The Navy Modernization Program:
Estimating the Cost of Upgrading AEGIS Guided Missile Cruisers

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Abstract

The Navy is well into its 20 year, $16B (CY10$) plan to modernize 84 AEGIS warships[1]. This cost estimate covers eleven of the planned ships and accounts for maintenance and upgrades to the ship and the combat systems. The estimate leverages recent contract and shipyard performance data and interviews with engineers, resulting in a detailed study and recommended cost savings initiatives. The methods and data in this estimate will assist ship modernization cost efforts across the fleet for the foreseeable future.

[1] http://www.history.navy.mil/library/online/aegis_background.htm

Background

The Department of the Navy is recently faced with the challenge of providing a Hull, Mechanical, and Electrical (HM&E) Mid-Life Extension (MLE) maintenance program and a Combat System (CS) Modernization to eleven aging CG 47 class AEGIS Cruisers. Typically the HM&E MLE and CS Modernization would happen in distinctly separate availabilities. However, with the budget constraints the Navy is facing, an idea was proposed to induct all eleven cruisers by taking them out of the fleet and providing sustainment engineering services, an HM&E MLE, and a combat system modernization to two ships at a time in a single extended availability. In theory the Navy would save money by generating efficiencies as a result of performing each set of availabilities back to back and by taking the ships out of the fleet, saving the cost of the crew and other O&S costs. PMS 400F, the division of NAVSEA 21 that oversees the modernization of AEGIS Destroyers and Cruisers, tasked NAVSEA 05C to develop a cost estimate for the previously described extended availability.

To get a full scope of the cost estimate, the analysts needed to account for induction/assessment, sustainment, HM&E MLE, and CS Modernization. This is the first formal estimate done by NAVSEA 05C for the CS Modernization Program. The team was given a three month time frame to obtain and analyze the data, develop the cost estimate, and report our findings. The estimate was completed by two teams working in parallel; one team worked on the CS Modernization estimate, the other on the HM&E MLE estimate. For each phase of the extended availability, the authors will detail the process by which the cost estimate was developed to include scope, data collection, assumptions, methodology, calculations, and summary results.

Induction

The first portion of the cost estimate is induction phase. This phase occurs twice per ship, once just before the HM&E MLE and again just prior to the CS Modernization. The schedule was based on assumptions by PMS 400F for how the future induction could take place given available information at this point in time. It defined an HM&E induction occurring between three months to two years prior to the start of the MLE phase, and a CS induction occurring roughly six months prior to the start of the CS Modernization phase. During these inductions, a crew goes onboard the ship to identify and document all the repairs that are needed for the ship. Surface Maintenance Engineering Planning Program (SURFMEPP) has done analysis and developed an estimate, measured in man-days, of the time required to perform each induction. The analysts calculated the induction estimate by multiplying the man-day requirement by the appropriate industry labor rates.

Sustainment

Following the induction phase, the ship enters sustainment. The sustainment phase was defined as a time period during which engineers board the empty ship and perform occasional checks to ensure that the vessel has not endured additional damage or maintenance concerns, such as checking for leaks, and any other deterioration due to lack of use, since the induction phase. During this time frame, everything onboard is turned off except for essential systems. As with the induction phase, there are two sustainment phases per ship, one prior to the HM&E MLE and one prior to the CS Modernization. Based on the schedule provided by SEA 21, a sustainment phase prior to the HM&E MLE can range from zero to two years (ideally the first ship will not require a sustainment phase and will go directly to the HM&E MLE after induction). The schedule also defined the sustainment period prior to the CS Modernization phase, and after the HM&E MLE phase, can range between three months and five and half years. Much like induction, SURFMEPP did analysis and provided an estimate, in man-days, of the time required annually for each ship's sustainment period. The analysts calculated the sustainment estimate by multiplying the man-day requirement by the appropriate industry labor rates.

