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Analysis of Time-Phased Estimates Accuracy, Budget Profile and Under-Spending in Defense Acquisition Programs

Thinh Q. Tran

ANALYSIS OF TIME-PHASED ESTIMATES ACCURACY, BUDGET PROFILE AND UNDER-SPENDING IN DEFENSE ACQUISITION PROGRAMS

THESIS

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Abstract

As fiscal resources become more limited due to the expanding range of mission needs, accurate cost estimating and budgeting have become more important than ever before. Accurate cost estimates allow the Department of Defense (DoD) to budget with confidence and to effectively communicate its needs to Congress. This research looks to analyze estimates from Air Force's programs using Milestone B and Initial Operational Capability as the analysis window. Initial analysis of the linear interpolation of the percent budget change indicates that there is underspending in the earlier stages of acquisition programs' development cycle. Additionally, looking at the cumulative budget change in relation to the cumulative percent schedule, with the two outlier programs B2-RMP and SDB II accounted for, significant budget changes tend to occur near the end of acquisition programs' life cycle, particularly around the 70% - 80% schedule mark and on. Then, an analysis of the S-curve suggests that, overall, acquisition programs tend to reach 60% of total program budget around the 50% schedule mark. Finally, the years-prior analysis indicates that, overall, time-phased estimates tend to be more accurate when performed within two years of the budget year.

Acknowledgments

I would like to thank my committee, Dr. Edward D. White, Dr. Jonathan D. Ritschel, and Major Gregory E. Brown, and all of the cost analysts and program managers who had helped me on this journey. Last but not least, a heartfelt thanks to all of my classmates who have endured AFIT and its challenges with me.

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I. Introduction

Background

As fiscal resources become more and more limited due to the expanding range of mission needs, accurate cost estimating and budgeting have become more important than ever before. Accurate cost estimates allow the Department of Defense (DoD) to budget with confidence and to effectively communicate its needs to Congress. Elworth et al. (2019) observed that throughout the life cycle of a space program, costs tend to change significantly from what was initially estimated as the program moves through its phases. This leads to cost increases and schedule delays. Such cost growth tendency might not be unique to space programs and could potentially be observed for other non-space programs. One notable recent example of non-space cost growth is the F-35 program, which was called a "dysfunctional trillion-dollar fighter-jet program" by the New York Times, that received many criticisms due to schedule delays and cost overruns (Insinna, 2019). This research will examine if non-space programs share this characteristic.

Getting an accurate and reasonable cost estimate requires a lot of planning, data, experience and is a challenge by itself. To add to this challenge, time-phasing the cost estimate appropriately to ensure timely funding while minimizing underspending or overspending during a fiscal year (FY) makes cost estimating both an art and a science. Elworth et al. (2019) found that many of the space programs underspent at the beginning of the programs, but started to overspend after Milestone B (MSB) and through Initial Operation Capability (IOC). Milestone B is normally the initiation of an acquisition program authorizing entry into Engineering and Manufacturing Development (EMD), and Initial Operation Capability is normally the stage before Low Rate Initial Production (LRIP) begins (Department of the Air Force, 2007). Chapter

3 explains time-phasing in more detail. Note that schedule/milestone, analogy and the S-curve are the three methods to derive time-phased budget estimates. The S-curve is often preferred for Research Development Test & Evaluation (RDT&E) budget, a two fiscal years appropriation used for investment, scientific research, development, test and evaluation. This method is an extremely powerful tool when substantiated with historical data or analogous program (Department of the Air Force, 2007). With this, the question then becomes when should time-phased estimates be accomplished?

Elworth et al. (2019) results suggest that once an RDT&E budget is two years out, there is a 95% chance that the estimate for such fiscal year's budget is at most 26.8% from what the actual budget will be. We do not yet know if these findings extend to non-space programs RDT&E budget. There could be a different relationship between the budget variations and timing of estimates for each program types. This research looks to identify if the results discovered by Elworth et al. (2019) can be applied to all programs or if there's additional factors such as program types (aircrafts vs. missiles vs. software, etc.) that need to be considered.

Problem Statement

This research aims to first determine whether the underspending in the beginning and overspending after MSB of space programs carry over to other Major Defense Acquisition Programs (MDAP). Secondly, it seeks to determine whether two years out from the finalized budget is the optimal point to perform a time-phased estimate. Third, it also aims to determine whether there are additional factors such as technical differences (producing an aircraft vs. producing missiles vs. developing software, etc.) that are unique to each program types that need to be considered aside from timing to help explain budget variations. Finally, this research aims to compare different program types and determine if the differences are significant enough to recommend policies more specific to each type. Jones et al. (2014) suggest that it is impractical and imprudent to treat all DoD weapon systems the same with respect to life cycle cost. To accomplish this, we use historical data from the Selected Acquisition Reports (SAR), a document that summarizes estimates of cost, schedule and performance ("Department of Defense Selected Acquisition Reports (SARs) – December 2016", 2017). We will analyze data for cost estimates, actual budget at MSB and at IOC to see how these numbers change and what drove those changes. The following research questions serve as the foundation to achieve the previously stated goals.

Research Objectives

1. What curves best fit changes in the RDT&E budget of a program?
2. When do budget estimates change and what can be associated with those changes?
3. How different is the rate of change amongst the type of programs?
4. How should the S-curve be applied for RDT&E budget for different program types when looking at the time between MSB and IOC?
5. What specific recommendations can the United States Air Force (USAF) have for different types of program to minimize these estimate variations?

Methodology

This research extracts data from the SARs using databases such as the Cost Assessment Data Enterprise (CADE), which, according to the CADE website, was created as an initiative to increase efficiency and productivity for cost analysts by integrating data in a single web-based application (CADE, 2020). Data will also be extracted from the Defense Acquisition Management Information Retrieval (DAMIR), which can be used as a reporting and analysis tool to view acquisition program information, and Excel spreadsheets provided by some Air Force program offices. Once extracted, linear interpolation and percent schedule will be applied to the data for analysis. Linear interpolation is used so that budget differences, for example, can be expressed as percentages for comparison and trend analysis as acquisition programs' cost can vary widely making graph scaling an issue. Additional notes will be included in the dataset as well as a uniform format will be applied to presentation (color codes, naming, etc.) for potential future follow-on researches.

Way Ahead

Chapter 2 highlights previous relevant research and explains important concepts to provide a more complete picture as well as context for this research. Chapter 3 explains methodology in further details to provide readers a comprehensive understanding of how results of this research are derived. Next, Chapter 4 presents the analysis and results. Finally, Chapter 5 provides a summary of this research as well as discusses potential future researches.

II. Literature Review

Chapter Overview

This chapter first discusses what time phasing means and the three methods that the Air Force utilizes to time phase a program's cost estimate (which borrows heavily from the Air Force Cost Analysis Handbook). Then, this chapter explains the acquisition process, and the significance of MSB and IOC when implementing time phasing. The chapter concludes with what is considered cost growth, talking about potential factors that affect cost growth, discussing the underspending aspect of budget execution/cost estimation, and the limitation of using SAR data for cost growth analysis.

What is Time Phasing?

According to the Air Force Cost Analysis Handbook (AFCAH), time phasing divides a program's projected funding needs over its required activities such as labor, material, services, etc. These time-phased estimates must be consistent with budgetary regulations as well as the program's contract and schedule. Time phasing spreads a program's estimate so that its component costs can be identified to their correct appropriations and distribution over the fiscal years of the programs. It is essential that time phasing is done as accurately as possible because this directly affects a program's budget and execution (Department of the Air Force, 2007).

Once the cost analyst has developed a cost estimate for a program in Constant Year (CY) dollars, such cost estimate will then be allocated across an annualized funding profile and inflated to Then Year (TY) dollars for use in the program's budget. Constant Year is as fiscal year whose midpoint is selected as a reference point for purchasing power. Because the allocation directly affects budget and execution, the cost analyst should reach an agreement on the proposed cost spread with the budget and program analysts responsible for program implementation without compromising the estimate's integrity (Department of the Air Force, 2007).

1. Time Phase – The Schedule/Milestone Method

According to AFCAH, the Schedule/Milestone approach is the most exact but also most difficult method to use to spread development estimates as it requires a detailed program schedule of milestones (which may not be available). The cost analyst will then use this schedule to allocate costs to appropriate fiscal years (Department of the Air Force, 2007). The method involves five steps:

Step 1: Perform Schedule Review

Step 2: Identify Milestones

Step 3: Time Phase Milestones

Step 4: Estimate Percentage of Total Cost Required to Complete Each Milestone

Step 5: Allocate Costs to Appropriate Fiscal Years

2. Time Phase – The Analogy Method

According to AFCAH, this method uses the phasing of an analogous program as the basis for allocating costs for the new program. This is suitable when both the old and new program are similar with respect to the schedule of their key milestones as well as development period length. For example, a program that requires 18 months of design effort prior to RDT&E may have significantly different funds allocation requirements from a program that requires a three-year design effort. This method is easy to use once an analogous program has been identified. However, the challenge lies in finding a truly analogous program and verifying its funding profile (Department of the Air Force, 2007).

3. Time Phase – The S-Curve Method

According to AFCAH, this method is often preferred for RDT&E budget, a two fiscal years appropriation used for investment, scientific research, development, test and evaluation. It is an extremely powerful tool when substantiated with historical data or analogous program. It's called S-curve because development work, when graphed as cumulative effort (cost) versus development time, typically follows an S-shaped curve, and is often modeled using the normal distribution (Department of the Air Force, 2007).

This subsection describes the basic features of the normal S-curve. More complex distributions, such as the Beta, Rayleigh, and Weibull, may also be used to model the time phasing of a program's development dollars. Figure 1 taken from AFCAH shows development effort/cost plotted as a function of development project time in the form of a probability density function (PDF), which is a statistical expression that defines a probability distribution for a discrete random variable (Investopedia, 2019).

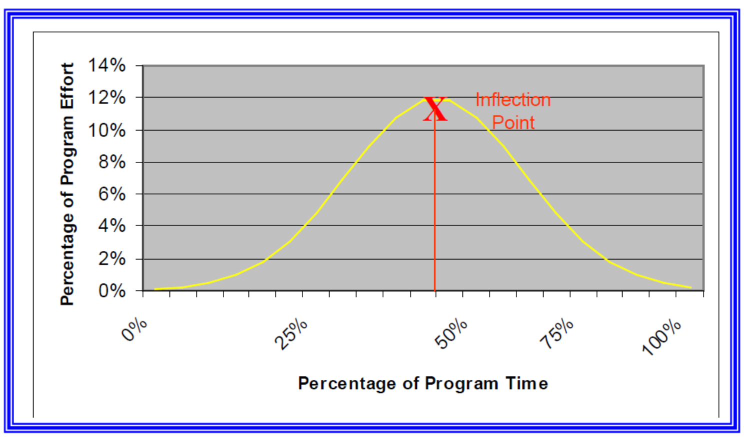


EXHIBIT 15-9, Normal Bell Curve (Probability Density Function) of Development Effort/Cost Versus Time

Figure 1: Normal Bell Curve (Probability Density Function) of Development Effort/Cost Versus Time (Department of the Air Force, 2007)

Figure 2 shows cumulative development effort/cost versus development project time, which begins with a slow initial research period followed by a rapid building phase and then tapers off towards program completion. This is a cumulative density/distribution function (CDF), which gives us the cumulative probability associated with a function. The CDF in Figure 2 shows the percentages of total program funds spent at certain percentages of total elapsed program time (Department of the Air Force, 2007).

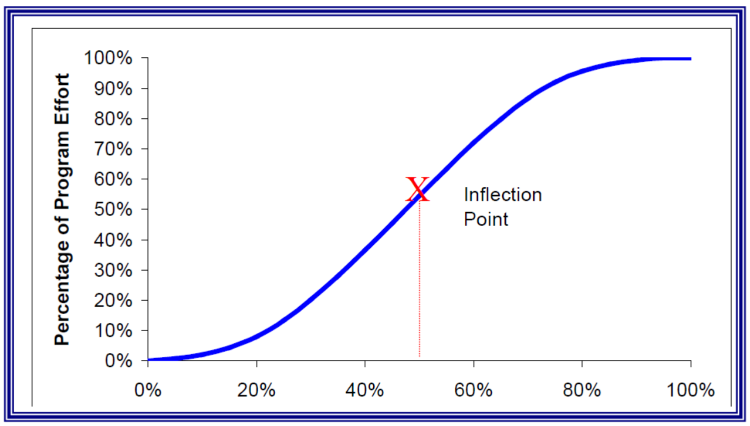


EXHIBIT 15-10, S-Curve of Cumulative Development Effort/Cost Versus Time

Figure 2: S- Curve Cumulative Development Effort/Cost Versus Time (Department of the Air Force, 2007)

The Air Force recognizes that no single S-curve fits all development programs' funding profile. The cost analyst needs to adjust the general S-shape so that the curve describes as accurately as possible a program's particular expenditure pattern. This adjustment tailors the S-curve's cumulative percentages to the program. The cost analyst then uses these percentages to allocate the development program's cost estimate over its program fiscal years for budgeting and execution (Department of the Air Force, 2007). Brown et al. (2015) also observed that one size does not fit all when it comes to the S-curve. He found that the traditional 60/40 rule is very limited as it does not account for the differences and unique characteristics of programs when performing time-phased estimates. He also suggested that the Weibull distribution is slightly more accurate. The Weibull model explained 74.6 percent of variation, the Rayleigh model explained 73.7 percent of variation and the Beta model explained 69.9 percent of variation compare to the 60/40 percent rule being able to explain only 68 percent of variation (Brown et al., 2015).

There are generally three techniques used to fit an S-curve to a program as explained by AFCAH (Department of the Air Force, 2007):

- **Skew of the normal curve:** this involves estimating the skew of the probability density curve which generates the cumulative S-curve. The amount of skew governs how early or late during the program the S-curve's inflection point occurs. Skew is estimated by determining what percentage of the effort/cost will be expended by what percentage of time through the development project. This is expressed as a ratio, such as 60/40; unfortunately, the cost analysis literature contains two different interpretations of this ratio:
    - **Interpretation One:** the first number is the percentage of effort expended by the time the program has reached a given percentage of its total duration being the second number.
    - **Interpretation Two:** the first number refers to the percentage of effort spent by the time the program is halfway completed, while the second refers to the remaining percentage of effort that will be spent during the second half of the program.
- **Skew and kurtosis of the normal curve:** involves estimating the kurtosis of the probability density curve which generates the cumulative S-curve, as well as its skew.

Kurtosis influences the speed at which effort/money will be spent, and skew influences when it will be spent. S-curve calculators and tables may use kurtosis in addition to skew, but they do not typically use kurtosis by itself. The curves in Figure 3 were modeled with the Beta distribution function. Per AFCAH S-curves are sometimes termed Beta curves since the Beta distribution is often used to model them; this terminology, strictly speaking, is incorrect since the S-curve is a cumulative curve built from the Beta's PDF.

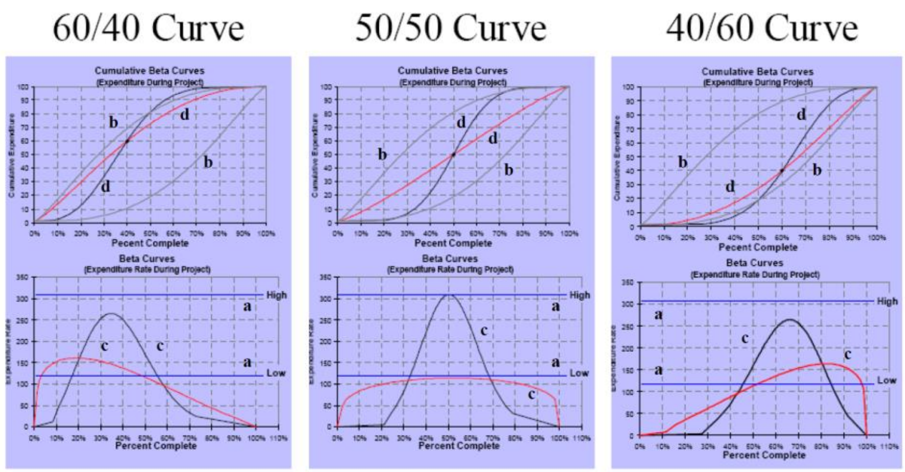


EXHIBIT 15-13, The Effect of Probability Density Curve Skew and Kurtosis on S-Curves

Figure 3: The Effect of Probability Density Curve Skew and Kurtosis on S-Curves (Department of the Air Force, 2007)

- **Shape-defining parameter(s) of an S-curve equation:** The third technique requires that a cost analyst estimate the value of parameters which drive a specially built equation that defines the shape of the S-curve. For example, NASA expresses the cumulative cost percentage of a program as a function of the cumulative time fraction, T, for an equation involving powers of that parameter, where $0 < T < 1$. The Air Force Aeronautical Systems Center (ASC) uses the same parameter but a different equation, while other organizations use more general approaches, such as the Rayleigh and Weibull distributions (Note: the Rayleigh and Weibull curves are continuous and each needs to be normalized to a discrete curve before being used for phasing).

The Acquisition Process and Why We Choose MSB and IOC

The primary reason this research chooses MSB as the beginning period because it's normally the initiation of an acquisition program authorizing entry into EMD as mentioned in Chapter 1. However, the reason for choosing IOC as the ending period is less obvious. According to AFCAH, IOC is the primary driver in determining a program's development and production schedule. As a result, the program's time phased estimate must be consistent with this schedule to support achieving the IOC (Department of the Air Force, 2007). In other words, IOC directly influences how the time phased estimate is constructed because it serves as the end point for the RDT&E estimate.

For the overall acquisition process, the entire acquisition framework is shown in Figure 4. It gives a graphical depiction of why this research selects MSB and IOC (usually before Low Rate Initial Production or LRIP) as the beginning and ending for SAR data collection and analysis. When LRIP begins, the procurement appropriation would be used as the funding source, stopping the use of the RDT&E appropriation.

Figure 4: Defense Program Acquisition Framework (Department of the Air Force, 2007)

Availability of Funds

To having funding available for a program to spend, a budget needs to be formulated and articulated to Congress. The quote below from AFCAH summarizes succinctly why time phasing is necessary for RDT&E budget formulation after a cost estimate has been derived.

"The budgeting process for a program typically begins with the development of an estimate which program analysts then use to determine the basic outline of the budget – that is, how much funding is required, and in what fiscal years. The cost estimate in this case drives the budget. A program, though, must often update the estimate to reflect new or existing budgetary constraints" (Department of the Air Force, 2007, p. 11-15).

RDT&E Budget Process

To receive a budget, information has to be rolled up to the top level and be included in the President's budget request submission to Congress for approval. According to the Department of Defense Financial Management Regulation 7000.14R, Volume 2B, Chapter 5, paragraph 050201, the exhibits that are required to be submitted to support the Budget Estimate Submission (BES) and the President's budget request are shown in Table 1 in their required arrangement (Department of Defense, 2017):

Table 1: Summary of Budget Exhibit Requirements

	Exhibit	Appropriation
R-1	RDT&E Programs	All
R-2	RDT&E Budget Item Justification	All
R-2a	RDT&E Project Justification	All
R-3	Cost Analysis	All
R-4	RDT&E Program Schedule Profile	All
R-4a	RDT&E Program Schedule Detail	All

There are more details involved for each of the exhibits and what information is required for their submission. This section serves to show only what are required overall for the RDT&E

portion of the entire program's budget and to provide just enough background for the readers to understand how an RDT&E budget come to be.

Weapon System Cost Growth Research

What is cost growth?

To achieve the goals this research outlined, the research subject (cost growth) must first be defined. Younossi et al. (2007) defined cost growth as the ratio between the most recent value given in the SAR and the cost provided in the SAR at some earlier milestone. In other words, comparing the cost provided in a SAR to its earlier version at previous fiscal years and noting the difference will show us how cost has changed. This research defines cost growth in a similar fashion. For example, in Table 2, the 2020 SAR of program A that shows a $20M in TY for Fiscal Year (FY) 2019 vs. $18M in TY for FY 2019 in the 2018 SAR of the same program will mean that the estimated budget for FY 2019 in the 2018 SAR has an estimate variance of $2M in TY when comparing to the finalized budget amount that was recorded in the 2020 SAR.

Table 2: Example Program

Example: Program A			
SAR	**FY 19**	**FY20**	**FY21**
2020	20M	21M	22M
…	…	…	…
2018	18M	19M	20M

Existing Literature on Cost Growth

Most of the existing researches investigate how potential independent variables explain cost growth as the dependent variable with the focus on overspending or going above the original amount. While some researches talk about the underspending aspect of budget execution and cost estimation, none provide substantial analysis on the subject. From the perspective of designing acquisition policy and drafting regulations, Younossi et al. (2007) suggest that many acquisition reform and other DoD management initiatives that were meant to reduce cost growth did not yield the desired result. Analysis showed that there's no significant improvement from the 1970s to the 1990s. Younossi et al. (2007) also noted that early estimates of important parameters are usually inaccurate in two respect, their bias towards over-optimism and substantial variation.

