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A Multivariable Statistical Approach to Managing United States Coast Guard Small Boats

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A Multivariable Statistical Approach to Managing United States Coast Guard Small Boats

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List of Acronyms

25 RB-S – 25 FT Response Boat Small

47 MLB – 47 FT Motor Life Boat

Ao – Asset Operational Availability

CG-LIMS – Coast Guard Logistics Information Management System

DCMS – Deputy Commandant for Mission Support

DHS – Department of Homeland Security

DOD – Department of Defense

EAL – Electronic Asset Log

FLS – Fleet Logistics System

FMC – Fully Mission Capable

IT – Information Technology

NMCD – Not Mission Capable Depot

NMCL – Not Mission Capable Lay-up

NMCM – Not Mission Capable Maintenance

NMCS – Not Mission Capable Supply

pdf – Probability Density Function

PL – Product Line Generic

PMC – Partially Mission Capable

PWCS – Port, Waterways, and Coastal Security

SAR – Search and Rescue

SBPL – Small Boat Product Line

SFLC – Surface Forces Logistics Center

USCG – United States Coast Guard

Abstract

The Coast Guard has developed several systems to measure the performance of its engineering and logistics organizations. The development of these measures is based upon the need to show where and how the organization meets the American taxpayer's needs. The use of multivariable regressions and determining the statistical distributions of the variables will show the adequacy of the measures and processes currently used. They will also determine a better way to measure the performance of the Coast Guard Small Boat Fleet. This research will analyze the 47 Motor Life Boat and 25 Response Boat-Small data from fiscal year 2011 to 2013. The focus will be on improving the measure used by the engineering and systems managers of the Coast Guard to manage assets and resources, as well as making recommendations on how to improve the processes involved in managing a robust engineering and logistics system.

Chapter 1: Introduction

United States Coast Guard Coast Guard

The United States Coast Guard is one of the five services of the United States Military, and is the only service outside of the Department of Defense that resides within the Department of Homeland Security. The Coast Guard was founded in 1790 as the Revenue Cutter Service, and has evolved into a large multi-mission maritime service that includes the U.S. Lifesaving Service, U.S. Light House Service, Steamboat Inspection Service and other former federal agencies. The Coast Guard's missions have remained relatively consistent since 1915, when the Revenue Cutter Service merged with the U.S. Lifesaving Service, becoming today's Coast Guard. The Coast Guard has 42,000 Active Duty Members, 8,000 Reservists and 8,800 Civilian employees that support 11 statutory missions: Port, Waterways and Coastal Security; Search and Rescue; Ice Operations; Drug Interdiction; Aids to Navigation; Living Marine Resources; Marine Safety; Defense Readiness; Migrant Interdiction; Environmental Protection; and other Maritime Law Enforcement missions. The Coast Guard operates a variety of aircraft, ships and small boats as part of its inventory to complete its diverse mission set, and each platform has a myriad of primary and secondary missions it can perform. Operating with a total annual budget of $8.1 billion, the Coast Guard has a total of 210 aircraft, 244 ships (or cutters) and 1,800 small boats. (United States Coast Guard)

The Coast Guard's headquarters is organized into two large directorates. The first is the Deputy Commandant for Operations (DCO), which oversees all operations and operations policy including how and where search and rescue is performed, interactions with combatant commands of Department of Defense, how ships are inspected and how mariners are licensed. The second directorate is the Deputy Commandant for Mission support that provides all personnel support, training, Command, Control, Communications, Computers, and Information Technology (C4IT), engineering and logistics, and acquisitions to support all of the DCO's missions. These two deputy commandants oversee the top-level executives in the Coast Guard for each area. The individual deputy commandant oversees the policy for which he or she is responsible. This provides the span of control necessary to operate a large, complex government organization with a variety of mission sets.

USCG Logistics System Overview

The U.S. Coast Guard's logistics model is based on four essential pillars of logistics combining a product line management, Bi-Level Maintenance, Total Asset Visibility and Configuration Management. The Deputy Commandant for Mission Support (DCMS) defines each of these at the enterprise level. The logistics system supports all of the Coast Guard's assets including aircraft, small boats, ships, installations and personnel. The system is broken down into several directorates, Commands and product lines, with the ultimate goal of providing "sustained and adequate readiness to all Coast Guard mission." (Currier, 2010)

The first of the four pillars is product-line management. This places the ultimate authority and responsibility for each asset under a single product line manager. Each manager and his or her staff is charged with producing the appropriate level of readiness and managing the other three pillars of the USCG Logistics Model.

The Bi-level maintenance model is broken into two categories — organizational level and depot level. The organizational level is completed by personnel at the specific station for a particular boat. The depot level is completed by the involvement of the specific product line responsible for the asset.

Total asset visibility creates transparency between the operational unit and the product line. This is achieved by the use of live databases to communicate asset statuses. The asset statuses are recorded, and this becomes the raw data for everything including crew, boat and maintenance hours. The system also allows operational units to communicate asset casualties and check the status of parts orders and upcoming maintenance.

Configuration management allows for mass purchases of parts and materials by the specific product line for a specific asset. A standard configuration also allows the quick transfer of the asset to a new or different station — the crew will know the operating characteristics and equipment locations or functions of the boat. This allows for rapid re-deployment of both assets and personnel, and also reduces training costs. (Currier, 2010)

The concepts for the four cornerstones of logistics are generally applied principles of total quality management. The Coast Guard's aviation community was the first to adapt to concepts in support of fixed and rotary wing aircraft. The four pillars of logistics provide for a high-level business blueprint for all Coast Guard Logistics organizations under the DCMS. The mission support system provides support for all personnel and assets including human resources, training, electronics, information technology, logistics, engineering and acquisitions. Each segment of mission support operations has its own directorate within the Coast Guard headquarters organization.

Surface Forces Logistics Center-Small Boat Product Line Organization

The Surface Forces Logistics Center (SFLC) is responsible for the maintenance, repair and lifecycle management of all Coast Guard Surface assets deployed throughout the world. The SFLC is divided into five product lines and four shared service divisions, and each has its own set of responsibilities and functions. The Small Boat Product Line (SBPL) is responsible product line for all 1,800+ Coast Guard Small Boats. (LeBeau, 2011) The SBPL is divided into four branches: Engineering, Planned Depot Maintenance, Supply, and Contracting. The engineering branch is responsible for the configuration management, unscheduled depot maintenance, and total asset availability of the boats. The Planned Depot Maintenance Branch schedules and completes the depot maintenance of the assets. The Supply Branch maintains the financial records and inventories for the assets. The Contracting Branch serves as the contracting office for each of the other branches. The basic organization is below in Figure 1.

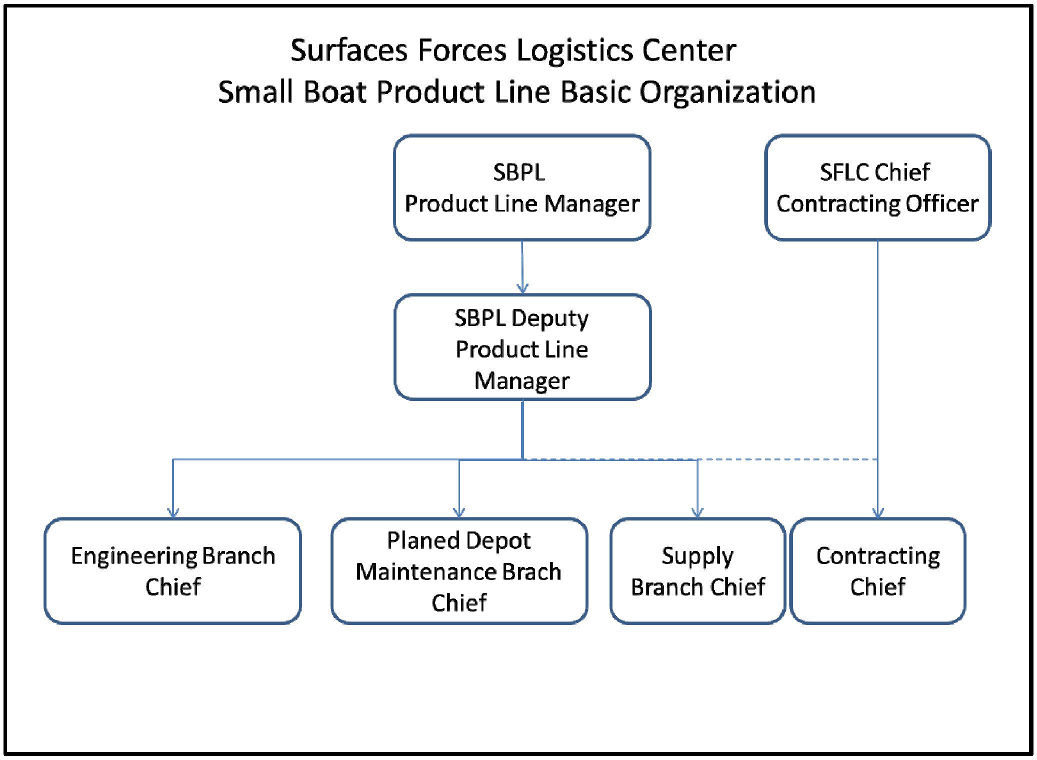

Figure 1: SFLC Small Boat Product Line Organization

The Engineering Branch is sub-divided into five sections that support heavy technical analysis or provide maintenance and lifecycle management of specific assigned assets. The Systems Equipment Specialist Section provides propulsion and electronics technical support, while the Asset Computerized Maintenance System Section provides data integrity in the maintenance system. The three other sections are the asset management sections that provide engineering and logistics support to the fleet and are responsible of the lifecycle management of the assigned assets. Often the asset management sections are comparatively "Mini-Product Line Managers" in their scope of responsibilities and duties.

The Planned Depot Maintenance Branch (PDM) is responsible for the scheduling, planning, and execution of the depot maintenance for those assets requiring depot maintenance. The Branch is split into two sections — one for each the East Coast and West Coast — that follow the same business structure and guidelines.

The Supply Branch is divided into three sections that cover three different assigned duties. The first is the inventory management section, which specifically ensures that inventory is purchased, delivered, and shipped to the various units. The equipment specialist section develops repair contracts for repairable items and works in conjunction with the inventory managers to ensure the inventory is packaged and delivered properly. The financial section maintains the financial records of the entire product line. (Keister, Small Boat Product Line Standard Operating Procedure, 2011)

Small Boat Operations

The Coast Guard has 188 small boat stations located throughout the continental United States, Alaska, Hawaii, and territories. These multi-mission stations perform or support each of the Coast Guard's 11 statutory missions. Stations maintain several capabilities for both inshore and offshore response efforts. Each station has a variety of platforms with several different combinations depending on the area of responsibility. Two of the most populous platforms in the Coast Guard inventory are the 25'Response Boat-Small "Defender" A/B Class (25 RB-S) and the 47 FT Motor Life Boat (47 MLB). These two platforms perform all of the Coast Guard's missions and play a key role in the execution of the tactical and strategic missions of the Coast Guard.

The 25 RB-S is a 25-foot semi-planning hull with cabin and two 225 horsepower Honda outboard engines. The boats were constructed by Safe Boats International from 2002 to 2009. The 25 RB-S was built in response to the September 11 terrorist attacks in order to provide the Coast Guard a standard response boat to preform SAR and PWCS missions. The Coast Guard currently operates 400 at Stations, Marine Safety and Security Teams (MSST), and Marine Safety Units, and is the largest boat class in inventory. (United States Coast Guard)

The 47 MLB is a 47-foot self-righting hull with two inboard Detroit Diesel 6v92 engines constructed by Textron Marine and Land Systems from 1995 to 2003. (Textron Marine and Land Systems) The platform's unique capability to right itself in an intact stability condition makes it best for heavy surf conditions. There are 117 47 MLBs in service and perform SAR missions in breaking surf and heavy weather as well as offshore. 47 MLB's are only operated from Stations. (United States Coast Guard)

Stations operate as independent units directed by a central tactical command called a Sector, which is also the parent unit of the station. Each station operates and performs organizational level maintenance on its own boats with some limited assistance from the Sector. Stations range in size based on location operating level and prevailing weather conditions in the geographic area. This also determines the station's allowance of boats. Therefore, Station New York is a significantly larger unit with more boats and personnel than Station Ludington in Michigan, because of the need to protect New York harbor and provide search and rescue operations in that heavily trafficked port. Sectors provide engineering and logistics support in the form of maintaining parts inventories and engineering sections that can augment the station crews. Stations have a 24- hour duty section, or crew. This varies between stations with the number of boats, personnel, and operational requirements of each station. (Krietemeyer, 2000)

Performance Measures

The Coast Guard uses many different methods to measure performance in operations and logistics, however, neither are consistent. Measures such as number of lives saved, amount of property saved, or illegal narcotics interdicted are important to establish the Coast Guard's impact on the nation, but do nothing for the executive level leadership in decision-making. The Office of Boat Forces uses operating hours to measure levels of operations at units and within classes of small boats. The SFLC-SBPL uses operational availability to measure the amount of time an individual boat or boat class fleet is available for operations to the tactical commander. The tactical commander cares solely about having the correct boat, aircraft, or ship available to respond to the mission. The final measure that is incorporated into all parts of the decision-making process is the amount of funding required to accomplish the needs of the individual measure. The funding level expended can be used as a measure or indicator.

At some level, these measures all have an effect on one another. Such a chain could be established that would show that if an asset was not operationally available during a period of time, the asset would not perform any operational hours, and therefore not be able to save a life or interdict illicit drugs. As can easily be deduced, the chain of variables have a cost that must be expended to maintain the assets.

This study will determine the relationship between operating hours, operational availability, and maintenance cost of the 47 MLB and 25 RB-S. The fuel, crew, and original acquisition costs will not be looked at, as part of this research. Fuel is managed in a separate Accounting Funding Code-30 (AFC) account not managed by the SFLC. Crew costs are supported through AFC-01. (Metruk, 2013) Both the 47 MLB and 25 RB-S are out of any production phase of their lifecycle as a class, thus the assets are already completely owned by the U.S. Coast Guard. The majority of systems cost come during the sustainment of the vessel, which includes the maintenance, repair, and upgrade of the vessel. (Hunt, 1999) The relationship will be shown in a managerial statistical manner by using multivariable statistical distributions in conjunction with multivariable regressions. The objective is to develop the most universally meaningful management measure for top-level executives, tactical commanders, and engineering and logistics managers, in order to use the same measure in making lifecycle and tactical decisions.

Chapter 2: Literature Review

Calculation of Asset Operational Availability

Asset operational availability (Ao) is a probability function showing the reliability, maintainability, and supportability of the system. (Moore, 2003) The data for input is tracked in Electronic Asset Log (EAL) as the small boat stations change the status of the boats from several different statuses. The statuses are tracked based on a length of time and then converted into probabilities. The USCG partially departs from the U.S. Navy's terminology when considering the statuses. The statuses outlined in the SBPL Standard Operating Procedure in the drop down menu are as follows:

- Fully Mission Capable (FMC) – the boat is ready for all assigned missions in every respect.
- Partially Mission Capable (PMC) – the boat is ready for certain missions however has a casualty that will prevent it from completing a specified task. Example: 25 RB-S Aft passenger seat is in-operable, the boat can get underway without any issue however no one can sit in one of the aft passenger seats.
- Not Mission Capable Supply (NMCS) – The boat is awaiting supplies or a parts order to be repaired, in this state the boat is not able to get underway and is not available for operations.
- Not Mission Capable Maintenance (NMCM) – The boat is undergoing organizational level scheduled maintenance or organizational level repair.
- Not Mission Capable Depot Maintenance (NMCD) – The boat is undergoing scheduled or unscheduled depot maintenance availability. The 47 MLB has four year scheduled maintenance availability, the 25 RB-S does not.
- Not Mission Capable Lay-up (NMCL) – The boat is in a lay-up status for seasonal reasons, decommissioning, or transfer to another unit. In cold climates that accumulate ice, such as the Great Lakes, the Coast Guard winterizes all small boats and places them in a lay-up status.

Most notably, the departure by the USCG from the Navy is with Mean time between failure, which is the sum of PMC and FMC. Mean time to repair is the sum of NMCM and NMCD. Mean logistics delay time and NMCS are equivalent. This change in terminology is to meet the operational nature of EAL — it would be hard for an operational unit to describe a boat being in the mean time between failure and the boat is ready for operations. These EAL statuses are monitored daily by the SBPL, Sector Engineers, and Sector or District Command Centers. The information provided in the status updates give a quick snap shot of the availability at a particular unit. The statuses are updated real time in the system and then recorded in the memory of the system.