HM&E Modernization

The HM&E MLE occurs after the first induction/sustainment phases but prior to the CS modernization. It is roughly one year long and followed by another induction and sustainment period prior to the CS Modernization. Within the HM&E MLE, the cost estimate needed to be further broken out to address the cost of the specific alterations, maintenance, dockside support, advanced planning (AP), Design Services Agent (DSA), and long lead time material (LLTM). An understanding of all the segments that go into the HM&E MLE at what times is crucial to capturing the full scope. Long lead time material costs are expended two years prior to each of the HM&E availabilities. Advanced Planning costs are captured a year prior to each of the HM&E availabilities. Design Services Agent costs are phased over several years beginning two years prior to the HM&E MLE.

Data Collection

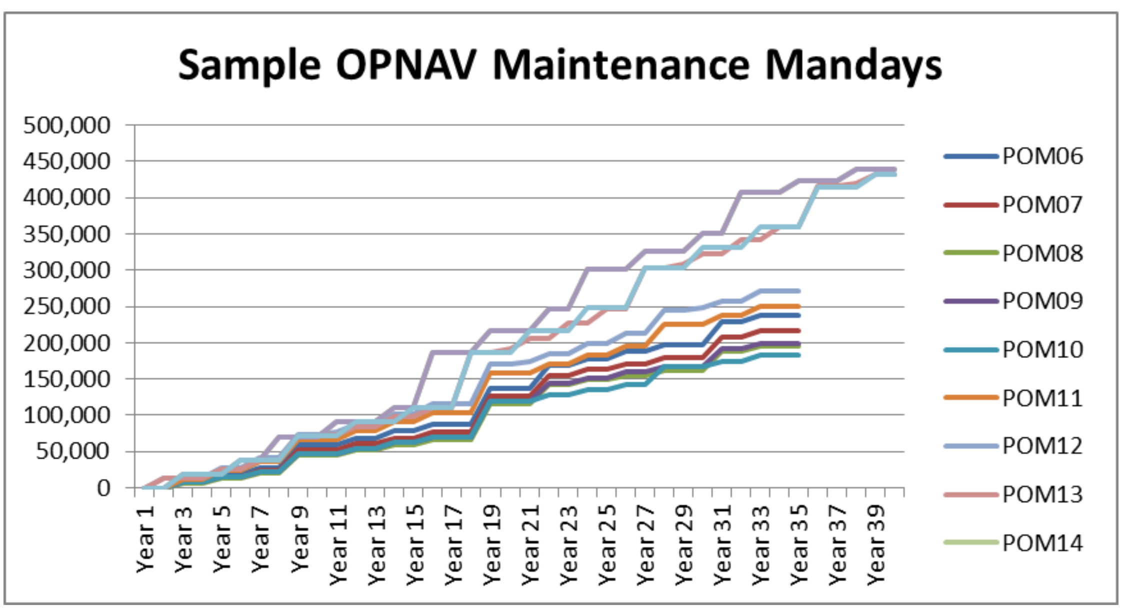
To determine where to obtain the data needed to estimate this effort, the team sorted through a variety of contractor and Government cost reports, including execution plans, Cost and Schedule Status Reports (CSSR), shipyard proposals, and results of SURFMEPP analysis. Execution plans were analyzed to identify and obtain DSA and LLTM costs. These plans contained the costs over past availabilities by ship alteration. CSSRs and shipyard proposals were gathered to capture the full cost of each ship alteration. Much like induction and sustainment, the results of the SURFMEPP man-day analysis was used for estimating the maintenance cost for the HM&E MLE. Each of the maintenance activities was different between each ship as a result of the different ages and the state of disrepair. PMS 400F provided the basic list of required alterations and maintenance activities for the HM&E MLE. Using this list, the team analyzed execution plans, CSSRs, and shipyard proposals. SURFMEPP was provided with the same list to conduct their analysis for maintenance requirements for the HM&E MLE. PMS 400F also provided a list of items considered part of dockside support which is also a component of the HM&E MLE estimate.