From another perspective, Lorell et al. (2015) approached cost growth by investigating six worst-performing Air Force MDAPs. The programs are the Advanced Extremely High Frequency (AEHF) satellite system, the C-130 Avionics Modernization Program (AMP), the Evolved Expendable Launch Vehicle (EELV) program, the Global Hawk (RQ-4 Global Hawk high-altitude long-endurance [HALE] unmannedaerial vehicle), the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) and the Space-Based Infrared System High (SBIRS High). Their analysis revealed that there are two main categories for common characteristics and conditions that were prominent. Those categories are the premature approval of MSB (with insufficient technology maturity and high complexity, unclear, unstable requirements, and unrealistic cost estimates), and the suboptimal acquisition strategies and program structure (inadequate risk management strategies, use of a combined MSB and Milestone C [MSC], premature award of MSC before achieving stable design and adequate production) (Lorell et al., 2015). Table 3 gives a perspective on how big these cost growths were.

Table 3: Six Air Force MDAPs with Extreme Cost Growth (Lorell et al., 2015)

		Budgetary Cost Growth			FY 2012	Unit Cost Growth	
Program	MS B OR B/C	Development	Procurement	Program	$M Growth	Procurement	Program
AEHF	Nov-01	58%	325%	119%	$ 7,600	217%	95%
C-130 AMP	Jul-01	148%	24%	47%	$ 2,000	194%	193%
EELV	Oct-98	29%	229%	210%	$ 36,700	299%	273%
Global Haw	Mar-01	277%	123%	157%	$ 8,800	86%	152%
NPOESS*	Aug-02	106%	101%	68%	$ 4,800	335%	154%
SBIRS High	Nov-96	235%	574%	315%	$ 14,800	407%	279%

NOTES: Percentages shown in bold represent extreme cost growth, defined as cost growth more than one standard deviation above the mean for that measure. Programs listed with an asterisk were terminated or truncated in the FY 2013 President's Budget

Taking a similar approach, Bolten et al. (2008) investigate cost growth by looking into 35 different acquisition programs and grouping the cost drivers into specific categories. Table 4 from their research shows that cost growth is primarily driven by decisions such as quantity changes (22 percent), requirement growth (13 percent), and schedule changes (9 percent). It was noted that cost estimation error, which was the only large contributor in the errors category, was 10 percent. Bolten et al. (2008) stated that the dominant influence of decision on cost growth was surprising given that previous studies have reported the reverse. This was attributed to the inclusion of the quantity changes that were responsible for more than one-third of total cost growth. Additionally, Bolten et al. (2008) also emphasized that error due to cost estimating accounted for nearly one-third of the overall development cost growth at 18 percent.

Table 4: Cost Growth, by RAND Category (mean for 35 mature programs) (Bolten et al., 2008)

Category	Development Cost Growth (%)	Procurement Cost Growth (%)	Total Cost Growth (%)
Errors	19.6	14.7	14.6
Cost estimate	18.0	8.4	10.1
Schedule estimate	1.0	0.9	0.9
Technical issues	0.6	5.4	3.5
Decisions	30.7	57.4	41.6
Requirements	17.5	9.5	12.9
Affordability	–1.9	–0.5	–1.3
Quantity	4.3	40.8	21.9
Schedule	6.0	10.0	8.9
Inter- or intraprogram transfers	4.8	–2.4	–0.7
Financial	1.0	1.8	1.4
Exchange rate	0.1	0.1	0.1
Inflation	0.9	1.7	1.3
Miscellaneous	5.2	1.4	2.4
Error correction	–0.5	–0.3	–0.4
Unidentified	–0.3	–0.3	–0.4
External events	6.0	2.1	3.1
Total	56.5	75.4	60.0

Limitations of SAR Data

Since this research relies heavily on SAR for budget and cost estimate data, it is important to be cognizant of the limitation of SAR data. According to Younossi et al. (2007), there are several limitations when using SAR data to study cost growth. The first limitation is the unfeasibility of analysis on major subsystem since data is rolled up and reported at the levels of annual development funding, Military Construction (MILCON) funding, and Operations & Maintenance (O&M) funding. The second limitation is due to the fact that program baselines and system configurations evolve over time making it difficult to analyze cost growth. The third limitation is the change in report requirements and guidelines. This makes comparing SARs across time periods challenging (Younossi et al., 2007).

The fourth limitation is the inconsistency of the allocation of cost growth among different programs in each of the SAR cost variance category. The fifth limitation is that SARs are not required for all programs; classified and special-access programs most likely do not generate SARs. Finally, the sixth limitation, and perhaps the most important one as stated by the Younossi et al. (2007), is that the initial estimates in the SAR are consistent with the program's early budget which may not reflect the most realistic cost estimate as well as any issues related to underspending (Younossi et al., 2007).

Additionally, Hough (1992) also noted the following problems with using SAR data. Some programs fail to use a consistent baseline cost estimate. There's exclusion of some significant cost elements, and of certain classes of major programs. Guidelines constantly changes and interpretations of the guidelines are inconsistent across programs. There is cost sharing in joint programs, unknown and variable funding levels for program risk, and the reporting of effects of cost changes rather than the root causes of those changes (Hough, 1992). These limitations directly influence how this research draws inferences and conclusions from SAR data.

III. Methodology

Chapter Overview

In this chapter, we explain how data was collected and criteria used to decide whether a program should be included. Then, we explain how we normalized data by converting the budget estimates from TY dollars to CY 2020 dollars, performing linear interpolation, calculating changes in budget and changes in schedule using percentages, and our approach to analyzing actual vs. estimate with the use of "years prior" calculation. Finally, we go into different analysis to address our research questions:

1. How should changes in the RDT&E budget of a program be reflected?
2. When do budget estimates change and what can be associated with those changes?
3. How different is the rate of change amongst the type of programs?
4. How should the S-curve be applied for RDT&E budget for different program types when looking at the time between MSB and IOC?
5. What specific recommendations can the USAF have for different types of program to minimize these estimate variations?

Data Source/Database Summary

This research uses data from SARs pulled from CADE. Within each SAR for each program, the costs in TY were used as estimate and budget amount for analysis. We chose to pull data from CADE because although it doesn't replace DAMIR, CADE centralizes all SAR data for all programs on DAMIR and provides users with a comprehensive Excel sheet that contains the related fiscal information for a selected acquisition program. In addition to going through DAMIR and CADE, we also reached out to multiple program offices for their assistance.

The majority of the acquisition programs pulled from CADE do not have available data or in some cases have missing data as shown in Table 5, and Table 6 shows all programs that are used for this research. For verification purposes, we did a cross check on DAMIR, which is the source system for CADE, and the budget data were equivalent. We suspect the reason for the majority of programs not having data is because SAR submission was not a requirement when these programs started or information was recorded on paper and have not been transferred electronically to CADE/DAMIR.

Data Selection

From CADE, DAMIR, and the program offices, we were able to gather required data on twenty-eight programs. In the case of programs that have three or more annual SAR submissions missing, we deem that doing interpolation for more than two years would risk the integrity of keeping our data "legitimate". This is a personal preference decision based on intuition alone. For programs that do not have their MSB or IOC listed on CADE or DAMIR, they were excluded as well because knowing the MSB and the IOC is critical to performing our research analysis. Programs that have not finished are also excluded because it would be unfair and inaccurate to analyze unfinished programs. Additionally, for Space programs, we were not able to obtain data for all of the programs analyzed by Elworth et al. (2019) because those data were not on CADE nor DAMIR.

Table 5: Program Exclusion Criteria

Program Exclusion Criteria	Number of Programs
Total Program Listed on CADE	285
No Data Available	-217
3 or more SARs submission missing	-26
Does not have a MS B	-2
Does not have an IOC	-1
Program has not finished	-7
Program is a duplicate	-4
Programs Available	**28**

Table 6: Programs Included for This Research

Program Name	Service	Program Commodity Type
B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability	AIRFORCE	AIRCRAFT
B-2 RMP - B-2 Radar Modernization Program	AIRFORCE	AIRCRAFT
C-130 AMP - C-130 Aircraft Avionics Modernization Program	AIRFORCE	AIRCRAFT
C-130J Hercules Transport Aircraft	AIRFORCE	AIRCRAFT
C-5 RERP - C-5 Aircraft Reliability Enhancement and Re-engining Program	AIRFORCE	AIRCRAFT
CRH - Combat Rescue Helicopter	AIRFORCE	AIRCRAFT
F-15 EPAWSS - Eagle Passive Active Warning Survivability System	AIRFORCE	AIRCRAFT
F-22A Increment 3.2B	AIRFORCE	AIRCRAFT
F-35 - Lightning II Joint Strike Fighter (JSF) Program	AIRFORCE	AIRCRAFT
KC-46A Tanker	AIRFORCE	AIRCRAFT
MINUTEMAN III PRP - Propulsion Replacement Program	AIRFORCE	MISSILE
Integrated Air & Missile Defense (IAMD)	ARMY	MISSILE
B61 Mod 12 Life Extension Program Tailkit Assembly	AIRFORCE	ORDNANCE
SDB I – Small Diameter Bomb Increment I	AIRFORCE	ORDNANCE
SDB II – Small Diameter Bomb, Increment II	AIRFORCE	ORDNANCE
FAB-T – Family of Beyond Line-of-Sight Terminals	AIRFORCE	SOFTWARE
MP-RTIP - Multi-Platform Radar Technology Insertion Program	AIRFORCE	SOFTWARE
MPS – Mission Planning System	AIRFORCE	SOFTWARE
AEHF - Advanced Extremely High Frequency Satellite	AIRFORCE	SPACE
EELV - Evolved Expendable Launch Vehicle (EELV)	AIRFORCE	SPACE
EPS - Enhanced Polar System	AIRFORCE	SPACE
GBS – Global Broadcast Service	AIRFORCE	SPACE
GPS III - Global Positioning System III	AIRFORCE	SPACE
NPOESS - National Polar-Orbiting Operational Environmental Satellite System	AIRFORCE	SPACE
SBIRS-HIGH - Space-Based Infrared System Program, High	AIRFORCE	SPACE
WGS – Wideband Global SATCOM Program	AIRFORCE	SPACE
MUOS – Mobile User Objective System	NAVY	SPACE
GLOBAL HAWK (RQ-4A/B) - High Altitude Endurance Unmanned Aircraft System	AIRFORCE	UAV

Converting Budget and Estimates into Constant Year 2020 Dollars

After data collection, we proceed to arrange the fiscal information in a table format with SAR submissions as the columns and the fiscal years as the rows. Once this is done, all estimates and budget amount were converted to Constant Year 2020 by dividing the amount by the corresponding fiscal year indices so that inflation is accounted for in further analysis. The indices are from the weighted inflation indices table based on the Office of the Secretary of Defense (OSD) raw inflation rates. Table 7 and Table 8 are visual examples of how this step is done. Before inflation is accounted for:

Table 7: Before Inflation is Applied

In TY $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
FY \ SAR	2007	2008	2009	2010	2011	2012	2013	2014	2015
2005	$4.4 M	$4.4 M	$4.4 M	$4.4 M	$4.4 M	$4.4 M	$4.4 M	$4.4 M	$4.4 M
2006	$38.3 M	$38.3 M	$38.3 M	$38.3 M	$38.3 M	$38.3 M	$38.3 M	$38.3 M	$38.3 M
2007	$78.2 M	$77.0 M	$78.1 M	$78.1 M	$75.7 M	$75.7 M	$75.7 M	$75.7 M	$75.7 M
2008	$77.1 M	$74.4 M	$77.1 M	$77.1 M	$71.6 M	$71.6 M	$71.6 M	$71.6 M	$71.6 M
2009	$103.6 M	$94.3 M	$90.6 M	$90.9 M	$85.0 M	$85.0 M	$85.0 M	$85.0 M	$85.0 M
2010	$128.1 M	$88.8 M	$83.0 M	$53.0 M	$49.5 M	$49.5 M	$49.5 M	$49.5 M	$49.5 M
2011	$88.6 M	$68.8 M	$78.0 M	$76.9 M	$52.8 M	$49.0 M	$48.5 M	$48.5 M	$48.5 M
2012	$31.2 M	$38.0 M	$37.2 M	$57.1 M	$57.1 M	$44.7 M	$38.2 M	$38.2 M	$38.2 M
2013	$.5 M	$3.4 M	$6.4 M	$6.3 M	$6.3 M	$6.3 M	$.5 M	$.4 M	$.4 M

After inflation is accounted for:

Table 8: After Inflation is Applied

In CY2020 $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
FY \ SAR	2007	2008	2009	2010	2011	2012	2013	2014	2015
2005	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M
2006	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M
2007	$95.7 M	$94.2 M	$95.6 M	$95.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M
2008	$92.5 M	$89.2 M	$92.5 M	$92.5 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M
2009	$122.7 M	$111.7 M	$107.3 M	$107.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M
2010	$149.8 M	$103.8 M	$97.1 M	$62.0 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M
2011	$101.7 M	$79.0 M	$89.5 M	$88.3 M	$60.6 M	$56.2 M	$55.7 M	$55.7 M	$55.7 M
2012	$35.2 M	$42.8 M	$42.0 M	$64.4 M	$64.4 M	$50.4 M	$43.1 M	$43.1 M	$43.1 M
2013	$.6 M	$3.8 M	$7.1 M	$7.0 M	$7.0 M	$7.0 M	$.6 M	$.4 M	$.4 M

Percent Budget Change by Percent Schedule

Once our data are converted to CY 2020 dollars, we proceed with using the years from MSB to IOC as our beginning and end date for the schedule. If a program's MSB is in 2007 and its IOC is in 2014 as shown in Table 9, then the total length of time is considered 100% and each year would be 12%. This is represented visually by the decimals on the very top in Table 9 (0.12 – 0.96). Then, we calculate the total program budget change from MSB to IOC and use this number as the denominator for determining the annual percent budget change (cell M15). For example, we obtain the 2008 percent budget change (cell O15) by dividing the annual $ change (cell O14) by the total program change (cell M19). The calculation result for 2008 would be (-$73.7M/$162M) = -0.4554 which is -45.54%. The total program change in cell M18 is defined as the change of the entire program from MS B to IOC. The idea is to determine how much of the total program change (cell M19) has occurred in a given year in the entire schedule.

Table 9: Annual % of Total Change

	M	N	O	P	Q	R	S	T	U	V
1	In CY2020 $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
2	SAR / FY	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	2005	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M
4	2006	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M
5	2007	$95.7 M	$94.2 M	$95.6 M	$95.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M
6	2008	$92.5 M	$89.2 M	$92.5 M	$92.5 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M
7	2009	$122.7 M	$111.7 M	$107.3 M	$107.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M
8	2010	$149.8 M	$103.8 M	$97.1 M	$62.0 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M
9	2011	$101.7 M	$79.0 M	$89.5 M	$88.3 M	$60.6 M	$56.2 M	$55.7 M	$55.7 M	$55.7 M
10	2012	$35.2 M	$42.8 M	$42.0 M	$64.4 M	$64.4 M	$50.4 M	$43.1 M	$43.1 M	$43.1 M
11	2013	$.6 M	$3.8 M	$7.1 M	$7.0 M	$7.0 M	$7.0 M	$.6 M	$.4 M	$.4 M
12	Total	$651.9 M	$578.2 M	$584.7 M	$571.1 M	$522.8 M	$504.5 M	$490.1 M	$490.0 M	$490.0 M
13	5% Mark	$32.6 M	$28.9 M	$29.2 M	$28.6 M	$26.1 M	$25.2 M	$24.5 M	$24.5 M	$24.5 M
14	Annual $ Change		-$73.7 M	$6.6 M	-$13.7 M	-$48.3 M	-$18.3 M	-$14.3 M	-$.1 M	
15	Annual % of Total Change		-45.54%	4.07%	-8.44%	-29.83%	-11.34%	-8.86%	-0.07%	
16	Yr By Yr % Change		-11.30%	1.14%	-2.33%	-8.45%	-3.51%	-2.84%	-0.02%	
17	Cum % Change		-45.54%	-41.47%	-49.90%	-79.73%	-91.07%	-99.93%	-100.00%	
18	Total Program Change (-)									
19	$162 M									

This calculation is done all the way to the IOC year for all programs. After we have the annual percent budget change for all programs, we proceed to match the budget change with the respective schedule percent and perform linear interpolation to fill in the 1% increment. Table 10 is the visual depiction of this step.

Table 10: Percent Budget Change

	A	B	C	D	E	F
1	Program / Schedule Percent	AEHF - Advanced Extremely High Frequency Satellite	B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability	B-2 RMP - B-2 Radar Modernization Program	B61 Mod 12 Life Extension Program Tailkit Assembly	C-130 AMP - C-130 Aircraft Avionics Modernization Program
2	1%	0.83%	-1.92%	-89.18%	-0.07%	0.80%
3	2%	1.67%	-3.83%	-178.36%	-0.14%	1.60%
4	3%	2.50%	-5.75%	-267.54%	-0.21%	2.40%
5	4%	3.33%	-7.67%	-356.71%	-0.29%	3.20%
6	5%	4.17%	-9.58%	-445.89%	-0.36%	4.00%
7	6%	5.00%	-11.50%	-535.07%	-0.43%	4.80%
8	7%	5.83%	-13.42%	-624.25%	-0.50%	5.60%
9	8%	6.67%	-15.33%	-713.43%	-0.57%	6.40%
10	9%	7.50%	-17.25%	-802.61%	-0.64%	7.20%
11	**10%**	8.33%	-19.17%	-891.79%	-0.71%	8.00%
12	11%	9.17%	-21.08%	-980.96%	-0.79%	8.80%
13	12%	**10.00%**	-23.00%	-1070.14%	-0.86%	9.60%
14	13%	0.50%	-24.92%	-1159.32%	-0.93%	10.40%
15	14%	1.00%	-26.83%	-1248.50%	-1.00%	11.20%
16	15%	1.50%	-28.75%	-1337.68%	-1.07%	12.00%
17	16%	2.00%	-30.67%	-1426.86%	-1.14%	12.80%
18	17%	2.50%	-32.58%	-1516.04%	-1.21%	13.60%
19	18%	**3.00%**	-34.50%	-1605.21%	-1.29%	14.40%
20	19%	4.67%	-36.42%	-1694.39%	-1.36%	15.20%
21	**20%**	9.33%	-38.33%	-1783.57%	-1.43%	**16.00%**
22	21%	14.00%	-40.25%	-1872.75%	-1.50%	-0.60%
23	22%	18.67%	-42.17%	-1961.93%	-1.57%	-1.20%
24	23%	23.33%	-44.08%	-2051.11%	-1.64%	-1.80%
25	24%	**28.00%**	**-46.00%**	-2140.29%	-1.71%	-2.40%
26	25%	-0.50%	0.33%	-2229.46%	-1.79%	-3.00%
27	26%	-1.00%	0.67%	-2318.64%	-1.86%	-3.60%
28	27%	-1.50%	1.00%	-2407.82%	-1.93%	-4.20%
29	28%	-2.00%	1.33%	**-2497.00%**	**-2.00%**	-4.80%
30	29%	-2.50%	1.67%	-176.14%	-0.64%	-5.40%
31	**30%**	**-3.00%**	2.00%	-352.29%	-1.29%	**-6.00%**
32	31%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The red percentage numbers are the calculated annual percent budget change from Table 9 and the black percentage numbers are linearly interpolated to fill the 1% increment gap. This is done by diving the annual percent budget change by the total number of data points (including the calculated annual percent budget change). For example, in Table 9, the B-2 EHF first calculated annual percent budget change was -45.54% at the 24% schedule mark. Each 1% increment before this data point is calculated by diving -45.54% by 24. This step is necessary so that all programs can be normalized and analyzed at the 10%, 20%, …, 90%, 100% schedule increment.

Cumulative Percent Budget Change by Cumulative Percent Schedule

The cumulative percent budget change (cell O17 – cell U17) is calculated by adding more percent budget changes (cell O15 – cell U15) on top of the previous one as the program progresses. For example, in Table 11, to obtain the cumulative percent budget change in 2009 (cell P17), we add the annual % of total change for 2008 to the annual % of total change for 2009 (cell O15 + cell P15). The result for 2009 (cell P17) would be -45.54% + 4.07% = -41.47%.

