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Forecasting DoD Mid-Acquisition Space Program Final Costs Using WBS Level 2 and 3 Data

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THESIS

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Abstract

Predicting Estimates at Complete (EAC) for Department of Defense (DoD) space programs has proven to be a daunting task. Although the use of Earned Value Management (EVM) formulations have been around for several decades, research has validated the need to conduct specific investigations based on commodity type and contract completion percentage. A recent Air Force Cost Analysis Agency (AFCAA) study improved space program EAC accuracy using a Budgeted Cost of Work Performed (BCWP) model. This research was conducted based exclusively on program level Work Breakdown Structure (WBS) data. The DoD requires contractors to report lower level WBS data, and current guidance supports the notion that lower level data are useful for program analysis. This study assesses the BCWP model using lower level WBS data. In addition, the second phase of this research investigates whether or not knowledge concerning lower level WBS activities can improve the analytical ability to predict EAC cost growth. The results indicate that lower level WBS data does not improve space program EAC accuracy in combination with the BCWP model. This research also finds that space programs contain a great deal of variability at lower level WBS activities making it difficult to draw comparisons across contracts.

Acknowledgments

I would like to first give all the glory to the Great Architect of the Universe, God All Mighty. Next, I would like to thank my family who has stuck by my side every second along the way. Lastly I would like to thank my educational advisors, whose guidance helped me throughout each step of this research effort.

Rey A. Heron

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FORECASTING DOD MID-ACQUISITION SPACE PROGRAM FINAL COSTS USING WBS LEVEL 2 AND 3 DATA

I. Introduction

General Issue

In today's ever-changing fiscal climate, the one aspect that can be assured is that Department of Defense (DoD) major acquisition programs will need to be procured at cheaper costs and with more efficient methods. Cost estimating is one avenue of the DoD that is becoming more important as funding limitations continue to rise. The ability to predict final program cost estimates is an essential element in today's planning for tomorrow's future. Space acquisition programs are no exception to this notion, as they continue to experience "billions of dollars in cost increases, stretched schedules, and increased technical risks" (Government Accountability Office [GAO], 2011).

Within the DoD, declining budgets and the propensity for underestimation have an inverse relationship; that is, as budgets continue to decline, the propensity for underestimating continues to grow. Programs that are traditionally funded at sufficient levels will see even more scrutiny of their annual targets, and as a result, competition for funding ensues. This idea of competing for funding incentivizes the notion of bringing forth the lowest revised cost estimate, which may not necessarily be the most reasonable one (GAO, 2006). Although several factors, in addition to this incentive, are typically the cause of underestimating, poor cost estimating and prediction techniques continue to be a recurring area of concern.

Problem Statement

Earned value management (EVM) techniques for predicting final program costs have been used for nearly half a century, yet space systems acquisition continues to observe areas of extreme cost growth – nearly 230 percent in one recent GAO study (GAO, 2013). The preeminent problem lies in the inability to accurately predict final space program costs; this problem results in excessive cost growth and cost overruns. In the realm of space acquisition programs, little research has been accomplished to examine alternative methods to estimating final program costs (Rusnock, 2008). Although the techniques for calculating final program costs have evolved over time, the basic premise remains the same. This premise attempts to use current data to predict future final costs. The calculated cost is known as the program's Estimate at Complete (EAC). The EAC value provides pertinent information that decision makers require to make funding decisions for an acquisition program. In situations where the initial EAC value is underestimated, a funding gap develops between what was budgeted for a program and what the program currently requires. The magnitude of this gap is imperative, as the "affordability of a single program can affect the affordability of the entire portfolio of systems" (Keaton, 2013).

Reasonableness, within the DoD, is often described as the "price that a prudent businessperson would pay for an item or service under competitive market conditions" (Defense Acquisition University [DAU], 2009). Reasonableness, specifically in terms of cost estimating, can be perceived as how well an estimate takes into account all known data at the time the estimate is prepared. The EAC is used to forecast final program costs using the latest available performance data; however, an EAC's reasonableness might be valid for only a finite period of time. As highlighted in one 2006 GAO study, it is possible for space programs to continue for up to four years without an update to the program's final cost estimates. In that timeframe, a program may see numerous changes that have substantial impacts on cost. Some of these changes include "changes in planned quantities, funding instability, design changes, quality variances resulting from rework, manufacturing or engineering changes, changes in supply chain and logistics management and support, [and] technology-related problems" (GAO, 2006). As a result of this reasonableness paradigm, Air Force policy requires major defense acquisition programs to update their cost estimates at least annually (AFI65-508, 2012).

Due to the importance of developing accurate EAC figures, cost analysts at the Air Force Cost Analysis Agency (AFCAA) conducted a study to improve the accuracy of EACs for space programs that are midway through their acquisition lifecycles. The results of the study demonstrated that EACs could be improved by approximately 15% over the span representing the 20%-70% completion levels (Keaton, 2013). This accuracy improvement is measured in comparison to the status quo EVM "Gold Card" approach. Due to time and resource constraints, research was not conducted beyond the Work Breakdown Structure (WBS) program level, and AFCAA determined that further research would be needed to determine the full extent of how much EACs could be improved (Keaton, 2013). The analysis of lower level WBS data is accomplished through this research.

Research and Investigative Questions

The investigative questions aim to assist in answering the research question: can lower level WBS data improve the overall accuracy of EVM based prediction models for mid-acquisition space programs? Analysis and investigation is conducted utilizing both levels two and three WBS space program data. The following investigative questions serve as the basis of this examination:

- What is the predictive capability of WBS level two data on mid-acquisition space program EACs?
- What is the predictive capability of WBS level three data on mid-acquisition space program EACs?
- Are there alternative predictors of cost estimates and growth that can be found through analysis of WBS two and three data?

In answering these investigative questions, this research provides a detailed analysis of the effectiveness of lower level WBS data on forecasting final cost estimates.

Methodology

The methodological approach aims to explore the significance of using WBS level two and three data to predict actual program costs. WBS level two and three data are summed and used to develop EACs using several calculation methods. These calculated EACs are then compared to programs' level one actual costs to examine the accuracy of the measures.

The investigation is comprised of two separate phases of research. The first phase aims to provide a direct comparison to the AFCAA study. This phase analyzes lower level WBS data, while using similar techniques used in the AFCAA study. The second phase of the investigation aims to explore whether or not commonalities exists at lower levels that may be indicative of EAC fluctuations.

Research Contribution

The predominant focus of this research is to determine the accuracy of using lower level WBS elements to predict mid-acquisition space program final cost estimates. The results of this research provide AFCAA and other DoD entities primary and cross-check analytical tools to project costs of space systems at several completion percentages in their acquisition lifecycles. Results of the study may not be generalizable to all defense acquisition program types; however, the results may provide key information and data to the space acquisition community.

Chapter Summary

This chapter provided an overview of the current fiscal environment within the DoD, the importance of EVM and EAC calculations, and specific research questions to be addressed in subsequent chapters. The next chapter discusses the relevant literature surrounding EVM principles and how EVM has evolved into the current form. Chapter III describes the data used, the sources for the data, and the methodologies behind our approach. Chapter IV presents the results of our analysis and our research findings. Lastly, Chapter V presents our conclusions, discusses significant findings and implications, and recommends areas for future research.

II. Literature Review

Chapter Overview

The purpose of this chapter is to explain pertinent background information and review previous literature concerning Earned Value Management (EVM) and cost growth. This chapter first explains concepts and terminology used throughout this research. Following this explanation, an overview of previous research efforts is provided. This overview highlights the history of predicting cost growth, an investigation into various Estimate at Complete (EAC) formulation methods, and lower level EVM data analysis.

Concepts

Work Breakdown Structure (WBS)

The WBS is defined as a product-oriented structural framework composed of hardware, software, services, data, and facilities. It acts as the blueprint, or outline, for the complete end product and the product's tasks. The WBS begins with top, or program, level data and segments the program into lower level sub-components. At each subsequent level of the WBS, the elements are more defined. Figure 1 displays an example of items seen in the top three levels of a DoD space program. To the extent possible, the levels of the WBS should be mutually exclusive and collectively exhaustive. This concept necessitates that WBS elements do not overlap and that they capture all deliverables for the entire program. The DoD mandates any program or contract to include the top three levels for reporting purposes; however, complex programs may require greater levels of detail (MIL-STD-881C, 2011). Figure 2 displays the typical numbered-naming convention used to define each WBS level. The WBS is essential in defining the necessary tasks and building the framework for EVM.

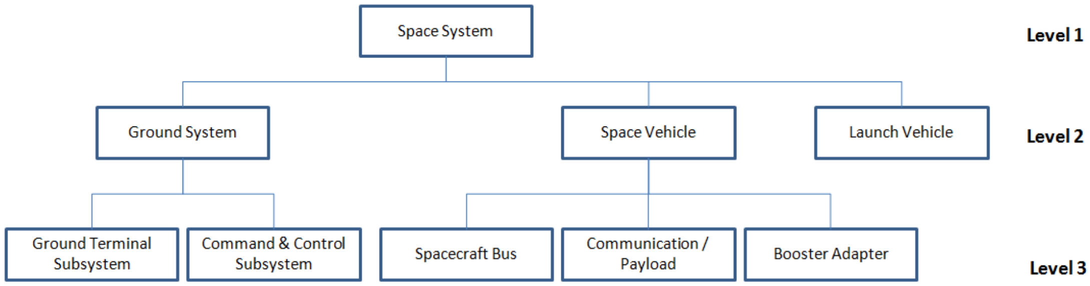


Figure 1. DoD Space Program WBS Example

MIL-STD-881C
APPENDIX F

F.3 WORK BREAKDOWN STRUCTURE LEVELS

WBS #	Level 1	Level 2	Level 3	Level 4	Level 5
1.0	Space System				
1.1		SEIT/PM and Support Equipment (1…s) 1			
1.1.1			Systems Engineering		
1.1.2			Assembly, Integration and Test		
1.1.3			Program Management		
1.1.4			Support Equipment		
1.2		Space Vehicle 1..n (Specify)2			
1.2.1			SEIT/PM and Support Equipment		
1.2.1.1				Systems Engineering	
1.2.1.2				Assembly, Integration and Test	
1.2.1.3				Program Management	
1.2.1.4				Support Equipment	
1.2.2			Bus		
1.2.2.1				SEIT/PM and Support Equipment	
1.2.2.1.1					Systems Engineering
1.2.2.1.2					Assembly, Integration and Test
1.2.2.1.3					Program Management
1.2.2.1.4					Support Equipment
1.2.2.2				Structures and Mechanisms (SMS)	

Figure 2. MIL-STD-881C Space WBS

Earned Value Management

In general terms, EVM is a quantitative project management technique for assessing the performance and progress of a program. One researcher, Joseph Lukas, defined EVM as a methodology for controlling a project, while relying on the WBS work performance and an integrated schedule and budget (Lukas, 2008). Lukas frames his argument on the concept of differentiating among earned value analysis, EVM, and an earned value management system. For the purpose of this research, EVM is used as an all-encompassing term to describe the overall subject matter.

EVM data are the product of various formulas and calculations linked to three key cost elements: Budgeted Cost of Work Performed (BCWP), Budgeted Cost of Work Scheduled (BCWS), and Actual Cost of Work Performed (ACWP). The BCWP represents the "value of the work actually completed"; the BCWS represents the "portion of the approved cost estimate planned to be spent on the project activity in a given time period"; and the ACWP represents the "total of costs incurred in accomplishing work on the activity" (Godbole, 2004). These three elements function as the basic foundation for EVM; remaining EVM measurements are computed using a combination of these three elements. A detailed description of common EVM terms and their calculations is found in Table 1, which is a reproduction of information found in the Defense Acquisition Guidebook (DAU, 2013).

Table 1. EVM Terms

EVM Term	Meaning	Formula
BCWP	"Earned value"; how much budgeted cost the program has gained	Sum of the budgeted cost of all completed work packages
BCWS	"Planned value"; how much budgeted value the program should have gained	Sum of the budgeted cost of all work packages scheduled
ACWP	"Actual cost"; how much cost has been incurred for the completed work packages	Sum of actual costs of all completed work packages
Cost Variance (CV)	Difference between planned and actual cost to date	BCWP - ACWP
Schedule Variance (SV)	Difference (expressed in dollars) between planned and actual schedule to date	BCWP - BCWS
Cost Performance Index (CPI)	Cost efficiency of the program	BCWP / ACWP
Schedule Performance Index (SPI)	Schedule efficiency of the program	BCWP / BCWS
Budget at Complete (BAC)	Planned total cost of the program	Sum of all BCWS of program
Budgeted Cost of Work Remaining (BCWR)	Budgeted cost of uncompleted work packages to reach program's completion	BAC – BCWP
EAC	Forecasted/estimated total cost of program	Various formulas
To Complete Performance Index (TCPI)	Projected CPI for the remainder of the project to meet the BAC	Various formulas
Variance at Complete (VAC)	Estimated cost variance at completion of program	BAC – EAC
Percent Complete	Percentage of the entire program that is complete	BCWPcum / BAC
Total Allocated Budget (TAB)	Total of all contract's work budgets	Sum of all budgets
Contract Base Budget (CBB)	Total budget allotted to the contractor	Sum of the negotiated contract cost and authorized undefined work
Management Reserve (MR)	Amount of the budget allotted for unknown costs or risk management	Determined at start of contract

Over the course of the past 50 years, the analysis of EVM data has proven to be an adequate technique for controlling cost, schedule, and performance for government contracts (Defense Contract Management Agency [DCMA], 2006). One area of controlling costs, involves predicting program EACs. Although it is not explicitly stated, Table 1 implicitly denotes that EACs can be calculated using various methodologies and techniques. The primary source for obtaining program specific EVM data from contractors is the contractor performance report (CPR). The CPR serves as the unbiased reporting method for delivering program status updates to the government and program analysts.

Contractor Performance Report

The CPR is a management document that provides summary-level EVM data to DoD system managers. Managers are then able to compare cost and schedule performance data with technical performance measures, identify both actual and potential problem areas, and provide valid, timely program updates to senior leaders. CPRs come in seven different formats, as seen in Table 2 (OUSD: AT&L, 2005). This research

Table 2. CPR Formats

Title	Requirement	Description
Format 1 - WBS	Mandatory	Provides data to measure cost and schedule performance by product-oriented WBS elements
Format 2 - Organizational Categories	Optional	Provides the same data as Format 1, but by the contractor's organization
Format 3 - Baseline	Optional	Provides the budget baseline plan against which performance is measured
Format 4 - Staffing	Optional	Provides staffing forecasts for correlation with the budget plan and cost estimates
Format 5 - Problem Areas	Mandatory	Provides narrative information used to explain significant cost and schedule variances and other identified contract problems and topics
Format 6 - Integrated Master Schedule	Optional	Provides details as to how and when the integrated master plan (IMP) is accomplished
Format 7 - Electronic History and Forecast File	Mandatory	Provides time phased cost data to include both historical and forecasted information

focuses on Format 1, the WBS approach. An example of the Format 1 CPR can be seen in Appendix A. The WBS CPR is required at least monthly, but can be required more frequently in certain circumstances. This CPR provides the necessary data to conduct earned value analyses at each of the first three levels of the WBS. Research shows that these analyses are vital in continually improving EAC estimation and the identification of overall program growth (Rosado, 2011).