During the HM&E MLE analysis, the team obtained 14 different Cost and Schedule Status Reports (CSSR) from PMS 400F and used those numbers as analogous costs. These CSSRs came from shipyards in San Diego, Norfolk, and Pearl Harbor. The team analyzed the CSSR data and incorporated the range of costs and labor hours associated with the ship alterations completed at the various shipyards. Each CSSR contained hundreds of lines and required the team to thoroughly analyze and locate the specific alterations that would be required for each of the eleven ships. One of the challenges the analysts encountered was that each ship required different alterations. Additionally, the team found that the CSSRs were not all formatted the same way. Some of the CSSRs listed the ship alteration numbers while others listed full or partial description names in lieu of alteration numbers. The CSSRs did provide the team with historical actuals for labor hours, material dollars, and subcontractor costs for each ship alteration.

Assumptions

One of the most important assumptions used in the HM&E MLE cost estimate is that there is no further scope needed outside of the data available to us. It is important to understand that there is no way to accurately predict the maintenance and SHIPALT requirements prior to performing a ship assessment. The team also assumed that advanced planning is a fixed percentage of the total HM&E MLE effort. This assumption is evident in past HM&E MLE availabilities and is not controversial. The team assumed that none of the ship alterations require LLTM other than the ones that have been procured in past availabilities. For HM&E MLE ship alterations, the different CSSRs and the range captures the variability of how much and how long it would take for each of the ship alterations. Within each of the CSSRs, it is further broken out in labor, material, and subcontractor costs. An assumption is made that the total subcontractor costs also include both labor and material cost and that the ratio is analogous to what was observed for the prime contractor. Another assumption is that all ship alterations will be completed during the HM&E MLE phase of the program. In other words, the HM&E MLE schedule will not be extended to accommodate work that is not completed within the allotted schedule. For ship maintenance, the shipyard will conduct the amount of maintenance possible during the HM&E MLE schedule, which could result in more or less maintenance then initially estimated by SURFMEPP. As shown in Figure 1 below, the number of man-days for maintenance is estimated each year for the Program Objective Memorandum (POM). Future maintenance estimates show a trend to be higher each subsequent review. This is a due to maintenance activities not being completed during their scheduled year or being deferred due to budget or operational concerns.

Figure 1: CG 47 POM Maintenance Mandays Estimates



Methodology and Calculations

HM&E MLE included AP, DSA, and LLTM. AP was calculated as a percentage of each ship alteration labor man-days in the HM&E MLE. This included the man-days derived from the subcontractor costs in which the ratio of labor and material costs incurred by the shipyard was the same ratio incurred by the subcontractors. LLTM and DSA costs were obtained from the execution plans associated with previously completed HM&E MLE availabilities. These plans were analyzed and costs associated with the each ship alteration were averaged together. The average became the point estimate. The highest and lowest costs associated with each ship alteration were used to bound the risk analysis. This process allowed the team to account for differences between the average and the actuals.

After analyzing all 14 CSSR files, the team identified an analogous cost for each alteration, which had a range of up to seven data points. For the alterations that did not have any data points, the team used information from PMS 400F SME interviews to develop a cost estimate. For the alterations that we returned only one data point, as seen below in Figure 2: Example of a Single Data Point, the team used the one data point as an analogous cost. For the alterations that returned multiple data points, as seen below in Figure 3: Example of Multiple Data Points, the team calculated the average cost and applied risk around this value. This process was implemented for all data sets including labor, subcontractor and material costs. Ultimately, risk analysis was conducted on the labor hours, material dollars, and subcontractor costs to account for variations between shipyards and across individual ships.

