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Comparing Estimated to Actual Development Budgets for Air Force Space Programs

Christopher J. Elworth

COMPARING ESTIMATED TO ACTUAL DEVELOPMENT BUDGETS FOR AIR FORCE SPACE PROGRAMS

Christopher J. Elworth, Captain, USAF

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DEPARTMENT OF THE AIR FORCE
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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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Captain, USAF

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Abstract

The accuracy of budget estimates is vital in ensuring cost efficiency and decreasing the possibility of budget and schedule growth. The goal of this study was to determine when budget estimates increase and what may cause those increases. Percent schedule and linear interpolation was used to analyze the budget changes. Space program budget growth does not increase at a constant rate between Milestone B (MS B) and Initial Operational Capability (IOC). When an exponential curve was fit to the deviations in budget growth, the mean and median R^2 for the programs in this study were .83 and .91, respectively. Many programs had negative annual budget growth in the first one or two fiscal years of their schedule, this even included large satellite programs with substantial budget growth later in their schedules. Much of the cumulative % budget growth was also in the later fiscal years of the schedule between MS B and IOC. The mean and median of cumulative % budget growth change at the 90% to 100% schedule mark are 25.30% and 22.51% than while they are only 7.12% and 0.96% at the 30% to 40% schedule mark. The original objective, to determine how close previous fiscal year budget estimates are to the actual budget, was also achieved. This accuracy has increased in recent years as well. As a program nears a specific fiscal year, the mean difference in the estimate to actual decreases from 42.3% four years out to 15.9% one year out. A confidence interval can also be created for these differences. At four years out, there is 95% confidence that the budget estimate is between 38.2% and 51.3% of the actual budget, and, at one year out, there is 95% confidence that the budget estimate is between 8% and 21.6% of the actual budget.

Acknowledgments

I want thank to my committee, Dr. Edward D. White, Dr. Jonathan D. Ritschel, and Major Gregory E. Brown, and all of the cost analysts and program managers at LCMC and SMC, for their guidance and support throughout the course of this thesis effort. I also can't forget all of my 19M Cost Analysis classmates who helped me get through the suck.

Christopher J. Elworth

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I. Introduction

Background

Space is becoming increasingly more important for defense. There has been much growth and change in the space realm in recent decades, ultimately culminating in the proposed creation of a new military branch specifically for space by 2022, first officially suggested by President Trump in March of 2018 (Koren, 2018). However, behind all of this growth is a history of ballooning costs, schedule overruns, and fragmented leadership (Chaplain, 2017). Throughout the life cycle of a space program, expected costs tend to change significantly from those at initial project conception and there are many issues that may plague the program, increase the cost, and delay the schedule. To help provide reliable cost and schedule estimates and decrease the difference between those and the actual costs and schedule, analysis and estimating techniques are utilized through the life cycle of a program.

These issues are not specific to space acquisition. Research even dating back to the 1950s (Younossi, 2007) reveals extreme problems for cost analysis for DoD weapons systems. In 1959, Marshall and Meckling provide two aspects that create inaccurate estimates: First such estimates are “biased” toward over-optimism. Second, aside from the bias, the errors in the estimate evidence a substantial variation. Younossi also showed that development growth in the 1970s – 1990s remained high with no significant improvement, despite multiple acquisition reforms and management initiatives.

Belcher and Dukovich (1999) introduced 12 different, specific aspects which contribute to Research and Development (R&D) costs. Unger (2001) illustrated that funding constraints explained 53.4% of the cost overrun and 50.5% of schedule slippage. He estimated a relationship between initial budget profile and schedule slippage and cost overruns. Even though we do not look at budget profiles in this study, we estimate a similar relationship comparing the estimated R&D costs to the actual costs. This can identify potential factors, such as the ones illustrated in Figure 1 from Belcher and Dukovich (1999), which explain the difference and may be causing similar schedule slippages, cost overruns, and any trends in the Space acquisition programs as well.

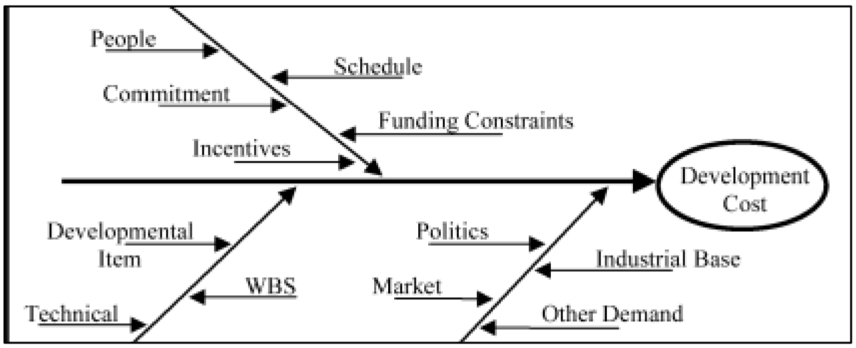

Figure 1: Factors Contributing to Development Costs

This research, however, looks specifically into space acquisition Research, Development, Training & Evaluation (RDT&E) costs. There have been many studies analyzing cost increases in weapons systems, a few looking specifically Air Force and National Aeronautics and Space Administration (NASA) space systems' RDT&E costs. In Government Accountability Office (GAO) (1992) analyzed 29 NASA projects with at least $200 million in development costs and reported that 25 of them experienced a median cost growth 77 percent and GAO (2004) found of 27 development space projects, over half experienced cost growth, some as much as 94%.

The schedule performance of the NASA portfolio of major projects has deteriorated as shown in Figure 2, but the extent of cost performance deterioration is unknown. The average launch delay for the portfolio in 2018 was 12 months, the highest delay GAO has reported in its

10 years of assessing major NASA projects and up from less than 4 months in 2017 (GAO, 2018).

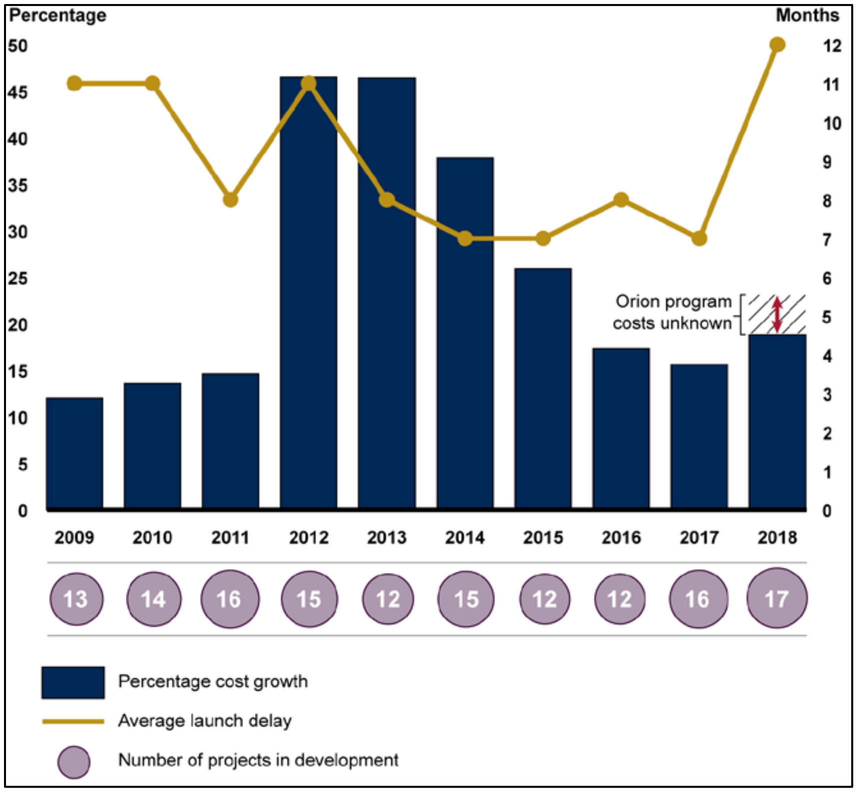

Figure 2: NASA Major Project Portfolio Cost & Schedule Performance Deteriorated 2018

These issues are not just limited to NASA and phasing of estimates continues to present challenges in recent years. Space & Missiles Systems Center (SMC) often finds itself identifying portfolio re-phasing candidates for SAF/AQXE (Office of the Deputy Asst Secy for Acquisition Integration, Execution Oversight) and SAF/FMBI (Budget Investment) where funding is early to need or, to a lesser degree, unfunded requirements (UFRs) baseline target review (BTR) candidates for shortfalls.

Problem Statement

There are three specifics goals for this study. First, to determine if the budget deviations are constant or vary over time. Many acquisition programs are delayed and over budget. Determining what is associated with these deviations may help prevent them in the future. Next, we address at what point in the program the largest deviations occur. Lastly, we determine if there any specific factors that are present in multiple programs that are associated with the deviations. Additionally, historic estimates at major Milestone B (MS B) and Initial Operational Capability (IOC) milestones need to be reviewed to see what the recommended phasing was at the time as well as program actual cost at completion. This also shows how much of the total budget is spent at differents point in the schedule. To meet these objectives, we next present our research questions that form the foundation for our research.

Research Objectives

1. Does a linear or exponential function best reflect how RDT&E budget changes as a space program progresses through its schedule?

2. When do those budget estimates actually change and what are associated with those changes?

3. Do actual RDT&E budgets following the 60/45 rule when looking at the time between MS B and IOC?

4. As estimates get closer to actual budgets, how much do these differ?

Research Approach

The identification of data and methodology for this study consisted of multiple sources, which includes Cost Assessment Data Enterprise (CADE), Selected Acquisition Reports (SAR) data from Defense Acquisition Management Information Retrieval (DAMIR) System, and multiple spreadsheets from Life Cycle Management Center (LCMC). CADE is a conglomerate of tools used by DoD to support cost and earned value data analysis. A SAR is a summary of a Major Defense Acquisition Program (MDAP) Acquisition Category (ACAT) I program. Most of the data used came from SAR data and verified using a new CADE SAR database and LCMC spreadsheets.

Way Ahead

Current acquisition policy emphasizes the importance of developing an accurate point estimate. Through the following research, we aim to identify and explain the difference between the estimate and actual budgets. In Chapter 2, prior research concerning this topic is discussed. Chapter 3 reviews how we collected our data, what is currently being used, and the proposed methodology for analyzing space program budget deviations. Chapter 4 illustrates our results. Finally, Chapter 5 summarizes this study, its results, and potential future research on this topic.

II. Literature Review

Chapter Overview

This chapter describes the methods of time phasing, topics and previous findings of time-phasing studies from the Air Force, DoD, and NASA, and previous studies on weapon system cost factors and cost growth. There are multiple methods to time-phase programs: schedule/milestone, analogy, and S-curve (Department of the Air Force, 2007). Estimating an appropriate funding profile for development programs is critical to their financial success. Inefficiently funded programs can either consume funding needed elsewhere, or cause program management crises in the form of funding shortfalls. In the absence of a standard model to establish development program costs, theorists developed mathematical models to derive the appropriate development funding profiles.

Cost of development is tied to the process itself. Development can include system requirements review, preliminary design review, critical design review, software coding, system tests, etc. Even for multi-year funding of development funds, one must still look at incremental funding. It is available for a period of two years but still must be allocated by fiscal year (FY).

One of the largest issues that create cost and schedule growth is due to budgets [that did] not match the work expected to be accomplished (NASA, 2015). Since budget constraints may limit what can be accomplished in a given fiscal year, the different phases of the program may be delayed, increasing the overall cost and timeframe of development.

Methods of Time Phasing

The three types of methods of time-phasing we go further into are schedule/milestone, analogy, and the S-curve. Determining which method to use depends on information availability of the program as well as information availability of historically analogous programs.

The next couple of paragraphs borrow heavily from AFCAH, 2007 and NASA CEH, 2015. The Schedule/Milestone approach is the most exact but also most difficult method to use to spread development estimates, since it requires a detailed program schedule (which may not be available) of milestones and uses this to allocate costs to appropriate fiscal years. One must determine the milestones, time-phase those milestones based on the program schedule, estimate the percent of the total cost required to complete each milestone, and then allocate the cost to appropriate fiscal years.

The next method, analogy, uses information from a previous program similar to the current one being estimated. The old and new programs should be similar with respect to the scheduling of their key milestones as well as the length of their development period. For example, a program which requires 18 months of design effort prior to RDT&E may have significantly different funding requirements than one with a three year design effort. Similarly, a program with concurrency and advance procurement is not a good analogy for the time phasing of an estimate for a program without these features.

The last type of time phasing, and the often preferred for RDT&E, is S-curve. A typical distribution (Rayleigh, Weibull, or Beta) illustrates the percentage spent and the elapsed time between two points in time. By way of illustrating the concept, if an analyst has developed an estimate of $100 million for a satellite, without any other knowledge of funding needs, the analyst could use the rule of thumb that assumes a 60:40 Beta Curve (60 percent of the cost at the halfway mark and 40 percent for the remainder of the project). A 60/45 Beta curve is currently utilized at SMC to adjust for risk for top level phasing Curve (60 percent of the cost at the 45% point). Table 1 illustrates the phasing implementation process.