Table 11: Cum % Change

	M	N	O	P	Q	R	S	T	U	V
1	In CY2020 $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
2	SAR / FY	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	2005	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M
4	2006	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M
5	2007	$95.7 M	$94.2 M	$95.6 M	$95.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M
6	2008	$92.5 M	$89.2 M	$92.5 M	$92.5 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M
7	2009	$122.7 M	$111.7 M	$107.3 M	$107.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M
8	2010	$149.8 M	$103.8 M	$97.1 M	$62.0 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M
9	2011	$101.7 M	$79.0 M	$89.5 M	$88.3 M	$60.6 M	$56.2 M	$55.7 M	$55.7 M	$55.7 M
10	2012	$35.2 M	$42.8 M	$42.0 M	$64.4 M	$64.4 M	$50.4 M	$43.1 M	$43.1 M	$43.1 M
11	2013	$.6 M	$3.8 M	$7.1 M	$7.0 M	$7.0 M	$7.0 M	$.6 M	$.4 M	$.4 M
12	Total	$651.9 M	$578.2 M	$584.7 M	$571.1 M	$522.8 M	$504.5 M	$490.1 M	$490.0 M	$490.0 M
13	5% Mark	$32.6 M	$28.9 M	$29.2 M	$28.6 M	$26.1 M	$25.2 M	$24.5 M	$24.5 M	$24.5 M
14	Annual $ Change		-$73.7 M	$6.6 M	-$13.7 M	-$48.3 M	-$18.3 M	-$14.3 M	-$.1 M	
15	Annual % of Total Change		-45.54%	4.07%	-8.44%	-29.83%	-11.34%	-8.86%	-0.07%	
16	Yr By Yr % Change		-11.30%	1.14%	-2.33%	-8.45%	-3.51%	-2.84%	-0.02%	
17	Cum % Change		-45.54%	-41.47%	-49.90%	-79.73%	-91.07%	-99.93%	-100.00%	
18	Total Program Change (-)									
19	$162 M									

This calculation is done all the way to the IOC year for all programs. After we have the cumulative percent budget change for all programs, we proceed to match the budget change with the respective cumulative schedule percent and perform linear interpolation to fill in the 1% increment. Table 12 is the visual depiction of this step.

Table 12: Cumulative Percent Budget to Cumulative Percent Schedule

	A	B	C	D	E
1	Program / Schedule Percent	AEHF - Advanced Extremely High Frequency Satellite	B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability	B-2 RMP - B-2 Radar Modernization Program	B61 Mod 12 Life Extension Program Tailkit Assembly
2	**1%**	0.79%	-1.90%	-89.19%	-0.07%
3	2%	1.59%	-3.80%	-178.38%	-0.13%
4	3%	2.38%	-5.69%	-267.57%	-0.20%
5	4%	3.17%	-7.59%	-356.77%	-0.26%
6	5%	3.97%	-9.49%	-445.96%	-0.33%
7	6%	4.76%	-11.39%	-535.15%	-0.39%
8	7%	5.55%	-13.28%	-624.34%	-0.46%
9	8%	6.35%	-15.18%	-713.53%	-0.52%
10	9%	7.14%	-17.08%	-802.72%	-0.59%
11	**10%**	7.93%	-18.98%	-891.91%	-0.66%
12	11%	8.73%	-20.87%	-981.11%	-0.72%
13	12%	**9.52%**	-22.77%	-1070.30%	-0.79%
14	13%	9.97%	-24.67%	-1159.49%	-0.85%
15	14%	10.41%	-26.57%	-1248.68%	-0.92%
16	15%	10.86%	-28.46%	-1337.87%	-0.98%
17	16%	11.30%	-30.36%	-1427.06%	-1.05%
18	17%	11.75%	-32.26%	-1516.25%	-1.11%
19	18%	**12.19%**	-34.16%	-1605.45%	-1.18%
20	19%	16.94%	-36.05%	-1694.64%	-1.25%
21	**20%**	21.68%	-37.95%	-1783.83%	-1.31%
22	21%	26.43%	-39.85%	-1873.02%	-1.38%
23	22%	31.18%	-41.75%	-1962.21%	-1.44%
24	23%	35.92%	-43.64%	-2051.40%	-1.51%
25	24%	**40.67%**	**-45.54%**	-2140.59%	-1.57%
26	25%	40.15%	-45.20%	-2229.78%	-1.64%
27	26%	39.63%	-44.86%	-2318.98%	-1.70%
28	27%	39.11%	-44.52%	-2408.17%	-1.77%
29	28%	38.58%	-44.18%	**-2497.36%**	**-1.84%**
30	29%	38.06%	-43.84%	-2673.47%	-2.46%
31	**30%**	**37.54%**	-43.50%	-2849.57%	-3.08%
32	31%	39.26%	-43.16%	-3025.68%	-3.71%
33	32%	40.99%	-42.82%	-3201.79%	-4.33%
34	33%	42.71%	-42.49%	-3377.90%	-4.95%
35	34%	44.43%	-42.15%	-3554.00%	-5.58%
36	35%	46.16%	-41.81%	-3730.11%	-6.20%
37	36%	**47.88%**	**-41.47%**	-3906.22%	-6.83%

The red percentage numbers are the calculated cumulative percent budget change and the black percentage numbers are linearly interpolated to fill the 1% increment gap. This is done by diving the cumulative percent budget change by the total number of data points within that range (including the calculated cumulative percent budget change). For example, the B-2 EHF program first calculated cumulative percent budget change was -45.54% at the 24% schedule mark. Each 1% increment before this data point is calculated by diving -45.54% by 24. This step is necessary so that all programs can be normalized and analyzed at the 10%, 20%, …, 90%, 100% schedule increment.

The S-Curves

The effort performed by a given percent schedule mark is calculated by dividing the sum of all dollars allocated up to that point by the estimated total program at that same point. For example, in Table 13, the total resources allocated up to 2008 (including 2008) divided by the estimated total program in 2008 (cell O12) is 41%. As mentioned earlier, the decimals at the top 0.12 – 0.96 (cell N1 – cell U1) represents the schedule percentages chronologically. Looking at Table 13, for the B2-EHF program, at the 24% schedule mark, 41% of the total program has been allocated.

Table 13: S-Curve Calculations

	M	N	O	P	Q	R	S	T	U	V
1	In CY2020 $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
2	SAR / FY	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	2005	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M
4	2006	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M
5	2007	$95.7 M	$94.2 M	$95.6 M	$95.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M
6	2008		$89.2 M	$92.5 M	$92.5 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M
7	2009			$107.3 M	$107.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M
8	2010				$62.0 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M
9	2011					$60.6 M	$56.2 M	$55.7 M	$55.7 M	$55.7 M
10	2012						$50.4 M	$43.1 M	$43.1 M	$43.1 M
11	2013							$.6 M	$.4 M	$.4 M
12	Total	$651.9 M	$578.2 M	$584.7 M	$571.1 M	$522.8 M	$504.5 M	$490.1 M	$490.0 M	$490.0 M
13	S-Curve	23%	41%	60%	72%	86%	99%	100%	100%	100%
14	5% Mark	$32.6 M	$28.9 M	$29.2 M	$28.6 M	$26.1 M	$25.2 M	$24.5 M	$24.5 M	$24.5 M
15	Annual $ Change		-$73.7 M	$6.6 M	-$13.7 M	-$48.3 M	-$18.3 M	-$14.3 M	-$.1 M	
16	Annual % of Total Change		-45.54%	4.07%	-8.44%	-29.83%	-11.34%	-8.86%	-0.07%	
17	Yr By Yr % Change		-11.30%	1.14%	-2.33%	-8.45%	-3.51%	-2.84%	-0.02%	
18	Cum % Change		-45.54%	-41.47%	-49.90%	-79.73%	-91.07%	-99.93%	-100.00%	
19	Total Program Change (-)									
20	$162 M									

This calculation is done all the way to the IOC year for all programs. After we have the S-Curve percent for all programs, we proceed to match the percent of resources allocated with the respective cumulative schedule percent and perform linear interpolation to fill in the 1% increment. Table 14 is the visual depiction of this step.

Table 14: S-Curve Linear Interpolation

	A	B	C	D	E	F
1	Program / Schedule Percent	AEHF - Advanced Extremely High Frequency Satellite	B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability	B-2 RMP - B-2 Radar Modernization Program	B61 Mod 12 Life Extension Program Tailkit Assembly	C-130 AMP - C-130 Aircraft Avionics Modernization Program
2	**1%**	2.00%	1.71%	1.07%	0.50%	0.60%
3	2%	4.00%	3.42%	2.14%	1.00%	1.20%
4	3%	6.00%	5.13%	3.21%	1.50%	1.80%
5	4%	8.00%	6.83%	4.29%	2.00%	2.40%
6	5%	10.00%	8.54%	5.36%	2.50%	3.00%
7	6%	12.00%	10.25%	6.43%	3.00%	3.60%
8	7%	14.00%	11.96%	7.50%	3.50%	4.20%
9	8%	16.00%	13.67%	8.57%	4.00%	4.80%
10	9%	18.00%	15.38%	9.64%	4.50%	5.40%
11	**10%**	20.00%	17.08%	10.71%	5.00%	6.00%
12	11%	22.00%	18.79%	11.79%	5.50%	6.60%
13	12%	**24.00%**	20.50%	12.86%	6.00%	7.20%
14	13%	27.00%	22.21%	13.93%	6.50%	7.80%
15	14%	30.00%	23.92%	15.00%	7.00%	8.40%
16	15%	33.00%	25.63%	16.07%	7.50%	9.00%
17	16%	36.00%	27.33%	17.14%	8.00%	9.60%
18	17%	39.00%	29.04%	18.21%	8.50%	10.20%
19	18%	**42.00%**	30.75%	19.29%	9.00%	10.80%
20	19%	43.50%	32.46%	20.36%	9.50%	11.40%
21	**20%**	45.00%	34.17%	21.43%	10.00%	**12.00%**
22	21%	46.50%	35.88%	22.50%	10.50%	13.40%
23	22%	48.00%	37.58%	23.57%	11.00%	14.80%
24	23%	49.50%	39.29%	24.64%	11.50%	16.20%
25	24%	**51.00%**	**41.00%**	25.71%	12.00%	17.60%
26	25%	53.33%	42.58%	26.79%	12.50%	19.00%
27	26%	55.67%	44.17%	27.86%	13.00%	20.40%
28	27%	58.00%	45.75%	28.93%	13.50%	21.80%
29	28%	60.33%	47.33%	**30.00%**	**14.00%**	23.20%
30	29%	62.67%	48.92%	32.57%	14.29%	24.60%
31	**30%**	**65.00%**	50.50%	37.29%	14.57%	**26.00%**
32	31%	66.17%	52.08%	42.00%	14.86%	26.30%
33	32%	67.33%	53.67%	46.71%	15.14%	26.60%
34	33%	68.50%	55.25%	51.43%	15.43%	26.90%
35	34%	69.67%	56.83%	56.14%	15.71%	27.20%
36	35%	70.83%	58.42%	60.86%	16.00%	27.50%
37	36%	**72.00%**	**60.00%**	65.57%	16.29%	27.80%

As with before, the red percentage numbers are the calculated S-Curve percent and the black percentage numbers are linearly interpolated to fill the 1% increment gap. This is done by diving the S-Curve percent by the total number of data points within that range (including the calculated cumulative percent budget change). For example, the B-2 EHF program first calculated cumulative S-Curve percentage was 41% at the 24% schedule mark. Each 1% increment before this data point is calculated by diving 41% by 24. This step is necessary so that all programs can be normalized and analyzed at the 10%, 20%, …, 90%, 100% schedule increment.

Budget Variation Analysis Based on Years Prior

To help determine how many years out should an estimate be completed, we look to perform our "years prior" analysis. Using data from SAR submissions, we rearrange the data points with fiscal years being the columns and the number of years prior as the rows. We use the IOC year as the end point and work backward. For example, the B-2 EHF program has its MSB in 2007 and IOC in 2014. Because there's no fiscal data for FY 2014 for the B-2 EHF program, we use FY 2013 as the end point and work backward. For FY 2012, the SAR two years prior would be 2010 SAR submission for FY 2012 (cell Q10). Additionally, to avoid any possible major outliers, we apply the "no estimate less than 5% of the total program" rule. For any budget estimate data in a given year (column N), if the estimate data (cell N3 as an example) is less than the 5% of the total program for that year (cell N13), then that estimate data will be excluded from the years-prior analysis. The excluded data are in red color. The missing data in 2008 for all programs that are filled by linear interpolation are in purple color.

After the amount for "years prior" was recorded, we calculate the delta between the "years prior" data point and the final RDT&E for a given FY. The final RDT&E amount is from the most recent SAR submission because we want the numbers to be the most up to date. Once the delta between "years prior" and the final RDT&E amount is calculated, we divide the delta by the respective final RDT&E to obtain the percentage difference. Table 15 is the visual depiction of this step. The yellow highlighted cells are the years prior calculation example above.

Table 15: Years Prior Estimates

	M	N	O	P	Q	R	S	T	U	V
1	Table 1 in CY2020 $	0.12	0.24	0.36	0.48	0.6	0.72	0.84	0.96	
2	SAR / FY	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	2005	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M	$5.7 M
4	2006	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M	$48.1 M
5	2007	$95.7 M	$94.2 M	$95.6 M	$95.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M	$92.6 M
6	2008	$92.5 M	$89.2 M	$92.5 M	$92.5 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M	$85.9 M
7	2009	$122.7 M	$111.7 M	$107.3 M	$107.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M	$100.6 M
8	2010	$149.8 M	$103.8 M	$97.1 M	$62.0 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M	$57.9 M
9	2011	$101.7 M	$79.0 M	$89.5 M	$88.3 M	$60.6 M	$56.2 M	$55.7 M	$55.7 M	$55.7 M
10	2012	$35.2 M	$42.8 M	$42.0 M	$64.4 M	$64.4 M	$50.4 M	$43.1 M	$43.1 M	$43.1 M
11	2013	$.6 M	$3.8 M	$7.1 M	$7.0 M	$7.0 M	$7.0 M	$.6 M	$.4 M	$.4 M
12	Total	$651.9 M	$578.2 M	$584.7 M	$571.1 M	$522.8 M	$504.5 M	$490.1 M	$490.0 M	$490.0 M
13	5% Mark	$32.6 M	$28.9 M	$29.2 M	$28.6 M	$26.1 M	$25.2 M	$24.5 M	$24.5 M	$24.5 M
14	Annual $ Change		-$73.7 M	$6.6 M	-$13.7 M	-$48.3 M	-$18.3 M	-$14.3 M	-$.1 M	
15	Annual % of Total Change		-45.54%	4.07%	-8.44%	-29.83%	-11.34%	-8.86%	-0.07%	
16	Yr By Yr % Change		-11.30%	1.14%	-2.33%	-8.45%	-3.51%	-2.84%	-0.02%	
17	Cum % Change		-45.54%	-41.47%	-49.90%	-79.73%	-91.07%	-99.93%	-100.00%	
18	Total Program Change (-)									
19	$162 M									
20										
21	Table 2 in CY2020 $									
22	FY / Years Prior	2005	2006	2007	2008	2009	2010	2011	2012	2013
23	Five Years Prior SAR	$ M	$ M	$ M	$ M	$ M	$ M	$ M	$35 M	$3.8 M
24	Four Years Prior SAR	$ M	$ M	$ M	$ M	$ M	$ M	$102 M	$43 M	$7.1 M
25	Three Years Prior SAR	$ M	$ M	$ M	$ M	$ M	$150 M	$79 M	$42 M	$7.0 M
26	Two Years Prior SAR	$ M	$ M	$ M	$ M	$123 M	$104 M	$90 M	$64 M	$7.0 M
27	One Year Prior SAR	$ M	$ M	$ M	$92 M	$112 M	$97 M	$88 M	$64 M	$7.0 M
28	Budget Year	$ M	$ M	$96 M	$89 M	$107 M	$62 M	$61 M	$50 M	$.6 M
29	Post Year	$ M	$48 M	$94 M	$92 M	$108 M	$58 M	$56 M	$43 M	$.4 M
30	Final RDT&E $	$5.7 M	$48.1 M	$92.6 M	$85.9 M	$100.6 M	$57.9 M	$55.7 M	$43.1 M	$.4 M
31										
32	Delta of Years Prior vs Final RDT&E									
33	FY / Years Prior	2005	2006	2007	2008	2009	2010	2011	2012	2013
34	Five Years Prior SAR	$.0 M	$.0 M	$.0 M	$.0 M	$100.6 M	$57.9 M	$55.7 M	$7.9 M	-$3.3 M
35	Four Years Prior SAR	$.0 M	$.0 M	$.0 M	$85.9 M	$100.6 M	$57.9 M	-$46.0 M	$.3 M	-$6.7 M
36	Three Years Prior SAR	$.0 M	$.0 M	$92.6 M	$85.9 M	$100.6 M	-$91.9 M	-$23.3 M	$1.1 M	-$6.5 M
37	Two Years Prior SAR	$.0 M	$48.1 M	$92.6 M	$85.9 M	-$22.0 M	-$46.0 M	-$33.9 M	-$21.3 M	-$6.5 M
38	One Year Prior SAR	$5.7 M	$48.1 M	$92.6 M	-$6.6 M	-$11.0 M	-$39.2 M	-$32.6 M	-$21.3 M	-$6.5 M
39	Budget Year	$5.7 M	$48.1 M	-$3.1 M	-$3.3 M	-$6.6 M	-$4.1 M	-$4.9 M	-$7.3 M	-$.1 M
40	Post Year	$5.7 M	$.0 M	-$1.5 M	-$6.6 M	-$7.0 M	$.0 M	-$.6 M	$.0 M	$.0 M
41	Final RDT&E $	$5.7 M	$48.1 M	$92.6 M	$85.9 M	$100.6 M	$57.9 M	$55.7 M	$43.1 M	$.4 M
42										
43	% Years Prior									
44	FY / Years Prior	2005	2006	2007	2008	2009	2010	2011	2012	2013
45	Five Years Prior SAR	0%	0%	0%	0%	100%	100%	100%	18%	-750%
46	Four Years Prior SAR	0%	0%	0%	100%	100%	100%	-83%	1%	-1500%
47	Three Years Prior SAR	0%	0%	100%	100%	100%	-159%	-42%	3%	-1475%
48	Two Years Prior SAR	0%	100%	100%	100%	-22%	-79%	-61%	-49%	-1475%
49	One Year Prior SAR	100%	100%	100%	-8%	-11%	-68%	-59%	-49%	-1475%
50	Budget Year	100%	100%	-3%	-4%	-7%	-7%	-9%	-17%	-25%
51	Post Year	100%	0%	-2%	-8%	-7%	0%	-1%	0%	0%
52	Final RDT&E $	$5.7 M	$48.1 M	$92.6 M	$85.9 M	$100.6 M	$57.9 M	$55.7 M	$43.1 M	$.4 M

Because we are concerned with the estimate accuracy, a negative percent (over-estimate) can be treated the same as a positive percent (under-estimate) in this context. Overestimating prevents resources from being allocated to other programs in the same year while underestimating could cause shortage of funds. As a result, looking at the percentage difference (for example, cell P51) in absolute value allows us to treat all estimate errors the same and prevents the negative percent from lowering the effect of the positive percent or vice-versa.

Table 16: Years Prior Analysis

Years Prior	Commodity Type	Average of % Difference	Average of Abs % Dif	Median	Abs % Dif Median	Sum of Over estimate	Sum of Under estimate	Sum of Accurate	Sum of Near Accurate (-10% to +10%)
5		-8.26%	51.29%	7.92%	42.66%	20	27	0	6
4		-14.57%	44.54%	4.81%	30.24%	35	35	0	15
3		-23.01%	38.19%	-15.27%	24.80%	65	34	0	28
2		-21.73%	25.74%	-13.61%	15.63%	106	22	0	54
1		-18.34%	20.89%	-8.62%	11.10%	126	20	9	81
0		-14.01%	15.26%	-3.41%	4.12%	81	26	65	136
-1		-11.87%	13.38%	-3.78%	3.79%	55	16	94	139
Grand Total		**-16.36%**	**24.73%**	**-6.09%**	**13.91%**	**488**	**180**	**168**	**459**

Table 16 shows the result after all the years-prior estimate error data are combined and analyzed. Average of % Difference is the mean of all the years-prior percentages for estimate errors without applying absolute values. Average of Abs % Dif is the same data with absolute value applied. The same notation is used for the medians.

To test for statistical significance of the estimate variations, we will employ the Kruskal-Wallis test and the Steel-Dwass test. These non-parametric tests do not require the normality assumption to hold and are more conservative.

The Kruskal-Wallis test is used in place of the one-way ANOVA test:

- Null Hypothesis: There's no difference between the years
- Alt Hypothesis: There's a difference between the years

The Steel-Dwass test is then used for pairwise comparisons between the years-prior:

- Null Hypothesis: There's no difference between the year 3 and year 4
- Alt Hypothesis: There's a difference between the year 3 and year 4

Summary

This chapter commenced with the source of the data, how it was collected, and calculated for analysis. Then the chapter discussed the details of database and shows why the majority of programs listed on CADE and DAMIR were excluded. Next, the chapter explains how we convert our data into CY 2020 for consistency when performing analysis. Finally, the chapter discusses our use of linear interpolation calculations and "years-prior" approach to prepare data for analysis. For Chapter 4, we will employ simple descriptive statistics, scatter plots, histograms, perform the Kruskal-Wallis test, the Steel-Dwass test and discuss the results to answer our research questions.