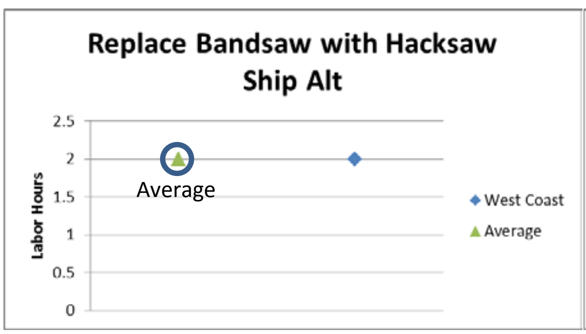


Figure 2: Example of a Single Data Point

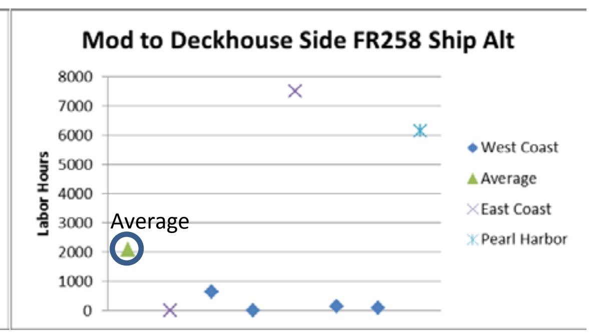


Figure 3: Example of Multiple Data Points

One particular challenging cost element worth discussion was the repair to the ship superstructure. Past availabilities included repairs to the ship superstructure; however, they were not done to the same magnitude that is required for the eleven ships being analyzed. The ships being analyzed required repairs to fatigue and cracking that is occurring to much larger sections of the superstructure of these ships. The previous availabilities required repairs to only small portions of the superstructure. To estimate the cost of this work package, the team analyzed proposals that were submitted by industry. PMS 400F maintained an internal not-to-exceed value for the superstructure alterations.

Other items that were part of the HM&E MLE cost estimate included maintenance and support efforts. The team had to estimate the scheduled maintenance that is required during the HM&E MLE. The team used the results from the SURFMEPP man-day analysis for each of the ships and calculated the cost by multiplying the man-day requirement by the appropriate labor rate. For dockside support costs, PMS

400F provided the team with a list of requirements. The team analyzed the CSSRs to identify line items related to the support requirements described by PMS 400F. Several different methodologies were developed to account for the range of potential work scope, and the results of that analysis are included in Figure 4.

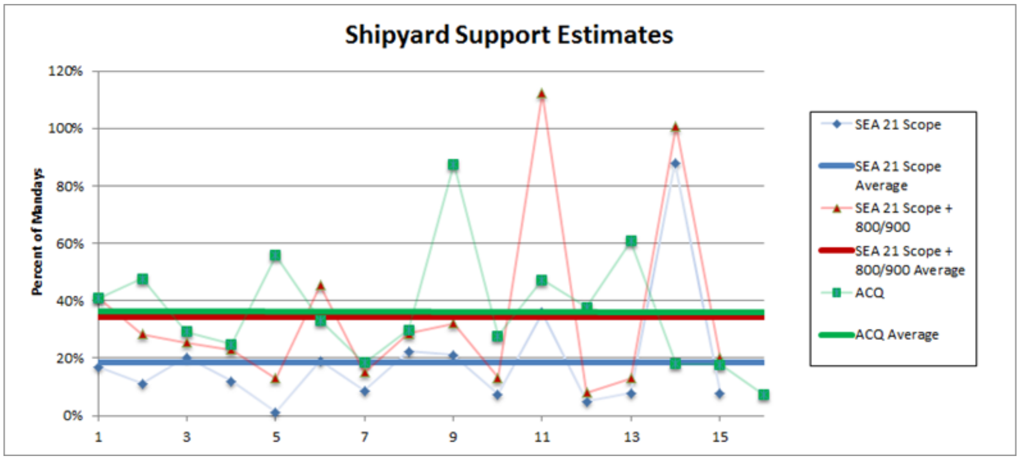


Figure 4: Support Level of Effort Estimates

Combat System Modernization

The AEGIS Modernization Program is the upgrade and overhaul of the AEGIS Combat System on AEGIS surface combatants. Each ship that receives a modernization is upgraded to the current AEGIS baseline at the time of the upgrade. Because each ship may enter the modernization from a different starting baseline as well as from different maintenance perspectives, each modernization has both unique and common work packages.