Table 1: SMC Phasing Implementation Process

Steps
1. Generate risk adjusted estimate at desired BY (Base-Year) and confidence level
2. Apply 60/45 Beta curve to BY risk adjusted estimate to get annual phased expenditures (BY)
3. Convert BY$ to TY$ (Then-Year) using the appropriate Raw Index Calculate phased cumulative TY expenditures over time
4. Calculate %OCTL (Open Commitment plus Termination Liability) using %Time a. Apply %OCTL to phased cumulative TY expenditures to calculate the cumulative OCTL dollars (TY) b. Apply credit and debit to calculate annual OCTL dollar adjustment
5. Add annual Expenditures (TY) to annual OCTL adjustment (TY) for Final Budget Profile

SMC currently utilizes a type of Constructive Systems Engineering Cost Model (COSYSMO) called the Unmanned Space Vehicle Cost Model (USCM). COSYSMO is a unique cost model as it was created for space systems in that the model elements are mapped for space systems' WBS's and phases are mapped according to the National Security Space (NSS) acquisition policy. USCM is a parametric model that provides linear and nonlinear Cost Estimating Relationships (CERs) to estimate the costs of satellite development and production. Eleven USCM CERs describe bus and communication payload costs, as well as their associated system engineering; program management; and integration, assembly, and test costs. The model includes all satellite buses, but focuses on communication satellite payloads. Non-communication satellite data points are primarily used for their platform/bus costs, and their associated payload costs are captured in the database but not used for CER development. The majority of the costs included in USCM are end-of-program actual costs. SMC published the first USCM edition in 1969. Since that time, it has gone through seven iterations. The USCM database, currently in its eighth version, includes 12 NASA, 22 military, and 12 commercial programs in its data repository. Of interest in this paper is the WBS assumed in the model, particularly the systems engineering activities as shown in Table 2.

Table 2: USCM WBS

1 Space Vehicle	1.3 Communications Payload
1.1 Integration, Assembly, & System Test	1.3.1 Transmitter
1.2 Spacecraft	1.3.2 Receiver/Exciter
1.2.1 Structure, Interstage/Adapter	1.3.3 Transponder
1.2.2 Thermal Control	1.3.4 Digital Electronics
1.2.3 Attitude Determination Control System	1.3.5 Analog Electronics
1.2.3.1 Attitude Determination	1.3.6 Antennas
1.2.3.2 Reaction Control System	1.3.7 RF Distribution
1.2.4 Electrical Power Supply	1.4 Program-Level
1.2.4.1 Power Generation	1.4.1 Program Management
1.2.4.2 Power Storage	1.4.2 Systems Engineering
1.2.4.3 Power Conditioning and Distribution	1.4.3 Data
1.2.5 Telemetry, Tracking, and Command	2 Aerospace Ground Equipment
1.2.5.1 Transmitter	3 Launch and Orbital Operations
1.2.5.2 Receiver/Exciter	
1.2.5.3 Transponder	
1.2.5.4 Digital Electronics	
1.2.5.5 Analog Electronics	
1.2.5.6 Antennas	
1.2.5.7 RF Distribution	

Space System Life Cycle Phases

The National Security Space Acquisition Policy 03-016, shown in Figure 3, highlights the key guidelines and processes associated with the acquisition of DoD space systems (National Security Space Acquisition Policy 2004). Many acquisitions, DoD and elsewhere, focus on high quantity programs, but most space programs are different as they are low quantity, much higher technically complex programs. Since these programs have smaller quantities, more emphasis is placed on development and launch capabilities instead of operation and support (O&S).

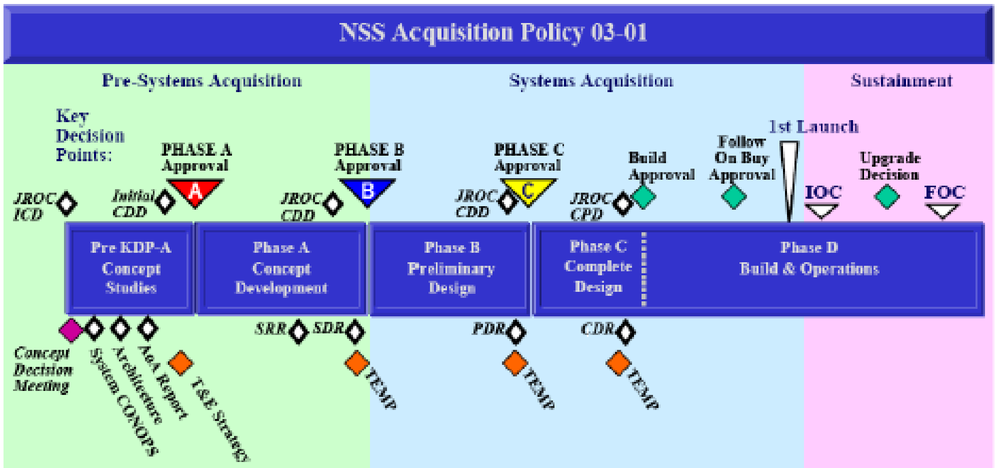

Figure 3: Acquisition Phases

Time Phasing Research

After briefly discussing how a space program's budget profile is created, we now briefly discuss findings from a couple of studies which analyzed actual development budgets. Brown (2015) tested if the "rule of thumb" of 60 percent of expenditures occur at halfway of the program's development schedule and, for aircraft development models, which distribution provides the best S-curve model. He found that the application of the 60/40 rule for aircraft is limited since it does not account for difference in the time phasing of programs. He determined that the time to first flight, length of development, and upgrade were all significant for estimation. He concluded that the Weibull distribution is slightly more accurate that the other two models. The Weibull model explained 74.6 percent of variation and the Rayleigh and Beta models explained 73.7 percent and 69.9 percent of variation, respectively, while the 60/40 rule explained only 68 percent of variation.

Burgess (2006) simultaneously tests the Rayleigh, Weibull, and Beta distributions. He sued 3 steps: (1) Estimating time from contract award to launch; (2) developing a time-phased expenditure profile; and (3) converting cost to budget. The researched concluded that there is a fixed-cost component to development programs as well, especially for long programs where launch slips and integration delays arise after most development work is complete. His results show that the Weibull distribution outperforms both the Rayleigh and Beta distributions in fitting expenditure patterns for 26 DoD RDT&E space contracts (Burgess, 2006: 24-25). Further research was done working with 26 National Reconnaissance Office (NRO) and DoD space satellite systems. Burgess concluded that the Beta was more accurate than the Rayleigh and that the programs averaged 65% spent expenditures at 50% schedule, shown in Figure 4.

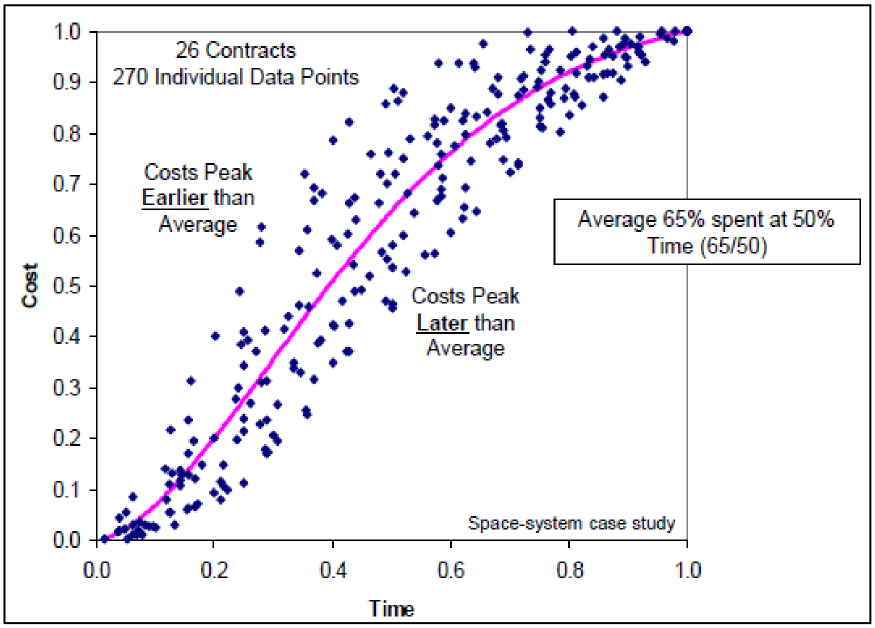

Figure 4: Data Points from Burgess Research

Weapon System Cost Growth Research

Now that we have described how estimates are created and some research on building models from actual budgets, we look into research pertaining to analyzing the differences between the estimates and actuals. There has been much research on causes of cost growth in weapon systems since the 1960s. However, few have found consistent causes of that growth across multiple programs, which is one of our goals in this research. According to Younossi (2008), who looked at SAR reports from the 1960s through the 2000s, there has been a 46% average cost growth factor for completed Major Defense Acquisition Programs (MDAPs). This study also revealed the underestimation of Space programs was larger than other weapon systems.

Space program cost growth causes can be summarized into four general categories: contractor execution errors, work content changes, technology development difficulty, and integration difficulty (Kim, 2015). Many previous studies confirmed these results and interviews with Subject Matter Experts (SMEs) were also not surprised by these findings. The purpose of this study was to accomplish the following:

- Analyze the performance of selected DoD space programs in terms of cost growth, schedule delays, and satellite on-orbit performance.
- Identify enterprise-level systemic issues and key factors that contributed to cost growth, schedule overrun, and technical problems in space acquisition.
- Characterize the current status of the following programs: Advanced Extremely High Frequency (AEHF), Global Positioning System (GPS IIF), GPS III, Space-Based Infrared System Hi (SBIRS HI), and Wideband Global SATCOM (WGS) (all of which except GPS IIF is included in this research).
- Identify future acquisition challenges that the next-generation space systems might face.

According to Leonard (2014), which researched 38 different programs, 8 of which being space, emphasized the statistically significant difference of cost growth between space programs and non-space programs. Table 3 displays the results, showing space development cost growth 126 percent higher than that of non-space programs.

Table 3: Average Cost Growth in Space and Non-Space programs (%)

	Budgetary Cost Growth			Unit Cost Growth	
Program Cat	Development	Procurement	Total	APUC	PAUC
Space	179	240	187	139	129
Non-Space	53	48	50	40	41

Porter (2009) examined 11 programs with significant cost growth, including one of the programs we researched as well, SBIRS-HI. He identified two major causes of cost growth: weaknesses in management visibility, direction, and oversight, which included inappropriate policy implementation, reliance on unproven strategies, and poor contractor oversight, and weaknesses in initial program definition and costing, which included unstable requirement processes, use of immature technology, inefficient front-end analysis, and excessive schedule compression. We will reference some of these results of these programs in Chapter 4 as well as results from Younossi (2008), who also thoroughly researched GPS and again SBIRS-HI, when we dive into research of cost growth above our threshold.

Summary

AFCAH provides three methods as discussed earlier to increase the accuracy of time phasing: schedule/milestone, analogy, and S-curve. The S-curve is preferred for development costs, and even more specifically, the Weibull and Beta distributions have become used more frequently after the previous research done as mentioned above.

Previous research mainly looked into different qualitative causes of cost growth in MDAPs as well as specifically in Space programs. In our methodology, explained in the next chapter, we explore more quantitative causes of cost growth from Milestone B (MS B) through the Initial Operational Capability (IOC), starting with fitting a curve of the overall change between estimated and actual budgets as well as investigating further into when those changes actually occurred and if there are any commonalities in what caused those changes.

III. Methodology

Chapter Overview

The previous chapter reviewed research on how estimates are created, curves created from actual budgets, and causes of cost deviation between the estimate and actual costs. As stated before, this study looks at that deviation quantitatively. In this chapter, we explain the data methods and the sources utilized to address the research questions in Chapter 1. We then explain how we normalized the data as well as standardized it into a percent schedule. Finally, we go into the three different specific analyses to address our research questions:

1. Does a linear or exponential function best reflect how RDT&E budget changes as a space program progresses through its schedule?

2. When do those budget estimates actually change and what are associated with those changes?

3. Do actual RDT&E budgets following the 60/45 rule when looking at the time between MS B and IOC?

4. As estimates get closer to actual budgets, how much do these differ?

Data Source

Previous S-curve researchers have used two different sources for their data: either Select Acquisition Reports (SAR) total obligation authority (TOA) or actual contractor cost reports' expenditure data. For this research, we use SAR data. Through our exploration into the two different sources, we found that SAR data has been consistently more reliable than current contractor data, mainly when looking for estimated costs for programs through the Automated Cost Estimating Integrated Tools program (ACE-IT). We were not able to confirm what percentage of the RDT&E costs were represented on these reports as well as how to match them up with the coordinated actual costs for the same program.

Also, SAR data is consistently available and updated. According to Title 10 USC § 2432 “Selected Acquisition Reports”, SAR reports are reported annually and include budgeted TOA amounts as well as actual costs amounts for every fiscal year of RDT&E. These yearly reports were crucial in determining not only the overall RDT&E cost growth, but also the analysis of the cost growth per year. Also, a new CADE SAR database as well as LCMC reports were used to verify information.

Data Selection

From those three data sources, we were able to gather the required data on eleven programs for the first two parts of the research and data on a twelfth program, GPS UE, which was missing a planned IOC date, was included in the inferential part of our analysis. The number of programs we could select was determined by what different information was available. For part of this research, we required each program have a reported engineering and manufacturing development (EMD) contract date (coinciding with Milestone B) and an IOC date. The program criteria list is in Table 4 and all included programs are in Table 5, of which 11 of the 12 programs are Air Force and 8 of the 12 are satellites. Also, we needed enough SAR data between those two dates to use in the yearly analysis. For the older programs, the new CADE SAR data tool, still in beta status, was very useful in filling in those gaps.