Relevant Research

In the research study, "Predicting Cost and Schedule Growth for Military and Civil Space Systems," Rusnock attempts to develop a set of models that can be used to predict space system cost and schedule growth. Rusnock separately analyzes both DoD and National Aeronautics and Space Administration (NASA) space programs to determine which characteristics provide the best indication as to whether or not, and to what extent, cost and schedule growth will occur. Rusnock finds that communications missions, ground equipment, firm-fixed price contracts, and increased program manager tenure are all found to be predictive of lower cost growth for DoD space programs. Rusnock provides various cost growth regression equations and possible explanations for the existence of the relationships (Rusnock, 2008). Rusnock's research effort provides models and characteristics of programs that pose a risk for cost growth; however, with this information alone, analysts can not make strategic decisions to mitigate these risks. For example, analysts do not generally have control over the commodity type, contract type, or length of PM tenure; therefore, analysts would be able to use Rusnock's findings only to assess whether or not their program contains attributes that are consistent with lower or higher levels of cost growth. Although useful, Rusnock's research does not provide analysts with tools that they can utilize to convey final EACs to upper management.

EAC formulas and calculation approaches are abundant within the acquisitions community. It is often difficult for PMs and analysts to determine which methods are appropriate for their particular program. In a 1995 review by Christensen et al., this difficulty level was further reinforced. The paper reviews 25 studies on EAC formulas and models to determine which method is the most accurate. The results indicate that the accuracy levels of the various approaches are dependent upon several factors; therefore, no one method was deemed to be the most accurate in all settings. Index-based formulas' accuracy was shown to be dependent on both the system type and the contract completion stage (Christensen et al., 1995). These results enforce the need for independent research that compares various EAC calculation methods across specific system types at different completion percentages. As noted in the preceding AFCAA research study, current space system cost estimation techniques using EVM methods are particularly sparse (Keaton, 2013).

The research study by AFCAA analysts focuses on predicting EACs for space programs using program level data; however, the author also suggests that subsequent level data could provide useful analysis as well (Keaton, 2013). The DCMA EVM System guidance supports this suggestion when it states that detailed analysis on contractor EACs should be performed at the lowest WBS level available (DCMA, 2012). In 2011, Rosado conducted the first documented research study aimed at determining the predictive capability of lower level EVM data using regression based techniques. The study focuses solely on Research, Development, Test and Evaluation (RDT&E)

contracts. Rosado discovers that there are little to no WBS lower level commanlities between contracts; this holds true even within the same service, commodity type, and contractor. With the one commonality he is able to find, level three Development Test and Evaluation, the data prove to be significant drivers for program EAC growth; however, these findings are not generalizable to all DoD acquisition contracts. Rosado also notes that the results are not dependent upon service, contractor, or acquisition category. Lastly, Rosado expresses that future research should provide analysis based on specific program characteristics such as commodity type. (Rosado, 2011).

Although the accuracy of calculated EACs can vary greatly, it is important to recognize the propensity for PMs and contractors to select the most optimistic estimates to bring forward. Christensen articulates this tendency in his article "Project Advocacy and the Estimate at Completion Problem." Christensen uses the A-12 program to demonstrate how optimism, by both contractors and government project managers (PM), can be dangerous, which ultimately led to the A-12 program's cancellation. Christensen believes that contractors and PMs knowingly provide optimistic EAC figures in an effort to prolong programs by securing funding. The results of Christensen's research effort show that the cumulative Cost Performance Index (CPI), which had been commonly used as a ceiling in numerous estimates, was in fact a floor to the average final costs. The research also showed that there was a significant correlation between the reported EACs and the estimates calculated using cumulative CPI. Other common index-based estimates were proven to be more accurate; however, they were less correlated to the reported EACs. These results suggested that although more accurate methods existed, PMs and contractors knowingly chose the lowest estimate as a basis for their reported figures

(Christensen, 1996). This inclination to report the estimate that presents the most favorable outcome represents an inherent limitation to any EAC prediction model research study. One theory suggests that "perhaps the future of this discipline [cost estimation] will focus on methods of controlling program cost, rather than the futile attempt to predict it" (Keller et al., 2014).

This theory on controlling program costs is the concluding thought of a recent study by Keller et al., "What is Wrong with Space System Cost Models? A Survey and Assessment of Cost Estimating Approaches," which initially aimed to gather a deeper understanding of the causes cost growth in space programs. Keller et al. find that current methods and approaches to cost estimating space programs are inadequate due to their inability to predict the future, lack of insight, and the idea of processes replacing good judgment in decision making. The authors first state that parametric models lack the ability to extrapolate beyond the programs of the past which they are founded upon. Next the authors state that prediction models and techniques do not possess the ability to accurately define cause and effect relationships in cost growth. Without this ability, it becomes rather difficult to improve upon final cost estimation modeling. Lastly, the article explains that analysts are too overwhelmed by the possibility of program failure. This fear drives analysts to accept the mindset that insight and accuracy are "less important than providing a number that will be approved by senior management and the Office of Management and Budget" (Keller et al., 2014).

Summary

In summary, there is a long history of cost growth models and EAC formulation practices. In order to provide maximum value, new research must be founded on information that is readily available to program analysts, and the findings should be quantitative in nature so that analysts can provide useful information to their leadership. Through his research, Christensen established the need to conduct EAC analysis on specific system types and at various completion percentages. Lower level EVM data has shown to be rather inconsistent when making comparisons of various system types and across services; however, deeper analyses can uncover elements that may be indicative of program cost growth. Taking all this into consideration, the inclination to report the estimate that presents the most favorable outcome represents an inherent limitation to any EAC research study. This mentality has even led some to believe that we should stop trying to predict space program costs altogether. The next chapter discusses the data sample and methodological approaches taken to address the issue of developing better space program estimates.

III. Data Collection and Methodology

Chapter Overview

The purpose of this chapter is to provide background information on the data collection and research methodology for the analyses in this thesis. This chapter first provides a detailed explanation of the sample data collected. It then explains the methodological approach taken and formulas used to conduct data analysis. The primary tools utilized for this research are Microsoft Excel and the Defense Cost and Resource Center (DCARC) CPR Viewer.

Data Source

The dataset used in this research is comprised of program data drawn from the DCARC EVM central repository. DCARC was established in 1998 and is the largest source of DoD cost data available to the cost community. DCARC's primary mission is to "collect current and historical Major Defense Acquisition Program (MDAP) and Major Automated Information System (MAIS) cost and software resource data in a joint service environment" (DCARC, 2007). These program data were assembled from monthly CPRs, contract history files, data reports, Integrated Program Management Reports, and other miscellaneous submissions generated from program offices and contractors.

Due to the necessity of having data at WBS levels two and three, many of the EVM data had to be manually transcribed into Excel; however, the primary method of gathering level two and three data consisted of downloading the latest history file and opening the file using the DCARC CPR File Viewer. The "export to Excel" function was utilized to put the data in a useable, easily modifiable format. The selected data are broken into two distinct samples. The smaller sample, dataset one, consists of the six space acquisition contracts used in the previous AFCAA study (Keaton, 2013). The larger sample, dataset two, contains all space program contracts found within the DCARC repository.

Dataset one is linked to the preceding research study in which Keaton selected programs that were representative of the field and contained sufficient data to conduct their research. Space acquisitions, as a whole, is a vast field of study, and there are many different focuses within its realm; some of the more common areas include space vehicles, ground systems, satellites, ground control centers, and shuttles. For this reason, the previous research study sample was used to focus the study on areas deemed most important to field experts. Furthermore, one of the main goals of this research is to determine the predictive capability of level two and three data. Taking this concept into account, the use of the six contracts used in the AFCAA study would allow for a conclusive assessment of the predictability of level two and three data in comparison to the AFCAA study which used level 1 data. Table 3 displays the contracts that are considered for dataset one.

Table 3. Dataset One Contracts

Program Name
AEHF – Advanced Extremely High Frequency (AEHF) Satellite Program
GPS III – Global Positioning Satellite III
SBIRS HIGH - Space-Based Infrared System Program, High
WGS – Wideband Global SATCOM Program
MUOS – Mobile User Objective System
FAB-T – Family of Beyond Line-of-Sight Terminals

Unfortunately, one of the six contracts, Space-Based Infrared System (SBIRS), could not be assessed at the level two and three WBS levels due to inaccessibility of the data. Attempts were made to acquire the data from AFCAA, but the data were not available in a useable format. In addition to the inaccessibility of the SBIRS data, the program exhibited traits that would have made it difficult to assess. Most notably, the contract completion percentages experienced a "roller-coaster" effect when graphed due to the number of Over Target Baselines (OTB). This is clearly seen in Figure 3.

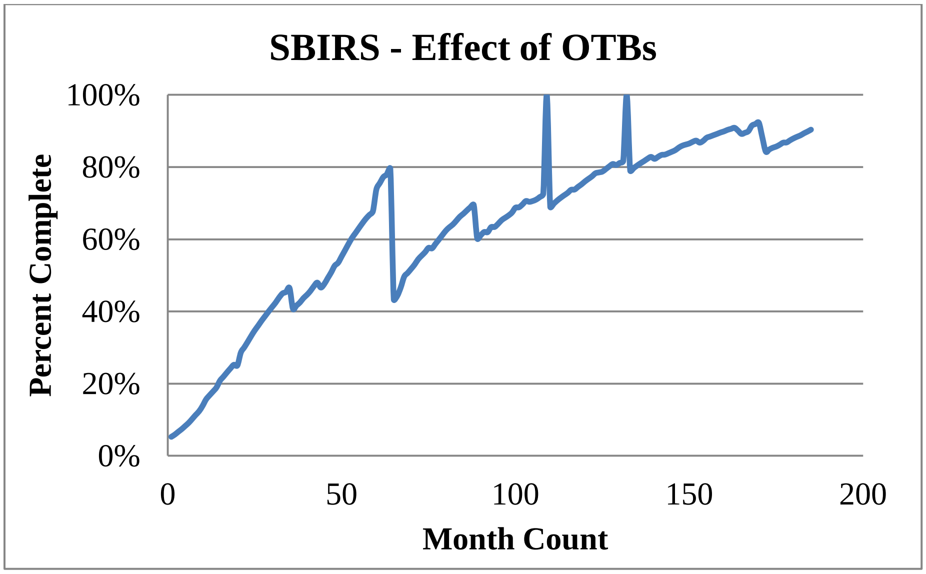


Figure 3. SBIRS OTB Effects

Dataset two initially encompasses all space program contracts found within DCARC. This initial assessment results in 41 total space contracts. 9 contracts are removed due to their absence of CPR data within DCARC. 15 contracts are removed due to not being at least 85% complete in terms of BCWP and BAC. An 85% completion limitation is placed on the data set in order to ensure that the contract is somewhat nearing completion. Although previous research suggests that the 92.5% completion point is a better representation of a contract's final costs (Tracy and White, 2011), the 85% point is used in order to include as many contracts as possible. Imposing this lower rate limitation, results in three additional contracts being retained in the dataset; two of which were used in the preceding AFCAA study. Lastly, 8 contracts are removed due containing missing, insufficient, or inaccurate data at WBS levels two and three. Of the 41 total space contracts, only 9 contracts meet the final specifications for this research. Table 4 illustrates this gradual decline in the number of contracts used in dataset two.

Table 4. Dataset Two Contracts

Program Name	Contracts Considered	w/ CPR Data	>85% Complete	Met Criteria
*AEHF – Advanced Extremely High Frequency (AEHF) Satellite Program	2	2	1	1
EELV – Evolved Expendable Launch Vehicle	2	2	2	1
EPS - Enhanced Polar System	2	1	0	-
*GPS III – Global Positioning Satellite III	2	2	1	1
GPS OCX – Global Positioning Satellite Next Generation Control Segment	3	3	2	1
JTN - Joint Tactical Networks	5	2	2	0
MGUE - Military GPS User Equipment	3	3	1	0
NAVSTAR GPS – Global Positioning System	4	4	4	1
NPOESS - National Polar-Orbiting Operational Environmental Satellite System	1	1	0	-
SBIRS HIGH - Space-Based Infrared System Program, High Component	7	5	1	0
*WGS – Wideband Global SATCOM Program	2	2	2	2
*MUOS – Mobile User Objective System	1	1	1	1
*FAB-T – Family of Beyond Line-of-Sight Terminals	6	3	1	1
Space Fence	1	1	0	-
Total	**41**	**32**	**18**	**9**

The five programs marked with an asterisk are utilized in both finalized datasets. The final 9 contracts in dataset two stem from 8 of the total 14 different space programs in DCARC. This is significant since a large percentage of contracts did not meet the final criteria, yet over half of all the space programs in DCARC are still represented in this study. The contract start dates for both datasets span over a period of approximately 14 years. The quantity by time period is captured in Table 5.

Table 5. Number of Contracts by Contract Start Date

Contract Start Date	**Number of Contracts**
1 Jan 2000-31 Dec 2004	3
1 Jan 2005-31 Dec 2009	4
1 Jan 2010-31 Dec 2013	2
Total	**9**

Descriptive statistics regarding the various amounts of contract completion percentages are found in Table 6. Although the 85% completion point was used as the cutoff, the mean final reported EAC point was 96% for the 9 contracts. The completion percentages for each contract can be seen by contract in Figure 4. These completion percentages are representative of the available level one data. On occasion, subsequent level data is not available at this same completion level; however, this results in a difference of only a few percentage points. For example, the AEHF contract has level one data available up until the 99% completion point; however, the level two and three data is available up until only the 95% completion point. This difference is caused by a lag in history file reporting within DCARC.

Additionally, there are two contracts that contain data issues worth noting. Although most of the data used in this research is taken from the primary source, DCARC, one contract necessitated the use of a secondary source. The FAB-T contract began in September 2002, yet the data available in DCARC does not begin until October 2006. Hence, the data for this contract was supplied by AFCAA. Secondly, the

NAVSTAR contract encounters a unique occurrence late into its duration. At the 92% completion point, the nomenclature of the level two and three WBS activities drastically changes beyond the point of reconciliation. Many of the previous WBS activities begin with a new EAC figure of zero and remain there for several reporting periods. For these reasons, the portion of analysis using lower level data covers the period up until this point.