Scope of CS Estimate

Defining the scope of the modernization estimate turned out to be a particular challenge, not because there were no documents defining the technical baseline, but because as a cost estimator, the analysts were not particularly familiar with the technical documents that were being provided and didn't understand how to get the required information from them. Ultimately, the technical team was able to point us to the Capabilities Definition Document (CDD) which, in the case of the CG 47 class, details the combat system elements and their integration. The CDD includes not only a system list, but descriptions of the various systems, as well as diagrams outlining the interconnectivity. The cost estimating team had the opportunity to interview the PMS 400F baseline manager to validate the specific systems in the CDD that are being upgraded and/or replaced. As a result of this meeting, the systems in the below table were identified as upgrades or new installations.

Table I: CG 47 Class Systems for modernization

AEGIS Weapon System (AWS)	MK 34 Gun Weapon System (GWS)	SQQ-89 Sonar System	SPQ-9B Radar

Cooperative Engagement Capability (CEC)	MK 41 Vertical Launch System (VLS)	Internal Communications (ICOMM)	Light Airborne Multipurpose System (LAMPS)
Battleforce Tactical Trainer (BFTT)	Moriah Wind System	SPA 25H Indicator Group	CKT 16 TV

In addition to procurement of the above systems, the modernization estimate includes cost for the Combat System Engineering Agent (CSEA) services who support systems integration and the Design Services Agent (DSA) who develops the ship installation drawings (SIDs) and technical data packages (TDPs) for each ship. These engineering services are critical to the planning process associated with each modernization to ensure the rip-out, installation, and test programs are successful.

The next stop in the modernization is the rip-out of old equipment and the installation of the new equipment. This scope of the rip-out and installation is guided by the systems being upgraded, but ultimately defined in the Request for Proposal that will go out to industry. Once the installation is complete, the ship will undergo sea trials testing and the Combat System Ship Qualification Test (CSSQT) before finally being returned to the fleet.

Data Collection

The first pieces of data that were immediately available were Form 7300s and Task Planning Sheets (TPSs). The Form 7300 is a means for compiling and consolidating cost estimates for new construction ships utilizing a common work breakdown structure. Though the estimate was for the modernization of existing CG 47 class ships, the Form 7300s for the DDG 51 class destroyers provided a starting point for prioritizing the systems. The TPSs gave us additional insight because they told us by system what PMS 400F was budgeting for each system, including both the unit cost and the Government support costs, including program management, systems engineering, technical engineering support, installation and checkout (w/spares), integrated logistics support, and test and evaluation. The TPSs are submitted by the Participating Acquisition Resource Managers (PARMs) for each system. There is one TPS for each performer for each system. The TPSs provide a detailed statement of work broken into major tasks and subtasks and include a program office cost estimate and FTE requirement for each subtask. The scope and FTE requirements in the TPSs provide estimators with technical baseline necessary for estimating engineering services.

The next step in the data collection process was to start pulling historical contracts for hardware procurement. With the help of the PARMs, the team was able to pull contract awards for eight of the twelve systems. Of the remaining four, one has a NAVSEA 05C approved life cycle cost estimate which includes modernization upgrade kits and the other three are valued at $500k or less and did not require a detailed estimate; the budgeted amounts were acceptable for these systems. The team analyzed the contracts to understand the CLIN structure. In many cases, the team found that the contract CLINs not only identified the components as forward-fit or back-fit systems, but occasionally they even specified the hull number for which the system was being procured.

Once the contracts, TPSs, and 7300s were analyzed and sorted by system, the team was able to make comparisons to further understand the scope associated with each procurement. Where there were significant differences between costs in each of these analyses, the team approached the procuring PARM to learn more about the system and the cost differences. This analysis allowed the estimators to understand changes in the program or differences in scope that might not be obvious on paper. One clear example of this is the GWS procurement. The Form 7300s and TPSs were somewhat consistent, however the most recent contract award was noticeably less than both. After much discussion with the PARM, the estimators learned that of two important facts surrounding the system procurement. First, that the Prime contractor was undergoing overhead rate changes that were unforeseen and unpreventable and second, that there was a major system component that was previous provided as Government Furnished Material (GFM), but which currently is being fabricated by the prime contractor. Without the described analysis, any single piece of data would have led to an inaccurate estimate, even though on paper there would have been nothing amiss.