Table 4: Program Inclusion Criteria

Program Inclusion Criteria	Number of Programs
Space Programs listed in DAMIR	40
No Schedule Data Unavailable	-15
Cancelled/Failed Programs	-2
Could Not Separate Subprograms/Duplicates	-5
IOC has not Occurred yet	-3
Not all SARs Available between MS B & IOC	-3
Programs Available	**12**

Table 5: Included Programs

Program	Service	Weapon Type	MS B – act	IOC – pln	IOC – act
Advanced Extremely High Frequency (AEHF)	Air Force	Satellite	1-Nov-01	1-Nov-07	1-Jul-15
Defense Satellite Communications System (DSCS) III	Air Force	Satellite	1-Feb-77	1-Mar-82	1-Mar-82
Defense Support Program (DSP)	Air Force	Satellite	1-Jul-81	1-Jan-87	1-Dec-88
Evolved Expendable Launch Vehicle (EELV)	Air Force	Launch Vehicle	16-Oct-98	1-Dec-01	1-Aug-02
Enhanced Polar System (EPS)	Air Force	Space	1-Apr-14	1-Jun-18	1-Jun-18
Global Positioning System (GPS) Blk IIR	Air Force	Satellite	1-Jun-89	1-Oct-95	1-Aug-96
Global Positioning System (GPS) III	Air Force	Satellite	15-May-08	1-Apr-14	1-Aug-16
Global Positioning System User Equipment (GPS UE)	Air Force	Electronic	1-Jul-79	Unavailable	1-Jul-88
Mobile User Objective System (MUOS)	Navy	Satellite	24-Sep-04	1-Mar-10	30-Dec-11
Space-Based Infrared System Hi (SBIRS HI)	Air Force	Satellite	1-Nov-96	1-Sep-01	1-Aug-04
Space Fence	Air Force	Space	2-Jun-14	1-Jul-19	1-Oct-18
Wideband Global SATCOM (WGS)	Air Force	Satellite	1-Jan-01	1-Dec-04	26-Jan-09

CADE SAR Database

The objective of the CADE SAR database is to: provide a relational, authoritative database hosted on CADE, generate reports via a user interface, and provide download functionality. The database includes all known, available SAR data from:

- Authoritative data from DAMIR (PM-submitted data via DAMIR’s automated submit function);

- Data predating DAMIR from recognized databases previously keystroked from authoritative paper SARs.
- Rule-based, objective, calculated data

The database is a union of authoritative DAMIR data and, for historical completeness, select non-DAMIR data. It is relational in order to support the analyses across multiple fields in the database and it generates flat file outputs/reports to automate the SAR analysis process for cost community users. The CADE SAR database does not replace Defense Acquisition Management Information Retrieval (DAMIR) for current SAR reporting. DAMIR will continue to be the authoritative source of SAR data.

Converting TOA (Budget) to Annual Expenditures (Base Year)

RDT&E (appropriation 3600) is a unique appropriation in that funds are available for two fiscal years as long they are approved for the second fiscal year by the acquisition program's Chief Financial Officer. The OSD-Comptroller outlay rate must therefore be apply to approximate multi-year spending. The example we use to illustrate this, as well illustrate the other methods in this chapter, is a shorter program, EELV, in Table 5. Previous related research have had to use an outlay rate to approximate multi-year spending. However, looking at our numbers and talking with experts who have done this research we decided to not take that into effect and just allocate RDT&E as a one-year appropriation.

After collecting the then year expenditures from DAMIR, LCMC reports, and the CADE SAR beta site, we converted them to base year values due to the effects of inflation using the OSD Weighted Index 3600 inflation table. Appendix A shows the weighted index inflation values which, when the then year values are divided by them, are used to obtain the 2018 base year dollars. Now, to compare each program standardized, we must place each program into a percent schedule by using the Millstone B and IOC dates.

Converting Annual Expenditures to Percent Schedule by Percent Expenditures

As stated previously, the two dates, Milestone B and IOC were selected because both were consistently published for all of our chosen programs. So the first estimates are from the closest SAR to MS B and the actuals are from the SAR directly after IOC. IOC was chosen as the end date because the IOC is a primary driver in determining the program's development and production schedules…the program's time phased estimate therefore must be consistent with the schedule…so that its budgetary inputs can support the achievement of the IOC. (AFCAH, 2007)

Each program is truncated from MS B to the actual IOC date. In the EELV example shown in Table 6, Fiscal Year 1999 is truncated from 16 October 98, the actual MS B. So then the 1999 $417.28M estimate and the $419.21M actual budgets are now $399.89M and $401.74M, respectively. The same was done for 2002. The $355.11M estimate and $477.14M actual budgets are now $295.93M and $397.62M to account for only 10 months in Fiscal Year 2002. Then the difference between those two budgets for each fiscal year was taken and added up to acquire the cumulative budget difference from MS B to IOC. In the far right of Table 7, the percent schedule and percent budget change were then determined by taken the change from each year and divided by the total schedule (1382 days) and cumulative budget change (45.53%).

Table 6: EELV RDT&E BY 18 Calculations without IOC Change

	A	B	C	D	E	F
1	SAR Date:	Dec-97	Dec-02			
2	1999	$417.28	$419.21		MS B - act	10/16/1998
3	2000	$507.88	$503.19		IOC - pln	12/1/2001
4	2001	$467.02	$573.49		IOC - act	8/1/2002
5	2002	$355.11	$477.14			
7	SAR:	Dec-97	Dec-02	Annual Diff	Annual %	Cum % Diff
8	1999	$399.89	$401.74	$1.85	0.46%	0.4610%
9	2000	$507.88	$503.19	-$4.69	-0.93%	-0.31%
10	2001	$467.02	$573.49	$106.47	18.56%	7.01%
11	2002	$295.93	$397.62	$101.69	25.57%	10.94%
13	Total	$1,670.72	$1,876.04	$205.32		10.94%

A. Analysis of Program Budget Change Using Percent Schedule

Once the data was normalized and bracketed, we fit both an exponential and linear curve to each program's graph. To do this, we first create a table as seen in the example of Table 7. Then, we graph the data, cumulative % schedule vs. cumulative % budget change, to see if the change can be explained better linearly or exponentially, meaning is the change consistent between MS B and IOC or does the amount of change increase as we move toward IOC? In this analysis, the schedule does not change, meaning we assumed we already knew when IOC was going to occur. The schedule, in Column F of Table 7, is the cumulative of the number of days of each fiscal year divided by the total number of days between MS B and IOC (Cell C8 of Table 7). For the budget change, Column H, the cumulative of Column G, which was calculated by dividing the Annual Difference (Column D of Table 6) by the Total Difference (Cell D13 of Table 6). For some programs, Column I in Table 7 (Cum% Change Above Curve) had to be used instead of Column H since an exponential curve will not fit a curve with negative values. So in this case, a small number, specifically .02, was added to each value to move the curve above the y-intercept value of zero.

We analyzed the R^2 of the exponential and linear functions of each program. R^2 is a statistical measure of explained variance for two variables, usually one dependent and one independent variable. In our case, the R^2 measures the variation in the budget change, the dependent variable, through the change in schedule, the independent variable. These results are further explained in Chapter 4.

Table 7: EELV RDT&E BY 18 Calculations without IOC Change

	A	B	C	D	F	G	H	I
1	**start date**	**end date**	**days**	**% Sched**	**Cum % Sched**	**% Change**	**Cum % Change**	**Cum % Change Above Curve**
2	10/16/1998	9/30/1999	349	25.25%	0.25	0.01	0.01	0.03
3	10/1/1999	9/30/2000	365	26.41%	0.52	-0.02	-0.01	0.01
4	10/1/2000	9/30/2001	364	26.34%	0.78	0.52	0.50	0.52
5	10/1/2001	8/1/2002	304	22.00%	1.00	0.50	1.00	1.02
7		Total Days:	1382					

B. Analysis of Continuous RDT&E Budget Changes

Once we calculated these differences, and if there was a curve fit to the growth, we were determined to see if there were any trends on when exactly the budget changes occurred. Part A of the methodology showed the overall difference from the estimate at Milestone B and the actual at IOC for specific fiscal years, but cannot tell us when, between those two dates, the changes occurred. To do this, we first looked at the RDT&E budget changes from SAR to SAR. Again, we analyzed 11 programs.

After looking at the overall budget change, we investigated the difference between each estimate from one SAR to the next SAR via three different ways: Annual % Budget Difference (Column D of Table 6), Cumulative % Budget Difference (Column E of Table 6), and Cumulative % Budget Change (Column I of Table 7). To standardize these between all of the programs, the data was linearly interpolated at 10% increments. 10% was chosen as the increment amount since Christensen (1994) identified overruns in costs around 10% program completion and Kozlak (2016) discovered that, even though it was for aircraft, that the cost growth factor of as program at IOC to be very close to the cost growth factor at program completion. After the difference between each increment was calculated, we conducted further research of any change of overall budget between increments that was above 10%.

Table 8: Variables Analyzed between SARs

Day Change in IOC Estimate
Cum Schedule Change
Total Days between MS B & IOC
% Change Days btwn MS B & IOC
Cum % Schedule Change
$$ Change in Budget Estimate
Cum Budget Change
Total RDT&E Budget
% Change in Budget Estimate
Cum % Change

The variables listed in Table 8 were placed into a correlation matrix to see if there was any correlation between the schedule variables and the budget variables. If there were any large correlations and they made sense, after we removed all of the data points when there was 0% schedule change, we researched those variables further to see if any specific data points stood out from the rest.

C. 60/45 Risk Adjusted Beta Curve Analysis

As stated in Chapter 2, SMC utilizes a 60/45 Beta Curve to help time-phase their top level estimate. This assumes that 60% expenditures occur by the 45% schedule mark. In our case, the expenditures only include the RDT&E budgets of the fiscal years between MS B and IOC. That time period between those two dates is also our 100% schedule. We decided to quickly investigate how these programs' RDT&E budget hold up to that rule. To get to the budget at the 45% schedule mark, we again used linear interpolation from fiscal year to fiscal year for each program.

D. Inferential Analysis of Deviation from Actual Budget a Certain Number of Years Prior

The last analysis performed was, as we got closer to each fiscal year's actual budget, to determine how far away yearly estimates were to the associated actuals. To accomplish this, we aligned each fiscal year with the December SAR that occurred for that year, starting with the FY that IOC occurred and worked backwards. As an example, you can look at Table 9 and Figure 5 for multiple fiscal years from AEHF.

Table 9: AEHF Fiscal Year Changes Prior to Actual Budget

Years Prior	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Five Years Prior	$305.97	$371.71	$205.25	$247.43	$71.14	$29.28	$0.00	$51.40	$0.00	$39.52
Four Years Prior	$521.99	$402.53	$491.15	$240.31	$127.03	$28.83	$192.16	$51.40	$67.84	$39.83
Three Years Prior	$570.16	$759.76	$490.31	$424.36	$125.19	$405.18	$192.16	$171.29	$67.84	$162.77
Two Years Prior	$863.31	$761.37	$724.04	$452.84	$532.78	$391.60	$303.95	$187.64	$214.26	$221.06
One Years Prior	$851.14	$758.40	$719.49	$450.97	$529.45	$391.60	$300.91	$208.48	$213.95	$264.02
Final RDT&E Amount	$829.87	$741.57	$734.93	$515.16	$523.49	$421.43	$300.91	$163.71	$225.75	$255.57

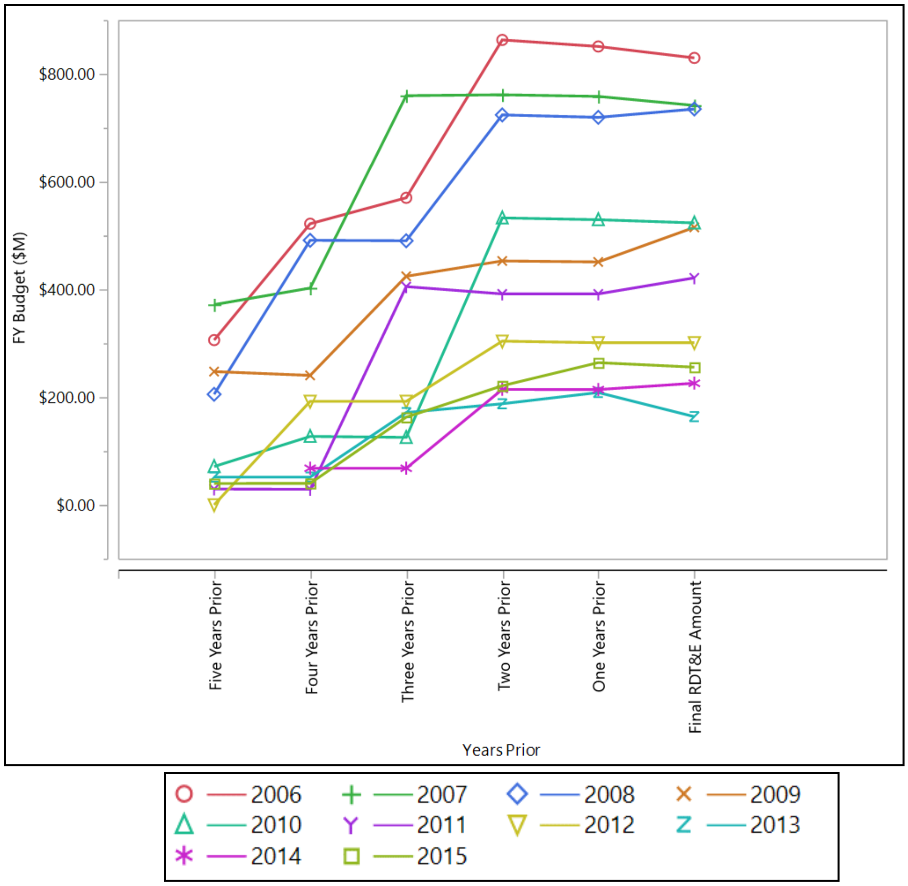

Figure 5: Graphed AEHF Fiscal Year Changes Prior to Actual Budget

From just a simple eye test from this program, one can tell there is a significant trend for all of the fiscal years that RDT&E does not change very much from the estimate from the SAR two years prior to the actual budget. Therefore, we collected data from 5 years all the way up to 1 year prior to the actual RDT&E budget. Table 10 displays the sample sizes available for all prior year analyses. The Fiscal Years 2000 and 2008 for many of the programs were unusable since there was acquisition reform during those two timeframes and SARs we not required, therefore no actual data for those fiscal years was available.

Table 10: FY Sample Sizes

Years Prior	FY Amount
5 Years	23
4 Years	109
3 Years	124
2 Years	139
1 year	143

The tables in Appendix B display how the SAR RDT&E data for AEHF was initially adjusted to line up each SAR at the end of that FY. The results from this analysis, which includes all of the programs' fiscal years, are explained further in Chapter 4.