Table 6. Contract Coverage Statistics

Minimum EAC Coverage	87%
Maximum EAC Coverage	100%
Median EAC Coverage	99%
Mean EAC Coverage	96%
Standard Deviation	5%

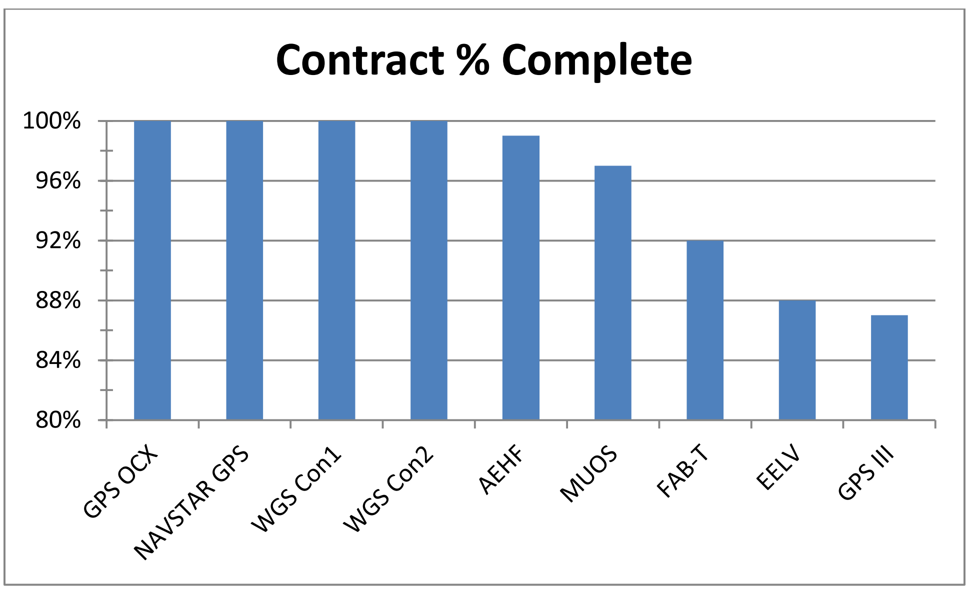


Figure 4. Contract Completion Percentages

Methodology

The methodological approach taken for this thesis consists of two phases. The first phase makes use of dataset one and is primarily influenced by the preceding study. The goal of this approach is to recreate similar procedures to those used in the AFCAA study in an effort to make a direct comparison to the results derived from utilizing lower level EVM data. By conducting the analysis in this manner, variations in the results of the two studies can be directly attributed to the use of level two and three data. This is important so that disparities are not credited to differences in the procedural or technical approaches. The second phase of the methodology aims to explore the extent of underlining relationships found within lower level EVM data. Phase two provides detailed analysis that searches beyond the EVM summary level two and three totals. In this phase, the research involves looking into EAC cost drivers, finding commonalities between programs and contracts, and seeing how changes in those drivers affect the EAC estimates.

Phase One

Phase one of the methodological approach consists of steps that are comparable to those used in the preceding study. First, WBS level one, two, and three EVM data are gathered for each contract and placed in an Excel worksheet. These data consist of the contract start date, estimated completion date, BAC, EAC, BCWS, BCWP, and the ACWP. Next, the completion points are determined for each contract. Completion points, in 10% increments, are identified from the 20% point to the 70% contract completion point. Following this identification process, the cumulative Cost Performance Index (CPI) and Schedule Performance Index (SPI) performance measures are calculated for each contract at every monthly reporting period. In formulating these measures, a performance baseline EAC can be established. This baseline is considered as the standard, or traditional, approach with which most members of the cost community are familiar (Keaton, 2013). The formula for this baseline is found on the Defense Acquisition University (DAU) EVM "Gold Card" and is known as the EAC Composite:

$$EAC_{Composite} = \frac{BAC}{CPI_{Cum} * SPI_{Cum}} = \frac{BAC}{SCI} \qquad (1)$$

The use of the EAC Composite as the baseline is a critical aspect of this research. It is often thought that this EAC represents the cost ceiling in most programs which are traditionally over cost and behind schedule. As stated in the Defense Management Contractor Agency (DCMA) EVM System Program Analysis Pamphlet, "the EAC Composite formula provides an upper bound, or the most pessimistic IEAC [Independent EAC]" (DCMA, 2012). Hence, if a program is severely over budget and exceeds estimated initial costs, the EAC Composite should represent the most accurate figure, in terms of proximity, of the traditional EVM based estimates.

The next segment of phase one consists of calculating EACs using the BCWP model. The BCWP model utilizes the relationship between remaining contract months, the BCWP burn rate, and BCWP to date to estimate final costs. Final cost predictions for contracts are made from the 20% - 70% incremental completion points. This approach may vary from other EVM approaches because it "focuses exclusively on the rate at which work is accomplished rather than cost efficiency" (Keaton, 2013). In other words, this approach assumes linearity. The relationship among the variables is displayed in the following equation:

$$EAC_{BCWP} = (Month_{Est\ Completion} - Month_{Current}) * BCWP_{Burn\ Rate} + BCWP_{To\ Date} \quad (2)$$

In the AFCAA study, the remaining number of months is derived as a function of the total number of estimated months and the earned schedule up until the respective completion point. The total number of estimated months, or program duration, for each contract is calculated by taking the difference between the most recent estimated completion date and the contract start date. The current month portion of the BCWP model is calculated based on the previous period's earned schedule, plus the earned schedule for the current period:

$$Earned\ Schedule = ES_{Prev} + \frac{(BCWP_{Current} - BCWP_{Prev})}{(BCWS_{Current} - BCWS_{Prev})} \quad (3)$$

In addition to this approach of evaluating the remaining number of months, the actual number of estimated remaining months is also assessed in the BCWP model. For example, at the 70% completion point for the FAB-T contract, the estimated program duration is 111 months. At this same point, the earned schedule is calculated at 26 months, while the actual month count is 69 months. Using the earned schedule approach would result in an estimated number of remaining months of 85. Using the actual figures, results in an estimated number of remaining months of 42.

The BCWP model utilizes ordinary least squares regression to calculate the BCWP burn rate. This burn rate is simply the coefficient from a prediction model generated from the elapse number of months and the cumulative BCWP figures. At each of the measured completion points, 20%-70%, the elapsed months are used as the explanatory variable to predict the response, the cumulative BCWP. For example, if Contract A reaches the 20% completion point at 13 months, a prediction model is derived using each of the elapsed months, 1 through 13, as predictors for their respective cumulative BCWP. The derived coefficient for the elapsed months is used in the BCWP model as the burn rate. In Figure 5, this burn rate would be approximately $20,629,032.

20% SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997726669
R Square	0.995458506
Adjusted R Square	0.995045643
Standard Error	5667688.673
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.74514E+16	7.74514E+16	2411.110414	3.06772E-14
Residual	11	3.5335E+14	3.21227E+13		
Total	12	7.78047E+16			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-10545492.3	3334575.593	-3.1624691	0.009039083	-17884843.66
X Variable 1	20629031.63	420117.0356	49.10305911	3.06772E-14	19704360.27

Figure 5. BCWP Regression Coefficient Example

In addition to this approach of evaluating the burn rate, the monthly average burn rate is also assessed in the BCWP model. For example, if the cumulative BCWP for the same Contract A is $266,700,245 at the 20% completion point, then the burn rate would be

$20,515,404. This is derived from simply dividing the cumulative BCWP by the number of elapsed months.

As a result of the variations to the original BCWP burn rate formula, Equation 2, three additional models are tested. Model 1 is the formula as it was utilized in the previous research study. The BCWP burn rate is calculated using the regression based approach, and the remaining number of months is calculated based on the estimated number of total months minus the earned schedule up until that point in time. Model 2 is similar to Model 1; however, Model 2 uses the actual schedule in place of the earned schedule to calculate the remaining number of months. Model 3 uses the monthly average BCWP burn rate in place of the regression based burn rate. Model 4 uses the monthly average BCWP burn rate and the actual schedule. Table 7 displays the details of all four models.

Table 7. BCWP Model Variations

Model	BCWP Burn Rate	Remaining Months
Model 1	Regression	Earned Schedule
Model 2	Regression	Actual Schedule
Model 3	Average	Earned Schedule
Model 4	Average	Actual Schedule

After calculating the various predicted EAC figures, the accuracy percentages are measured based on the numerical proximity to the final EAC. The accuracy of the calculated figures is measured using an absolute percent error measurement. This measurement formulates the percentage of error by dividing the difference between the final and predicted EAC values by the last reported EAC. This number is then multiplied by 100 to develop a percentage of error. As an example, a zero percent error rate would mean that the model predicted the exact final EAC. The following formula further illustrates this method:

$$\% \; Error = \left| \frac{(EAC_{Final} - EAC_{Predicted})}{EAC_{Final}} * 100 \right| \quad (4)$$

Once the error percentages are formulated for each contract, the averages at each completion point are calculated to determine the overall accuracy of the model. Accuracy percentages are assessed for predictability of the program level final reported EAC.

Phase Two

Phase two of the methodology is slightly more open-ended than phase one. The purpose of this phase is to reveal commonalities amongst contracts that are indicative of cost growth. In this phase, each contract is analyzed to determine which elements found at the lower levels are driving EAC cost growth. DCARC's CPR Viewer and Microsoft Excel are the primary tools utilized to conduct the assessment of cost drivers. In addition, the level two and three activities are explored to determine which common activities and elements exists between the different contracts that may be explanatory in terms of EAC growth and changes. The commonalities are then further assessed to determine the extent of the relationship between changes in the EAC and changes in the WBS activity.

In hopes of finding additional trends, occurrences of EAC cost growth exceeding either 5% or 10%, dependent upon the contracts total cost growth, in subsequent reporting periods is researched to determine which lower level WBS activities may have driven the increase. Inferences are made by assessing the timing and magnitude of the excessive cost growth periods. In addition, contracts are assessed to identify the WBS activities that experienced the largest EAC growth in terms of dollar figure and percent growth. Following these steps, conclusions are drawn based on trends and patterns seen in the dataset.

Summary

In summary, this chapter provided the sources of the sample data and the methodological approaches taken to address the research question. Characteristics of the sample data, formulas used, and research steps were presented. Finally, this chapter explained the two phased approach to provide background on the structural framework for this research effort. Chapter 4 presents the results of the discussed methodological approaches.

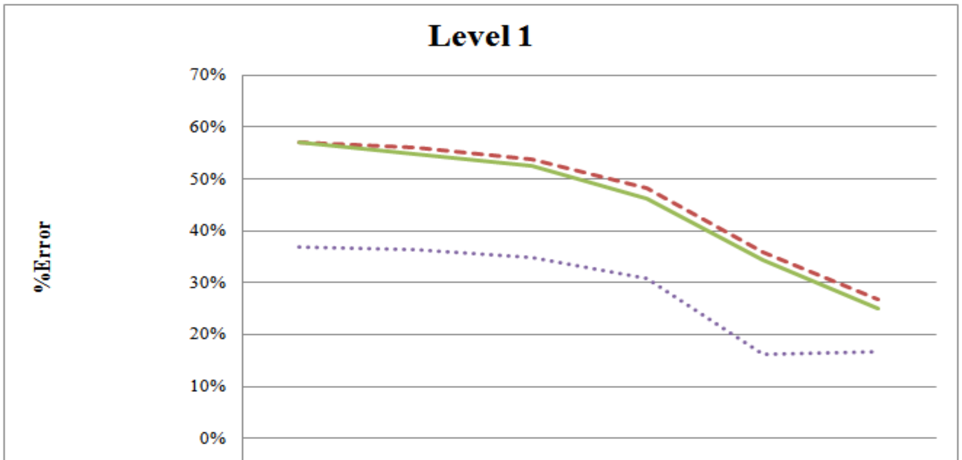
IV. Analysis and Results

Chapter Overview

The purpose of this chapter is to provide the results of the methodology outlined in Chapter 3. The results are presented in a consistent manner as the methodology; first, phase one results are presented and then phase two results are given. Phase one results detail the findings based on WBS level and using the variations of the BCWP model. Phase two provides a detailed analysis of each of the nine contracts and then determines if revealed commonalities amongst programs and contracts are indicative of cost growth.

Phase One Results

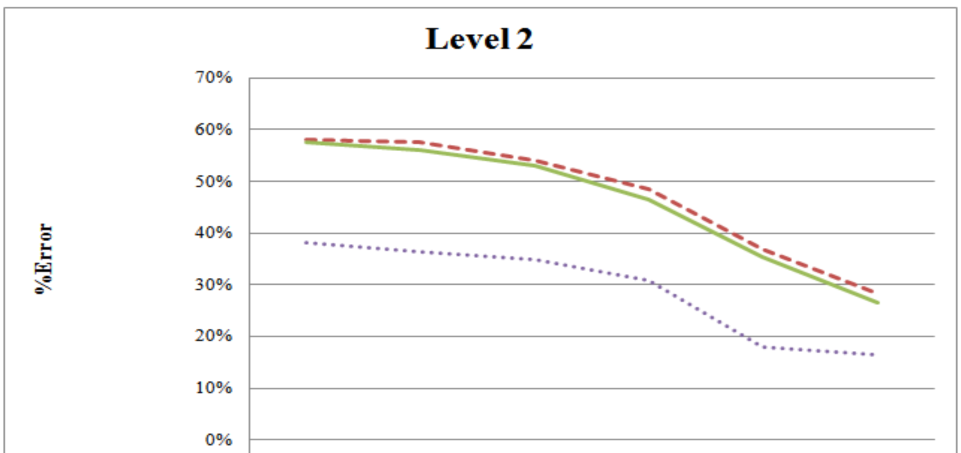
The results of phase one examine the differences in outcomes based on using data from the different WBS levels. The BCWP model distributes traits consistent with previous research at WBS level one. The model is on average 16% more accurate than the EAC Composite and 18% more accurate than the reported EAC. These averages are derived from assessing the model at each completion point from 20% to 70% and taking the average of the six calculations. At the 60% completion point, the model levels out in terms of accuracy. In fact, the average error is 1% less accurate at the 70% completion point than the 60% completion point; this seems counterintuitive to the idea that as a program matures, you can predict the final costs more accurately. These results are attributed to the fact that the BCWP model does not have a built in mechanism to account for the reduced spending seen at the end of the contracts in the dataset. Hence, the model over estimates for all five contracts at the 70% completion point. Figure 6 displays the full detail of the level one BCWP model results.



%Complete	20%	30%	40%	50%	60%	70%
Reported	57%	56%	54%	48%	36%	27%
EACComposite	57%	55%	53%	46%	34%	25%
BCWP Burn Rate	37%	36%	35%	31%	16%	17%

Figure 6. Level 1 Summary

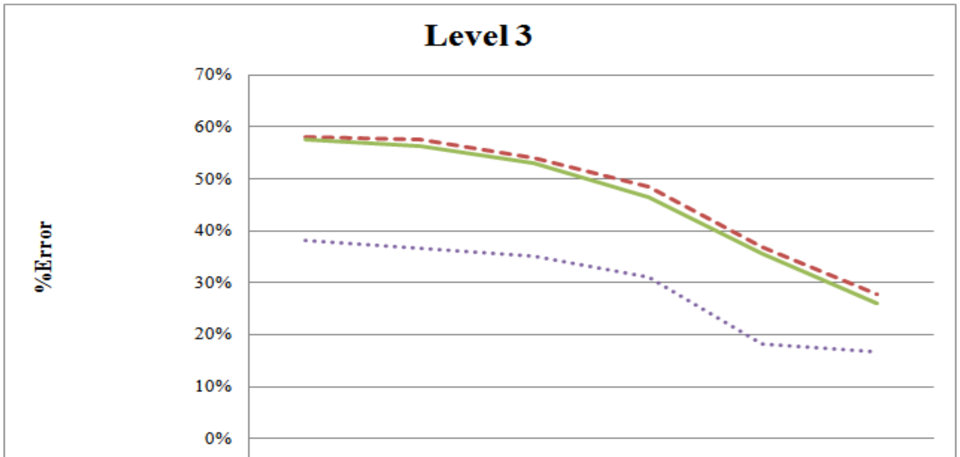
The BCWP model at level two is on average 17% better than the EAC Composite and 19% better than the reported EAC. As one would expect, the model improves at each subsequent completion percentage point. The results are fairly consistent with those seen at level one and are seen in Figure 7.