With the procurements understood, the next step in the data collection process involved the CSEA and DSA support. Since these Government support activities are annual fixed costs to the program the best source of information available were the TPSs. This analysis provided the scope and FTE requirements for both work packages.

The next step in the data collection process was to understand the rip-out and installation costs for the effort. For this, we were able to collect to recent Contractor Performance Reports (CPRs) for the modernization efforts of the two most recent CG 47 ships to go through a modernization program. Each of the system upgrades is associated with an approved Ordinance Alteration (ORDALT) which in turn is linked to a specific work package in the CPR. With the help of the PMS 400F program management team, the estimators were able to obtain copies of the ORDALTs and trace them to the CPR work packages. The estimators found that the scope and cost of the most recent modernizations were similar and therefore used the most recent of the two contracts as the basis for estimating the rip-out and installation cost of the planned modernizations.

Lastly, data was needed to support sea trials and CSSQT test events. For sea trial testing, PEO IWS 1.0 provided a study that was conducted with the support of the AEGIS Test Manager in NSWC Norfolk which identified the list of test procedures required for a baseline 9C modernization effort and the hours associated with each test procedure, as well as the hours required for the oversight and management of the test team. For CSSQT events, TPSs were sufficient to describe the scope and FTE requirements. Since CSSQT events are custom for every ship, the planning data in the TPSs were the best data available, though they did present a particular cost risk. Please refer to Figure 5 for the distribution of the data collected across each category.

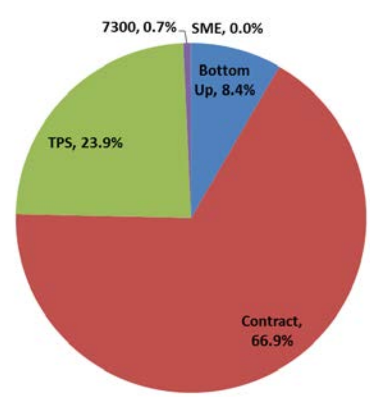


Figure 5: Data by Category

Assumptions

The estimate assumes that contract prices are consistent with future prices of the same systems. The disadvantage of using contract awards is that they give no insight into system engineering, program management, factory testing, or other engineering services. Without CPRs, it's difficult to ascertain whether or not costs are inflated by heavy program management and engineering services. However the advantage of contract values is that they are "all-inclusive" sell prices. They are easy to understand, packed up with scope statements, and easy to analyze. Additionally they are typically reflective of what the Government actually paid as it is rare for a contractor to underrun their contract unless they are incentivized to do so with bonus fees. If an estimator were to assume that the contract acquisition process correctly controlled for engineering and program management services as well as fee either via a competitive award or a negotiated sole source award, then the contract price assumption is not unreasonable.

For system procurement, the cost estimate assumes that actual costs are 30% below the Form 7300 value. This is based on historical analysis of other systems. The inference is that Form 7300s carry very little risk and are assumed to be at or above the 80th percentile of the risk curve. The 30% reduction presumes to bring the cost near the 50/50 value on the risk curve. This assumption is applicable to only two systems, the Moriah Wind System and the SPA-25H Indicator Group. Both systems are valued at ~$500k.

In computing installation costs, we assume that the most recent CG 47 modernization installation costs are reflective of the future modernization costs. This is not unreasonable because the most recent CG 47 modernization cost was an upgrade to baseline 9C just as the future CG 47 modernizations are planned to be. Further, the installation work packages are consistent with the installations planned for and validated by the ORDALT packages and CDD for the future CG 47 modernizations. We further assume that the prime contractor fee for the modernization effort is 10%. This is consistent with historical competitive contract awards. Finally, we assume that installation support costs are 20% below the TPS values. This assumption follows the same line of reasoning as the previously discussed Form 7300 assumption. The estimators believe there is little risk factored into the TPSs values and they are representative of the 70% or higher point on the risk curve. Decreasing these values by 20% brings the cost in line with a 50/50 value.