SBPL then converts the periods of time into probabilities by dividing the sum of each status total by the total time available for the asset class. Availability as defined by OPNAVINST 3000.12A is "a measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at an unknown (random) point in time." The mathematical definitions are as follows for each probability:

$$P(FMC) = \frac{\sum(FMC)}{\sum(FMC + PMC + NMCS + NMCM + NMCD)}$$

$$P(PMC) = \frac{\sum(PMC)}{\sum(FMC + PMC + NMCS + NMCM + NMCD)}$$

$$P(NMCS) = \frac{\sum(NMCS)}{\sum(FMC + PMC + NMCS + NMCM + NMCD)}$$

$$P(NMCD) = \frac{\sum(NMCD)}{\sum(FMC + PMC + NMCS + NMCM + NMCD)}$$

$$P(NMCM) = \frac{\sum(NMCM)}{\sum(FMC + PMC + NMCS + NMCM + NMCD)}$$

The mathematical definition of Ao:

$$Ao = \frac{\sum(FMC + PMC)}{\sum(FMC + PMC + NMCS + NMCD + NMCM)}$$
$$= P(FMC \cup PMC)$$
$$= 1 - P(NMCS \cup NMCD \cup NMCM)$$

*Note: NMCL is dropped from all calculations as the boat is in a special status

The Ao figures are calculated once a month for each asset class and as an overall average for the entire boat fleet. The current target for Ao is 80%, for each class with a SAR requirement. Both the 47 MLB and 25 RB-S are SAR vessels and at units that have a SAR mission requirement. Recent changes in the small boat fleet due to the Coast Guards Boat Optimization initiative potentially have changed the Ao target for the 47 MLB and 25 RB-S due to the elimination of spare assets in areas. The SBPL expects the requirement to increase Ao to a new target of 85% Ao, while maintaining comparable levels of operating hours. (Keister, Small Boat Product Line Manager, 2013)

Process Control

To ensure that the accuracy of the forecasting models being derived, the data that will be the source of the forecasting model must be in control. Statistical Process Control allows for a variance in the data while still allowing for the needed controls of the product. (Groover, 2002) In the case of the SBPL, there are two products that are produced as a result of the logistics system, which are that it supports operating hours and operational availability. Both products are tracked on a monthly basis either by reports or by calculation. Mean was calculated by simply taking the average of the variable either operational availability or operating hours for fiscal year 2010. (Demming, 1982) The standard deviation was

$$Sample\ Mean = \mu = \frac{\sum[x]}{n}$$

$$Sample\ Standard\ Deviation = s = \sqrt{s^2} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{N}(x-\mu)^2}$$

Using good general management practice, the control limits were calculated by using three standard deviations. The data appeared to fit a normal distribution for both operational availability and operating hours when put into a histogram.

$$Control\ Limits = \mu \pm 3 \times s$$

Having calculated the upper and lower control limit, the next three fiscal years were plotted on the control chart. For each asset class, the control charts were then used to determine if the asset was within statistical control or had fallen out of statistical control. To determine statistical control, one must look at each data point to determine if it is between the upper and lower control limit and look for trends in the data itself. If the data moves within the control limits in a trend for a number of periods, the system is out of control. The data set that moves randomly within the control limits is in statistical control. There are allowances for seasonality, as certain products are seasonal in nature and will have natural tendencies to behave with a high season and a low season, so they may not appear as random as a product that is not seasonal. (Heizer, 2008)

Normal Distribution

The normal distribution is often used in manufacturing and management as it is a distribution that is often naturally occurring with random variables. (Devoure, 2000) The assumption that will need to be proven in the analysis will be that the variables of operational availability and operating hours fit or closely fit the description of a normal distribution. Mathematically, the normal distribution is defined as the probability distribution function:

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\left[\frac{(x-\mu)}{2\sigma^2}\right]^2}, -\infty < x < \infty$$

This will be applied to the distribution of the actual variable graphed in a histogram for the period being evaluated. The resulting plot will show the continuous function of the normal distribution over the interval covered by the histogram. (Hogg, 2010) When the assumption is proven true, the variables of operational availability and operating hours will be treated as random variables with a normal distribution throughout the rest of the analysis.

Bivariate Normal Distribution

The bivariate normal distribution takes the normal distribution of several random variables and makes another variable a function of the first group of random variables. The probability density function turns into the volume of the area under the curve verse the area under the curve as is the basis of the normal distribution or any other two dimensional distribution.

The Bivariate Normal Distribution accounts for the covariance in the expected value of the two random variables used in calculating the pdf. The covariance of two random variables is calculated using the standard deviation of the two random variables and the correlation coefficient, or stated mathematically:

$$Cov(X,Y) = \rho\sigma_x\sigma_Y$$

$$\rho = Correlation\ Coefficient$$

The useful portion of this when deriving the pdf of the bivariate normal distribution is the correlation coefficient. This describes the relationship between the X and Y random variables. The correlation coefficient falls between negative one and one, and when equal to zero, the random variables X and Y are said to be independent. (Hogg, 2010)

$$-1 < \rho < 1$$

$$\rho = 0, X\ and\ Y\ are\ Indepenent\ Random\ Varialbes$$

The bivariate distribution for independent variables is quite simple and one could expect with the correlation coefficient equal to zero.

$$f(X,Y) = \frac{1}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}} e^{\frac{-1}{2}\left[\left(\frac{X-\mu_x}{\sigma_X}\right)^2 + \left(\frac{X-\mu_Y}{\sigma_Y}\right)^2\right]}$$

When X and Y are not independent, the equation is essentially the same. However, the correlation coefficient appears as it is not equal to zero and adds to the equation.

$$f(X,Y) = \frac{1}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}} e^{\frac{1}{1-\rho}\left[\left(\frac{X-\mu_x}{\sigma_X}\right)^2 - 2\rho\left(\frac{X-\mu_x}{\sigma_X}\right)\left(\frac{Y-\mu_Y}{\sigma_Y}\right) + \left(\frac{Y-\mu_Y}{\sigma_Y}\right)^2\right]}$$

This is also known as the bivariate normal distribution. Just like a two-dimensional pdf, the resulting three-dimensional pdf will be equal to one from X and Y negative infinity to positive infinity. (Hogg, 2010) The analysis will have to calculate the correlation coefficient in order to determine which form of the bivariate normal distribution to use. The bivariate normal distribution when evaluated between negative infinity and infinity for both X and Y.

$$1 = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(X,Y)dx\,dy$$

Expected Value

The expected value of a probability function is simply the product of the utility function and the probability function. When dealing with continuous probability functions it becomes the integral of the product of the probability density function (pdf) and the utility function or mathematically:

$$E(X) = \int_{-\infty}^{\infty} u(x)f(x)dx = \mu$$

With

$$f(x) = pdf$$

$$u(x) = utility\ function$$

By definition, the expected value is equal to the mean of the distribution. The expected value combines the probability and the value of the utility function. The expected value will be applied in the business sense as the expected profit of the decision. In the case of a government or non-profit organization, avoiding or reducing cost is the basis. In this analysis, the reduction of cost is the basis, so selection of the least cost will be utilized.

Expected value of the bivariate is calculated similarly to the expected value of a single variable. Thus the mathematical equation is:

$$E(A,H) = \int \int C(A,H)f(A,H)dHda$$

With,

$$C(A,H) = cost\ regression$$

$$f(A,H) = Bivariate\ Normal\ Distribution\ of\ Cost\ as\ a\ function\ of\ A\ and\ H$$

Forecasting Models

Business forecasting models are based on data point collected to project the next period's sales, earnings, amount to manufacture or other measure. The objective is to determine how much to produce, purchase, or sell. The Coast Guard and the SBPL are not profit-making organizations, but can still use some of the same principles to develop decision models. The objective of forecasting is to predict the future demand or production of a system. In this sense, the system produces both Ao and operating hours. The study will evaluate each of the product data sets, operational availability and operating hours, to provide estimates of the individual outputs throughout the year.

Coast Guard operations have very regular seasonality that must be accounted for when forecasting the next period or next year. This is apparent when looking at the operating hours control chart of the 25 RB-S. The number of operating hours from May to September far exceeds that of December to March. There are reasons for this such as ice in the Great Lakes, inclement or out of parameters weather in the northern half of the country, and reduced numbers of shipping and recreational boating during these periods. To calculate the seasonal indexes for the classes followed the below process:

$$Seasonal\ Index = \alpha = \frac{Monthly\ Average}{Overall\ Monthly\ Average}$$

This monthly forecast will be compared to the actual produced in the month. The SBPL or SFLC do not have control of the number of operating hours completed by the operational units because they are under the control of USCG Districts and Sectors. However, operating hours have a direct relationship with cost that can easily be explained.

Maintenance Cost per Operating Hour

Maintenance Cost per Operating Hour is a measure currently used for all surface assets by the SFLC. The measure is a simple linear function that shows the relationship between cost and operating levels. Current SFLC policy is to calculate and publish the Maintenance Cost per Operating Hour (MCPOH) on an annual basis. The SBPL has been able to calculate MCPOH for the past three years using the data collected from the various fleet information systems including Asset Logistics Information System (ALMIS), Fleet Logistics System (FLS), and Abstract of Operations System (AOPS). The calculation is based on the average boat of each boat class.

The MCPOH formula used by the SBPL is as follows:

$$MCPOH = \frac{\Sigma(Average\ Cost\ per\ boat\ in\ class)}{\Sigma(Average\ Operating\ Hours\ per\ boat\ in\ class)}$$

$$\Sigma(Average\ Cost\ per\ boat\ in\ class) = \frac{\Sigma(Annual\ Expenditures)}{Number\ of\ Boats\ in\ Class}$$

$$\Sigma(Average\ Operating\ Hours\ per\ Boat\ in\ Class) = \frac{\Sigma(Annual\ Operating\ Hours)}{Number\ of\ Boats\ in\ Class}$$

Using the averages of each class provides for a robust figure that is accurate, but limited in its ability to apply or act as an indicator of a change in operations or budgetary stability of the boat class. However, comparison and changes in asset operational availability are not considered in the calculation. The Ao is considered separate of the MCPOH, however, it is an important separate indicator evaluated by the executive steering committee and USCG Headquarters Directorates. Using it as an annual review does not provide for a continuous measure of the cost of operations and does not allow for the use of statistical controls of the variables. However, MCPOH definitively shows the relationship between maintenance and repair costs and operations. (Haycock, 2012) When shown graphically, the MCPOH curve has a positive slope, meaning that the more money spent on a particular asset class, the higher the asset's operating hours.

Small Boat Allocation Optimization

The study of asset allocation and the size of the small boat fleet has always been a discussion within the Coast Guard and the subject of several studies. The most recent study, completed by Michael Wagner and Zinovy Radovilsky, resulted in the Office of Boat Forces Boat Optimization Plan. The study then ran a linear algebra problem based on the boat class makeup, historical operating hours, and stated mission needs at each station. This determined the capacity or number of boats and types needed at each station based on the operating hours from fiscal years 2005-2009. The end result of the study was a relocation of several 47 MLB's from the southeast United States to the Pacific Northwest and Northeast and an overall reduction in the number of 25 RB-S in the fleet. Other classes were involved in the study as well, including the long haul ice rescue airboats, 24 Special Purpose Craft-Shallow Water, 45 Response Boat-Medium, 52 Special Purpose Craft-Heavy Weather, and 42 Near Shore Lifeboat. The study proposes reducing costs by using a capacity plan and assuming that maintenance costs are fixed costs due to doing the same amount of hours with fewer boats.

Wagner and Radovilsky's study assumed that the SBPL could maintain a 0.76-0.85 Ao average across all classes without additional resources or additional expense. This would be based upon the pilot program of modernized small boat logistics support run at Sectors Baltimore and San Francisco. The SBPL was established and the transition to the current Coast Guard Logistics model pilot with small boats occurred in last year of the study. At the time, there were many outside influences assisting to support small boats and a very limited number of boats — only two Sectors' worth — that were being supported by a disproportionately larger amount of logistics support personnel than when the program was brought to full operating capability.

Wagner and Radovilsky's study showed a potential to save approximately 4.6% of the Coast Guard's overall small boat budget by reducing the overall number of multi-mission station based small boats by 10.9%, this could be achieved while maintaining the same level of operating hours across the boat fleet. By re-allocating some resources, Wager and Radovilsky propose that there was excess in the Coast Guard Boat small boat fleet, and that it need to be addressed. The Coast Guard responded by developing the boat optimization plan. (Wagner, 2012)

Chapter 3: Methodology

Monthly Seasonal Index

The operating hours for the 25 RB-S and the 47 MLB both follow some amounts of seasonality. The 25 RB-S is extremely seasonal in its operating hours profile, with the peak operating hours period between May and September of each year. This is explained by increased operations in the summer time, when there is increased recreational boating and commercial traffic in the northern parts of the United States. Also present in the data of both the 47MLB and 25 RB-S is a decline of operating hours over the five-year period FY09-FY13. This can be explained by the reduced number of missions due to better analysis of security threats requiring escorts. Operating hours over the previous 10-year period had peaked around FY02-FY03, which was a result of the attacks of September 11 and the ensuing military operations. Taking the trend and seasonality into context, the need for a seasonal index and trend forecast were appropriate. Trials were conducted using the trend and seasonality of the previous five and three years.

The Seasonality indexes were calculated using:

$$Seasonality\ Index = \alpha = \frac{\text{Average Operating Hours in each month in period}}{Total\ Average\ Monthly\ Operating\ Hours\ in\ n\ period}$$

For example to calculate the seasonal index for November:

$$November\ Index\ (n = 5) = \frac{\text{Average of November for n} = 5}{Total\ Average\ for\ n = 60}$$
$$= \frac{\Sigma(Nov08 + Nov09 + \cdots + Nov12)/5}{\Sigma(Oct08 + Nov08 + \cdots + Sep13)/60}$$

The monthly indexes were calculated for each month, to be applied to the lifecycle cost model for the specific month. (Heizer, 2008) The seasonal indexes are listed below in Table 1 and Table 2

25 RB-S Seasonal Index		
Month	Average	Index
October	6956	1.0169
November	6558	0.9587
December	5661	0.8276
January	4806	0.7026
February	5116	0.7478
March	6023	0.8804
April	6672	0.9753
May	7667	1.1209
June	8357	1.2217
July	8519	1.2454
August	8074	1.1803
September	8097	1.1837
Total Average	6841	

Table 1: Seasonal Index for 25 RB-S

47 MLB Seasonal Index		
Month	Average	Index
October	3655	1.1091
November	3403	1.0326
December	2898	0.8796
January	3114	0.9451
February	2779	0.8435
March	2960	0.8983
April	2946	0.8940
May	3440	1.0439
June	3760	1.1412
July	3468	1.0525
August	3573	1.0843
September	3341	1.0141
Total	3295	

Table 2: Seasonal Index for 47 MLB

Two Dimension Regressions

A comparison of two regressions that will provide a two-dimension regression formula for operational availability as a function of cost and operating hours as a function of cost, these will show the changes in operational availability and operating hours individually as a function of cost. The expected format for Operating Hours as a function of Cost is a simple linear curve:

$$H(C) = aC + b$$

The inverse function of H(C) becomes the utility function of C(H):

$$C(H) = \frac{H - b}{a}$$

The expected form of the function of operational availability as a function of cost is a logarithmic function:

$$Ao(C) = a \times log(C) + b$$

The inverse function of Ao(C) becomes the single variable or two dimensional utility function of cost or C(Ao):

$$C(Ao) = e^{\frac{Ao-b}{a}}$$

These will define the individual relationships between cost and the opposing variable, showing what the financial investment is creating in terms of operational availability and operating hours. These individual relationships will define the parts of the system, not the overall system. (Moore, 2003)

These functions become the single variable form of the utility function for cost. When expected value of the cost is calculated using a single variable the functions of C(Ao) and C(H) are the utility functions.

Statistical Process Control and Normal Distribution

Two major assumptions that will require substantial validation are statistical process control and normal distribution of the variables' operational availability and operating hours. The process involved does not require more than a 95% certainty that they are accurate, so three standard distributions are acceptable to calculate the upper and lower control limits for each variable. The upper and lower control limits will be calculated about the mean and plotted into a control chart. The control chart will be evaluated on the basis of having the data points with in the upper and lower control limits, trends, and random nature of the plot over time. (Heizer, 2008) As the data sets are not conducive to breaking apart the fleet into specific data samples, the cost data does not assign cost to a specific platform. For example, SBPL does not have the cost of the RB-S carrying the hull number 25401 for each month of the analysis and would be too costly to attempt to figure out for each hull. Thus, the analysis is forced to work with the overall fleet as the sample not individual platforms.

The second assumption is that the operational availability and operating hours are random variables that are normally distributed about the mean. The variables will be plotted into frequency histograms to show the number of times the variable has fallen between specific intervals. Superimposing the normal probability density function for the mean and variance over the histogram will indicate the accuracy of this assumption. (Hogg, 2010) When this assumption is true, the cost will also be a random variable, as the cost is the sum of the products of operational availability.

When these assumptions are true, the cost is also a random variable with a normal distribution, as the function linking the two will involve two random variables being added together. Even though, all of the variables are entirely human controlled, there are so many managers and controllers involved in the process that it forms a normal distribution.

Having two normally distributed random variables will allow the use of the bivariate normal distribution to calculate the pdf of the cost random variable. Cost can also be calculated as a function of x as a traditional two dimensional normal distribution.