IV. Analysis and Results

Chapter Overview

In this chapter, we present the results from the methodology and data discussed in Chapter 3. First, we talk about linear interpolation calculations which helps us spot whether underspending is present in the acquisition programs we analyzed. Data will also be plotted using scatter plots and histograms for budget change vs. schedule analysis, S-curve analysis and "years-prior" analysis. Next, we discuss the results from our statistical tests which suggests how far out from the actual budget should an estimate be performed.

Linear Interpolation

We begin by visually investigating the overall budget changes which includes all acquisition programs that we used for this research. Then, we take a more detailed look by separating the programs into commodity types which include aircraft, missile, ordnance, software, space, and UAV. The forthcoming charts (Figure 5 – Figure 11) give us a quick visual of what the trend lines look like over time as we move from MSB to IOC for our acquisition programs. However, the charts do a poor job of telling us whether there's an underspending trend at the beginning of the programs due to scaling issue from outliers and the descriptive statistics (Table 17 – Table 23) following Figure 5 – Figure 11 will give us a better understanding.

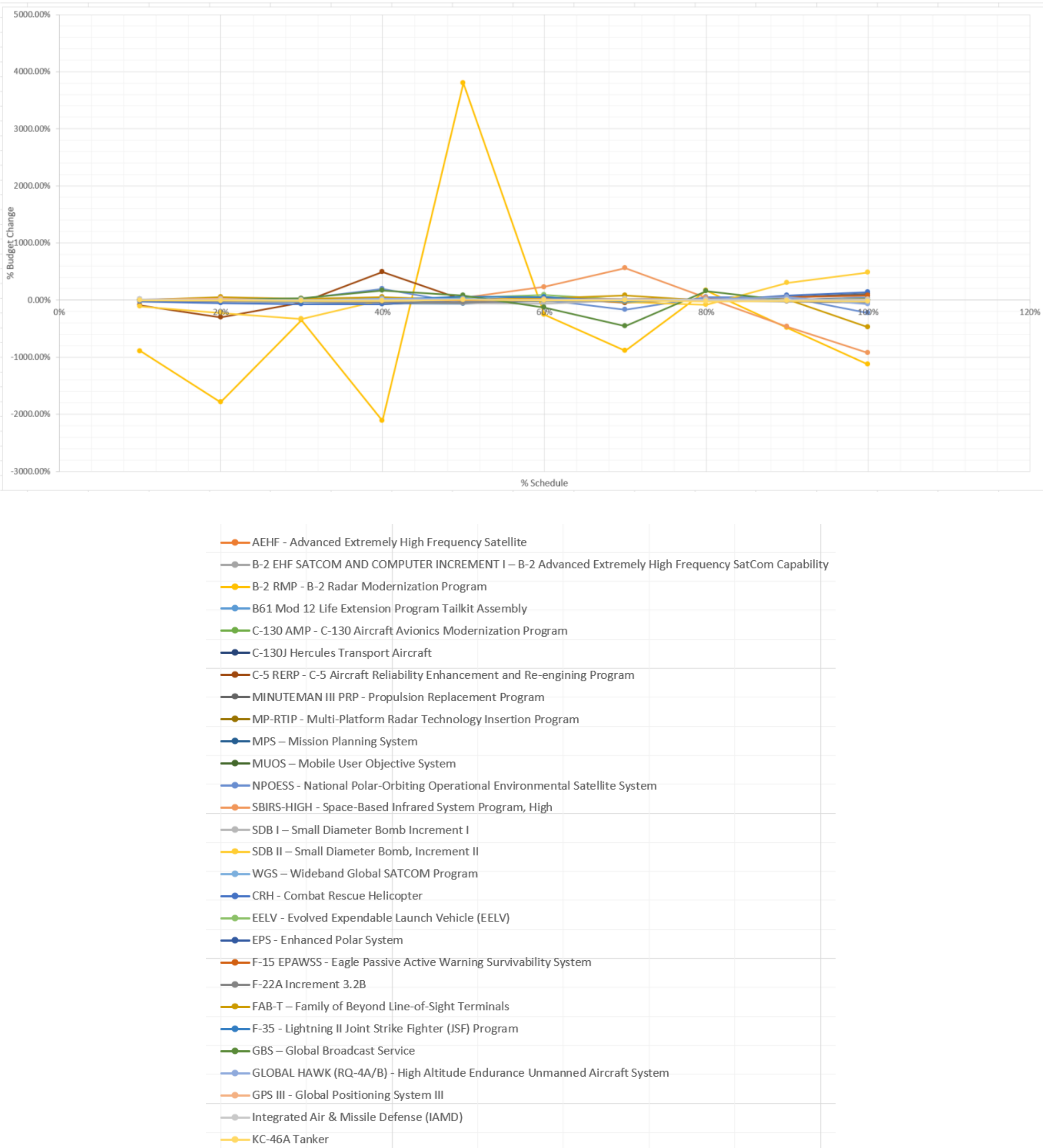


Figure 5: Overall % Budget Change vs % Schedule

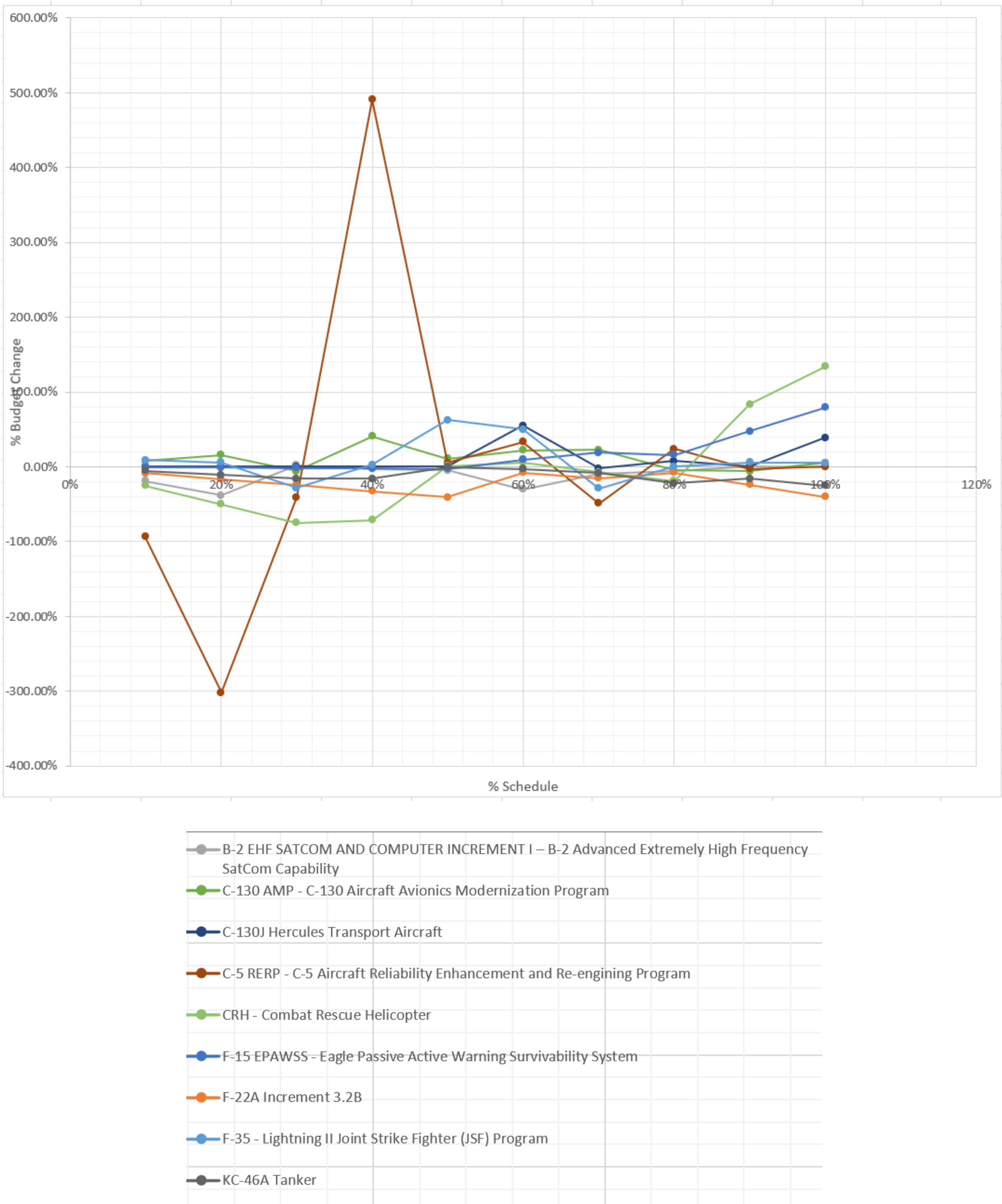


Figure 6: Aircraft % Budget Change vs % Schedule

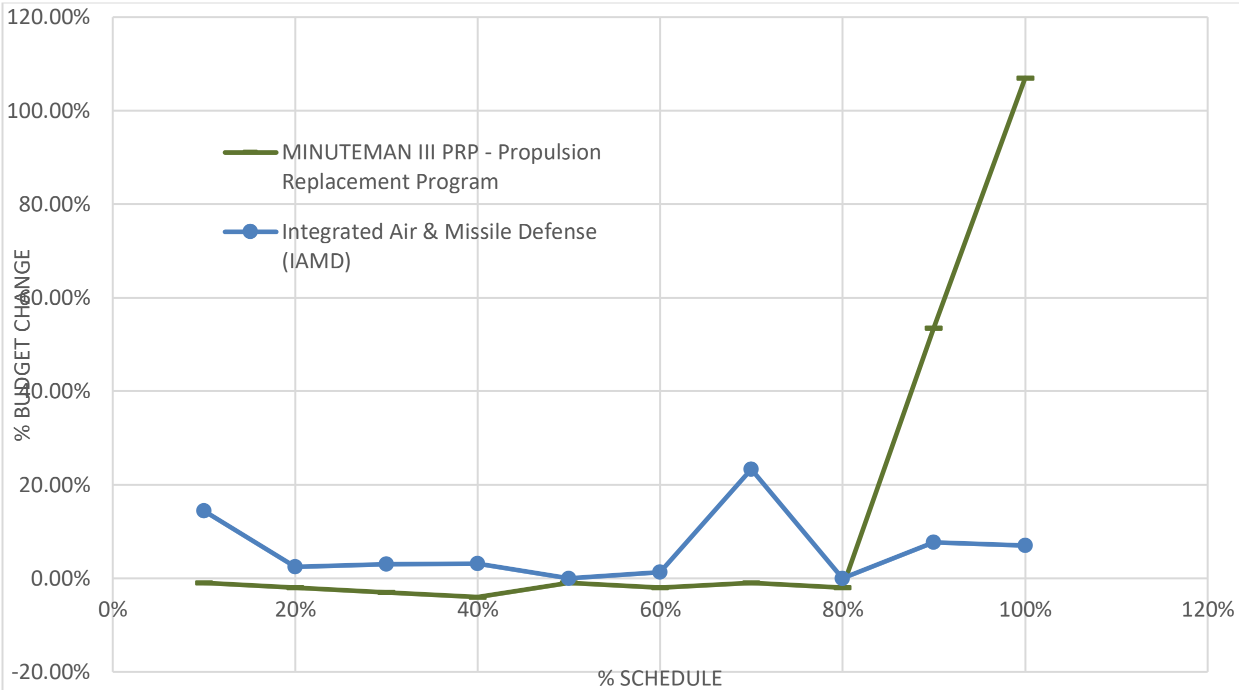


Figure 7: Missiles % Budget Change vs % Schedule

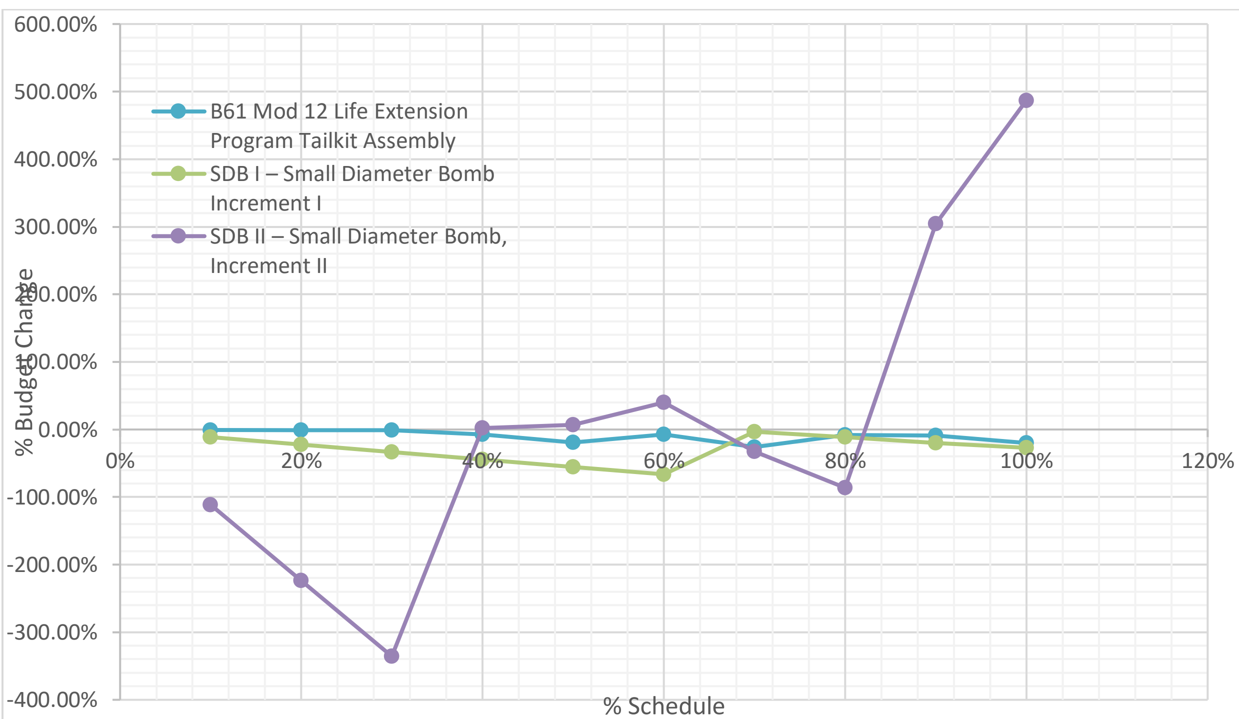


Figure 8: Ordnance % Budget Change vs % Schedule

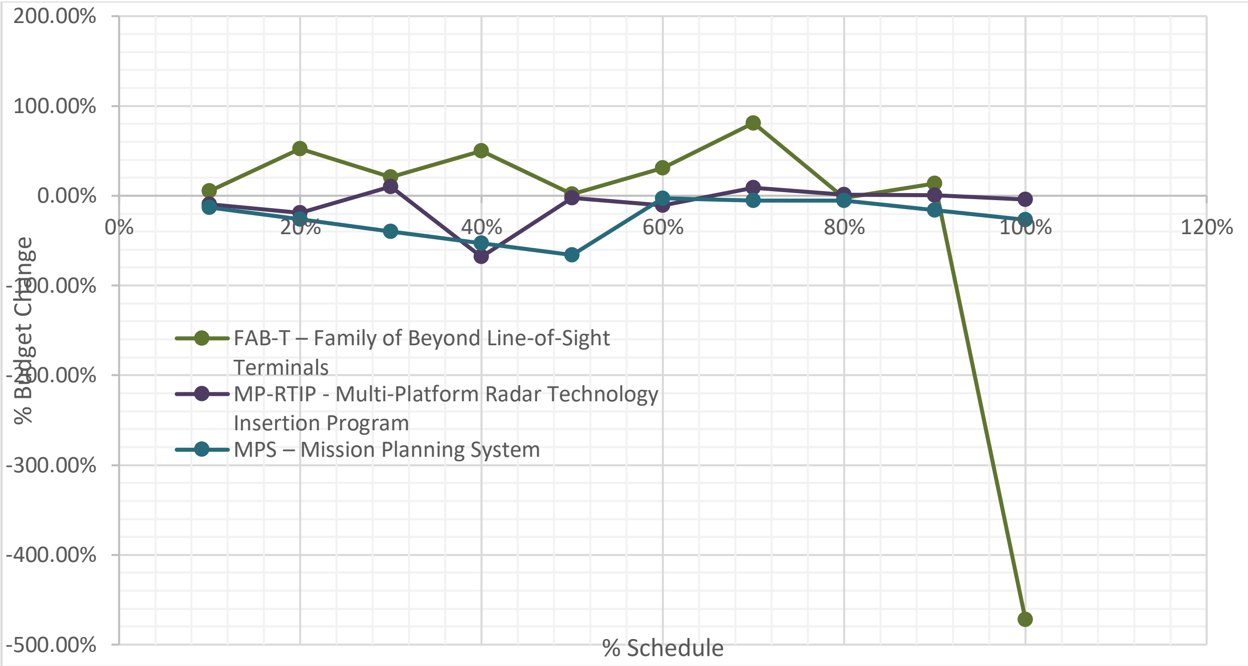


Figure 9: Software % Budget Change vs % Schedule

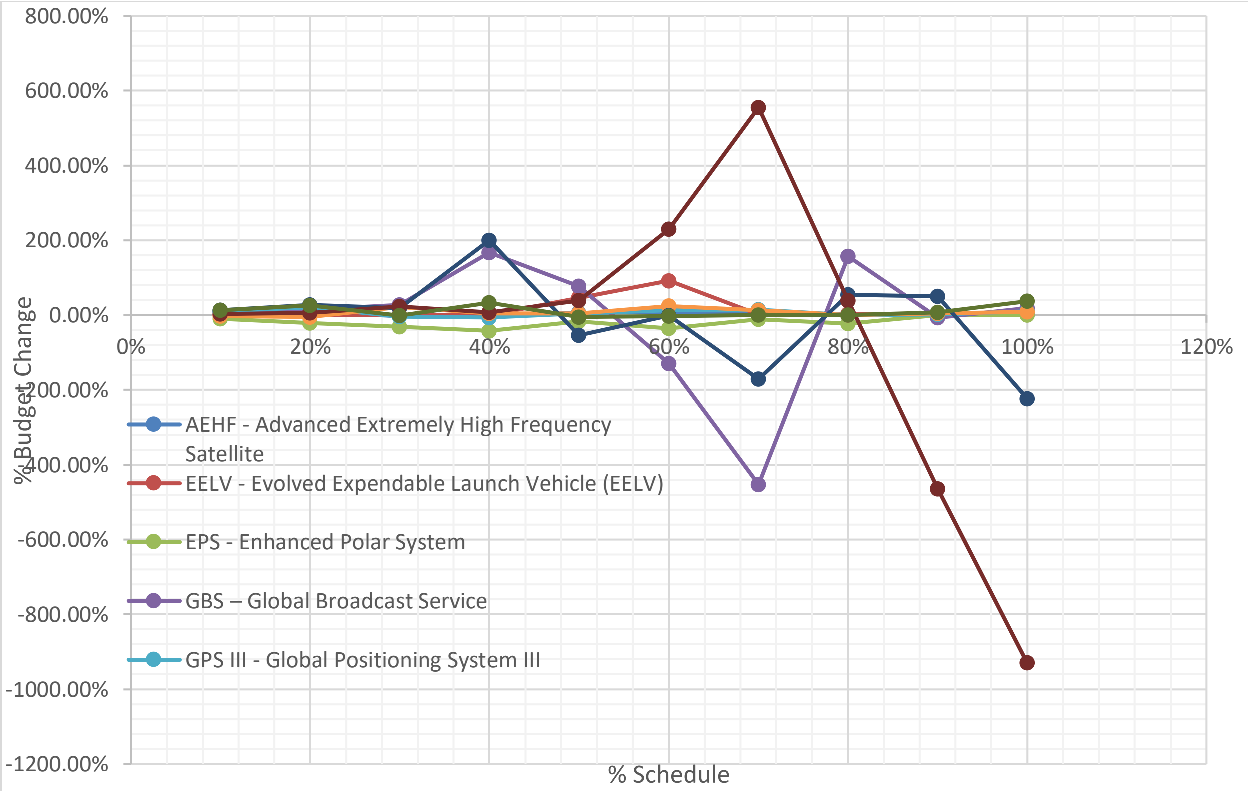


Figure 10: Space % Budget Change vs % Schedule

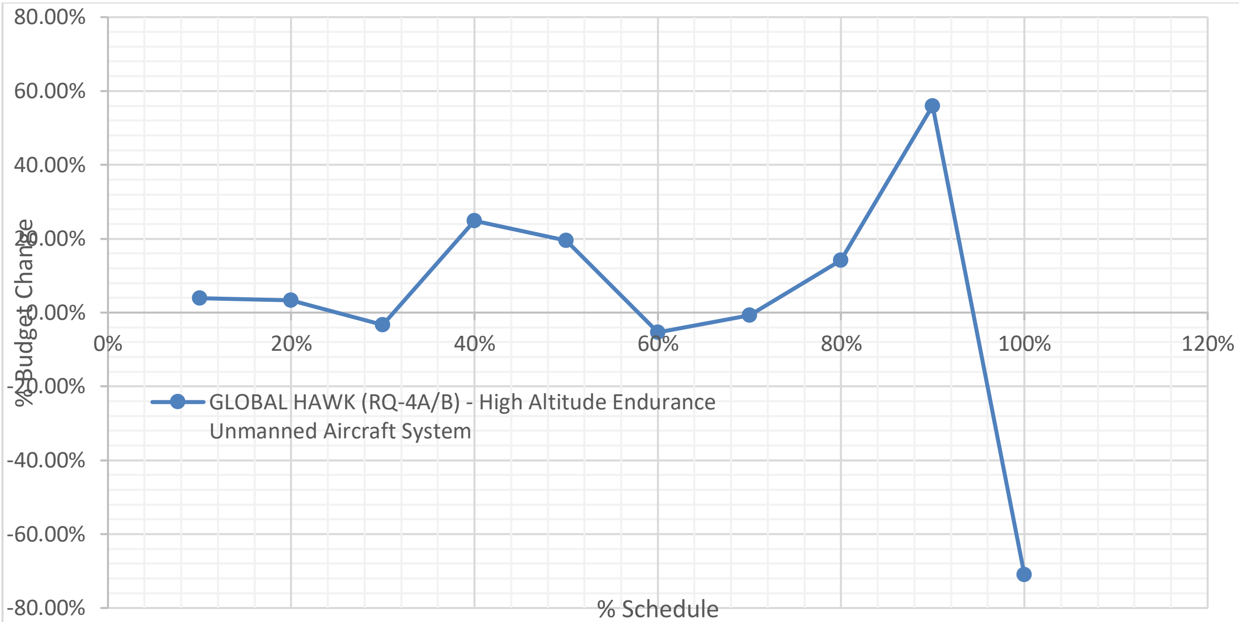


Figure 11: UAV % Budget Change vs % Schedule

Descriptive Statistics for Linear Interpolation

Because we couldn't quite detect any underspending or overspending trend using the charts due to extreme outliers, we look to the descriptive statistics to spot potential indication of either underspending or overspending. In this case, using the medians would make more sense given that there are extreme outliers (SBIRS-HI, B-2 RMP, etc.) that heavily affected the mean.