For sea trial tests and CSSQT test events, we assume the prime contractor's future pricing rate agreement (FPRA) on file is consistent with the future labor rates for this contractor. A labor rate assumption is necessary to compute the engineering services cost associated with the test events and, since this rate has been evaluated by the Defense Contracting Auditing Agency (DCAA), it seems to be the most reasonable.

Specific to the AEGIS Computing Plant upgrade, we assume that Advanced Capability Build (ACB) 12 is representative of the procurement, installation, and test cost of ACB 16 and ACB 20. Since the procurement, installation, and test is related to the hardware components, and the hardware components are primarily computer processors and related parts, we believe this assumption to be reasonable.

Finally, there are several assumptions associated with the risk calculations. First we assume the sample populations are bounded at the 10^{th} percentile by an amount which is 20% below the point estimate. Second, we assume the sample populations are bounded at the 90^{th} percentile by an amount which is the greater of 10% above the point estimate or 5% above the program office estimate. Since this is the first combat system modernization effort, there is a lack of risk data which is readily available to the estimators. The boundaries that were chosen are consistent with other system estimates that have been conducted by NAVSEA 05C. Finally, a 30% correlation is assumed between all of the inputs to the risk calculation. This is consistent with previous NAVSEA 05C estimates. Further it is reasonable to expect that any true risk parameters that have an impact on one component of the estimate could have spill over effects to other components of the estimate. For example, if procurement costs increase due to a failed factory test, which causes delivery to slide to the right, then installation could also slide to the right, which can impact the installation schedule and cause installation costs to increase.

Methodology

Most of the procurement costs are estimated based on historical actuals, in so far as we assume that contract prices are reflective of actual costs plus fee. For two systems, Moriah Wind System and SPA-25H Indicator Group, the estimate are estimated from an engineering build up, where the data sources are SME inputs as reflected in the Form 7300. The CEC estimate is created from extrapolation from historical actuals. As previously mentioned, the CEC system has an approved SEA 05C life cycle cost estimate which is based on historical actual costs from CPRs. Finally, the CKT-16TV costs are engineering build up based on SME input.

CSEA and DSA costs are based on engineering build up from FTEs as stated in the TPSs.

Installation costs are based on analogy to the most recent CG 47 modernization installation.

Sea trials and CSSQT test events are based on engineering build up from FTE inputs.

Calculations

<u>Procurement</u>

Combat System procurement costs were broken down into two major categories – prime contractor and Government support costs. The prime contractor costs were calculated by identifying the relevant CLINs in the most recent contract award and summing the obligations for these CLINs. Each of the contracts is structured differently. In some cases the contractor's program management and engineering services were identified on separate CLINs. In other cases, a single CLIN represented all of the contractor's cost (inclusive of fee, program management, and engineering/ILS support) to deliver a complete system to the ship. As previously mentioned, we assume the sum of the amounts awarded in the contract are representative of all of the prime contractors cost and fee. Gov't support costs were calculated by multiplying the FTEs by the labor rates for each performer for each system. The FTE requirements were provided by the program offices. A summary of relative procurement cost can be found in Figure 6 below.

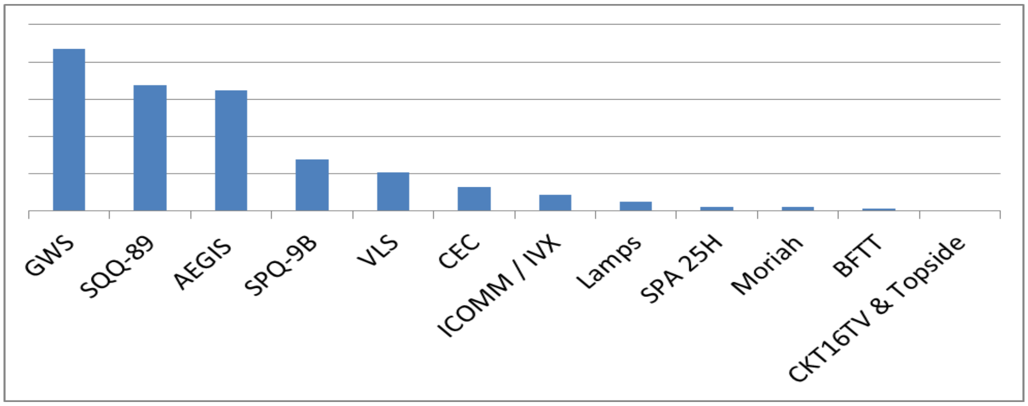


Figure 6: Relative Procurement Cost

<u>Engineering Support Services</u>

Engineering Support Services costs were computed by multiplying the FTE requirement by the labor rate for each performer.

