Expanding the Range of Your Data: A Small Ships Case Study

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Abstract

Like other Department of Defense Services, the Navy maintains a comprehensive database that records and tracks Operating and Support (O&S) costs each year, known as the Visibility & Management of Operating and Support Costs (VAMOSC) database. This database captures O&S data from ships currently in the fleet, such as combatants, carriers, and amphibs, and maintains the historical record back to 1984. However, the Navy has not built many smaller ships since VAMOSC's inception, meaning the database does not contain much data for smaller ships. Therefore, it is challenging to use this database to estimate the costs of these smaller ships.

With increasing technological advances, evolving mission focuses, and a renewed effort to reduce personnel, smaller ships are receiving increased interest. Since the Navy does not have many of these smaller ships in their fleet, cost analysts must look outside of VAMOSC for good data points, making the Coast Guard a logical extension.

This paper explores using Coast Guard O&S data to supplement Navy data to estimate O&S costs for smaller ships. Topics include the following:

1. Data sources and data collection
2. Data normalization
3. Comparisons of data between the services

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I. Introduction

Large aircraft carriers, amphibious assault ships, and surface combatants make up most of the Navy's fleet. However, as evidenced by the emphasis on the Littoral Combat Ship (LCS) and the Small Surface Combatant (SSC) programs, there is a renewed effort to build smaller ships to reduce the crew size and the costs of the ships.

When reviewing the lifecycle of a program, ships incur the majority of costs during the Operating and Support (O&S) phase, as shown in Figure 1 below. Investment is typically the focus of many analyses, because of its near term consequences, but the ultimate cost of the ship will be determined in the O&S phase. Therefore, it is vitally important to have an accurate picture of the ship's estimated O&S costs.

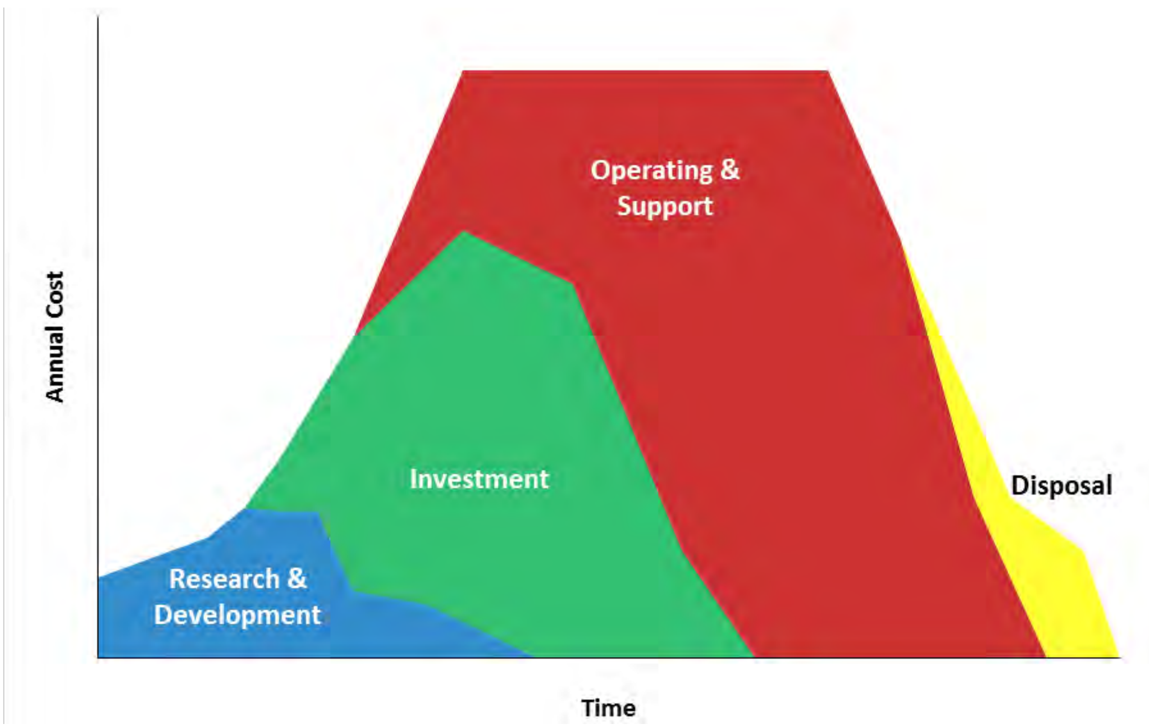

Figure 1: The Costs Incurred at each Program Phase (International Cost Estimating and Analysis Association, 2013)

Because the Navy has not built many small ships, there is limited data available to support an O&S estimate, making developing a realistic picture of the O&S costs of a small ship more challenging. This paper will explore the typical potential data sources for ship O&S data and then explore the idea of supplementing Navy O&S data with Coast Guard O&S data.

II. Definitions

Prior to discussing any data sources or analysis, it is important to define a few terms used throughout this paper. Clear definitions ensure a common meaning and understanding when reviewing this paper.

CAPE Structure. In March 2014, the Office of the Secretary of Defense (OSD) Cost Assessment and Program Evaluation (CAPE) office released an Operating and Support Cost-Estimating Guide. Within this guide was an O&S Cost Element Structure (CES) that the CAPE recommends using for all O&S elements. This CES has six major categories:

- 1.0 Unit-Level Manpower
- 2.0 Unit Operations
- 3.0 Maintenance
- 4.0 Sustaining Support
- 5.0 Continuing System Improvements
- 6.0 Indirect Support

In addition, each element has sub elements (Cost Assessment and Program Evaluation, 2014), but this paper will focus on these level one categories. This CES was used in all analysis presented in this paper and will be referenced throughout.

Regression. For the purposes of this paper, regression will mean a linear statistical relationship between two variables. It is the “best fit” line established to relate a dependent variable (cost) to an independent variable (weight, crew size, etc.) (International Cost Estimating and Analysis Association, 2013). Additionally, as is common practice in ship cost estimating, the y-intercept variable is omitted, as it was not a statistically significant variable for most regressions. The result is $/Long Ton (LT) or $/person metrics that have been statistically derived from several data points.

Prediction Interval. A prediction interval is a measure of the uncertainty around an estimate developed using a regression equation. It is often confused with the confidence interval, but it will always be wider than the confidence interval since confidence intervals include the residual error past the endpoints of the confidence interval. Prediction intervals are used for risk analysis (International Cost Estimating and Analysis Association, 2013) and will be used as a measure of uncertainty throughout this paper with an alpha value of 5%. In addition, for this paper, one can assume that the prediction intervals were not allowed to fall below $0.

Small Ship. A small ship can mean many things to many people and is often a relative term. However, for the purposes of this paper, a small ship will refer to ships less than 5,000 LT. This definition does not include boats, for, to the surface Navy, a boat is something that goes on a ship. This paper will focus on small ships and will therefore, exclude Rigid-Hulled Inflatable Boats (RHIBs), landing crafts, and other boats. An estimate for a small ship will be built using a weight and appropriately sized crew that is considerably less than 5,000 LT. For this estimate, one can assume that the ship has a steel hull, is not nuclear, and will be staffed by an officer and enlisted crew.