Summary

This chapter explains our proposed steps to analyze the deviation between RDT&E budget estimates and actuals. We begin by collecting our data from DAMIR, CADE, and LCMC. After normalizing the data, it was placed into a percent schedule. Next, we fit a curve to the deviation between estimated budgets at Milestone B and the actual budgets for at IOC. Next, we analyze the large changes from FY to FY was to determine when the largest deviations occurred and if there is any correlation between schedule variables and budget variables. We also see if these budget amounts fit the 60/45 linearly interpolated. Lastly, estimates from specific years prior from each actual amount are examined to see how different those estimates were from said actuals.

IV. Analysis and Results

Chapter Overview

This chapter presents the results from the methodology and data introduced in Chapter 3, starting with the exponential and linear fits we identified using scatter plots. From our database, we determined which type of curve fit the programs delta between the RDT&E estimated and actual budgets. Second, each program's specific fiscal year (FY) was looked at to determine when the largest changes occurred. Also, using this data, we determined how much the estimate changed each year within 5 years of said FY.

A. Analysis of Program Budget Change Using Percent Schedule

Each program was graphed separately to illustrate if we could apply different fit lines. This then allowed us to further investigate any significant reason why the change in RDT&E budget was so large. Figures 6 through 17 display the graph and Table 10 displays the R^2's for each program.