<u>DSA Services</u>

DSA Services costs were calculated by inflating the DSA Services costs that were obligated for previous CG modernization efforts.

<u>Installation</u>

Installation costs were calculated by inflating the installation costs for each system from the CG 62 installation cost report from the prime contractor. Each work package was identified discretely in the cost report, resulting in a straight forward calculation.

<u>Ship Integration and Test</u>

Ship Integration and Test costs were calculated by multiplying the FTE requirement by the labor rate for each performer.

<u>Risk Analysis</u>

Risk analysis was performed with Monte Carlo simulation utilizing 10,000 iterations. An S-Curve and tornado chart was developed to display the risk results.

Summary Results

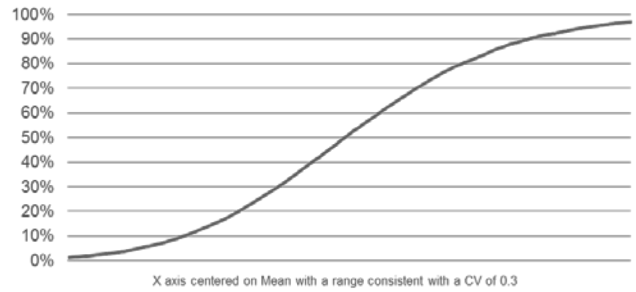


Figure 7: Risk Curve

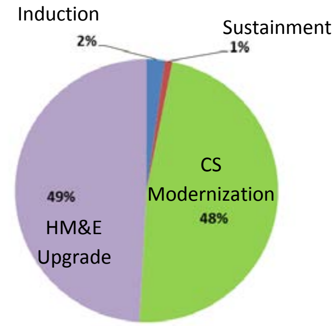


Figure 8: Distribution of Cost by WBS Category

Conclusion

Although this effort only took three months to complete, there are significant lessons to be learned. The analysis brought up the concept of competition and/or economic order quantity (EOQ) as a means of controlling future HM&E MLE and CS Modernization costs. Though these concepts are common place in cost estimating, these acquisition strategies have not been analyzed for potential cost savings to the PMS 400F community. The team also evaluated the effects of a learning curve on alterations that are the same across ship availabilities. There are some challenges associated with implementing EOQs and competition based strategies in the CG 47 modernization program. The EOQ method becomes logistically prohibitive due to the shipyards not having sufficient space to store materials. Competition is likely to have limited impact as only certain shipyards have the capacity and abilities to perform the availability.

The team believes that with more time and further analysis there could be a methodology proposed to better estimate the availabilities. The team believes that additional data on the CSSRs being analyzed, and other alterations not being specifically analyzed would provide a more complete overview of the labor and material cost swings and provide a better risk factor for the alterations. In conclusion, developing a credible, defensible, and repeatable cost estimate for these eleven CG 47 class modernizations is possible. Using cost estimators early to generate availability estimates could provide an advantage to the Government for developing contracting strategies for future availabilities. This could also allow the Government additional leverage during negotiations due to the use of existing historical data as a basis for the estimate. Additionally, if more ship availabilities are planned to occur back to back, the cost estimators may be able to leverage learning curve analysis for specific shipyards since they would have a better assessment of future work that would allow for skilled employee retention. The methodologies developed while estimating availabilities will allow the Government to become more aware of the driving factors of cost increases beyond normal inflation. With further refinement and continued research, estimating availabilities can be a new area for cost estimation that will propagate and provide the Government with additional information to guide future decisions.