Table 17: Overall % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	-39.59%	-0.66%	287%	169%
20%	-83.57%	-1.31%	1162%	341%
30%	-31.21%	-3.00%	83%	91%
40%	-51.29%	0.00%	1751%	418%
50%	135.93%	0.50%	5149%	718%
60%	2.05%	0.17%	59%	77%
70%	-34.52%	-2.64%	486%	220%
80%	10.38%	0.02%	24%	49%
90%	-14.55%	1.27%	206%	143%
100%	-72.18%	1.00%	942%	307%

Looking at the averages for overall, there seems to be signs of underspending during the early portion of a program's life cycle. At 10% schedule, the average is -39.59%. At 20% schedule, the average is -83.57%. The average remains negative until we reach the 50% schedule mark, which shows an average of 135.93%. The overall medians also move in the same direction. This suggests that, overall, programs tend to underspend prior to reaching halfway given that the time frame is between MSB and IOC

Table 18: Aircraft % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	-14.96%	-5.31%	10%	32%
20%	-44.07%	-10.63%	98%	99%
30%	-21.13%	-15.94%	6%	25%
40%	45.50%	-2.40%	288%	170%
50%	3.35%	0.00%	7%	27%
60%	15.02%	9.60%	8%	28%
70%	-8.58%	-8.25%	5%	22%
80%	-1.40%	-5.00%	2%	15%
90%	9.88%	-0.05%	12%	34%
100%	21.88%	5.00%	30%	54%

A similar case can be made for Aircraft acquisition program type, however, after the 50% schedule mark, Aircraft programs tend to go back to underspending instead of leveling off or becoming overspent. Due to extreme outliers at the end of the programs' life (visually observable from Figure 5 to Figure 11), it would make more sense to look at the overall medians instead of the averages which show inconsistent result with cost growth that is commonly associated with acquisition programs.

Table 19: Missiles % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	6.72%	6.72%	1%	11%
20%	0.22%	0.22%	0%	3%
30%	0.00%	0.00%	0%	4%
40%	-0.44%	-0.44%	0%	5%
50%	-0.50%	-0.50%	0%	1%
60%	-0.33%	-0.33%	0%	2%
70%	11.17%	11.17%	3%	17%
80%	-1.00%	-1.00%	0%	1%
90%	30.60%	30.60%	10%	32%
100%	57.00%	57.00%	50%	71%

Table 20: Ordnance % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	-41.22%	-11.06%	38%	61%
20%	-82.43%	-22.12%	151%	123%
30%	-123.36%	-33.18%	340%	185%
40%	-16.49%	-7.71%	6%	25%
50%	-22.51%	-18.86%	10%	31%
60%	-11.35%	-7.43%	28%	53%
70%	-20.51%	-26.00%	2%	15%
80%	-35.10%	-11.45%	19%	44%
90%	92.06%	-8.57%	338%	184%
100%	146.67%	-20.00%	869%	295%

Table 21: Software % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	-5.92%	-9.55%	1%	10%
20%	2.26%	-19.09%	19%	43%
30%	-2.95%	10.18%	10%	32%
40%	-23.63%	-52.80%	41%	64%
50%	-22.39%	-2.73%	14%	38%
60%	5.72%	-2.80%	5%	22%
70%	28.04%	8.73%	22%	46%
80%	-2.09%	-2.14%	0%	3%
90%	-0.61%	0.73%	2%	15%
100%	-167.67%	-27.00%	696%	264%

For the Missile programs, underspending happens between the 40% schedule and 60% schedule mark followed by overspending to the 100% schedule mark. For Ordnance, underspending remains until overspending starts at the 90% schedule mark. For Software programs, there seems to be no trends or patterns, underspending and overspending happens through out the percent schedule.

Table 22: Space % Budget Change vs % Schedule

Schedule Percent	Average	Median	Var	Std
10%	4.67%	7.14%	1%	8%
20%	8.54%	9.33%	2%	16%
30%	5.64%	0.00%	4%	19%
40%	40.50%	5.00%	70%	84%
50%	10.93%	4.00%	15%	38%
60%	22.10%	8.00%	94%	97%
70%	-5.06%	1.50%	678%	260%
80%	25.91%	1.00%	30%	54%
90%	-45.07%	2.00%	251%	158%
100%	-119.22%	5.00%	986%	314%

Table 23: UAV % Budget Change vs % Schedule

Schedule Percent	Average	Median
10%	3.89%	3.89%
20%	3.33%	3.33%
30%	-3.33%	-3.33%
40%	24.89%	24.89%
50%	19.44%	19.44%
60%	-5.33%	-5.33%
70%	-0.78%	-0.78%
80%	14.22%	14.22%
90%	56.00%	56.00%
100%	-71.00%	-71.00%

Unexpectedly for Space programs, overspending seems to be the trend up until the 70% schedule mark. This is very different from the results found in Elworth's research. We suspect this is due to our smaller sample size, a slightly different methodology as well as being able to obtain only 7 out of the 12 programs used in Elworth's research. There are 9 Space programs used in our research, perhaps the 2 new programs we included somehow skew our results to be much different. For UAV, we were able to obtain data for one program and it seems there's no pattern associated with this program for either underspending or overspending.

Cumulative Percent Budget Change by Percent Schedule

Now we investigate when most of the budget changes happen as well as how budget changes should be reflected (linearly, exponentially, etc.) by looking at the cumulative percent budget change by percent schedule.

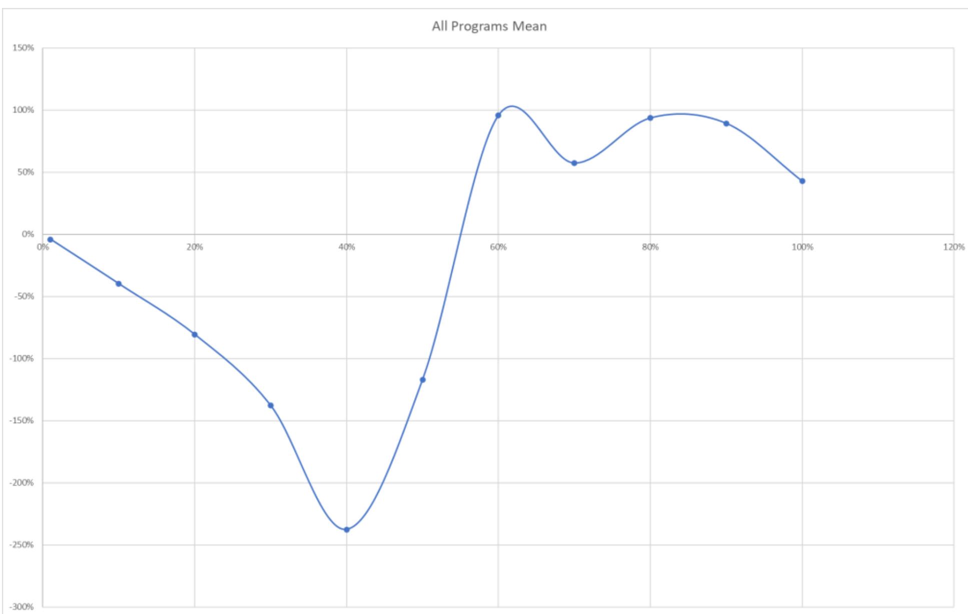


Figure 12: Overall Cumulative Percent Budget (Y) Change by Percent Schedule (X)

Looking at Figure 12, it suggests that budget changes in relation to percent schedule should not be reflected linearly and most of the changes at or before the 60% schedule mark. However, this could be caused by the B-2 RMP and the SDB II programs as most of their data points are well beyond 100% (Table 24). Figure 13 does not include B2-RMP and SDB II and it seems that the timing of budget changes has been shifted more towards the end of acquisition programs' development cycle.

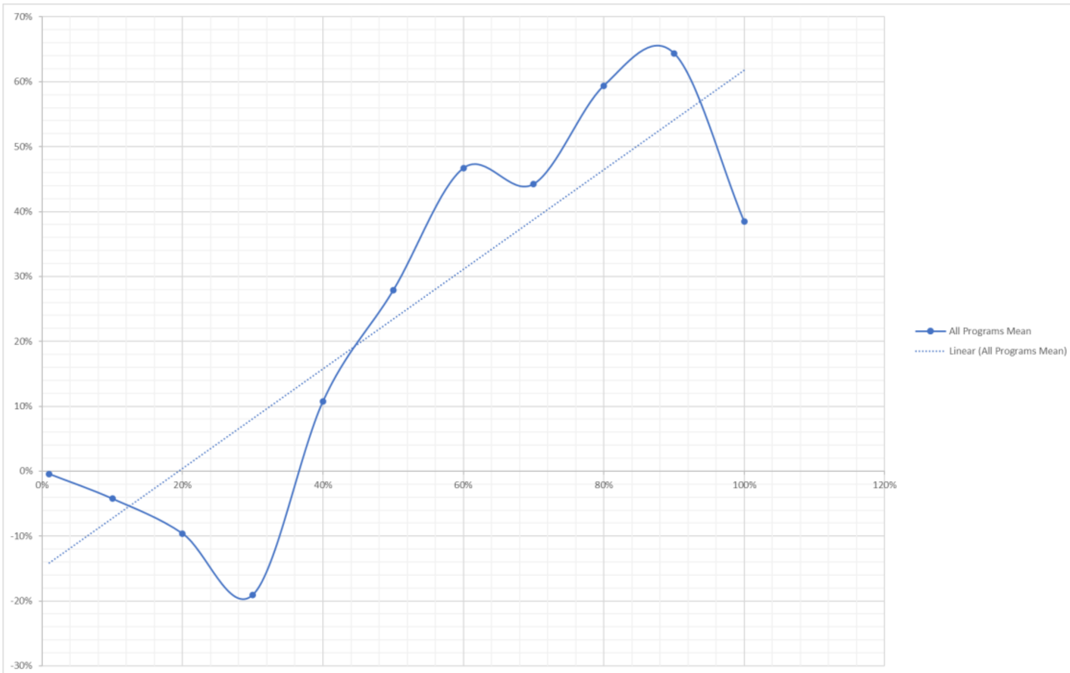


Figure 13: All Programs without B2-RMP and SDB II

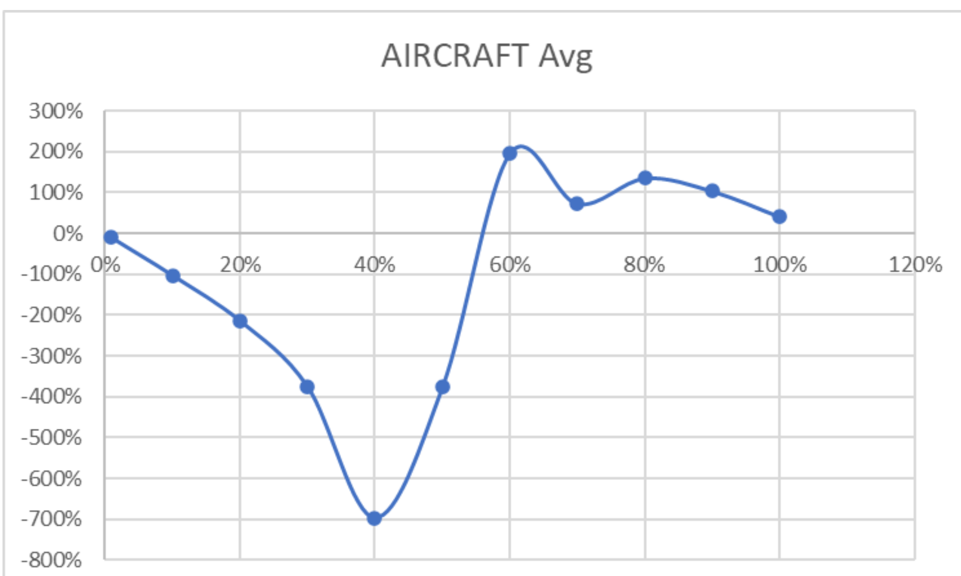


Figure 14: Aircraft Cumulative Percent Budget (Y) Change by Percent Schedule (X)

If we look at aircraft programs separately in Figure 14, then it seems to shadow Figure 12 which makes sense as Aircraft data makes up the majority of all acquisition programs. Figure 14 tells us that significant Aircraft program budget changes happen earlier in the life cycle represented by steeper slopes. Figure 15 suggests that significant changes for Missile programs happen at the end of the life cycle represented by what seems to be an exponential curve. Figure 15 indicates that for Ordnance programs, significant changes tend to happen earlier in the life cycle at or before the 30% schedule mark as well as later in the life cycle at or after the 80% schedule mark, not much movement is seen between 30% and 80%.

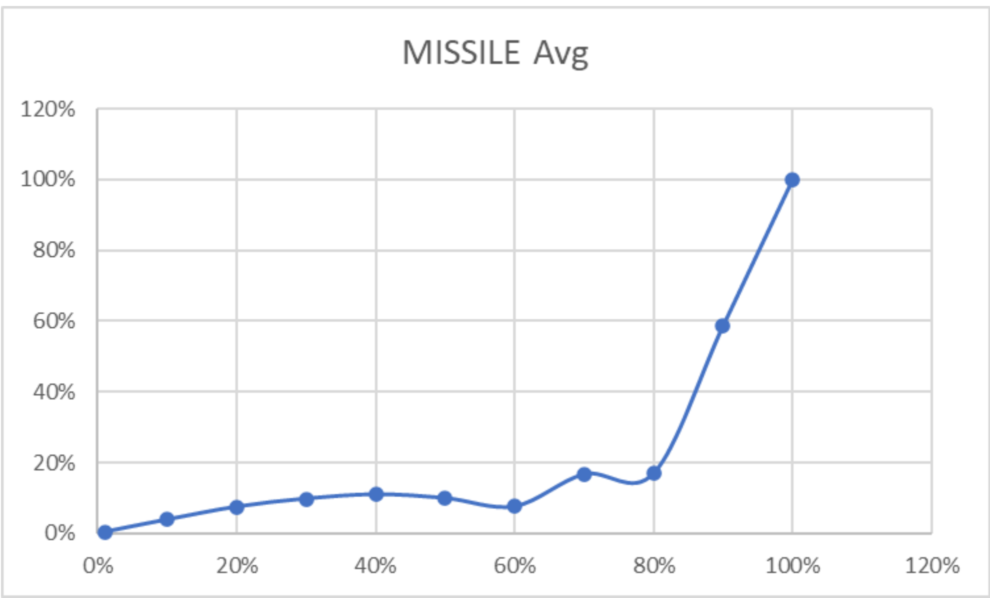


Figure 15: Missile Cumulative Percent Budget (Y) Change by Percent Schedule (X)

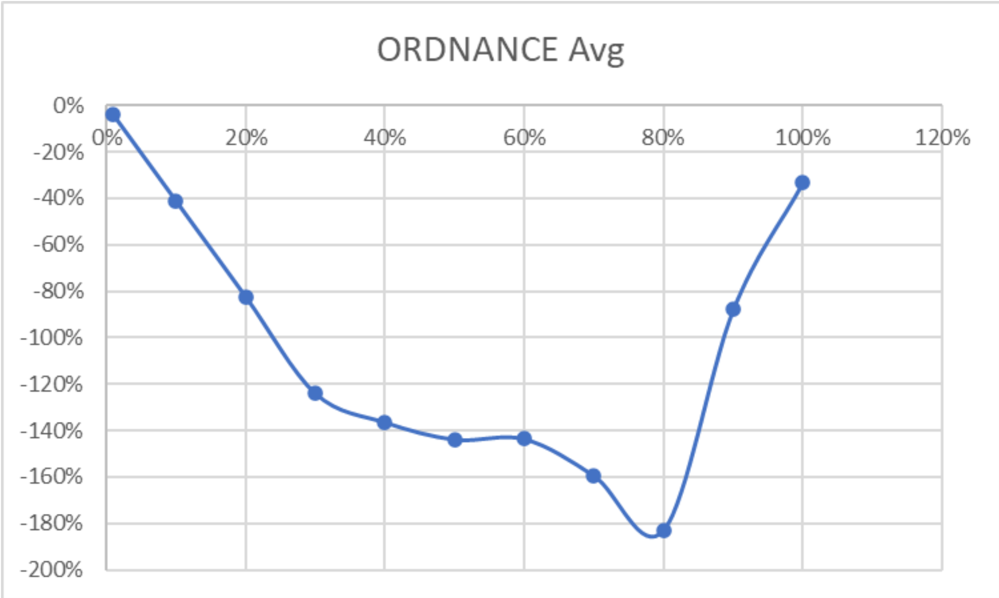


Figure 16: Ordnance Cumulative Percent Budget (Y) Change by Percent Schedule (X)

Cumulative budget changes for Ordnance overall seems to be best reflected by a quadratic curve. For Software programs depicted by Figure 17, significant budget changes happen near the end of the life cycle at or after the 60% schedule mark represented by the steep slopes. From visual observation, it seems that cumulative budget changes for Software programs would best fit an exponential curve with little movement in the early stages of the life cycle and significant changes near the end of the life cycle.

