ABSTRACT

Title of Document: AN ANALYSIS OF THE COAST GUARD'S SURFACE FLEET RELIABILITY PROGRAM FOR MEDIUM ENDURANCE CUTTERS

Heidi L. Koski, M.S., 2011

Directed By: Professor Jeffrey Herrmann, Department of Reliability Engineering

In 2009, the Coast Guard Surface Forces Logistics Center implemented a reliability program in an effort to improve mission availability of its aging surface fleet. This thesis is an exploratory analysis of the current status of the newly implemented program using Soft Systems Methodology (SSM) and statistical techniques with the objective of determining how the shift to reliability-centered maintenance has affected the availability of the medium endurance cutter fleet. The SSM analysis led to the examination of eight (8) years of cutter machinery failure data as a measure to transform cutter maintenance. This revealed lower than desired availability percentages and a worsening trend in cutter availability over time. Key opportunities for improvement are identified as well as several next analysis steps or areas for future work are proposed.

AN ANALYSIS OF THE COAST GUARD'S SURFACE FLEET RELIABILITY PROGRAM FOR MEDIUM ENDURANCE CUTTERS

By

Heidi L. Koski

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Masters of Science
2011

Advisory Committee:
Professor Jeffrey Herrmann, Chair
Professor Ali Mosleh
Professor Linda Schmidt

Acknowledgements

I would like to thank the United States Coast Guard for funding my education. My time at the University of Maryland has been a wonderful experience thanks to the many friends I have made here and all the wonderful professors who have guided me, especially my committee members Dr. Ali Mosleh and Dr. Linda Schmidt. A special thanks to my advisor, Dr. Jeffrey Herrmann, for all the time and effort he spent helping me and furthering my understanding of reliability engineering principles.

A special thank you to my family – Mom and Dan, thank you for all the hours spent proofreading; Dad and Kay – thank you for your support. And to my husband Kevin, thank you for your love and support through everything. I love you all!

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

With recent events such as Hurricane Katrina of 2005 and the Deepwater Horizon oil spill of 2010 affecting our nation and the earthquake that hit Haiti, the United States Coast Guard has been under the spotlight with major response efforts in addition to the other mandated missions that must be performed. In 2010 alone, the "Coast Guard also saved more than 4,300 lives, responded to more than 22,000 search and rescue cases, prevented more than 200,000 pounds of cocaine from reaching the U.S., boarded more than 2,100 High Interest Vessels bound for U.S. ports, interdicted nearly 4,700 undocumented migrants attempting to illegally enter the United States from the sea, and conducted more than 5,000 fisheries conservation boardings" [1]. The increase on the already high operational tempo puts more pressure on Coast Guard engineers to maintain an aging cutter fleet. Reliability, availability, and maintainability are the top priorities in the Coast Guard's surface fleet engineering program. Reliability centered maintenance principles are being employed to maximize the availability of cutters in order to complete all Coast Guard missions. It is imperative that analytical tools and methods are employed to utilize all assets to their potential safely and effectively.

1.1 Coast Guard Overview

The Coast Guard is the smallest of the United States' five armed forces and operates under the Department of Homeland Security. As of May 2010, the Coast Guard consists of the following personnel: over 42,000 active duty, 7,000 reservists, 8,000 civilians and 30,000 auxiliary members. The Coast Guard currently is mandated by law to conduct the following primary missions:

1. **Ports, waterways and coastal security**: This is the Coast Guard's designated primary mission. This mission involves protection of the U.S. maritime domain to include counterterrorism (offensive) actions, antiterrorism (defensive) actions and response operations.

2. **Drug interdiction**: The Coast Guard combats the flow of illegal drugs into the United States over a six million square mile area. In 2009, almost 400,000 pounds of cocaine and over 35,000 pounds of marijuana were seized. The Coast Guard's cocaine seizures account for approximately fifty percent of total U.S. seizures.

3. **Aids to navigation**: The Coast Guard provides continuous monitoring and control of navigation and positioning systems to include differential global positioning system, nationwide automated identification system and visual aids to navigation (buoys, lighthouses, etc.).

4. **Search and rescue**: Search and rescue is one of the oldest and most-well known Coast Guard missions. Search and rescue units are located throughout the entire contiguous U.S. and in all outlying states and territories. Since its inception the Coast Guard has saved over 1,000,000 lives.

5. **Living marine resources**: This mission gives the Coast Guard authority to protect the United States' exclusive economic zone from foreign

encroachment. Authority is also given to enforce domestic fisheries laws which protect marine mammals. Development and enforcement of international fisheries agreements also occurs under this mission.

6. **Marine safety**: This mission focuses on the maritime industry and its success. The Coast Guard works hand in hand with civilians in every major and minor port to maintain continuous commerce through vessel and port inspections.

7. **Defense readiness**: Prior to September 11, 2001, at times of war, the Coast Guard operated under the Navy. After 9/11, defense readiness took on a new meaning and now the Coast Guard has a daily defense readiness regimen that is heightened as terror threats occur.

8. **Migrant interdiction**: Illegal immigration has been a growing problem for the United States since the 1980 mass exodus from Cuba. In the 1990's, a mass exodus occurred from Haiti as well. Today, the Coast Guard intercepts migrants from these and other Caribbean nations, as well as from several Asian nations. The Coast Guard conducts this mission primarily as protection of loss of life at sea.

9. **Marine environmental protection**: This mission is to "develop and enforce regulations to avert the introduction of invasive species into the maritime environment, stop unauthorized ocean dumping, and prevent oil and chemical

spills" [2]. Since 2008, emergency and incident management response was added under the scope of this mission.

10. **Ice operations**: Northern waterways are kept navigable year-round for commerce through the Coast Guard's ice-breaking operations. The Coast Guard also provides the only year-round access to the polar regions.

11. **Other law enforcement**: The Coast Guard enforces other domestic and international laws pertaining to fisheries, maritime safety, and maintaining the waterways.

The accomplishment all of these missions relies on the Coast Guard's physical assets at sea, on land and in the air. There are currently 248 cutters (a Coast Guard vessel that is 65 feet or greater), 1,784 boats (less than 65 feet) and 198 aircraft [2]. A listing of the classes of each type of asset is given below:

Cutters:
420' Icebreaker
418' National Security Cutter
399' Polar Class Icebreaker
378' High Endurance Cutter
295' Training Barque Eagle
282' Medium Endurance Cutter
270' Medium Endurance Cutter
240' Seagoing Buoy Tender/Icebreaker
225' Seagoing Buoy Tender
210' Medium Endurance Cutter
179' Patrol Coastal
175' Coastal Buoy Tender
160' Inland Construction Tender
140' Icebreaking Tug
110' Patrol Boat
100' Inland Buoy Tender
100' Inland Construction Tender
87' Coastal Patrol Boat

75' River Buoy Tender
75' Inland Construction Tender
65' River Buoy Tender
65' Inland Buoy Tender
65' Small Harbor Tug

Boats: 47' Motor Life Boat
41' Utility Boat
21'-64' Aids to Navigation Boats
25' Transportable Port Security Boat
25' Defender Class Boats

Aircraft: HC-130H Hercules
HU-25 Guardian
HH-60 Jayhawk
H-65 Dolphin

To accomplish the varying missions, assets are designed to be multi-mission, such as conducting search and rescue operations one day and interdicting drugs the next. Operating and maintaining multi-mission assets is costly. The Coast Guard operates with a total budget of approximately ten billion dollars with only $62 million going towards surface and air asset operation and maintenance and $856 million going towards production of new cutters and major maintenance overhauls of older "legacy" cutters. Legacy cutters are the high and medium endurance cutters (HEC and MEC) that have long been the workhorses of the modern Coast Guard. On average, these cutters are forty-one years old, while Navy assets are on average only fourteen years old [3]. In order to accomplish all of the aforementioned missions, maintenance is a growing concern to ensure availability of cutter assets when required.

1.2 Surface Fleet Reliability Engineering Program

The Coast Guard is currently undergoing an organizational modernization, involving business practices, command structure, and support services. With the decommissioning of the long range enforcer cutters and delays in the commissioning of the new national security cutters, more emphasis on mission completion has been delegated to the medium endurance cutters (MEC). These aging cutters are expected to meet a minimum of ninety percent availability during the fifty-five percent minimum of the year (i.e., 4,820 hours per year minimum) that each cutter deploys. Maintenance periods have grown shorter as patrols have increased which has necessitated multiple crew rotations. Constant funding constraints have caused continuous amounts of deferred maintenance, jeopardizing the availability of cutters to meet operational needs. A large portion of the modernization program focuses on engineering and maintenance with emphasis on streamlining maintenance through the implementation of a reliability engineering program within the surface fleet.

1.2.1 Setting the Foundation through Coast Guard Aviation

The surface fleet community is implementing a reliability program based on the aviation community's program, which is simply described as the "aviation model." Before giving a brief overview of the aviation model and how the surface fleet is trying to mimic this, it is important to understand how the current aviation model came to fruition within the Coast Guard. The aviation industry as a whole started investigating new maintenance methods of improving aircraft reliability in the 1960's through a joint effort of the Federal Aviation Administration and the airlines. Out of this effort came the MSG-1 Handbook which detailed the development of preventive maintenance for new aircraft, specifically, the Boeing 747 [16]. This document was updated several times over the next two decades to include decision logic and analysis procedures with a focus on promoting optimized and cost effective maintenance, thus laying the foundation for the reliability-centered maintenance (RCM) programs in use today [4].

Prior to the nineties, the Coast Guard aviation program conducted preventive maintenance through routine and specified inspections, replacements, or overhauls. Unplanned maintenance was dealt with on a case by case basis, with little to no trend analysis to predict future casualties. While preventive maintenance can restore a component's inherent reliability, it cannot improve upon it. Manufacturers' maintenance recommendations were made the standard, regardless of operating conditions. All maintenance was, and still is, conducted mainly by Coast Guard technicians who also serve as members of the aircrew, operating the aircraft during each mission. This creates a unique environment in that those individuals who conduct maintenance are also the operators, thereby jeopardizing their own safety if reliability is compromised.

In the seventies, the Coast Guard aviation program implemented a new and progressive maintenance program based on the FAA MSG-1 Handbook. With the strictly preventive maintenance program, maintenance tasks were conducted in large groups; however, in the new progressive program, each individual maintenance task was conducted and tracked separately. It was not until the nineties, when a reorganization of the aviation community created a centralized and streamlined maintenance management program, that the current RCM program was fully introduced into the aviation community [5].

1.2.2 Shift in Maintenance Ideology for the Surface Fleet

Like the aviation community, preventive maintenance was the dominating theory for the Coast Guard's surface fleet maintenance program until recently. Invasive inspections, overhauls and even expensive drydocks occurred at set intervals regardless of the condition of the machinery or cutter as a whole. This type of maintenance not only did not improve the reliability or availability of machinery, but sometimes even worsened it. Both large-scale and small-scale root cause failure analyses revealed that incorrect and unnecessary maintenance often contributed to component casualties. This, and other organizational factors, sparked the transformation towards aligning surface fleet maintenance with the aviation model.

In 2000, the Coast Guard's surface fleet engineering community took the first steps in implementing RCM procedures in order to meet the maintenance demands currently on the Medium Endurance Cutter (MEC) fleet. Use of RCM was mandated in 2004 in the Naval Engineering Manual in order to develop optimal maintenance requirements. In 2009, the full-scale surface fleet reliability engineering program was approved for implementation. It was impossible to implement a cookie cutter copy of the aviation model due to the operational and configuration differences of cutters compared to air assets. Like in the commercial aviation industry, each class of the Coast Guard's air assets are configured exactly the same. Any qualified pilot can fly any operational asset that they have trained on in the Coast Guard. Maintenance is also conducted exactly the same way utilizing kits based on the task. When maintenance is conducted on an aircraft, it is completely unavailable for the repair duration until all systems are one hundred percent. Cutter operation and maintenance does not work like this, though in an ideal world, it would. All cutter personnel, regardless of their having been on a similar cutter in the past, must re-qualify on the new cutter because of its nuances and different operating environment. Cutters are significantly older than the air assets. Replacement parts are expensive, have long lead acquisition times, or are even obsolete and no longer supportable due to their age. When a component breaks on a cutter, it is not tied to the pier until repairs are complete. As long as it can get underway (deploy) safely, it will, and the maintenance will occur as time and parts availability allows.

Another major difference between the aviation and surface fleets is the fact that cutter crews have to live and work onboard the cutter. This causes many deviations from a standard machinery configuration that cutters strive to maintain. The crew obviously wants to make the cutter a better environment for them to live and work, and do not consider the repercussions of modifying layout and components because it does not affect their direct safety. The impact on operational readiness and availability due to logistics, however, is quite large. Buy-in from all organizational levels has been a constant challenge during the implementation of both the air and surface reliability programs. The "old" way of doing business was personality-dependent, with many tasks completed and resources found based on who you know in what job. The new process-dependent system opposes the cultural environment in place within the maintenance and logistics realm. To counteract opposition and gain buy-in, the reliability program must clearly define its goals, processes, and how it affects individuals on a personal basis.

Because of the aforementioned challenges, the implementation of the reliability program began on a small scale with the small boat product line. This product line, which includes all surface assets up to sixty-four feet in length, "aligns all boat support resources under a single entity with authority and accountability for maintenance and logistics" [2]. The focus of the product line is "affordable readiness" through a logistics transformation process. In the implementation of the aviation reliability program, maintenance logistics proved to be the most costly and difficult aspect. It is also the one aspect of affordable readiness (see Figure 1) that can be controlled through more efficient processes within the organization [6].

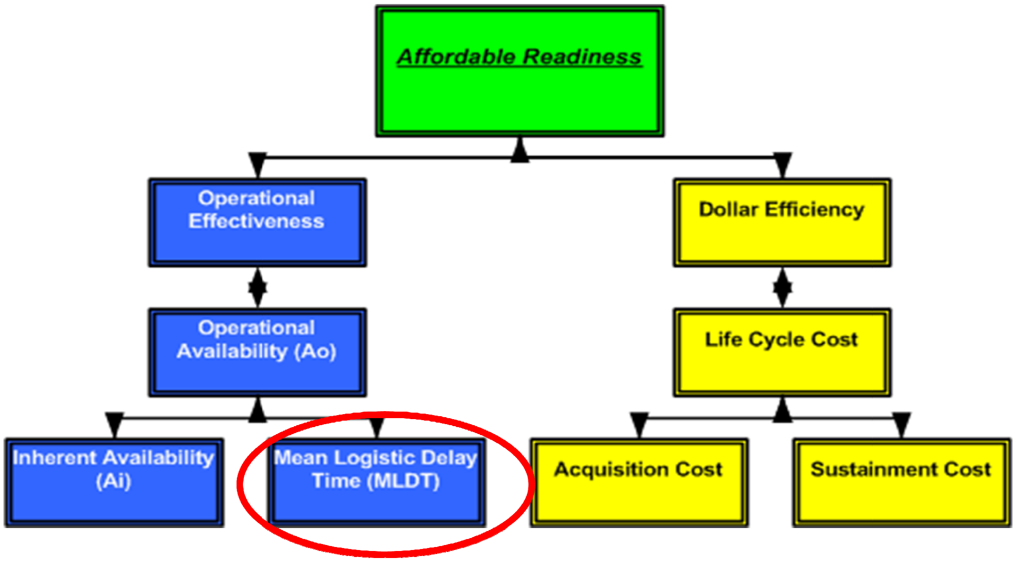


Figure 1: Affordable readiness [6]

Because most of the surface fleet assets have been in service for many years (only the National Security Cutters are new), the Coast Guard is using the "Backfit RCM" process [7]. "Backfit RCM" was developed by Naval Sea Systems Command (NAVSEA) to use operating experience to validate, adjust, or update existing maintenance procedures when there is a significant amount of operational and maintenance history. A key aspect of RCM is continuous improvement, meaning that no maintenance program should remain the exact same over time. Implementing "Backfit RCM" utilizes this concept in developing optimized maintenance requirements. "Backfit RCM" looks at four main areas: reliability degradation, task applicability, task effectiveness, and recommending change. First, equipment failure modes are looked at, specifically for age degradation and the associated causes. Each maintenance task is then looked at individually for its applicability and effectiveness in restoring inherent reliability. Lastly, any improvements that can be made should be documented and implemented [8]

1.2.3 Assessment of Current State Defines Future Goals

The problematic current state of the surface fleet reliability engineering program defines several key go-forward goals of the Surface Fleet Reliability Engineering Program. First, it is essential to determine a way to integrate the core concepts of the Coast Guard's aviation reliability engineering model into the surface fleet product lines' maintenance requirements. When the surface fleet's reliability program was implemented in 2009, the existing organization did not have the infrastructure necessary to accomplish the goals outlined in the Reliability Engineering Process Guide, and the personnel affected were not prepared for a major organizational transformation.

Secondly, the surface fleet must determine what data needs to be utilized in order to fully implement a reliability engineering program. Once this is established, program managers should ascertain whether the necessary data is already being gathered from the cutters, or whether a new data-gathering process must be developed and instituted.

Thirdly, it is essential to develop a method to transform engineering data into constructive operational information. As in other industries, the Coast Guard focuses on the bottom line. In the Coast Guard organization, the bottom line is having the assets necessary to complete all required missions. The way to accomplish this is approached very differently by operators and engineers. Engineers focus on the equipment failures and ways to prevent failures, while operators want final asset availability percentages. Thus, engineering data must be transformed into constructive operational information.

1.3 Review of Prior Work

Reliability engineering principles and their impact on the Coast Guard have been studied over the past thirty years. Now retired Captain William Spitler (USCG-Ret) investigated the possible incorporation of RCM for the aviation program in a Master of Science in Management program from the Massachusetts Institute of Technology in 1990 [5]. As previously mentioned, the aviation fleet introduced reliability principles to aircraft maintenance shortly after this timeframe. In-depth analyses were conducted on the air assets such as the loss of in-flight power for the HH-65 helicopter engine by CDR Donna Cottrell in 2004 [14]. This analysis was of particular importance because it investigates correlations between the flight mishaps and engine component replacements, as well as the funding and political impacts on mission availability. Because the Coast Guard is a federal agency, politics can play a large role in business operations, sometimes negatively impacting the way maintenance must be conducted to meet federal mandates. Based on this study, the Coast Guard revised overhaul times for this particular engine, and conducted further studies on various systems on all the aircraft platforms.

Using the Coast Guard aviation fleet's RCM program's analyses and the United States Navy's RCM programs, the Coast Guard surface fleet community began investigating the opportunities and benefits of incorporating RCM principles into cutter maintenance. Analyses were conducted in 2008 by outside resources on various critical systems (e.g., Firemain, HVAC, Ventilation, Gaylord hood, etc.) to determine their status fleet-wide. An example of the gathered data for the Firemain system is shown below in

Figure 2. The final conclusions of these analyses recommended “continued diagnostics using RCM principles to determine the root cause of failures” [15].

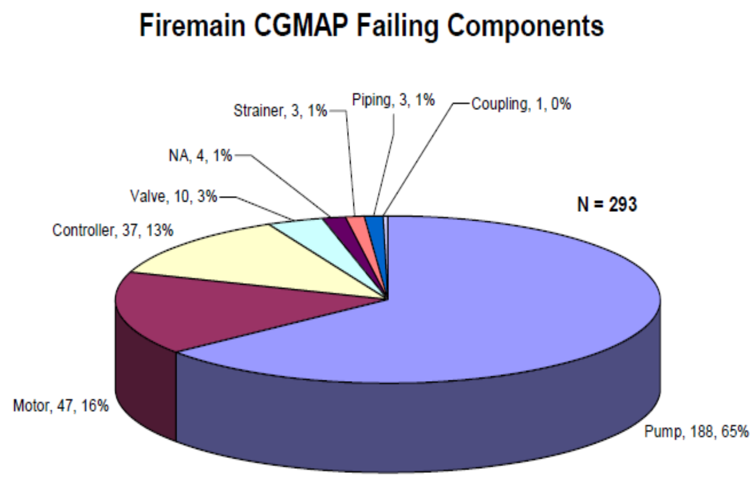


Figure 2: Breakdown of Failures by Subsystem for the Firemain System taken from 2008 Engineering Logistics Center (now SFLC) Report

While individual components and some systems have been analyzed from a reliability standpoint, the program as a whole has only begun being analyzed. The firm, “Linton, Galle, and Harris”, the Coast Guard’s leading RCM process consultants, have published numerous documents on implementation of RCM into the USCG surface fleet. They published “RCM Baseline for USCG Maintenance Development” in 2009 discussing how RCM-based principles could revamp the current maintenance system into a more effective program within the modernization and logistics transformation taking place at that time [7].

The research accomplished in this thesis will provide the Coast Guard senior leadership an overview of how cutter availability relates to overall mission availability using machinery failure data over a seven year period. By identifying the subsystems that lead to operational downtime, the naval engineering program can determine if new systems should be introduced or maintenance procedures revised to improve system reliability. This thesis will also provide recommendations for improvements to the surface fleet reliability program and how individuals within naval engineering can adapt to the new program.

1.4 Research Questions and Thesis Organization

Based on the go-forward goals of the Coast Guard reliability engineering program described above and a review of the prior work done in this area, this thesis will consider four basic research questions as follows:

1. What is the status of the Coast Guard's reliability engineering program within the surface fleet?
2. How can engineering data about cutter maintenance activities be transformed into constructive operational information about availability?
3. How has the shift in maintenance ideologies impacted the medium endurance cutters' availabilities?
4. How can the Surface Forces Logistics Center improve its implementation of the reliability engineering program?

Accordingly, the thesis is organized as follows: Chapter 1 provides subject matter background, a review of prior work, and a clear definition of the basic research questions to be examined and answered by this thesis. Chapter 2 begins with an overview of soft systems methodology (SSM) and its application to analysis of the Coast Guard's medium endurance cutter (MEC) fleet reliability engineering program. Chapter 3 details the data analysis of casualty reports over a seven year time period, and analyzes how component and system failures affect mission availability for medium endurance cutters. Lastly, Chapter 4 provides a summary of findings, discussions, conclusion, and recommendations for follow-on research and actions.

Chapter 2

Investigation of

USCG's Medium Endurance Cutter Reliability Program

2.1 Organization, Resources, and Processes

To understand the problematic situations surrounding the surface fleet reliability engineering program and answer research question two, "What is the status of the Coast Guard's reliability engineering program within the surface fleet?", one must first have a general understanding of the Surfaces Forces Logistics Center (SFLC), the entity that owns the reliability program. The SFLC, whose mission is to "provide the surface fleet and other assigned assets with depot level maintenance, engineering, supply, logistics and information services to support Coast Guard missions," is a large unit consisting of five divisions and five product lines as shown in Figure 3 [2].