Linking Monthly Data to Derive Curve

The data provides a multivariable relationship between cost, operational availability, and operating hours. The cost can then be estimated by calculating the plane as a function of operational availability and operating hours. The plots are then estimated by using the multivariable regression in NCSS. The regression provides a volume when integrated.

$$Cost(Ao, H) = C(Ao, H) = a(Ao) + b(H) + c$$

The general regression provides the relationship between the three variables. This relationship becomes the utility function of the expected value in the three dimension form.

With the relationship established determining if a dominate variable in calculating cost is required, this is done by completing a sensitivity analysis. To calculate the sensitivity of the cost function, the cost must be calculated several times. The first is to calculate the cost keeping availability fixed at the mean and calculating the cost while varying the hours between the upper and lower control limit. The second step is to calculate the cost by keeping the hour fixed at the mean and changing the availability between the upper and lower control limit. The swing squared is then calculated and summed, and a percent variance is calculated.

$$Swing^2 = (Cost\ High - Cost\ Low)^2$$

$$Variance = \frac{Swing^2}{\sum Swing^2}$$

The variable that creates the greatest variance in the cost is the dominant variable, or the controlling variable. (Clemen, 2001)

Expected Value

Calculating the expected value of each model on a monthly basis will show the new lifecycle cost estimate based upon the probability of maintaining the revised operational profiles of the 25 RB-S and the 47 MLB. The end result will be the expected cost of the individual boat classes per month. The expected value does not account for a fleet reduction and assumes a static fleet size. However, dividing by the number of current boats will not give an accurate answer of how much it will cost to operate each boat, because of economies of scale. Because it is cheaper to operate 400 boats of the same kind than 50 of the same kind. The bivariate normal distribution will be used as an estimate of the probability distribution function of the cost variable. It will be called an estimate or approximation due to the use of the sample mean and sample standard deviation. (Hogg, 2010)

Both operating hours and operational availability are continuous variables. The variables have infinite number of points between the limits. Both random variables measure a time period, either by percentage or actual, and by the nature of time being continuous and not discrete. The random variables will be treated as continuous.

The lowest expected value will be the best case in this function. The expected value will be calculated using the bivariate normal distribution and the cost function as a result of operational availability and operating hours. The bivariate normal distribution has defined limits in this case as operational availability is only valid from zero to one for both the 25 RB-S and 47 MLB. The operating hours are also limited as the 47 MLB can only produce between 0 and 84,240 hours and the 25 RB-S can only produce between 0 and 254,400 hours in a 30 day month. Thus the pdf of A and H for the 47MLB is:

$$1 \cong f(A, H) = \int_0^1 \int_0^{84,240} f(A, H)\, dH\, dA$$

And for the 25 RB-S:

$$1 \cong f(A, H) = \int_0^1 \int_0^{254,400} f(A, H) dH\, dA$$

The expected value will be calculated using the product of the pdf and cost function, integrated between the upper and lower integration limits as described in the literature review.

Models Resulting From a Mandate to Increase Operational Availability

In a cost avoidance effort to reduce acquisition costs related to small boats, the Coast Guard developed and executed what has become known as the Office of Boat Forces Boat Optimization Plan. The plan is based off a linear programing model that accounts for boats as resource hours or operating hours, and focuses heavily on the operations of the Coast Guard with little mention of maintenance time or cost. (Wagner, 2012) The plan was adapted and is in the process of implementation by the Coast Guard. The estimated increase in operational availability is not discussed, but is essential to the full implementation of the plan. This analysis will focus on three options that have been recommended by the Small Boat Product Line. (Keister, Small Boat Product Line Manager, 2013) Option one proposed by CDR Scott Keister is an average boat availability of 0.85, which would result in control limits of three standard deviations above and below. This would be an increase of the target average boat availability for the 25 RB-S and 47 MLB of 0.02 and 0.06, respectively. The second option sets the minimum acceptable operational availability at 0.80 for each boat class, and calculates the mean as three standard deviations above the lower control limit. The third option is to retain the current model and is simply the mean of the previous three years (FY2011-13). Each model maintains the assumption that the operating hours will remain close to the average and within the control limits calculated off of the last three years.

25 RB-S Standard Deviation = 0.0295

25 RB-S Projected Operational Availability Models			
Option	Mean	Upper Control Limit	Lower Control Limit
1	0.8500	0.9385	0.7615
2	0.8885	0.9770	0.8000
3	0.8257	0.9142	0.7371

Table 3: 25 RB-S Projected Availability Models

47MLB Standard Deviation = 0.0304

47MLB Projected Operational Availability Models			
Option	Mean	Upper Control Limit	Lower Control Limit
1	0.8500	0.9412	0.7588
2	0.8912	0.9824	0.8000
3	0.8102	0.9013	0.7190

Table 4: 47 MLB Projected Availability Models

The analysis will keep the operating hours constant throughout in order to compare the new availability models via expected value or expected cost and lifecycle cost estimates. This will allow the models to be compared without further adjustment.

Lifecycle Cost Estimates

The remaining lifecycle cost estimates are looked at and determined by combining the multivariable regression, the hours forecasting model and revised operational availability models. The revised operational availability models are representative of the Coast Guard's attempt to reduce cost by reducing the number of boats while keeping the same overall availability requirements at each individual station. The current and two other availability models will be used, — outlined in Table 2 and Table 3 — and the calculated standard deviation will remain the same. However, the mean or a limit will be fixed to change the model.

By using a programmed spreadsheet to develop random variables within the new controls, projected realistic availabilities were generated. While not forecasts, the assumption was made that the SBPL would maintain the system within the control limits of the model. Thus, a random number could be used as long as it was within the control limits. (Keister, Small Boat Product Line Manager, 2013)

$$Random\ Availability = Random\ Number\ (LCL\ \times 1000, UCL \times 1000)/10{,}000$$

The availabilities are multiplied by 1,000 and divided by 10,000 to maintain the number less than one and so that a new random number program did not have to be programmed. Microsoft Excel random number program uses whole numbers without decimal places.

The hours were generated by assuming the last two years FY12 and FY13 were typical of the rest of the lifecycle of each of the assets. As the current budget posture statement by the Coast Guard Commandant, Admiral Papp indicates the hours will stabilize over the next number of years. (Papp, United States Coast Guard Posture Statement, with 2014 Budget in Brief, 2013) By holding the hours stable for the out years, each model will allow the availability comparisons to be made. The hours model was based upon projections for FY14 and beyond using a random number generator. A second operation is also underway with the 25 RB-S. It is under a recapitalization plan, so the mathematical operation is a ratio that reduces the hours keeping the same level of operating hours. The numbers inserted are based off an assumption made for this analysis that the 25 RB-S will be phased out in the next five years with the last boat being decommissioned on September 30, 2018.

$$25\ RB - S\ Random\ Hours = \frac{Seasonal\ Index\ \times Random\ Number\ (1921, 11238) \times Projected\ Number\ of\ Boats}{Current\ Number\ of\ Boats}$$

$$47\ MLB\ Random\ Hours = Seasonal\ Index\ \times Random\ Number\ (LCL, UCL)$$

This model reflects current normal operations of the Coast Guard and does not reflect a substantial change to the national level operating levels. A significant event such as Hurricane Katrina or major terrorist event could cause a spike in operating hours that could not be foreseen. A different set of requirements with an emergency funding string would potentially need to be enacted. While in the years used to develop the model, Super Storm Sandy struck, it did not cause the massive spike in small boat operations that were seen during Hurricanes Katrina and Rita in September and October of 2005.

Ignored in the analysis are the acquisition cost of the assets, as both boat classes are completely out of the acquisition stage of the lifecycle and fully in sustainment. There are no savings available in system acquisition costs as the projects are complete and in sustainment. Thoughts of reducing fleet size to avoid cost of purchase of a boat can only start with a new acquisition. The potential of this would be with the 29 RB-S, also known as RB-S Generation II. The lifecycle cost of the replacement will need to be calculated separately, during the development of the Capability Development Plan prior to Acquisition Decision Event 1: Validation of Need. (Rabago, Major Systems Acqusition Mannual, COMDTINST M5000.10B, 2010)

Chapter 4: 25 RB-S Results

Statistical Process Control

The 25 RB-S operating hours and operational availability were measured each month between October 2009 and September 2013, beginning with Fiscal Year 2010 and ending with Fiscal Year 2013. The base year to calculate control limits was FY10 for both operational availability and operating hours. Three standard deviations were used to determine if the two variables were in control. Operational availability was the first calculated with a sample standard deviation of 0.0295 and a sample mean of 0.8257. The resulting control chart is below, in Figure 2.

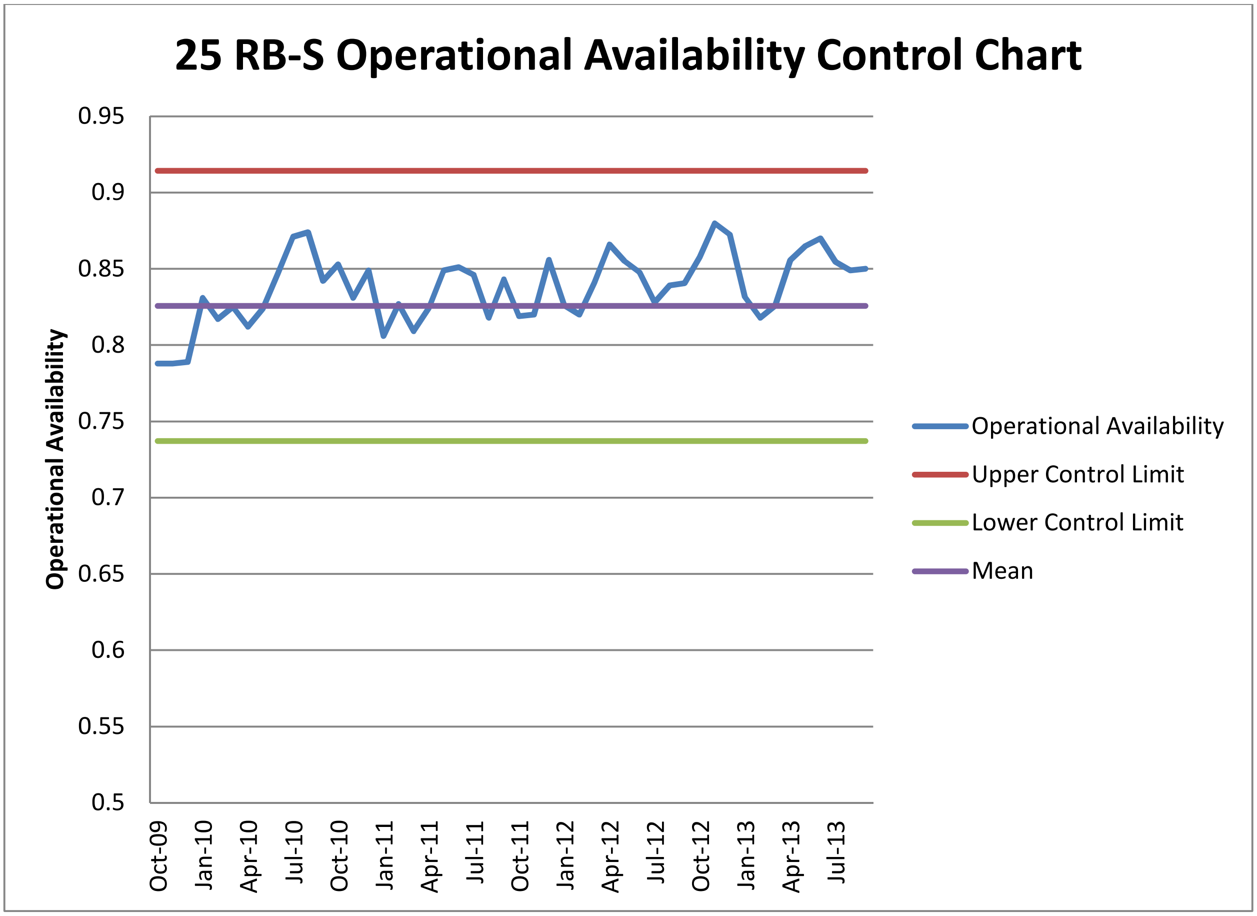

Figure 2: 25 RB-S Operational Availability Control Chart

The 25 RB-S falls randomly within the upper and lower control limits with normal variation. When the data is plotted in a histogram, it appears to have a normal distribution about the mean, Figure 2. The result is the 25 RB-S system or fleet and both mechanically and logistically is within statistical process control in regards to operational availability. The probability mass function is plotted as well, in the generic format of:

$$f(x) = \frac{1}{\sigma\sqrt{(2\pi)}} e^{-\left(\frac{(x-\mu)}{2\sigma^2}\right)^2}$$

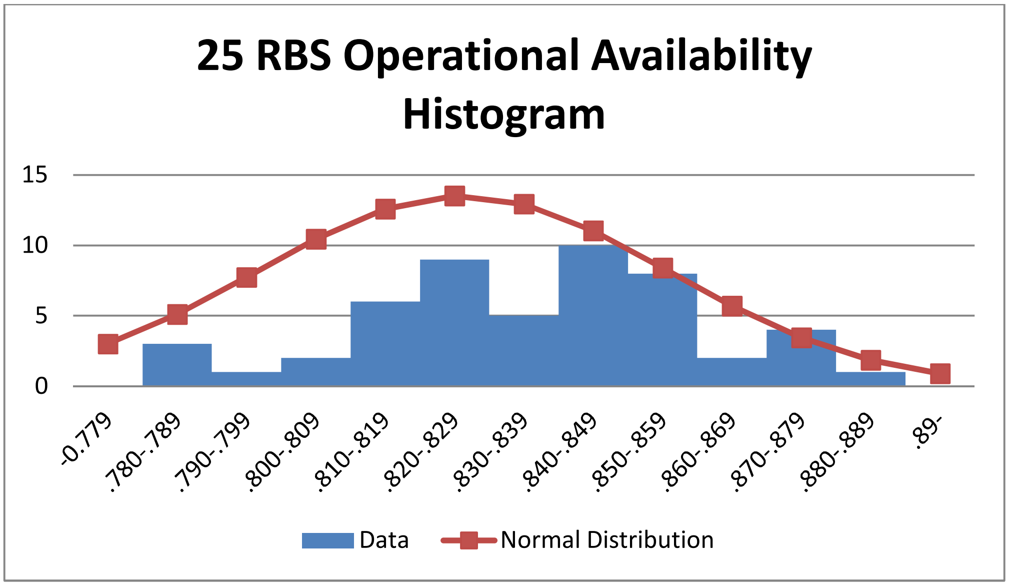

Figure 3: 25 RB-S Operational Availability Histogram

Operating hours were also placed into control charts and histograms. The 25 RB-S operating hours has a sample standard deviation of 1,763 Hours and a sample mean of 7,665 Hours, Figure 3 depicts the operating hours control chart. The operating hours as previously discussed are seasonal due to the lower levels of operations from late fall to early spring.