III. Ship Operating and Support Databases

In 1988, Congress mandated that each service establish and maintain a database to track O&S costs (Naval Center for Cost Analysis, 2017), and all three services continue to maintain and enhance these databases to this day. The Air Force maintains the Air Force Total Ownership Cost (AFTOC) system, the Army maintains the Operating and Support Management Information System (OSMIS), and the Navy maintains the Naval Visibility and Maintenance of Operating and Support Costs (VAMOSC) system. Each system has expanded over the years to include new data and new systems and has made the data available online to Department of Defense (DoD) employees and contractors. Each system and its associated ship data are discussed individually below.

A. Air Force: Air Force Total Ownership Cost

Though the Air Force does maintain a small number of ships, AFTOC does not identify ships by system and does not identify any ships comprehensively across the OSD CAPE O&S Elements (AFTOC HelpDesk, 2017). Therefore, AFTOC is not a useful data source for any ship O&S data at this time.

B. Army: Operating and Support Management Information System

The Army operates and maintains several small ships, but OSMIS focuses on ground and air systems. OSMIS does capture and report some ship data, but it is unclear if it is comprehensive. Some ship and boat data is captured in data collection, but it is not reported on the OSMIS website. In addition, there is uncertainty if there are additional data sources not reported to OSMIS for ship data. One must recognize that ships and boats are a small piece of the total Army inventory of ground and air systems, so they have not been a focus of OSMIS (OSMIS HelpDesk, 2017). Without a full picture of the O&S costs, OSMIS is not a useful data source for comprehensive ship O&S data at this time.

C. Navy: Visibility and Maintenance of Operating and Support Costs

The Navy's Visibility and Maintenance of Operating and Support Costs (henceforth "VAMOSC") is an excellent source for ship O&S data. It is a comprehensive and current data repository containing vast amounts of historical O&S costs for the United States (US) Navy's and US Marine Corps (USMC) prior and current major programs. VAMOSC, initiated in 1984, and its legacy data repository preceded the Congressional mandate that each service in the DoD maintain a system of verifiable operating and support costs. The Naval Center for Cost Analysis (NCCA) maintains Naval VAMOSC. The data is available to US government and approved contractors via a web portal for easy data querying and extraction to support a variety of cost studies and analysis (Naval Center for Cost Analysis, 2017).

Across all data universes, VAMOSC incorporates at least annual data from over 125 data providers to support over 1,200 cost and non-cost data elements. VAMOSC reports costs for ships, aviation programs, weapons and other ship systems, personnel (both military and civilian), and infrastructure. Annual ships costs are available back through fiscal year (FY) 1984 (Naval Center for Cost Analysis, 2017). For most commodities, including ships, VAMOSC reports annual costs using both the Navy's internal standard CES and the 2014 CAPE structure (Naval Center for Cost Analysis, 2017). VAMOSC is the gold standard in terms of data breadth, depth, and availability in the DoD, serving as a reputable basis for historical maintenance costs for Navy ship cost studies.

The Ships Universe in VAMOSC contains annualized cost data for active and reserve ships in the Navy for each FY 1984-2016. As illustrated in Figure 2 below, VAMOSC makes data available across a variety of dimensions (Naval Center for Cost Analysis, 2017):

- Individual hull-level or as class averages
- By FY and/or by hull age
- Navy CES or 2014 CAPE Structure

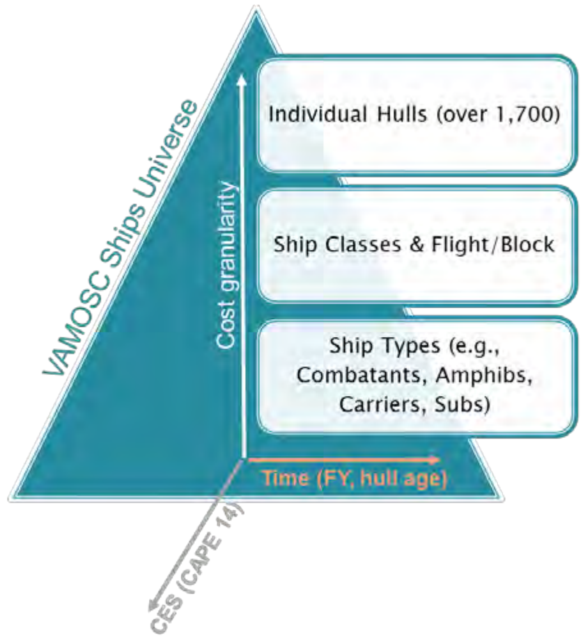

Figure 2: VAMOSC Ships Universe Data Dimensions

The VAMOSC Ships universe additionally provides non-cost data for cost normalization to enable meaningful comparisons across a variety of ship types, sizes, and maintenance strategies. Non-cost data in VAMOSC includes annualized hull counts, percent of Fiscal Year the hull was commissioned, crew size, maintenance hours, and steaming hours (Naval Center for Cost Analysis, 2017). One can supplement the VAMOSC data with weight information, to allow for normalization by ship size. Therefore, with its depth and breadth of ship data, VAMOSC is an excellent source for ship data.

IV. Motivation

Though Naval VAMOSC contains O&S data for nearly every ship in the US Navy, it is limited by the types and sizes of ships that the Navy builds. To illustrate this, in Figure 3 below, all non-nuclear ship classes contained in the VAMOSC ships universe are plotted according to their weight, for classes that have been active in the past 5 years. There appears to be a significant number of ships weighing less than 5,000 LT. This analysis excludes ships operated by the Military Sealift Command (MSC), as they are operated and maintained differently than other Navy ships (e.g., contain civilian staff, switch in and out of MSC operation, etc.)

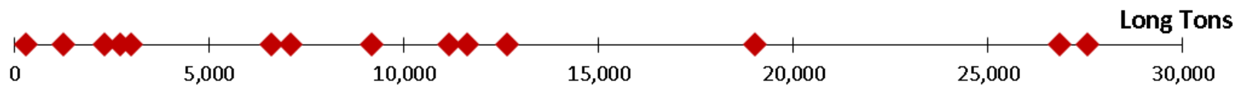

Figure 3: Weights of Ships in VAMOSC (NAVSEA Shipbuilding Support Office, 2017)

After a careful examination of the data points in Figure 3, one can determine that there are several ship classes that are often not analogous to most other Navy ships. Specifically, those with the following characteristics:

- Rotational crews: In VAMOSC, some of the rotational crew data is not included in the dataset, producing inconsistent results.
- Overseas homeports: Most ships have homeports within the US, but for a few classes, all of the ships' homeports are overseas. This results in atypical operating and maintenance costs because of the uncharacteristic requirements.
- Wood hulls: A few ships in the Naval fleet were built with wooden hulls. Most ships are built with steel, aluminum, or composite hulls. As one would expect, these hulls have different maintenance requirements than other hulls.
- Brand new classes: The brand new classes will soon be good analogies, but they likely do not have enough hulls in service or data points overall to be trusted as of yet. The first few years of the first few ships in a class produce higher than normal costs and are therefore usually not trusted as reliable data points.

The ships with these characteristics also do not match those of the notional "small ship" defined above. Therefore, they were removed from the dataset, and the resulting plot is displayed in Figure 4 below. All except one data point below 5,000 LT were removed. This leaves only one "small ship" as a good data point, still leaving a lot of room for even smaller ships that would fall outside of the available dataset.