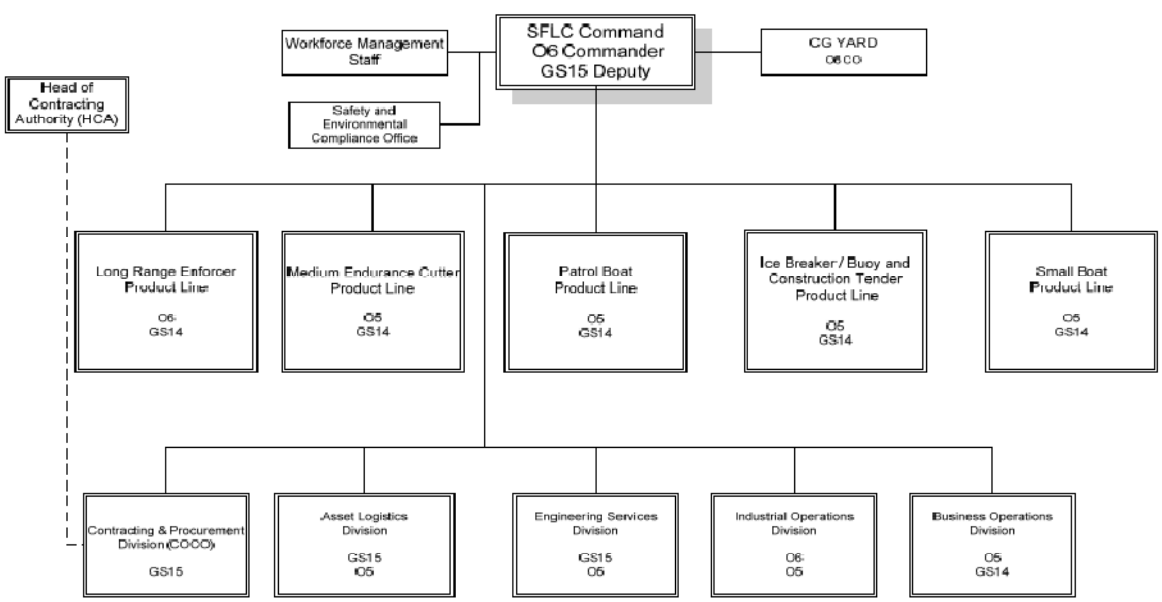


Figure 3: SFLC High Level Organizational Chart [2]

The divisions and a brief description of each are provided below:

- Asset Logistics: The fiscal, finance, supply and logistics resource for the entire command structure.
- Business Operations: Ensure the product lines have the information they require on a timely basis and that the organization focuses on affordable readiness.
- Engineering Services: Manages asset maintenance and logistics support to include the naval architecture section, the aging cutter and boat branch which controls the reliability program, and other specific technical sections.
- Industrial Operations: Oversees all naval engineering support units.
- Contracting and Procurement: Has sole authority and control over contracting and procurement for all surface assets [2].

The product lines are: small boat product line (SBPL); patrol boat product line (PBPL); ice breaker, buoy and construction tender product line (IBCTPL); medium endurance cutter product line (MECPL); and the long range enforcer product line (LREPL). The product lines and support units are geographically-distributed throughout the country based on the location of assets to provide the best support for all cutters and boats as pictured in Figure 4.

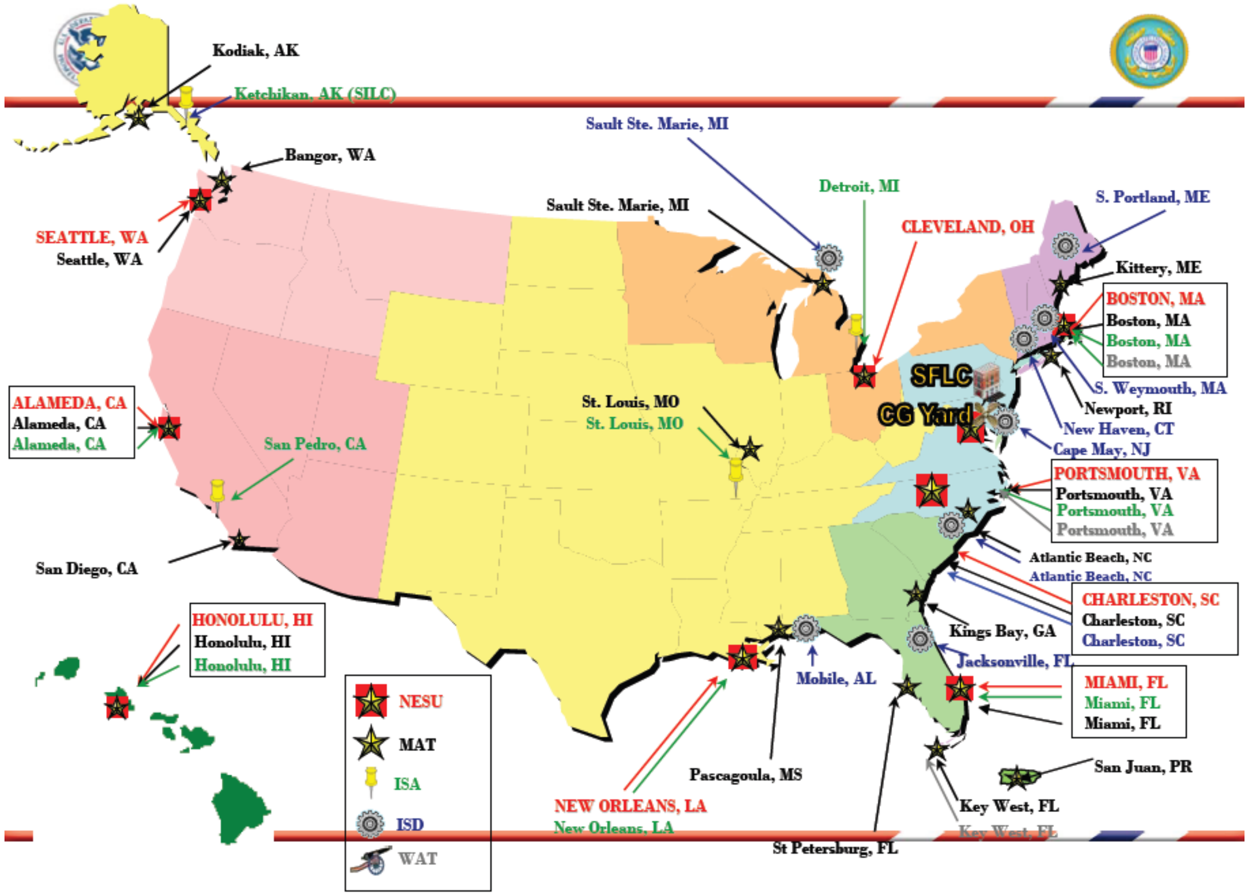


Figure 4: Location of Engineering/Logistics Units [13]

Each product line is divided into four branches, each with specific roles and responsibilities listed below (see Figure 5):

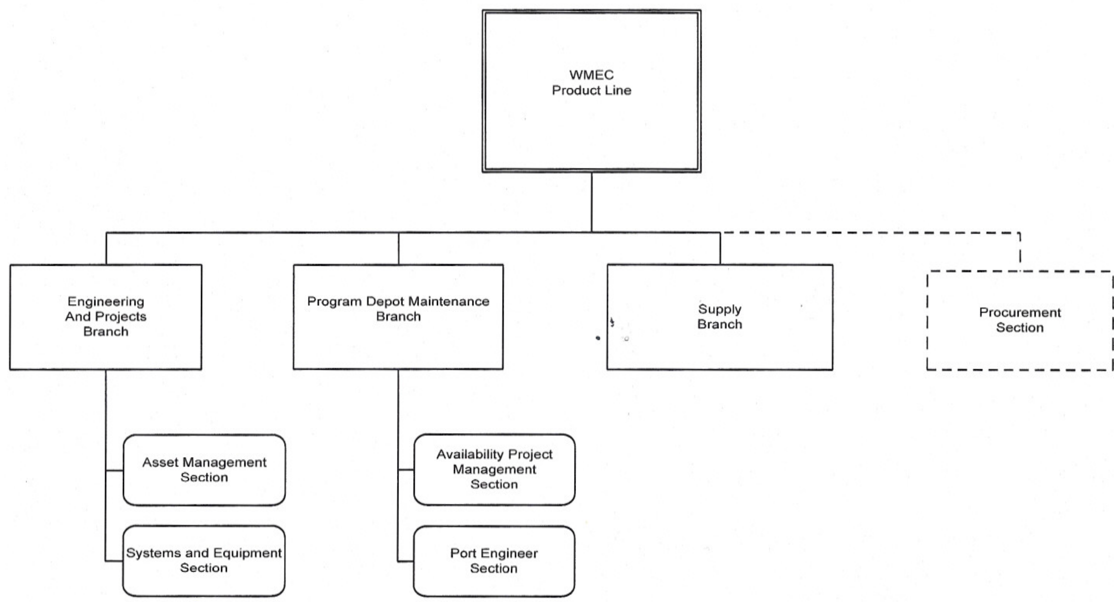


Figure 5: MEC Product Line Organizational Chart

- Engineering: Consists of asset management and systems sections for unplanned maintenance.
- Depot Maintenance: Consists of availability project management section for planned maintenance and manages port engineers who are on-site product line representatives at the assets for major maintenance availabilities.
- Supply: Handles all supply issues through an inventory management team and a customer service section.
- Procurement: Individuals under the main Contracting and Procurement division that are designated for a specific product line [2].

2.2 Application of Soft Systems Methodology (SSM) to Current Problem

Systems engineering methodology and techniques have long been used to tackle technical problems in a variety of industries. However, not all problems can be solved using only mathematical and quantitative techniques ("hard" approaches). In many cases, improving a real world system requires a "soft" approach that considers multiple perspectives and attempts to create a synthesis that better explains the problem situation and leads to feasible, desirable improvements. The system analyzed in this thesis encompasses the following features. The system has a purpose and achieves a transformation (i.e. maintenance that 'transforms' cutters). It has metrics to measure performance and a decision-making management structure. It has components (divisions/departments) that are related and interact with each other. The system exists as part of a broader system but also has its boundaries that define what is in and what is not in the system. The system also has its own resources. Lastly, the system expects continuity to the future and will adapt as necessary [9].

In 1966 Peter Checkland and other researchers developed the Soft Systems Methodology (SSM) which 1) provides a framework to evaluate the way individuals interact with various system processes from their different viewpoints, and 2) provides a tool for discovering and implementing improvements into the system. This thesis investigates the Coast Guard's surface fleet reliability engineering program using the SSM, focusing on the medium endurance cutters of the 210' Reliance Class and 270' Famous Class platforms.

To use Soft Systems Methodology (SSM), one has to operate both in the real world which involves the people and their interactions with the problem system and also in the systems world where the focus is on the system processes. Because of this, the SSM is best understood in a diagram format as shown in Figure 6 below.

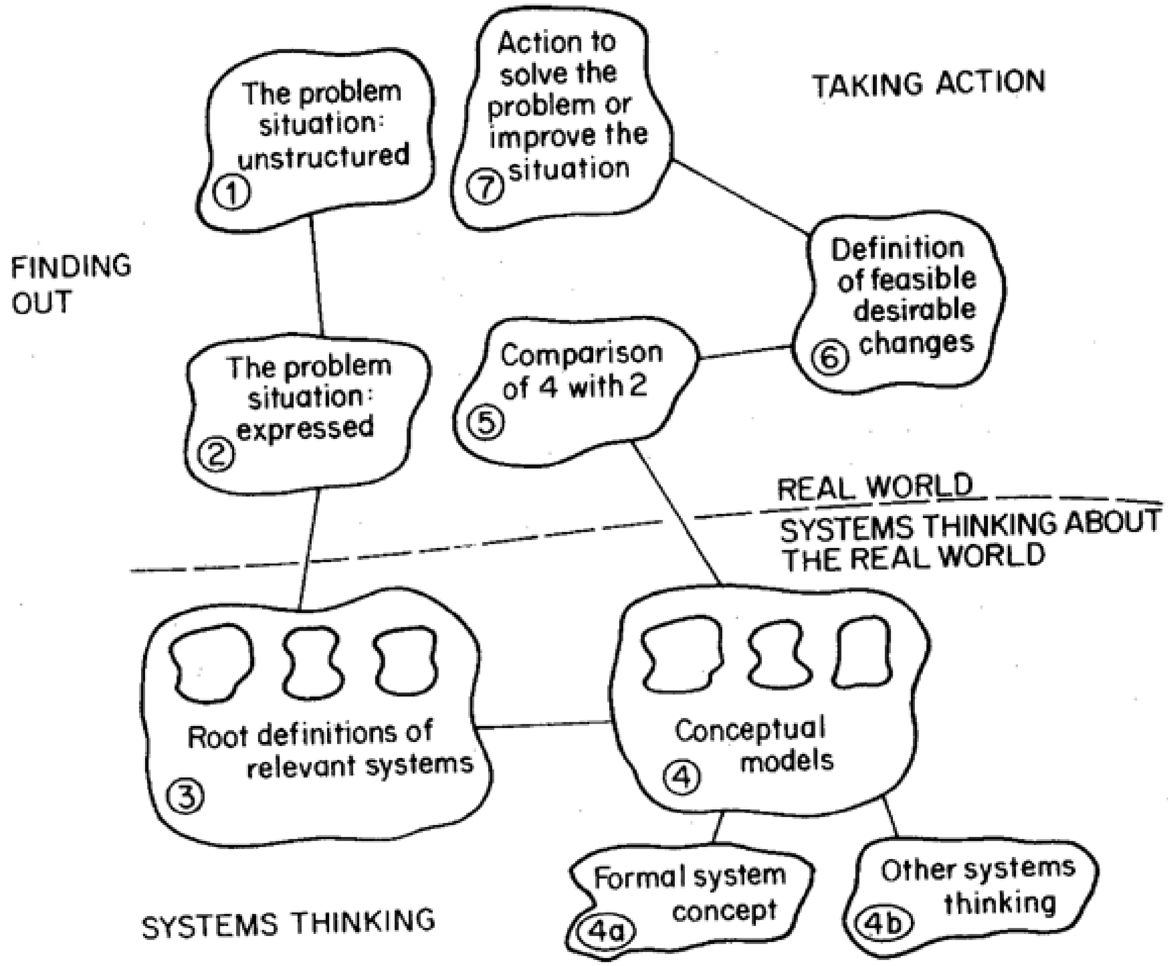


Figure 6: Summary of Methodology [10]

The SSM is an investigative process. It provides the framework for thinking about complex human interaction situations and formulating potential solutions. The process is not as “clean” or easy as one might expect based on the above diagram. It is not required to complete the steps in numerical order. Many of the steps are visited multiple times with multiple iterations to move from step to step. Each methodology step is detailed below.

1. **Unstructured problem situation**: This step is merely where a problematic situation is identified.

2. **Expressed problem situation**: In this step, the problematic situation is visualized in a "rich picture." The rich picture is a tool that combines the perceptions of many individuals across all levels of the problematic situation to provide an accurate depiction of human interactions within the organization. The rich picture can display the complex situation in manner, so that the problematic areas can be identified and sorted out more easily. The rich picture is not a "pretty" depiction of the system; it is often quite messy. It should not contain every detail of the system, but just the important elements from the many perception viewpoints. An example of a rich picture (about rich pictures) is shown below.

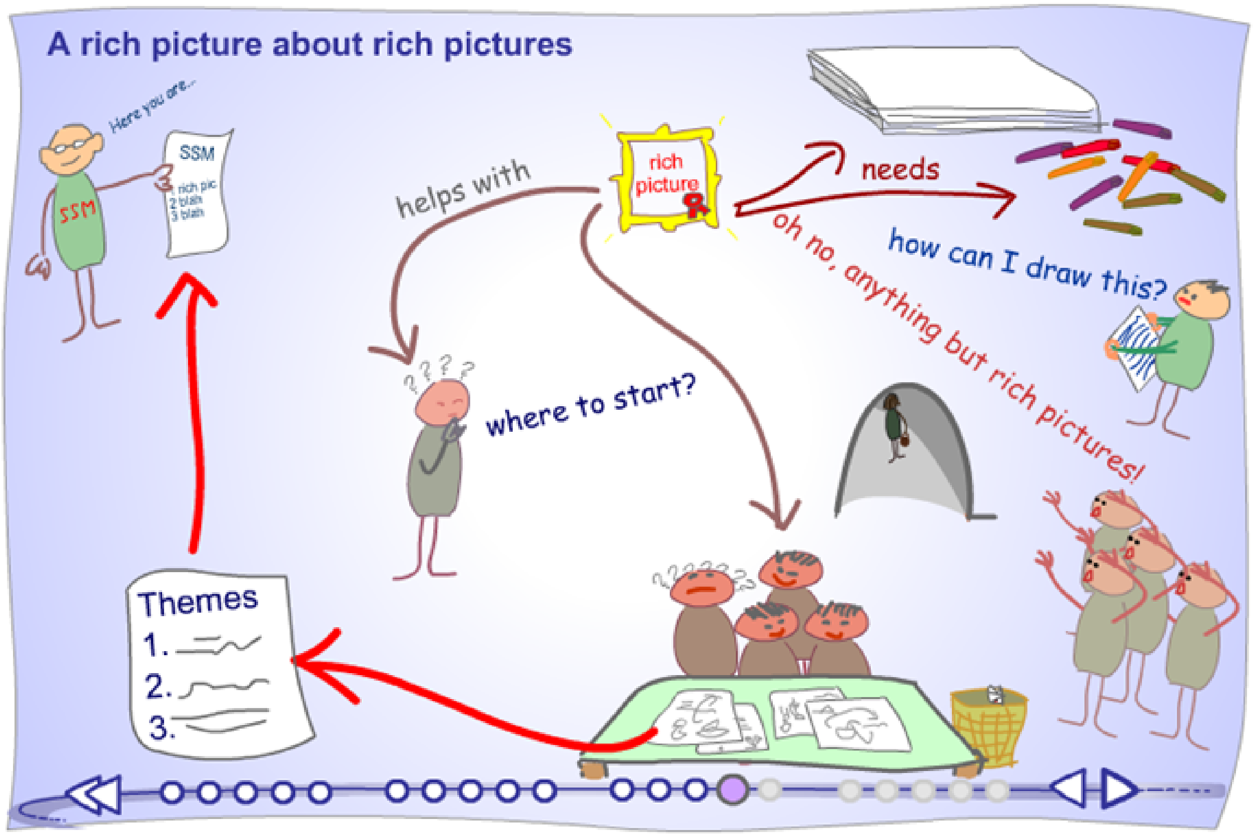


Figure 7: Rich picture example [11]

3. **Develop root definition**: Determining the root definition of the system is the crux, or critical step, in the methodology. Instead of focusing on what the system is not providing, one must first determine the purpose, or root, of the system, hence the root definition. There are three parts to the root definition: what the system does; how it should be done; and why it is being done. In order to develop a comprehensive root definition, the acronym CATWOE is often used to ensure all essential pieces of the system are included. CATWOE revolves around "T", the Transformation process through which the input to the system becomes the output of the system. "C" are the Customers, or those who are affected by the transformation process. "A" are the Actors who do the transformation process. "W" can be a bit difficult to understand. It stands

for Weltanschauung, the worldview that makes the root definition meaningful. "O" are the Owners who control the transformation process. Lastly "E" are the Environmental concerns that are outside of the system's control, but still affect its processes.

4. **Build conceptual model**: Creating a conceptual model of a system is often the most challenging step in the SSM process. A conceptual model will demonstrate the activities as defined by one's root definition. The conceptual model should describe the system using only a minimal number of verbs to show the core of the system. An example of a conceptual model for a healthcare scenario is given below in Figure 8 along with the system's root definition and CATWOE. During this step each human activity should be analyzed to determine if it meets the three E's which are efficacy, efficiency, and effectiveness. Within the system there should be mechanisms in place to measure the performance of each activity with respect to the three E's.

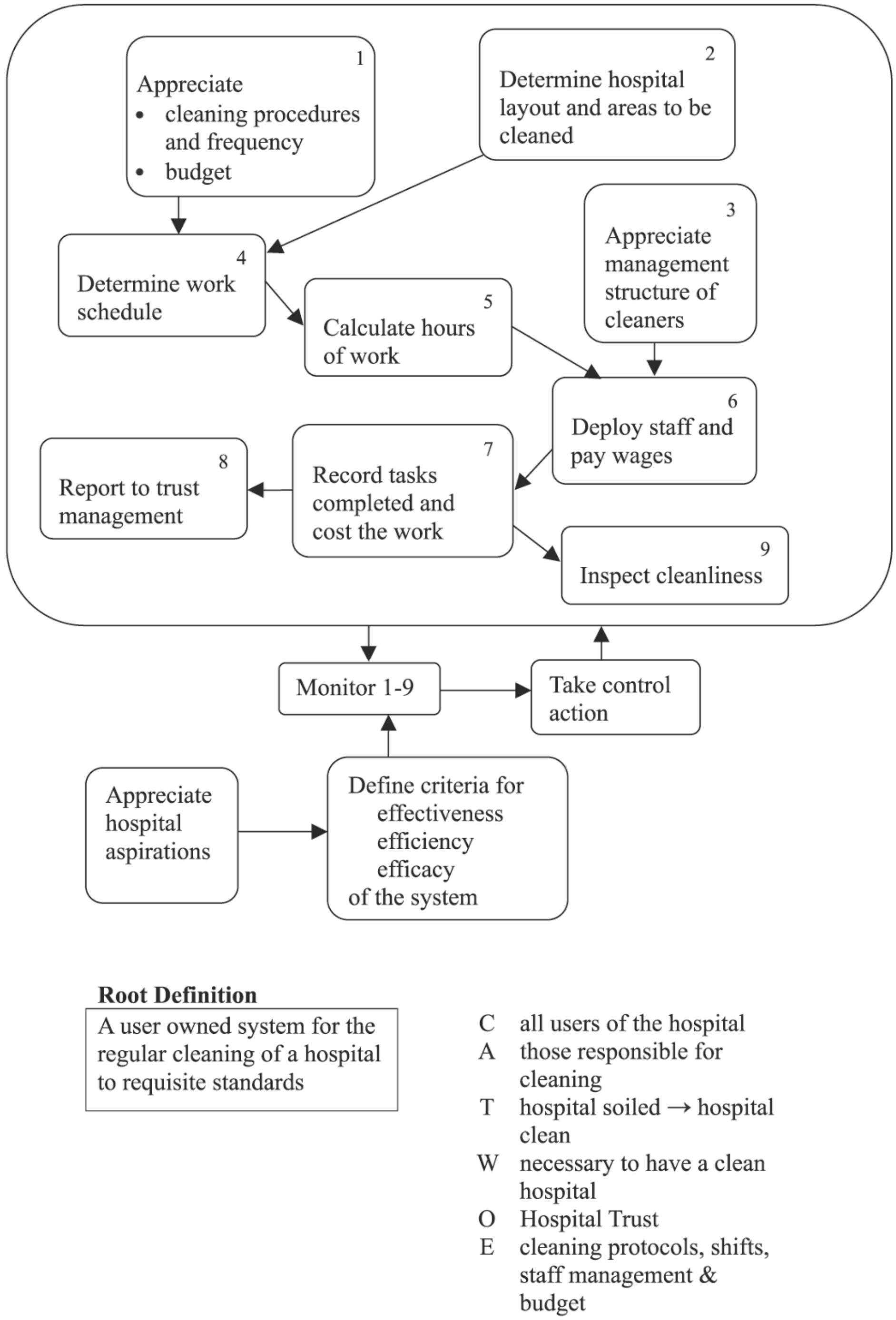


Figure 8: National Healthcare System in "England and Wales" Conceptual Model [12]

5. **Compare conceptual model with reality**: During this stage, the systems problems identified initially and the rich picture are compared to the

developed conceptual model. The purpose of this comparison is to generate possible solutions/changes to assuage the problem situation. The comparison must be accomplished through an in-depth systems viewpoint, not merely a surface comparison of two diagrams.