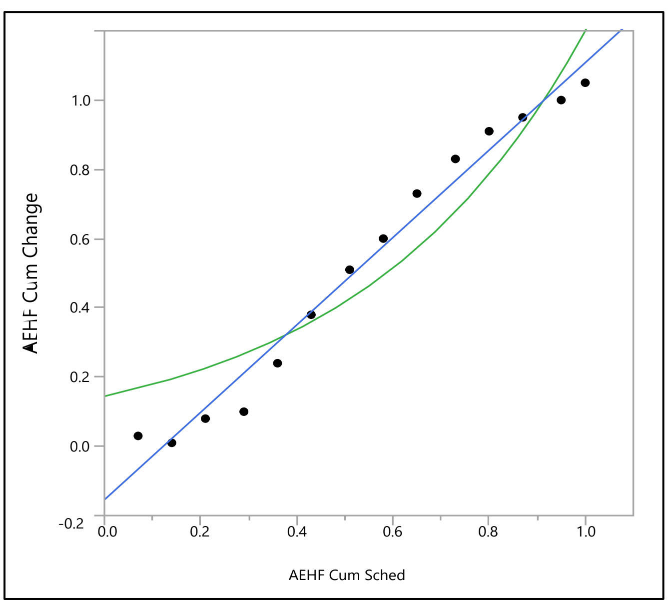

Figure 6: AEHF Overlay Plot w/o IOC Change

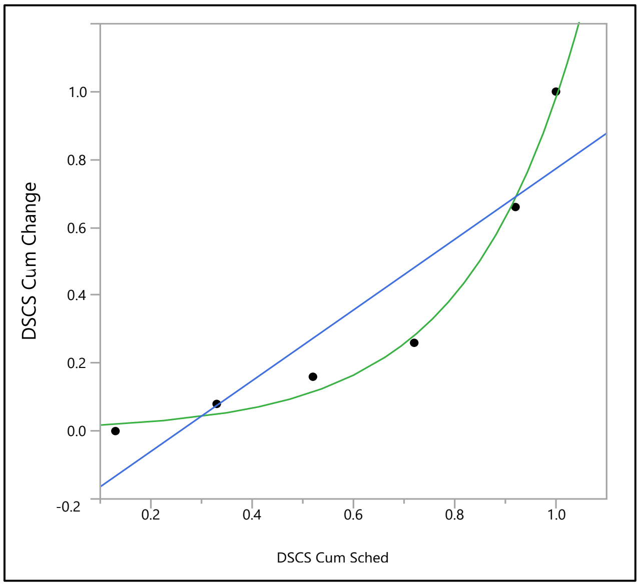

Figure 7: DSCS III Overlay Plot w/o IOC Change

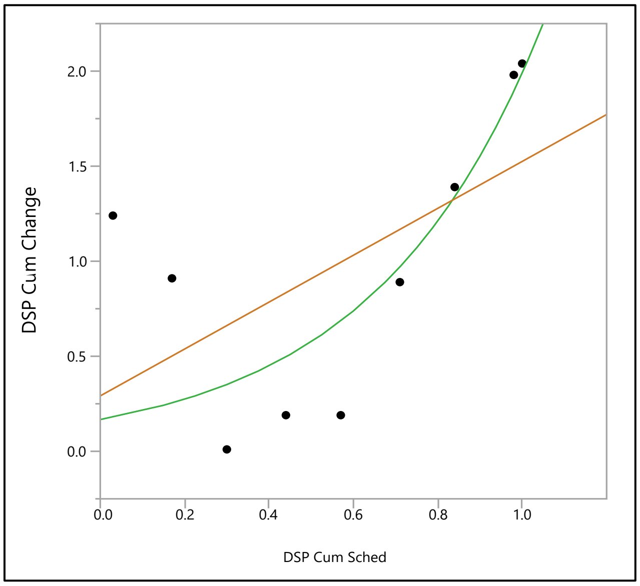

Figure 8: DSP Overlay Plot w/o IOC Change

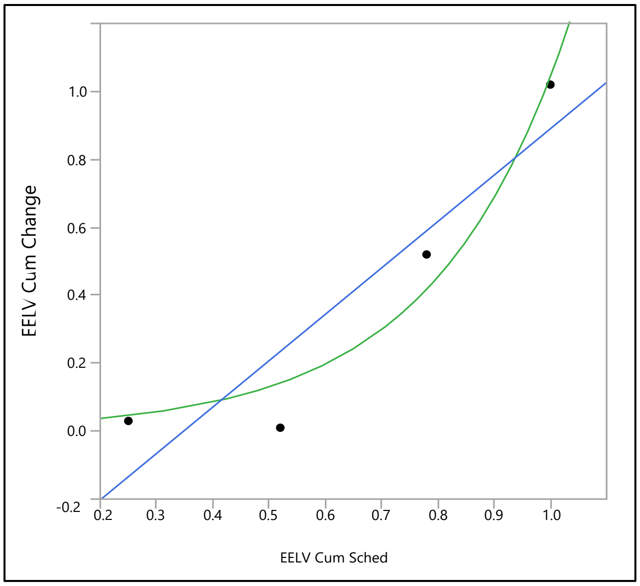

Figure 9: EELV Overlay Plot w/o IOC Change

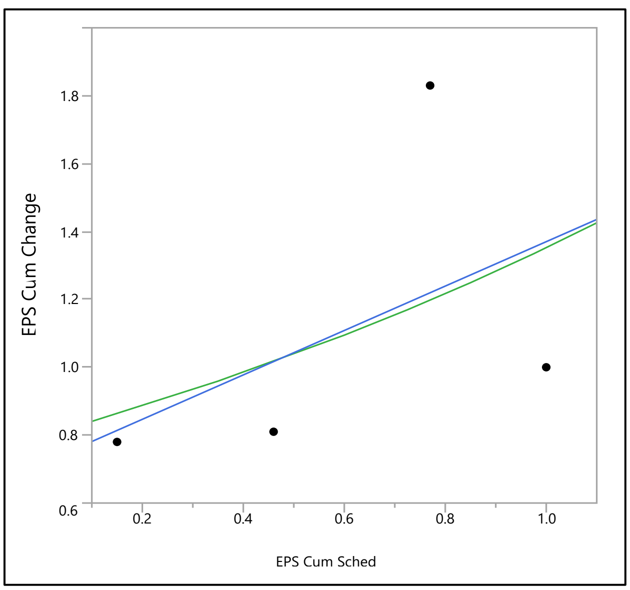

Figure 10: EPS Overlay Plot w/o IOC Change

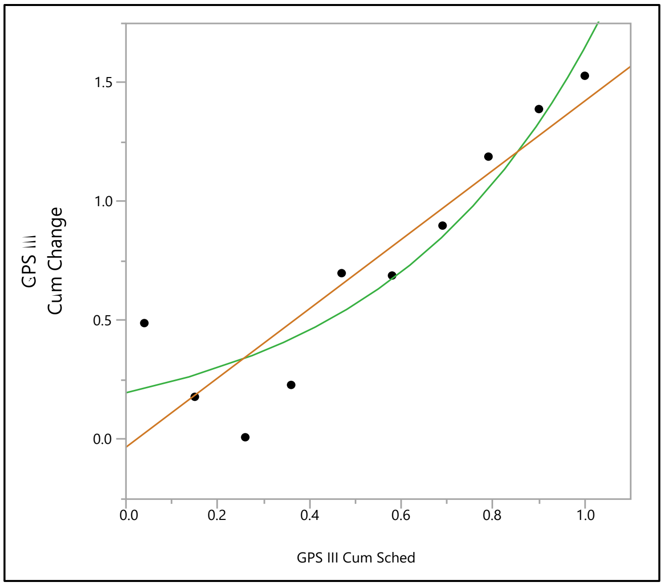

Figure 11: GPS III Overlay Plot w/o IOC Change

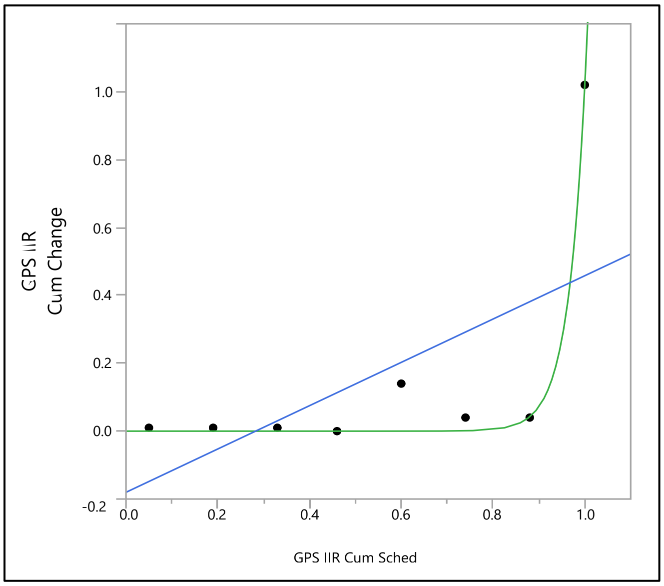

Figure 12: GPS IIR Overlay Plot w/o IOC Change

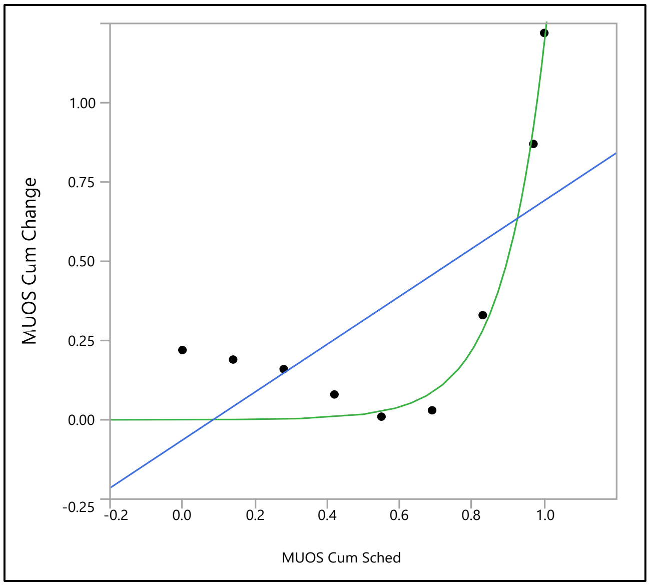

Figure 13: MUOS Overlay Plot w/o IOC Change

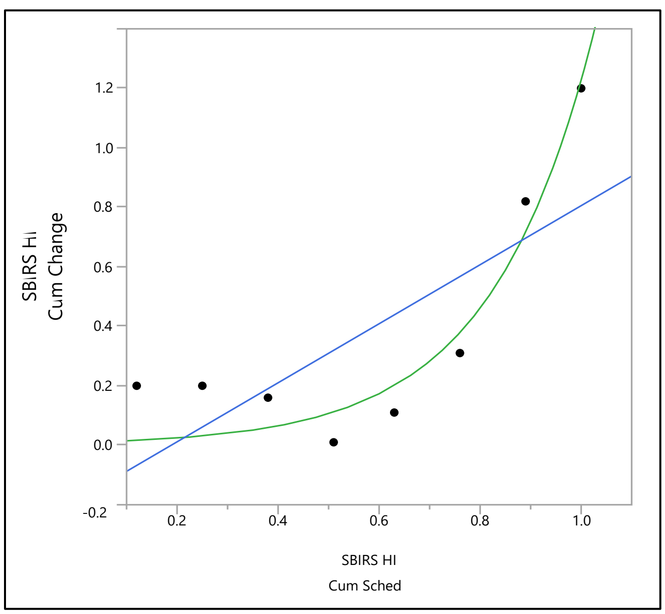

Figure 14: SBIRS HI Overlay Plot w/o IOC Change

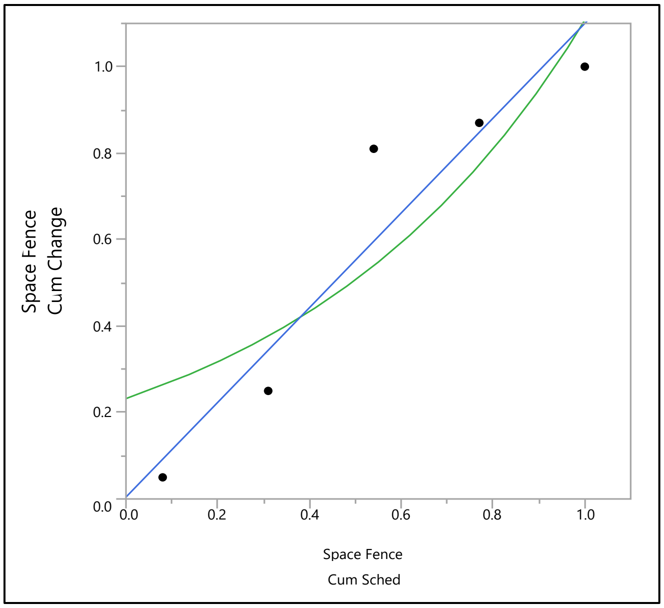

Figure 15: Space Fence Overlay Plot w/o IOC Change

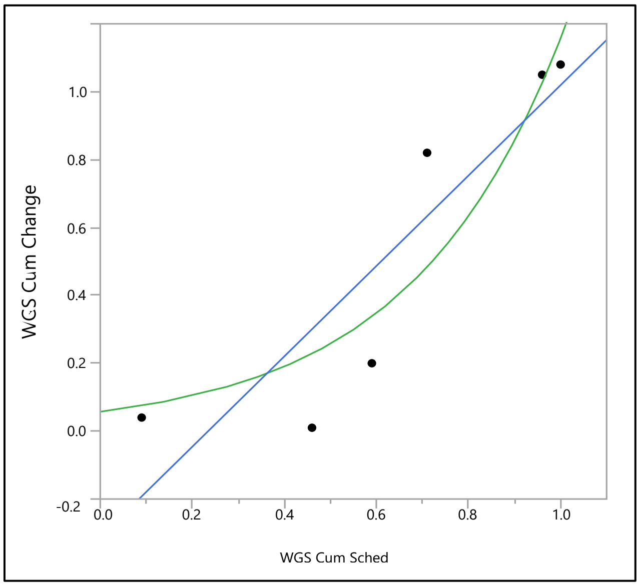

Figure 16: WGS Overlay Plot w/o IOC Change

Table 11: Program R^2's

Program	Exponential R^2	Linear R^2
AEHF	0.9776749	0.8880131
DSCS III	0.9935748	0.8258368
DSP	0.5552271	0.3289354
EELV	0.9584397	0.8558863
EPS	0.21337	0.2411105
GPS III	0.8785845	0.8167186
GPS IIR	0.9751514	0.3700347
MUOS	0.883401	0.4224695
SBIRS HI	0.9102613	0.5539839
Space Fence	0.9047185	0.7785527
WGS	0.8533301	0.7973553
Mean	0.830186273	0.625398791
Median	0.9102613	0.7785527

As mentioned earlier, the delta each fiscal year of each program was graphed using its estimate at Milestone B and its actual at IOC. Through graphing these using a percent schedule graph, we discovered that only 1 R^2 from the exponential function was less than .85, which was EPS at .21. 10 out of 11 programs' exponential R^2s were larger than the linear R^2 for the same program and the mean and median were larger for exponential as well.

B. Analysis of Continuous RDT&E Budget Changes

Since most of the deviations fit an exponential curve better than a linear curve, this means that budget growth does not occur at a constant rate. We were determined to see when the largest budget changes occurred. Therefore, we analyzed the Annual % Budget Difference (Column D of Table 5), Cumulative % Budget Change (Column I of Table 6), and the Cumulative % Budget Difference (Column E of Table 5).

Table 12: Annual % Budget Difference

Sched Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
AEHF	-0.09	0.18	0.17	0.69	0.68	0.74	0.96	0.94	0.91	0.94
DSCS	0.00	0.03	0.07	0.11	0.16	0.23	0.32	0.55	0.82	0.97
DSP	0.24	-0.27	-0.61	0.06	0.18	0.27	1.19	1.20	1.23	0.79
EELV	0.00	0.00	0.00	0.00	-0.01	0.05	0.13	0.19	0.22	0.26
EPS	-0.07	-0.09	-0.06	-0.02	-0.02	-0.07	-0.12	-0.11	0.07	0.24
GPS III	-0.22	-0.21	0.02	0.54	0.71	0.14	1.06	3.26	6.67	7.38
GPS IIR	-0.01	0.00	0.00	-0.01	0.05	0.23	-0.16	-0.18	0.08	0.50
MUOS	-0.03	-0.04	-0.05	-0.06	-0.07	-0.04	0.05	0.36	0.66	0.93
SBIRS HI	0.01	0.01	-0.04	-0.15	-0.43	0.05	0.35	0.55	0.77	0.86
Space Fence	-0.06	-0.08	-0.10	-0.15	-0.19	-0.17	-0.09	-0.08	-0.18	-0.29
WGS	-0.07	-0.07	-0.06	-0.06	0.28	0.81	0.98	1.00	1.00	1.00
Mean	-0.03	-0.05	-0.06	0.09	0.12	0.20	0.42	0.70	1.11	1.23
Median	-0.03	-0.04	-0.04	-0.01	0.05	0.14	0.32	0.55	0.77	0.86

Table 12 highlights all intervals for each program that had a negative budget growth in green. Many programs, including major programs that eventually had substantial budget growth later in their RDT&E budgets, even had negative budget growth early on between MS B and IOC. The larger growth toward the end of the schedule shows that programs may be being delayed for certain reasons and budgets are increasing and being pushed farther into the program's life. Tables 13 through 16 display cumulative budget difference, in cumulative % budget change and cumulative % budget difference.

The highlighted cells in Table 14 show the largest % budget change for each program. Cumulative % budget change can be misleading, especially when a program has negative budget changes or overall negative budget changes, which happened with two programs, EPS and Space Fence. Table 11 shows EPS having above a 100% cumulative budget change from the 60% to 90% intervals while its overall budget change is negative. Also, Space Fence has an overall negative budget change but one could not tell by looking at Tables 13 and 14 because all of the percentages are positive.

Table 13: Cumulative % Budget Change

Sched Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
AEHF	-2.69%	2.07%	7.13%	26.64%	44.66%	58.75%	74.57%	86.10%	91.91%	100.00%
DSCS	0.00%	2.78%	6.75%	10.90%	15.13%	20.11%	25.17%	42.25%	62.33%	100.00%
DSP	3.76%	-33.70%	-102.92%	-89.83%	-84.69%	-69.87%	-20.08%	19.69%	60.50%	100.00%
EELV	0.36%	0.72%	0.48%	-0.37%	-1.21%	14.57%	34.52%	54.97%	77.49%	100.00%
EPS	52.06%	78.57%	79.53%	80.48%	94.15%	126.91%	159.66%	171.82%	135.91%	100.00%
GPS III	-20.88%	-42.90%	-43.46%	-13.02%	16.86%	19.61%	39.45%	67.86%	86.36%	100.00%
GPS IIR	-0.54%	-0.55%	-0.64%	-1.15%	2.26%	11.79%	4.89%	2.02%	18.23%	100.00%
MUOS	-1.94%	-4.34%	-7.53%	-12.68%	-18.03%	-20.07%	-16.79%	4.22%	37.56%	100.00%
SBIRS HI	0.22%	0.24%	-1.30%	-6.12%	-18.06%	-11.40%	2.02%	26.91%	65.51%	100.00%
Space Fence	6.53%	15.50%	24.46%	46.95%	70.93%	82.27%	85.17%	88.87%	94.43%	100.00%
WGS	-3.97%	-4.91%	-5.85%	-6.79%	-1.26%	17.62%	69.24%	82.50%	91.50%	100.00%
Mean	2.99%	1.23%	-3.94%	3.18%	10.98%	22.75%	41.62%	58.84%	74.70%	100.00%
Median	0.00%	0.24%	-0.64%	-1.15%	2.26%	17.62%	34.52%	54.97%	77.49%	100.00%

Table 14: Cumulative % Budget Change Year to Year

Sched Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
AEHF	-2.69%	4.77%	5.06%	19.51%	18.02%	14.09%	15.82%	11.54%	5.81%	8.09%
DSCS	0.00%	2.78%	3.97%	4.15%	4.23%	4.98%	5.06%	17.07%	20.08%	37.67%
DSP	3.76%	-37.46%	-69.23%	13.10%	5.14%	14.82%	49.79%	39.78%	40.80%	39.50%
EELV	0.36%	0.36%	-0.24%	-0.85%	-0.85%	15.79%	19.94%	20.46%	22.51%	22.51%
EPS	52.06%	26.51%	0.96%	0.96%	13.67%	32.75%	32.75%	12.15%	-35.91%	-35.91%
GPS III	-20.88%	-22.02%	-0.56%	30.45%	29.88%	2.75%	19.84%	28.40%	18.51%	13.64%
GPS IIR	-0.54%	-0.01%	-0.09%	-0.51%	3.40%	9.53%	-6.90%	-2.87%	16.21%	81.77%
MUOS	-1.94%	-2.39%	-3.19%	-5.16%	-5.34%	-2.04%	3.28%	21.01%	33.33%	62.44%
SBIRS HI	0.22%	0.02%	-1.54%	-4.82%	-11.93%	6.66%	13.42%	24.89%	38.60%	34.49%
Space Fence	6.53%	8.96%	8.96%	22.48%	23.99%	11.33%	2.90%	3.70%	5.57%	5.57%
WGS	-3.97%	-0.94%	-0.94%	-0.94%	5.53%	18.88%	51.62%	13.26%	9.00%	8.50%
Mean	2.99%	-1.77%	-5.17%	7.12%	7.80%	11.78%	18.87%	17.22%	15.86%	25.30%
Median	0.00%	0.02%	-0.24%	0.96%	5.14%	11.33%	15.82%	17.07%	18.51%	22.51%

To help with this we also investigated the Cumulative % Budget Difference. This difference again illustrates the % difference from year to year but is not distorted when negative values are present. The highlighted cells in Table 16 show the top 10% of the budget differences.

Table 15: Cumulative % Budget Difference

Sched Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
AEHF	-9.28%	2.15%	6.55%	19.60%	27.82%	32.62%	37.97%	41.33%	42.79%	44.76%
DSCS	0.00%	2.23%	5.40%	7.36%	8.79%	10.61%	12.53%	18.42%	25.29%	35.28%
DSP	29.25%	-13.50%	-38.11%	-28.48%	-22.70%	-16.68%	-4.07%	2.99%	8.67%	13.35%
EELV	0.18%	0.37%	0.32%	0.03%	-0.26%	1.94%	4.76%	7.37%	9.16%	10.94%
EPS	-7.47%	-10.14%	-8.01%	-5.88%	-4.99%	-5.95%	-6.92%	-7.08%	-5.36%	-3.64%
GPS III	-25.15%	-29.20%	-19.25%	-4.78%	4.09%	4.18%	7.80%	12.52%	15.34%	17.29%
GPS IIR	-0.78%	-0.60%	-0.52%	-0.69%	0.79%	4.92%	1.97%	0.71%	3.75%	19.53%
MUOS	-2.19%	-3.38%	-3.94%	-4.67%	-5.15%	-4.88%	-3.59%	0.68%	6.38%	15.71%
SBIRS HI	1.47%	0.99%	-1.35%	-6.13%	-15.12%	-7.95%	0.45%	10.57%	23.14%	31.09%
Space Fence	-5.58%	-7.51%	-9.45%	-12.54%	-15.76%	-16.29%	-15.02%	-14.31%	-14.87%	-15.44%
WGS	-7.06%	-6.84%	-6.62%	-6.41%	-1.65%	11.07%	34.15%	38.73%	41.25%	43.54%
Mean	-2.42%	-5.95%	-6.82%	-3.87%	-2.19%	1.23%	6.36%	10.17%	14.14%	19.31%
Median	-2.19%	-3.38%	-3.94%	-4.78%	-1.65%	1.94%	1.97%	7.37%	9.16%	17.29%

Table 16: Cumulative % Budget Difference Year to Year

Sched Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
AEHF	-9.28%	11.43%	4.40%	13.05%	8.22%	4.79%	5.35%	3.36%	1.46%	1.97%
DSCS	0.00%	2.23%	3.18%	1.96%	1.43%	1.82%	1.92%	5.88%	6.88%	9.98%
DSP	29.25%	-42.75%	-24.61%	9.64%	5.77%	6.02%	12.61%	7.05%	5.68%	4.68%
EELV	0.18%	0.18%	-0.05%	-0.29%	-0.29%	2.20%	2.82%	2.61%	1.79%	1.79%
EPS	-7.47%	-2.67%	2.13%	2.13%	0.89%	-0.97%	-0.97%	-0.16%	1.72%	1.72%
GPS III	-25.15%	-4.05%	9.95%	14.47%	8.87%	0.09%	3.62%	4.72%	2.83%	1.95%
GPS IIR	-0.78%	0.19%	0.08%	-0.17%	1.48%	4.13%	-2.95%	-1.26%	3.05%	15.78%
MUOS	-2.19%	-1.19%	-0.56%	-0.73%	-0.48%	0.27%	1.29%	4.28%	5.70%	9.33%
SBIRS HI	1.47%	-0.48%	-2.34%	-4.78%	-8.99%	7.16%	8.40%	10.13%	12.57%	7.95%
Space Fence	-5.58%	-1.93%	-1.93%	-3.09%	-3.22%	-0.53%	1.27%	0.72%	-0.56%	-0.56%
WGS	-7.06%	0.22%	0.22%	0.22%	4.76%	12.72%	23.08%	4.58%	2.52%	2.29%
Mean	-2.42%	-3.53%	-0.87%	2.94%	1.68%	3.43%	5.13%	3.81%	3.97%	5.17%
Median	-2.19%	-0.48%	0.08%	0.22%	1.43%	2.20%	2.82%	4.28%	2.83%	2.29%

With such a small sample size of space programs, we were able to investigate to determine if any similar causes emerged that created these very large budget increases in Tables 14 and 16. The next sections includes details about some of the major causes in this budget growth.