%Complete	20%	30%	40%	50%	60%	70%
Reported	58%	57%	54%	48%	37%	28%
EACComposite	58%	56%	53%	47%	35%	26%
BCWP Burn Rate	38%	36%	35%	31%	18%	17%

Figure 7. Level 2 Summary

The BCWP model at level three is on average 17% better than the EAC Composite and 19% better than the reported EAC. The results are fairly consistent with those seen at levels one and two, and are seen in Figure 8.

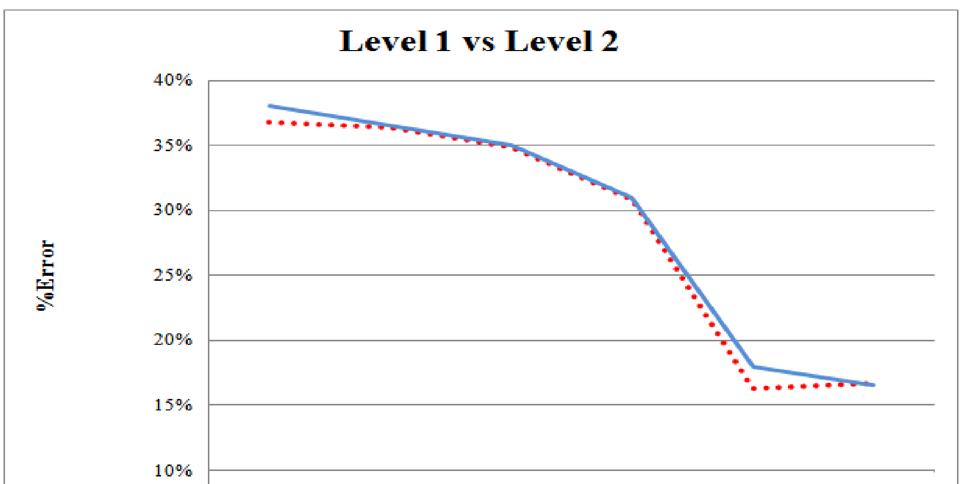


%Complete	20%	30%	40%	50%	60%	70%
Reported	58%	58%	54%	48%	37%	28%
EACComposite	58%	56%	53%	47%	36%	26%
BCWP Burn Rate	38%	37%	35%	31%	18%	17%

Figure 8. Level 3 Summary

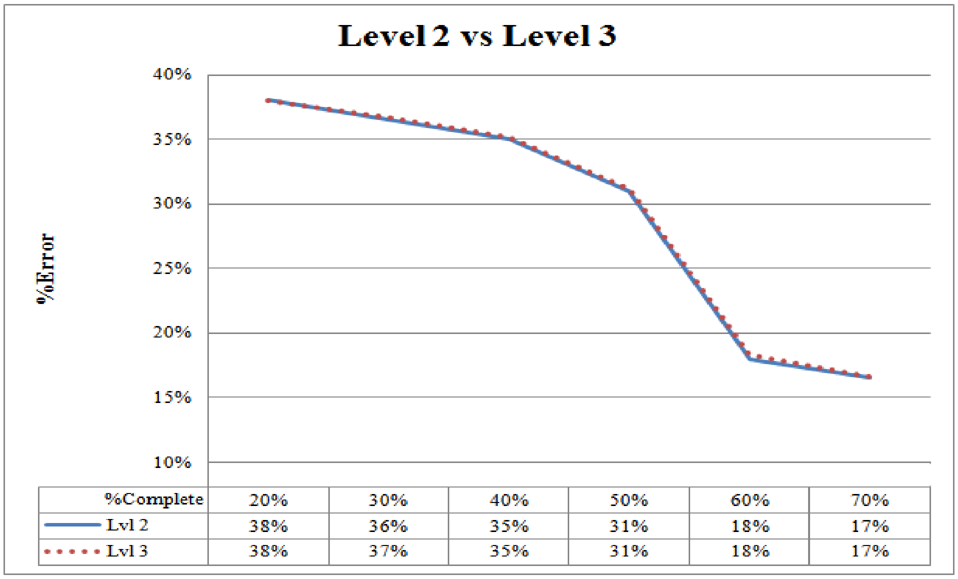
Although there is not a large difference between the three WBS levels, level one is slightly more accurate than levels two and three. A comparison of levels one and two is seen in Figure 9. There are no practical differences between levels two and three. Minor differences between these two levels can likely be attributed to accounting errors within the DCARC EVM data. Level two and three comparison results are shown in Figure 10.

The results of testing multiple models reveal interesting findings. No one model performs the best throughout the various levels of contract completion percentage. As a reminder, Model 1 is the original BCWP model which utilized a regression based burn rate and earned schedule; Model 2 is the first variation which utilizes actual schedule in place of earned schedule; Model 3 utilizes a monthly average burn rate and earned schedule; and Model 4 utilizes both a monthly average burn rate and an actual schedule. Model 1 has an average error rate of 29%. This model performs the best in the early stages of the contract. At the 20% and 30% completion points, Model 1 outperforms all other models. Model 2 has an average error rate of 31%. It displays similar results to Model 1 throughout all of the contract percentage completion stages. Model 2 is slightly less accurate than Model 1, and it does not perform the best at any completion points. Model 3 has an average error rate of 30%. In the early stages of the contract, it does not perform well and has an average error rate of nearly 50% at the 20% and 30% completion points. After these completion points, Model 3 out performs all other models. Model 4 has an average error rate of 33%. It displays similar results to Model 3; however, Model 4 is slightly less accurate than Model 3 throughout the contract percentage completion stages. It does not perform the best at any completion points.



%Complete	20%	30%	40%	50%	60%	70%
Lvl 1	37%	36%	35%	31%	16%	17%
Lvl 2	38%	36%	35%	31%	18%	17%

Figure 9. Level 1 & 2 Comparison



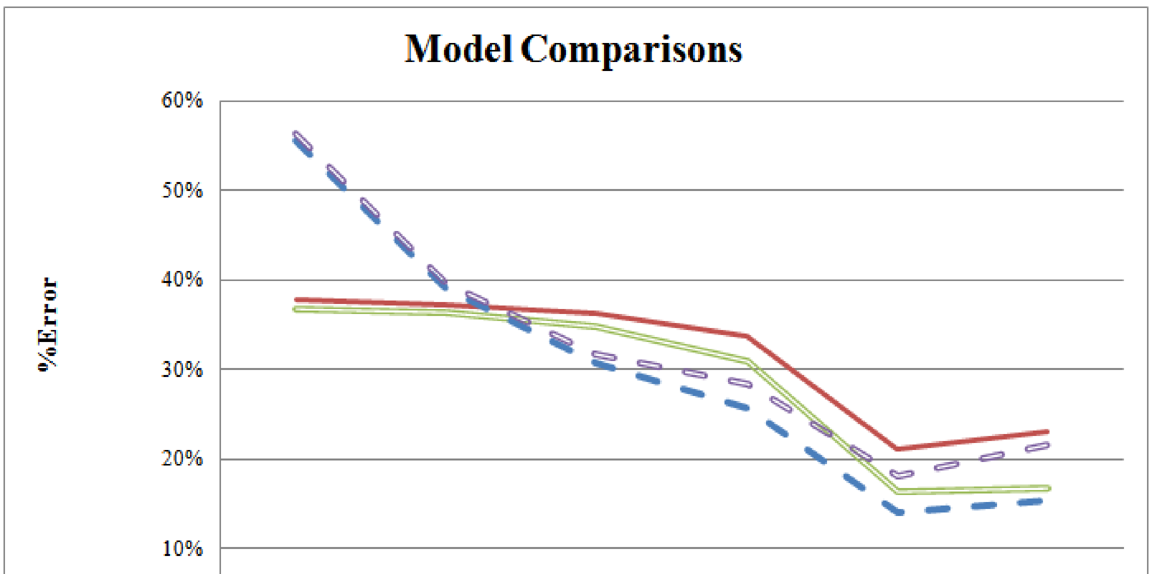
%Complete	20%	30%	40%	50%	60%	70%
Lvl 2	38%	36%	35%	31%	18%	17%
Lvl 3	38%	37%	35%	31%	18%	17%

Figure 10. Level 2 & 3 Comparison

The results of the four models are illustrated in Figure 11. The results suggest that the regression based burn rate works the best early on in the contract's completion stage; hence, why Models 1 and 2 performed better in the beginning. The monthly average BCWP burn rate works the best after the 40% completion point. The earned schedule approach seems to outperform the actual schedule method at all stages of completion. This is seen in the inferior performances of Model 2 and Model 4 in comparison to Model 1 and Model 3 respectively.

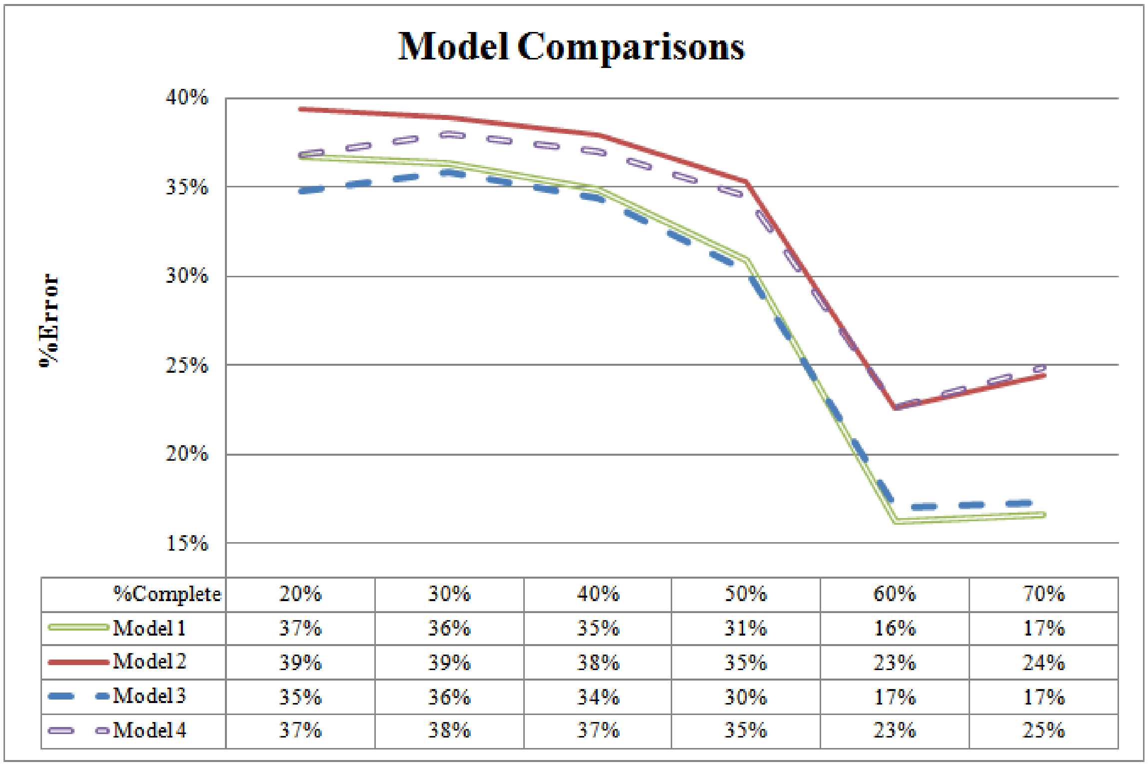
A deeper assessment of the data reveals that the monthly average burn rate models, Models 3 and 4, are highly influenced by one contract – the Advanced Extremely High Frequency (AEHF) contract. The AEHF contract has a significant gap between the contract start date and when EVM reporting began. The contract started in November 2001, but the first reporting period did not occur until October 2002. This delay, results in the data improperly suggesting that 17% of the total contract is spent in the first month.

This would mean that any formulation method that utilizes a burn rate based on monthly averages, will most likely overestimate due to the appearance of a 17% per month spending rate. To control for this error, spending was straight-lined over the number of missing months in the dataset. Following this correction, Models 3 and 4 no longer display an extremely large error percentage early on in the contract. Model 3 outperforms all models in nearly all stages of completion percentage. These results are found in Figure 12. The results suggest that a monthly average BCWP burn rate is superior to the regression based approach. This is seen in the comparison of Models 1 and 3, and the comparison of Models 2 and 4.



%Complete	20%	30%	40%	50%	60%	70%
Model 1	37%	36%	35%	31%	16%	17%
Model 2	38%	37%	36%	34%	21%	23%
Model 3	56%	39%	31%	26%	14%	15%
Model 4	56%	40%	32%	28%	18%	22%

Figure 11. Model Comparisons



%Complete	20%	30%	40%	50%	60%	70%
Model 1	37%	36%	35%	31%	16%	17%
Model 2	39%	39%	38%	35%	23%	24%
Model 3	35%	36%	34%	30%	17%	17%
Model 4	37%	38%	37%	35%	23%	25%

Figure 12. Modified Model Comparisons

Phase Two Results

The results of phase two present an in-depth analysis of each of the nine programs. The WBS lower level composition for each contract was vastly dissimilar. Due to the vast number of differences found at each subsequent WBS level, a stronger emphasis is placed on the analysis of WBS level two activities in hopes of findings similar elements across the contracts. Not only were the naming conventions unique to each contract, but the number of elements found at each level varied greatly as well. Figure 13 displays the variation in the number of lower level elements.

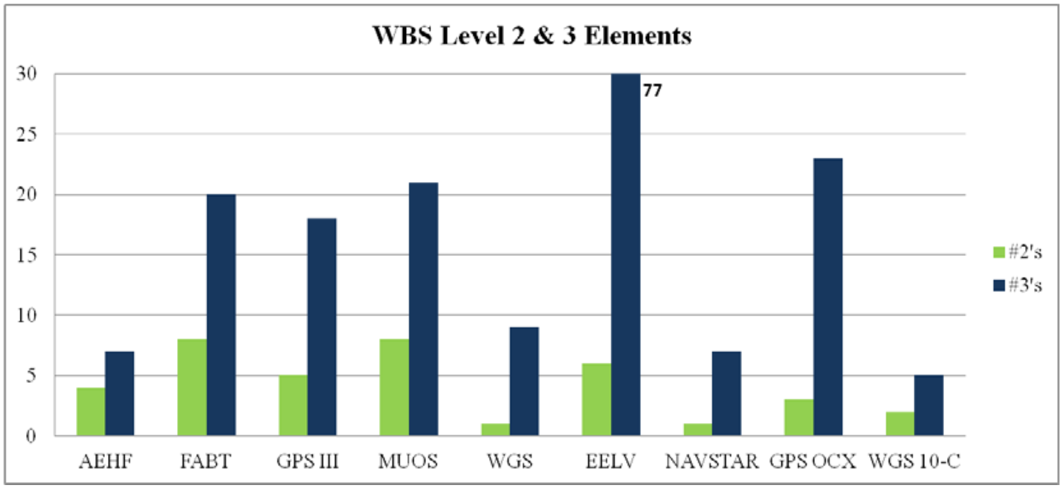


Figure 13. WBS Elements by Contract

AEHF

The AEHF contract is an agreement with Lockheed Martin for the purchase of six communication satellites. It is composed of four level two activities and seven level three activities; however, the traditional military standard space WBS level two naming convention does not occur until WBS level four and carries out through level seven. For this reason, levels four and five are treated as levels two and three respectively for this portion of the analysis. The AEHF contract exhibited a total EAC cost growth of 147% over its duration. This cost growth was incited by several periods of large cost growth. In an effort to discover what activities may have stimulated this cost growth, any growth exceeding 10% from one reporting period to the next was further investigated by assessing which elements of the program experienced representative changes; this occurred on four occasions. In all occasions, there is no immediate representative effect found within the lower level cost elements. Instead, the level one summary level element, Undistributed Budget (UB), is the first to experience an immediate increase.