6. **Accessing feasible and desirable change**: The comparison of the conceptual model and the rich picture should be used to discuss what changes could be implemented, and what effect the changes would have on the system. There are three types of changes that should be investigated: structural changes, procedural changes, and attitude changes. Structural changes are those changes that are made to elements of the system which do not typically change such as functional responsibility and reporting chain of commands. Procedural changes are made to more fluid elements of the system like a reporting process. Attitude changes are changes to the human perceptions of those that interact within the system.

7. **Action to improve the problem situation**: Once the feasible and desirable changes are agreed upon, they should be implemented to improve the problem situation. While structural and procedural changes are more straightforward and easier to implement, attitude changes can present challenges since human emotions and thought processes are involved [10]. This is a classic example of "Change Management" and part of the improvement actions involve certain actions to enable or facilitate the people who are affected by the changes.

2.3 Analysis of Problem Situation

2.3.1 Unstructured Problem Situation

This thesis focuses primarily on how the newly implemented reliability engineering program affects the MECPL processes. The MECPL is comprised of the 282', 270', and 210' cutters, with 1, 13, and 14 cutters, respectively, still in service. The 282' is not included in the data analysis due to its one of a kind platform and the fact that it operates more as a LRE asset. The MEC's are eleven percent of the entire cutter fleet (see Table 1), and are on average the oldest cutters still in operation in the fleet. Because of this, their maintenance requirements are different and more critical than the newer cutters in order to maintain their operational readiness. The MECs complete the widest range of mandated Coast Guard missions, which emphasizes their importance and implies that analyzing their maintenance history will provide availability data for a variety of applications, as discussed in Chapter 3. The MEC's were also chosen because the researcher is more familiar with the platforms due to her having been stationed aboard CGC Vigilant, a 210' cutter, as Assistant Engineer Officer and as a Port Engineer at a Naval Engineering Support Unit for several 210's and 270's where she was responsible for scheduling and implementing large-scale maintenance repair availabilities.

Cutter	Number in Service	Percentage of Cutter Fleet
420' Icebreaker	1	0.40
418' National Security Cutter	2	0.81
399' Polar Class Icebreaker	2	0.81
378' High Endurance Cutter	12	4.84
295' Training Barque Eagle	1	0.40
282' Medium Endurance Cutter	1	0.40
270' Medium Endurance Cutter	13	5.24

240' Seagoing Buoy Tender/Icebreaker	1	0.40
225' Seagoing Buoy Tender	16	6.45
210' Medium Endurance Cutter	14	5.65
179' Patrol Coastal	3	1.21
175' Coastal Buoy Tender	14	5.65
160' Inland Construction Tender	4	1.61
140' Icebreaking Tug	8	3.23
110' Patrol Boat	41	16.53
100' Inland Buoy Tender	2	0.81
100' Inland Construction Tender	1	0.40
87' Coastal Patrol Boat	73	29.44
75' River Buoy Tender	12	4.84
75' Inland Construction Tender	8	3.23
65' River Buoy Tender	6	2.42
65' Inland Buoy Tender	2	0.81
65' Small Harbor Tug	11	4.44
Total	**248**	**100**

Table 1: Percentage Breakdown of Cutter Fleet (> 64 ft Length)

Figure 9: 270’ Medium Endurance Cutter, TAHOMA [2]

Figure 10: 210’ Medium Endurance Cutter, CONFIDENCE [2]

2.3.2 Expressed Problem Situation

To express the problem situation, a general diagram of the integral organizational units/areas to the MEC reliability engineering program was developed. This diagram shown below (Figure 11) gave a starting point of the key personnel to interview and what entities and processes should be focused on in the rich picture and further system analysis. The major players and available resources at each unit are listed, and the interactions between these units are shown, but not in a hierarchal or information flow manner.

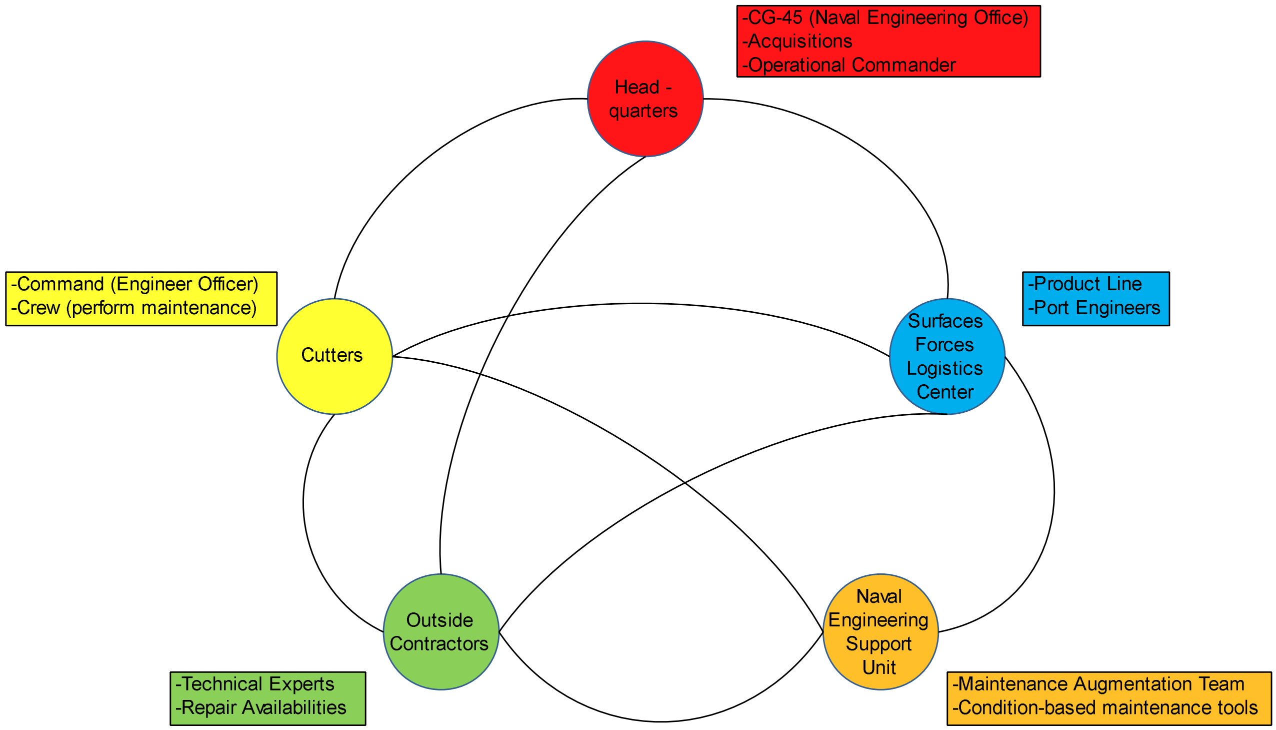


Figure 11: Initial MEC Reliability Program Diagram

Developing the rich picture of the MEC reliability engineering program involved interviewing individuals across all levels of the naval engineering organization to gain as many viewpoints as possible within the reliability engineering program. The Aging Cutters and Boats branch at SFLC was a logical starting point to gather initial information from which to develop a rich picture of the reliability engineering program. This branch is composed of civilian employees supplemented with minimal active duty members, who are responsible for implementing the reliability engineering program across the existing cutter fleet. These individuals detailed the issues their branch has had since the reliability program came online in 2009. Two major issues stood out among the other more logistic-related issues. First is the issue of establishing credibility with the rest of the engineering organization. Proponents of reliability engineering principles exist at high levels in the command structure. While specific opposition to the reliability program does not exist, resistance to change is found at the lower levels. The goal is to have a senior reliability engineer within each product line; however, in order for this to occur, there needs to be program advocates (or champions) at all management levels to help justify the position's existence and purpose. The second major issue is gathering usable data from the fleet. The reliability team is currently working with the SBPL to trend data to set a baseline for mission-critical components and restore their inherent reliability. Without proper data from the fleet, this trending will be inaccurate. This issue also goes back to stressing the importance of the reliability program to ensure buy-in from those inputting the data.

An in-depth investigative look into the problematic situation began with mid-level managers who run the product line. The product line provides complete logistic and engineering support for assets that fall into their category. These individuals interact with personnel both at lower and higher levels in the organization. Because of this, the mid-level managers would provide the best overall picture of the current reliability program and how the information flows throughout the various management levels. The mid-level managers interviewed consisted of the following positions:

- Asset Manager (AM) responsible for unplanned maintenance necessary due to a casualty;
- Asset Project Manager (APM) responsible for all planned maintenance usually in the form of dockside and drydock availabilities;
- Planned Depot Maintenance Branch Manager (PDM) who controls the branch funds and oversees the APM and Port Engineers.

After detailing the information flow, a recurring frustration revealed itself amongst the individuals. The product line, who spends a large amount of time gathering fleet data, does not understand the real bottom line objective of the reliability program. The gathered data sits in a database or document, and only rarely is the loop completed with maintenance procedures or product line processes changing because of the information. Thus, while data is being "collected", it is not being fully "mined." From these interviews, an initial rich picture was developed. Figure 12 shows a portion of the rich picture.

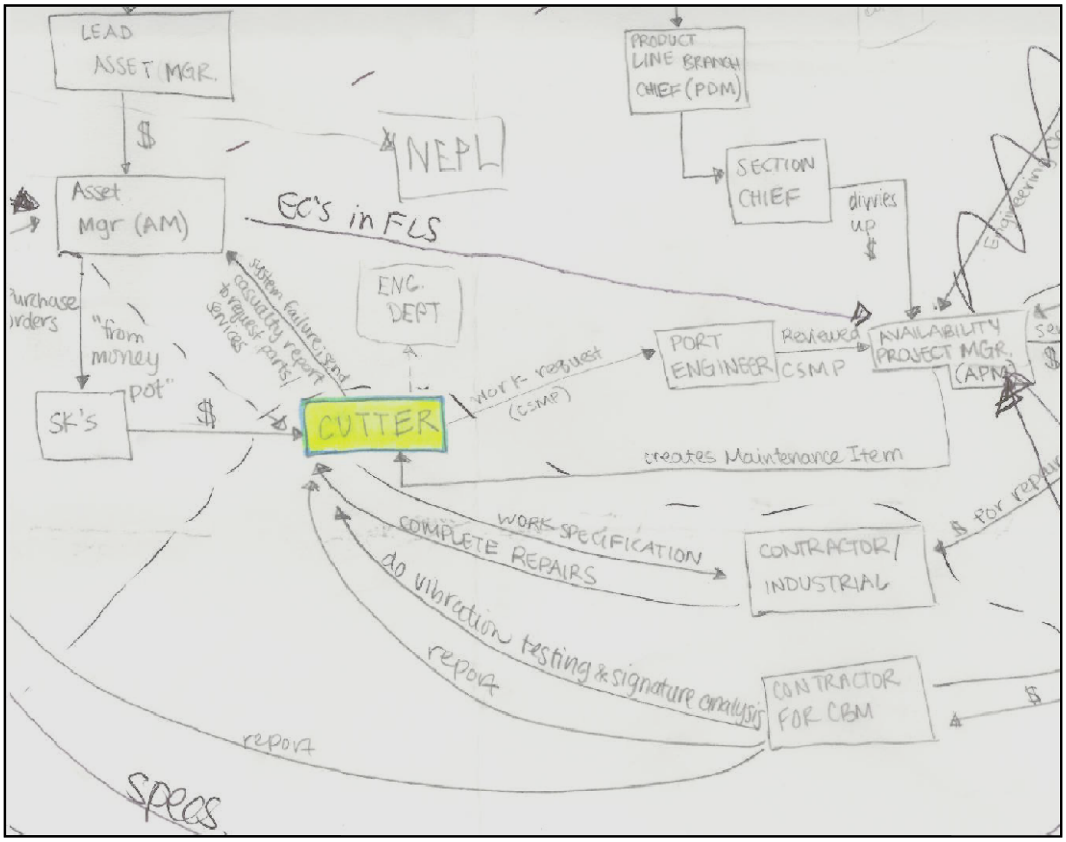


Figure 12: Initial Rich Picture

The rich picture shown above centers on the cutter, because bottom line of the process is to have the cutter operational. Currently, the organization has dictated that the cutter should be available ninety-seven percent of its operational time. On average, cutters are deployed from homeport 185 days out of the year for scheduled missions. While the cutter is deployed, it always has a primary mission, but is "on call" for any tasking that is deemed necessary. The Coast Guard says that they can complete any mission, anytime, anywhere; therefore, assets need to be available at a moment's notice.

While in homeport, maintenance is the crew and supporting commands' primary focus. Maintenance is either completed by the crew itself or through contractors. In-depth maintenance periods (drydocks and docksides) where large amounts of work are to be completed are scheduled approximately every eighteen (18) months. Maintenance during these times periods is completed by outside contractors. Because the cutters are so old, the crew is inundated with maintenance constantly, both at sea and inport. Because of this, providing the requested maintenance reports to the product line becomes a secondary thought, thus the data that is captured is often vague and lacking in the necessary information to conduct further analyses.

The next logical step was to investigate the reliability program from the high level management stance to see the differing viewpoints. The Commanding Officer (CO) of the SFLC is one of the biggest proponents behind the reliability program implementation. The CO works directly for the headquarters engineering branch responsible for Coast Guard wide engineering policies and procedures, also a large proponent of the reliability program. This particular CO, a naval aviator, was involved with the implementation of the reliability program into the aviation world and provided insight into the similarity of today's challenges and struggles to those twenty years ago in the aviation program. The high-level managers feel that most of the challenges faced in the surface fleet are cultural and, through time and training, most issues can be dealt with. One large difference that needs to be implemented into the surface fleet is the concept of a maintenance control supervisor, a single person designated to monitor all maintenance tasks for a particular asset(s) based on a computer-generated task list. Within the surface fleet, this responsibility is spread out amongst many individuals, causing confusion and extra unnecessary oversight layers that hinder maintenance. The computer-generator task lists for surface assets are also very inaccurate and difficult to work with.

The next step in the process was to update the initial rich picture based on the amplifying information and explanations received from the interviewing process. The final rich picture in Figure 13 is the resulting product. As seen in the intricate rich picture, the system is complex, with many individuals, processes, and documents involved in order for cutter maintenance to occur. The rich picture is color-coded to help distinguish the entities belonging to specific units. Red items are those associated with Coast Guard Headquarters at a high level in the command structure. Blue items belong to the MEC product line. Yellow items are specific to the cutter, while the green item is outside of the Coast Guard, but interacts with the system. The papers with a clip represent physical documents that are the result of the work of a combination of many of the entities. Lastly, the computer represents the main operating system in which information is recorded. The computer represents the operating system in which all documents are recorded and it is accessible by all Coast Guard entities.

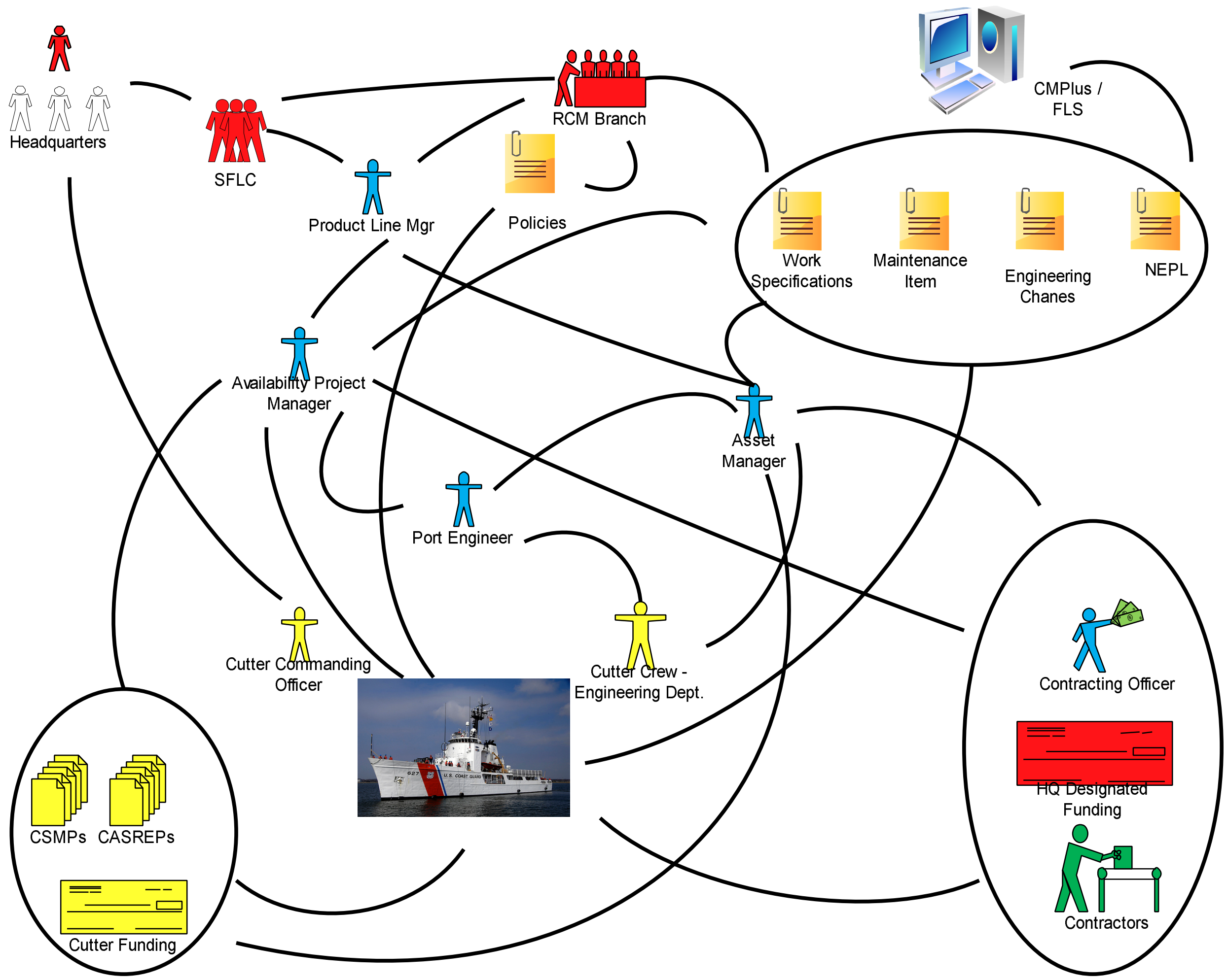


Figure 13: Final Rich Picture

The activities and entities expressed in the final rich picture are of particular importance to the system; however, some of these activities and entities are not considered critical aspects of the system. The critical entities and activities within the system are determined through the development of the system's root definition.

2.4 Root Definition Development

Development of the reliability engineering program within the product line scope was a crucial step in the investigative process using the SSM. As discussed in Section 2.2, the root definition should tell the what, why, and how of the system using action words and abstract terms. Using the rich picture and personal organizational knowledge, the root definition of the reliability engineering program is "**a cutter maintenance system that supports monitoring, reporting, management decision-making, and execution of maintenance activities to keep aging cutters operational**."

The CATWOE for this system is:

Symbol	**General Definition**	**Current System**
C	Customers	All Coast Guard Members
A	Actors	Engineers
T	Transformation	Cutter unavailable → Cutter available
W	Worldwide View	Necessary to complete Coast Guard missions
O	Owners	SFLC
E	Environmental Aspects	Congressional funding; federal mandates on operations; constant personnel transfers

2.5 Conceptual Model Development

The conceptual model gives an account of the activities which the system must do in order to be the system named in the root definition. It should only contain approximately five to nine activities because the model does not represent the real world, just the root definition. To begin with, one should consider all the inputs, outputs, and action words necessary to go from the input to the output. Figure 14 shows this initial train of thought for this system.