AEHF

The September 2008 SAR was an exception as it was submitted for a Nunn-McCurdy unit cost breach. The breach was mainly due to an addition of a 4TH Space Vehicle (SV-4) after a production break of four years. Part of the recertification process was that the Air Force worked on an Above Threshold Reprogramming (ATR) to address an FY09 RDT&E shortfall. In this SAR, the total amount for FY10 and FY11 increased from $154.02M to $947.15M with the addition of $192.16M for FY12. In the December 2010 SAR, FY12 and FY13 RDT&E funding increased from $243.56M to $475.25M. In the December 2012 SAR, FY14 and FY15 RDT&E funding increased from $107.67M to $377.03M.

DSCS III

Throughout the three SARs, FY82 RDT&E costs increased from $22.01M to $268.75M in those 4 years. Since this was before SARs were uploaded into DAMIR, we do not have specific reasoning for why these fiscal years increased by this much.

GPS III

The increase for FY16 can be contributed to delays and cost overruns, mainly from Navigation Payload design issues, which caused a breach in the APB schedule and led to an Over Target Baseline (OTB) for a new cost and schedule baseline. The OTB started in July 2014 and was completed in March 2015. The technical issues in the Navigational Payload had been resolved in that timeframe and the parts were delivered in March 2015 as well.

MUOS

The total 2012 RDT&E budget increased from $116.25M to $267.09M in the December 2009 SAR. The production schedule had technical issues that created delays. Based on findings, the program was then restructured to support a Dec 2011 On-Orbit Capability, a delay of 21 months from the original.

SBIRS HI

SBIRS-HI experienced a Nunn-McCurdy breach and an Acquisition Program Breach (APB) in December 2001. This was from significant cost and schedule delays and an inability to meet the original IOC schedule. At the end of 2001, there was a Program Acquisition Unit Cost (PAUC) increase of 70%. To support future funding requirements, the defense appropriations bill provided an additional $40M in RDT&E funding. However, it was denied additional procurement funding which caused a need to requalify radiation-hardened parts due to industry obsolescence issues.

Another SBIRS-HI issue found by Porter (2009) were with the specific format of contractor reports. They used their own format to report cost and schedule. He also mentioned that SBIRS-HI did not have a Milestone A review, which could have identified some of the very costly system engineering problems in the early stages and could have mitigated some of the program's issues, the same issues that prior, analogous programs had encountered and SBIRS-HI suffered from weak oversight on the contractor, who was "inadequately-qualified".

WGS

Fiscal Years' 2004 and 2005 RDT&E budgets were affected by WGS' Space Vehicle 3. SV-3 actually started as SV-1 but additional time was needed replace and inspect the fasteners that were installed incorrectly. The original launched was pushed back by 15 months, resulting in an IOC threshold delay of 12 months, and SV-2 became SV-1 and SV-1 became SV-3. All of the RDT&E for WGS went towards the Ground and Block II development. So the delay pushed out all extraneous WGS activities, therefore pushing out all RDT&E funding by a year.

As stated in Chapter 3, we also looked at each program's overall budget change from SAR to SAR. Table 17 shows our entire correlation matrix for all of our schedule variables vs. all of our budget variable. From this, we analyzed the three largest correlations illustrated in Figures 17 to 19. The relationships between the two variables in Figures 17, 18, and 19 had an R^2 of .825, .876, and .837, respectively. With these high R^2's, a program office can potentially predict how much of a budget increase, or decrease, it can expect, if there is a schedule increase or decrease, or vis-a-versa.

Table 17:

	$$ Change in Budget Estimate	Cum Budget Change	Total RDT&E Budget	% Change in Budget Estimate	Cum % Budget Change
Day Change in IOD Estimate	0.307199112	0.359482248	0.315322515	0.071343334	0.271615415
Cum Schedule Change	0.001408175	0.668447701	0.406905536	-0.184143515	0.837436105
Total Days between MS B & IOD	0.14389639	0.825105965	0.665485202	-0.17185459	0.669635447
% Change Days btwn MS B & IOD	0.335594135	0.147217136	0.123067797	0.167996033	0.153108409
Cum % Schedule Change	-0.01679616	0.418146798	0.160363442	-0.09346429	0.875691691

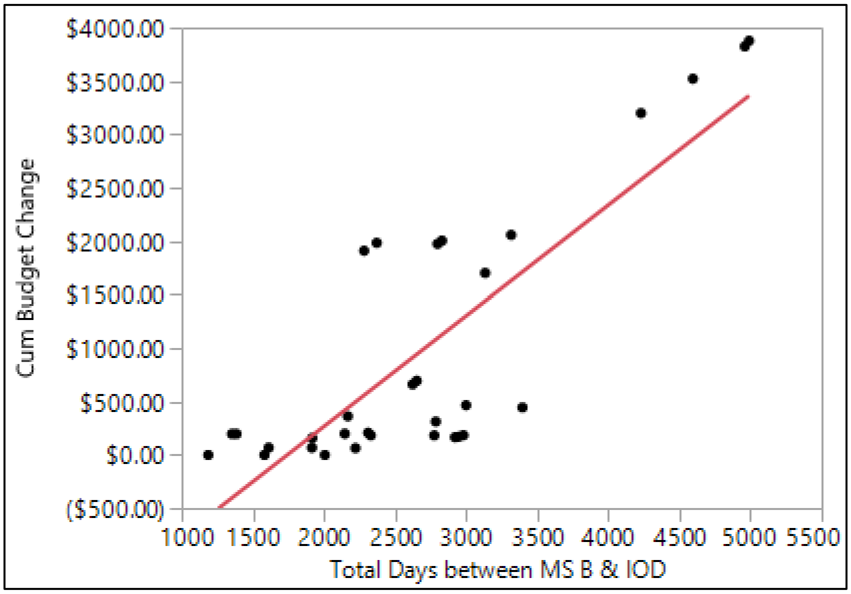

Figure 17: Bivariate Fit of Cum Budget Change By Total Days btwn MS B & IOC

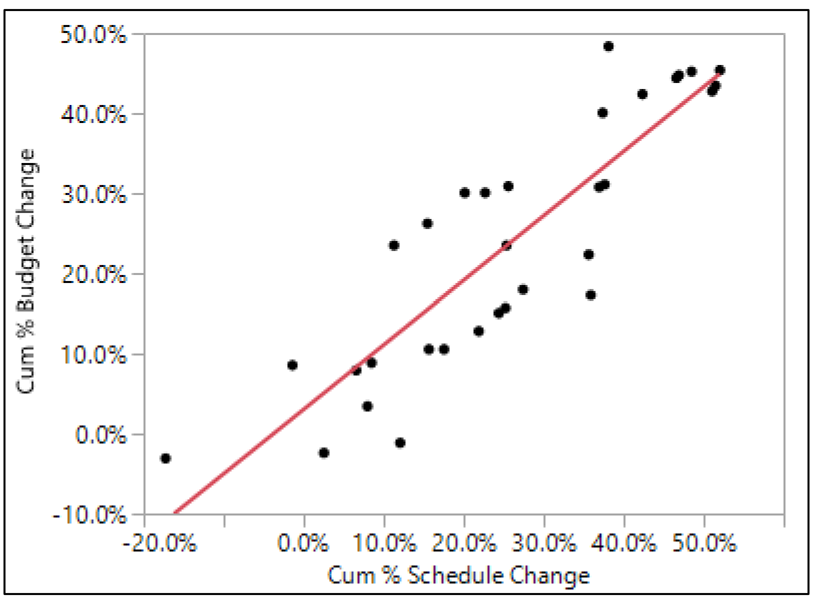

Figure 18: Bivariate Fit of Cum % Budget Change By Cum % Schedule Change

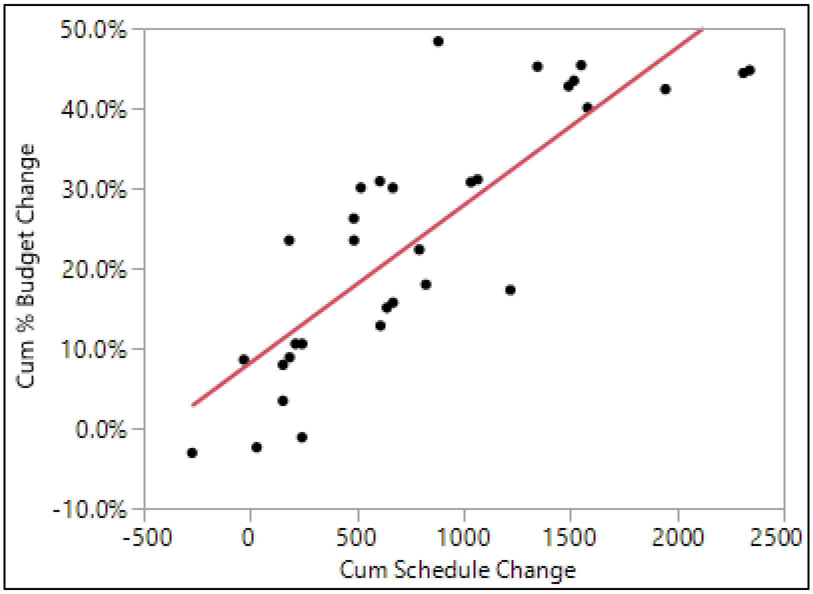

Figure 19: Bivariate Fit of Cum % Budget Change By Cum Schedule Change

C. 60/45 Risk Adjusted Beta Curve Analysis

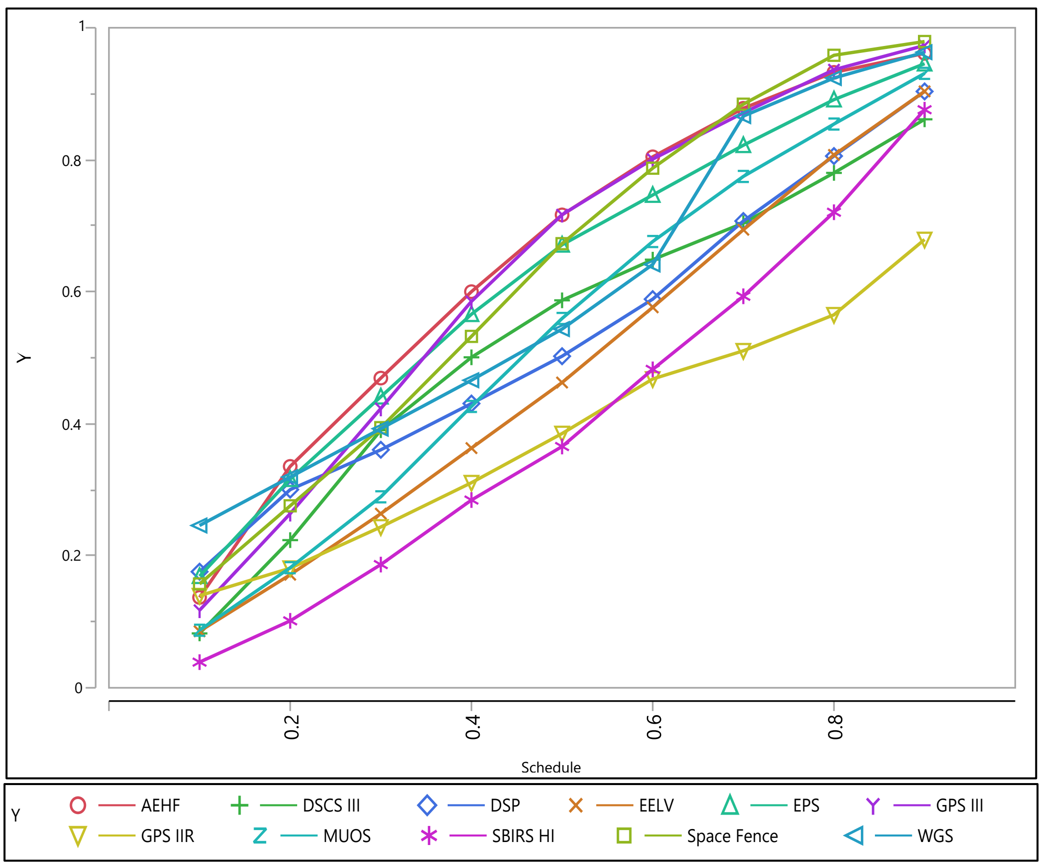

Figure 20: Program Budget % at 45% Complete Overlay Plot

Table 18: Program Budget % at 45% Complete Overlay Plot

Schedule	0%	10%	20%	30%	40%	45%	50%	60%	70%	80%	90%	100%
AEHF	0.00	0.14	0.34	0.47	0.60	0.65	0.72	0.80	0.88	0.93	0.96	1.00
DSCS III	0.00	0.08	0.22	0.39	0.50	0.54	0.59	0.65	0.70	0.78	0.86	1.00
DSP	0.00	0.18	0.30	0.36	0.43	0.46	0.50	0.59	0.71	0.81	0.90	1.00
EELV	0.00	0.09	0.17	0.26	0.36	0.41	0.46	0.58	0.69	0.81	0.90	1.00
EPS	0.00	0.17	0.32	0.44	0.57	0.62	0.67	0.75	0.82	0.89	0.95	1.00
GPS III	0.00	0.12	0.26	0.42	0.59	0.66	0.72	0.80	0.87	0.94	0.97	1.00
GPS IIR	0.00	0.14	0.18	0.24	0.31	0.34	0.39	0.47	0.51	0.57	0.68	1.00
MUOS	0.00	0.09	0.18	0.29	0.43	0.49	0.56	0.68	0.77	0.85	0.93	1.00
SBIRS HI	0.00	0.04	0.10	0.19	0.28	0.32	0.37	0.48	0.59	0.72	0.88	1.00
Space Fence	0.00	0.16	0.28	0.39	0.53	0.60	0.67	0.79	0.88	0.96	0.98	1.00
WGS	0.00	0.25	0.32	0.39	0.47	0.50	0.54	0.64	0.87	0.92	0.96	1.00
Mean	0.00	0.13	0.24	0.35	0.46	0.51	0.56	0.66	0.76	0.83	0.91	1.00
Median	0.00	0.14	0.26	0.39	0.47	0.50	0.56	0.65	0.77	0.85	0.93	1.00

Figure 20 and Table 18 illustrate the results from the linear interpolation of budget expenditures at 45% schedule between MS B and IOC. The mean is 51% and median is 50%, both short of the 60% goal. 4 of our programs were at or above the 60% mark while the other 7 are below that same mark.