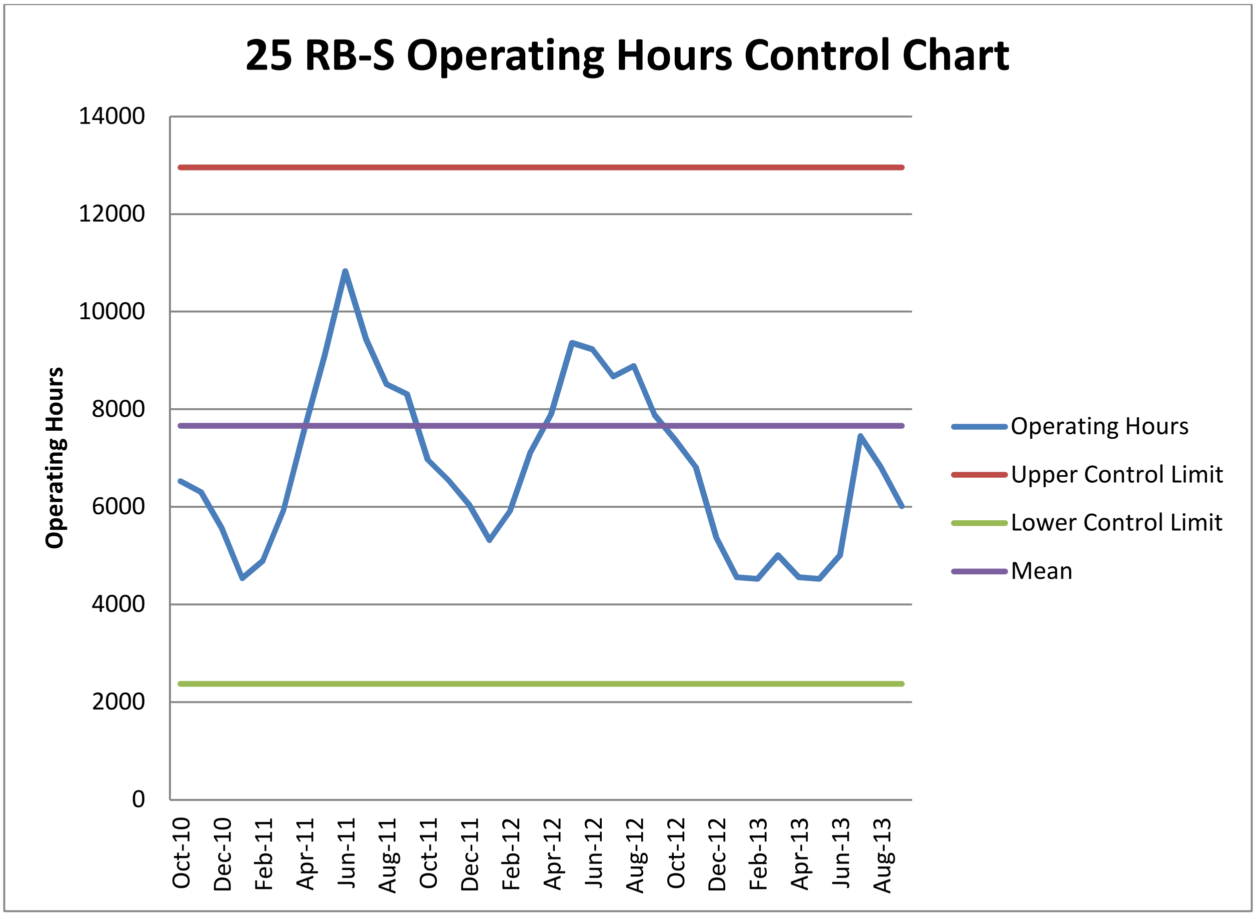

Figure 4: 25 RB-S Operating Hours Control Chart

The operating hours fall into the control limits and take a fairly random nature in the controls after considering the seasonal nature of the operating hours. Also of interest is the reduction in operating hours in FY13 and where operating hours no longer follow their natural seasonality. This is most likely due to the impacts of the Budget Control Act of 2011 that placed a cap and reduced government spending. Reducing operating hours is seen as a simple and easy-to-implement strategy to reduce budget costs. Thus, there is a cost savings, as fuel is not consumed and equipment does not face the wear and tear as it would while underway. (Papp, ALCOAST 074/13 Subj: Shipmates 24 - Potential Sequestration, 2013) The operating hours follows a normal distribution as well, except for it being truncated at the lower end, Figure 4. Again, the normal distribution is plotted on the histogram with the points being the average of the division upper and lower limit.

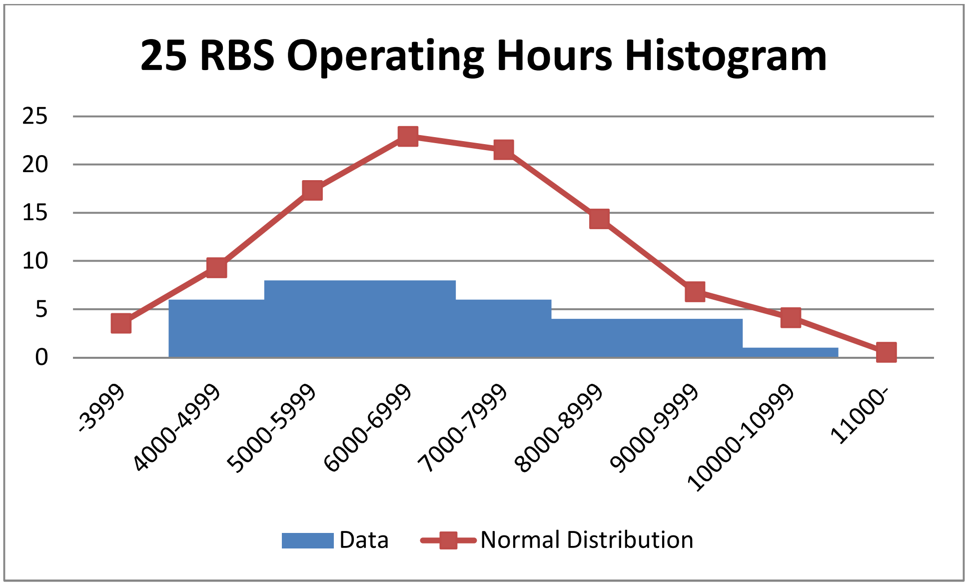

Figure 5: 25 RB-S Operating Hours Histogram

The histogram is truncated and no month has fallen below 4,000 hours. This is due to a minimum training requirement for all coxswains and boat crew to maintain proficiency at operating the boats. Each coxswain and crew member must have 36 hours total with 10%, or 3.6, of those hours being at night every six months. This minimum for crew proficiency skews the operating hours higher than what there would be if there were no minimum hours for proficiency. There is no perceived cost savings by eliminating the underway hour's proficiency requirement as there are higher potential for accidents and loss or damage due to them. (Cross, 2002) The end result is that the operating hours are as randomly distributed as the actual data will allow and do fall within the control limits, even with the reduced operating hours in FY13.

Cost Versus Operating Hours

The cost versus operating hours was plotted in an x-y scatter, and a regression was performed to validate the measure of maintenance cost per operating hour. This is a current measure used by the Coast Guard Headquarters Staff, SFLC, and SBPL to measure performance of the product line. On average in FY12 (the latest year available), the 25 RB-S cost $38 per operating hour. The number fluctuates with operating hours and dollars spent over the year. The regression will show the relationship between the dollars spent and the operating hours by showing the operating hours as a function of cost, Figure 6.

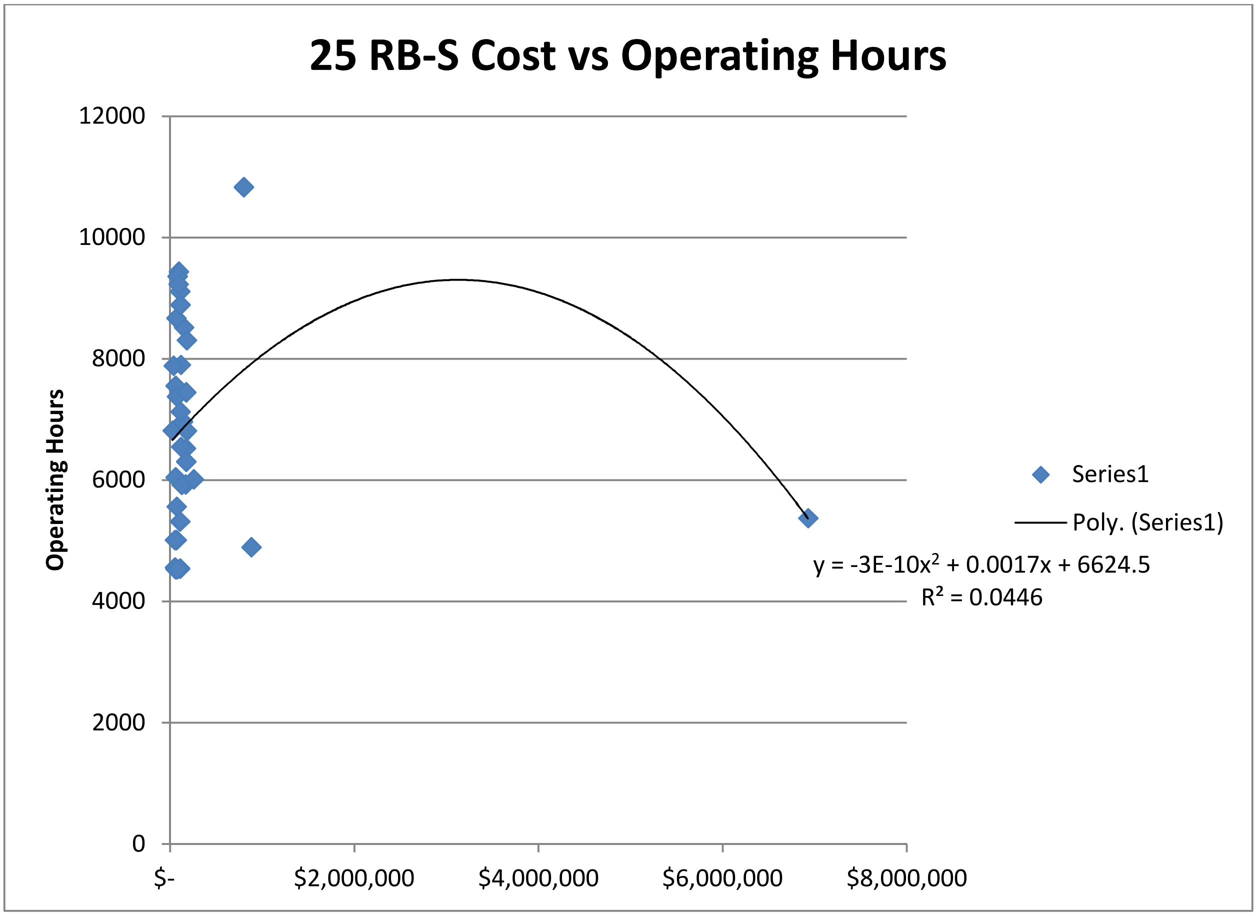

Figure 6: 25 RB-S Cost versus Operating Hours

The regression was done as a polynomial as the model provided the best relationship of the various regression models attempted. The original thought was that the regression would be linear, as one would expect the more you pay, the more operating hours one would get. Skewing the data is the data point from December 2012, when SBPL spent nearly $7 million on the 25 RB-S system when the system had relatively low hours in that month. This expense was necessary, as the positive effects are seen through the remainder of the fiscal year in increased operational availability.

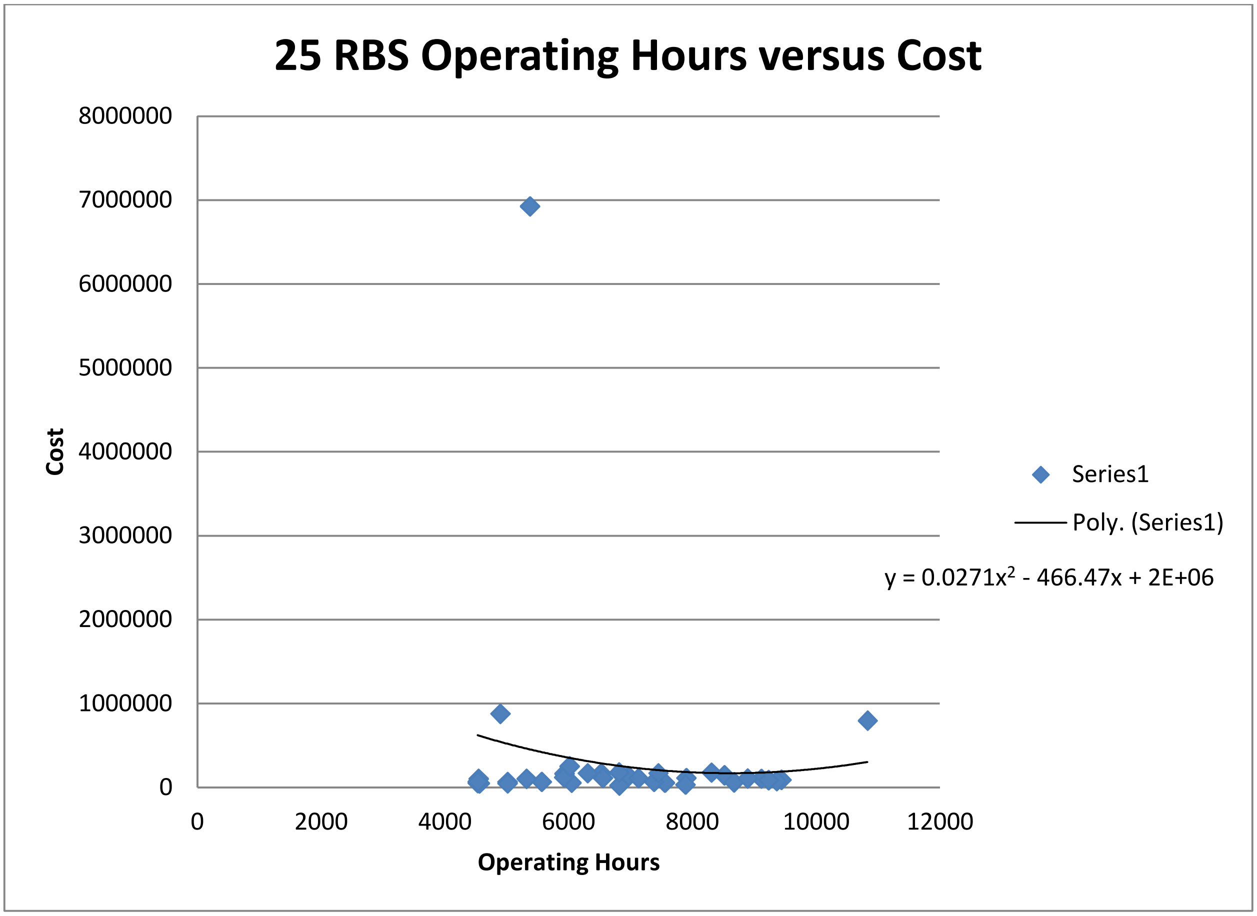

Figure 7: 25 RB-S Operating Hours versus Cost

A second regression was run having cost as a function of operating hours which results in the separate linear polynomial expression. The resulting function:

$$C(H) = 0.0271H^2 - 466.47H + 2{,}000{,}000$$

Cost versus Operational Availability

Similarly to the cost versus operating hours, the same plot and regression were run with cost and operational availability to determine the type of relationship. The plot with trend line is predicted by the OPNAV INST, stating that the expected curve is a logarithmic curve, thus the regression was performed with the use of the logarithm model, Figure 8.

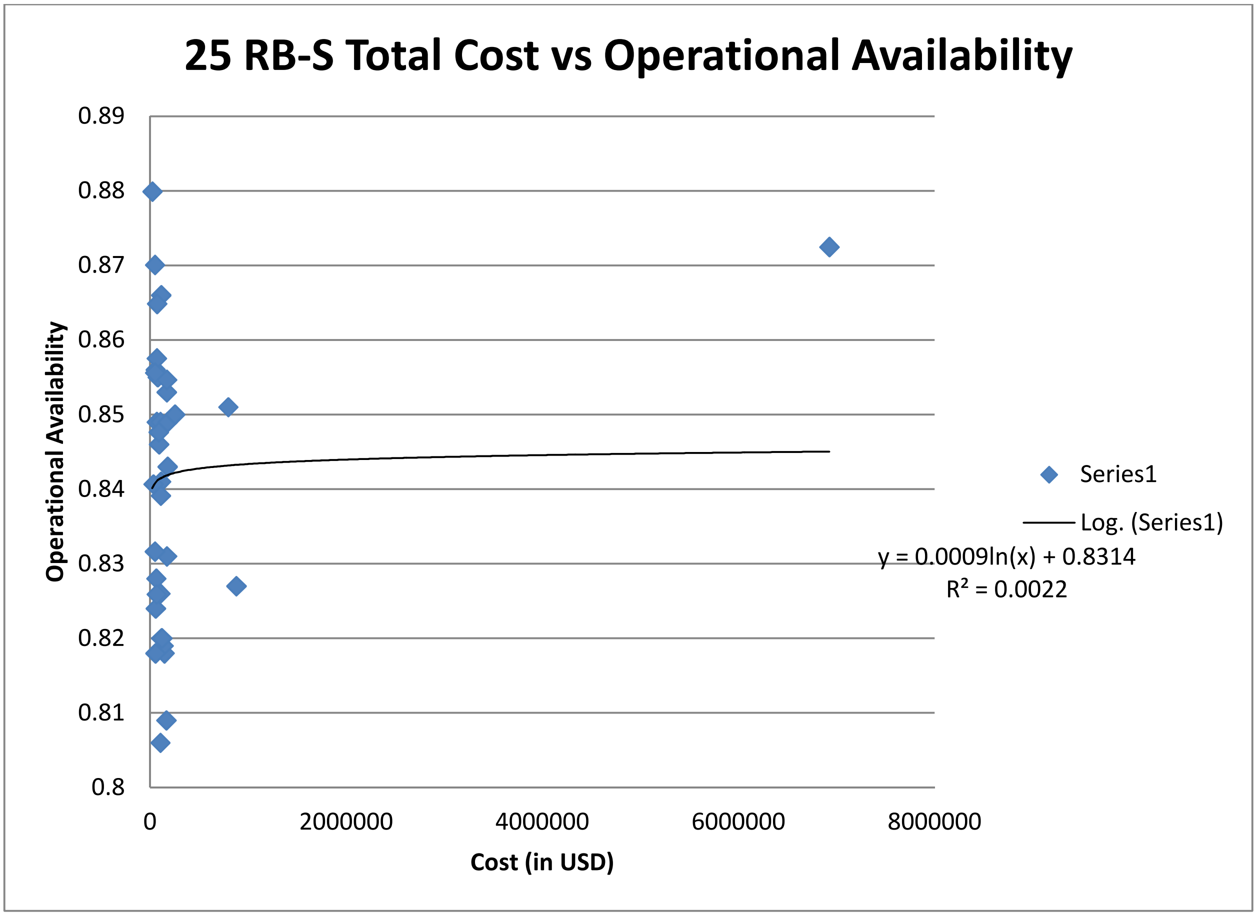

Figure 8: 25 RB-S Total Cost vs Operational Availability

The expected curve per the OPNAV has a limit of 1 as the dollars, or cost, goes toward infinity; this is true for this regression. (Moore, 2003) Although the regression nearly has no slope, the more data added, the stronger the relationship will become, and the more positive the slope, as data with greater variation is collected.

$$Ao(C) = \lim_{Ao=1 \to C=\infty} [0.0009 \times \ln(C) + 0.8314]$$

With,

Ao = Operational Availability

C = Cost

Manipulating the regression to have cost as a function of availability results in:

$$C(Ao) = e^{\frac{Ao-0.8314}{0.0002}}$$

Which respects the limit of Ao still being 1, as cost is infinite.