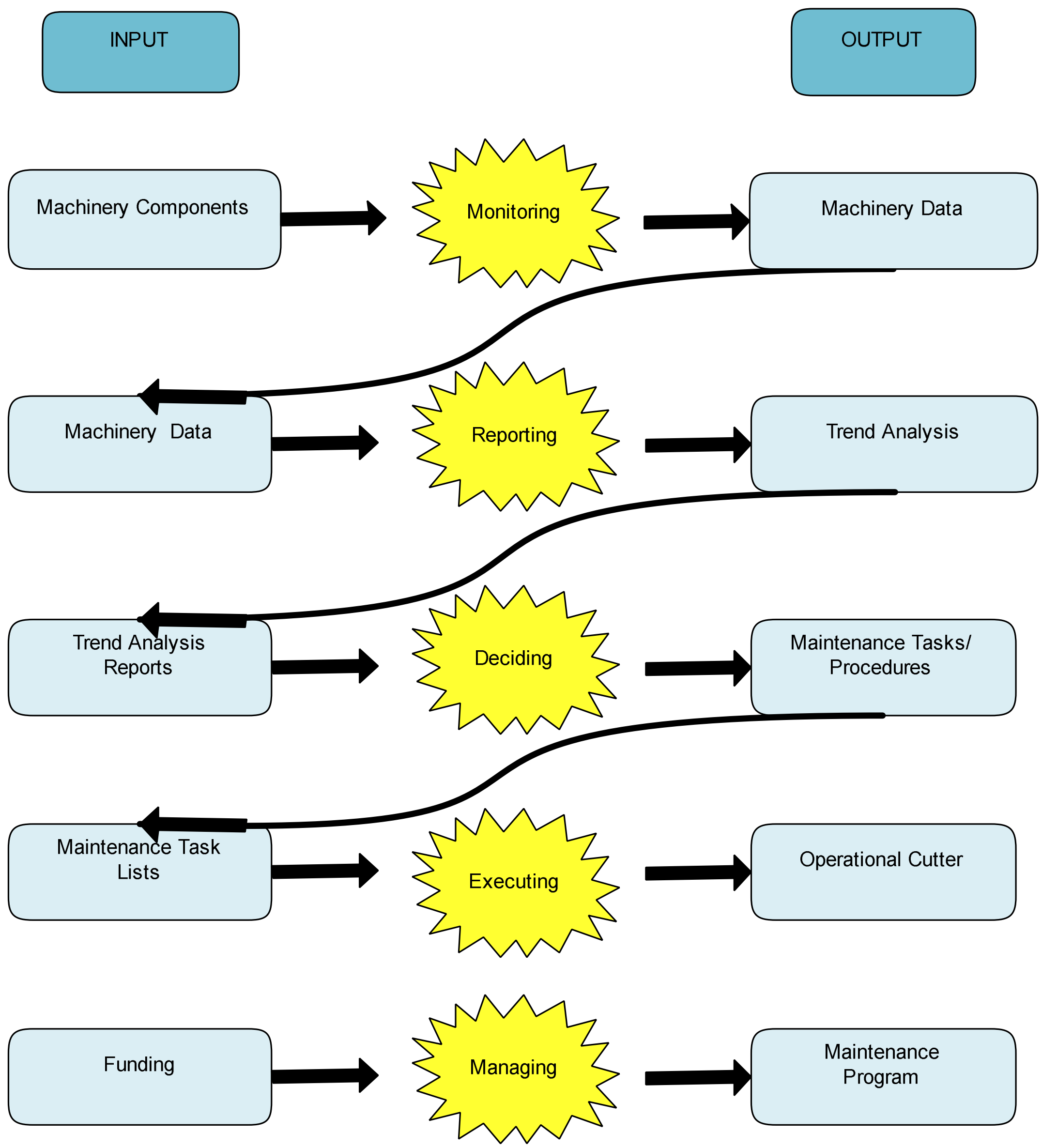


Figure 14: Initial Conceptual Model

After the development of the initial conceptual model, it should be evaluated using the three E's introduced in Section 2.2 to ensure that each activity has a method of determining its performance. The first E, efficacy, is the system's ability to produce an effect, or is the system working? To measure this, metrics should be in place to determine the operational availability of the cutters. The second E, efficiency, is a comparison of the value of the output of the system to the total resources needed to achieve that output. This is done in order to determine the third E, effectiveness, which is a measure of the worth of the new system [9]. For the surface fleet reliability program, performance measures are needed to determine if maintenance and casualty repairs occur faster and more cost effectively than in the past. Determining how the three E's will be measured occurs during the comparison between the conceptual model and reality.

From the initial conceptual model and determination of the three E's, a final conceptual model was developed (see Figure 15). The conceptual model differentiates between reactive and proactive maintenance. Reactive maintenance refers to maintenance that occurs as a result of a machinery casualty. Proactive maintenance includes both schedule-based and condition-based maintenance. Proactive maintenance does not have to occur on a large-scale such as a drydock or dockside availability. An important note is that funding going into the system comes out of the system as operational cutters. At this point, it cannot be concluded if this model is completely correct and appropriate for the real system, but that will be determined during the comparison step. The final conceptual model provides a spark in the debate to discover the logical feasible and desirable for the real world system.

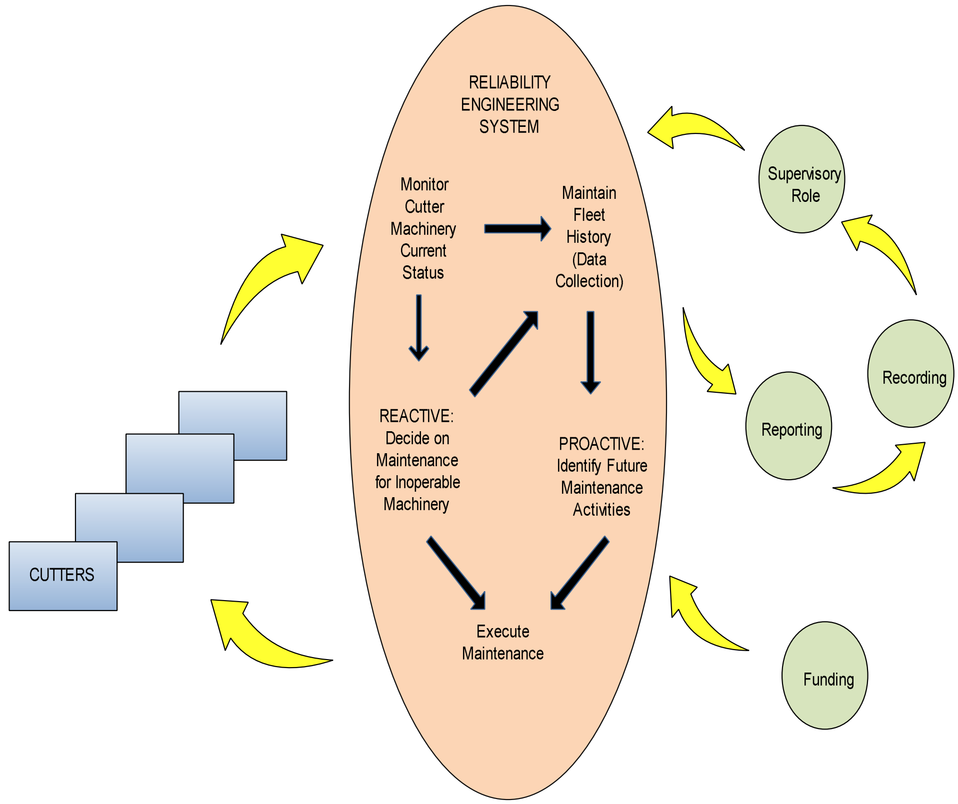


Figure 15: Final Conceptual Model

2.6 Comparison of Conceptual Model to Reality

The purpose of this step is to compare what should happen as described through the conceptual model to what actually does happen in the real world situation to spot areas that need improvement or modification. An easy way to make these comparisons is in a table format, as follows:

Conceptual Model Activity	Is it done in the real world?	If so, how?	Comments / Recommendations
Monitor machinery	Yes	On both the 210's and 270's, cutter personnel monitor all machinery hourly through gauges. Alarms are also utilized to provide continuous monitoring for abnormalities. The 270's have a main propulsion control management system that uses sensors to continuously monitor all propulsion machinery components.	Monitoring and recognition of an immediate problem falls on junior personnel with minimal training and experience. The Engineer Officer is responsible for reviewing all data to notice trends in machinery operation. Not all engineer officers are fully trained to recognize important trends.
Report / record fleet history	Yes	Each cutter maintains its own machinery history in CMPlus, a computer system that only the cutter has access to. Product line personnel must obtain machinery history from the cutter directly. Casualty reports (CASREPs) are sent to the product line when a component breaks. These CASREPs are maintained in a large database in Fleet Logistics System (FLS). Non-emergent required maintenance is captured in the cutter's class maintenance plan (CMP) that is updated yearly.	All captured data is based on user input, meaning the data can vary greatly from one cutter to the next. While standard terminology is used, the coding of equipment using equipment identification codes (EIC's) is subjective based on the individual. Prioritizing the casualty is also subjective. CMPs are only updated annually and still have many inaccuracies. CMPs are not controlled by individuals outside of the product line.
Decide on maintenance (reactive)	Yes	Once a CASREP is issued, the Asset Manager has 24 hours to set up replacement parts or repair work for major casualties. For minor casualties the Asset Manager works with the cutter Engineer Officer to handle the situation in a non-emergent manner.	Because a high priority CASREP will get the cutter replacement parts faster, sometimes the cutter "upgrades" their casualty to a higher priority than it is. When an Asset Manager has multiple high priority CASREPs to respond to, this unnecessary upgrade can hinder the process.

Conceptual Model Activity	Is it done in the real world?	If so, how?	Comments / Recommendations
Identify future maintenance (proactive)	Yes	The Availability Project Manager and the cutter work together to identify work to be completed in a large availability period. This work is documented in a Current Ship Maintenance Project (CSMP) form with FLS to be completed during the next major contact. The Availability Project Manager also sets up stand-alone contracts for major items that need overhauling or replaced prior to the next scheduled repair availability.	There Coast Guard uses the following tools and techniques to try and identify future maintenance and any machinery trends: motor circuit analysis; diesel engine signature analysis; vibration monitoring; ultrasonic testing; and boroscope inspections.
Execute maintenance	Yes	Maintenance is completed by the cutter crew, Coast Guard engineering support units, or outside contractors.	While there are processes in place to close the loop and document completed maintenance, this step is not always completed.
Supervise reliability program	No		The program is still in its infancy without a real presence within the product line. All supervision is within the high-level of the command structure.

Table 2: Comparisons to Conceptual Model

2.7 Change Assessment – Desirable and Feasible

Currently the Coast Guard is going through a modernization and logistics transformation. Because of this, it is difficult to identify structural changes to the reliability engineering program. Even with all the organizational changes, there is one structural change that should be incorporated during this period of major change to assist in a successful implementation, and that is, adding a civilian reliability engineer into each product line. With the current billet (job assignment) structure, the APM (Asset Project Manager) and AM (Asset Manager) do not have the time or resources to gather and trend data while simultaneously setting up repair contracts. A civilian is necessary because it needs to be a permanent position, as opposed to a military transfer every three to four years. It would be expected that the civilian employee would be specifically trained in reliability engineering in order to gather the required data for each system on their specified platform and trend the data to provide maintenance recommendations to the product line manager. Until the large command units have been changed at the macro level, determining structural changes at the mid and lower levels, where the biggest impact on implementation will occur due the number of personnel, will remain an area for future analysis.

There are many procedural changes that could be implemented into the reliability engineering program. The casualty reporting system is one such area that has room for improvement. While standard terminology, priority levels, and equipment identification codes (EICs) already exist, they are still subjectively used. The Coast Guard uses the Navy's EIC list with EICs structured in the following format:

1st character – Category
2nd character – System
3rd character – Equipment or Set
4th character – Assembly or Unit
5th character – Subassembly or Assembly
6th character – Component or Subassembly [17].

The current list is so detailed that individuals are unsure as to what EIC their casualty is associated with; therefore, they tend to pick whatever seems best, normally the more general number, though it may not be the best choice. For example, on a 210' cutter, one casualty reports an EIC of B10300 for a down main diesel engine control, but another reports it as B100000. The same equipment on a 270' cutter was reported by the EIC BA00000. Less room for judgment and error in the EIC list needs to be made by compressing the list to subsystem levels only. Parts are not ordered based on this EIC, but data trending can occur; therefore, increasing the accuracy of EICs increases the accuracy of trend reports. The Coast Guard should modify the Navy list to fit the services needs and revamp it to make it more user-friendly. The EIC list should also be reviewed annually to make changes as equipment changes occur on the cutters.

Training is also a key aspect of implementing a successful reliability engineering program. Buy-in is needed across all levels for the program to be successful. Currently, lower level employees, the ones actually doing the maintenance, have not bought into the program, not because they do not care, but because it has not explained to them. Training can be provided during "A" school, the rate specific school where individuals are trained on their job qualifications. The lower ranking individuals will do as they are trained, and this is a key opportunity to filter information to the fleet on a large-scale. It will require more effort to reach those that have already completed "A" school, but this can be accomplished by doing road shows to the cutters and support units to provide an overview of the reliability engineering program, what it hopes to accomplish, and how they (the individuals) fit into the program.

A key link between what maintenance occurs on the cutter and the documentation received at the product line is the Engineer Officer (EO). Because of this fact, training should be heavily focused on the EO. Training can be incorporated into the current Afloat Engineering Petty Officer School that trains prospective EO's for the 110' and below cutters. Currently there is not a school/training period for perspective EO's of larger cutters. A short course could be implemented that would cover the main principles of the reliability engineering program. One important aspect that should be focused on is the under-reporting that occurs. Many commands feel it reflects poorly on them if repeated casualties occur; therefore, some casualties are dealt with through improper channels. This under-reporting only hampers maintenance improvement efforts fleet-wide.

Lastly, there needs to be a closed loop in the maintenance reporting process. Cutter crews who do report their maintenance and casualties properly sometimes get frustrated with the lack of information they receive back in order to resolve or improve the situation. Also, there are large amounts of data in multiple databases that is not touched due to lack of time and knowledge in compiling the information. The aforementioned reliability engineer within the product lines can help to alleviate this issue by trending data and reporting back to the fleet their findings. Attitude changes will occur when members are informed.

2.8 Actions to Improve the Problem Situation

The analysis presented in Chapter 2 clearly identifies several key areas for improvement in the Coast Guard surface fleet reliability engineering program. The following Table 3 summaries several important change opportunities resulting from the work presented in Chapter 2 and provides a qualitative assessment of the important of the change to the overall reliability engineering program.

Improvement Opportunity	Description of Change	Importance Ranking (Low, Med, High)
1	Billet a civilian Reliability Engineer into each Coast Guard fleet product line.	High
2	Revamp the casualty reporting system (CASREP) to make it simpler and more accurate. Note: Customize current Navy EIC to specifically apply to US Coast Guard fleet.	High
3	Add a procedure that requires an annual update of the EIC list (Equipment Identification Codes) to reflect cutter equipment changes.	Med
4	Create and implement a new Reliability training program focused on the EO (Engineering Officer) during the Afloat Engineering Petty Officer School for Petty Officers who are prospective new EO's.	High
5	Add new reliability training program to new enlisted engineering personnel in "A" school.	High
6	Create and implement a "road show" method for training and updating current engineering personnel on cutters and in support units. Training to include both enlisted personnel as well as engineering officers.	High
7	Implement a new "closed loop" process into the maintenance reporting process. The new process will enable data trending of information reported by the fleet and a mechanism for reporting results back to the fleet.	High

Table 3: Improvement Opportunities

The above changes will take time to implement. There are daily organizational and operational challenges that will prevent these changes from occurring overnight, but with support and resources from the upper levels of the command, they can filter throughout all levels of the organization. It will need to be a coordinated from both the operations and engineering parts of the organization in order to be successful.

2.9 Summary of Investigation

This chapter investigates the status of the Coast Guard's reliability engineering program (thesis research question #1) by applying Soft Systems Methodology (SSM). Using SSM's comparison of the conceptual model to reality allows one to readily observe both positive aspects and current shortcomings of the current USCG reliability engineering program; i.e., what's working and what needs improvement.

Key issues discovered include shortcomings in a) procedures, b) personnel training, c) casualty reporting system (CASREP), d) an inadequate and out-of-date Equipment Identification Code (EIC) list, and e) lack of a closed-loop process whereby reliability information and trending data is not being properly fed back to fleet personnel. This last item is directly related to thesis research question #2, "how can engineering data about cutter maintenance activities be transformed into constructive operational information about availability?".

Chapter 2 (Sections 2.7 and 2.8) identifies specific change opportunities for significant improvement in the USCG fleet reliability engineering program. See Section 2.8 for a summary of key identified change opportunities. Chapter 3 "Data Analysis and

Methodology" will analytically investigate actual reliability data from the cutter fleet in order to more fully address thesis research questions #2 through #4 and, specifically, relate reliability data to actual cutter availability which is the critical measure of program mission success.

Chapter 3

Data Analysis and Methodology

From the SSM process in Chapter 2, it was found that currently, reliability engineering analyses and results are not filtered through the engineering community, let alone the entire Coast Guard. It is important to transform asset reliability information into a usable form for the operational side of the Coast Guard, so that assets are used effectively and efficiently while still being properly maintained from the engineering aspect. This chapter describes the research methods used and the analysis performed in the study of mission availability as it relates to casualty reports for the 210' and 270' cutters. This study is an exploratory, empirical analysis of system and component failures. The scope of this study is limited to examination of equipment failures from 27 cutters from October 2003 through January 2011. Research questions two and three (See Section 1.4) will be answered through this analysis.

3.1 Source of Data

Casualty Report (CASREP) data was obtained through the Coast Guard's Fleet Logistics System (FLS), a centralized cutter logistics database that works in conjunction with other software to maintain cutter configuration, maintenance, and supply. Data was consolidated for both classes of cutters into spreadsheet format, which includes the following categories:

- Resource
- Equipment Identification Code (EIC) Category

- EIC System
- EIC Subsystem
- EIC Code
- EIC
- CASREP Number (Each cutter has their own numbering system)
- CASREP Date
- CASCOR (Casualty Correct) Data
- Severity
- Status
- CASREP Days (How long the equipment was down)

3.1.1 Explanation of CASREPs

CASREPs are a message reporting tool used by non-modernized Coast Guard assets to report inoperable or malfunctioning equipment. Currently all product lines, with the exception of the SBPL, use CASREPs as their primary reporting method. There are four types of casualty reports: 1) "Initial" to identify the casualty; 2) "Update" to keep abreast of any changes with the casualty; 3) "Correct" to notify the product line when the equipment is operating properly; and 4) "Cancel" when the equipment was restored by unit capabilities. This thesis analyzes "Initial" and "Correct" CASREPs to identify the amount of downtime for each corresponding piece of equipment.

CASREPs are assigned a severity category by the unit. Each category corresponds to the amount of mission degradation due to the equipment casualty. Table 4 from the CASREP Reporting Manual details the severity categories [18]. For this study, any CASREP, regardless of its severity code, will indicate that the system is unavailable. In real-world operations, this may not be the case. Even if a system is degraded, due to operational needs such as Hurricane Katrina, a cutter will be used even if it does not provide complete mission availability. Those priorities and judgment calls are made in the operation side of the Coast Guard with input from the engineers.

Category	**Code**
This category is not used by Coast Guard units.	1
Deficiency exists in mission essential equipment which causes a minor degradation in a primary mission; or a major degradation or a total loss of a secondary mission.	2
Deficiency exists in mission essential equipment which causes a major degradation, but not the loss, of a primary mission.	3
Deficiency exists in mission essential equipment that is worse than casualty category 3, and causes a loss of at least one primary mission.	4

Table 4: CASREP Severity Categories

CASREPs only report a single instance of failure. If investigation of the initial failure reveals further equipment failures, new CASREPs must be issued for each subsequent component. This is to ensure that each failed component is identified and logistics in place for each replacement.

3.1.2 Limitations of CASREP Data

Although there are reporting requirements, due to the subjective response of cutter crews to casualties, this data may not include all component casualties during the period of study. Unit Engineer Officers write CASREPs. While these officers are trained to write these reports, there is still an element of investigative technique involved in determining the exact component that failed. Because of this, many CASREPs are general in that they refer to a major component (e.g., main diesel engine) instead of the actual component that failed (e.g., raw water pump on the main diesel engine).

Other variables that are not examined in this study can affect cutter availability. A cutter's homeport can affect its availability for a particular mission. For instance, a cutter homeported out of Florida does not carry cold weather gear for its crewmembers; therefore, if a mission required this, that cutter would be unavailable until the proper equipment was obtained. This thesis only analyzes the large-scale systems necessary for mission completion as shown in Section 3.2.1.1.

3.1.3 Building the Database

An original version of the data was maintained in one database, and a modified database was created using only the categories necessary for analysis. Categories that did not affect the analysis (CASREP Number, CASREP Date, CASCOR Date, and Status) were not used in the initial operational availability calculations for research question two. Before analysis, the data was inspected for errors and inconsistencies. Data that was too general to determine the failed component or system was taken out of the main data list. Examples of usable and unusable data are provided below in Table 5. Most of the unusable data, 1,069 data entries, appears to have been uploaded incorrectly from the cutter's reporting system to FLS, as shown in the first unusable data line for CGC Decisive. Other unusable data was too general to identify the system the CASREP was associated with as with the CGC Harriet Lane CASREP. In total, 1,383 CASREPs out of 9,378 were unusable, leaving 7,995 usable CASREPs to analyze. Further analysis necessitated that the CASREPs to be separated into three distinct time periods as follows: 10/1/2003 – 12/31/2004; 1/1/2005 – 12/31/2009; and 1/1/2010 – 1/7/2011.

	Resource	EIC Category	EIC System	EIC Subsystem	EIC Code	EIC	Severity	CASREP Days
Usable	CGC VIGILANT (000003)	HME	PROPULSION SYSTEM, MAIN DIESEL, ELECTRIC DRIVE	CONTROLS, CENTRALIZED, MN PRPLN AND AUX	CE00000	CONTROLS, CENTRALIZED, MN PRPLN AND AUX	2	10
Unusable	CGC DECISIVE (000621)	OTHER	UNKNOWN	UNKNOWN	-1	UNKNOWN	2	150
Unusable	CGC HARRIET LANE (000514)	HME	AUXILIARY SYSTEMS	AUXILIARY SYSTEMS	T000000	AUXILIARY SYSTEMS	3	4

Table 5: Examples of Usable vs. Unusable Data

3.2 CASREP Data Analysis

Much of the analysis involves categorizing each CASREP with its specific system and subsystem, and then mapping the systems to each mission. Out of the eleven (11) mandated missions, the 210’ and 270’ cutters complete seven (7) of them on a routine basis. The missions examined in this study are as follows. *Note: Mission number is not indicative of priority, but for identification and readability in this thesis.*

1. Search and Rescue
2. Migrant Interdiction
3. Drug Interdiction
4. Living Marine Resources
5. Defense Readiness
6. Port Waterways and Coastal Security
7. Other Law Enforcement

3.2.1 System to Mission Mapping Using the Goal Tree Success Tree Technique

Coast Guard missions are complex to carry out, involving multiple systems onboard and associated with the cutter acting simultaneously. It is vital that each system works at the exact moment it is necessary to fulfill its requirement. Determining the required equipment to accomplish a particular mission can be accomplished using an application of Goal-Tree-Success-Tree (GTST) technique developed by Dr. Mohammed Modarres [20]. The GTST technique is a functional analysis technique used to model complex systems by identifying the system objective (goal) and its functions (sub-goals) as well as the success paths to the objective as shown in Figure 16 below [20]. The GTST technique is used in a variety of applications from plant operations to ship design. This thesis examines the use of the GTST technique to consider the mission to system mapping in a systematic manner and thus to provide a measure of mission availability based on system availability calculated using CASREP data.