Over the subsequent months, the newly allocated budget is distributed amongst the specific WBS activities.

The first large cost growth increase occurs in October 2004 at the 50% completion point. The main level two activities that increase in EAC resulting from this growth are 1.0 Space Vehicle, 3.0 Systems Engineering and Program Management (SEPM), and 7.0 Operations and Support (O&S). The second large increase occurs in January 2006 at the 60% completion point. The main level two activity that increases from this growth is 1.0A Space Vehicle. The third large increase occurs in October 2008 at the 80% completion point. The main level two activities that increase from this growth are 1.0 Space Vehicle, 1.0A Space Vehicle, and 1.0C Space Vehicle, and 3.0 SEPM. The last increase exceeding 10% occurs in November 2011 at the 90% completion point. The main level two activity that increases from this growth is 7.0 O&S. Figure 14 displays the EAC cost growth of the total AEHF contract and several key WBS level two activities contributing to this growth. Following the growth of the key activities displayed in Figure 14, WBS level two activity 1.0A Space Vehicles becomes the primary driver for EAC cost growth.

The main level two contributors to EAC cost growth for the AEHF contract are the activities associated with the actual satellite space vehicles. The 1.0 Space Vehicles activity incurs $1.5B and 94% in EAC cost growth. SEPM also appears to be indicative of EAC cost growth. This WBS activity incurs $243M and 97% in EAC cost growth. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 8 and Table 9. The “EAC Change” represents the total growth in EAC for the activity, and the “% Total EAC” represents the percentage of the final EAC that the activity accounts for. Table 9 is not all inclusive due to the fact that some activities are not present in the early stages of the contract. These activities would have a base EAC amount of zero and result in an undefined cost growth. Attempts aimed at using the first reported EAC results in impractical results. For example, the first reported EAC for 3.0 Intersegment SEPM is $400, while the final reported EAC is nearly $57M. This results in an EAC growth of over 14M percent. It is probably unrealistic to assume that contractors believed this activity would require only $400. Instead, the early estimates for many of the added activities appear to be placeholders used until additional funding became available. This was a common theme found amongst many of the nine contracts. Similar analysis conducted for level three activities can be found in Appendix B.

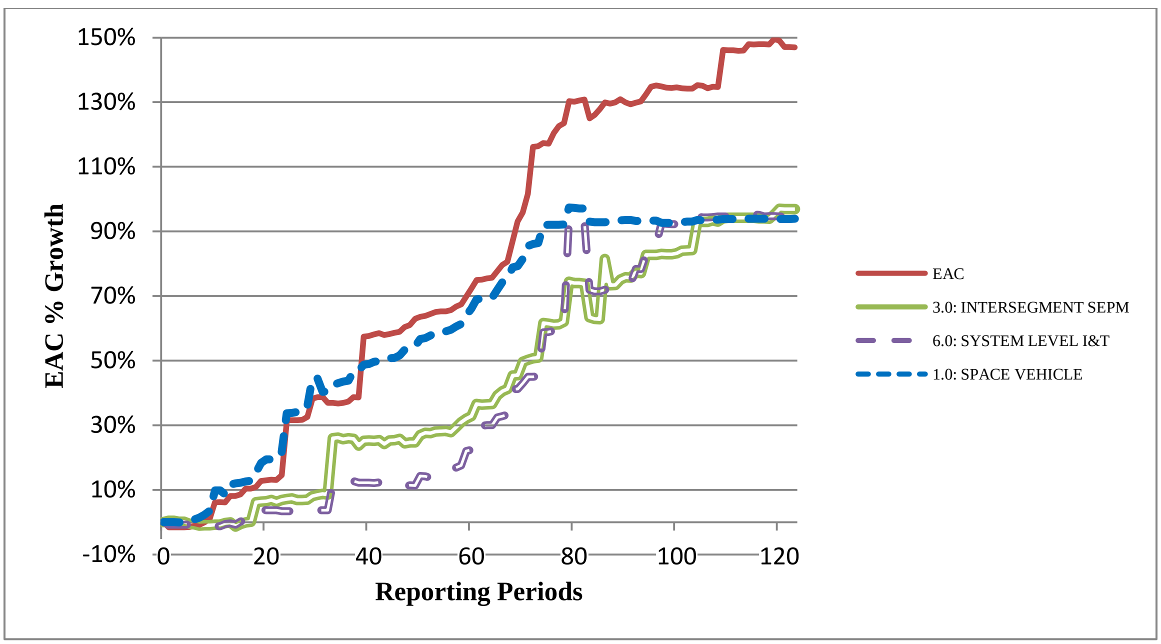


Figure 14. AEHF EAC Cost Growth

Table 8. AEHF Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.0: SPACE VEHICLE	$1,461,250	48%
1.0A: SPACE VEHICLE	$658,606	11%
7.0: OPERATIONS & SUPPORT	$426,446	7%
2.0: MISSION CONTROL SYSTEM	$357,167	14%
3.0: INTERSEGMENT SYS ENG/PGM MGMT	$243,287	8%

Table 9. AEHF Level 2 % EAC Change

WBS Activity	EAC Change	% Total EAC
3.0: INTERSEGMENT SYS ENG/PGM MGMT	97%	8%
6.0: INTERSEGMENT/SYSTEM LEVEL I&T	95%	4%
1.0: SPACE VEHICLE	94%	48%
2.0: MISSION CONTROL SYSTEM	66%	14%

FAB-T

The FAB-T contract is an agreement with Boeing for satellite communications terminals designed for airborne, ground-fixed, and ground-transportable applications. It is composed of eight level two activities and twenty level three activities. The FAB-T contract exhibited an EAC cost growth of 77% over its duration. There were two back-to-back reporting periods around the 70% completion point in which the FAB-T contract experience EAC growth exceeding 10%. The first occurred in February 2010, but no level two activities saw any representative increases. The only notable increase was to the level one UB account. The second large increase occurred in March 2010. This increase resulted in a representative growth in nearly all level two activities. Figure 15 displays the EAC cost growth of the total FAB-T contract and several key WBS level two activities contributing to this growth.

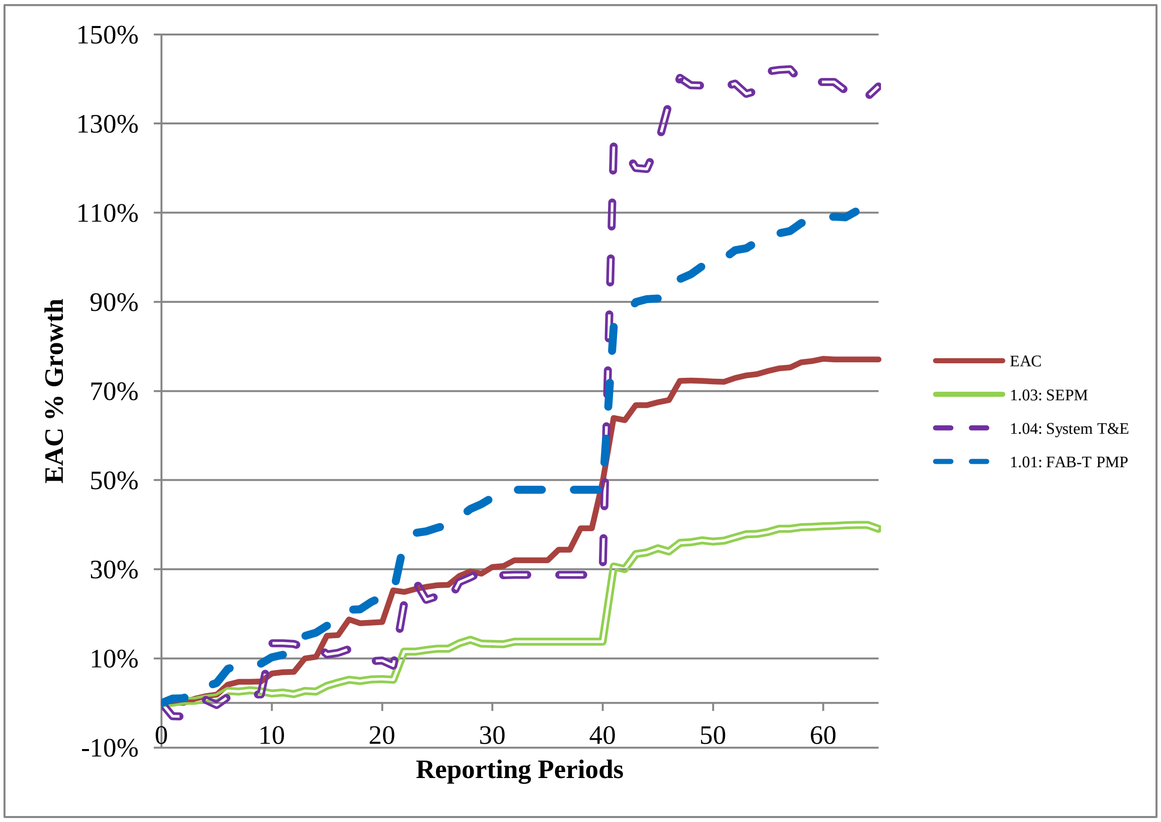


Figure 15. FAB-T EAC Cost Growth

The main level two contributors to EAC cost growth for the FAB-T contract are the Prime Mission Product (PMP) and SEPM. PMP incurred an EAC cost growth of $500M and 111%; SEPM incurred a cost growth of $126M and 39%. Although the dollar amount was not as significant, the Test and Evaluation activity experienced a 138% EAC cost growth. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 10 and Table 11. Similar analysis conducted for level three activities can be found in Appendix B.

Table 10. FAB-T Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.01: FAB-T PRIME MISSION PRODUCT (PMP)	$500,381	64%
1.03: SYSTEMS ENGINEERING / PROGRAM MANAGEMENT	$125,870	30%
1.04: SYSTEM (GOVERNMENTAL) TEST AND EVALUATION	$36,284	4%
1.05: TRAINING	$3,212	1%
1.09: OPERATIONAL/SITE ACTIVATION (GROUND)	$1,165	0.4%

Table 11. FAB-T Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.04: SYSTEM (GOVERNMENTAL) TEST AND EVALUATION	138%	4%
1.01: FAB-T PRIME MISSION PRODUCT (PMP)	111%	64%
1.03: SYSTEMS ENGINEERING / PROGRAM MANAGEMENT	39%	30.0%
1.05: TRAINING	34%	1%
1.09: OPERATIONAL/SITE ACTIVATION (GROUND)	22%	0.4%

GPS III

The GPS III contract is an agreement with Lockheed Martin for satellite communications. It is composed of five level two activities and eighteen level three activities. Three of the level two activities are not populated with data throughout the contract. The GPS III contract exhibited an EAC cost growth of 52% over its duration. The contract did not experience any cost growth exceeding 10% from one reporting period to the next; however there were three instances that cost growth exceeded 5%. In all instances, the level two 1.2 GPS III activity, which accounts for over 90% of the contract, experienced representative growth increases. The first instance occurred in December 2010 around the 50% completion point. The level one UB account and the level two 1.2 GPS III activity had the largest increases. The second increase occurred in May 2012 around the 70% completion point. This increase also resulted in representative increases to the UB account and the 1.2 GPS III activity. The third increase occurred in December 2013 around the 84% completion point. This increase resulted in a direct increase to the 1.2 GPS III activity. Figure 16 displays the EAC cost growth of the total GPS III contract and both WBS level two activities contributing to this growth.

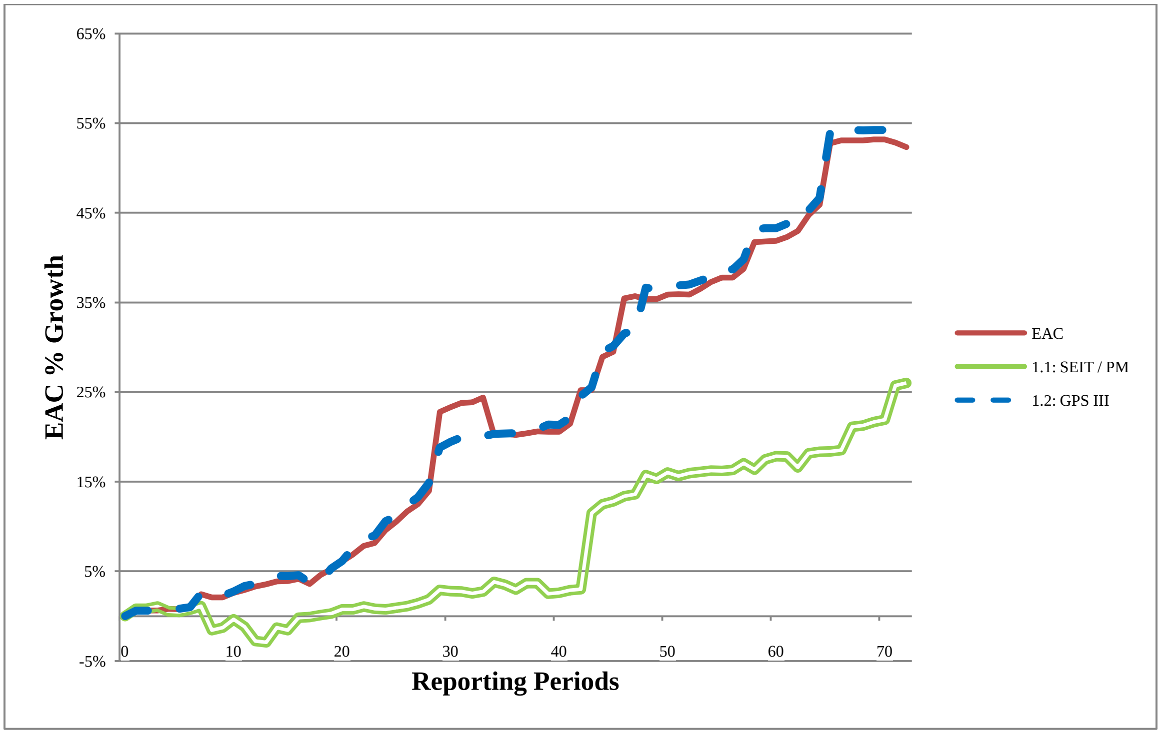


Figure 16. GPS III EAC Cost Growth

The main level two contributors to EAC cost growth for the GPS III contract are the Satellite and SEPM activities. The GPS Satellite activity incurred an EAC cost growth of $649M and 55%; SEPM grew by $35M and 26%. Results of the GPS III EAC cost growth for WBS level two activities are found in Table 12 and Table 13. Similar analysis conducted for level three activities can be found in Appendix B.