Multi-Regression of Cost as a function of Operational Availability and Operating Hours

A multi-regression was run in NCSS to determine the interrelationship between cost, operational availability and operating hours. (Hintze, 2004) This regression resulted in a linear formula that estimated the function of the three-dimensional plot, Appendix A.

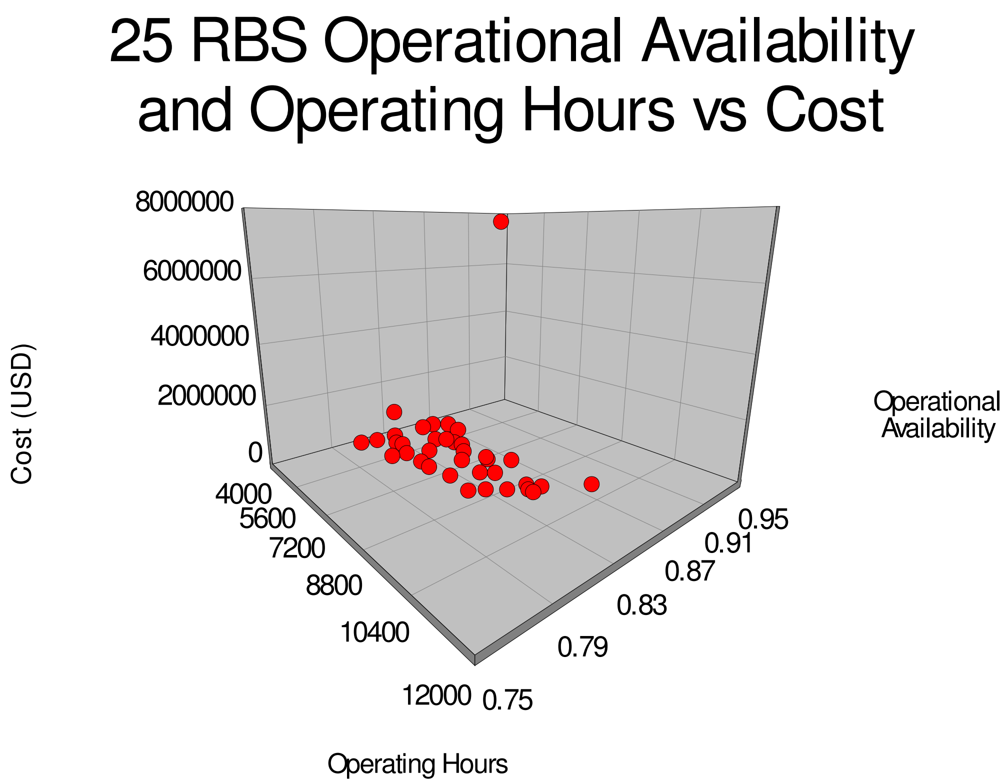

Figure 9: 3-D Plot of Cost as a function of Operational Availability and Operating Hours

The resulting regression formula from this regression is:

$$C(Ao, H) = 22781100 \times Ao - 17.10694 \times H - 18660110$$

With

$$C = Cost$$

$$Ao = Operational\ Availability$$

$$H = Operating\ Hours$$

The regression formula was run through a sensitivity analysis to determine if a controlling or dominate variable exists. The upper and lower control limits were used to calculate the high and the low with the mean as the control.

Variable	Low	Mean	High	Low Cost	Base Cost	High Cost	Swing	Swing^2	% Var
Hours	2375	7665	12955	109615.2875	19119.57	-71376.1	-180991.43	32757895996	0.002008428
Availability	0.7371	0.8257	0.9142	-1999285.89	19119.57	2035247	4034532.8	1.62775E+13	0.997991572
								1.63102E+13	

Table 5: 25 RB-S Sensitivity Analysis

Operational availability is dominating in the cost equation and accounts for 0.9980 of the change in cost. One could also say for every dollar spent on the 25RB-S system $0.99 goes toward paying for operational availability. The cost equation is based on normal operations and maintenance of the 25 RB-S and does not include any costs of a mid-life or recapitalization effort. The fact that operational availability so heavily controls the cost equation intuitively makes sense as the mission of the 25 RB-S is to respond to emergencies more than complete scheduled patrols. The mindset of the operational commander, or customer, is more that of "how many boats do I have ready to go today" than how many hours have my boats completed. This is important when creating this metric and measuring the amount of operational availability, as this is also the loan variable that the mission support organization of the Coast Guard controls and is out of the hands of the operational commander.

Bivariate Normal Distribution

The bivariate normal distribution was plotted for the 25 RB-S between the upper and lower control limits of the operational availability and the operating hours. Similarly to the normal distribution in the two-dimension form when integrated using both variables is equal to the probability.

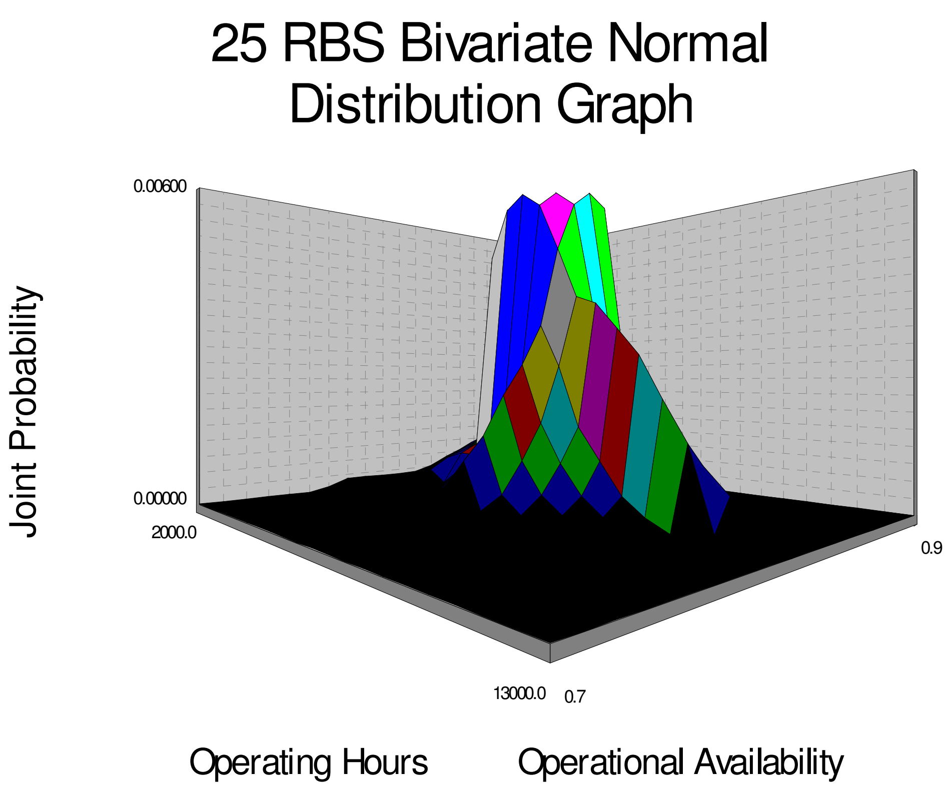

Figure 10: 25 RB-S Bivariate Normal Distribution Graph

Figure 10, is a graphical representation of the 25 RB-S pdf using the bivariate normal distribution. (Hintze, 2004)

Expected Cost

Calculating the expected value or expected cost of the 25 RB-S using the multivariable cost function and the bivariate normal probability distribution function. The multivariable cost regression becomes the utility function and the bivariate normal probability distribution function is the pdf. Because the variables of operational availability and operating hours are interrelated it would make senses that the correlation coefficient (ρ) is not equal to zero, this is true for the 25 RB-S. The concept being that in order for the boat to get underway and produce operational hours it must be operationally available. The resulting equations:

$$C(Ao, H) = 22781100 \times Ao - 17.10694 \times H - 18660110$$

$$f(Ao, H) = \frac{1}{2\pi\sigma_{Ao}\sigma_H\sqrt{1-\rho^2}} e^{-\frac{1}{2\sqrt{1-\rho^2}}\left\{\left(\frac{Ao-\mu_{Ao}}{\sigma_{Ao}}\right)^2 - 2\rho\left(\frac{Ao-\mu_{Ao}}{\sigma_{Ao}}\right)\left(\frac{H-\mu_H}{\sigma_H}\right) + \left(\frac{H-\mu_H}{\sigma_H}\right)^2\right\}}$$

$$\sigma_{Ao} = 0.018662$$

$$\mu_{Ao} = 0.841501$$

$$\sigma_H = 1709.563$$

$$\mu_H = 6817.563$$

$$\rho = 0.141609$$

$$E[X] = \int_{A_{min}}^{A_{max}} \int_{1,921}^{11,238} C(Ao, H) \times f(Ao, H) dH dAo$$

Option	Amin	Amax	E[X]
1	0.7615	0.9385	$3,427,420
2	0.800	0.977	$3,582,660
3	0.7371	0.9142	$3,331,110

Table 6: 25 RB-S Operational Availability Models

Calculations were performed using Mathematica Software. (Mathematica Version 9.0, 2013)The least cost of the three options without regard to changes in the 25 RB-S fleet size is option 3. This is expected as the cost function or the utility function is almost completely controlled by the operational availability in the sensitivity analysis. Option 1 is representative of a 0.0281 percent increase in cost per month over option 3. Option 2 represents approximately a 0.0702 increase in cost over option 3.

Lifecycle Cost Estimate

The total lifecycle cost for each option available was calculated using a normally distributed random number generator with in each new operational availability distribution. The operating hours account for the seasonality of the operating hours variable, and the total cost is reduced through the remainder of the lifecycle by a factor based on the reduction of fleet size from month to month based upon deliveries of 29 RB-S Generation II and the boat optimization plan. The results are presented in Table 7

Option	Estimated Total Lifecycle Cost
1	$33,431,847
2	$44,685,253
3	$33,529,491

Table 7: 25 RB-S Estimated Total Lifecycle Cost

The option 1 and 3 are very close and definitely within the margin of error of this analysis. Assuming a 10 percent margin of error the models fall within each other. This makes sense as there is significant overlap between option 1 and option 3, the overlap being approximately 76 percent. Option 2 is extraordinarily high as it also produces the highest operational availability of any of the three models.

Chapter 5: 47 MLB Results

Statistical Process Control

The 47 MLB operating hours and operational availability were measured each month from October 2009 to September 2013, all months in FY11 thorough FY13 inclusive. The base year was FY10 to calculate statistical limits. The first calculated control limits were for operational availability, which had a mean of 0.8102 and a standard deviation of 0.0304. The three years were then plotted with the control limits set at three standard deviations from the mean; the resulting control chart is in Figure 10.

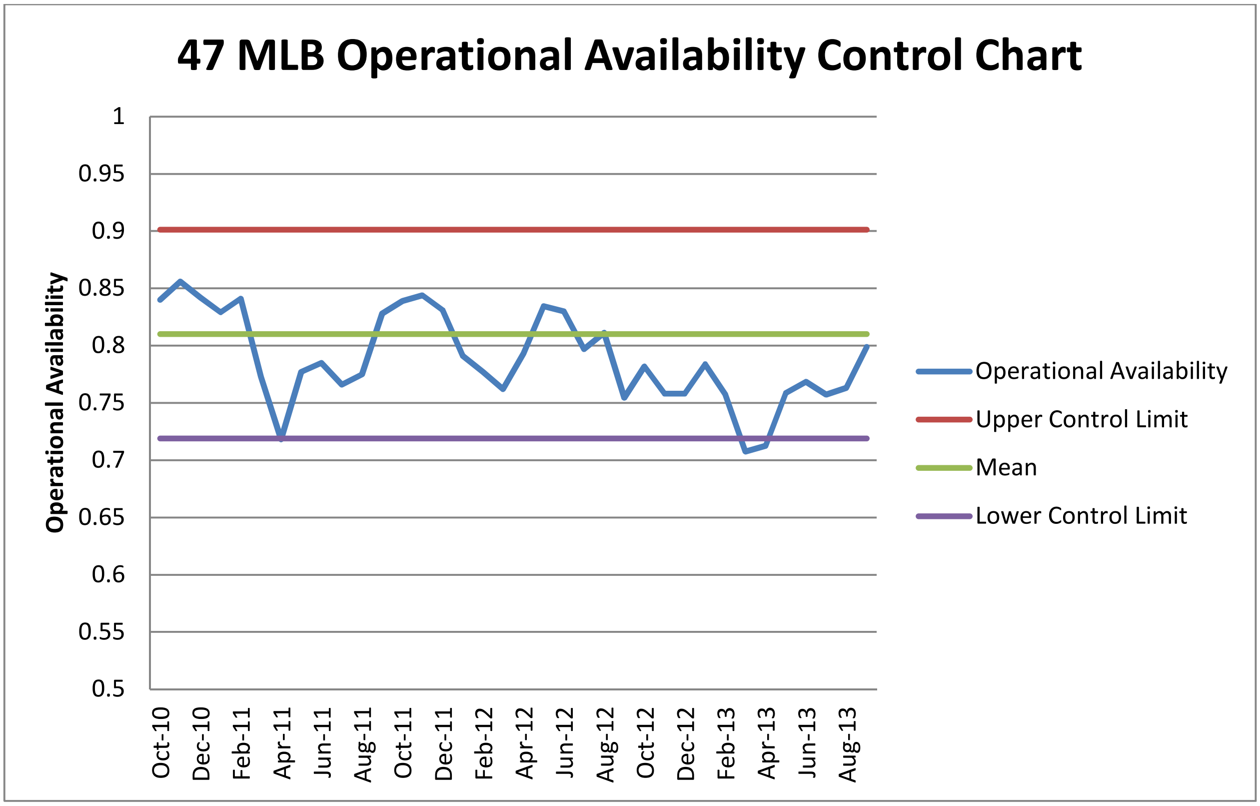

Figure 11: 47 MLB Operational Availability Control Chart

There are several reasons for the 47 MLB being out of statistical control, the first is system age and obsolescence. The 47 MLB was designed and constructed prior to Environmental Protection Agencies (EPA) Tier II requirements were in place. Although the boat is grandfathered for continued operations, the main propulsion engine is no longer manufactured on a large scale. Meaning that as the engine fleet ages, it requires increasingly scarce parts that are expensive and take time to manufacture, thus increasing delays in supply and logistics. The downward trend over the twelve-month period from May 2012 to April 2013 is indicative of the problems within the 47 MLB as a whole system. The fact that FY2013 never saw an operational availability above the mean from FY2010 shows that the system has accepted a lower level of operational availability. This is indicative of the out of control roller coaster effect in that the process will continue to produce; however, significant upward and downward trends will continue to be the norm unless the system is changed in some manner.

The Operational Availability was also plotted into a histogram to assess the distribution of the random variable. The resulting distribution was approximated using a normal distribution curve, in figure 11.

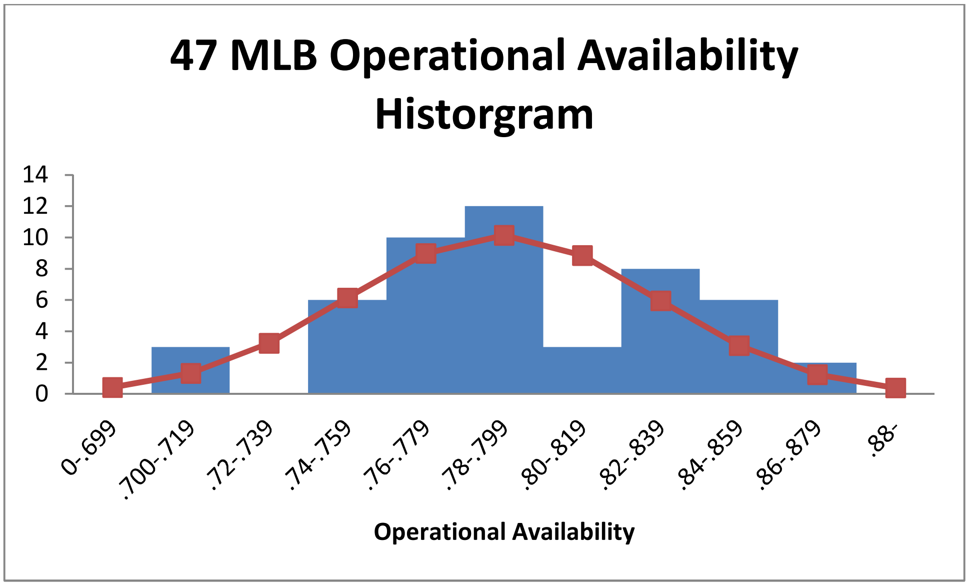

Figure 12: 47 MLB Operational Availability Histogram

The three-year period has a relatively normal distribution; however, the problem becomes the defined trends that were discussed with the control chart. The normal distribution does provide a good estimate of the distribution of operational availability for the operational availability and that it is a random variable.