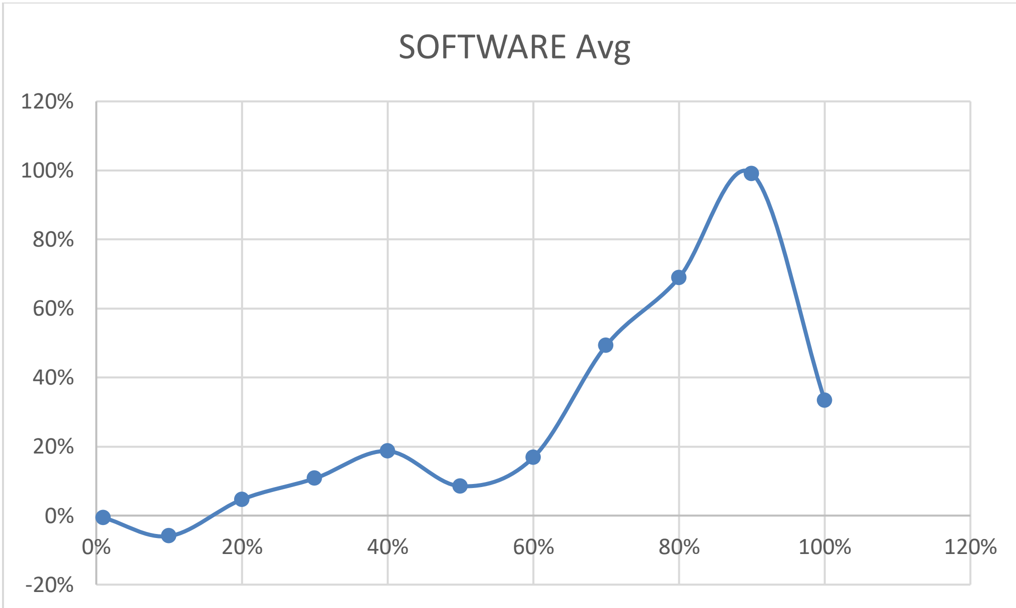


Figure 17: Software Cumulative Percent Budget (Y) Change by Percent Schedule (X)

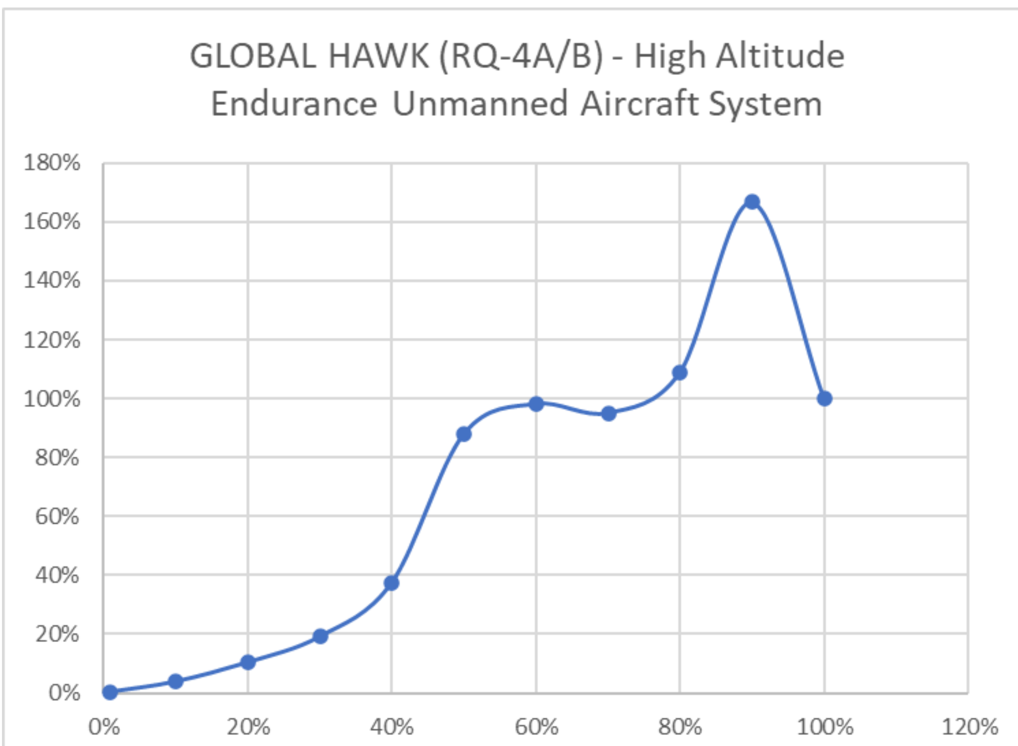


Figure 18: UAV Cumulative Percent Budget (Y) Change by Percent Schedule (X)

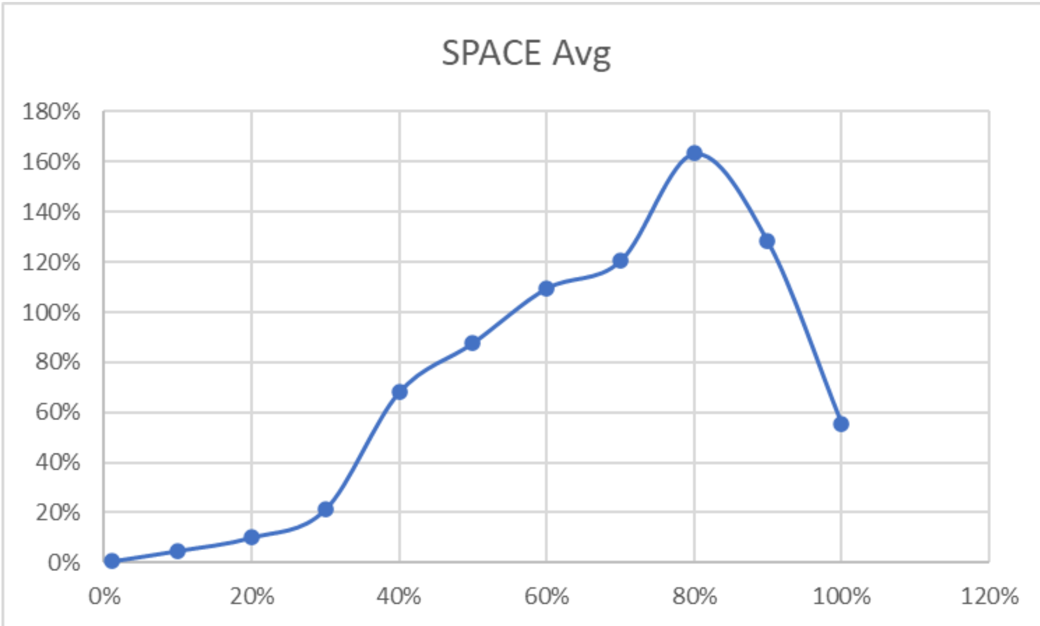


Figure 19: Space Cumulative Percent Budget (Y) Change by Percent Schedule (X)

For UAV, because we were able to only collect data for the Global Hawk program, it would be unrealistic to use this as a representation for UAV all programs. However, from Figure 18, it seems that a linear curve would best reflect the cumulative budget changes for the Global Hawk program. Now looking at Space programs, Figure 19 indicates that most of the significant budget changes happen later in the life cycle represented visually by steeper slopes. The graph for Space programs suggests at first glance that cumulative budget changes are best reflected with an exponential curve.

Table 24: Cumulative Budget Change by Percent Schedule

Program Name	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Program Commodity Type
B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability	-2%	-19%	-38%	-44%	-44%	-55%	-80%	-89%	-97%	-100%	-100%	AIRCRAFT
B-2 RMP - B-2 Radar Modernization Program	-89%	-892%	-1784%	-3028%	-6573%	-3651%	1781%	788%	1463%	909%	100%	AIRCRAFT
C-130 AMP - C-130 Aircraft Avionics Modernization Program	1%	8%	16%	10%	51%	62%	84%	107%	102%	95%	100%	AIRCRAFT
C-130J Hercules Transport Aircraft	0%	0%	0%	0%	0%	0%	55%	53%	61%	61%	100%	AIRCRAFT
C-5 RERP - C-5 Aircraft Reliability Enhancement and Re-engining Program	-9%	-93%	-432%	-729%	-341%	38%	101%	76%	71%	100%	100%	AIRCRAFT
CRH - Combat Rescue Helicopter	-3%	-25%	-50%	-75%	-152%	-222%	-216%	-222%	-234%	-150%	-100%	AIRCRAFT
F-15 EPAWSS - Eagle Passive Active Warning Survivability System	0%	-1%	-1%	-2%	-2%	-3%	7%	16%	37%	68%	100%	AIRCRAFT
F-22A Increment 3.2B	-1%	-8%	-16%	-24%	-33%	-41%	-48%	-56%	-68%	-84%	-100%	AIRCRAFT
F-35 - Lightning II Joint Strike Fighter (JSF) Program	1%	9%	176%	159%	159%	155%	331%	110%	89%	95%	100%	AIRCRAFT
KC-46A Tanker	-1%	-5%	-10%	-16%	-33%	-50%	-52%	-61%	-75%	34%	100%	AIRCRAFT
AIRCRAFT Avg	**-10%**	**-103%**	**-214%**	**-375%**	**-697%**	**-377%**	**196%**	**72%**	**135%**	**103%**	**40%**	
MINUTEMAN III PRP - Propulsion Replacement Program	-1%	-7%	-14%	-21%	-28%	-34%	-40%	-46%	-52%	24%	100%	MISSILE
Integrated Air & Missile Defense (IAMD)	1%	15%	29%	40%	50%	54%	55%	79%	86%	93%	100%	MISSILE
MISSILE Avg	**0%**	**4%**	**8%**	**10%**	**11%**	**10%**	**8%**	**17%**	**17%**	**59%**	**100%**	
B61 Mod 12 Life Extension Program Tailkit Assembly	0%	-1%	-1%	-3%	-9%	-29%	-51%	-70%	-77%	-89%	-100%	ORDNANCE
SDB I – Small Diameter Bomb Increment I	-1%	-11%	-22%	-33%	-44%	-55%	-66%	-76%	-84%	-93%	-100%	ORDNANCE
SDB II – Small Diameter Bomb, Increment II	-11%	-112%	-224%	-336%	-356%	-347%	-314%	-333%	-387%	-83%	100%	ORDNANCE
ORDNANCE Avg	**-4%**	**-41%**	**-82%**	**-124%**	**-136%**	**-144%**	**-144%**	**-160%**	**-183%**	**-88%**	**-33%**	
FAB-T – Family of Beyond Line-of-Sight Terminals	0%	5%	59%	82%	183%	208%	248%	352%	359%	370%	100%	SOFTWARE
MP-RTIP - Multi-Platform Radar Technology Insertion Program	-1%	-9%	-19%	-10%	-75%	-116%	-129%	-133%	-114%	-103%	-100%	SOFTWARE
MPS – Mission Planning System	-1%	-13%	-26%	-40%	-53%	-66%	-69%	-71%	-38%	31%	100%	SOFTWARE
SOFTWARE Avg	**-1%**	**-6%**	**5%**	**11%**	**19%**	**9%**	**17%**	**49%**	**69%**	**99%**	**33%**	
AEHF - Advanced Extremely High Frequency Satellite	1%	8%	22%	38%	48%	65%	85%	92%	97%	100%	100%	SPACE
EELV - Evolved Expendable Launch Vehicle (EELV)	0%	0%	0%	0%	0%	46%	92%	93%	95%	97%	100%	SPACE
EPS - Enhanced Polar System	-1%	-10%	-21%	-31%	-42%	-59%	-77%	-88%	-100%	-100%	-100%	SPACE
GBS – Global Broadcast Service	1%	7%	14%	48%	188%	293%	222%	-102%	55%	110%	100%	SPACE
GPS III - Global Positioning System III	1%	10%	21%	18%	10%	10%	27%	57%	84%	92%	100%	SPACE
NPOESS - National Polar-Orbiting Operational Environmental Satellite System	1%	13%	27%	44%	245%	190%	189%	19%	74%	123%	-100%	SPACE
SBIRS-HIGH - Space-Based Infrared System Program, High	0%	3%	6%	31%	62%	115%	306%	861%	1011%	565%	100%	SPACE
WGS – Wideband Global SATCOM Program	1%	13%	25%	27%	60%	74%	67%	64%	63%	70%	100%	SPACE
MUOS – Mobile User Objective System	0%	-2%	-5%	15%	42%	55%	75%	88%	92%	96%	100%	SPACE
SPACE Avg	**0%**	**5%**	**10%**	**21%**	**68%**	**88%**	**110%**	**121%**	**163%**	**128%**	**56%**	
GLOBAL HAWK (RQ-4A/B) - High Altitude Endurance Unmanned Aircraft System	0%	4%	10%	19%	37%	88%	98%	95%	109%	167%	100%	UAV
Overall Statistics	**1%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**	
All Programs Mean	-4%	-40%	-81%	-138%	-237%	-117%	96%	57%	94%	89%	43%	
All Programs Median	0%	-1%	-1%	-1%	-1%	5%	55%	36%	62%	81%	100%	

The S-Curve

Analyzing the S-curve will help us understand what is the most suitable way to time-phase budget estimates. Note that the percentage of budget allocated is the vertical axis and the percent schedule is the horizontal axis.