Table 12. GPS III Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.2: GPS III - GLOBAL POSITIONING SATELLITE III	$649,144	91%
1.1: SEIT / PM AND OTHER COMMON ELEMENTS	$35,201	9%

Table 13. GPS III Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.2: GPS III - GLOBAL POSITIONING SATELLITE III	55%	91%
1.1: SEIT / PM AND OTHER COMMON ELEMENTS	26%	9%

MUOS

The MUOS contract is an agreement with Lockheed Martin for five satellites aimed at significantly improving ground communications. It is composed of eight level two activities and twenty-one level three activities. Four of the level two activities are not populated with data throughout the contract. The MUOS contract exhibited an EAC cost growth of 96% over its duration. There were two periods of large cost growth exceeding 10% with the MUOS contract. Both occurred after the contract reached the 70% completion point. The first occurred in November 2008. There is an immediate increase seen in the level one UB account and the level two 1000 Satellite activity. In the following reporting period, sharp increases are seen in both the 3000 Integrated Ground and 4000 SEPM level two activities. The second large increase occurs in January 2009. This increase is primarily driven by an increase to the 3000 Integrated Ground activity. Figure 17 displays the EAC cost growth of the total MUOS contract and several key WBS level two activities contributing to this growth.

The main level two contributors to EAC cost growth for the MUOS contract are the Satellite, Integrated Ground, and SEPM. The SA activity incurs $787M and 122% in EAC cost growth; the IG activity incurs $551M and 74%; and the SEPM activity incurs $208M and 75%. The System Support activity experiences over 250% in EAC cost growth, but the costs are not as significant as other activities. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 14 and Table 15. Similar analysis conducted for level three activities can be found in Appendix B.

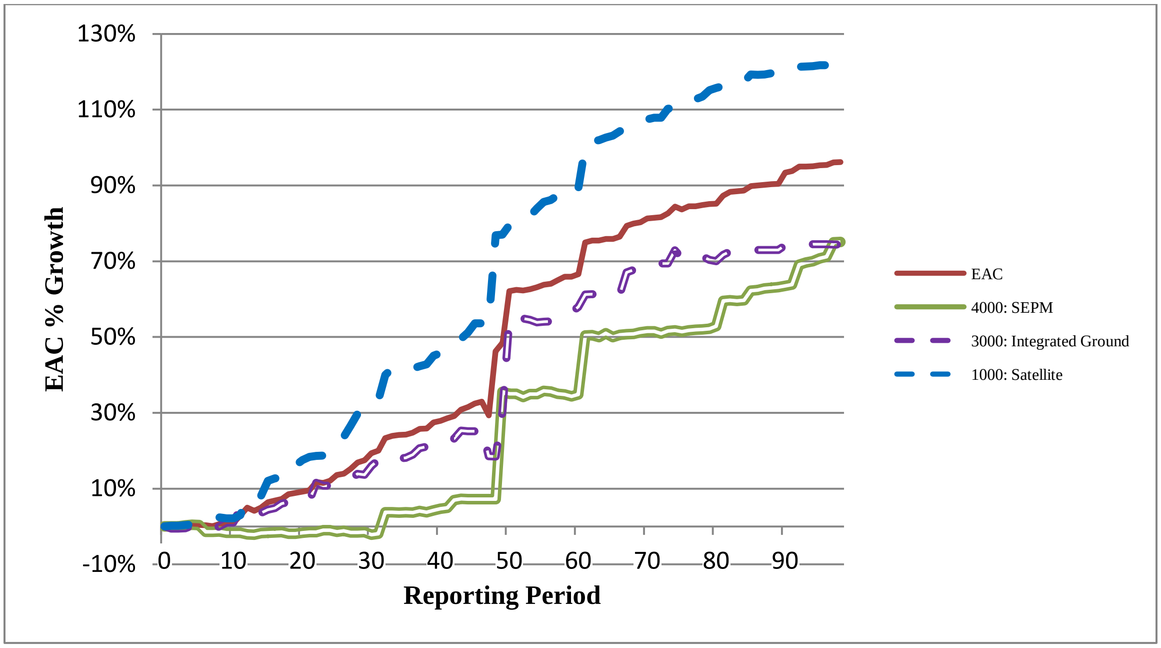


Figure 17. MUOS EAC Cost Growth

Table 14. MUOS Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1000: SATELLITE (SA)	$787,195	43%
3000: INTEGRATED GROUND (IG)	$551,115	39%
4000: SYSTEM ENGINEERING/PROGRAM MANAGEMENT	$208,176	15%
5000: SYSTEM SUPPORT AND SUPPORTABILITY (ILS)	$86,046	4%

Table 15. MUOS Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
5000: SYSTEM SUPPORT AND SUPPORTABILITY (ILS)	256%	4%
1000: SATELLITE (SA)	122%	43%
4000: SYSTEM ENGINEERING/PROGRAM MANAGEMENT	75%	15%
3000: INTEGRATED GROUND (IG)	74%	39%

WGS

The WGS contract is an agreement with Boeing for a constellation of military communications satellites. It is composed of one activity at the second WBS level and nine activities at the third WBS level; however, the traditional military standard space WBS level two naming convention does not occur until WBS level three and carries out through level nine. For this reason, levels three and four are treated as levels two and three respectively in this portion of the analysis. Three of the respective level two activities are not populated with data throughout the contract. In addition, three other activities do not experience positive EAC cost growth. The WGS contract exhibited an EAC cost growth of 207% over its duration. This cost growth was incited by three occurrences of cost growth exceeding 10%.

In all three instances, the UB account instantly exhibits a representative increase, followed by the distribution of funding to the 1.1 Satellite Vehicles and 1.2 SEPM WBS level two activities. The first occurs in January 2007 around the 16% completion point. The funding behind this increase remains in the UB account for six reporting periods before it is distributed to the 1.1 Satellite Vehicles and 1.2 SEPM WBS level two activities. The second occurs in January 2008 around the 34% completion point. This funding remains in the UB account for two reporting periods before it is distributed to the same level two accounts. The third large cost increase occurs in December 2008 around the 49% completion point. This funding results in increases to the same level two accounts spread over the next three reporting periods. Figure 18 displays the EAC cost growth of the total WGS contract and several key WBS level two activities contributing to this growth.

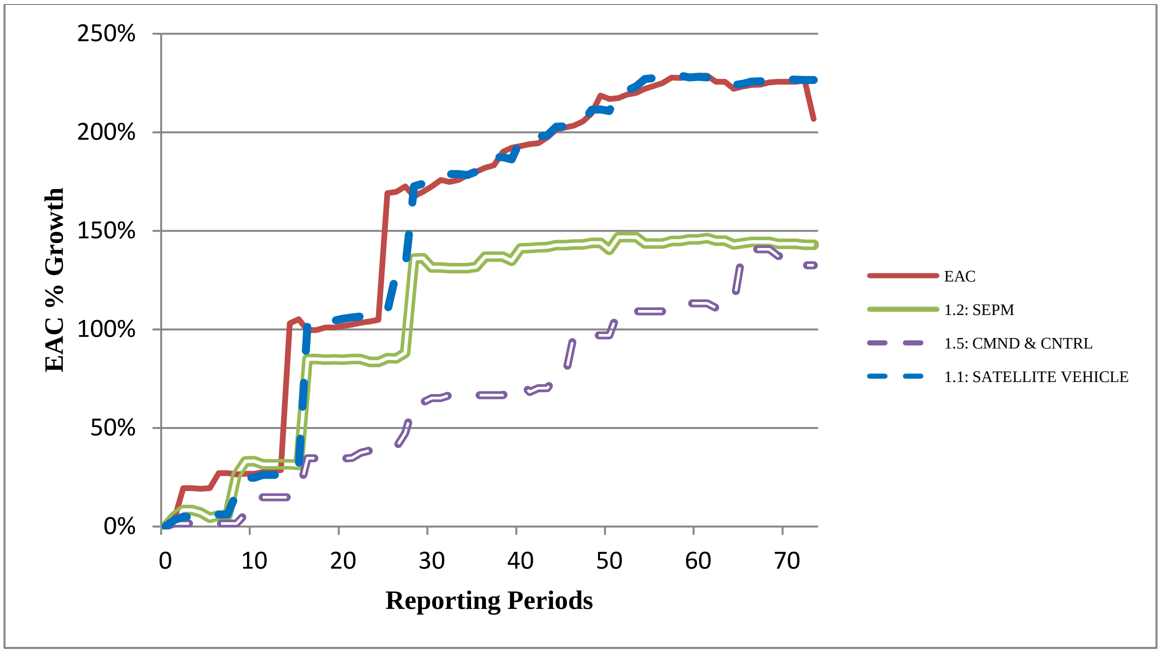


Figure 18. WGS EAC Cost Growth

The main level two contributors to EAC cost growth for the WGS contract are the Satellite Vehicle (SAV) and SEPM activities. The SAV activity incurs $569M and 227% in EAC cost growth; the SEPM activity incurs $101M and 143% in cost growth. The Command and Control activity incurs 133% EAC cost growth, but the dollar amount is relatively small. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 16 and Table 17. Similar analysis conducted for level three activities can be found in Appendix B.

Table 16. WGS Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.1: SATELLITE VEHICLE	$569,024	82%
1.2: SYSTEM LEVEL SYS ENGRG/PROG MGMT	$101,044	17%
1.5: COMMAND & CONTROL SUBSYSTEM	$3,383	1%
1.7: ENGINEERING SUPPORT/STUDIES	$818	0.1%
1.9: DATA	$51	0.01%

Table 17. WGS Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.1: SATELLITE VEHICLE	227%	82%
1.2: SYSTEM LEVEL SYS ENGRG/PROG MGMT	143%	17%
1.5: COMMAND & CONTROL SUBSYSTEM	133%	1%

EELV

The EELV contract is an agreement with the United Launch Alliance to improve U.S. space launch capabilities. It is composed of six level two activities and seventy-seven level three activities. At the time of the data collection point cut-off, the EELV contract exhibited an EAC cost decline of 3% and was 88% complete. In addition, no level two activities changed by more than 10%, and the level three activities that did experience significant percentage change were insignificant in dollar amount. As of January 2015, the EELV contract is at 55% complete, and it has an estimated EAC growth of over 100%. All populated level two WBS activities experience greater than 73% in EAC cost growth. The SEPM activity is currently estimated to incur over $300M in EAC growth which is greater than twice the amount of any other activity. Although the EELV contract is mentioned throughout this research, it is not utilized to draw conclusions and make recommendations due to its revised completion percentage.

NAVSTAR

The NAVSTAR contract is an agreement with Raytheon Company for next-generation global positioning receivers. It is composed of one level two activity and seven level three activities. Although the naming convention is atypical, the standard level two activities are represented as level three in this contract; for this reason, levels three and four are treated as levels two and three respectively. The NAVSTAR contract exhibited an EAC cost growth of 107% over its duration. This cost growth was driven by two distinct periods of growth exceeding 10%. The first instance occurred in December 2011 at the 67% completion point. Both the 15: SEPM and 13: Common Components level activities experienced immediate EAC growth. The second instance occurred the following month, January 2012, at the 69% completion point. The funding for this increase is distributed to the level one UB account prior to getting distributed to the 12: MUE PMP#2, 13: Common Components, and 15: SEPM level two activities the following month. Figure 19 displays the EAC cost growth of the total NAVSTAR contract and several key WBS level two activities contributing to this growth.

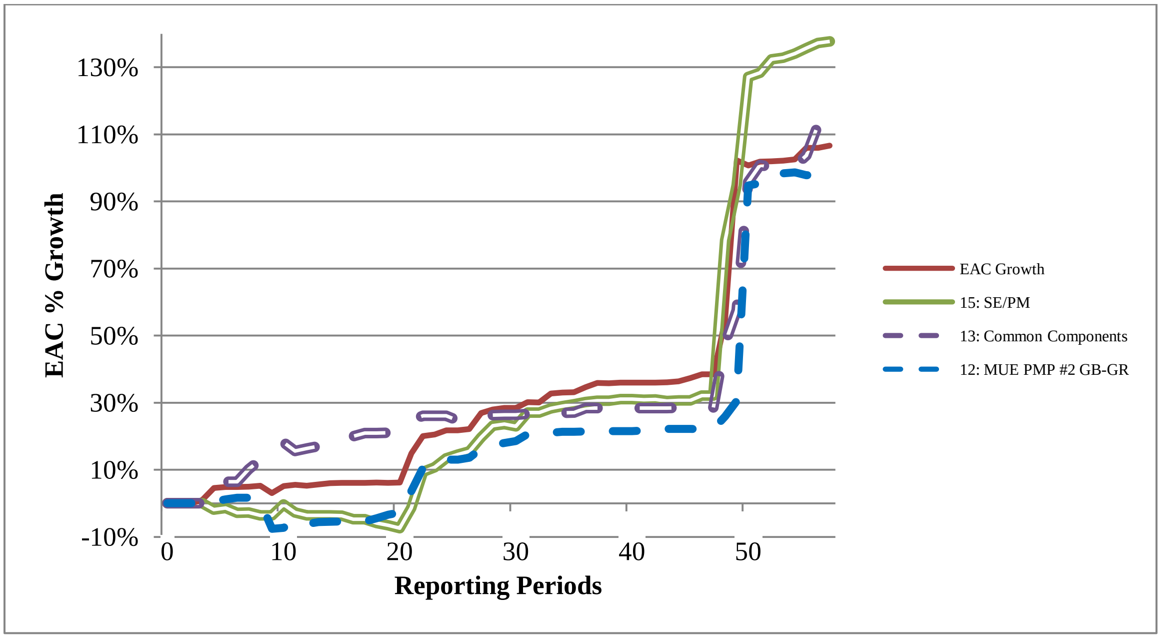


Figure 19. NAVSTAR EAC Cost Growth

The main level two contributors to EAC cost growth for the NAVSTAR contract are the Common Components, PMP#2, and SEPM activities. The Common Components activity incurs $16.6M and 115% in EAC cost growth; PMP#2 incurs $15.5M and 98%;

and SEPM incurs $14M and 138%. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 18 and Table 19. Similar analysis conducted for level three activities can be found in Appendix B.

Table 18. NAVSTAR Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
13: COMMON COMPONENTS	$16,635	27%
12: MUE PRIME MISSION PRODUCT (PMP) #2 GB-GR	$15,548	27%
15: SE/PM	$13,904	21%
11: MUE PRIME MISSION PRODUCT (PMP) #1 GRAM	$7,966	16%
18: DATA	$62	0.4%

Table 19. NAVSTAR Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
15: SE/PM	138%	21%
13: COMMON COMPONENTS	115%	27%
12: MUE PRIME MISSION PRODUCT (PMP) #2 GB-GR	98%	27%
11: MUE PRIME MISSION PRODUCT (PMP) #1 GRAM	76%	16%
18: DATA	14%	0.4%

GPS OCX

The GPS OCX contract is an agreement with Northrop Grumman Corporation for ground control communication systems. It is composed of three level two activities and twenty-three level three activities. The traditional military standard space WBS level two naming convention does not occur until WBS level three. For this reason, levels three and four are treated as levels two and three respectively for this portion of the analysis. The GPS OCX contract exhibited an EAC cost growth of 33% over its duration. The contract did not experience any cost growth exceeding 10% from one reporting period to the next; however there were two instances of cost growth exceeding 5%. In both occurrences, the level one UB account experiences a representative increase; funds are then distributed to the 1.01 OCX SEPM WBS level two activity. The first instance occurred in February 2009 around the 76% completion point, and the second instance occurred in September 2009 around the 94% completion point. Figure 20 displays the EAC cost growth of the total GPS OCX contract and several key WBS level two activities contributing to this growth.