The Operating Hours of the 47 MLB were also plotted into a statistical control chart, again with the control year being FY2010. The mean was 3,725 hours with a standard deviation of 310 hours; the resulting control chart is in figure 12.

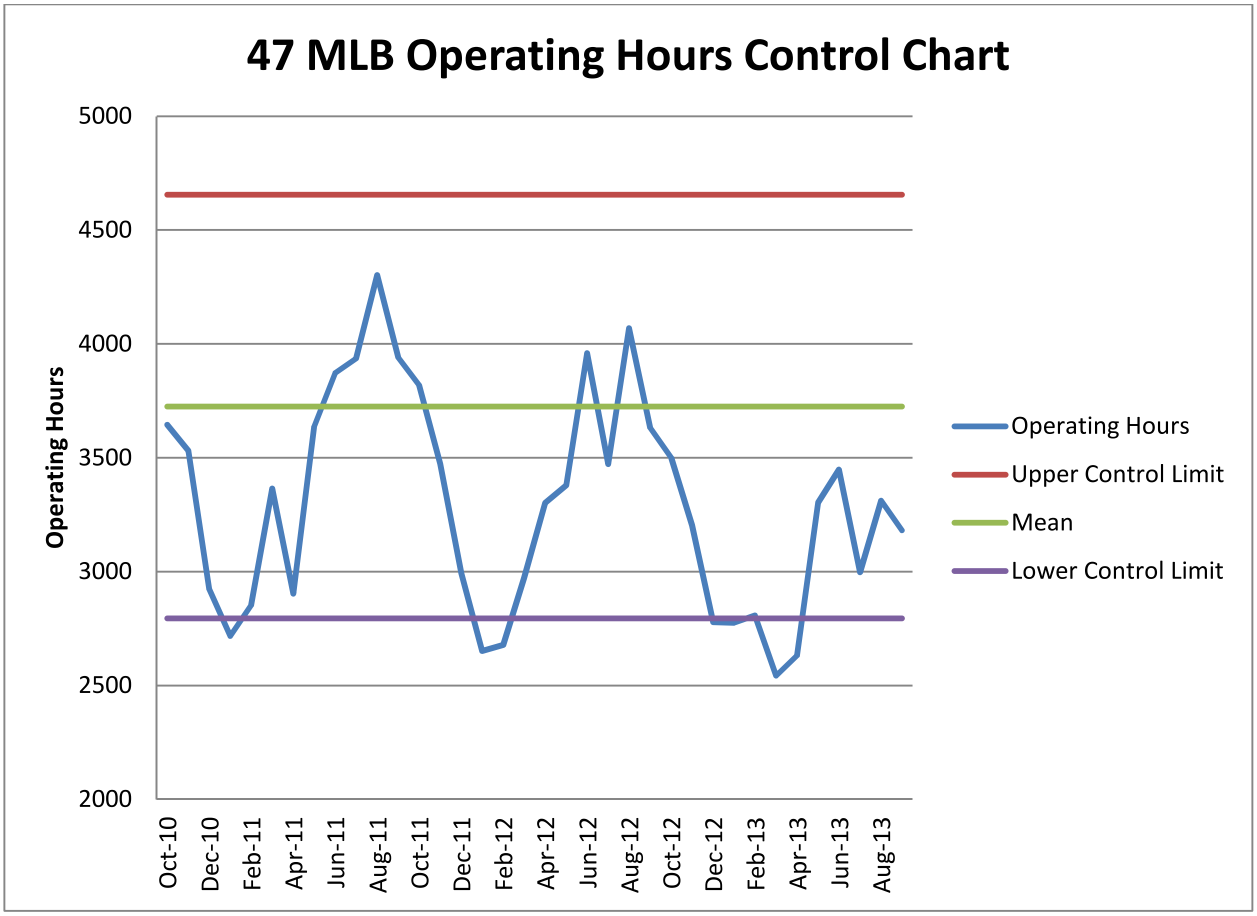

Figure 13: 47 MLB Operating Hours Control Chart

The operating hours are out of statistical control for the 47 MLB, discounting the seasonality of the variable the hours consistently dropped below the lower control limit each year in early spring. In FY2013 this drop below was extended into March and April most likely as a result of the Budget Control Act. Each year is consistent with the overall downward trend in operating hours, however FY2013 does not reach the mean level of FY2010, this indicates a shift in the mean over the time period, and most likely a change in the way the operational commanders are using the 47 MLB.

A histogram plot of the monthly operating hours shows relatively normal distributions with the 36 months are looked at as the sample.

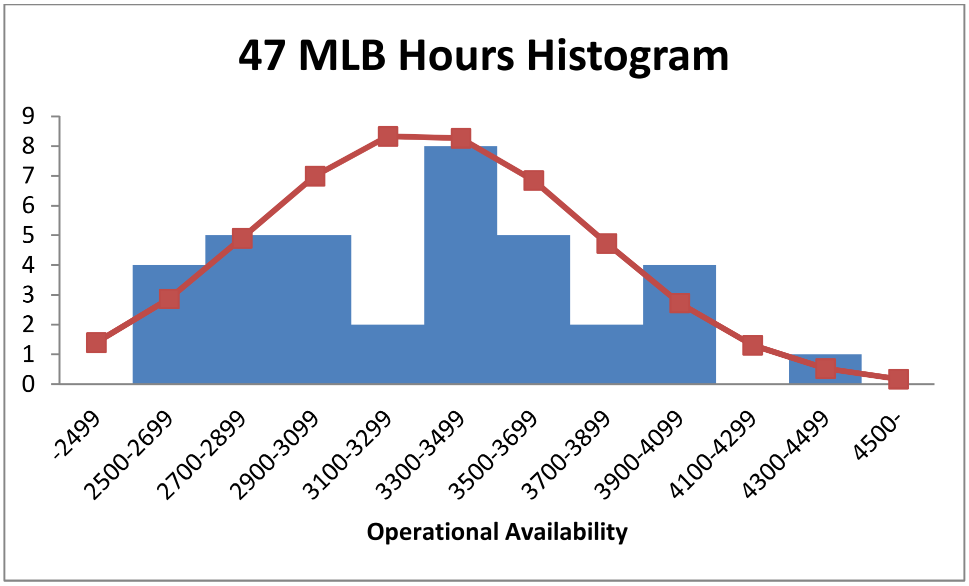

Figure 14: 47 MLB Operating Hours Histogram

In figure 13, the red line shows the calculated normal distribution for the operating hours. The distribution appears to be, for the most part, random although the data is denser in the lower operating hour's levels. It can be concluded that the operating hours of the 47 MLB are random around the mean with the exception of the seasonality inherit in the data for operating hours.

Cost Versus Operating Hours

The operating hours as a function of the cost were plotted and a regression run for the 47 MLB, shown in figure 14.

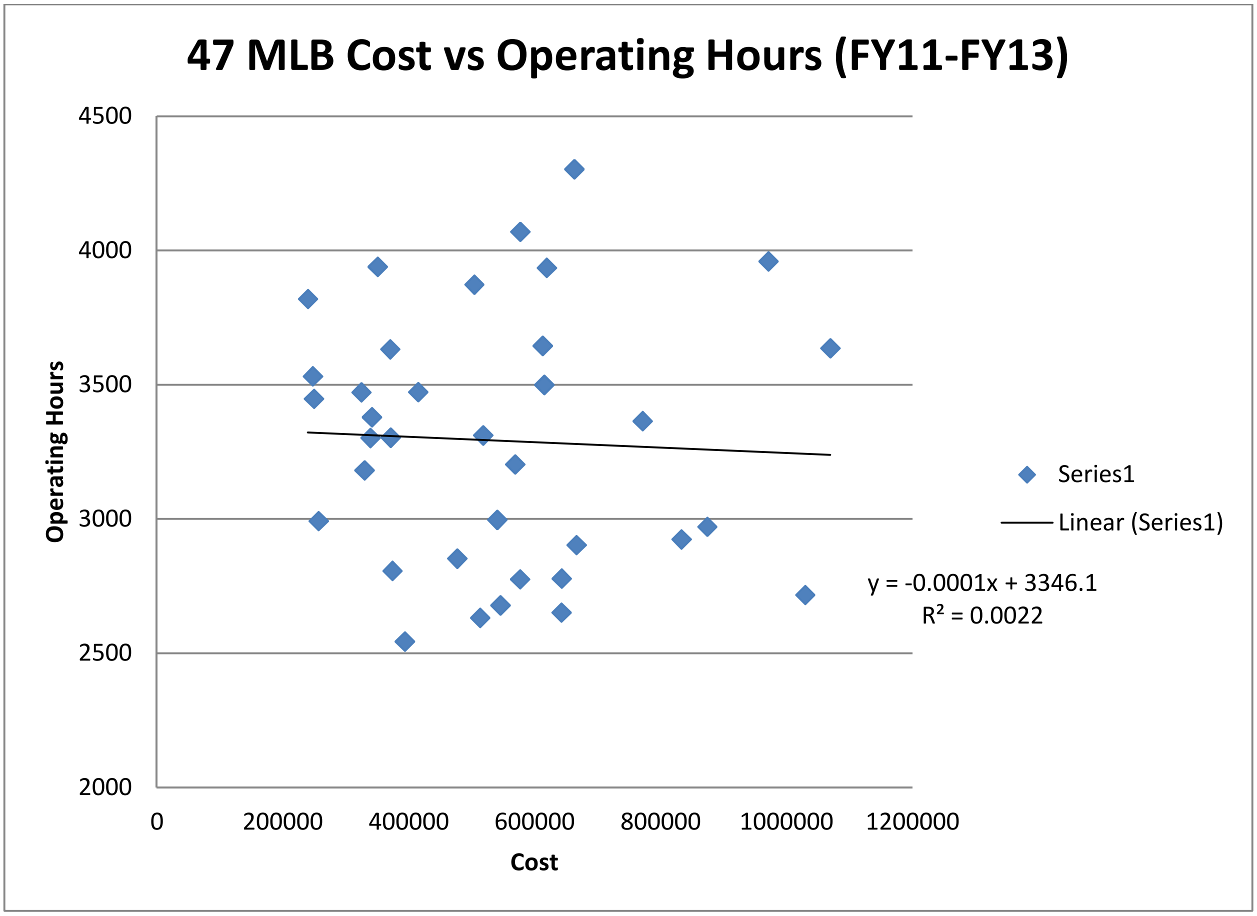

Figure 15: 47 MLB Cost versus Operating Hours

The resulting regression shows a decreasing number of operating hours as more funding is invested. Two potential causes are in play, first are planned depot maintenance (PDM) costs from dry dock availabilities to prevent the boats from performing underway hours. Some significant delays have potential to not only increase cost but also reduce operating hours. The second factor that is in play is the increased cost of material and across the board reduction in operating hours. Both factors contribute to the deficit however neither is entirely responsible.

Cost versus Operational Availability

Similarly to operating hours, operational availability was plotted as a function of cost, the resulting graph and regression is below in figure 15.

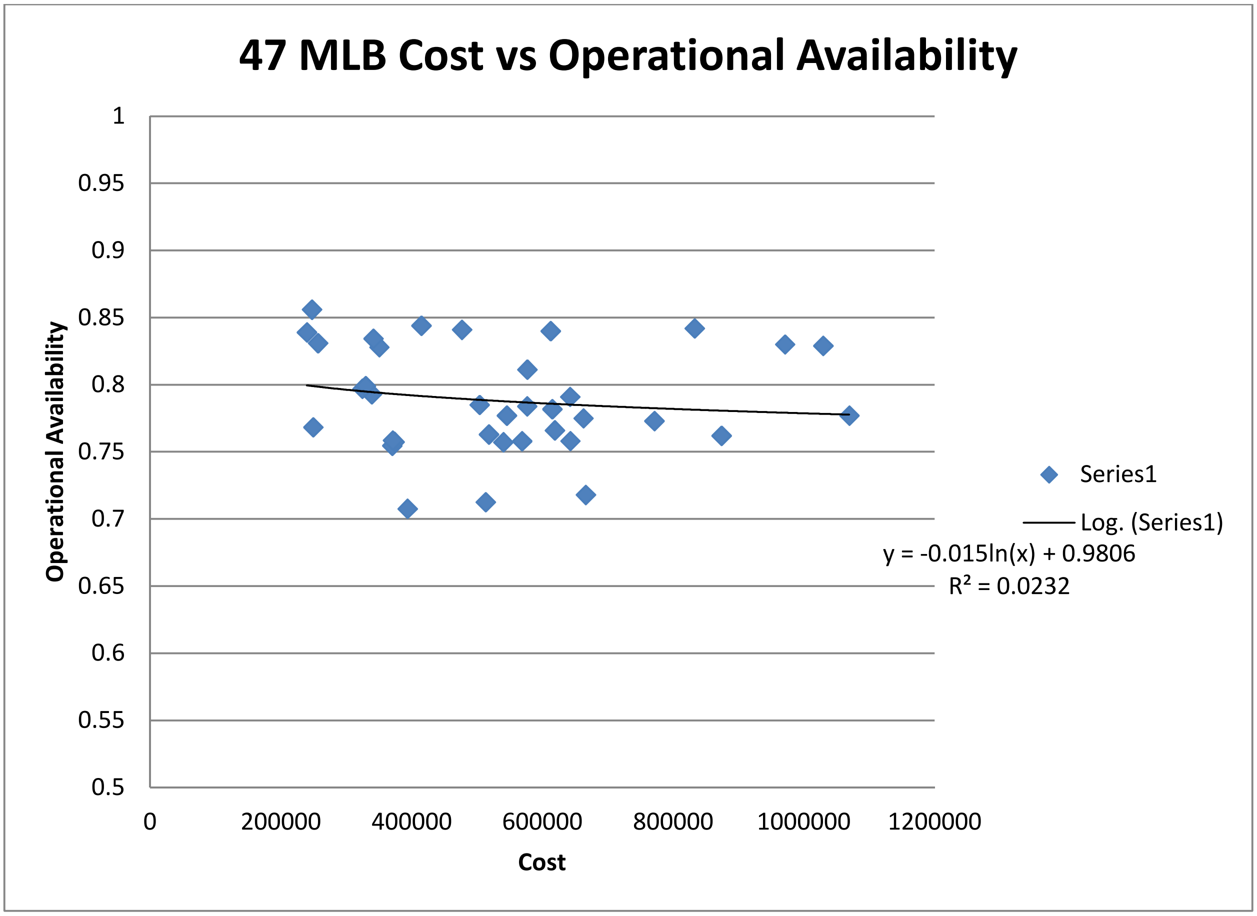

Figure 16: 47 MLB Cost versus Operational Availability

The resulting curve has a negative slope, which is not the predicted slope. The negative slope is due to the increasing costs of maintaining an obsolete system, as described in the latest Ships Structure and Machinery Evaluation Board. (Keffer, 2010) The resulting formula does not mean that the less funding the SBPL expends the higher the operational availability, in actuality the inverse is true. Cost is increasing and less operational availability is being produced for many of the same reasons of the trending nature of the operational availability variable.

Multi-Regression of Cost as a Function of Operational Availability and Operating Hours

The cost regression as a function of operational availability and operating hours was run in NCSS. (Hintze, 2004) The resulting plot and regression is in Figure 16.