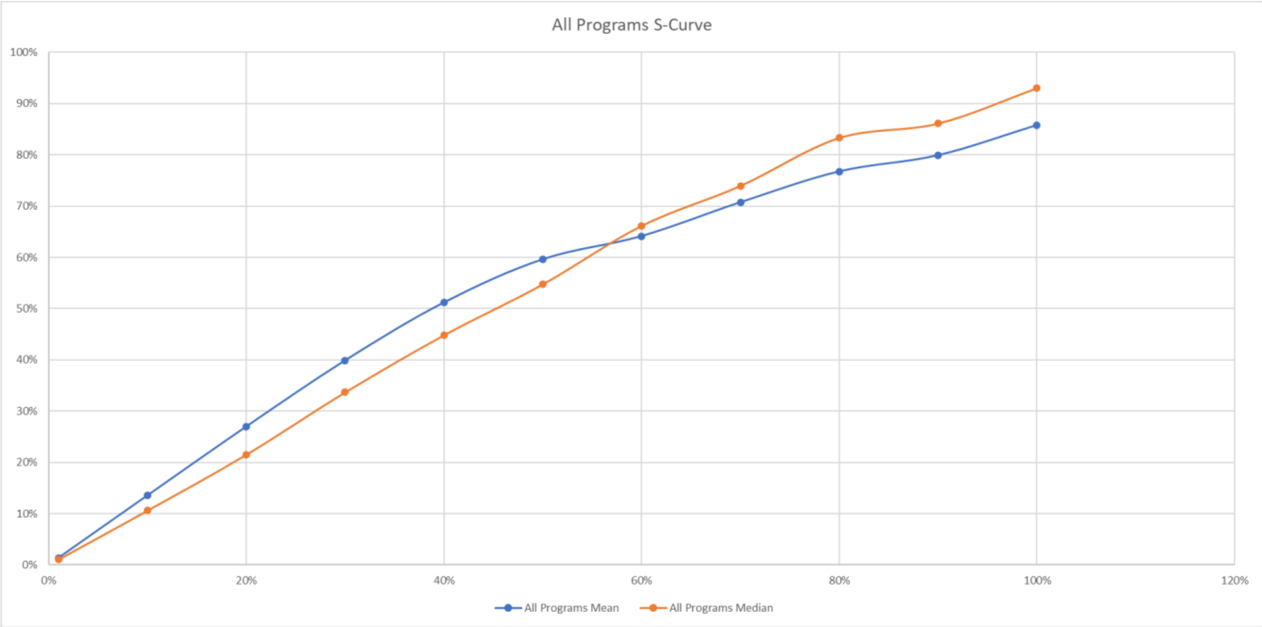


Figure 20: Overall S-Curve

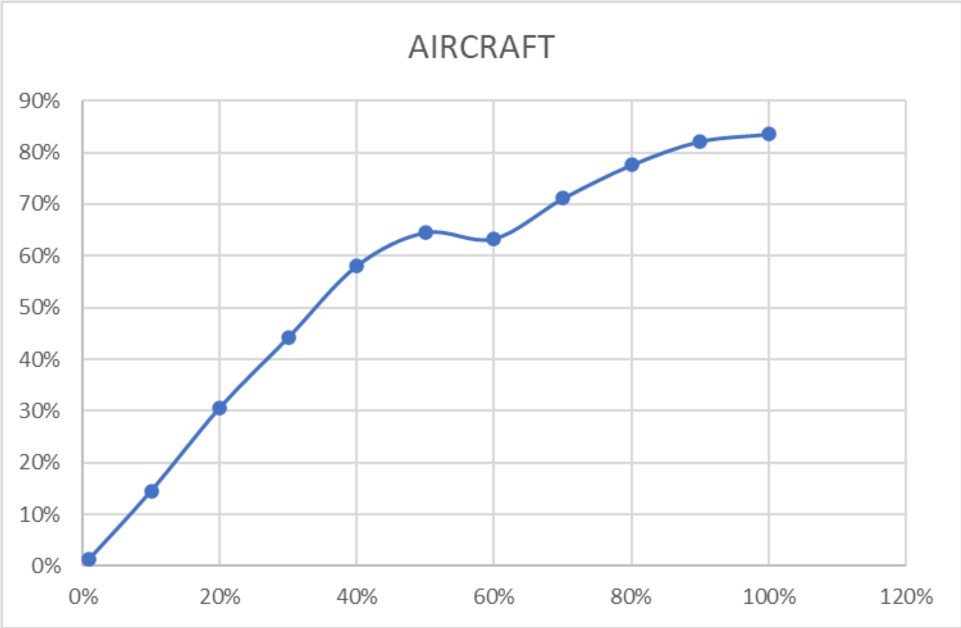


Figure 21: Aircraft S-Curve

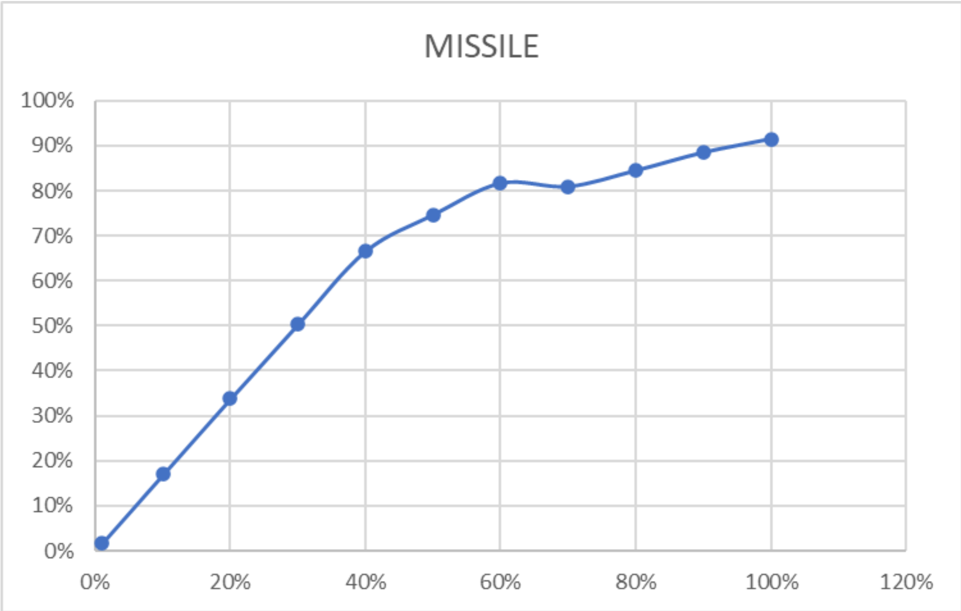


Figure 22: Missile S-Curve

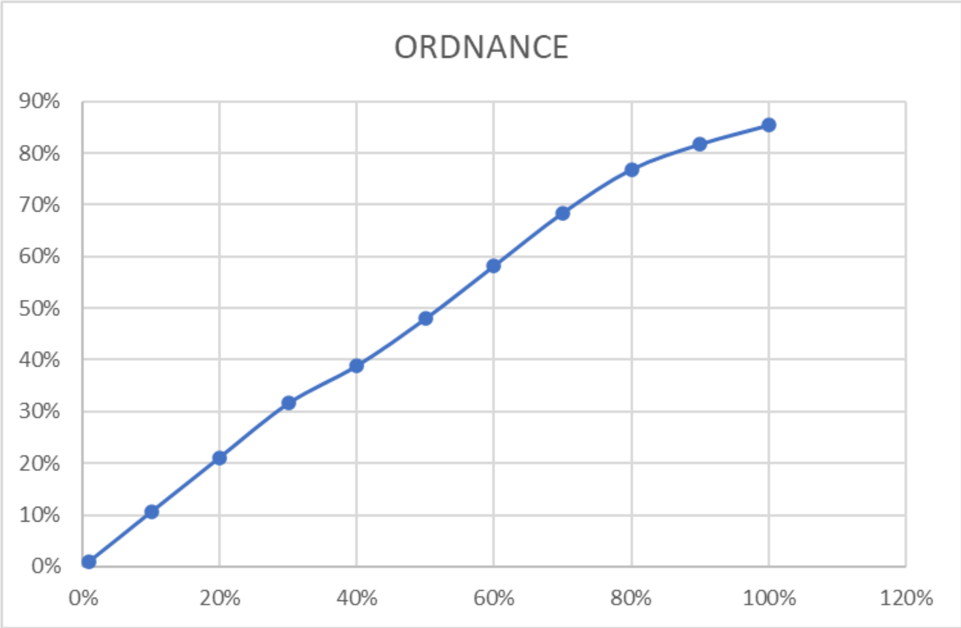


Figure 23: Ordnance S-Curve

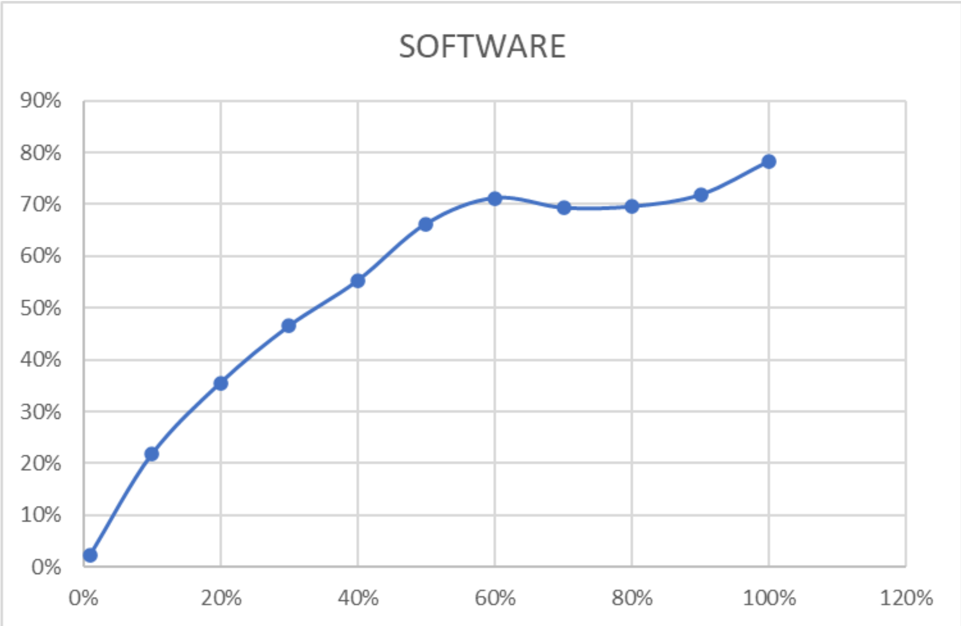


Figure 24: Software S-Curve

Figure 25: Space S-Curve

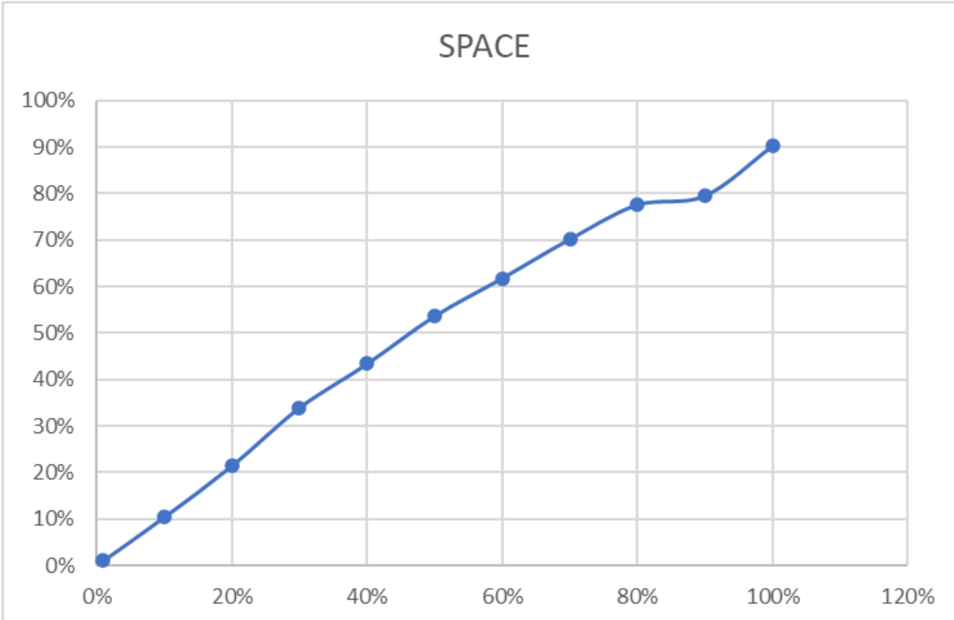


Figure 26: UAV S-Curve

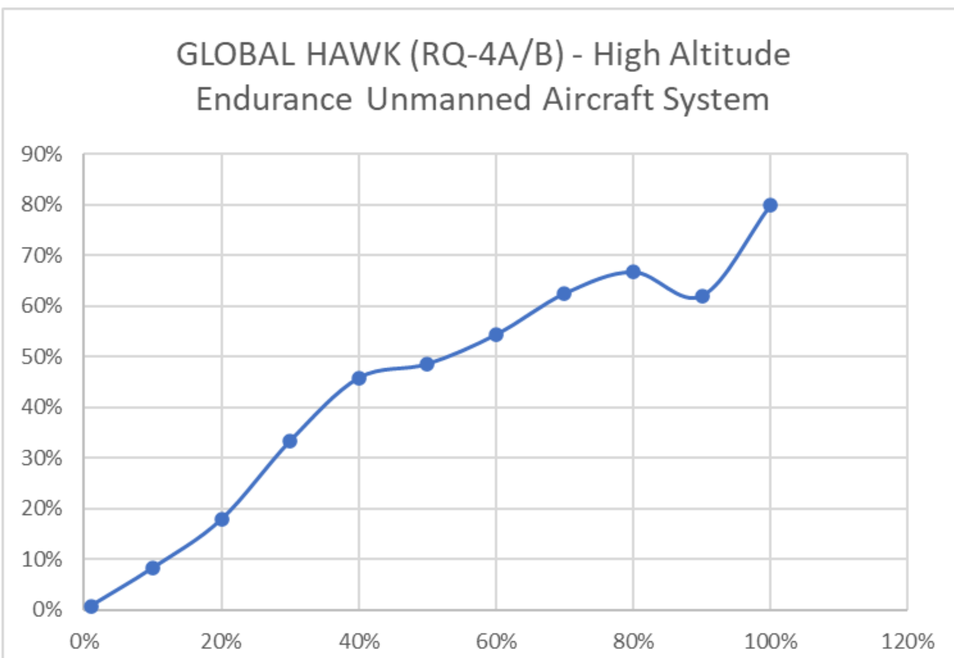


Figure 20 indicates that, overall, acquisition programs tend to reach 60% of total program budget around the 50% schedule mark. For Aircraft programs, Figure 21 suggests that they tend to reach 60% of total program budget around the 40% schedule mark. Figure 22 tells us that for Missile programs, they tend to also reach 60% of total program budget around the 40% schedule mark. Next, for Ordnance programs, Figure 23 indicates that they tend to reach 60% of total program budget around the 60% schedule mark. Software programs, on the other hand, as visually depicted by Figure 24, tend to reach 60% of total program budget around the 45% schedule mark. Lastly, Space programs tend to reach 60% of total program budget around the 55% schedule mark (Figure 25) and the Global Hawk program reaches 60% of total program budget around the 65% schedule mark (Figure 26).

Years Prior Estimates

Now we look at the years prior results and analyze to determine if performing estimates within two years of budget year would yield better accuracy. The forthcoming charts are plotted from the absolute values of the estimate errors (negative is the same as positive) because we are only concerned with how close the estimate is to the ground truth. The absolute value of the error percentage is on the vertical axis and the number of years prior is on the horizontal axis.

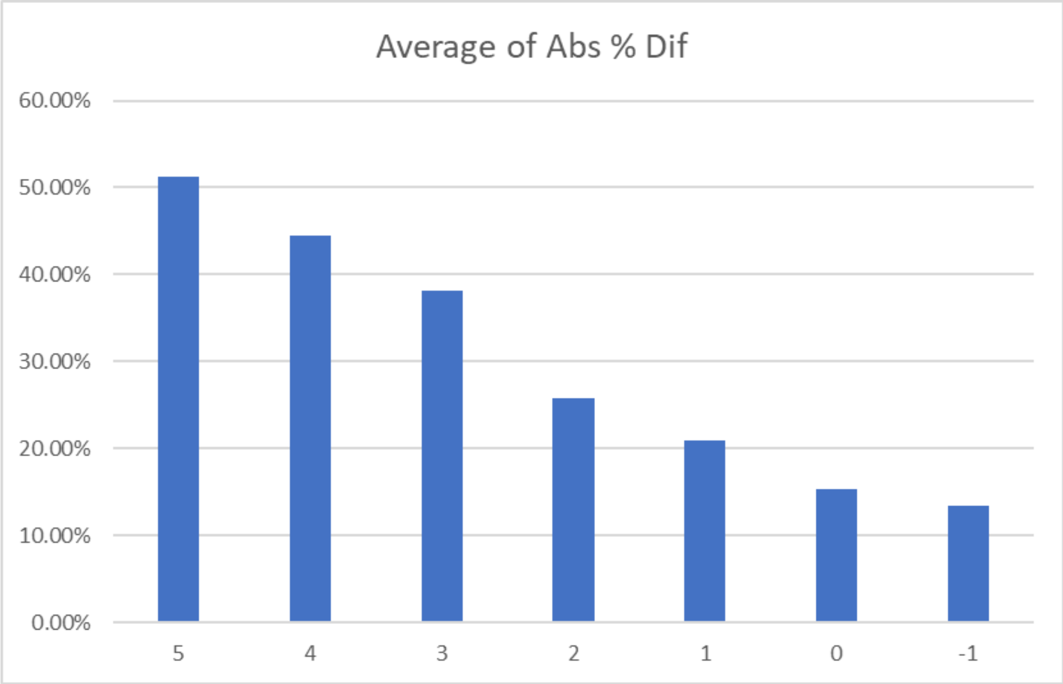


Figure 27: Overall Years Prior Estimates

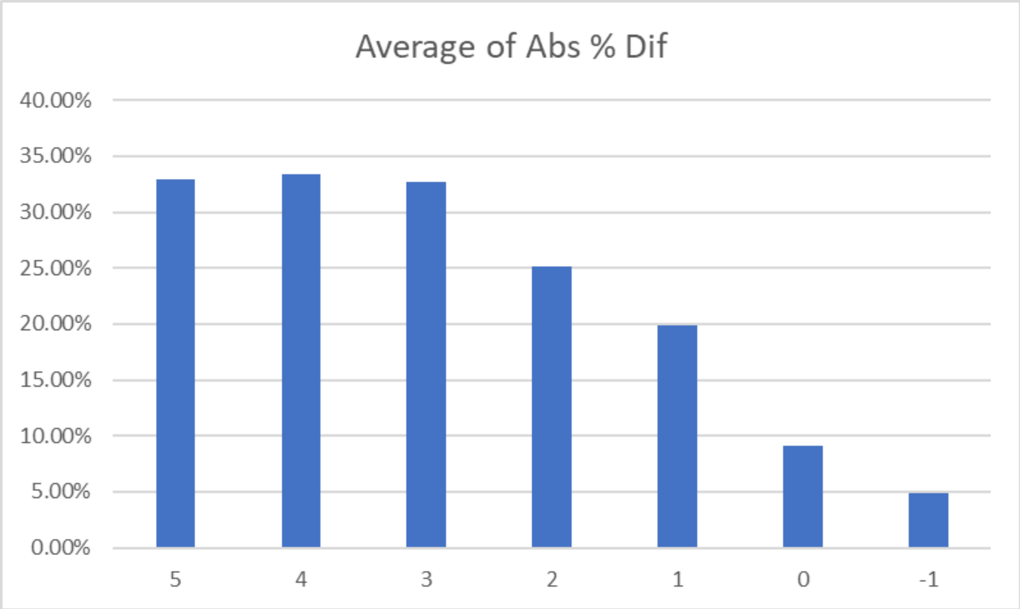


Figure 28: Aircraft Years Prior Estimates

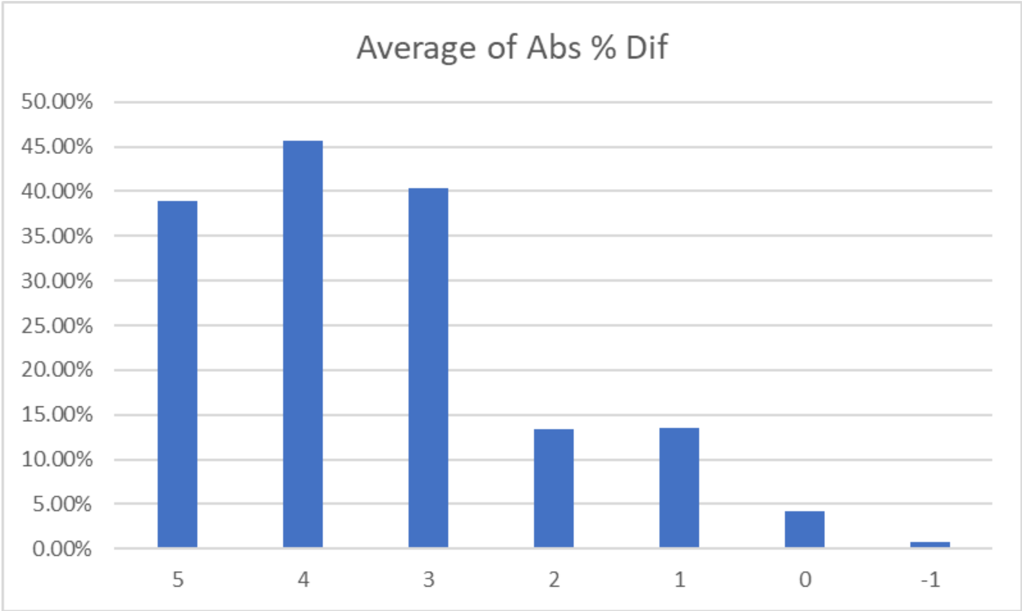


Figure 29: Ordnance Years Prior Estimates

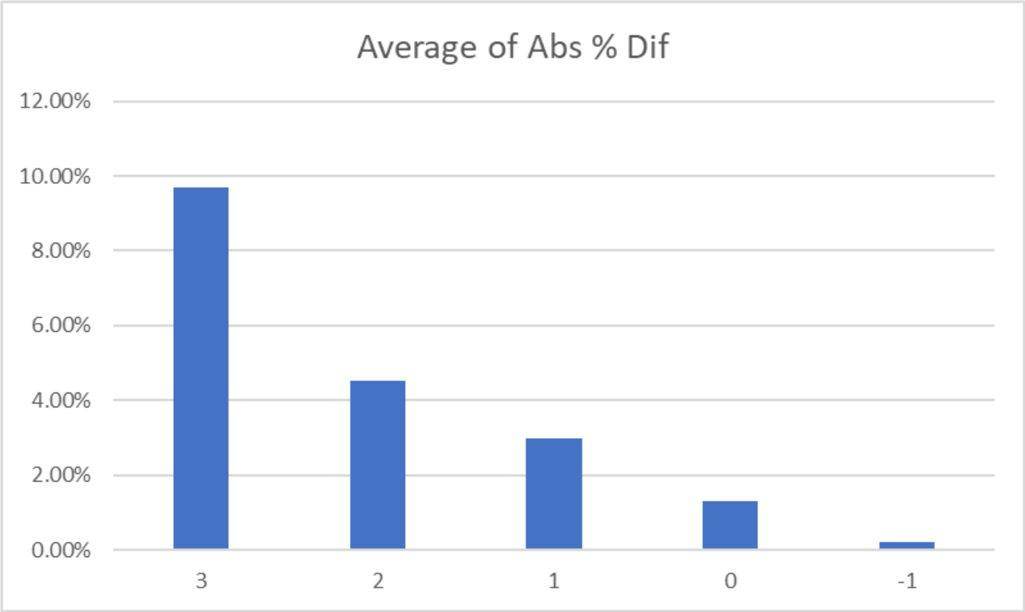


Figure 30: Missile Years Prior Estimates

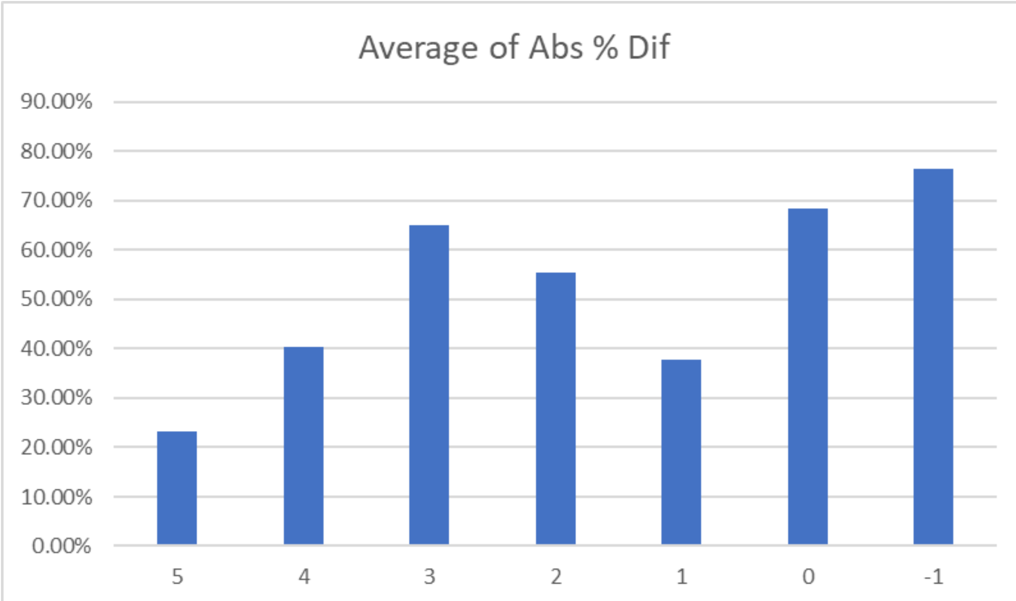


Figure 31: Software Years Prior Estimates

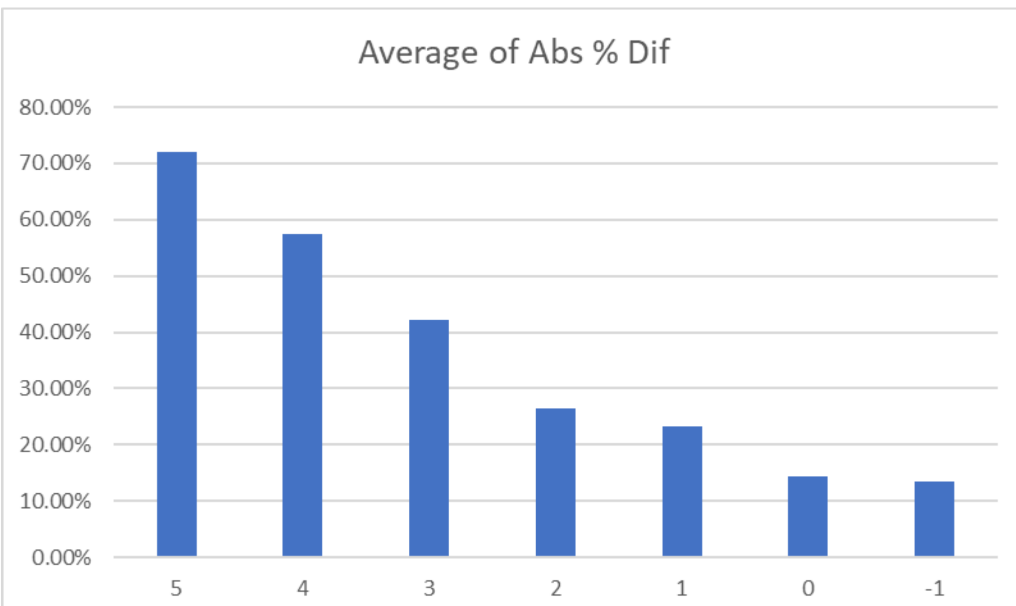


Figure 32: Space Years Prior Estimates

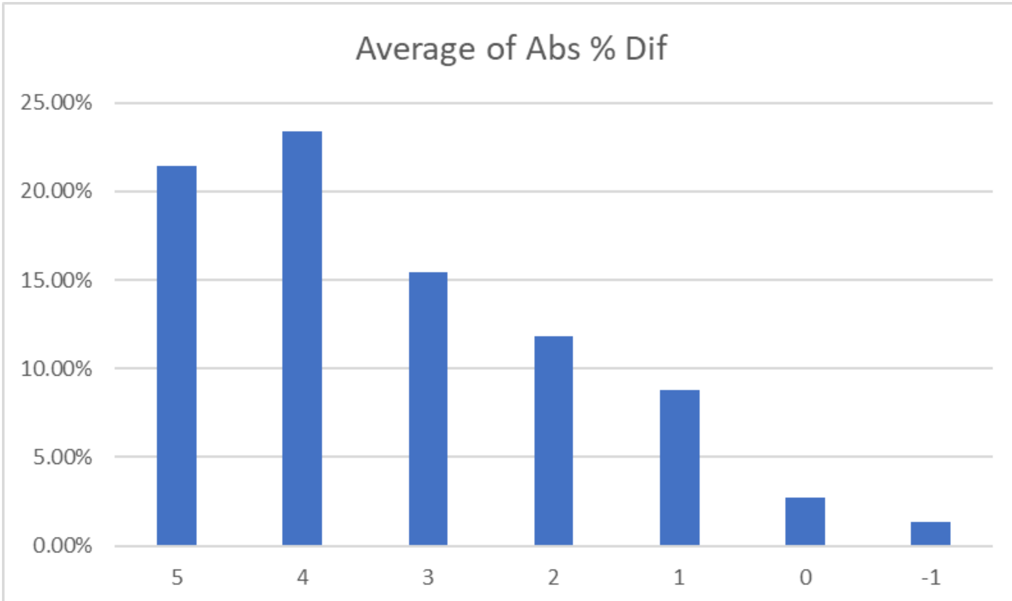
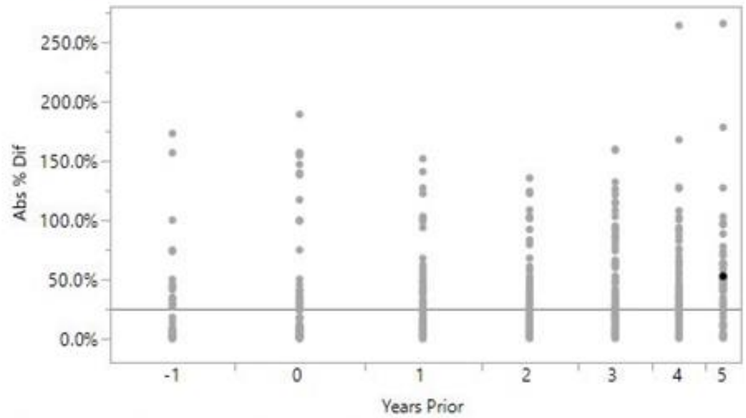


Figure 33: UAV Years Prior Estimates

With the exception of software, the chart for other program commodities indicates that estimate accuracy is better when performed within two years prior to budget year. Figure 27 shows that, overall, estimates get closer to the ground truth as the time between when the estimates were performed and the budget year shorten. However, we need to perform statistical test to determine if this finding is statistically significant using the Kruskal-Wallis and the Steel-Dwass tests.