D. Inferential Analysis of Deviation from Actual Budget a Certain Number of Years Prior

Lastly, for our inferential analysis. In addition to looking at the trend of the delta of each fiscal year, the percentage change in the years leading up to the actual RDT&E budget was examined here as well. After during a test trial using fiscal years we had estimates for at least 5 years prior, we did a larger test with all programs with all of the data available. Table 19 shows the descriptive statistics of the years' prior tests including all fiscal years, including the associated confidence intervals. Therefore, we are 95% confident that the true difference between the true budget and the estimate of that budget, two years out, is between 13.8% and 26.8%.

Table 19: Years Prior Descriptive Statistics

Years Prior	Sample Size	Mean	Std Dev	Upper 95% Mean	Lower 95% Mean
5 Years	23	.593	.304	.724	.461
4 Years	110	.448	.346	.513	.382
3 Years	124	.338	.453	.419	.258
2 Years	139	.203	.387	.268	.138
1 year	143	.148	.412	.216	.080

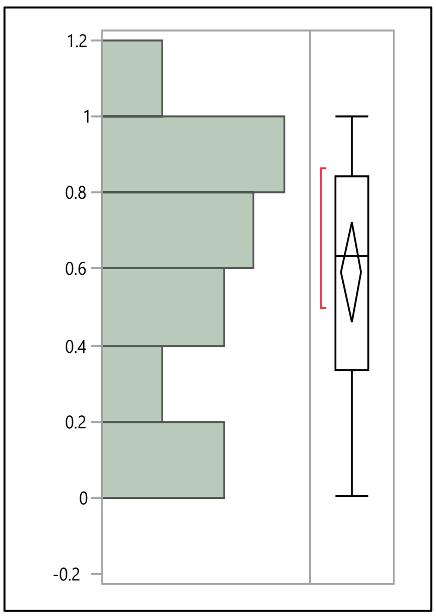

Figure 21: Program Fiscal Year 5 Years Prior

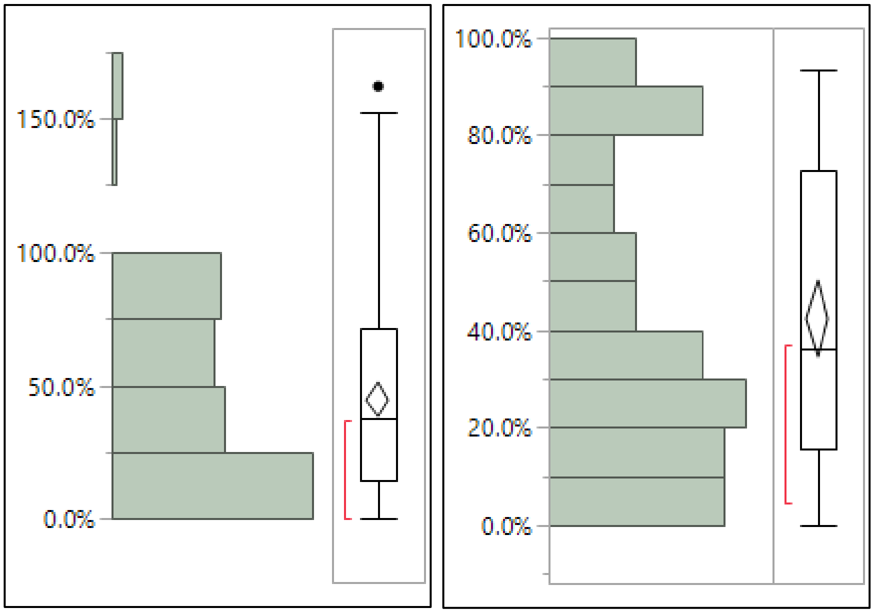

Figure 22: Program Fiscal Year 4 Years Prior

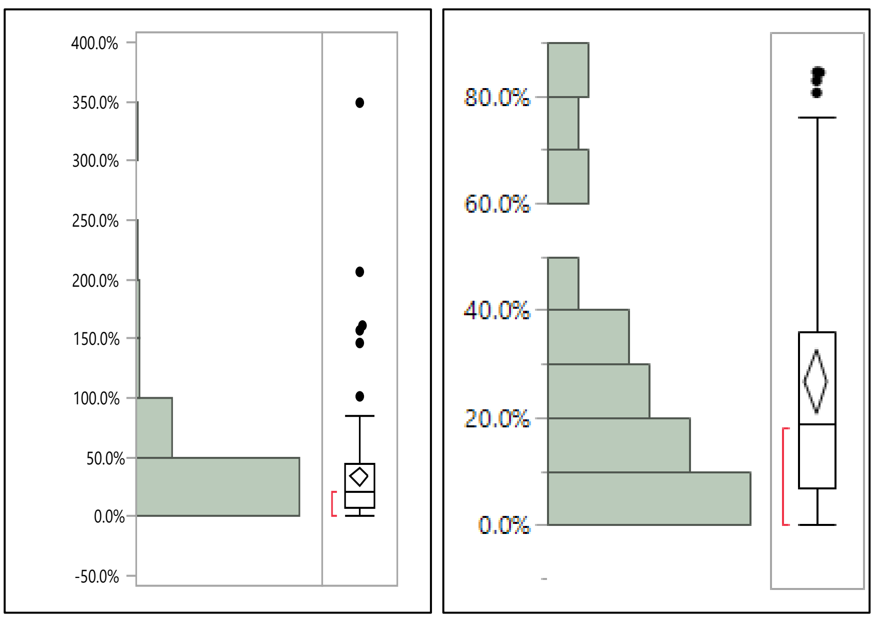

Figure 23: Program Fiscal Year 3 Years Prior

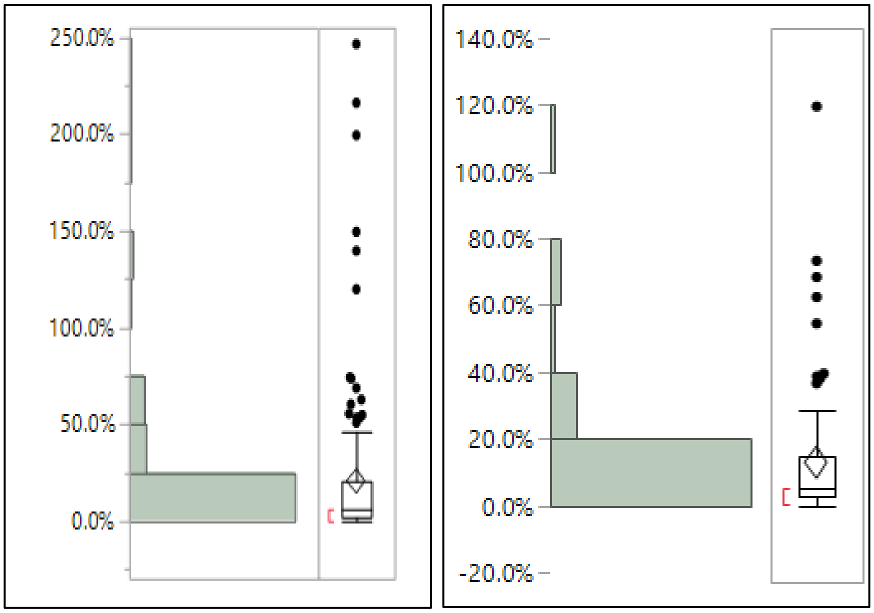

Figure 24: Program Fiscal Year 2 Years Prior

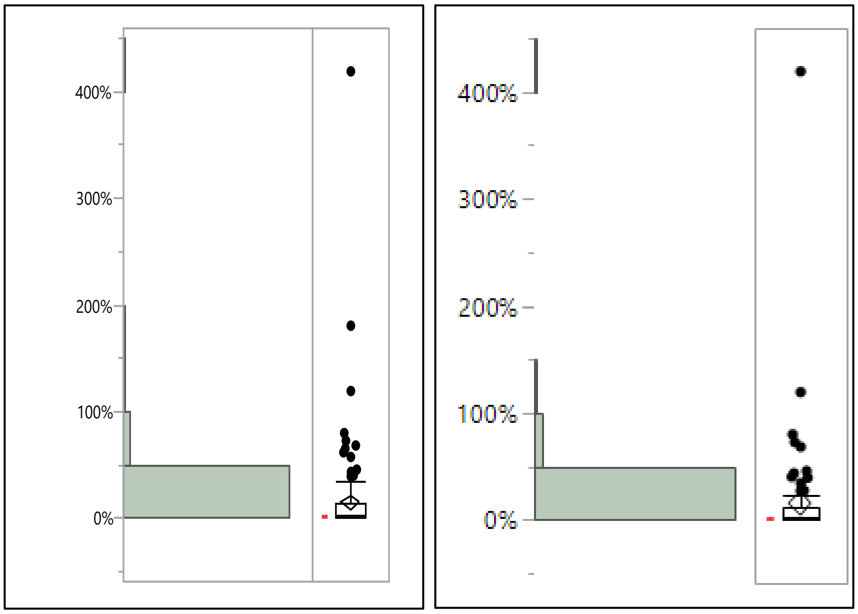

Figure 25: Program Fiscal Year 1 Year Prior

Table 20: Years Prior Descriptive Statistics After 2002

Years Prior	Sample Size	Mean	Std Dev	Upper 95% Mean	Lower 95% Mean
4 Years	57	.423	.296	.502	.345
3 Years	66	.267	.245	.328	.207
2 Years	76	.131	.200	.176	.085
1 year	82	.159	.495	.267	.0498

In Figure 24, there were 6 outliers outside 2 standard deviations. Of those 6, 5 of those years are Fiscal Year 2001 or earlier. Since this was the first test we ran, we limited all our second histograms for 4 to 1 year prior to data points 2002 and later. So the first histogram in each of the last 5 figures includes all available data points while the second in each was limited to only all data points 2002 and later. The last outlier from 2 years prior was 2016 AEHF (119.49%) and the one extreme outlier from 1 year prior is EELV 2008 (418.75%). However, both of these actual budget values are less than the estimated budgets 2 and 1 year prior.

Summary

Many of the findings from both the statistical and inferential analysis indicate that many of the programs are underspending at the beginning of the programs, after MS B, and almost all are overspending toward the end at IOC. This is compared to what is time-phased for, i.e. 60% spent by 45% schedule. This could potentially indicate that a new phasing method may need to be utilized for new space programs. The next chapter goes more into these results with their respective research question as well as talks about some limitations as well as potential future research.

Chapter V: Conclusions & Recommendations

Chapter Overview

In this chapter, we restate and address our research questions to ensure we accomplished our intended goal. We also state the limitations of our research, make recommendations for future research, and summarize the overall significance of this research.

Research Questions Answered

1. Does a linear or exponential function best reflect how RDT&E budget changes as a space program progresses through its schedule?

From the 11 programs analyzed, 10 of the R^2's from an exponential function were larger than the R^2 from the linear function. The exponential curve can better fit the deviation of each fiscal year's RDT&E budget between a program's MS B and IOC. That deviation is therefore not constant and more of the estimate changes occur later, rather than earlier or at the same rate, between those two dates. This could potentially infer that many programs, especially longer ones, need more time to mature and develop or this trend of exponential growth will continue.

2. When do those budget estimates actually change and what are associated with those changes?

Since the exponential line fit better than the linear line, deviations in budget to not occur at a constant rate. With the deeper dive into when the largest deviations occurred, there was no huge commonality on when these largest deviations occurred and what caused them. Many of the large deviations occurred toward the end of the schedule so again displaying the same evidence as in the first part of our analysis that change is not constant and much of the change occurs in the later part of the schedule.

3. Do actual RDT&E budgets following the 60/45 rule when looking at the time between MS B and IOC?

The mean and median, 51% and 50% respectively, at 45% schedule are a decent amount off from the 60% SMC uses. This is again using the MSB to IOC as the schedule and only looking at RDT&E. Even though the programs' RDT&E budgets are being spent at about the predicted rate, this test does not take cost growth for each year into effect. This 56% compares to Burgess' 65% at 50% schedule for space programs, but he used "launch date" as the end point instead of IOC and also used a Beta curve instead of linear interpolation.

4. As RDT&E estimates get closer to actual budgets, how much are they off the actual budget?

As a program nears a specific fiscal year, the chance that it will be closer to the actual budget increases, as seen in Chapter 4. Budgets for programs are updated every year, if not more. It is very hard for a Program Manager to give a specific point estimate. With this research, he or she can now continually decrease the range of the confidence interval each year. Once an RDT&E budget is two years out, there is a 95% chance that that fiscal year's budget is at most 26.8% from what the actual budget will be. The most important product to come out of this inferential analysis is that the sooner a program office can recognize that a change will occur, whatever the cause was, the better off the both the schedule and budget estimates will be.

Limitations

We recognized that there were few limitations during our research. First, we were unable to receive actual contract information so we had to use SAR budget RDT&E costs instead.

Therefore, we did not account RDT&E costs as 2-year appropriations. With the small amount of programs with the requisite data available, we could not compare if there were any statistical differences between different types of programs. Also, we did not normalize for quantity amount or quantity changes within the programs.