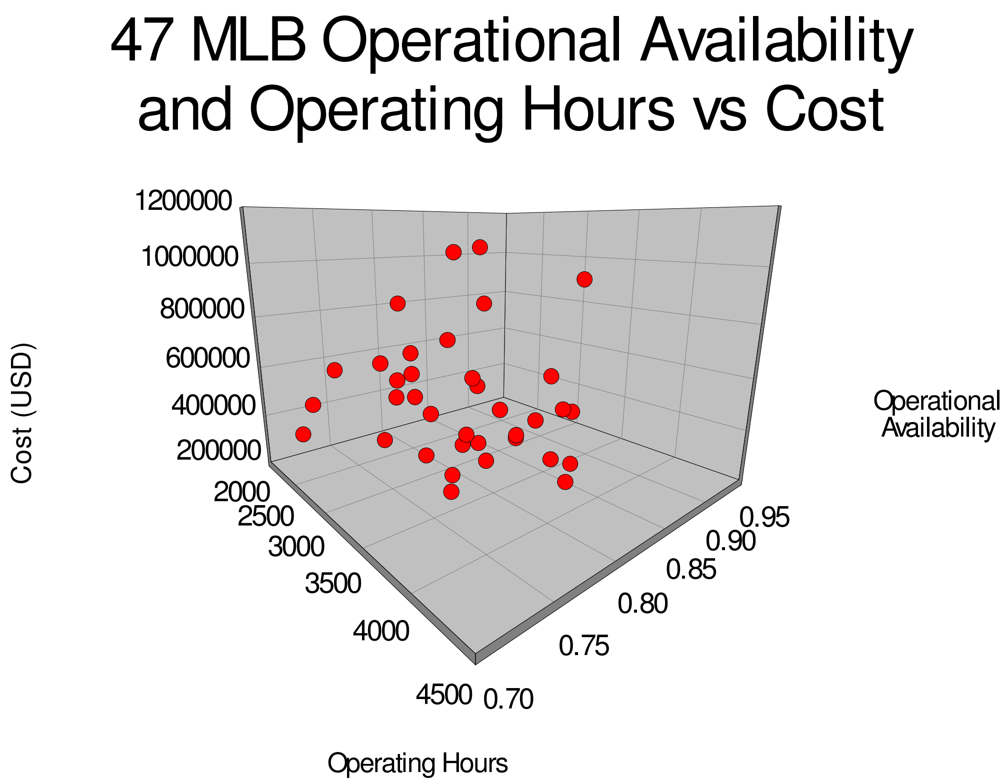

Figure 17: 47 MLB 3-D Scatter Plot of Cost as a function of Hours and Availability

The resulting regression formula as calculated by NCSS is:

$$Cost\ (Ao, H) = -434185.1\ \times Ao - 22.47113\ \times H + 955754.1$$

With

$$C = Cost$$

$$Ao = Operational\ Availability$$

$$H = Operating\ Hours$$

The regression from NCSS is in Appendix B. The regression formula was then run through a sensitivity analysis to determine if a dominant variable exists and to identify the variable.

	Low	Mean	High	Low Cost	Base Cost	High Cost	Swing	Swing^2	% Var
Hours	2514	3975	5436	546703.4	513873.1	481042.7	-65660.6	4311319889	0.401597
Availability	0.7197	0.812	0.9043	553948.3	513873.1	473797.8	-80150.6	6424113785	0.598403
								10735433674	

Table 8: 47 MLB Sensitivity Analysis

The operational availability variance trumps the variance caused by the operating hours, making operational availability the dominant or driving variable of the equation. For every dollar spent by the SBPL $0.60, goes toward paying for operational availability. The operating hours do incur significant cost and cannot be completely ignored, but the operational availability or the readiness of the boat class is the driving cost. Again this intuitively makes sense in that the primary mission of the platform is search and rescue which requires a high level of system readiness.

Bivariate Normal Distribution

The bivariate normal distribution was graphed for the area between three standard deviations from the mean of the period between FY2011 and FY2013. Using the upper and lower control limits from the control charts for operating hours and operational availability, as the area to be graphed. The resulting graphical representation of the plan is below in Figure 17

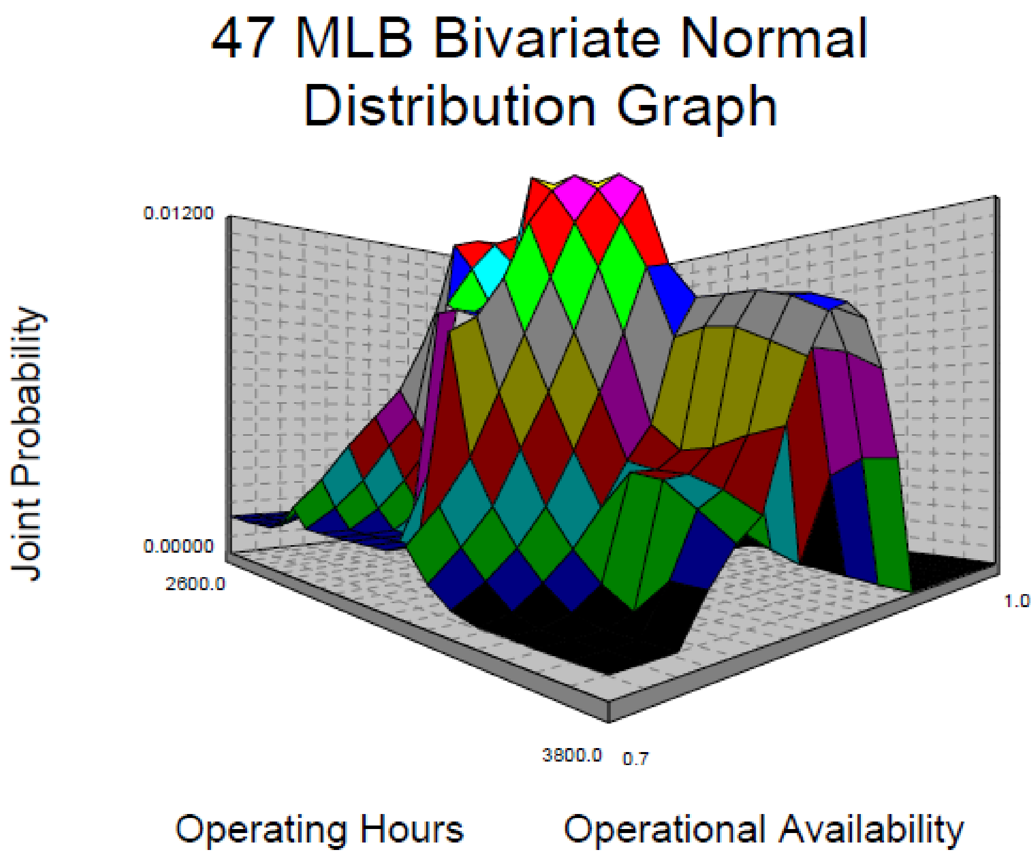

Figure 18: 47 MLB Bivariate Normal Distribution

The resulting graph is valid between the limits of the operational availability and the operating hours. Thus the probability is estimated to equal one:

$$1 = \int_0^1 \int_0^{84,240} f(A, H) dH dA$$

The bivariate normal is being used as an estimate of the actual, due to the substitution of sample standard deviation for standard deviation. However with the larger amount of data being over 30 data points the approximation will be closer to the actual.

Expected Value

The expected value or expected cost was calculated for one month operating cost based on the cost regression formula and the bivariate normal probability distribution of cost as function of operational availability and operating hours. The best option to reduce operating costs will have the lowest expected value, due to the utility function or cost regression calculating cost.

$$E(C) = E(A,H) = \int_{Amin}^{Amax} \int_{2774}^{3633} C(A,H) \times f(A,H) dHdA$$

The results are in the table below:

Option	Availability Min	Availability Max	E[C]
1	0.7588	0.9412	$ 67,316.00
2	0.8	0.9824	$ 70,578.90
3	0.719	0.9013	$ 64,124.90

Table 9: 47 MLB Calculated Expected Value

By the criteria of the lowest expected cost, option 3, which is the current model, has the lowest cost. This makes sense due to the availability being the major source of cost with the 47 MLB. The savings per month of $3,200 and $5,500 per month over option 1 and 2 respectively, while maintaining the operating hours constant during each month. (Mathematica Version 9.0, 2013)

Lifecycle Cost Estimate

The remaining lifecycle cost of the 47 MLB was calculated as the sum of the cost per month of the remaining life of the boat pending that no changes to the configuration are made. The end result based of the random number generation with in the control limits of the operating hours and the options operational availability

Option	Availability Min	Availability Max	Total Lifecycle Cost
1	0.7588	0.9412	$ 77,548,877
2	0.8	0.9824	$ 91,891,239
3	0.719	0.9013	$ 79,891,650

Table 10: 47 MLB Operational Availability Models

Based off the lifecycle cost option 1 provides the lowest total lifecycle cost that would represent an increase of operational availability from the current up to approximately a mean of 0.85. However this may not be possible without a significant investment into the fleet considering the obsolescence of the main propulsion system. This can be attributed to the end of production of the engine series.

Chapter 6: Recommendations

Use of Statistical Process Control

Before this analysis the Coast Guard had not used control charts or probability distribution histograms to monitor the health of the operational availability of a class of small boat on a regular basis. The SBPL had set target levels for operational availability this provides a minimum level of average availability. This does not show a statistical control, by calculating and evaluating control limits on an annual basis will assist in reducing cost and identifying when a system problem exists. By placing the target as the mean and knowing that three standard deviations are within an acceptable range will allow the asset line managers and section chiefs to track on a monthly basis. By taking this manufacturing principle and applying it to the product produced by the SBPL, Operational Availability, it will provide a higher quality product in the end. This is a zero cost change for SBPL.

Unify the Information Technology System

The SBPL operates in several different information technology systems. Specifically to track costs, this analysis required data reports from three major accounting systems and had to ignore a number of other systems that held smaller amounts of costs associated with the two classes of small boats. The IT at the point of having three different accounting and inventory systems creates an inherit inefficiency. Reports should be able to be driven by asset class in each system, as having just an annual report by part number or code does not mean that a part was associated with a particular class of boat especially when the part is installed on multiple classes of assets. By having the capability of breaking down a managerial accounting report by boat class, month, and funding type will be necessary.

This recommendation is being addressed with the acquisition of Coast Guard-Logistics Information Management System (CG-LIMS) by the Coast Guard as a replacement for ALMIS. (United States Coast Guard) However the first step for SBPL will be to unify the information management systems of AMMIS and NESSS into one database. By transitioning into one supply and accounting database will not only reduce the IT infrastructure required, it will save time, and overhead. FLS will have to remain as neither AMMIS nor NESSS can provide the project detail that FLS offers for planned depot maintenance availabilities. The secondary payout for SBPL is when it is time to transition to CG-LIMS the IT developer only has to move a single database instead of two, to transition the supply portion of the system.

Management Track on a Monthly Basis

Currently all ratios are calculated and tracked on an annual basis, this provides a meaningful consistent number that does summarize the abilities of the SBPL and SFLC over the course of that long period. However this process does not provide the information in this case in a timely manner in order to make adjustments to the managerial level plan. Essentially the strategic plan is being executed well however the managerial level plan is not developed. Tracking and calculating ratio such as MCPOH monthly will show a variance and could eventually be used to predict future budgets and assist in spend plan development. The single ratio is only good for the length of the next period. (Werner, 2004) By calculating ratios in a more frequent periodicity will provide the most current decision information to the top level managers with in the SBPL and SFLC. With more frequent data points generated the big picture of what is happening with the system will develop faster.

By adapting basic financial accounting principles of publishing the ratio from a smaller period of time a trends can be established. The trends can then be analyzed to show the consistency in both funding levels throughout the year and operating hours.

Managing Operational Availability

Asset operational availability plays a significant role in cost. Operational availability is also the only variable controlled entirely by the engineering, maintenance, and logistics system managed by the SBPL. With the 47 MLB the cost of $0.60 per dollar spent goes to paying for the operational availability of the boat class. Availability controls approximately 0.5984 percent of the cost or approximately two-thirds of the cost. The 25 RB-S the cost of availability is much higher with $0.99 of every dollar going toward paying for availability. Or approximately all of the cost of the boat class goes toward the operational availability discounting fuel.

Managing by using operating hours alone does not show a clear picture of the health of the system. This is especially true for engineering, maintenance, and logistics managers as there is no control over the operating hours of the asset classes under their responsibility, operating hours are entirely controlled by the operational commander. Programmed operating hour limits and increasing operating hours does change the cost however these are all set and controlled by the operational side of the Coast Guard not the Mission Support side of the Coast Guard. Mission Support Managers need to be fixated on the operational availability of their assets, as this is the variable that Mission Support Managers have the greatest impact on.

Major Changes in the number of assets and the requirements for operational availability need to be placed through a technical change order or change in operational requirements board that heavily involves the asset manager of the specific class. The lifecycle cost between the changes from the current operational availability to the new requirement should be calculated. The balance between what is affordable and what is required will need to be maintained, especially in the current government budgetary climates. The asset manager must stay fixated on what is within the control of the asset manager, not what is within the control of the operational manager.

Develop New Metric

A new metric to show the readiness level of a particular boat class at each station required to have a boat ready for a mission by class. Currently there is no standard process or tool that measures the hours a boat spends in a heightened level of readiness. The best measure that is currently used is operational availability which shows the ratio of how many hours the class spends fully mission capable and partially mission capable throughout the entire month. However the level of readiness is based on a measure of percentages and does not measure the specific stations readiness. Two examples will be offered.

The first is a station with the requirement to have one 25 RB-S ready 24 hours/7days for the entire month will need to have 720 hours of readiness. A single 25 RB-S can only expect to produce between 531 to 658 hours of readiness. In this case the system needs two 25 RB-S to meet the requirements of having one 25 RB-S ready at any given time. It does not matter which of the two 25 RB-S is in a readiness position or if one is not available if the other is.

The second is a station with the requirement of having two 47 MLB ready 24 hours/7days for the entire month will need to have a total 1,440 hours of readiness or 720 hours each. A single 47 MLB can only expect to produce between 518 – 649 hours of readiness per month. The conservative analyst will compute that three 47 MLB's will be required to meet a two boat readiness requirement based off the lower control limit. This will reduce the risk of not being able to launch on a mission to near zero. The least conservative approach by taking two boats with the highest possible availability of near 649 hours per boat or 1298 total would leave a 0.0986 chance of not having two boats available to meet the requirements. Again it would not matter which combination of two boats is in a readiness position.

There are numerous permutations to the numbers size and type of stations in the Coast Guard and will not be calculated here. The point in being is that a certain level of readiness is required for the overall station potentially with an inshore and offshore requirement that could require two different types of platforms. The measure that could potentially follow is how is the SFLC and SBPL meeting the availability requirements of the station regardless of the asset operational availability. There for availability requirements would have to be calculated by class into overall hour's figures and boats in both underway and standby status would have to be measured. (Standby status meaning a boat is waiting to perform a mission or it is the ready SAR boat.) Thus the ratio in comparison to operational availability will be significantly closer to one. Thus for the class the overall readiness ratio would look something like total number of actual readiness hours performed over the total number of readiness hours required.

$$Readiness\ Ratio = \frac{\sum Number\ of\ Readiness\ Hours\ Performed\ for\ n\ period}{\sum Number\ of\ Readiness\ Hours\ Requried\ for\ n\ Period}$$

This could also be expressed as Maintenance Cost per Readiness Hour (MCPRH):

$$MCPRH = \frac{\sum Maintenace\ Cost\ for\ n\ period}{\sum Number\ of\ Readiness\ Hours\ performed\ for\ n\ period}$$

In order to measure the number of readiness hours performed for n period a significant software change in Electronic Asset Log (EAL) would have to be made that would require station personnel to identify the ready boat or boats at their station based off the operational requirements of the station. The analyst could then use all the data inputs from the individual stations to calculate the readiness hours performed for n period and compare that to the required total. Feasibly anything less than 0.9999 would stand out as a problem.

The second ratio Maintenance Cost per Readiness Hour would show the comparison between the readiness hours produced by the system and the maintenance cost to produce those hours. Similar to the Maintenance Cost per Operating Hour is could show that shows the interrelationship between the maintenance costs and operating hours. This ratio would show the interrelationship between the maintenance costs and readiness hours.

Again these readiness measures are not resource neutral and would require significant changes to the IT infrastructure of the USCG's EAL program. The end result being a measure of readiness throughout the Coast Guard that could also be broken down by Area, District, all the way to an individual unit, meaning that the tactical commanders will have the answer to the question to "is there a boat ready?" and confidence that the measure would be meaningful and applicable at the various levels.

Maintenance Cost per Availability Hour

In response to the inherit cost in producing the readiness ratio and maintenance cost per readiness ratio an alternative needs very serious evaluation by the Coast Guard. Maintenance Cost per Availability Hour, now that it is known that availability is the major cost driver of the two classes of small boats evaluated a measure that relates availability and cost is needed. This type of measure would place a dollar figure on every hour that a boat is available in a fleet. So the figure for the fleet would be calculated using metrics and figures already measured and used. Thus making this specific measure a very feasible alternative to the maintenance cost per readiness hour.

The operational availability is already calculated based upon the time each boat spends in a FMC and PMC status. Recall the operational availability formula:

$$Operational\ Availability = \frac{\sum Fleet\ (FMC + PMC)\ \ for\ n\ period}{\sum Fleet\ (FMC + PMC + NMCS + NMCD + NMCM) for\ n\ period}$$

The time available is simply the numerator of the availability equation in hours. These are data reports that are available for the entire fleet from the EAL Dashboard screen. The proposed formula to calculate the fleet average of maintenance cost per availability hour (MCPAH) would appear something to be:

$$MCPAH = \frac{\sum Maintenace\ Cost\ for\ n\ period}{\sum Fleet\ (FMC + PMC) for\ n\ period}$$

Feasibly this would paint a better picture of the driver behind the cost of operating the particular boat class than MCPOH. The fact that the data and information required to calculate this ratio is already being collected means that at no financial cost to the SFLC or SBPL the MCPAH could be calculated. This would in effect of the Coast Guards readiness missions on cost than the MCPOH. MCPAH also shows a better relationship between the tactical operational commanders concerns, back to the question of all operational commanders "do we have an asset able to respond?" This type of ratio would show the cost of being able to answer that question to the affirmative.