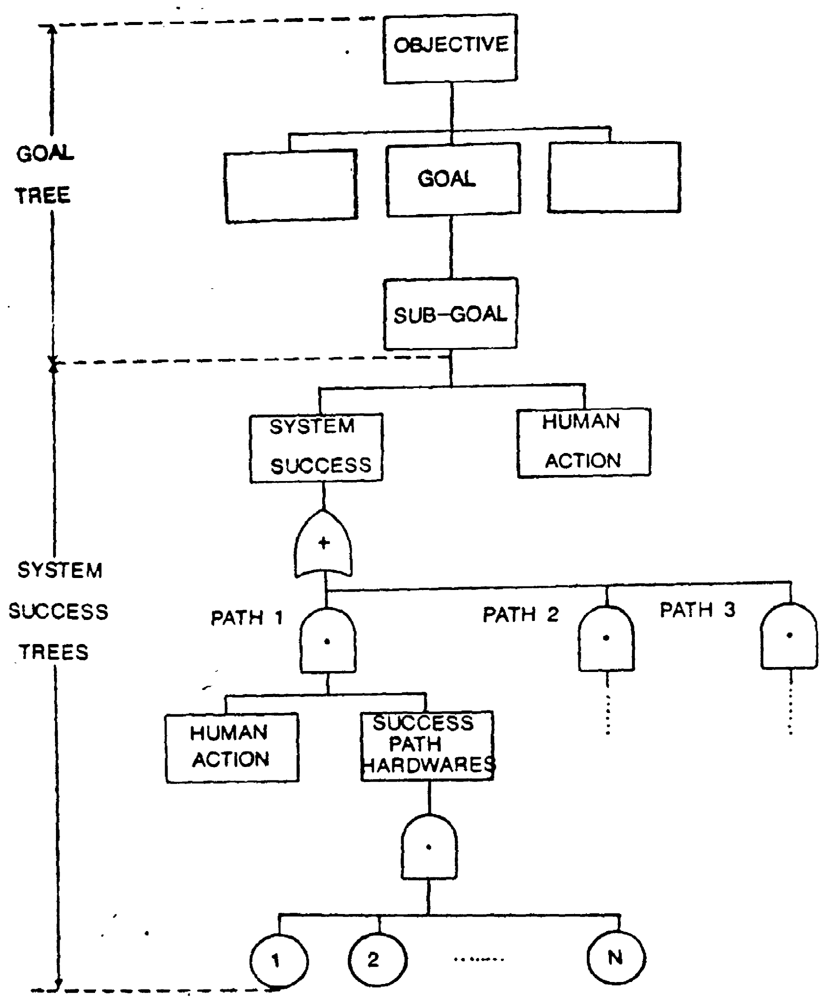


Figure 16: GTST Example [20]

3.2.1.1 Creating the Goal Tree

To build a GTST, the main goal is identified and broken into sub-goals to form the goal tree portion of the technique. The goal trees for each 210'/270' mission are given below. When constructing a goal tree, it is implied that all sub-goals are necessary to accomplish the overall goal; therefore, an 'AND' logic gate is not used [20]. Edraw Max, a graphics software, was used to depict the goal trees [21].

Figure 17: Coast Guard Mission #1 Goal Tree: Search and Rescue

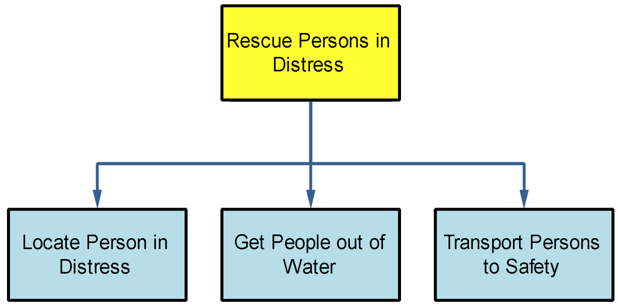


Figure 18: Coast Guard Mission #2 Goal Tree: Migrant Interdiction

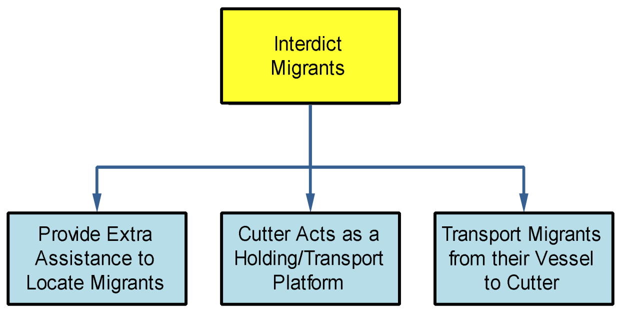


Figure 19: Coast Guard Mission #3 Goal Tree: Drug Interdiction

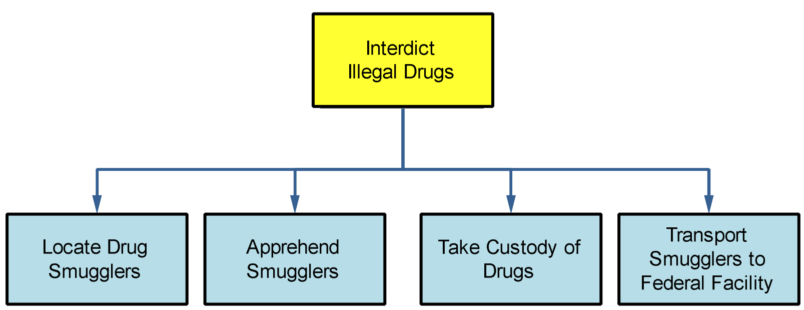


Figure 20: Coast Guard Mission #4 Goal Tree: Living Marine Resources

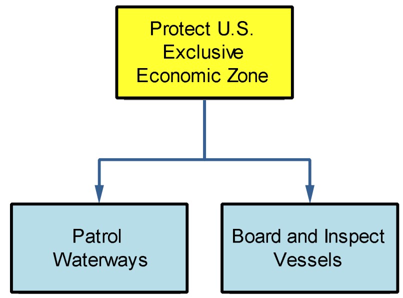


Figure 21: Coast Guard Mission #5 Goal Tree: Defense Readiness

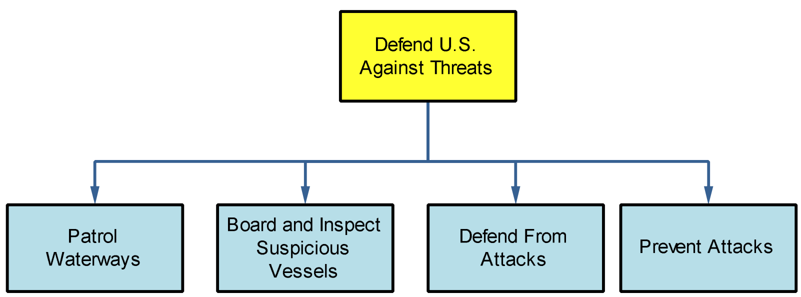


Figure 22: Coast Guard Mission #6 Goal Tree: Ports, Waterways, & Coastal Security

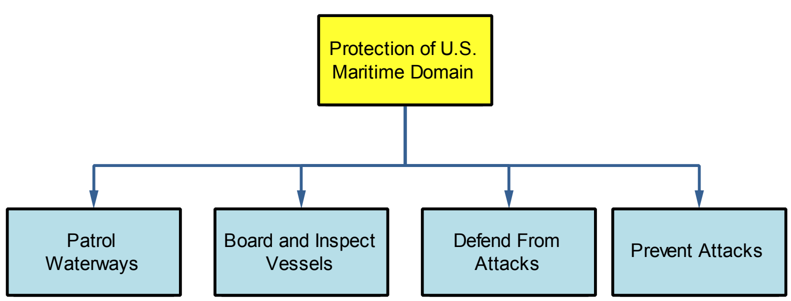
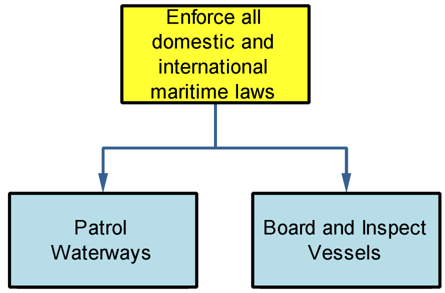


Figure 23: Coast Guard Mission #7 Goal Tree: Other Law Enforcement



There is some overlap between the different missions and their subgoals because the mission definitions are very similar in some cases. There are two important requirements to be concerned with regarding the goal tree portion of the GTST technique:

1. Looking upwards from any sub-goal towards the target root goal, the top of the tree, it is possible to find out explicitly why the specific goal or sub-goal must be achieved.

2. Looking downwards from any goal towards the bottom of the tree, it is possible to find out explicitly how the specific goal or sub-goal is achieved" [20, 22].

3.2.1.2 Creating the Success Tree

Once specific hardware must be referred to in order to describe a sub-goal, the boundary between the goal tree and the success tree is made. The success tree then defines the path(s) to achieve the overall goal. Success trees illustrate the relationship between the hardware and sub-goals using typical logic gates. Figure 24 shows the success tree for the sub-goal "Transport Migrants from their Vessel to Cutter" for the overall goal of "Interdict Migrants."

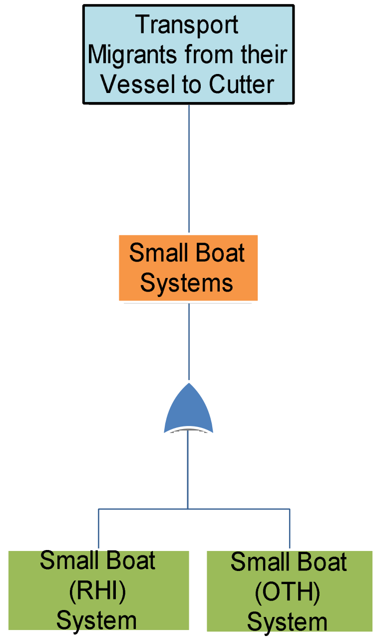


Figure 24: Success Tree Example

There are are a large number of success trees for the various hardware systems. All of the success trees will be compiled to form the total GTST for each Coast Guard Mission.

3.2.1.3 Combining to Form the Final GTSTs

The use of a GTST is effective for dynamic system goals such as Coast Guard missions which can be modified based on the current political and operating environments, as well as the changing hardware systems installed on cutters as technology improves. The GTST for the migrant interdiction mission is shown below in Figure 25. GTSTs for the remaining aforementioned Coast Guard missions can be found in Appendix I.

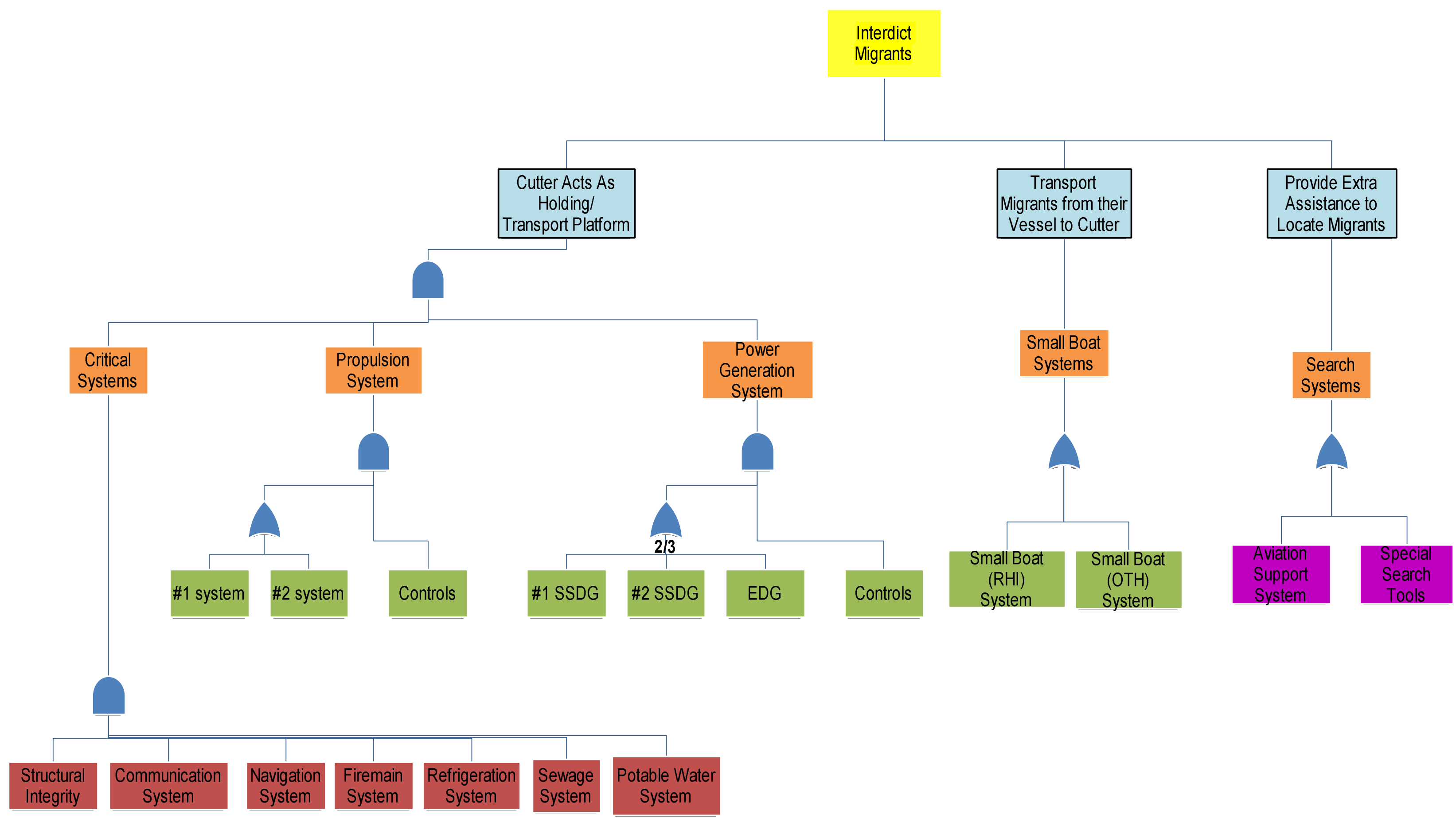


Figure 25: Migrant Interdiction Success Tree

3.2.2 Subsystem Availability Calculations

One important metric to assess the performance of a repairable system's reliability and maintainability is through availability. Availability can be looked at from a number of ways, but this study will focus on operational availability, or the "ratio of system uptime to total time" [19]. Mathematically this is represented by Equation 1

$$A_s = \frac{nT - \sum_i^m r_i}{nT},$$

where
- A = availability of the system
- s = system
- n = number of cutters
- T = total number of days over the 7 year data period
- r = repair time of i-th CASREP for each system
- m = total number of CASREPs for each system
- i = individual CASREP for each system.

Downtime due to routine maintenance was not analyzed due to the unavailability of that information. It is known that cutters do not normally take down equipment for routine maintenance during their scheduled operational periods; therefore, any downtime associated with routine maintenance would have little effect on the overall availability of the cutter for scheduled missions. That data would come into play when cutters that are not scheduled to be operational have to become operational due to an increased need for assets such as during the Gulf Oil Spill or Hurricane Katrina.

An example of a subsystem calculation for the main diesel engine subsystem of propulsion system is given below (Equation 2).

$$A_s = \frac{nT - \sum_i^m r_i}{nT} = \frac{(27 * 2 * 2657) - \sum_1^{709} r_i}{(27 * 2 * 2657)} = 0.77$$

For this subsystem, a multiplier of 2 is used because there are two identical engines for each cutter in operation during the time period nT.

3.2.3 Mission Availability Calculations

Research question two (See Section 1.4) asks "How can engineering data about cutter maintenance activities be transformed into constructive operational information about availability?" To answer this, the GTST's and subsystem availability percentages are combined to find the total mission availability for the 210' and 270' cutters.

Using Microsoft Excel and the above availability equation, the CASREP data was analyzed to find the individual subsystem availabilities shown for each mission below. Major system availabilities (A) were calculated using Boolean algebra analysis of their respective success logic trees. Logic tree events are referred to in the equations by the following:

Mission Availability - MA

Propulsion – P
#1 Main Diesel Engine Subsystem - #1 MDE
#2 Main Diesel Engine Subsystem - #2 MDE
Controls - C_p

$$\mathrm{A}(P) = [\mathrm{A}(\#1\ MDE) + \mathrm{A}(\#2\ MDE) - (\mathrm{A}(\#1\ MDE) * \mathrm{A}(\#2\ MDE))] * A(C_p)$$

Power Generation – PG
#1 Ship Service Diesel Generator Subsystem - #1 SSDG
#2 Ship Service Diesel Generator Subsystem - #2 SSDG
Emergency Diesel Generator Subsystem - EDG
Controls – C_{PG}

$$A(PG) = \left[(A(\#1\ SSDG) * A(\#2\ SSDG) * A(EDG)) + \left(A(\#1\ SSDG) * A(\#2\ SSDG) * (1 - A(EDG))\right) + (A(\#1\ SSDG) * (1 - A(\#2\ SSDG)) * A(EDG)) + \left((1 - A(\#1\ SSDG)) * A(\#2\ SSDG) * A(EDG)\right)\right] * A\ (C_{PG})$$

Critical – C

Structural Integrity – SI
Communications Subsystem – COMMS
Navigation Subsystem – N
Firemain Subsystem – F
Refrigeration Subsystem – R
Potable Water Subsystem – PW

$$A(C) = A(SI) * A(COMMS) * A(N) * A(F) * A(R) * A(PW)$$

This equation is only valid if the subsystems' repair times were independent of the other subsystems, but in actuality, they are not. These repair times are dependent on the repair times of other machinery. For instance, if no other systems are broken, and a critical item breaks, its repair time will be short in order to keep the cutter available; however, if another system such as the propulsion system is keeping the cutter unavailable, the repair time of critical systems will be longer due to the amount of time the other system will be unavailable. Because of this, the availability of the critical systems is equated using the following equation:

$$A(C) = MIN(SI, COMMS, N, F, R, PW)$$

Each mission availability calculation contains the terms $A(P) * A\ (PG) * A\ (C)$; therefore for simplification of the availability tables, these terms will be simplified in the tables that follow.

Small Boats – SB
RHI Subsystem – RHI

OTH Subsystem – OTH

$$A(SB) = A(RHI) + A(OTH) - (A(RHI) * A(OTH))$$

Search System – SS
Aviation Support Subsystem – A
Special Search Components – SSC

$$A(SS) = A(A) + A(SSC) - (A(A) * A(SSC))$$

Weapons – W
Small Arms – SA*
Countermeasure System – CM*
25 mm Gun – 25
50 cal Guns – 50
76 mm Gun – 76
Ammo Hoist – AH

For a 270' cutter: $A(W) = [A(76) + A(50) - (A(76) * A(50))] * A(AH)$

For a 210' cutter: $A(W) = [A(25) + A(50) - (A(25) * A(50))] * A(AH)$

*Not included in overall weapons system availability – See GTST

Any deviations from all of the equations listed above will be noted as it applies to an individual mission. The following tables provide results of the availability analysis for each of the seven (7) missions being examined. *Note: The tables shown for Missions #1 to #5 include both 210 ft and 270 ft. cutters. Due to weapon differences, separate charts are shown for 210 ft and 270 ft cutters for Missions #6 to #7.*

Table 6: Availability Analysis for Mission #1, "Search and Rescue"

$$MA = A(P) * A(PG) * A(C) * [A(A) + A(RHI) + A(OTH) - (A(A) * A(RHI)) - (A(A) * A(OTH)) - (A(RHI) * A(OTH)) + (A(A) * A(RHI) * A(OTH))]$$

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Persons to Safety	Combined	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Locate Person In Distress	**Small Boats**	RHI Subsystem	0.83	
		OTH Subsystem	0.83	
	Search Systems	Aviation Support Subsystem	0.80	
		Special Search Components	0.98	
			Subgoal Availability	**0.99**
Get Person Out Of Water	**Small Boats**	RHI Subsystem	0.83	
		OTH Subsystem	0.83	
	Aviation	Aviation Support Subsystem	0.80	
			Subgoal Availability	
			Search and Rescue Mission Availability	**0.50**

Table 7: Availability Analysis for Mission #2, "Migrant Interdiction"

$$MA = A(P) * A\ (PG) * \ A(C) * A(SB) * A(SS)$$

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Cutter Acts As Holding/ Transport Platform	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Transport	**Small**	RHI Subsystem	0.83	0.97

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Migrants to Cutter	**Boats**			
		OTH Subsystem	0.83	
			Subgoal Availability	**0.97**
Locate Migrants	**Search Systems**	Aviation Support Subsystem	0.80	1.00
		Special Search Components	0.98	
			Subgoal Availability	**1.00**
			Migrant Interdiction Mission Availability	**0.48**

Table 8: Availability Analysis for Mission #3, "Drug Interdiction"

$$MA = A(P) * A\,(PG) * A(C) * [(A(RHI) + A(OTH) - A(RHI) * A(OTH)) * A(SA)$$

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Smugglers to Federal Facility	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Locate Drug Smugglers	**Small Boats**	RHI Subsystem	0.83	
		OTH Subsystem	0.83	
	Search Systems	Aviation Support Subsystem	0.80	
		Special Search Components	0.98	
			Subgoal Availability	**0.97**
Take Custody Of Drugs	**Small Boats**	RHI Subsystem	0.83	
		OTH Subsystem	0.83	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
Apprehend Smugglers	**Small Boats**	RHI Subsystem	0.83	
		OTH Subsystem	0.83	

	Weapons	Small Arms	1.00	
			Subgoal Availability	
			Drug Interdiction Mission Availability	**0.49**

Table 9: Availability Analysis for Mission #4, "Living Marine Resources"

$$MA = A(P) * A(PG) * A(C) * A(SB)$$

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterway	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	
			Subgoal Availability	**0.97**
			Living Marine Res. Mission Availability	**0.49**

Table 10: Availability Analysis for Mission #5, "Defense Readiness"; 210 ft. Cutter

$$MA = A(P) * A(PG) * A(C) * A(SB * SA) * A(W) * A(CM)$$

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterways	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From	**Weapons**	25 mm Gun	0.98	

Attacks		50 cal Guns	1.00	
		Ammo Hoist	0.98	
			Subgoal Availability	**0.98**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			Defense Readiness Mission Availability (210' Cutter)	**0.46**

Table 11: Availability Analysis for Mission #5, "Defense Readiness"; 270 ft. Cutter

$$MA = A(P) * A(PG) * A(C) * A(SB * SA) * A(W) * A(CM)$$

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterways	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.69	
		50 cal Guns	1.00	
		Ammo Hoist	0.98	
			Subgoal Availability	**0.98**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			Defense Readiness Mission Availability (270'	**0.46**

	Cutter)	

Table 12: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (210 ft. Cutter)

$$MA = A(P) * A(PG) * A(C) * A(SB * SA) * A(W) * A(CM)$$

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterways	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	25 mm Gun	0.98	
		50 cal Guns	1.00	
		Ammo Hoist	0.98	
			Subgoal Availability	**0.98**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			PWCS Mission Availability (210' Cutter)	**0.46**

Table 13: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (270 ft. Cutter)

$$MA = A(P) * A(PG) * A(C) * A(SB * SA) * A(W) * A(CM)$$

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	Combined	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.69	
		50 cal Guns	1.00	
		Ammo Hoist	0.98	
			Subgoal Availability	**0.98**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			PWCS Mission Availability (270' Cutter)	**0.46**

Table 14: Availability Analysis for Mission #7, "Other Law Enforcement"

$$MA = A(P) * A(PG) * A(C) * A(SB * SA)$$

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterway	**Combined**	Propulsion		0.76
		Power Generation		0.88
		Critical		0.75
			Subgoal Availability	**0.50**
Board And Inspect	**Small Boats**	RHI Subsystem	0.83	0.97
		OTH Subsystem	0.83	

Vessel				
	Weapons	Small Arms	1.00	1.00
			Subgoal Availability	**0.97**
			Other Law Enf. Mission Availability	**0.49**

A summary of mission availabilities from the analysis is provided in Table 15 below.

