central Processing Unit
CSG	Carrier Strike Group
CTC	Critical-to-the-Customer
CTP	Critical-to-Process
CTQ	Critical to Quality
CTX	Critical to X
DCOV	Define, Characterize, Optimize, and Validate
DFLSS TOOLS	Design for Lean Six Sigma tools
DFLSS TOOLSBB	Design for Lean Six Sigma tools Black Belt
DL	Distance Learning
DMEDI	Define, Modify, Explore, Design, Implement
DoD	Department of Defense
EMI	Electromagnetic Interference
EOIR	Electro Optical Infra Red
ESG	Expeditionary Strike Group
FMEA	Failure Mode and Effect Analysis
FRACAS	Failure Reporting and Corrective Action System
HOQ	House of Quality
HQ	Headquarters

Acronym	Term
HSPD-13	Homeland Security Presidential Directive 13
HVA	High Value Asset
HVA2	High Value Asset 2
JTIC	Joint Tactical Intelligence Center
KTS	Knots
LCC	Life Cycle Cost
LCS	Littoral Combat Ship
LOS	Line of Sight
LVA	Low Value Asset
M&S	Modeling and Simulation
MARS	Mission Agile Robotic Systems
MDS	Maritime Domain System
MFR	Multi-Function Phased Array Radar
Min	Minutes
MIW	Mine Warfare
MOC	Maritime Operations Center
MOOTW	Military Operations Other Than War
MTBF	Mean Time Between Failures
MSSE	Masters of Science in Systems Engineering
NATO	North Atlantic Treaty Organization
NCW	Network Centric Warfare
Nm	Nautical Miles
NPS	Naval Postgraduate School
NSWCCD	Naval Surface Warfare Center, Carderock Division
NSWCDL	Naval Surface Warfare Center, Dahlgren Lab
PLC	Programmable Logic Controller
QFD	Quality Function Deployment
RADHAZ	Radiation Hazards
RCS	Radar Cross Section
RSS	Remote Sea Station
RF	Radio Frequency
RPG	Rocket Propelled Grenade
RPN	Risk Prioritization Number
SIMIO	Simulation modeling software
SIPOC	Supplier, Input, Process, Output, and Customer

Acronym	Term
SME	Subject Matter Expert
SSGNs	Special Service Groups Navy
SUW	Surface Warfare
TOC	Theory of Constraints
UAV	Unmanned Aerial Vehicle
USV	Unmanned Surface Vehicle
VOC	Voice of the Customer
WBS	Work Breakdown Structure

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