Continuing Training

Training is integral to any organization but especially imperative to an organization providing services. Service industries as call centers are dependent upon the interaction between those working in the call center and the customer. Those working in the call center at a large firm providing parts to a customer receive considerable formal training on how to handle the customer, IT systems, and the process in which they are a part of, and then spend several weeks or months under instruction before the employee starts working on their own. In the SBPL, and SFLC (other product lines included), there is no formal job specific training for new members responding to emergencies and no under instruction time to really learn the job of an asset manager or casualty responder. The end result is more than likely an underperforming organization, in that the common use of individual workarounds for the IT systems are used and standard process are not precisely followed due to the lack of knowledge of the process by the employee.

The adoption and formalization of the port engineering training program has brought a bridge to the depot level maintenance program. These personnel work independently and are responsible for project management of scheduled dry docks and other depot availability projects. This is a step in the right direction but never addressed the call center problem of supply and asset management that essentially operate a call center for unscheduled repairs. The lack of a formal job specific training program also is compounded by having these personnel distributed throughout the country and the use of rotating military personnel in these positions. The military personnel are the right personnel to use because of the experience background in common with the customer. (Rabago, Naval Engineer Personal Qualification Standard, COMDTINST M3502.11series, 2013)However, being on the other side in the position of a call center representative changes the dynamic and becomes a situation that most are not prepared for.

Recommendation would be to adopt a formal school and qualification program equivalent to the port engineering program for the asset management section members. This should be a cross product line school and have recurring training for those already in the duty rotation on an annual basis to retrain for updates and changes in business policy. A formal school and training program costs money, however the potential for increase in operational availability due to personnel knowing their responsibilities and how to do their job better will give the potential to reducing costs while increasing availability.

Chapter 7: Conclusion

The Coast Guards small boats perform a readiness mission that is measured at the headquarters level of the organization as the amount of operating hours produced by the fleet. This is a poor measure, as operating hours has very little bearing on the cost of the boats nor does it have anything to do with answering the readiness question. The most realistic measure is readiness hours in Coast Guard operational terms the time that a boat spends either “alpha or bravo-zero” in a month in comparison to the number of required boats to remain ready at the specific station. An average of this ratio would be an excellent measure to relate the fleet readiness and the cost of fleet readiness at the headquarters level and executive levels of Department of Homeland Security. This meets the needs of the Coast Guard by being able to answer the question do we have a boat ready? This measure could also be used to develop a maintainable boat allocation that meets the budgetary needs.

Cost is mostly controlled by producing operational availability. Increase in operational availability will substantially increase lifecycle cost. Similarly small to significant decreases can also have an increasing effect on cost. The 25 RB-S is in the process of a recapitalization which will limit the opportunities to reduce cost of the asset considering the limited life cycle remaining. The 47 MLB is awaiting a mid-life project to ensure that it meets its service life objective. The 47MLB will remain on an uncontrollable operational availability roller coaster seeing large rises followed by declines. Until the systems are updated to logistically sustainable systems the Small Boat Product Line will continue to struggle to maintain obsolete engines and auxiliary systems.

The Coast Guard in an effort to control costs needs to manage by using operational availability or another readiness metric with operating hours a supporting metric not a primary for these two small boat systems. The belief that maintenance cost is entirely driven by operating hours is a farce with the 25 RB-S and the 47 MLB, readiness and operational availability are the main drivers behind the system cost. The engineering and logistics manager needs to be fixated on the fluctuation and changes of the operational availability of the two systems, as this is what is being produced by the Surface Forces Logistics Center and Small Boat Product Line. This makes simple sense when one considers the primary mission profile of a USCG small boat is to stand at the ready for a search and rescue mission. The small boat station does not operate like an airline or shipping line, it more operates like a cross between a local police department and fire department. Thus it has periods of operations that require large amounts of resources such as the Super Bowl (Vega, 2013), and periods of waiting for the SAR alarm to ring.

The ever changing world events will continue to require an agile maritime force that is trained in domestic response to world and national events in the littorals of the United States. With the tightening of government budgets and the need to acquire and sustain a fleet of vessels must be done in a more efficient manner and must with stand the public scrutiny. In order to do this realistic financial, readiness, and operating levels need to be recorded and shown to prove the programs worth to the American public. The next major storm of national significance that affects a maritime port, oil spill, or tsunami can happen at any point in time.

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Appendix A: 25 RB-S

Multivariable Regression Data

Page/Date/Time	1 10-29-2013 10:15:50
Database	C:\Users\Brian Fitzpatrick\D ... R7000\Analysis\RBS Prelim.S0
Dependent	C259
Weight	C2

Regression Equation Section

Independent Variable	**Regression Coefficient**	**Standard Error**	**T-Value (Ho: B=0)**	**Prob Level**	**Decision (5%)**	**Power (5%)**
Intercept	-1.866011E+07	9480137	-1.9683	0.057744	Accept Ho	0.479791
C257	-17.10694	122.9011	-0.1392	0.890170	Accept Ho	0.052092
C258	2.27811E+07	1.135903E+07	2.0055	0.053422	Accept Ho	0.494165
R-Squared	0.112106					

Regression Coefficient Section

Independent Variable	**Regression Coefficient**	**Standard Error**	**Lower 95% C.L.**	**Upper 95% C.L.**	**Standardized Coefficient**
Intercept	-1.866011E+07	9480137	-3.797052E+07	650298	0.0000
C257	-17.10694	122.9011	-267.4483	233.2345	-0.0234
C258	2.27811E+07	1.135903E+07	-356489.8	4.591868E+07	0.3372
T-Critical	2.036933				

Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Prob Level**	**Power (5%)**
Intercept	1	4.356583E+12	4.356583E+12			
Model	2	5.107772E+12	2.553886E+12	2.0202	0.149204	0.210369
Error	32	4.045439E+13	1.2642E+12			
Total(Adjusted)	34	4.556217E+13	1.340064E+12			

Root Mean Square Error	1124366	R-Squared	0.1121
Mean of Dependent	386713.7	Adj R-Squared	0.0566
Coefficient of Variation	2.907491	Press Value	7.294173E+13
Sum |Press Residuals|	2.469889E+07	Press R-Squared	-0.6009

Normality Tests Section

Assumption	**Value**	**Probability**	**Decision(5%)**
Skewness	6.3461	0.000000	Rejected
Kurtosis	5.3032	0.000000	Rejected
Omnibus	68.3963	0.000000	Rejected

Serial-Correlation Section

Lag	**Correlation**	**Lag**	**Correlation**	**Lag**	**Correlation**
1	-0.158121	9	0.016906	17	0.085510

2	-0.002028	10	-0.041779	18	-0.053507
3	0.009272	11	-0.067577	19	0.001663
4	0.050726	12	0.078470	20	0.054778
5	-0.096190	13	0.058591	21	0.117781
6	-0.149649	14	-0.037679	22	0.042330
7	-0.169866	15	0.046098	23	-0.075991
8	-0.050807	16	-0.045615	24	0.027146

Above serial correlations significant if their absolute values are greater than 0.333333
Durbin-Watson Value 2.3101

Multicollinearity Section

Independent Variable	**Variance Inflation**	**R-Squared Vs Other X's**	**Tolerance**	**Diagonal of X'X Inverse**
C257	1.018801	0.018454	0.981546	1.194802E-08
C258	1.018801	0.018454	0.981546	102.0626

Eigenvalues of Centered Correlations

No.	**Eigenvalue**	**Incremental Percent**	**Cumulative Percent**	**Condition Number**
1	1.135847	56.79	56.79	1.00
2	0.864153	43.21	100.00	1.31

All Condition Numbers less than 100. Multicollinearity is NOT a problem.

(Hintze, 2004)

Appendix B: 47 MLB Multivariable Regression Data

Database	C:\Users\Brian Fitzpatrick\D ... R7000\Analysis\MLB Prelim.S0
Dependent	C7
Weight	C2

Regression Equation Section

Independent Variable	Regression Coefficient	Standard Error	T-Value (Ho: B=0)	Prob Level	Decision (5%)	Power (5%)
Intercept	955754.1	817441.6	1.1692	0.250958	Accept Ho	0.205487
C5	-22.47113	87.80071	-0.2559	0.799640	Accept Ho	0.057095
C6	-434185.1	1080021	-0.4020	0.690345	Accept Ho	0.067607
R-Squared	0.009681					

Regression Coefficient Section

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95% C.L.	Standardized Coefficient
Intercept	955754.1	817441.6	-709320.1	2620828	0.0000
C5	-22.47113	87.80071	-201.3153	156.3731	-0.0470
C6	-434185.1	1080021	-2634117	1765746	-0.0739
T-Critical	2.036933				

Analysis of Variance Section

Source	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1	3.545943E+16	3.545943E+16			
Model	2	5.820173E+13	2.910086E+13	0.1564	0.855863	0.060866
Error	32	5.953991E+15	1.860622E+14			
Total(Adjusted)	34	6.012193E+15	1.768292E+14			

Root Mean Square Error	1.364046E+07	R-Squared	0.0097
Mean of Dependent	538706.8	Adj R-Squared	0.0000
Coefficient of Variation	25.32075	Press Value	1.694249E+12
Sum |Press Residuals|	6191793	Press R-Squared	0.9997

Normality Tests Section

Assumption	Value	Probability	Decision(5%)
Skewness	2.1843	0.028938	Rejected
Kurtosis	0.5565	0.577858	Accepted
Omnibus	5.0810	0.078826	Accepted

Serial-Correlation Section

Lag	Correlation	Lag	Correlation	Lag	Correlation
1	0.007043	9	-0.158894	17	0.268700
2	0.167749	10	0.139657	18	0.057131
3	0.185914	11	-0.112468	19	-0.027634
4	0.110392	12	-0.137567	20	0.075978
5	0.046848	13	0.140665	21	-0.030423
6	-0.204627	14	0.017182	22	-0.031865
7	0.102612	15	0.033823	23	-0.042926
8	-0.135269	16	-0.144844	24	-0.035325

Above serial correlations significant if their absolute values are greater than 0.333333

Durbin-Watson Value 1.9541

(Hintze, 2004)

Appendix C: 25 RB-S Expected Value Calculations

In[1]:= _ Integrate__22781100 x _ 17.10696_y _ 18660110___1_2_Pi_0.018662_
1709.563_Sqrt_1 _ 0.141609^2__Exp___1_2__1 _ 0.141609^2______x _
0.841501__0.018662_^2 _ 2_0.141609___x _ 0.841501__0.018662____y _
6817.563__1709.563_ __y _ 6817.563__1709.563_^2_, x, 1921, 11238_
_22781100 x _ 17.10696_y _ 18660110___1_2_Pi_0.018662_1709.563_Sqrt1 _ 0.141609^2__Exp
Result
_0.0150645 _ E^x _ __18 660 110 22 781 100 _ x _ 17.107 _ y_
Out[1]= _0.0150645 _x __18 660 110 22 781 100 x _ 17.107 y_

In[2]:= _ Integrate__22781100 x _ 17.10696_y _ 18660110___1_2_Pi_0.018662_
1709.563_Sqrt_1 _ 0.141609^2__Exp___1_2__1 _ 0.141609^2______x _
0.841501__0.018662_^2 _ 2_0.141609___x _ 0.841501__0.018662____y _
6817.563__1709.563_ __y _ 6817.563__1709.563_^2_, y, 1921, 11238_
_22781100 x _ 17.10696_y _ 18660110___1_2_Pi_0.018662_1709.563_Sqrt1 _ 0.141609^2__Exp
Result
_0.0150645 _ E^x _ __18 660 110 22 781 100 _ x _ 17.107 _ y_
Out[2]= _0.0150645 _x __18 660 110 22 781 100 x _ 17.107 y_

In[3]:= _ Integrate__22781100 x _ 17.10696_y _ 18660110___1_2_Pi_0.018662_
1709.563_Sqrt_1 _ 0.141609^2___Exp___1_2__1 _ 0.141609^2______x _
0.841501__0.018662_^2 _ 2_0.141609___x _ 0.841501__0.018662____y _
6817.563__1709.563_ __y _ 6817.563__1709.563_^2__, y, 1921, 11238_
Integrate 22781100
Indefinite integral
Integrate_22 781 100, x_
Out[3]= 22 781 100 x

In[4]:= _ **Integrate_22781100 x, x, 0.7371, 0.9142_**
Integrate_22 781 100 _ x, x, 0.7371, 0.9142_
Out[4]= 3.33111 _ 10^6

In[5]:= _ **Integrate_22781100 x, x, 0.7615, 0.9385_**
Integrate_22 781 100 _ x, x, 0.7615, 0.9385_
Out[5]= 3.42742 _ 10^6
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In[6]:= _ **Integrate_22781100 x, x, 0.8, 0.977_**
Integrate_22 781 100 _ x, x, 0.8, 0.977_
Out[6]= 3.58266 _ 10^6
2 *Untitled-1*
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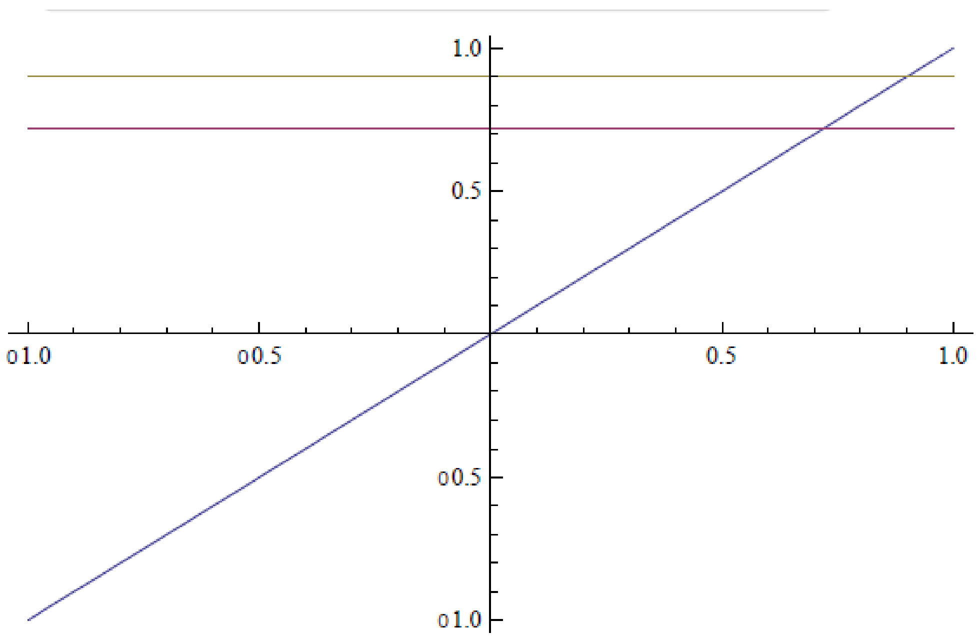
Appendix D: 47 MLB Expected Value Calculations

In[14]:= _ Integrate___434185.1_x _ 22.47113_y _ 955754____1 2 Pi 0.039346
470.3368 Sqrt_1 _ 0.328257^2__Exp___1 2 _1 _ 0.328257^2______x _
0.788882_ 0.039346_^2 _ 2_0.328257___x _ 0.788882_ 0.039346____y _
3921.872_ 470.3368__ __y _ 3921.872_ 470.3368_^2_, _y, 2774, 3633_
Integrate 434185.1
Indefinite integral
Integrate_434 185.1, x
Out[14]= 434 185. x

In[15]:= _ Integrate_Out_14, _x, 0.719, 0.9013_
x, 0.719, 0.9013
Plot
Plot__x, 0.719, 0.9013_, _x, _1, 1_

Out[15]=



In[16]:= _ **Integrate_434185. x,_x,0.719,0.9013_**
Integrate_434 185. _ x, _x, 0.719, 0.9013_
Out[16]= 64 124.9

In[17]:= _ **Integrate_434185. x, _x, 0.7588, 0.9412_**
Integrate_434 185. _ x, _x, 0.7588, 0.9412_
Out[17]= 67 316.

In[18]:= _ **Integrate_434185. x,_x,0.8,0.9824_**
Integrate_434 185. _ x, _x, 0.8, 0.9824_
Out[18]= 70 578.9
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(Mathematica Version 9.0, 2013)

Vita

Brian Fitzpatrick is a United States Coast Guard Lieutenant assigned to the University of New Orleans for graduate studies as duty under instruction. LT Fitzpatrick is a Coast Guard designated Naval Engineer having served tours afloat, in acquisitions, and support. Most recently LT Fitzpatrick was assigned to Surface Forces Logistics Center Small Boat Product Line as engineering Asset Management Section Chief for small response boats. LT Fitzpatrick graduated from the United States Merchant Marine Academy at Kings Point, New York in June 2005 with a B.S. in Marine Engineering and Shipyard Management and an Unlimited Horsepower Third Assistant Engineers License for Steam, Diesel, and Gas Turbine vessels. LT Fitzpatrick currently holds a Project Management Professional Certification from Project Management Institute and a Department of Homeland Security Level I Program Manager Certification.