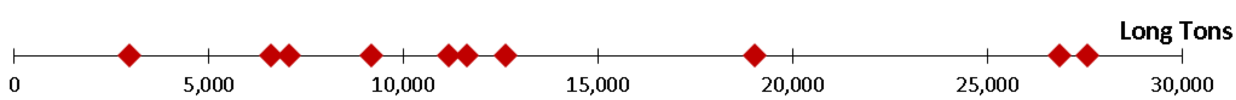

Figure 4: Weights of ships in VAMOSC with non-analogous ships removed

With only one ship falling in the less than 5,000 LT category, one could build an analogy off this ship or use the larger ships to run a regression line for smaller ships. However, there is a danger to performing this analysis. One should always try to gather data so that the estimate will fall in the middle of the dataset. If one were to use a regression line to predict the costs for small ships using only the Navy data, the prediction intervals at these smaller sizes would be very large. Prediction intervals forecast increased uncertainty the farther one travels from the mean of the dataset. Therefore, as displayed in Figure 5 below, the uncertainty surrounding these smaller data points would be very large. The regression developed using the green data points (representing medium and large ships), when applied to data points in purple (representing smaller ships) fits well at the mean of the dataset, but as one moves away from the mean, the prediction bands grow, which indicates increasing uncertainty in the estimate. Therefore, supplementing this Navy data with data from smaller ships could significantly reduce the uncertainty around the estimate and tighten the prediction interval.

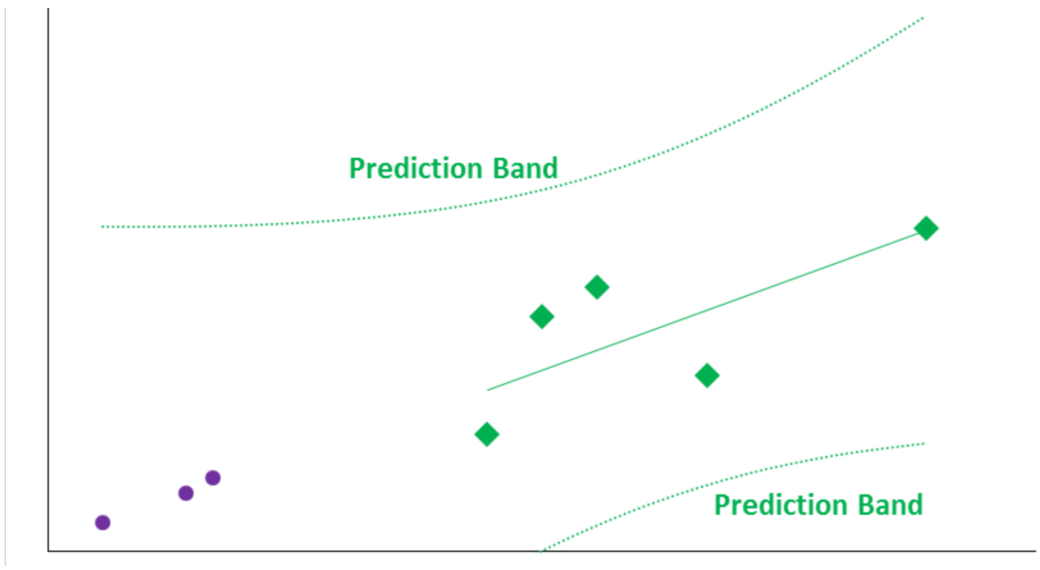

Figure 5: Notional Regression with Prediction Bands

Since there are no other Navy Ships (outside of the largely civilian-staffed MSC) that are in existence, one must look outside of Naval VAMOSC for smaller ship O&S data. However, as previously discussed, there is no other good DoD data source for ship data. Therefore, one must even look outside of DoD for small ship data. Fortunately, the US Coast Guard (USCG) has historically built smaller classes of ships, which could supplement the Naval VAMOSC dataset used to develop regression estimates for the small ships in question. In Figure 6 below, several USCG ships, all of which appear in the less than 5,000 LT range, were added as blue dots. One can see from this figure that this idea shows promise from a ship size standpoint. This paper explores the team's hypothesis that supplementation of Navy data with USCG data for small ships results in significantly reduced sizes of prediction intervals, leading to a significantly more confident estimate for a small ship. The paper will follow the team's data collection through to the implications for an estimate.

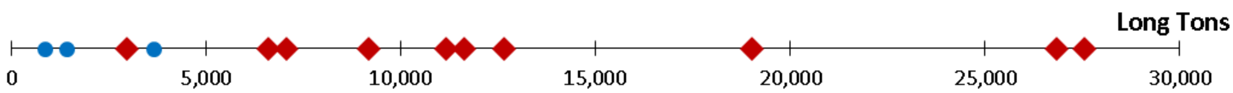

Figure 6: Weights of ships in VAMOSC with USCG ships added (blue)

V. Data Collection, Data Sources, and Data Normalization

A. Data Collection Process

Unfortunately, when the team began looking at USCG O&S data, it was quickly obvious that there is no single data repository for O&S data like the DoD services maintain. Therefore, the team began researching available data sources. As with many data collection efforts, initially, the focus started with readily available data, budget data, and therefore appropriations for the budgets. The USCG utilizes several appropriations, but Acquisition, Construction, and Improvements (AC&I) and Operating Expenses (OE) capture ship-related O&S costs. The AC&I budget includes both acquisition costs and, for the purposes of O&S, major modernization costs. However, the OE budget includes the bulk of the O&S costs. Figure 7 below shows all USCG Appropriations, with AC&I and OE highlighted in red. Additionally, the Allotment Fund Control (AFC) codes, the further segregation of appropriation by function, are broken out for OE (USCG Assisstant Commandant for Resources, 2013).