Mission	Availability
1 - Search and Rescue	0.5
2 - Migrant Interdiction	0.48
3 - Drug Interdiction	0.49
4 - Living Marine Resources	0.48
5 - Defense Readiness	0.46
6 - Ports, Waterways, and Coastal Security	0.46
7 - Other Law Enforcement	0.48

Table 15: Summary of Overall Mission Availability (210/270 ft. Cutters)

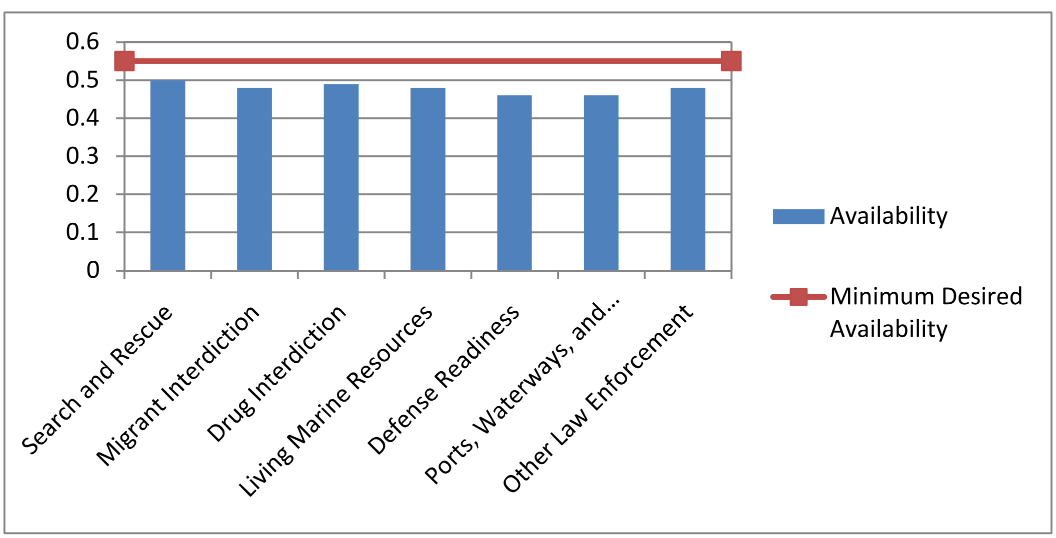


Figure 26: 210/270 ft. Cutter Mission Availability (2003-2010)

3.2.3.1 Summary of Research Question Two

Research Question #2 asks: "How can engineering data about cutter maintenance activities be transformed into constructive operational information about availability?" Coast Guard operations are concerned with cutters being available to complete the mandated missions. The above analysis shows how casualty repair times can be transformed into operational availability. From the operational standpoint, cutters are expected to be available a minimum of 55% of the year. Therefore, this analysis shows that, for the past seven years, the medium endurance cutters (210 ft and 270 ft) have not met their target availability as shown in Figure 26. This is, in part, why reliability-centered maintenance principles were mandated in 2004 and a reliability engineering program was implemented in 2009. Using data from 2003 to 2010, one can see that the limiting factors of availability come from the critical and propulsion systems categories. Improving the availability of just these two systems alone will improve overall total mission availability. This then can be construed as a primary goal for US Coast Guard fleet reliability engineering program.

3.2.4 Comparison of Mission Availability by Maintenance Program Principles Timeline

As noted in Chapter 1 and above, the Coast Guard surface fleet has shifted from preventive maintenance to reliability centered maintenance in recent years. Research Question #3 asks "How has the shift in maintenance ideologies impacted the medium endurance cutters' mission availabilities?". This is answered by comparing mission availabilities based on the three time periods of differing maintenance ideologies. The above total CASREP data was separated into three categories: a) "Prior to 2004" when preventive maintenance was the dominant maintenance ideology, b) "2005-2009" when reliability centered principles were mandated, but no real program stood up, and c) "After 2009" when the reliability program was implemented. The three categories of data were analyzed using the same approach as in section 3.2.3. A summary of the mission availability percentages is shown in Table 16. Tables detailing each mission individually can be found in Appendix II. A comparison of these availabilities to the minimum desired availability of 0.55 is shown in Figure 27. Tables 17 and 18 detail availability, number of casreps, and repair times by system and subsystem. Analyzing the data in this manner could be useful for making decisions regarding allocating maintenance resources.

Mission	Prior to 2004 Availability	2005-2009 Availability	After 2009 Availability
Migrant Interdiction	0.66	0.44	0.37
Search and Rescue	0.69	0.46	0.38
Living Marine Resources	0.68	0.45	0.37
Other Law Enforcement	0.68	0.45	0.37
Drug Interdiction	0.6	0.38	0.3
Defense Readiness	0.63	0.43	0.36
Ports, Waterways, and Coastal Security	0.63	0.43	0.36

Table 16: Mission Availabilities by Time Period Category

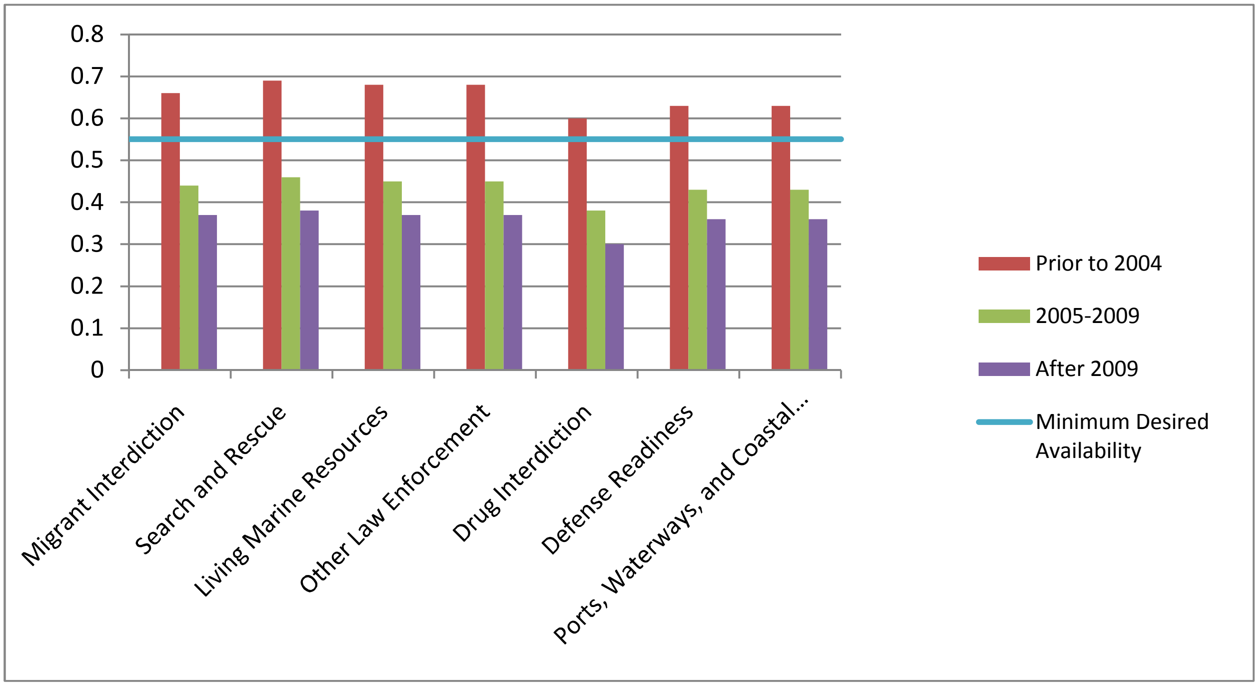


Figure 27: Mission Availabilities by Category Compared to Minimum Desired

System and Subsystem Availability	Prior to 2004 Availability	2005-2009 Availability	After 2009 Availability	Overall Availability
Propulsion	**0.89**	**0.75**	**0.67**	**0.76**
#1 Main Diesel Engine Subsystem	0.79	0.76	0.73	0.77
#2 Main Diesel Engine Subsystem	0.79	0.76	0.73	0.77
Propulsion Controls	0.93	0.79	0.73	0.8
Power Generation	**0.94**	**0.83**	**0.83**	**0.88**
#1 Ship Service Diesel Generator Subsystem	0.93	0.94	0.92	0.93
#2 Ship Service Diesel Generator Subsystem	0.93	0.94	0.92	0.93
Emergency Diesel Generator Subsystem	0.96	0.95	0.92	0.95
Generator Controls	0.95	0.84	0.84	0.89
Critical	**0.83**	**0.74**	**0.69**	**0.75**
Structural Integrity Components	0.91	0.76	0.75	0.79
Communications Subsystem	1	1	1	1
Navigation Subsystem	1	1	1	1
Firemain Subsystem	0.88	0.84	0.87	0.78
Refrigeration Subsystem	0.91	0.84	0.85	0.85

Sewage Subsystem	0.98	0.97	0.98	0.98
Potable Water Subsystem	0.83	0.74	0.69	0.75
Weapons	-----	-----	-----	-----
76 mm Gun	0.68	0.68	0.67	0.67
25 mm Gun	0.98	0.97	1	0.98
50 cal Guns	1	1	1	1
Ammo Hoist	0.96	0.99	0.96	0.98
Small Arms	1	1	1	1
Countermeasure System	0.94	0.95	0.97	0.94
Other	-----	-----	-----	-----
RHI Boat Subsystem	0.87	0.82	0.81	0.83
OTH Boat Subsystem	0.87	0.82	0.81	0.83
Aviation Support System	0.88	0.85	0.81	0.8
Special Search Tools	0.79	0.98	0.99	0.98

Table 17: System and Subsystem Availability during Designated Time Periods

System and Subsystem Availability	**Prior to 2004**		**2005-2009**		**After 2009**		**Overall**	
(average repair time in DAYS)	**# of Casreps**	**Avg. Repair Time**	**# of Casreps**	**Avg. Repair Time**	**# of Casreps**	**Avg. Repair Time**	**# of Casreps**	**Avg. Repair Time**
Propulsion	**342**	**29**	**1161**	**49**	**345**	**39**	**1848**	**39**
#1 Main Diesel Engine Subsystem	148	34	467	52	132	41	747	42
#2 Main Diesel Engine Subsystem	148	34	467	52	132	41	747	42
Propulsion Controls	46	19	227	45	81	34	354	33
Power Generation	**122**	**40**	**553**	**52**	**157**	**45**	**832**	**46**
#1 Ship Service Diesel Generator Subsystem	45	37	211	30	54	29	310	32
#2 Ship Service	45	37	211	30	54	29	310	32

System and Subsystem Availability	Prior to 2004		2005-2009		After 2009		Overall	
Diesel Generator Subsystem								
Emergency Diesel Generator Subsystem	8	58	48	52	13	62	69	57
Generator Controls	24	26	83	96	36	45	143	55
Critical	**451**	**47**	**2312**	**55**	**645**	**37**	**3408**	**46**
Structural Integrity Components	20	58	122	95	52	49	194	67
Communication Subsystem	232	40	892	43	242	36	1366	40
Navigation Subsystem	85	44	728	44	198	33	1011	40
Firemain Subsystem	33	46	152	51	34	43	219	47
Refrigeration Subsystem	23	46	128	63	36	41	187	50
Sewage Subsystem	5	54	32	39	10	18	47	37
Potable Water Subsystem	53	41	258	49	73	43	384	44
Weapons	**192**	**25**	**592**	**47**	**118**	**24**	**902**	**32**
76 mm Gun	151	26	486	33	98	34	735	31
25 mm Gun	17	17	57	25	3	5	77	16
50 cal Guns	0	0	4	29	0	0	4	10
Ammo Hoist	6	66	4	130	5	84	15	93
Small Arms	0	0	0	0	0	0	0	0
Countermeasure System	18	42	41	65	12	23	71	43
Other	**269**	**44**	**900**	**46**	**278**	**38**	**1447**	**43**
RHI Boat Subsystem	93	33	422	41	118	32	633	36
OTH Boat Subsystem	93	33	322	41	118	32	533	35
Aviation Support	23	67	130	56	39	49	192	57

System and Subsystem Availability	Prior to 2004		2005-2009		After 2009		Overall	
System								
Special Search Tools	60	44	26	45	3	40	89	43

Table 18: Number of Casreps and Average Repair Times by System and Subsystems

3.2.4.1 Summary of Research Question Three

Research Question #3 asks "How has the shift in maintenance ideologies impacted the medium endurance cutters' mission availabilities?". It is apparent that there is a downward trend in mission availability based on the implementation of the full-scale reliability engineering program. This trend could be due to several factors. First, the data available prior to 2004 and after 2009 was quite limited by the information captured within FLS and therefore could have impacted the availability percentages. More data would provide a more accurate picture. It may also be several years before the full impact of the reliability engineering program are seen. Lastly, even though new maintenance programs are introduced, the cutters are still aging. With an average of 37 years in operation, maintaining these cutters in general is a challenging task. However, based on the data analysis, if the Coast Guard hopes to improve the mission availability of the medium endurance cutters, it must improve upon the current status of the surface fleet reliability engineering program

3.3 Chapter Summary

This chapter investigates in detail the relationship between component and subsystem reliability/availability and overall cutter availability for seven key missions of the medium endurance class cutters (210 ft and 270 ft in length). This investigation is an exploratory, empirical analysis of component and subsystem failures based on actual collected failure data and repair times (via the CASREP system). The investigation analyzes a time period of October 2003 through January 2011. See Section 3.2 for a description of the analytical model and methods used in this investigation. Section 3.3 provides the primary results for each study.

Overall cutter availability is a key metric for the US Coast Guard fleet reliability engineering program. From an operational standpoint, Coast Guard cutters are expected to be available of minimum of 55% of the year. This corresponds to 4,820 hours of availability per year. Key results of this analysis and investigation are as follows:

- The calculated total cutter availability for the seven analyzed missions ranges from 46% to 50%, compared to the mandated minimum requirement of 55%. Thus, for the past seven years, medium endurance cutters have not achieved their target availability. See Section 3.2.3 for specific results.

- The primary limiting factors causing less than mandated availability metrics are two categories of equipment: a) main propulsion subsystems and b) critical subsystems grouping, including communications, navigation, firemain, refrigeration, sewage, and potable water. Increasing the availability of only these two categories will dramatically improve overall total mission availability.

- The mission availabilities of the medium endurance cutters have decreased over time even as new maintenance principles have been introduced. The analysis was performed for three distinct time periods: a) "Prior to 2004" when preventive maintenance was the dominant maintenance ideology, b) "2005-2009" when reliability centered principles were mandated, but no real program stood up, and c) "After 2009" when the reliability program was implemented. Unfortunately, overall medium endurance cutter availability has decreased significantly over these three time periods. See Section 3.2.4 for specific results.

- Several possible causes for the decrease in overall cutter availability are proposed. These include collected data limitations which may partially impact the availability percentages. Also, there is a probable time delay before the full impact of the improvements already made in the reliability engineering program will be observed. Last, and very importantly, the Coast Guard medium endurance cutter fleet continues to age with the average cutter being in operation for 37 years.

Chapter 4

Discussion, Conclusions, and Recommendations

4.1 Analysis Conclusions

One major goal of the surface fleet reliability engineering program is to increase cutter mission availability through improved maintenance policies and practices. The analysis and investigation in Chapter 3 yielded lower than desired cutter mission availability percentages and also a worsening trend in mission availability over time. See Table 19 below for a summary of key analysis results (see also Section 3.3).

Item	Key Result	Impact or Discussion
1	Total medium endurance cutter availability over last 8 years ranges from 46% to 50%, pending mission type.	Cutters are not meeting desired annual availability of 55% (4,820 hours per year).
2	The primary two cutter subsystem categories accounting for the bulk of the availability shortcoming are a) main propulsion and b) critical auxiliary systems.	Increasing the availability of only these two categories will dramatically improve overall cutter mission availability.
3	Cutter mission availabilities have decreased significantly over the analysis period, even as new maintenance principles have been introduced.	US Coast Guard must improve upon the current cutter reliability engineering program. Also, further analysis must be done to examine the impact of the average cutter age of 37 years.

Table 19: Key Results

Because cutter availability goals were not met, one must question why the current program has not increased availability percentages, and what actions can be taken to improve the current program. Through the SSM process and CASREP data analysis, it was found that while the reliability engineering program has identified the decline in cutter availability, the Coast Guard must increase its priority on further developing this program. First the current shortcomings of the program must be identified. The shortcomings in the current reliability program are due to the lack of funding, the age of existing assets, and the Coast Guard culture. Implementation improvements will be discussed in section 4.2 below.

4.1.1 Lack of Funding

One aspect of the new reliability engineering program that is working is the concept of centralized funding. Each product line controls their portion of the budget to maintain their assigned cutters. This provides the Coast Guard with a more accurate assessment of the relationship between cost, asset availability, and operating hours. Essentially, the goal is to enable each Product Line to be able to determine the cost of operating asset in terms of dollars per operational hour to include maintenance and CASREP costs along with operational costs. However, even with centralized funding, the money is not always available. The Coast Guard has a history of learning to do more with less, and this trend only continues as budget cuts mean that programs such as the reliability program face a lack of funding to accomplish their goals. Necessary maintenance is deferred or even cancelled due to lack of funding, which only exacerbates the growing maintenance needs. Budget cuts also cause logistics problems when trying to order spare and replacement parts for assets that are already at or nearing the end of their supportable life cycle, thus increasing repair times when a casualty increases, and decreasing cutter mission availability. This, and future analyses, of maintenance data could be used to improve the allocation of maintenance funding.

4.1.2 Age of Existing Assets

Coupled with the lack of funding, the age of existing assets hinders the success of the surface fleet reliability program. Maintaining 50+ years old assets proves to be a challenging task with even the most established maintenance programs, let alone a program in its infancy such as the one investigated in this thesis. Although the Coast Guard has done a very effective job keeping assets operational until onboard equipment is nearly unsupportable through the original equipment manufacturer, if the Coast Guard hopes to extend the mission availability of the medium endurance cutters, it must improve the surface fleet reliability program at a greater rate than the cutters are aging.

4.1.3 Coast Guard Culture

Lastly, the culture of the Coast Guard has a significant impact on the successful implementation of the surface fleet reliability program, and should not be overlooked. The program was implemented in 2009 to meet a modernization timeline; however, this was before all of the training and infrastructure on the lower levels of the chain of command was completed and in place. There is also little information known about the reliability program outside of the engineering realm of the Surface Forces Logistics Center. This means that the operators and maintainers of the aging assets do not understand the maintenance needs, casualty reporting, and data logging required to keep them in operation. Information needs to be filtrated throughout the entirety of the Coast Guard down to the deck plate level in order to obtain complete understanding and buy-in of the program.

4.2 Improving the Reliability Engineering Program

One of the key research questions for this work asks "How can the Surface Forces Logistics Center improve its implementation of the reliability engineering program?". This is identified as Research Question #4 in Section 1.4. Answers and conclusions on Research Questions #1 through #3 have provided the necessary background information to fully answer Research Question #4. Refer to Section 2.9 (Question #1), Section 3.2.3.1 (Question #2) and Section 3.2.3.2 (Question #3) for detailed discussion on each of the four research questions. The key recommendations to improving the current reliability engineering program were discovered through the SSM identifying desirable and feasible changes process. These are described in significant detail in Section 2.8 and summarized as follows.

4.2.1 Provide Appropriate Training for Each Command Level

The biggest improvement to the reliability program will be providing tailored training to each level of the organization. A large-scale program such as this relies on everyone to be successful from the Captain at the high-level that requests funding from Congress to the new machinery technician that completes the maintenance on system components. Training prior to implementing the new maintenance program may have had a large impact on its success during the program's infancy; however, training at this stage will still help the program to succeed in the future. Training on standard CASREP terminology and reporting procedures will improve the CASREP database to provide a more accurate picture of availability due to casualties. Along with this, the CASREP EIC's can be updated and modified to best serve the Coast Guard and its needs that may differ from the Navy with training on exactly what information the Coast Guard desires for its CASREP reporting system.

4.2.2 Cultural Change

A cultural change will also greatly improve the implementation of the reliability engineering program. As aforementioned, the Coast Guard, and engineers in particular, have learned to do more with less. This has caused individuals to circumvent the standard processes to effect machinery repairs quicker and cheaper, such as using non-standard replacement components. Unfortunately even though the component is repaired quicker, it undermines the goals and purpose of the reliability program. Without the necessary documentation to show that more money and personnel are needed to operate and maintain current assets, the Coast Guard cannot vie for more Congressional funding, which only hampers those who attempt to follow the proper maintenance channels. Once everyone is properly trained on the new reliability engineering program procedures, there needs to be accountability for those who do not follow the standardized maintenance procedures as outlined in the surface fleet reliability program guide.

4.2.3 Improved Information Flow

Along with a cultural change, a change in the overall information flow must occur for the reliability engineering program to be successful. Approximately twenty-five percent of a cutter crew rotates out each year which can cause challenges to accurately documenting the cutter condition as personnel responsibilities change as documentation requires the direct input of information into multiple databases. A streamlined "closed-loop" process for both planned and unplanned maintenance needs to be developed into a single database that can be accessed by all necessary individuals. Information also needs to be translated routinely to the operations division of the Coast Guard. By showing the current availability percentages and trends to operators, it will stress the importance of making maintenance a positive priority and rather than a hindrance. Once maintenance buy-in is achieved throughout the Coast Guard, the reliability engineering program will make a marked difference in achieving the desired cutter mission availability percentages.