The main contributor to EAC cost growth for the GPS OCX contract is the SEPM activity. The SEPM activity incurs $36M and 59% in EAC cost growth. Many of the activities exhibiting extremely high levels of cost growth are not practically significant in relation to total contract costs. Results of the greatest contributors to EAC cost growth for WBS level two are found in Table 20 and Table 21. Similar analysis conducted for level three activities can be found in Appendix B.

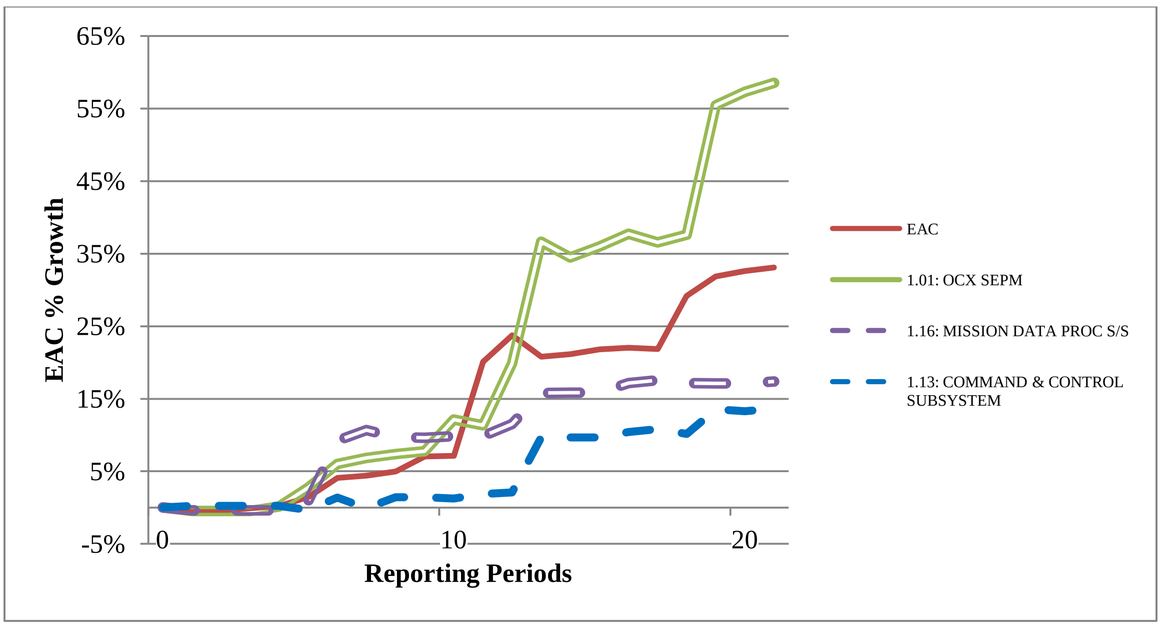


Figure 20. GPS OCX EAC Cost Growth

Table 20. GPS OCX Level 2 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.01: OCX SYSTEMS ENGINEERING / PROGRAM MGMT	$36,048	55%
1.18: OCX MISSION INFRASTRUCTURE S/S	$2,239	19%
2.02: GPS SYS/SYS RQS VERIF, VALADATION	$1,800	1%
1.13: COMMAND & CONTROL SUBSYSTEM (TT&C)	$1,447	7%
1.12 GROUND TERMINAL SUBSYSTEMS	$1,371	5%

Table 21. GPS OCX Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
2.01: SYSTEM INTEGRATION DEMOS	890%	0.4%
2.03: SYSTEM OF SYSTEMS TEST SUPPORT	466%	0.1%
2.02: GPS SYS/SYS RQS VERIF, VALADATION	301%	1%
1.17: MISSION DATA ANALYS & DISSEMINATION S/S	79%	1%
1.01: OCX SYSTEMS ENGINEERING / PROGRAM MGMT	59%	55%

WGS 10-C

The WGS 10-C contract is an agreement with Boeing for the seventh satellite of a constellation of satellites. It is composed of two level two activities and five level three activities. The WGS 10-C contract exhibited an EAC cost growth of 6% over its duration. Although this level of cost growth would be acceptable by most standards, analysis is still conducted on any sharp increases. There was one instance of cost growth exceeding 5%. This growth occurred in January 2012 around the 75% completion point. The growth resulted in an increase to the 1.2 Space Vehicle WBS level two activity. Figure 21 displays the EAC cost growth of the total WGC 10-C contract and both WBS level two activities contributing to this growth.

The main level two contributors to EAC cost growth for the WGS 10-C contract are the SEPM and Space Vehicle activities. These are also the only two activities at level two. The SEPM activity incurs a $5M and 11% EAC cost growth; Space Vehicle incurs $3.7M and nearly 4%. Results of these contributors to EAC cost growth for WBS level two are found in Table 22 and Table 23. Similar analysis conducted for level three activities can be found in Appendix B.

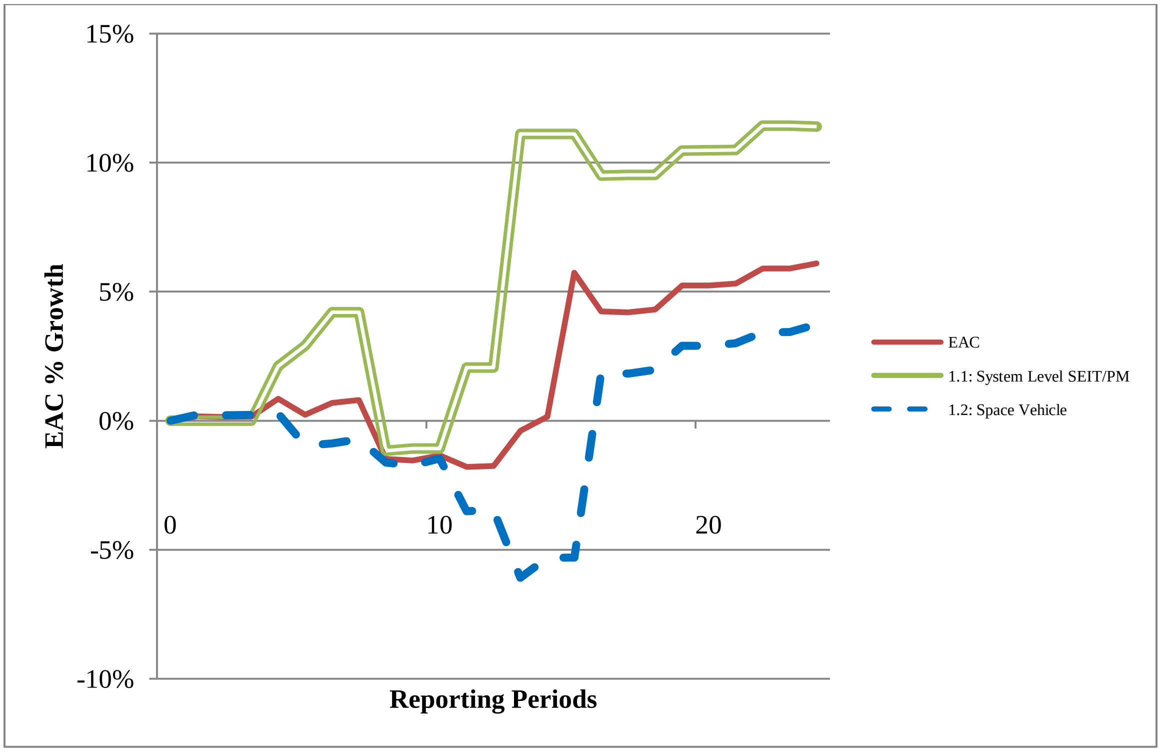


Figure 21. WGS 10-C EAC Cost Growth

Table 22. WGS C-10 Level 2 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.1: SYSTEM LEVEL SEIT/PM	$5,075	32%
1.2: SPACE VEHICLE	$3,727	68%

Table 23. WGS C-10 Level 2 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.1: SYSTEM LEVEL SEIT/PM	11%	32%
1.2: SPACE VEHICLE	4%	68%

Discussion

The only true commonality amongst cost drivers for the nine space contracts is the SEPM activity. Based on the findings, it would seem that SEPM is seemingly a significant factor in determining EAC cost growth. The fault in this logic is that SEPM is commonly estimated as a factor of either total costs or the PMP (AFCAA, 2007). Nonetheless, analysis is conducted to determine if there are certain traits involving SEPM that may dictate EAC cost growth.

Table 24 displays the descriptive statistics of the eight contracts and the SEPM WBS activity. Data is gathered at each monthly reporting period for every contract, and the percentage of SEPM is calculated. The findings suggest that there is not a positive correlation between the average amount of SEPM and the EAC cost growth. It would almost seem that the fewer amounts spent on SEPM, the higher the EAC cost growth. The standard deviations of the monthly SEPM percentages are relatively low, and there is a strong linear dependency between the percent change of SEPM and percent change of total EAC. These findings would support the thought of SEPM calculated as a percentage of total costs.

Table 24. SEPM Descriptive Statistics

Program Name	% Complete	EAC Cost Growth	Avg Monthly SEPM %	Std Dev	SEPM vs Tot EAC (Pearson's R)
AEHF	99%	147%	8%	0.8%	0.98
FAB-T	92%	77%	33%	2.8%	0.99
GPS III	87%	52%	9%	0.7%	0.95
MUOS	97%	96%	14%	0.9%	0.98
WGS	100%	207%	18%	2.1%	0.97
NAVSTAR GPS	100%	107%	18%	1.4%	0.99
GPS OCX	100%	33%	49%	3.4%	0.95
WGS 10-C	100%	6%	32%	1.0%	0.82

In addition to assessing the SEPM activity, attempts are made to group certain level two WBS activities together by calling them the Prime Mission Product (PMP) of the contract. By grouping activities in this manner, the goal is to discover any trends that may exist between the activities' cost growth and the programs' overall cost growth. In most cases, it is either explicitly stated or relatively intuitive in determining what might be called the PMP. For the purpose of this portion of the analysis, the PMP of the contract is defined as the WBS level activity that accounts for the largest percentage of the total contract costs. The one exception to this definition is the GPS OCX contract, in which the SEPM activity represents the highest percentage of costs. This exception is made due to the evidence suggesting that SEPM is often computed as a factor of another cost.

The PMP for each contract is assessed from the 20% to 70% completion points to determine if trends exists that are representative of EAC cost growth. The findings suggest that there are no common traits between the mid-acquisition EAC cost growth of the PMP and the overall cost growth of the contract. This assessment is conducted for the total contract mid-acquisition EAC cost growth as well. In both assessments, there does not appear to be any consistent themes. Some contracts experience PMP and total EAC cost growth early on, while others do not. In either case, the data do not present a strong argument to suggest that mid-acquisition growth will be indicative of overall EAC growth. Results of these assessments are found in Appendix C.

Summary

In summary, this chapter provided the results of the aforementioned methodology taken to answer the research and investigative questions. Analyses were presented from both phase one and phase two of the methodology. Many of the implications of these results were presented and briefly discussed in this chapter; however Chapter 5 presents the overarching conclusions and closing thoughts for the research.

V. Conclusions and Recommendations

Introduction

This thesis provides examination of the premise that lower level WBS data can improve assessments made on contract performance midway through its completion. Past research suggests that further investigation is needed to assess the distinct features of specific commodity types at various completion percentages. This thesis explores some of those distinctions within the space commodity. Analysis is conducted using WBS level two and three data in hopes of discovering methods that produce more accurate Estimate at Complete (EAC) figures and finding out which activities act as potential triggers for EAC cost growth.

Conclusions of Research

In attempting to answer the question of whether or not lower level WBS data can improve the overall accuracy of EVM based prediction methods, several findings were discovered. From the first portion of the analysis, we learned that lower level EVM data did not produce more accurate EAC figures. Our analysis focused on summing up the activities of the lower levels and using those totals in a BCWP model. As a result, one conclusion that can be drawn with little debate is that, when predicting program EACs, the use of lower level WBS data totals in models that are associated with some sort of burn rate calculation will produce estimates that are not as accurate as the program level data. This conclusion is driven by the fact that certain summary level accounts do not get distributed down to lower WBS levels.

Conclusions about the performance of the BCWP model itself can be drawn as well. As mentioned in Chapter 4, the model's accuracy seems to level out at the 60% completion point. This leveling out is the result of the model's tendency to overestimate final costs particularly in the latter stages of the contract. This discovery begs the question about the validity of the model altogether. In other words, if all the model does is produce an estimate that is higher than current methods, then it would make sense that it is generally more accurate. It is well known that DoD contracts are historically behind schedule and over budget. In the infrequent instances where a contract is not over budget, the BCWP model may end up being no more accurate than the EAC Composite or some other widely accepted calculation.

The second portion of the research brought on many interesting findings. First, the level of variation even within the same commodity was quickly brought to light. The use of the traditional Military Standard 881C WBS composition was very inconsistent. In many cases, lower WBS levels had to be treated as levels two and three just to make comparisons across different contracts. The assumption that the adjusted levels are accurately portrayed presents additional limitations to the findings of this study. Even with the adjustments, level two and three activities still vary greatly between contracts and within programs. This variation led to no common themes or elements being found that are indicative of EAC cost growth. Each contract seemed to have its own unique story.

An additional finding was the frequency utilization of the program level Undistributed Budget (UB) account. Many contracts appeared to use this account as a buffer for newly acquired funds. The issue this presents when conducting analyses is that it becomes difficult to track lower level cost drivers due to the lag in the distribution of the budget. While funding remains in the UB account, there are positive and negative adjustments made at lower levels that may or may not be related to the additional funding received. Analysts would have to guess where the funding was distributed based on the timing and magnitude of change found in the lower level activities. The Format 5 CPR provides some explanation for changes; however, the explanations are not always easily interpreted, provide limited details, and do not often point to a specific WBS activity.

Significance of Research

The findings presented in this research may at first glance appear to challenge the necessity of having lower level contract data altogether. The reality is that it may still be too early to draw a consideration that drastic. This research does, however, point out the fact that standardization of lower level WBS composition is desperately needed. The current methods of reporting lower level data do not seem to provide any additional benefits that cannot be gained by assessing contracts at the program level. Until a more uniform approach is adopted, it may be difficult for program managers and cost analysts to highlight activities across multiple contracts that are effecting total program costs.

The general statement that states: lower WBS levels should sum up to the level immediately preceding it, is a common misconception. This train of thought stems from what is known as the "100% Rule". Military Standard 881C defines this rule as the principle that states "the next level of decomposition of a WBS element (child level) must represent 100% of the work applicable to the next higher level (parent level)" (DoD, 2011). Although an experienced analyst may know the inherent assumption in this rule, many others do not. The assumption made is that every parent in the higher level actually has a child element. As seen in this research with the UB account, this is not always the case. If a higher level WBS activity does not have any lower level elements, the sum of the subsequent level will be lower than the higher level if this difference is not accounted for.

Recommendations for Future Research

This research defined model performance based solely on accuracy to the last reported EAC, but is accuracy really the only important attribute? A well-defined cost estimate should be somewhat accurate, but it should also be credible, reliable, and comprehensive; the same should hold true for a cost estimating model. The idea that the BCWP model may simply be a calculation method that produces higher cost estimates was presented earlier in this chapter. Additional research should be conducted to determine the robustness of the BCWP model. How well does the model do in realms other than space? How well does the model perform with contracts that are not behind schedule and over budget? Research should analyze alternative variables in addition to accuracy to measure model performance.