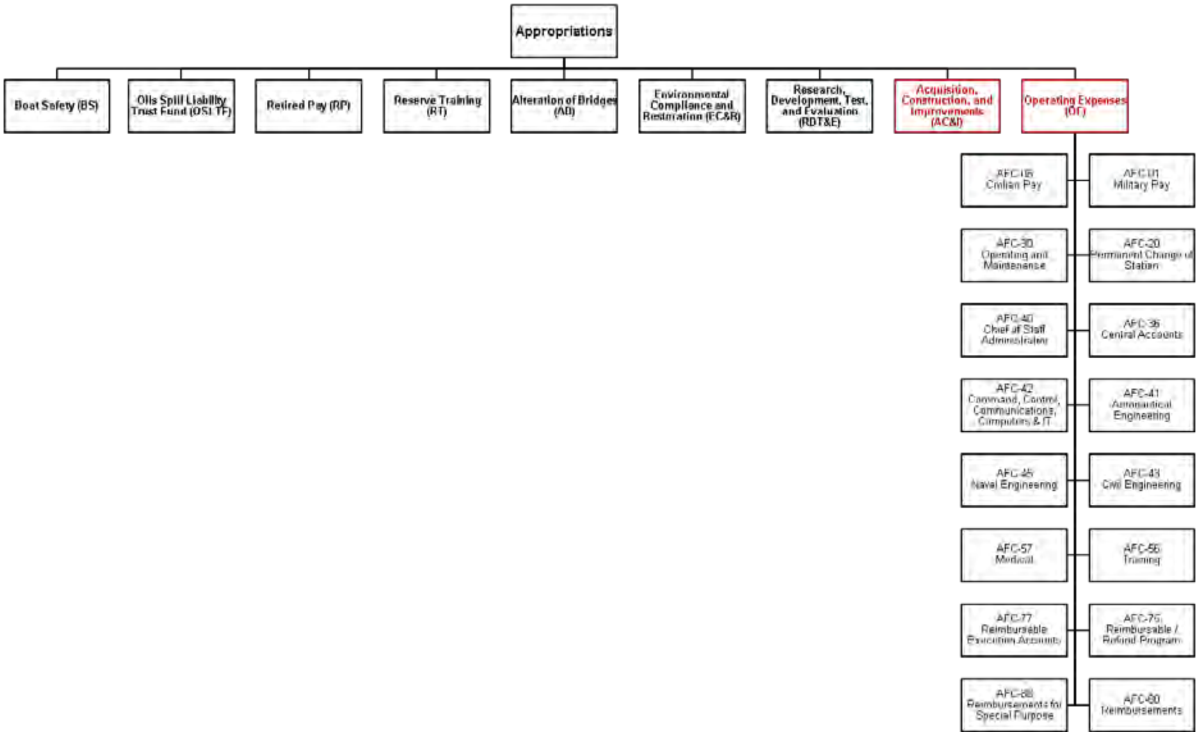

Figure 7: USCG Appropriations and AFC Codes

After repeated discussions with the USCG, the team learned that OE budget data was not as traceable to classes and hulls of ships as one would think. Therefore, the team looked into the way that the USCG tracks expenditures, inventory, and supplies in order to begin to build a database of USCG O&S costs. When exploring this data, the team found the Financial Procurement Desktop (FPD), the Fleet Logistics System (FLS), The Naval and Electronics Supply Support System (NESSS), the In-Service Vessel Sustainment (ISVS) Program, and the Aviation Logistics Management Information System (ALMIS) to be particularly useful in building up the USCG O&S costs. Each data source is discussed individually below.

B. Coast Guard Operating and Support Data Sources

Financial Procurement Desktop

Financial Procurement Desktop (FPD) creates and manages simplified procurement documents and maintains accurate accounting records. FPD is an enterprise-wide system used by other Department of Homeland Security (DHS) agencies besides the USCG, although for the purposes of collecting small ship data, the team explored only the USCG data. There is a variety of functions accomplished by FPD and those of particular interest for the purposes of this data collection effort include:

- Ledger management

- Budget and funds distribution
- Procurement requests and simplified acquisitions
- Receipt of goods/services
- Interoperability with the USCG Core Accounting System

When a program makes a payment, a funds manager enters a Purchase Order into FPD. FPD transmits the Purchase Order, integrates with the Core Accounting System, and reconciles its balance to show the reduced amount. Once the process is complete, FPD provides a simplified view of both funds spent and funds available, essentially an online checking account statement. Knowing the vast amount of different types of goods/services collected by FPD gave the team confidence that FPD data provides a good foundation for the data collection effort (Neuman, 2015).

FPD acts similarly to a statement that one receives for a bank account or credit card, for it captures expenditures. FPD is by far the largest and most comprehensive data source, encompassing many different types of expenses.

Fleet Logistics System

Fleet Logistics System (FLS) automates the management of USCG cutter and small boat logistics including (Neuman, 2015):

- Configuration Management (CM) and integration of maintenance actions
- Procurement and supply activities
- Automated Requisition Management (RM)
- Coast Guard Parts Availability Research Tool (CG-PART)
- Associated financial transactions

For the purpose of this data collection effort, FLS is a primary data source for labor associated with maintenance and contains costs for modernization.

Naval and Electronics Supply Support System

The USCG Yard and the Surface Forces Logistics Center (SFLC) are the primary users of the Naval and Electronics Supply Support System (NESSS). NESSS automates the maintenance and logistics management of USCG assets, linking the following functions (Neuman, 2015):

- Provisioning and cataloging

- Unit configuration
- Supply and inventory control
- Procurement
- Depot-level maintenance property accountability
- Full financial ledger

Although developed with those responsible for logistics management in mind, NESSS is a good source of parts and repairables cost data and became the primary source of data for this cost element.

In-Service Vessel Sustainment Program

In-Service Vessel Sustainment Program (ISVS) includes costs associated with major maintenance and upgrades for vessels to reach or extend their service lives (e.g., service life extension programs (SLEPs)). Much like the Navy, the USCG funds some of these efforts using construction-type funding. Acquisition, Construction and Improvements (AC&I) is the funding term most synonymous to the Navy's Shipbuilding Conversion, Navy (SCN) funding. Unlike the other data sources that report Operating Expense (OE) funding, ISVS captures AC&I funding. For data collection purposes, ISVS data provides costs associated with major modernization and maintenance events, and the team included it along with the other data sources reporting OE funding (US Coast Guard Acquisition Directorate, 2017). However, developing a budget quality estimate based on the data collected requires treating ISVS data separately as it is a different type of funding.

Aviation Logistics Management Information System

Aviation Logistics Management Information System (ALMIS) is another USCG data source. Though the title implies that the system only contains aircraft data, ALMIS does include some small ship data. However, there is no data for larger USCG ships, so ALMIS is a similar system to FLS, but for smaller ships (Department of Homeland Security, 2010). Therefore, when developing an estimate of a very small ship, an analyst should explore ALMIS. However, for most ship O&S cost estimates, the previously discussed data sources should be comprehensive.

C. Data Comprehensiveness

Data collection focused on collecting O&S data by hull by year. USCG Long Range Enforcer (LRE), Medium Endurance Cutters (MEC), and Patrol Boats (PB) were the focus of data collection. After working with the USCG and understanding the historical way data is collected and housed, the team learned that USCG O&S

data is only relevant from fiscal year 2010 onward to 2015 (the most recent available year for data). In 2009, the USCG significantly changed their processes to make them more rigorous and consistent coast to coast; thereby data collected from earlier than 2010 is likely not comprehensive.

Although data was not collected by AFC codes, they were useful in ensuring data comprehensiveness, for AFC codes were provided with each data point. Therefore, the team was able to display the costs collected by AFC code to help identify holes and compare across programs. Though not all AFC codes were accounted for, the team and the USCG agreed that the missing AFC codes would likely not have costs in them for ships (i.e., civil engineering, central accounts, etc.). This was consistent across all programs and each program's cost seemed reasonable when comparing it to other programs.

Despite best efforts, the team cannot be certain that the costs collected build the comprehensive picture, but the data source experts did not identify other sources that should be examined. If other sources become known and available, they should be incorporated into this database. As with all good data collection, the effort never fully ends, data should be continually re-evaluated and updated as more information becomes available.

Data collection, normalization, and mapping all occurred concurrently as to ensure a complete, auditable, and consistent database of O&S costs for the USCG.

D. Data Mapping

Since the 2014 CAPE O&S CES is the standard CES for O&S cost estimating, the team needed to map the USCG data collected into this structure. Initially, marrying USCG data to the CAPE structure was difficult. Since the USCG data sources were not initially designed to track the overall costs, the data providers had difficulty understanding what the team was trying to accomplish. Figure 8 displays the mapping system for each USCG data source to the CAPE CES structure, which resulted from and was validated through several mapping iterations and discussions with the data providers:

- **FPD**: Because each data line has an object class associated with it, the team was able to map these 500+ object classes to the CAPE structure. These object codes define what was purchased and are entered into the system with the purchase (USCG Financing Center, 2017). The mapping reflects linkages to nearly all CAPE elements.