SARs also have some limitations within themselves with respect to measuring budget growth discussed by Hough (1992):

- Some programs do not use a consistent baseline cost estimate
- Some programs exclude significant cost elements
- Some classes of programs, such as special action programs, are excluded
- Preparation guidelines constantly change and are inconsistently interpreted
- Some programs share cost
- Some programs report the effect of cost changes instead of the root causes
- Some programs have unknown and varying funding levels

The term IOC, was not consistently used for all programs to describe that Milestone. To the best of our knowledge, researching and cross checking all of our sources, i.e. DAMIR, CADE, and LCMC reports, the dates presented in the study consistently represent the definition of the Milestone which was explained in Chapter 3. Table 21 shows the definition from an LCMC report. This term was then confirmed on DAMIR. Also, reporting requirements have changed throughout the years and may differ between in the older and newer programs. An example of this would be DSCS IOC planned and actual dates being the same as this is most likely not accurate but it was not required to record such information 36 years ago.

Table 21: IOC LCMC Definitions

Program	IOC Definition from LCMC Report
AEHF	Initial Operational Capability
DSCS III	Initial Operational Deployment
DSP	Satellite 14 Delivery
EELV	MLV First Operational Flight - HLV First Operational Flight planned for Nov-07
EPS	Required Assets Available (RAA)
GPS-III	GPS IIIA SV-1 available for launch
GPS Sat Blk IIR/R(M)/F	Availability of first Blk IIR for launch
GPS UE	Initial Production Deliveries
MUOS	On Orbit Capability
SBIRS HI	Highly Elliptical Orbit (HEO) Sensor Delivery. First satellite (GEO 1) delivery/launch planned for June 2002
Space Fence	Required Assets Available (RAA)
WGS	Initial Operational Capability

Another limitation we dealt with is that there were some inconsistencies in the reasoning on why specific FY funding changed after that FY ended. A couple of the reasons that programs offices provided were small accounting errors as well as program RDT&E budgets being separated into subprograms. For example, the AEHF subprogram for SVs 1-4 reached 90% in FY17. Therefore on the December 2017 SAR, on RDT&E used for SV 5-6 was included, which decreased previous year budgets substantially. Since there was no consistency as well as too many budgets changing retrospectively, we used the amount in the SAR following the end of the fiscal year, such as the budget given for FY11 in the December 2011 SAR even if it changed in the December 2013 SAR, etc.

Recommendations for Future Research

One recommendation for future research is to apply this research to other program types as well as other types of money, such as aircraft and Procurement dollars, respectively. With a larger data set, one can determine if there are any statistical differences between different types of weapon systems, older and newer programs, complete and continuing programs, etc. There are many studies that research the causes of cost growth but fall short in determining if there is any correlation of when these changes in budget occur in each of these programs. Future research can help develop better estimates and confidence intervals as program offices continue to move through the different life cycle stages of programs. Also, after discovering that many programs underspend, a research project focusing on creating new phasing methods for space programs could also be significant.

Summary

Through this research, we showed that we can potentially narrow down when and why changes in RDT&E estimates occur for space programs. The closer a program gets to the actual budget, the smaller the difference is between the estimate and the actual budget. However, through this and further research, we can increase our confidence in the estimates we present and decrease cost and schedule variances in future programs.

There will always be variables that cannot be controlled at the program level, such as the political and economic environment. Also, we may need to look at a higher level, to not just change the game play. Drezner (1993) said it well:

> "Nonetheless, rather than suggest that we have reached the limits of our estimating ability, the apparent consistency in cost growth could be explained in terms of incomplete or incorrect implementation of the various cost control and budgeting initiatives, due to strong institutional barriers. We have not yet fully examined an important set of potential explanatory variables – institutional and incentive factors – that may be fundamental drivers of cost growth."

Research, such as ours, can assist in identifying some cost growth factors but even with all of these studies and continuous reforms there has not been much improvement seen. If there is to be significant change, there needs to be an overhaul of the rules of the game and the institution itself.

Appendix A: Raw Index

Program Base Year: 2018							
1949	0.07232	1979	0.25089	2009	0.85682	2039	1.79591
1950	0.07315	1980	0.28588	2010	0.87146	2040	1.84493
1951	0.07693	1981	0.3295	2011	0.89836	2041	1.89529
1952	0.07886	1982	0.35669	2012	0.91955	2042	1.94703
1953	0.08008	1983	0.38697	2013	0.93581	2043	2.00017
1954	0.08119	1984	0.41046	2014	0.9493	2044	2.05477
1955	0.08279	1985	0.42877	2015	0.95903	2045	2.11086
1956	0.08525	1986	0.43741	2016	0.97272	2046	2.16848
1957	0.08798	1987	0.4483	2017	0.99293	2047	2.22767
1958	0.08991	1988	0.46094	2018	1.02017	2048	2.28848
1959	0.09158	1989	0.48977	2019	1.04802	2049	2.35094
1960	0.09321	1990	0.50731	2020	1.07662	2050	2.41512
1961	0.09442	1991	0.52852	2021	1.10601	2051	2.48104
1962	0.09584	1992	0.54641	2022	1.1362	2052	2.54876
1963	0.09743	1993	0.5617	2023	1.16722	2053	2.61834
1964	0.09906	1994	0.57497	2024	1.19908	2054	2.68981
1965	0.1012	1995	0.58862	2025	1.23181	2055	2.76323
1966	0.10415	1996	0.59994	2026	1.26543	2056	2.83866
1967	0.1077	1997	0.60715	2027	1.29997	2057	2.91614
1968	0.11204	1998	0.61076	2028	1.33546	2058	2.99574
1969	0.11758	1999	0.62093	2029	1.37191	2059	3.07752
1970	0.12384	2000	0.63952	2030	1.40936	2060	3.16152
1971	0.12986	2001	0.65843	2031	1.44783	2061	3.24782
1972	0.13512	2002	0.67443	2032	1.48735	2062	3.33647
1973	0.13926	2003	0.6939	2033	1.52795	2063	3.42755
1974	0.14846	2004	0.7229	2034	1.56966	2064	3.52111
1975	0.17055	2005	0.75127	2035	1.6125	2065	3.61722
1976	0.19535	2006	0.78048	2036	1.65652	2066	3.71596
1977	0.21059	2007	0.80815	2037	1.70174	2067	3.81739
1978	0.23126	2008	0.83559	2038	1.74819	2068	3.92159

Appendix B: Analysis of Prior Year Differences

SAR:	Dec-01	Dec-02	Dec-03	Dec-04	Dec-05	Dec-06	Dec-07	Dec-08	Dec-09	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15
2006	$ 305.97	$ 521.99	$ 570.16	$ 863.31	$ 851.14	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87	$ 829.87
2007	$ 203.30	$ 371.71	$ 402.53	$ 759.76	$ 761.37	$ 758.40	$ 741.57	$ 741.57	$ 741.57	$ 741.57	$ 741.57	$ 741.57	$ 741.57	$ 741.57	$ 741.57
2008	$ 253.47	$ 204.65	$ 205.25	$ 491.15	$ 490.31	$ 724.04	$ 719.49	$ 734.93	$ 788.79	$ 788.79	$ 788.79	$ 788.79	$ 788.79	$ 788.79	$ 788.79
2009	$ 179.15	$ 127.33	$ 130.13	$ 247.43	$ 240.31	$ 424.36	$ 452.84	$ 450.97	$ 515.16	$ 514.35	$ 514.35	$ 514.35	$ 514.35	$ 514.35	$ 514.35
2010	$ 18.02	$ 18.02	$ 18.02	$ 82.62	$ 71.14	$ 127.03	$ 125.19	$ 532.78	$ 529.45	$ 523.49	$ 523.49	$ 523.49	$ 523.49	$ 523.49	$ 523.49
2011	$ 17.59	$ 17.59	$ 17.59	$ 67.23	$ 53.76	$ 29.28	$ 28.83	$ 405.18	$ 391.60	$ 391.60	$ 421.43	$ 421.43	$ 421.43	$ 421.43	$ 421.43
2012	$ 17.51	$ 17.51	$ 17.51	$ 17.51	$ -	$ -	$ -	$ 192.16	$ 192.16	$ 303.95	$ 300.91	$ 300.91	$ 308.30	$ 313.52	$ 313.52
2013	$ 17.63	$ 17.63	$ 17.63	$ 17.63	$ -	$ -	$ -	$ 51.40	$ 51.40	$ 171.29	$ 187.64	$ 208.48	$ 163.71	$ 162.43	$ 162.43
2014	$ 16.75	$ 16.75	$ 16.75	$ 16.75	$ -	$ -	$ -	$ -	$ -	$ 67.84	$ 67.84	$ 214.26	$ 213.95	$ 225.75	$ 231.54
2015	$ 16.37	$ 16.37	$ 16.37	$ 16.37	$ -	$ -	$ -	$ -	$ -	$ 39.52	$ 39.83	$ 162.77	$ 221.06	$ 264.02	$ 255.57

Years Prior:	Five Years Prior	Four Years Prior	Three Years Prior	Two Years Prior	One Years Prior	Final RDT&E Amount
2006	$ 521.99	$ 570.16	$ 863.31	$ 851.14	$ 829.87	$ 829.87
2007	$ 402.53	$ 759.76	$ 761.37	$ 758.40	$ 741.57	$ 741.57
2008	$ 491.15	$ 490.31	$ 724.04	$ 719.49	$ 734.93	$ 734.93
2009	$ 240.31	$ 424.36	$ 452.84	$ 571.19	$ 450.97	$ 515.16
2010	$ 127.03	$ 125.19	$ 541.96	$ 532.78	$ 529.45	$ 523.49
2011	$ 28.83	$ 405.18	$ 405.18	$ 391.60	$ 391.60	$ 421.43
2012	$ 192.16	$ 192.16	$ 192.16	$ 303.95	$ 300.91	$ 300.91
2013	$ 51.40	$ 51.40	$ 171.29	$ 187.64	$ 208.48	$ 163.71
2014	$ -	$ 67.84	$ 67.84	$ 214.26	$ 213.95	$ 225.75
2015	$ 39.52	$ 39.83	$ 162.77	$ 221.06	$ 264.02	$ 255.57

Years Prior:	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Five Years Prior	$ 305.97	$ 371.71	$ 205.25	$ 247.43	$ 71.14	$ 29.28	0	$ 51.40	$ -	$ 39.52
Four Years Prior	$ 521.99	$ 402.53	$ 491.15	$ 240.31	$ 127.03	$ 28.83	$ 192.16	$ 51.40	$ 67.84	$ 39.83
Three Years Prior	$ 570.16	$ 759.76	$ 490.31	$ 424.36	$ 125.19	$ 405.18	$ 192.16	$ 171.29	$ 67.84	$ 162.77
Two Years Prior	$ 863.31	$ 761.37	$ 724.04	$ 452.84	$ 532.78	$ 391.60	$ 303.95	$ 187.64	$ 214.26	$ 221.06
One Years Prior	$ 851.14	$ 758.40	$ 719.49	$ 450.97	$ 529.45	$ 391.60	$ 300.91	$ 208.48	$ 213.95	$ 264.02
Final RDT&E Amount	$ 829.87	$ 741.57	$734.93	$ 515.16	$ 523.49	$ 421.43	$ 300.91	$ 163.71	$ 225.75	$ 255.57

Appendix C: Acronyms

ACE-IT - Automated Cost Estimating Integrated Tools

AEHF - Advanced Extremely High Frequency

AFCAH - Air Force Cost Analysis Handbook

BTR - Baseline Target Review

BY – Base Year

CADE - Cost Assessment Data Enterprise

CEH - Cost Estimating Handbook

CER - Cost Estimating Relationships

COSYSMO - Constructive Systems Engineering Cost Model

DAMIR - Defense Acquisition Management Information Retrieval

DoD – Department of Defense

DSCS III - Defense Satellite Communications System III

DSP - Defense Support Program

EELV - Evolved Expendable Launch Vehicle

EPS - Enhanced Polar System

GAO – Government Accountability Office

GPS III - Global Positioning System

GPS Blk IIR - Global Positioning System

GPS UE – Global Positioning System User Equipment

IOC – Initial Operational Capability

LCMC - Life Cycle Management Center

MDAP - Major Defense Acquisition Program

MS B – Milestone B

MUOS - Mobile User Objective System

NASA - National Aeronautics and Space Administration

NRO - National Reconnaissance Office

NSS - National Security Strategy

OCTL - Open Commitment plus Termination Liability

OSD - Office of the Secretary of Defense

RAND - Research ANd Development

RDT&E - Research, Development, Training & Evaluation

SAF/AQXE - Office of the Deputy Asst Secy for Acquisition Integration, Execution Oversight

SAF/FMBI - Office of the Deputy Asst Secy for Acquisition Integration, Budget Investment

SAR – Selected Acquisition Report

SBIRS HI - Space-Based Infrared System Hi

SMC - Space and Missile Systems Center

TOA - Total Obligational Authority

TY – Then Year

UFR - Unfunded Requirements

USCM - Unmanned Space Cost Model

WBS – Work Breakdown Structure

WGS - Wideband Global SATCOM

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14. ABSTRACT
The accuracy of budget estimates is vital in ensuring cost efficiency and decreasing the possibility of budget and schedule growth. Space program budget growth does not increase at a constant rate between Milestone B (MS B) and Initial Operational Capability (IOC). When an exponential curve was fit to the deviations in budget growth, the mean and median R2 for the programs in this study were .83 and .91, respectively. Many programs had negative annual budget growth in the first one or two fiscal years of their schedule, this even included large satellite programs with substantial budget growth later in their schedules. Much of the cumulative % budget growth was also in the later fiscal years of the schedule between MS B and IOC. The mean and median of cumulative % budget growth change at the 90% to 100% schedule mark are 25.30% and 22.51% than while they are only 7.12% and 0.96% at the 30% to 40% schedule mark. The original objective, to determine how close previous fiscal year budget estimates are to the actual budget, was also achieved. This accuracy has increased in recent years as well. As a program nears a specific fiscal year, the mean difference in the estimate to actual decreases from 42.3% four years out to 15.9% one year out. A confidence interval can also be created for these differences. At four years out, there is 95% confidence that the budget estimate is between 38.2% and 51.3% of the actual budget, and, at one year out, there is 95% confidence that the budget estimate is between 8% and 21.6% of the actual budget.

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