The assessment of lower level data in a commodity other than space also presents an opportunity for additional research. Space has a long history of vastly exceeding cost estimates. Maybe a specific commodity that has been more stable in terms of cost estimating will have less variation at the lower levels.

Summary

There is little doubt that the Department of Defense's data requirement for the first three WBS levels results in added contractor costs. The findings of this research question the benefits of this data in the current construct. From a macro-perspective, this research also highlights the difficulty in attempting to predict EAC cost growth altogether. As Keller et al. also alluded to, perhaps effort should be redirected from improving cost estimation models, and instead aimed towards improving the way DoD management controls program costs (Keller et al., 2014). An array of reasons exists for program cost growth, each having a unique effect on the program's activities, yet, there lies an inherent expectation for cost estimates to holistically capture those changes and still remain somewhat accurate. In the end, this expectation may not lead to improved cost estimate accuracy at all; the result could very well be arbitrarily inflated estimates that are seen as improvements to the status quo based solely on their ability to capture a portion of the unpredictable cost growth likely to be seen.

Appendix A: Format 1 Example

Unclassified
CLASSIFICATION

COST PERFORMANCE REPORT
FORMAT 1 - WORK BREAKDOWN STRUCTURE
DOLLARS IN Thousands
Page 1 of 3

1. CONTRACTOR	2. CONTRACT	3. PROGRAM	4. REPORT PERIOD
a. NAME US LHC Accelerator Project Office	a. NAME US LHC	a. NAME US LHC Accelerator Project	a. FROM *(YYMMDD)* 990201
b. LOCATION *(Address and ZIP Code)* P.O. Box 500 MS 343 Batavia, IL 60510	b. NUMBER 1 c. TYPE: FPI d. SHARE RATIO: 100/0 100/0	b. PHASE *(X one)* x RDT&E x PRODUCTION	b. TO *(YYMMDD)* 990228

5. CONTRACT DATA

a. QUANTITY	b. NEGOTIATED COST	c. EST. COST AUTH UNPRICED WORK	d. TARGET PROFIT/ FEE	e. TARGET PRICE	f. ESTIMATED PRICE	g. CONTRACT CEILING	h. ESTIMATED CONTRACT CEILING
0/0/0	89,417.8	0.0	0.0 / 0.0%	89,417.8	89,417.8	110,000.0	110,000.0

6. ESTIMATED COST AT COMPLETION

	MANAGEMENT ESTIMATE AT COMPLETION (1)	CONTRACT BUDGET BASE (2)	VARIANCE (3)
a. BEST CASE	89,417.8		
b. WORST CASE	89,417.8		
c. MOST LIKELY	89,417.8	89,417.8	0.0

7. AUTHORIZED CONTRACTOR REPRESENTATIVE

a. NAME *(Last, First, Middle Initial)*	b. TITLE
Jim Strait	US LHC Project Manager
c. SIGNATURE	d. DATE SIGNED *(YYMMDD)* 990323

8. PERFORMANCE DATA

ITEM		CURRENT PERIOD					CUMULATIVE TO DATE					REPROGRAMMING ADJUSTMENTS		AT COMPLETION		
		BUDGETED COST		ACTUAL	VARIANCE		BUDGETED COST		ACTUAL	VARIANCE						
(1)		WORK SCHEDULED (2)	WORK PERFORMED (3)	COST WORK PERFORMED (4)	SCHEDULE (5)	COST (6)	WORK SCHEDULED (7)	WORK PERFORMED (8)	COST WORK PERFORMED (9)	SCHEDULE (10)	COST (11)	COST VARIANCE (12)	BUDGET (13)	BUDGETED (14)	ESTIMATED (15)	VARIANCE (16)
a. WORK BREAKDOWN STRUCTURE ELEMENT																
1.1 - Interaction Regions	2	621.5	307.8	664.0	-313.7	-356.2	11,283.0	8,792.9	10,064.7	-2,490.1	-1,271.8			35,919.7	34,701.4	1,218.3
1.1.1 - Quadrupoles	3	439.5	228.5	535.2	-211.0	-306.7	7,983.0	6,777.6	7,761.3	-1,205.4	-983.7			21,904.7	21,682.9	221.8
1.1.1.1 - Tooling	4	109.6	21.3	36.3	-88.2	-15.0	1,070.8	917.8	1,018.4	-153.1	-100.6			1,606.4	1,554.0	52.4
1.1.1.2 - Cold Mass	4	17.3	21.8	240.4	4.5	-218.6	1,436.1	1,380.4	2,431.0	-55.8	-1,050.6			4,056.2	5,051.1	-994.9
1.1.1.3 - Cryostat	4	3.8	0.0	6.1	-3.8	-6.1	123.8	105.9	486.7	-17.9	-380.9			3,298.4	3,661.3	-362.9
1.1.1.4 - Magnet Testing	4	154.2	0.7	15.8	-153.5	-15.1	449.8	215.9	325.0	-233.9	-109.1			2,675.8	2,550.9	124.8
1.1.1.5 - Cable & Wedges	4	7.2	0.5	19.4	-6.7	-18.9	1,260.0	858.9	710.4	-401.1	148.4			1,483.7	934.2	549.5
1.1.1.6 - Shipping	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			380.9	380.9	0.0
1.1.1.7 - EDIA	4	147.4	184.1	217.2	36.7	-33.1	3,642.5	3,298.8	2,789.7	-343.7	509.1			8,403.4	7,550.6	852.8
1.1.2 - Dipoles	3	136.1	69.8	77.8	-66.3	-8.0	2,203.9	1,124.9	1,425.5	-1,079.1	-300.6			5,150.6	4,372.2	778.4
1.1.2.1 - Tooling	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.6	0.0	-18.6			158.8	177.4	-18.6
1.1.2.2 - D1 Production	4	46.9	15.6	22.4	-31.3	-6.9	375.6	191.8	324.3	-183.8	-132.5			684.9	633.6	51.3
1.1.2.3 - D2 Production	4	72.2	54.2	49.5	-18.0	4.7	1,690.9	844.0	1,015.4	-846.9	-171.4			2,453.9	1,778.4	675.5
1.1.2.4 - Magnet Testing	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			527.2	527.2	0.0
1.1.2.5 - EDIA	4	17.0	0.0	5.8	-17.0	-5.8	137.5	89.1	67.2	-48.4	21.9			1,325.9	1,255.6	70.3

Unclassified
CLASSIFICATION *(When filled in)*

Appendix B: Level 3 EAC Analysis

AEHF Level 3 $ EAC Change ($K)

WBS Activity	EAC Change	% Total EAC
1.2: EHF PAYLOAD	$971,461	36%
1.2A: EHF PAYLOAD	$442,523	7%
2.1: MISSION OPERATIONS ELEMENT	$365,057	14%
7.3: INTERIM MAINTENANCE	$276,573	4%
1.1: SPACECRAFT BUS	$233,617	7%

AEHF Level 3 % EAC Change

WBS Activity	EAC Change	% Total EAC
1.4: SPACE VEH AGE/MAGE	852%	1%
1.6: SPACE VEH I&T	690%	2%
1.5: SPACE VEH SE/PM	233%	1%
1.3: LAUNCH SUPPORT OPERATIONS	233%	0.4%
3.1: SYSTEM ENGINEERING - 16	160%	3%

FAB-T Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.01.01: MODEM PROCESSOR GROUP (MPG)	$209,891	31%
1.01.03: ANTENNA	$129,436	16%
1.03.02: PROGRAM MANAGEMENT	$79,225	21%
1.01.07: INTEGRATION ASSEMBLY TEST AND CHECKOUT	$75,871	6%
1.03.01: SYSTEMS ENGINEERING	$46,646	9%

FAB-T Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.01.07: INTEGRATION ASSEMBLY TEST AND CHECKOUT	572%	6%
1.12.02: MAJOR SUBCONTRACTOR UNDISTRIBUTED BUDGET	274%	0.1%
1.01.04: ANCILLARY EQUIPMENT	227%	1%
1.04.01: DEVELOPMENT TEST AND EVALUATION	148%	3%
1.01.03: ANTENNA	121%	16%

GPS III Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.2.3: COMMUNICATION / PAYLOAD	$295,865	35%
1.2.1: SEIT & PM & OTHER COMMON ELEM	$154,365	26%
1.2.2: SPACECRAFT BUS	$149,873	27%
1.2.7: LAUNCH OPS & MISSION SPT	$53,721	4%
1.1.6: PECULIAR SUPPORT EQUIPMENT	$12,622	2%

GPS III Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.2.7: LAUNCH OPS & MISSION SPT	333%	4%
1.1.4: TRAINING	181%	0.1%
1.2.3: COMMUNICATION / PAYLOAD	73%	35%
1.1.6: PECULIAR SUPPORT EQUIPMENT	52%	2%
1.2.1: SEIT & PM & OTHER COMMON ELEM	43%	26%

MUOS Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1500: PAYLOAD (PL)	$429,616	25%
3100: IG SE/PMD	$176,338	12%
4100: SYSTEM ENGINEERING, INTEGRATION & TEST (SEIT)	$162,463	11%
1200: SATELLITE ASSEMBLY, INTEGRATION AND TEST (AI&T)	$141,010	6%
3300: GROUND TRANSPORT (GT)	$120,163	13%

MUOS Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
5200: PRE-DELIVERY INTERIM CONTRACTOR SUPPORT	328%	2%
1200: SATELLITE ASSEMBLY, INTEGRATION AND TEST (AI&T)	264%	6%
3800: USER ENTRY (UE)	245%	4%
5100: LOGISTICS SUPPORT AND SUPPORTABILITY DEV	213%	2%
1100: SATELLITE SE/PM	135%	5%

WGS Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.1.1: SPACECRAFT BUS	$226,239	31%
1.1.2: COMMUNICATIONS PAYLOAD	$224,971	37%
1.2.2: PROGRAM MANAGEMENT	$98,297	16%
1.1.4: SATELLITE VEH INTEG ASSY AND TEST (CA)	$73,704	9%
1.1.7: LAUNCH & EARLY ORBIT OPERATIONS	$42,251	4%

WGS Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.1.4: SATELLITE VEH INTEG ASSY AND TEST (CA)	344%	9%
1.1.1: SPACECRAFT BUS	281%	31%
1.2.2: PROGRAM MANAGEMENT	153%	16%
1.1.2: COMMUNICATIONS PAYLOAD	151%	37%
1.2.1: SYSTEM LEVEL SYS ENGRG	42%	1%

NAVSTAR Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
131: COMMON H/W	$12,340	15%
152: PROGRAM MGMT	$11,690	15%
121: GB-GRAM-M SSI HARDWARE	$8,214	13%
123: GB-GRAM-M SSI IAT&C	$4,922	9%
113: GRAM S/M IAT&C	$4,642	7%

NAVSTAR Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
131: COMMON H/W	274%	15%
152: PROGRAM MGMT	194%	15%
113: GRAM S/M IAT&C	148%	7%
124: GB-GRAM-M SSI SE/PM	127%	2%
111: GRAM S/M HARDWARE	127%	3%

GPS OCX Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.01.02: PROGRAM MANAGEMENT	$22,954	30%
1.01.01: SYSTEMS ENGINEERING	$10,689	22%
1.01.04: SPECIAL STUDIES	$2,542	1%
2.02.01: GPS SYS/SYS RQS VERIF, VALADATION	$1,800	1%
1.18.03 DEVELOPMENT LABS	$1,256	9%

GPS OCX Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
2.01.01: SYSTEM INTEGRATION DEMOS	890%	0.4%
2.03.01: SYSTEM OF SYSTEMS TEST SUPPORT	466%	0.1%
2.02.01: GPS SYS/SYS RQS VERIF, VALADATION	301%	1%
1.13.02: MASTER CONTROL STATION (MCS)	90%	1%
1.18.07: CREW TRAINING SYSTEM (CTS)	90%	0.4%

WGS C-10 Level 3 $ EAC Change ($K)

WBS ACTIVITY	EAC Change	% Total EAC
1.1.2: PROGRAM MANAGEMENT	$5,195	31%
1.2.3: PAYLOAD	$4,814	52%
1.2.1: SPACE VEHICLE SEIT AND SUPPORT EQUIPMENT	-$851	4%
1.2.2: BUS	-$236	12%
1.1.1: END TO END SYSTEMS ENGINEERING	-$120	1%

WGS C-10 Level 3 % EAC Change

WBS ACTIVITY	EAC Change	% Total EAC
1.1.2: PROGRAM MANAGEMENT	12%	31%
1.2.3: PAYLOAD	6%	52%
1.2.2: BUS	-1%	12%
1.1.1: END TO END SYSTEMS ENGINEERING	-5%	1%
1.2.1: SPACE VEHICLE SEIT AND SUPPORT EQUIPMENT	-13%	4%

Appendix C: Mid-Acquisition EAC Cost Growth by Completion Percentage

Mid-Acquisition PMP EAC Cost Growth by Completion Percentage

Program Name	% Complete						Last Reported EAC Cost Growth
	20%	30%	40%	50%	60%	70%	
AEHF	0%	1%	8%	13%	33%	35%	147%
GPS III	4%	4%	9%	19%	20%	30%	52%
MUOS	8%	16%	20%	33%	42%	48%	96%
WGS	5%	17%	103%	129%	174%	180%	207%
NAVSTAR GPS	0%	1%	2%	-8%	-5%	-6%	107%
GPS OCX	-1%	-1%	0%	2%	3%	4%	33%
WGS 10-C	0%	-1%	-1%	-2%	-4%	-6%	6%

Mid-Acquisition Total EAC Cost Growth by Completion Percentage

Program Name	% Complete						Last Reported EAC Cost Growth
	20%	30%	40%	50%	60%	70%	
AEHF	-2%	-1%	6%	11%	58%	63%	147%
GPS III	3%	5%	8%	23%	20%	29%	52%
MUOS	4%	9%	12%	19%	25%	29%	96%
WGS	19%	26%	100%	170%	170%	180%	207%
NAVSTAR GPS	1%	5%	5%	3%	6%	6%	107%
GPS OCX	0%	0%	1%	4%	4%	5%	33%
WGS 10-C	1%	1%	1%	-2%	-2%	0%	6%

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Vita

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14. ABSTRACT Predicting Estimates at Complete (EAC) for Department of Defense (DoD) space programs has proven to be a daunting task. Although the use of Earned Value Management (EVM) formulations have been around for several decades, research has validated the need to conduct specific investigations based on commodity type and contract completion percentage. A recent Air Force Cost Analysis Agency (AFCAA) study improved space program EAC accuracy using a Budgeted Cost of Work Performed (BCWP) model. This research was conducted based exclusively on program level Work Breakdown Structure (WBS) data. The DoD requires contractors to report lower level WBS data, and current guidance supports the notion that lower level data are useful for program analysis. This study assesses the BCWP model using lower level WBS data. In addition, the second phase of this research investigates whether or not knowledge concerning lower level WBS activities can improve the analytical ability to predict EAC cost growth. The results indicate that lower level WBS data does not improve space program EAC accuracy in combination with the BCWP model. This research also finds that space programs contain a great deal of variability at lower level WBS activities making it difficult to draw comparisons across contracts.						
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