- **FLS**: Most of these costs are associated with maintenance (CAPE 3.0). However, the USCG helped the team understand which line items were associated with modernization (CAPE 5.0), so the team mapped each line item accordingly.
- **NESSS**: The USCG maintained that all of these costs are associated with maintenance (CAPE 3.0) costs.
- **ISVS**: As previously discussed, these costs are for major modernization events, so all of these costs were mapped to modernization (CAPE 5.0) elements.
- **ALMIS**: Since this data source is similar to FLS, most of these costs were mapped to maintenance (CAPE 3.0), while a few of them were mapped to modernization (CAPE 5.0).

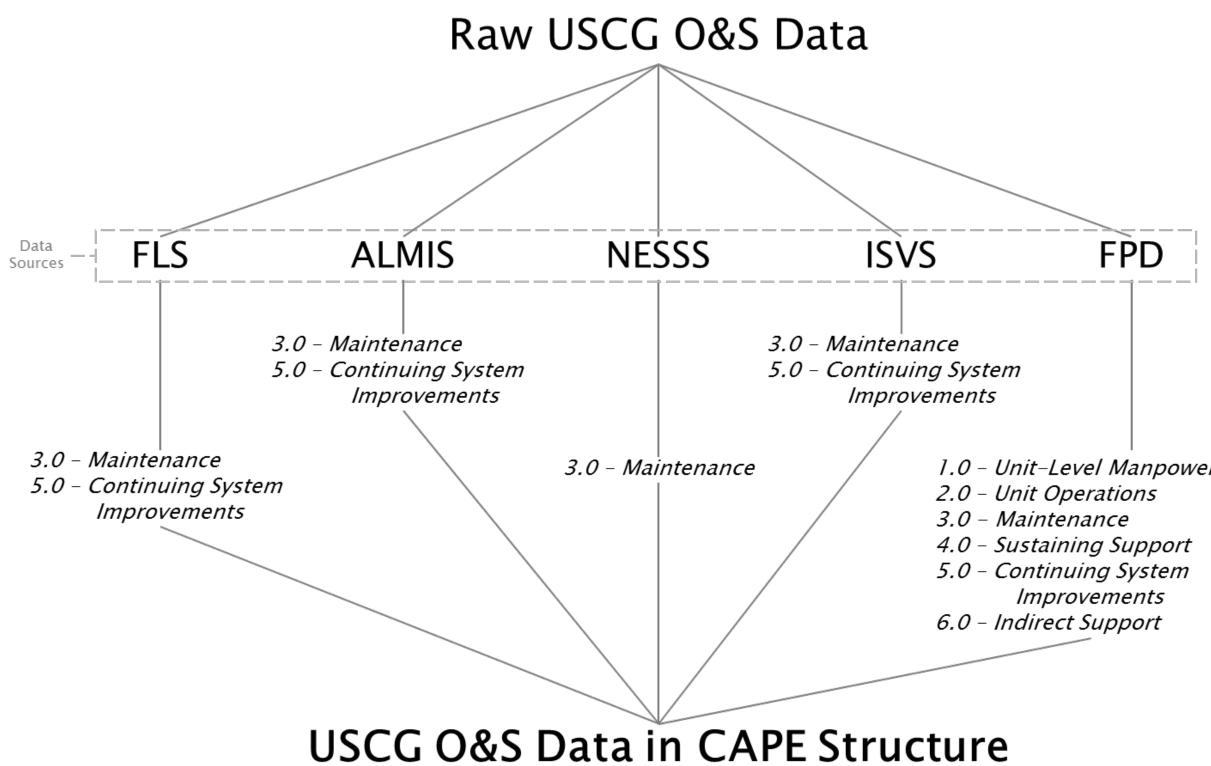

Figure 8: USCG O&S data mapped to the CAPE O&S Cost Element Structure

The team performed each mapping at the lowest level possible; i.e. the lowest level elements of the data sources were mapped to the lowest level CAPE element possible. As discussed in Section VI below, additional validation was performed against Naval VAMOSC data to ensure that each CAPE element was reasonable, as compared to Navy data.

E. Data Normalization

Once the assumptions for each data construct were known (VAMOSC, CAPE O&S, and USCG), the data was normalized to reflect Constant Year 2016 dollars using the Office of the Secretary of Defense Inflation Guidance and the appropriate appropriation index. The USCG normalization followed the same inflation guidance used by Naval VAMOSC and the Navy's O&S Cost Analysis Model (OSCAM).

Additional normalization accounted for technical parameters such as size, weight, and crew size, and programmatic parameters such as the number of hulls in service, technology complexity, and time/age.

F. Data Storage and Automation

Once the team began data collection, it quickly became apparent that both the volume of data provided and the manipulations required exceeded that of what was easily possible in a spreadsheet, such as Microsoft Excel. Therefore, the team selected Microsoft Access to store and manipulate the data. The team designed a relational database with nearly 20 tables; all linked together using primary keys. The team normalized the database to the third normal form of relational databases.

The Access database accepts data in its raw format, so each raw data source can be reproduced from data housed within the database. This also allows for easy updates, such as for incorporation of annual data refreshes, as minimal manipulation is required to import it into the database. It houses the relationships for all mapping, inflation, and rollups, documenting this methodology and making it easy to change. This method preserves traceability back to the original source and allows one to trace a number from its source to its final output.

The queries to produce the outputs in this database are very complex, but they all culminate in a single query output that contains all data sources, the CAPE elements, the class names, hull names, inventory, ship ages, technical data, and constant year dollar outputs. All of these calculations are setup and performed automatically, making extracting normalized new data very easy. The database design allows for this data aggregation and calculation to happen seamlessly and automatically. In fact, the team has linked their spreadsheets to this database and the spreadsheets can update automatically when new data is added. This database has been the key to nearly all data normalization and mapping techniques.

VI. Data Comparisons

Once the team was reasonably confident in a comprehensive dataset across all of the CAPE elements, the data required validation. Since Naval VAMOSC is the gold standard for ship O&S data, it makes for a logical data source for comparison data. Therefore, the team pulled class average data for several Navy combatant classes from VAMOSC that have been active in the last 5 years, as described in Section IV. Hull level data could have been used, but this would have increased the variance and made comparisons more difficult to see. The combatant classes selected have rich datasets with many hulls spanning many years. From the team's experience working with the data, these classes are among the most trusted ship classes in VAMOSC. In addition, these classes are the lightest analogous ship classes and are often used to build estimates for smaller ships.

From the USCG data collected, the team also needed to select data points to use for comparisons. For some ship classes, not many hulls existed, while for others, the class was very new, and for still others, all the ships were very old. Therefore, for the purposes of this paper, the team selected ship classes that had several hulls spanning several years. These classes were the focus of much of the data collection effort.

To illustrate the usefulness of this data, the team selected a notional small ship and the O&S data was used to build an estimate. The referenced notional small ship is a small surface combatant or USCG ship, with a notional small ship weight and appropriate crew size. Both the weight and crew size are smaller than any of the selected VAMOSC data points. This estimate data point is for illustration purposes only and does not reflect a true estimate.