4.2.4 In-Service Time

Time plays a large role in the success of a newly implemented program. All of the aforementioned implementation improvements will take time; therefore, as time progresses, so will the success of the reliability engineering program. With the ever-changing political and funding situations, the Coast Guard has learned to be an adaptable organization, but it cannot change overnight. As individuals receive training on the new program, a cultural change will occur. And as the cultural change occurs, information flow will happen, which will improve the cutter mission availabilities. The researcher is fully confident that using the data analysis from

Chapter 3 and the changes mentioned in this chapter, the surface fleet can evolve its current reliability engineering program into a more successful one.

4.3 Recommendations for Future Work

This thesis studied the current status of the Coast Guard's surface fleet reliability engineering program, and addressed the mission availability of cutters based on unplanned maintenance repairs to the larger and more vital cutter systems. Once the recently implemented reliability program has been in service longer, another study to evaluate its effectiveness with regards to casualty repair times and mission availability would be beneficial. It would also be useful to analyze availability versus the cutter operating area to see if a specific environment affects the rate of casualties more than others. As more data is gathered, it would be prudent to investigate the dependencies among the systems and subsystems in order to provide the most accurate view of availability. In addition, a study to evaluate the operating cost per hour under the reliability engineering program would assist senior leaders to make correct decisions regarding new acquisitions and the feasibility of maintaining aging assets.

4.4 Final Conclusions

This study revealed less than desirable outcomes of the implementation of the surface fleet reliability engineering program, specifically with the mission availability of the medium endurance cutters. The program was implemented before employee buy-in was achieved, and prior to training personnel on the new processes and procedures. With the improvement recommendations above and in Chapter 2, the

Coast Guard can adapt its program to fit the needs of the service. Funding has been, and will continue to be, an issue in maintaining Coast Guard assets. By conducting future analyses such as in this thesis, the Coast Guard will be able to justify to Congress the per hour operating cost necessary to properly maintain the cutters in order to complete all required missions while keeping crews safe.