Since the USCG database has been mapped to the CAPE structure and VAMOSC can produce its data in the CAPE structure, all comparisons were performed using the CAPE O&S CES structure. For the purposes of this paper, all comparisons are performed at the 1-digit level, but in the team's analysis, the estimate was performed at lower levels with similar results. All comparisons were performed using $/LT, $/Person, $/Steaming Hour Underway (SHU), or some other top level metric. This is a common ship O&S estimating technique, showcased in the VAMOSC VIEWS and the OSCAM Parametric Cost Tool (PCT). CAPE Element 6.0 (Indirect Support) was not compared, as Naval VAMOSC does not currently contain any data for that element in the Ships Universe.

In addition to testing how the USCG data points compared to the Navy data points, the team was also interested in how the Prediction Intervals would be affected by the additional smaller ship data points.

Therefore, for each comparison, both the Navy and the Navy/USCG prediction bands were calculated and graphed.

A. CAPE 1.0: Unit-Level Manpower

The CAPE 1.0 element is Unit-Level Manpower, containing mostly the costs of the crew and any direct support personnel. Therefore, using the size of the crew as an estimate for the cost of the CAPE 1.0 element is both logical and common practice. Therefore, in Figure 9 below, the Navy (red) and USCG (blue) data points are displayed, with regression lines displayed for both the Navy (red solid line) and the combined dataset (black dashed line). In addition, the prediction bands for both the Navy-only data points (red dotted line) and the combination of the data (gray dotted line) are also shown.

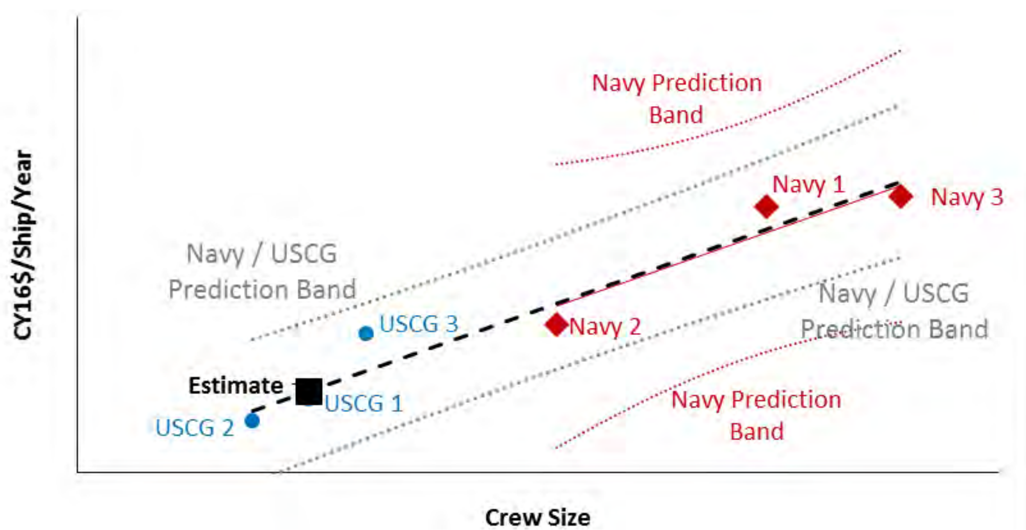

Figure 9: CAPE 1.0 Data Comparison

One can clearly see that the USCG data did not have a substantial impact on the regression line, only changing the estimate point by 2%. The new regression line also has excellent statistics, with an R^2 of 0.99 and a Coefficient of Variation (CV) of 0.15. However, the prediction bands show the significant effect that the USCG data points have on the estimate. At the estimate point, the prediction interval is reduced by 68%. When calculating the uncertainty around the estimate, this is a very significant impact that will translate to a large reduction. After performing this analysis, the team concluded that the USCG dataset is not only extremely comparable to the Naval VAMOSC data, but it can be used to reduce the uncertainty around an estimate of a small ship.

B. CAPE 2.0: Unit Operations

The CAPE 2.0 Element is Unit Operations, which contains Operating Material, Support Services, Temporary Duty, and Transportation. Though CAPE 2.0 contains many different elements, the Fuel cost within Operating Material typically contains most of the costs. Therefore, since the Fuel cost is the cost driver and the size of the ship drives the fuel consumption, the ship's weight was used as a normalization metric for the CAPE 2.0 element. Ship weight (in LT) is often used throughout ship cost estimating to represent the ship's size. Figure 10 below shows a comparison graph with all data points, regressions, and prediction bands displayed.

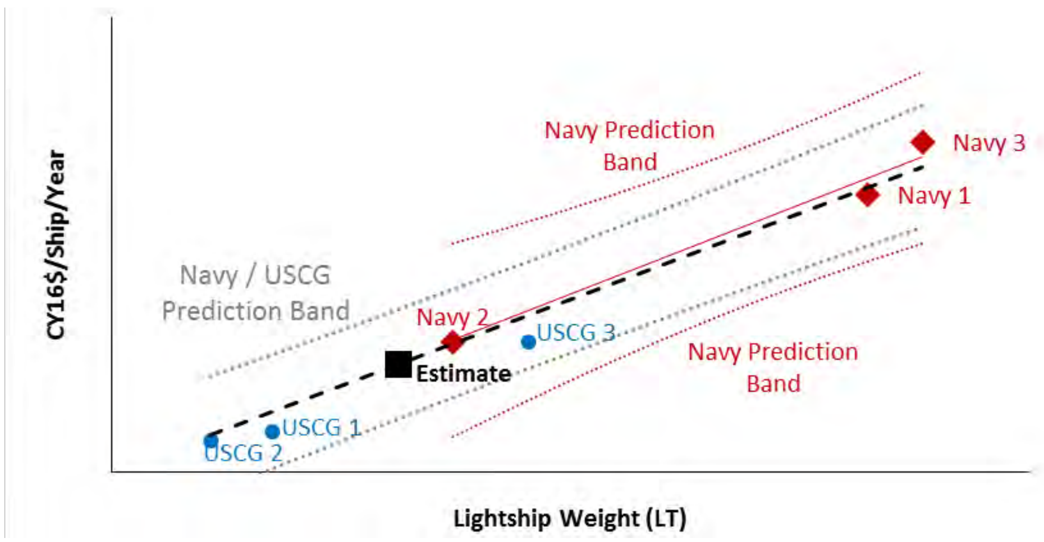

Figure 10: CAPE 2.0 Data Comparison

When the USCG data supplements the Naval VAMOSC data, the regression line does not move significantly, reducing the estimate point by less than 3%. The regression line continues to have excellent statistics, for it has an R^2 of 0.99 and a CV of 0.12. However, at the estimate point, the prediction interval is reduced by 47%, reducing the uncertainty around the estimate. After completing the analysis, the team concluded that the USCG data is comparable to Naval VAMOSC data, and it can be used to reduce the uncertainty around the estimate of a small ship.

C. CAPE 3.0: Maintenance

CAPE 3.0 contains the various maintenance activities associated with ships, and it is logical that the larger the ship is, the more maintenance it will require. Therefore, ship weight was used as a normalization metric for the CAPE 3.0 costs. Figure 11 below shows a comparison graph with all data points, regressions, and prediction bands displayed.

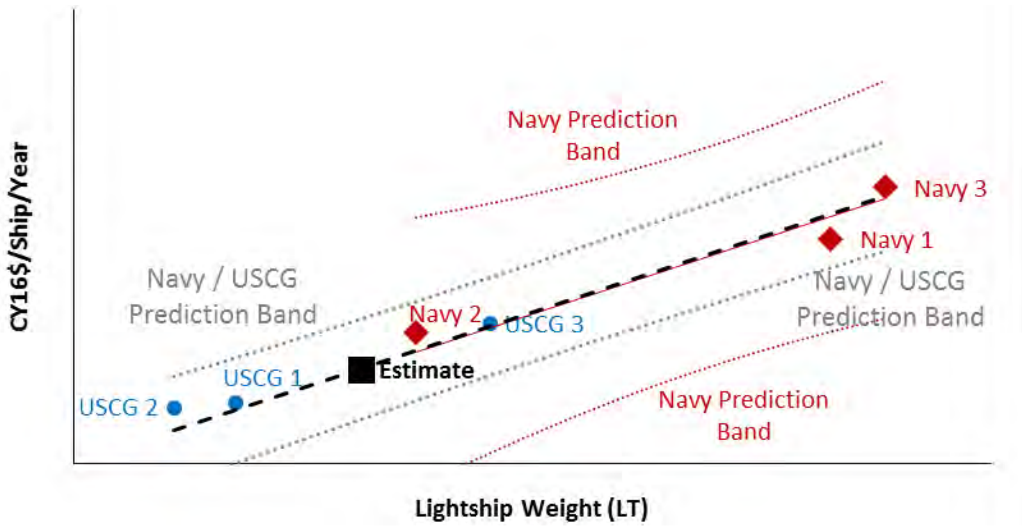

Figure 11: CAPE 3.0 Data Comparison

One can see that supplementing the Navy data with USCG data had minimal impact on the estimate regression, while still maintaining excellent statistics. In fact, the estimate point only increased by 1%, and the regression line had an R^2 of 0.99 and a CV of 0.12. However, when assessing the prediction bands, there was a significant reduction. At the estimate point, the prediction intervals were reduced by 65%, significantly reducing the uncertainty. After completing the analysis, the team concluded that the USCG data is comparable to VAMOSC and can be used to reduce the uncertainty around the estimate of a small ship.

D. CAPE 4.0: Sustaining Support

The CAPE Element 4.0 is Sustaining Support, and it contains Training, Support Equipment Replacement/Repair, Systems Engineering, Program Management, Information Systems, Publications, and Simulator Operations/Repair. Though this seems like many different things, Training is typically the majority of the costs for ships, and the training cost is typically largely driven by the size of the crew. Therefore, the crew size serves as a logical normalization metric for this CAPE Element. Figure 12 below shows both the Navy and USCG data points, with regression lines and prediction bands also displayed.

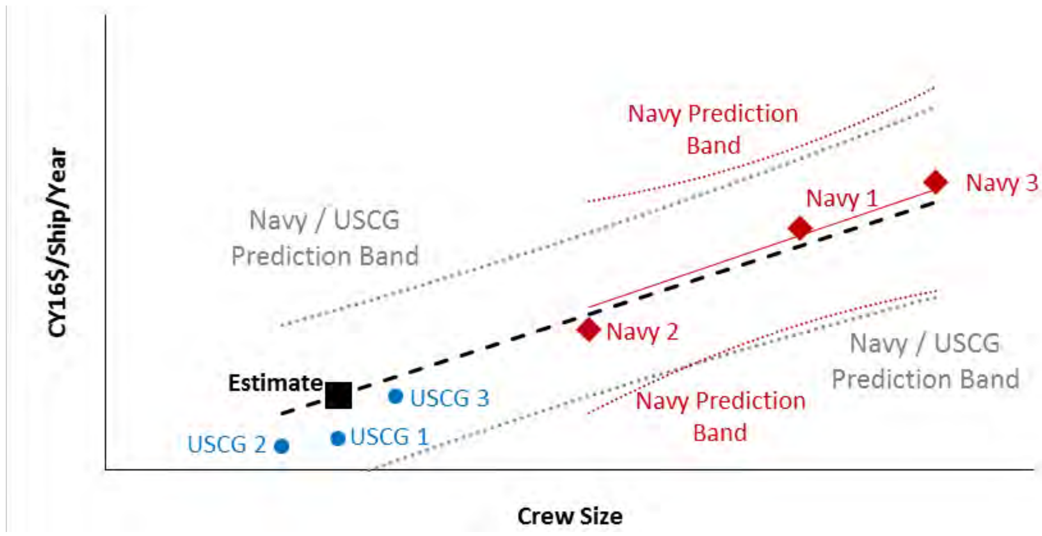

Figure 12: CAPE 4.0 Data Comparison

Once can see that the addition of the USCG data points into the Navy regression slightly reduces the regression line, equating to a 5% reduction at the estimate point. However, the statistics for the regression were still good, with an R^2 of 0.97 and a CV of 0.22. The difference in the regression lines may be due to different training requirements for the USCG verses the Navy. As with previous CAPE elements, the prediction bands were reduced, but they were not reduced as dramatically as other CAPE elements. At the estimate point, the prediction intervals were reduced by 47%. Though not as convincing as other CAPE elements, the team concluded that the data was comparable to VAMOSC data and can reduce the uncertainty of the estimate of a small ship.

E. CAPE 5.0: Continuing System Improvements

The CAPE 5.0 Element is Continuing System Improvements, often referred to as Modernization. It contains both Hardware Modifications and Software Maintenance. Similar to maintenance, it is logical that the larger the ship, the more modernization is required. Therefore, the ship weight was used as a normalization metric to approximate the ship size. Figure 13 below shows a comparison graph with all data points, regressions, and prediction bands displayed.

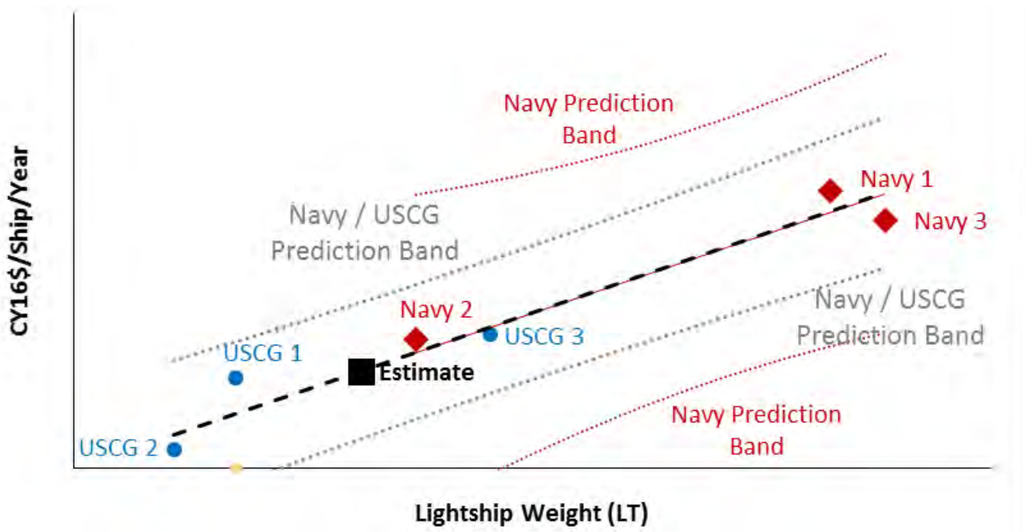

Figure 13: CAPE 5.0 Data Comparison

After examining the graph, one can see that supplementing the Navy data points with USCG data had virtually no effect on the regression line. The Estimate point was reduced by only 0.2%, and the regression R^2 is 0.98 and the CV is 0.16. As with other CAPE elements, the prediction bands were significantly tightened, resulting in a 60% reduction at the estimate point. The team concluded that the USCG dataset is line with VAMOSC, and can be used to reduce the uncertainty around the estimate for a small ship.