Appendix I – Mission GTST's

Appendix I Contents

Figure 28: Mission #1, "Search and Rescue" - Mission GTST

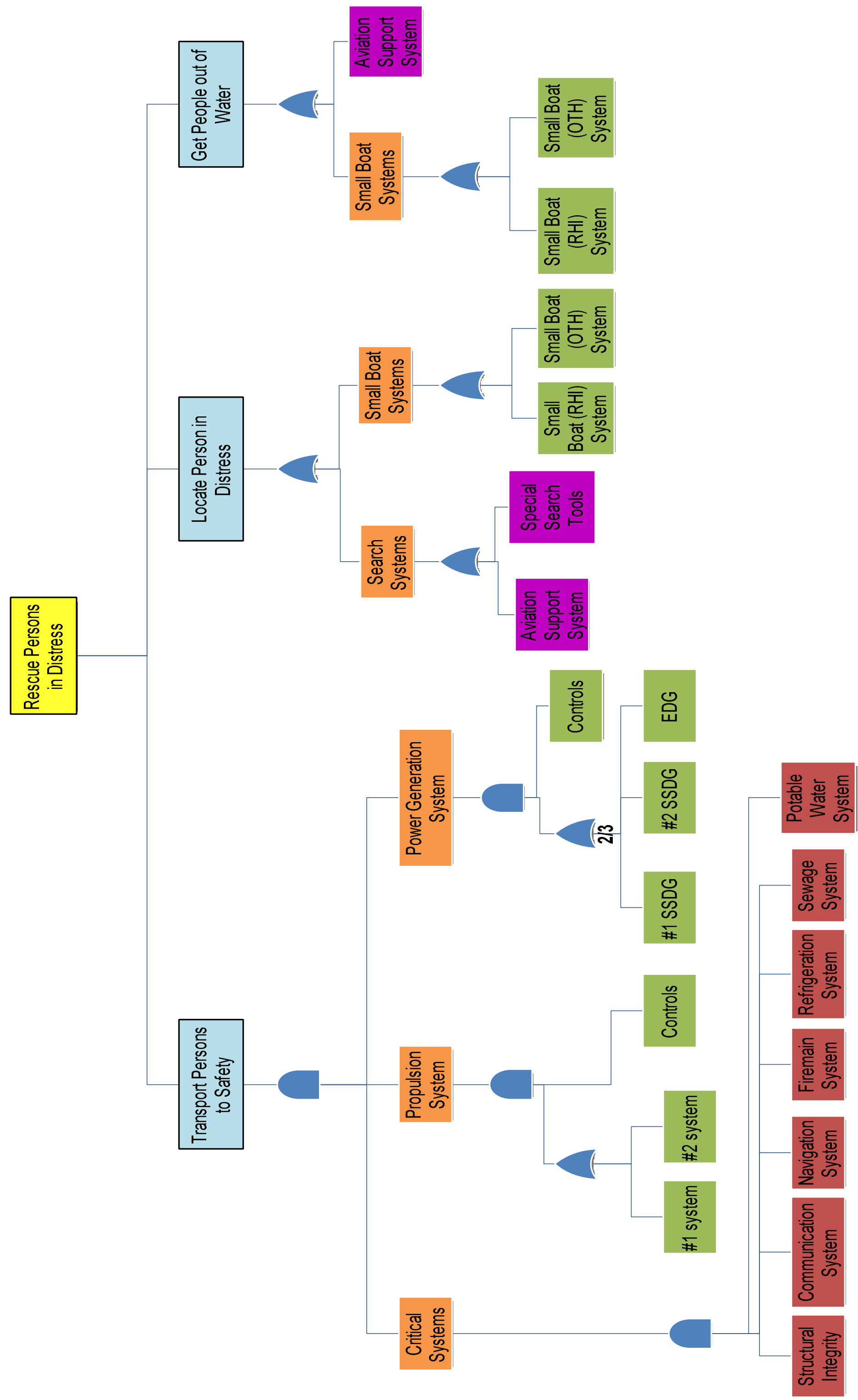


Figure 29: Mission #2, "Migrant Interdiction" – Mission GTST

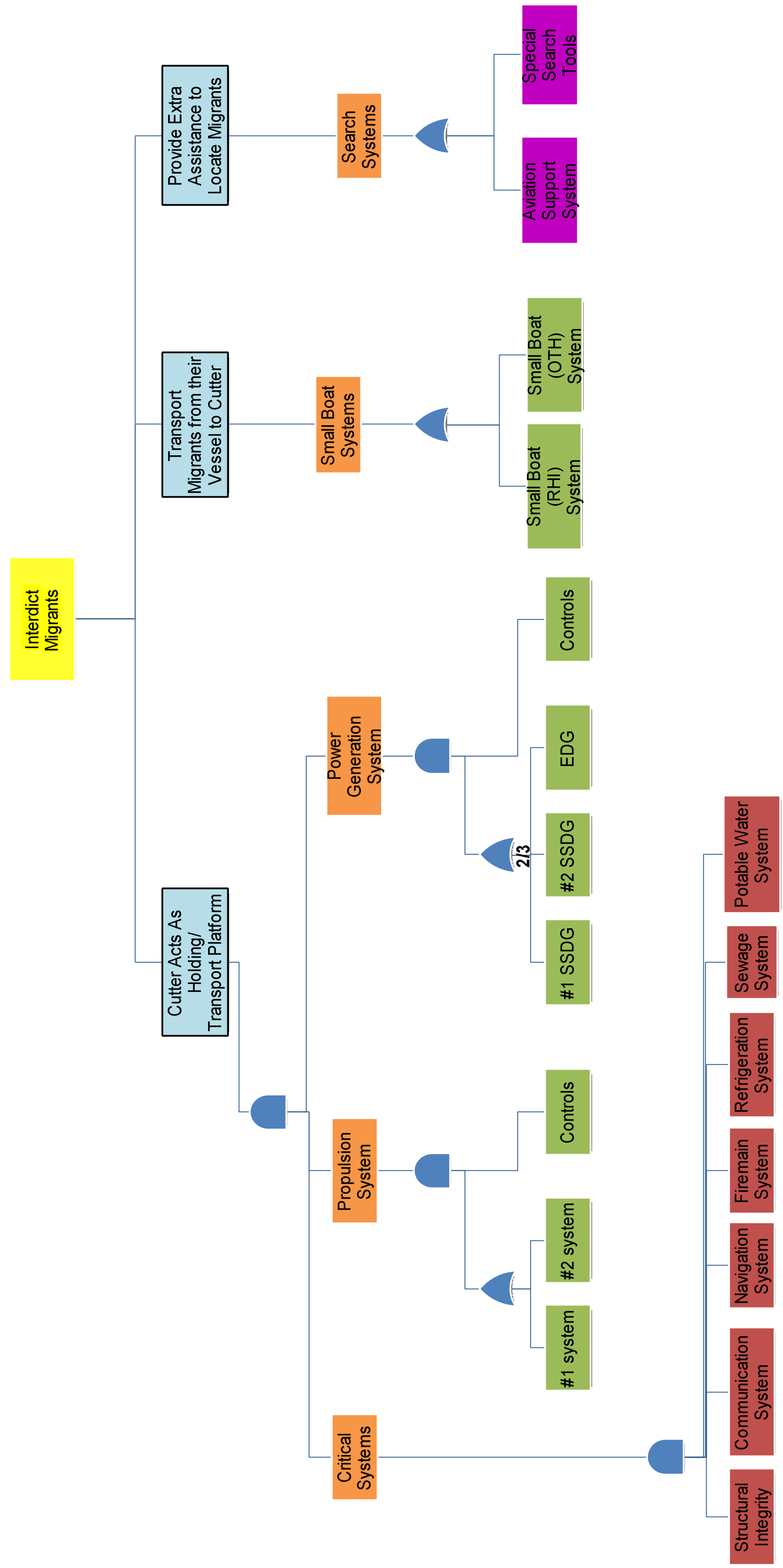


Figure 30: Mission #3, "Drug Interdiction" – Mission GTST

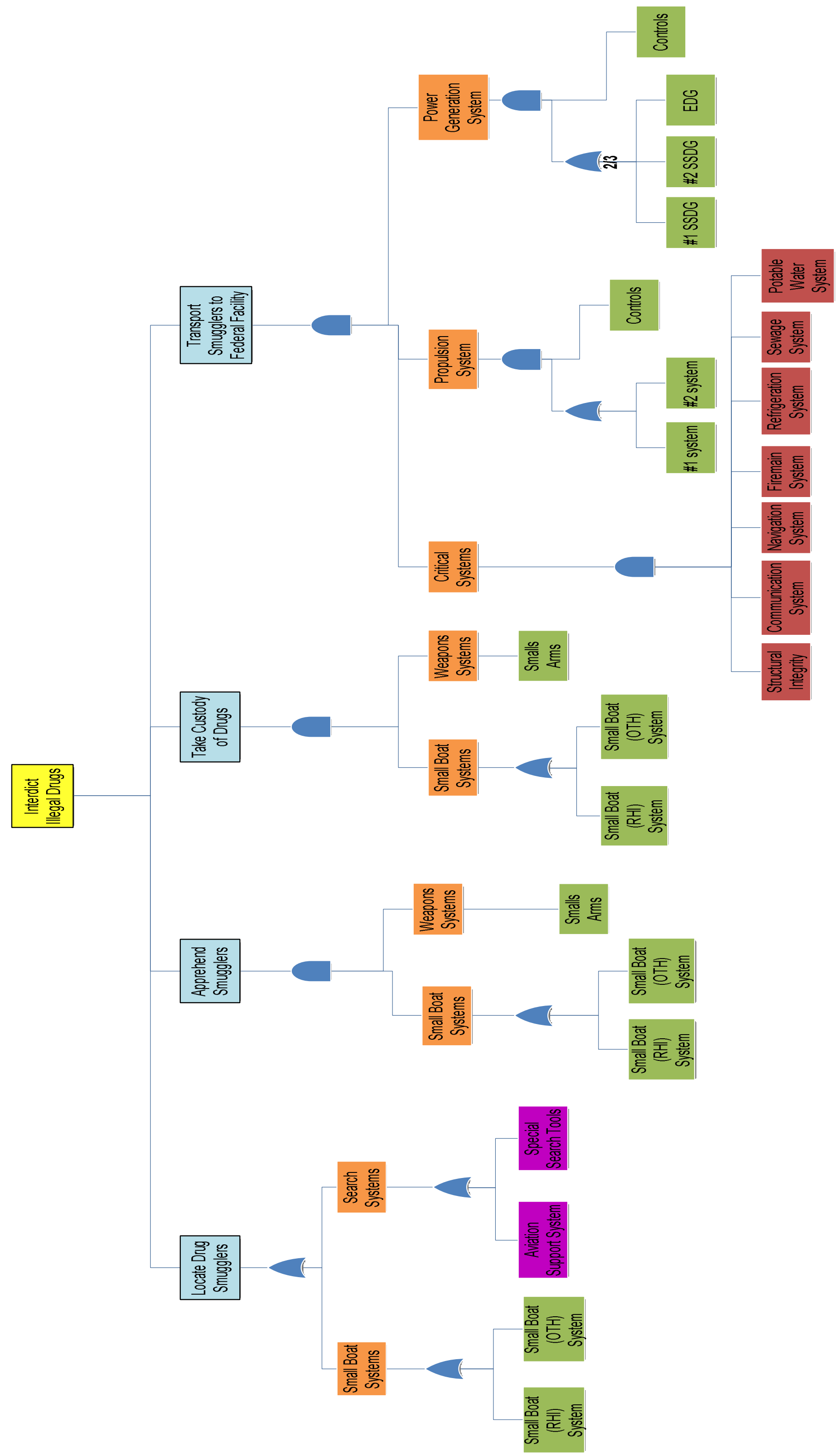


Figure 31: Mission #4, "Living Marine Resources" – Mission GTST

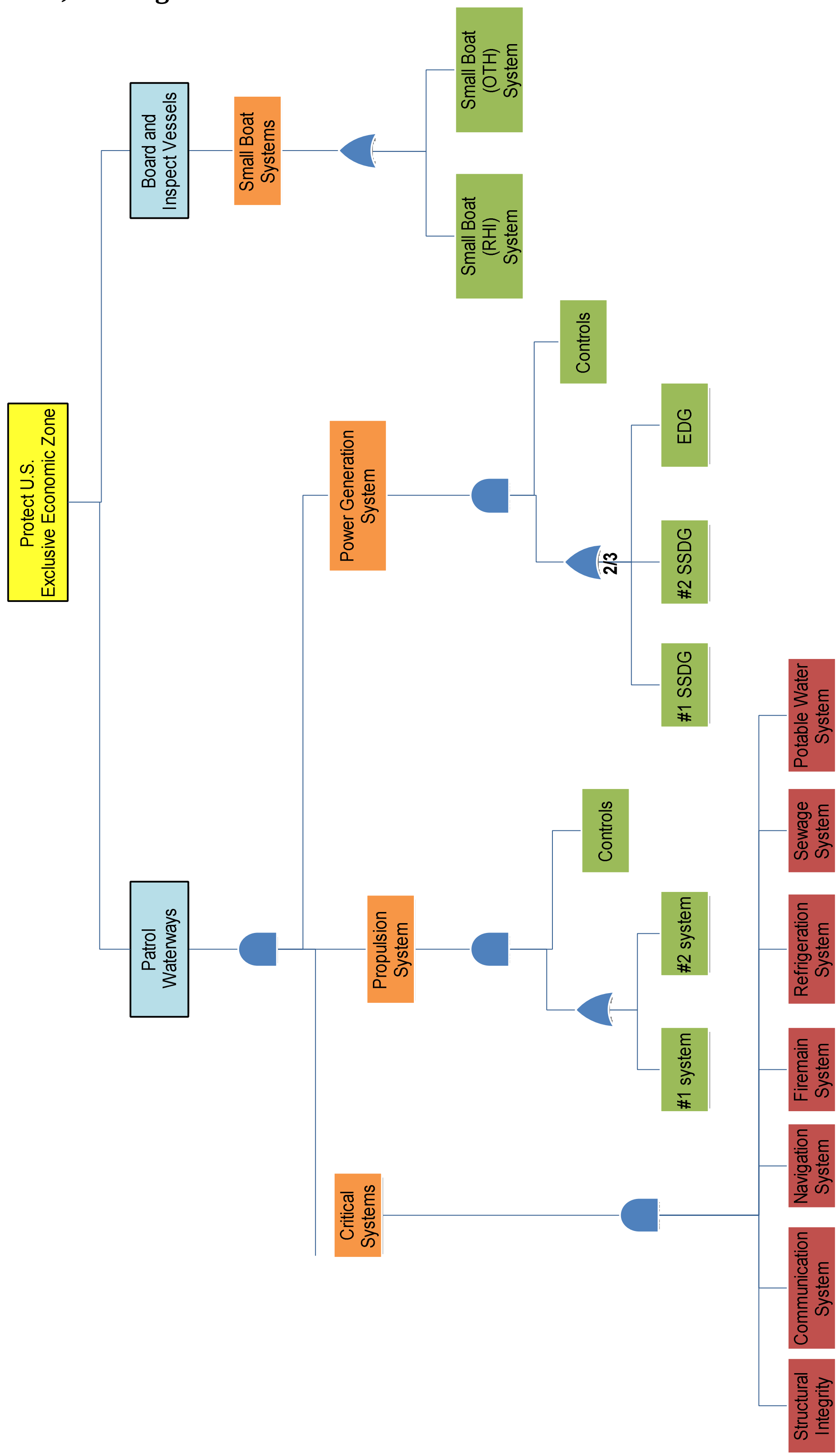


Figure 32: Mission #5, "Defense Readiness" – Mission GTST

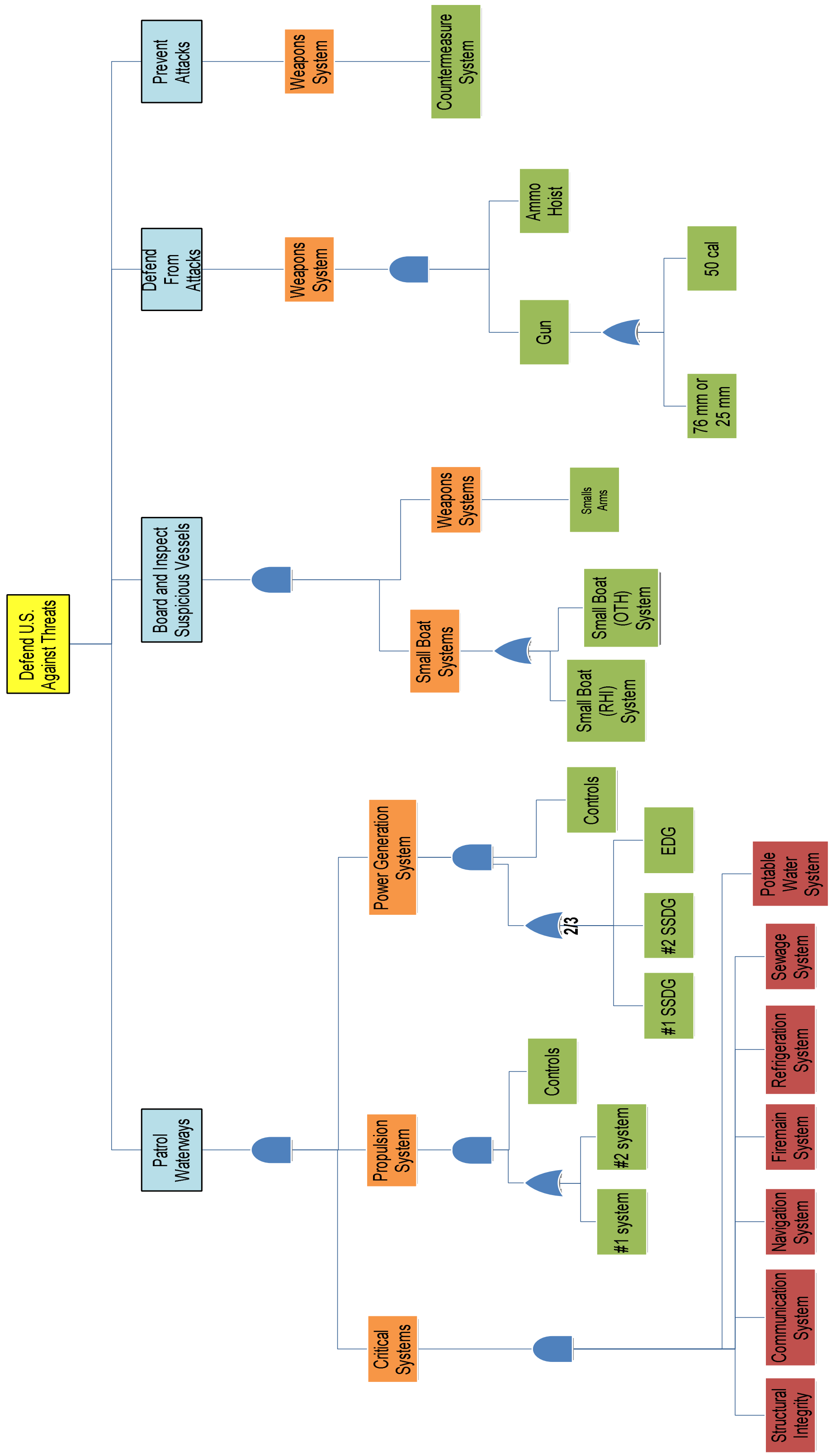


Figure 33: Mission #6, “Port Waterways and Coastal Security” – Mission GTST

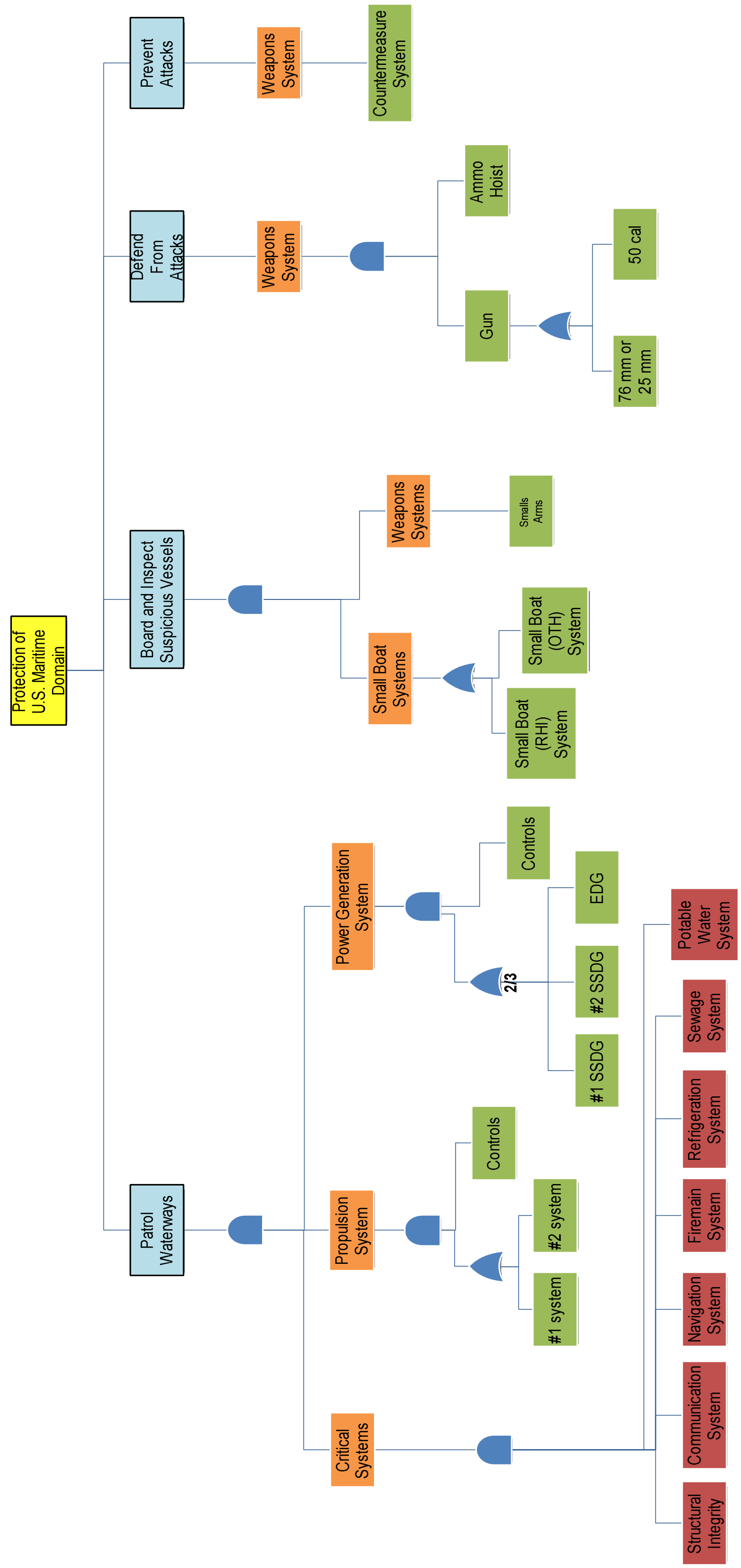
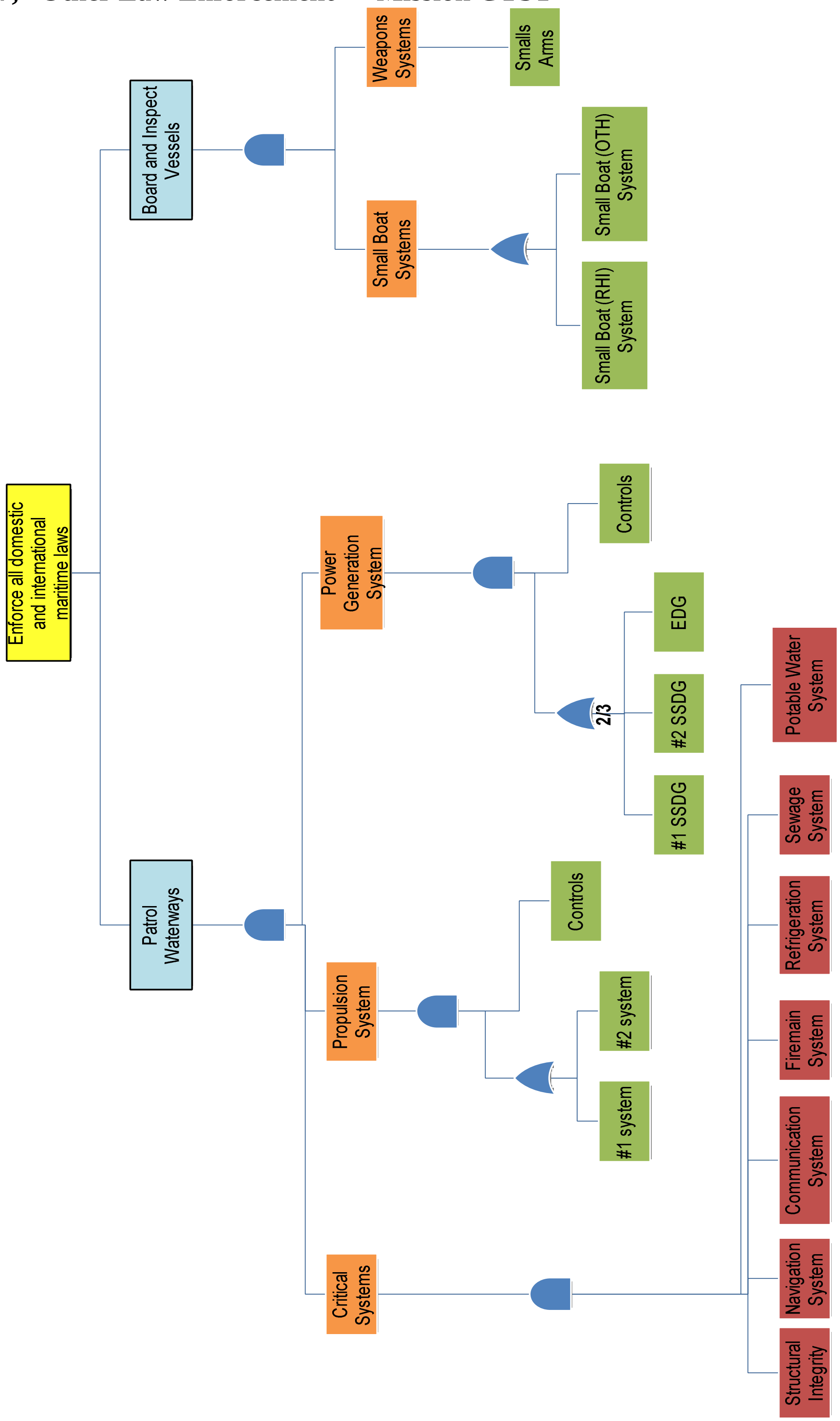


Figure 34: Mission #7, "Other Law Enforcement" – Mission GTST



Appendix II – Mission Availabilities

Appendix I Contents

Up to 2004: 10/1/2003 – 12/31/2004

2005 - 2009: 1/1/2005 – 12/31/2009

After 2009: 1/1/2010 – 1/7/2011

Up to 2004: 10/1/2003 – 12/31/2004

Table 20: Mission #1, "Search and Rescue" – Availability Calculations

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Persons to Safety	Combined	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Locate Person In Distress	Small Boats	RHI Subsystem	0.87	
		OTH Subsystem	0.87	
	Search Systems	Aviation Support Subsystem	0.88	
		Special Search Components	0.79	
			Subgoal Availability	**0.99**
Get Person Out Of Water	Small Boats	RHI Subsystem	0.87	
		OTH Subsystem	0.87	
	Aviation	Aviation Support Subsystem	0.88	
			Subgoal Availability	
			Search and Rescue Mission Availability	**0.69**

Table 21: Availability Analysis for Mission #2, "Migrant Interdiction"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Cutter Acts As Holding/Transport Platform	Combined	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Transport Migrants to Cutter	Small Boats	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	

			Subgoal Availability	**0.98**
Locate Migrants	**Search Systems**	Aviation Support Subsystem	0.88	0.97
		Special Search Components	0.79	
			Subgoal Availability	**0.97**
			Migrant Interdiction Mission Availability	**0.67**

Table 22: Availability Analysis for Mission #3, "Drug Interdiction"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Smugglers to Federal Facility	**Combined**	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Locate Drug Smugglers	**Small Boats**	RHI Subsystem	0.87	
		OTH Subsystem	0.87	
	Search Systems	Aviation Support Subsystem	0.88	
		Special Search Components	0.79	
			Subgoal Availability	**0.87**
Take Custody Of Drugs	**Small Boats**	RHI Subsystem	0.87	
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
Apprehend Smugglers	**Small Boats**	RHI Subsystem	0.87	
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	
			Subgoal Availability	

		Drug Interdiction Mission Availability	**0.60**

Table 23: Availability Analysis for Mission #4, "Living Marine Resources"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterway	**Combined**	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	
			Subgoal Availability	**0.98**
			Living Marine Res. Mission Availability	**0.68**

Table 24: Availability Analysis for Mission #5, "Defense Readiness"; 210 ft. Cutter

Subgoal	System	Subsystem/Componen t	Subsystem Availability	System Total Availability
Patrol Waterways	**Combine d**	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From	**Weapons**	25 mm Gun	0.98	

Attacks		50 cal Guns	1.00	
		Ammo Hoist	0.97	
			Subgoal Availability	**0.97**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			Defense Readiness Mission Availability (210' Cutter)	**0.63**

Table 25: Availability Analysis for Mission #5, "Defense Readiness"; 270 ft. Cutter

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterways	**Combined**	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.68	
		50 cal Guns	1.00	
		Ammo Hoist	0.97	
			Subgoal Availability	**0.97**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			Defense Readiness Mission Availability (270' Cutter)	**0.63**

Table 26: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (210 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	Combined	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board and Inspect Suspicious Vessels	Small Boats	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	Weapons	25 mm Gun	0.98	
		50 cal Guns	1.00	
		Ammo Hoist	0.97	
			Subgoal Availability	**0.97**
Prevent Attacks	Weapons	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			PWCS Mission Availability (210' Cutter)	**0.63**

Table 27: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (270 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	Combined	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board and Inspect	Small Boats	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	

Suspicious Vessels	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.68	
		50 cal Guns	1.00	
		Ammo Hoist	0.97	
			Subgoal Availability	**0.97**
Prevent Attacks	**Weapons**	Countermeasure System	0.94	
			Subgoal Availability	**0.94**
			PWCS Mission Availability (270' Cutter)	**0.63**

Table 28: Availability Analysis for Mission #7, "Other Law Enforcement"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterway	**Combined**	Propulsion		0.89
		Power Generation		0.94
		Critical		0.83
			Subgoal Availability	**0.69**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.87	0.98
		OTH Subsystem	0.87	
	Weapons	Small Arms	1.00	1.00
			Subgoal Availability	**0.98**
			Other Law Enf. Mission Availability	**0.68**

2005 - 2009: 1/1/2005 – 12/31/2009

Table 29: Mission #1, "Search and Rescue" – Availability Calculations

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Persons to Safety	Combined	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Locate Person In Distress	Small Boats	RHI Subsystem	0.82	
		OTH Subsystem	0.82	
	Search Systems	Aviation Support Subsystem	0.85	
		Special Search Components	0.98	
			Subgoal Availability	**0.99**
Get Person Out Of Water	Small Boats	RHI Subsystem	0.82	
		OTH Subsystem	0.82	
	Aviation	Aviation Support Subsystem	0.85	
			Subgoal Availability	
			Search and Rescue Mission Availability	**0.46**

Table 30: Availability Analysis for Mission #2, "Migrant Interdiction"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Cutter Acts As Holding/Transport Platform	Combined	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Transport Migrants to Cutter	Small Boats	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
			Subgoal Availability	**0.97**

Locate Migrants	**Search Systems**	Aviation Support Subsystem	0.85	1.00
		Special Search Components	0.98	
			Subgoal Availability	**1.00**
			Migrant Interdiction Mission Availability	**0.44**

Table 31: Availability Analysis for Mission #3, "Drug Interdiction"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Smugglers to Federal Facility	**Combined**	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Locate Drug Smuggler	**Small Boats**	RHI Subsystem	0.82	
		OTH Subsystem	0.82	
	Search Systems	Aviation Support Subsystem	0.85	
		Special Search Components	0.98	
			Subgoal Availability	**0.82**
Take Custody Of Drugs	**Small Boats**	RHI Subsystem	0.82	
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
Apprehend Smugglers	**Small Boats**	RHI Subsystem	0.82	
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
			Drug Interdiction Mission Availability	**0.38**

Table 32: Availability Analysis for Mission #4, "Living Marine Resources"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterway	Combined	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board And Inspect Vessel	Small Boats	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
			Subgoal Availability	**0.97**
			Living Marine Res. Mission Availability	**0.45**

Table 33: Availability Analysis for Mission #5, "Defense Readiness"; 210 ft. Cutter

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	Combined	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board and Inspect Suspicious Vessels	Small Boats	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	Weapons	25 mm Gun	0.97	
		50 cal Guns	1.00	
		Ammo Hoist	0.99	
			Subgoal Availability	**0.99**
Prevent Attacks	Weapons	Countermeasure System	0.95	
			Subgoal Availability	**0.95**

			Defense Readiness Mission Availability (210' Cutter)	**0.43**

Table 34: Availability Analysis for Mission #5, "Defense Readiness"; 270 ft. Cutter

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.68	
		50 cal Guns	1.00	
		Ammo Hoist	0.99	
			Subgoal Availability	**0.99**
Prevent Attacks	**Weapons**	Countermeasure System	0.95	
			Subgoal Availability	**0.95**
			Defense Readiness Mission Availability (270' Cutter)	**0.43**

Table 35: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (210 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	Combined	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	25 mm Gun	0.97	
		50 cal Guns	1.00	
		Ammo Hoist	0.99	
			Subgoal Availability	**0.99**
Prevent Attacks	**Weapons**	Countermeasure System	0.95	
			Subgoal Availability	**0.95**
			PWCS Mission Availability (210' Cutter)	**0.43**

Table 36: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (270 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board and Inspect	**Small Boats**	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	

Suspicious Vessels	**Weapons**	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.68	
		50 cal Guns	1.00	
		Ammo Hoist	0.99	
			Subgoal Availability	**0.99**
Prevent Attacks	**Weapons**	Countermeasure System	0.95	
			Subgoal Availability	**0.95**
			PWCS Mission Availability (270' Cutter)	**0.43**

Table 37: Availability Analysis for Mission #7, "Other Law Enforcement"

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Patrol Waterway	**Combined**	Propulsion		0.75
		Power Generation		0.83
		Critical		0.74
			Subgoal Availability	**0.46**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.82	0.97
		OTH Subsystem	0.82	
	Weapons	Small Arms	1.00	1.00
			Subgoal Availability	**0.97**
			Other Law Enf. Mission Availability	**0.45**

After 2009: 1/1/2010 – 1/7/2011

Table 38: Mission #1, "Search and Rescue" – Availability Calculations

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Transport Persons to Safety	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Locate Person In Distress	**Small Boats**	RHI Subsystem	0.81	
		OTH Subsystem	0.81	
	Search Systems	Aviation Support Subsystem	0.81	
		Special Search Components	0.99	
			Subgoal Availability	**0.99**
Get Person Out Of Water	**Small Boats**	RHI Subsystem	0.81	
		OTH Subsystem	0.81	
	Aviation	Aviation Support Subsystem	0.81	
			Subgoal Availability	
			Search and Rescue Mission Availability	**0.38**

Table 39: Availability Analysis for Mission #2, "Migrant Interdiction"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Cutter Acts As Holding/Transport Platform	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Transport Migrants to Cutter	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
			Subgoal Availability	**0.96**
Locate Migrants	**Search**	Aviation Support Subsystem	0.81	1.00

	Systems	Special Search Components	0.99	
			Subgoal Availability	**1.00**
			Migrant Interdiction Mission Availability	**0.37**

Table 40: Availability Analysis for Mission #3, "Drug Interdiction"

Subgoal	**System**	**Subsystem/Component**	**Subsystem Availability**	**System Total Availability**
Transport Smugglers to Federal Facility	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Locate Drug Smuggler	**Small Boats**	RHI Subsystem	0.81	
		OTH Subsystem	0.81	
	Search Systems	Aviation Support Subsystem	0.81	
		Special Search Components	0.99	
			Subgoal Availability	**0.78**
Take Custody Of Drugs	**Small Boats**	RHI Subsystem	0.81	
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
Apprehend Smugglers	**Small Boats**	RHI Subsystem	0.81	
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	
			Subgoal Availability	
			Drug Interdiction Mission Availability	**0.30**

Table 41: Availability Analysis for Mission #4, "Living Marine Resources"

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterway	Combined	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
			Subgoal Availability	**0.96**
			Living Marine Res. Mission Availability	**0.37**

Table 42: Availability Analysis for Mission #5, "Defense Readiness"; 210 ft. Cutter

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	25 mm Gun	1.00	
		50 cal Guns	1.00	
		Ammo Hoist	0.96	
			Subgoal Availability	**0.96**
Prevent	**Weapons**	Countermeasure System	0.97	

Attacks				
			Subgoal Availability	**0.97**
			Defense Readiness Mission Availability (210' Cutter)	**0.36**

Table 43: Availability Analysis for Mission #5, "Defense Readiness"; 270 ft. Cutter

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.67	
		50 cal Guns	1.00	
		Ammo Hoist	0.96	
			Subgoal Availability	**0.96**
Prevent Attacks	**Weapons**	Countermeasure System	0.97	
			Subgoal Availability	**0.97**
			Defense Readiness Mission Availability (270' Cutter)	**0.36**

Table 44: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (210 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board and Inspect Suspicious Vessels	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	25 mm Gun	1.00	
		50 cal Guns	1.00	
		Ammo Hoist	0.96	
			Subgoal Availability	**0.96**
Prevent Attacks	**Weapons**	Countermeasure System	0.97	
			Subgoal Availability	**0.97**
			PWCS Mission Availability (210' Cutter)	**0.36**

Table 45: Availability Analysis for Mission #6, "Port, Waterways, and Coastal Security"; (270 ft. Cutter)

Subgoal	System	Subsystem/Component	Subsystem Availability	System Total Availability
Patrol Waterways	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board and Inspect	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	

Suspicious Vessels	Weapons	Small Arms	1.00	
			Subgoal Availability	**1.00**
Defend From Attacks	**Weapons**	76 mm Gun	0.67	
		50 cal Guns	1.00	
		Ammo Hoist	0.96	
			Subgoal Availability	**0.96**
Prevent Attacks	**Weapons**	Countermeasure System	0.97	
			Subgoal Availability	**0.97**
			PWCS Mission Availability (270' Cutter)	**0.36**

Table 46: Availability Analysis for Mission #7, "Other Law Enforcement"

Subgoal	**System**	**Subsystem/Component**	**Subsystem/Component Availability**	**System Total Availability**
Patrol Waterway	**Combined**	Propulsion		0.67
		Power Generation		0.83
		Critical		0.69
			Subgoal Availability	**0.38**
Board And Inspect Vessel	**Small Boats**	RHI Subsystem	0.81	0.96
		OTH Subsystem	0.81	
	Weapons	Small Arms	1.00	1.00
			Subgoal Availability	**0.96**
			Other Law Enf. Mission Availability	**0.37**

Bibliography

[1] Braesch, Connie. (2010). “Your Vote Counts!” Coast Guard Compass – Official Blog of the U.S. Coast Guard. December 20, 2010. Retrieved online from http://coastguard.dodlive.mil/index.php/2010/12/your-vote-counts-coast-guard-video-of-the-year/.

[2] United States Coast Guard. U.S. Department of Homeland Security. Retrieved online from www.uscg.mil.

[3] Coast Guard Digest – Reviewed, authoritative content about the Coast Guard and its missions. Retrieved online from http://coastguarddigest.com.

[4] (n.d.) “Aviation Logistics Center RCM Overview.” Retrieved online from http://cgweb.arsc.uscg.mil/reliability.php.

[5] Spitler, William W. (1990). “A Study of Reliability Centered Aircraft Maintenance and Opportunities for Application by the United States Coast Guard.” Thesis for Master of Science in Management at the Massachusetts Institute of Technology.

[6] Butt, Mark CAPT. (2010). “Logistics Transformation – Affordable Readiness.” Coast Guard Presentation.

[7] Linton, E., Galle, J. Harris, M. (2009). “RCM Baseline for USCG Maintenance Development.” Paper presented at Fleet Maintenance and Modernization Symposium 2009.

[8] (2007). Reliability-Centered Maintenance Handbook, S9081-AB-GIB-010, Rev. 1, 18 Apr 2007. Naval Sea Systems Command.

[9] Rose, Jeremy. (2002). “Soft Systems Methodology.” The Manchester Metropolitan University. Retrieved online from http://*osiris.sunderland.ac.uk*

[10] Checkland, Peter. (1999). *Systems Thinking, Systems Practice*. New York: John Wiley & Sons, Ltd.

[11] (2006). “Rich Pictures.” The Open University: T552 Diagramming Course. Retrieved online from http://systems.open.ac.uk/materials/T552/.

[12] Shapiro, J. and Shapiro, R. (2003). "Towards an improved collaboration model for the national healthcare system in England and Wales: a critical and constructive approach using operational research." Logistics Information Management, *Vol. 16, No. 3/4.*

[13] (n.d.). "About SFLC presentation." Retrieved from Coast Guard Portal Intranet.

[14] Cottrell, Donna. (2004). "An Analysis of Coast Guard HH-65 Engine Reliability: A Comparison of Malfunctions to Component Renewals." Air Force Institute of Technology – Wright Patterson AFB Ohio, School of Engineering and Management.

[15] (2998) Coast Guard Firemain analysis. Engineering Logistics Center Report. Retrieved from Coast Guard Portal.

[16] Moubray, John. (1997). *Reliability-Centered Maintenance, Second Edition*. New York: Industrial Press, Inc.

[17] (1987). "NAVSEA Instruction 4790. 4A – Equipment Identification Code." Retrieved online from http://www.navsea.navy.mil/NAVINST/04790-004A.pdf.

[18] (2010). "Casualty Reporting (CASREP) Procedures (Materiel) Manual. COMDINST M3501.3F July 2010. Retrieved online from http://www.uscg.mil/directives/cim/3000-3999/CIM_3501_3F.pdf.

[19] (2007). "Reliability Basics – Availability and How to Calculate It." *Reliability HotWire* e-magazine, Issue 79, Sept 2007. Retrieved online from http://www.weibull.com/hotwire/issue79/relbasics79.htm.

[20] Kim, I.S. and Modarres, M. (1986). "Application of Goal Tree-Success Tree Model as the Knowledge-Base of Operator Advisory Systems." Systems Research Center for the University of Maryland College Park. Retrieved online from DRUM http://drum.lib.umd.edu/bitstream/1903/4565/1/TR_87-57.pdf.

[21] Edraw Max Vector-Based Software Version 5.7, 2011. Retrieved online from http://www.edrawsoft.com/EDrawMax.php.

[22] Ring, D., Shenoi, R., and Courts, M. (2001). "Application of the goal tree-success tree (GTST) technique to decompose ship design in a production context." *Proceedings of the Institute of Mechanical Engineers – Engineering Manufacture, Vol. 215, Part B, pp. 79-92.*