VII. Estimate Implications

Since the USCG data collected is likely comprehensive and very comparable to VAMOSC data, it can be used and trusted when building estimates. Though the data can be used to support a wide variety of ship estimates, there are two key areas where it is severely needed: supplementing Navy data for small ships and developing an estimate for a USCG ship.

Throughout the CAPE Element comparisons above, the idea of supplementing Navy data with USCG data was explored. When supplementing the Navy data, the all regressions resulted in good statistics, minimal impact to a small ship estimate point, and significantly reduced the uncertainty around the estimate. However, to take this analysis one step further, the team ran a Monte Carlo simulation using the estimate points and prediction intervals identified in the CAPE elements above. The team ran this simulation using both the Navy regressions and the Navy/USCG combined regressions, each with their associated prediction intervals. In addition, a correlation matrix between 1-digit CAPE elements was derived from VAMOSC data and used as a part of the simulation. Figure 14 below shows the Cumulative Probability

Curves for both simulations at the Estimate (notional small ship) point. The 50% estimates are within 0.1% of each other, but the further one looks from the 50% point, the more the curves diverge. The Navy/USCG combined curve is much tighter than the Navy curve because of the smaller prediction intervals used in the simulation. This results in a 38% reduction of the Coefficient of Variation (CV). Supplementing the Navy data with the USCG data reduces the uncertainty and therefore reduces the estimate when looking at any cumulative probability greater than 50%. Given these telling results, when estimating the costs for a small ship, analysts should look to incorporate USCG data wherever possible.

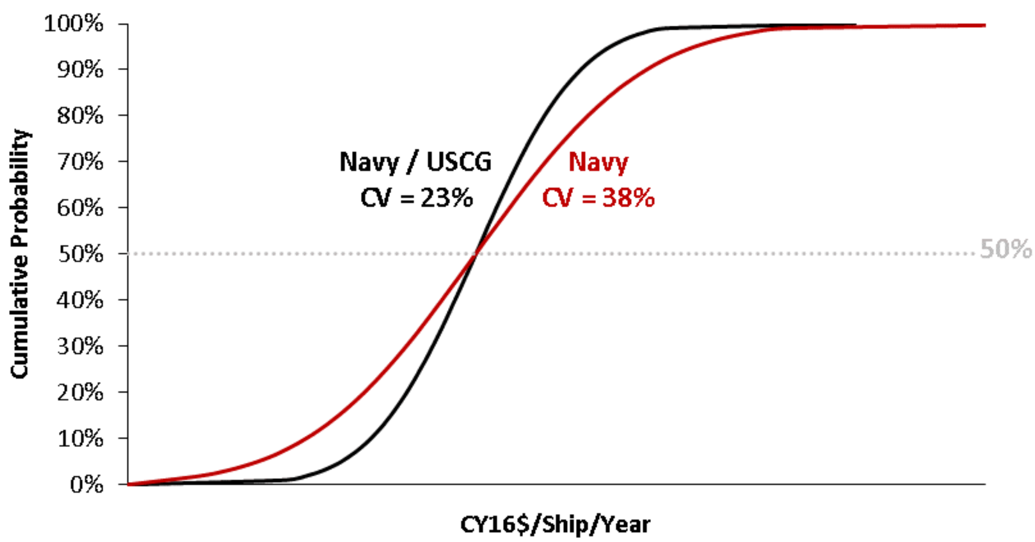

Figure 14: Cumulative Probability Curves for a Navy and Navy/USCG Estimate

The USCG is currently recapitalizing its fleet, with National Security Cutters and Fast Response Cutters currently under construction and Offshore Patrol Cutters in Detail Design, and they are likely in need of defensible O&S cost estimates. Therefore, these and other programs should utilize the USCG data or data sources identified in this paper to build their O&S estimates. This results in a comprehensive and defensible dataset, taking into account any USCG-specific requirements or philosophies. This was not the focus of this paper, but the data sources provided and analysis performed lend themselves to building an estimate based solely on USCG O&S data.

VIII. Conclusions

Supplementation of Naval VAMOSC data with small ship data from the USCG produced a richer dataset with which to build a regression-based estimate for the notional small ship. The case study demonstrated that this USCG data did not significantly change the regression estimates developed solely with Navy data;

meaning that across the O&S elements, the two services have costs largely in-line with each other. Incorporating these additional data points (when working with such small sample sizes), however, did lead to improved measures of statistical fit for the various regressions. More importantly, the USCG data for small ships produced significantly tighter prediction intervals at the notional Estimate point. In terms of a cost estimate for this notional ship, tighter prediction intervals mean less uncertainty in the estimate value, particularly valuable for cumulative probability estimates over 50% where estimated costs exceed the most likely value.

For this case study, the results demonstrate a method for realizing improved estimate confidence for a notional small ship, where incorporating data from another service made the regression sample dataset more representative of small ships. In a broader context, the case study suggests the value of ensuring one's regression sample data bounds the point to be estimated to reduce uncertainty. In addition, the study results reveal the utility of the USCG O&S dataset collected, and how it can serve as a defensible, comprehensive basis for a small ship estimate.

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Appendix A: Acronym List

Acronym	Definition
AC&I	Acquisition, Construction, and Improvements
AFC	Allotment Fund Control
AFTOC	Air Force Total Ownership Cost
ALMIS	Aviation Logistics Management Information System
CAPE	Cost Assessment and Program Evaluation
CES	Cost Element Structure
CG-PART	Coast Guard Parts Availability Research Tool
CM	Configuration Management
CV	Coefficient of Variation
DHS	Department of Homeland Security
FLS	Fleet Logistics System
FPD	Financial Procurement Desktop
FRMM	Financial Resources Management Manual
FY	Fiscal Year
ICEAA	International Cost Estimating and Analysis Association
ISVS	In-Service Vessel Sustainment
IT	Information Technology
LCS	Littoral Combat Ship
LRE	Long Range Enforcer
LT	Long Tons
MEC	Medium Endurance Cutters
MSC	Military Sealift Command
NAVSEA	Naval Sea Systems Command
NCCA	Naval Center for Cost Analysis
NESSS	Naval and Electronics Supply Support System
O&S	Operating and Support
OE	Operating Expenses
OSCAM	Operating and Support Cost Analysis Model
OSD	Office of the Secretary of Defense
OSMIS	Operating and Support Management Information System
PB	Patrol Boats
PCT	Parametric Cost Tool
RHIB	Rigid-Hulled Inflatable Boat
RM	Requisition Management
SCN	Shipbuilding Conversion, Navy
SFLC	Surface Forces Logistics Center
SHU	Steaming Hour Underway
SLEP	Service Life Extension Program
SSC	Small Surface Combatant
US	United States
USCG	United States Coast Guard
USMC	United States Marine Corps
VAMOSC	Visibility and Management of Operating and Support Cost