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	165	38347.0	69052.5	232.406	-11.100
0	172	50639.5	71982.0	294.416	-7.596
1	155	69838.5	64867.5	450.571	1.840
2	128	64347.0	53568.0	502.711	4.307
3	99	55434.0	41431.5	559.939	6.235
4	70	41721.0	29295.0	596.014	6.454
5	47	29539.0	19669.5	628.489	6.164

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
271.4978	6	<.0001*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
2	-1	99.95573	9.79650	10.20320	<.0001*	0.0960000	0.059000	0.1430000	
1	-1	94.82385	10.15911	9.33387	<.0001*	0.0610000	0.035000	0.0970000	
3	-1	94.38384	9.46274	9.97426	<.0001*	0.2000000	0.110000	0.2610000	
4	-1	87.24502	9.34969	9.33132	<.0001*	0.2550000	0.187000	0.3620000	
3	0	83.75250	9.80880	8.53851	<.0001*	0.1840000	0.097000	0.2460000	
2	0	82.88972	10.06687	8.23392	<.0001*	0.0830000	0.042000	0.1310000	
4	0	81.53430	9.81376	8.30816	<.0001*	0.2480000	0.162000	0.3470000	
5	-1	81.34184	9.64418	8.43429	<.0001*	0.3640000	0.220000	0.4980000	
5	0	78.57614	10.27172	7.64975	<.0001*	0.3410000	0.203000	0.4750000	
1	0	71.79649	10.40164	6.90242	<.0001*	0.0420000	0.027000	0.0870000	
5	1	54.30570	9.73343	5.57930	<.0001*	0.2700000	0.117000	0.4140000	
4	1	49.79032	9.37370	5.31170	<.0001*	0.1840000	0.074000	0.2860000	
3	1	41.92779	9.45175	4.43598	0.0002*	0.1100000	0.027000	0.1960000	
5	2	37.56857	8.64056	4.34793	0.0003*	0.2300000	0.071000	0.3820000	
0	-1	33.43282	9.97382	3.35206	0.0141*	0.0000000	0.000000	0.0060000	
4	2	32.58382	8.51810	3.82524	0.0025*	0.1440000	0.030000	0.2510000	
3	2	23.47565	8.78970	2.67081	0.1057	0.0700000	-0.005000	0.1690000	
2	1	22.35900	9.77386	2.28763	0.2499	0.0270000	-0.008000	0.0770000	
5	3	16.56738	7.49116	2.21159	0.2891	0.1200000	-0.046000	0.2940000	
4	3	10.15707	7.64095	1.32929	0.8383	0.0520000	-0.067000	0.1900000	
5	4	7.55699	6.39634	1.18145	0.9014	0.0685000	-0.122000	0.2560000	

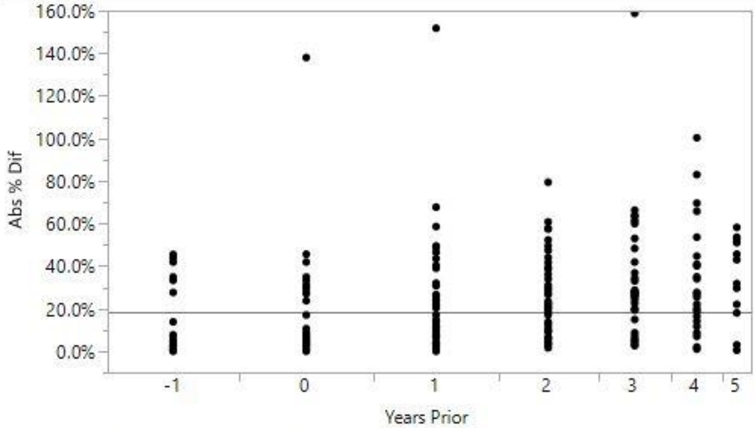
Figure 34: Years Prior Statistical Test

Figure 34 is the result from JMP showing that the difference between the means is statistically significant. The non-parametric comparisons for all pairs using the Steel-Dwass test suggests that the difference between the mean of the estimate errors for two years prior to the budget when compared with the mean for four years prior and five years prior to the budget year is statistically significant. The same is true when comparing one year prior to three years, four years and five years prior. The difference between the means is statistically significant at alpha = 0.05. We then look further into each commodity type to determine if this is true across all commodities.

With the exception of Software and Space programs, all other commodity types show statistical significance for the Kruskal-Wallis test but no statistical significance for the Steel-Dwass test all pairs comparisons for one year prior vs. two years prior vs. three years prior vs. four years prior vs. five years prior. Software programs did not show statistical significance the two statistical tests while Space programs show statistical significance for Kruskal-Wallis and statistical significance for the Steel-Dwass test for one year prior vs. two years prior vs. three years prior vs. four years prior vs. five years prior. This means that while at the higher all commodity types level, there's a difference when performing estimates at or less than two years out vs. more than two years out (estimates get better), there is no difference when performing estimates at or less than two years out vs. more than two years out for all other commodity types (estimates do not show a statistically significant improvement) with the exception of Space programs. The finding for Space program is consistent with what was discovered by Elworth et al. (2019).

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	59	4210.50	8584.50	71.364	-7.635
0	61	6082.50	8875.50	99.713	-4.815
1	56	9182.00	8148.00	163.964	1.840
2	45	8547.00	6547.50	189.933	3.880
3	33	6695.50	4801.50	202.894	4.190
4	23	4743.50	3346.50	206.239	3.632
5	13	2734.00	1891.50	210.308	2.860

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
115.7675	6	<.0001*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

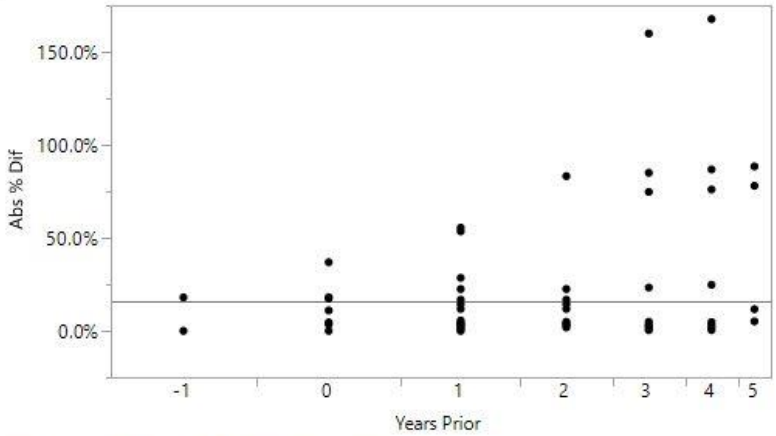
q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
2	-1	41.36497	5.865206	7.052603	<.0001*	0.1820000	0.088000	0.2780000	
1	-1	40.09685	6.124008	6.547485	<.0001*	0.0870000	0.040000	0.1980000	
3	-1	37.63636	5.656061	6.654165	<.0001*	0.2570000	0.143000	0.3290000	
2	0	35.19818	6.020843	5.846055	<.0001*	0.1580000	0.060000	0.2560000	
4	-1	33.99042	5.641837	6.024708	<.0001*	0.2480000	0.118000	0.4010000	
3	0	32.61749	5.866220	5.560222	<.0001*	0.2290000	0.072000	0.2870000	
1	0	30.20902	6.256032	4.828782	<.0001*	0.0700000	0.030000	0.1530000	
4	0	30.11547	5.927900	5.080292	<.0001*	0.2130000	0.089000	0.3640000	
5	-1	29.99218	6.065311	4.944870	<.0001*	0.2960000	0.136000	0.5050000	
5	0	26.17528	6.503933	4.024532	0.0011*	0.2590000	0.076000	0.4560000	
0	-1	16.15449	6.055147	2.667893	0.1065	0.0050000	0.000000	0.0350000	
3	1	15.19453	5.669415	2.680089	0.1033	0.1265000	-0.007000	0.2390000	
4	1	14.90450	5.683047	2.622625	0.1191	0.1255000	-0.018000	0.2850000	
5	1	13.93269	6.175588	2.256092	0.2657	0.1650000	-0.039000	0.3790000	
2	1	11.76329	5.864905	2.005709	0.4109	0.0590000	-0.028000	0.1720000	
5	2	6.84103	5.316985	1.286636	0.8584	0.0950000	-0.118000	0.3020000	
4	2	5.88019	5.068324	1.160185	0.9089	0.0600000	-0.101000	0.2310000	
3	2	5.41010	5.193397	1.041727	0.9443	0.0470000	-0.091000	0.1990000	
5	3	1.50117	4.395290	0.341540	0.9999	0.0310000	-0.203000	0.2620000	
5	4	1.14381	3.655520	0.312900	0.9999	0.0290000	-0.264000	0.2860000	
4	3	0.47958	4.429877	0.108260	1.0000	0.0070000	-0.186000	0.2060000	

Figure 35: Aircraft Years Prior Statistical Test

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	22	490.500	1111.00	22.2955	-5.307
0	22	750.500	1111.00	34.1136	-3.081
1	18	1148.50	909.000	63.8056	2.206
2	14	920.000	707.000	65.7143	2.171
3	11	766.500	555.500	69.6818	2.385
4	8	575.000	404.000	71.8750	2.228
5	5	399.000	252.500	79.8000	2.375

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
52.5889	6	<.0001*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

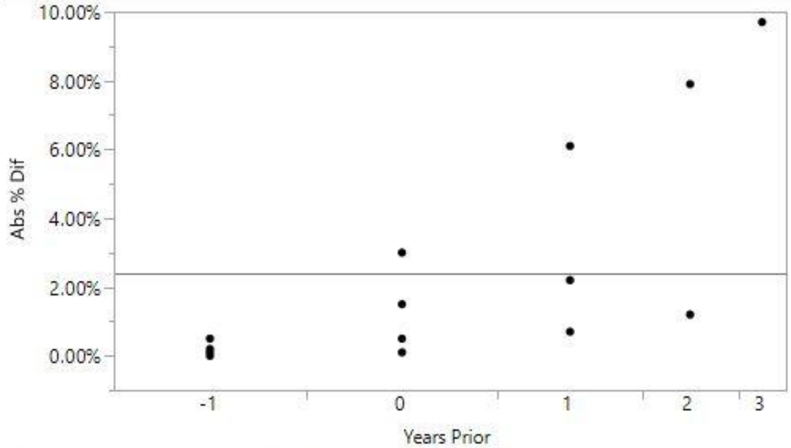
q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
1	-1	17.47475	3.392826	5.150500	<.0001*	0.0430000	0.030000	0.168000	
2	-1	16.53896	3.225047	5.128285	<.0001*	0.0430000	0.032000	0.168000	
3	-1	15.61364	3.077133	5.074085	<.0001*	0.0490000	0.014000	0.852000	
4	-1	14.23295	2.946925	4.829765	<.0001*	0.0575000	0.004000	0.868000	
5	-1	12.64091	2.861763	4.417176	0.0002*	0.1170000	0.051000	0.884000	
1	0	12.02020	3.570252	3.366766	0.0134*	0.0350000	0.008000	0.168000	
3	0	11.79545	3.361716	3.508760	0.0082*	0.0490000	0.004000	0.850000	
2	0	11.39610	3.440483	3.312356	0.0161*	0.0390000	0.011000	0.143000	
4	0	10.99432	3.348402	3.283452	0.0177*	0.0470000	0.001000	0.868000	
5	0	10.92273	3.499875	3.120891	0.0298*	0.1170000	-0.064000	0.884000	
5	1	4.98333	3.427790	1.453803	0.7722	0.0860000	-0.438000	0.854000	
0	-1	4.86364	2.466263	1.972067	0.4326	0.0000000	0.000000	0.035000	
5	2	4.20714	2.929191	1.436282	0.7821	0.0810000	-0.715000	0.866000	
4	1	2.61806	3.250000	0.805556	0.9845	0.0265000	-0.178000	1.122000	
5	3	2.32727	2.565978	0.906973	0.9716	0.0470000	.	.	
3	1	1.97727	3.258633	0.606780	0.9966	0.0155000	-0.132000	0.817000	
4	2	1.57143	2.876349	0.546327	0.9981	0.0190000	-0.139000	1.509000	
5	4	1.46250	2.217121	0.659639	0.9947	0.0405000	.	.	
3	2	1.05519	2.963637	0.356047	0.9998	0.0090000	-0.118000	0.816000	
4	3	0.64773	2.613642	0.247826	1.0000	0.0095000	-0.846000	1.444000	
2	1	0.50794	3.339472	0.152101	1.0000	0.0005000	-0.142000	0.111000	

Figure 36: Ordnance Years Prior Statistical Test

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	4	13.000	30.000	3.2500	-2.339
0	4	28.000	30.000	7.0000	-0.213
1	3	29.000	22.500	9.6667	0.936
2	2	21.000	15.000	10.5000	1.006
3	1	14.000	7.500	14.0000	1.492

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.4706	4	0.0758

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

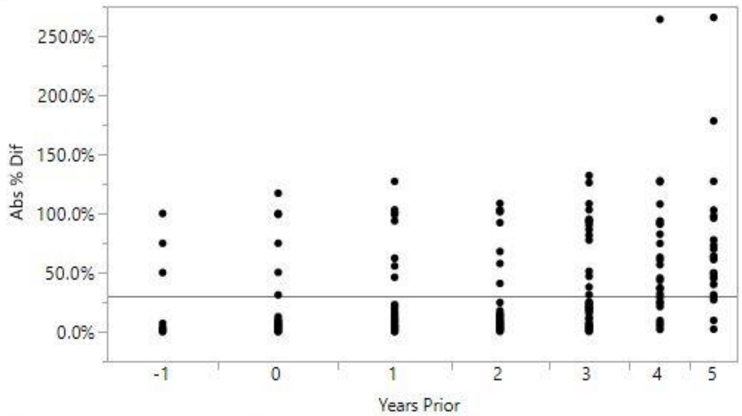
q*	Alpha
2.72777	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
1	-1	3.208333	1.649916	1.944544	0.2937	0.0205000	.	.	
2	-1	2.625000	1.620185	1.620185	0.4843	0.0430000	.	.	
0	-1	2.250000	1.711307	1.314785	0.6820	0.0075000	.	.	
3	-1	1.875000	1.767767	1.060660	0.8267	0.0955000	.	.	
3	0	1.875000	1.767767	1.060660	0.8267	0.0870000	.	.	
1	0	1.458333	1.649916	0.883883	0.9030	0.0120000	.	.	
3	1	1.333333	1.490712	0.894427	0.8991	0.0750000	.	.	
2	0	1.125000	1.620185	0.694365	0.9578	0.0300000	.	.	
3	2	0.750000	1.224745	0.612372	0.9732	0.0515000	.	.	
2	1	0.416667	1.443376	0.288675	0.9985	0.0115000	.	.	

Figure 37: Missile Years Prior Statistical Test

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	55	4446.00	8580.00	80.836	-6.873
0	59	5932.00	9204.00	100.542	-5.294
1	56	8951.50	8736.00	159.848	0.355
2	48	8372.50	7488.00	174.427	1.552
3	40	8339.00	6240.00	208.475	3.977
4	30	6877.50	4680.00	229.250	4.721
5	23	5597.50	3588.00	243.370	4.870

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
119.6580	6	<.0001*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
2	-1	36.90833	5.750862	6.417878	<.0001*	0.0710000	0.030000	0.1320000	
3	-1	35.21477	5.541668	6.354544	<.0001*	0.1920000	0.082000	0.3770000	
3	0	33.76907	5.815589	5.806646	<.0001*	0.1810000	0.077000	0.3340000	
1	-1	33.71445	5.929526	5.685859	<.0001*	0.0530000	0.020000	0.1120000	
4	0	32.78418	5.702197	5.749394	<.0001*	0.3555000	0.234000	0.6010000	
4	-1	32.11970	5.344896	6.009415	<.0001*	0.3620000	0.239000	0.6080000	
5	0	31.48268	5.736187	5.488433	<.0001*	0.4990000	0.307000	0.7280000	
2	0	31.30279	5.977437	5.236824	<.0001*	0.0640000	0.025000	0.1190000	
5	-1	30.15178	5.290451	5.699283	<.0001*	0.4990000	0.313000	0.7300000	
1	0	27.32294	6.146142	4.445544	0.0002*	0.0400000	0.011000	0.1050000	
5	1	25.42352	5.682736	4.473818	0.0002*	0.4470000	0.231000	0.6660000	
4	1	24.62262	5.648843	4.358878	0.0003*	0.2780000	0.110000	0.5130000	
5	2	20.90127	5.234102	3.993287	0.0013*	0.4230000	0.181000	0.6540000	
4	2	20.04167	5.273887	3.800170	0.0028*	0.2530000	0.068000	0.4950000	
3	1	19.99286	5.766373	3.467146	0.0095*	0.1275000	0.017000	0.2690000	
3	2	15.44583	5.469166	2.824166	0.0708	0.1080000	-0.003000	0.2470000	
5	3	11.98370	4.796680	2.498331	0.1597	0.2730000	-0.079000	0.5550000	
0	-1	11.29461	5.559184	2.031702	0.3944	0.0000000	0.000000	0.0060000	
4	3	8.80833	4.915125	1.792087	0.5534	0.1350000	-0.129000	0.3750000	
5	4	6.29855	4.280050	1.471607	0.7619	0.1400000	-0.219000	0.4530000	
2	1	5.49405	5.933107	0.925998	0.9685	0.0140000	-0.047000	0.0720000	

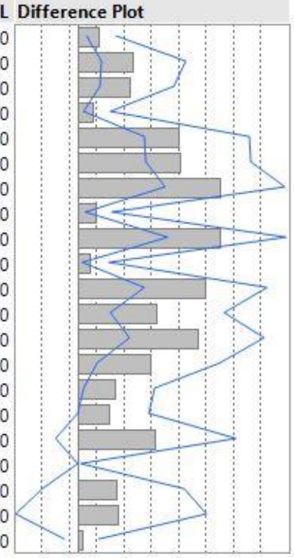
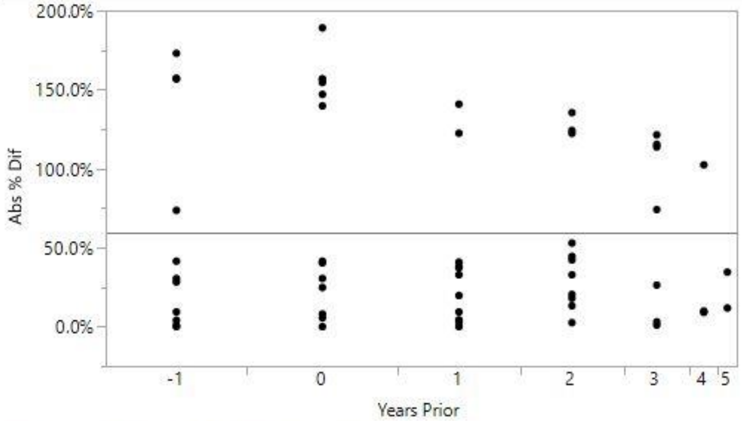


Figure 38: Space Years Prior Statistical Test

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	15	575.500	510.000	38.3667	0.978
0	16	541.000	544.000	33.8125	-0.037
1	13	372.000	442.000	28.6154	-1.103
2	11	403.500	374.000	36.6818	0.491
3	7	244.000	238.000	34.8571	0.113
4	3	86.000	102.000	28.6667	-0.470
5	2	56.000	68.000	28.0000	-0.424

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.3868	6	0.8809

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

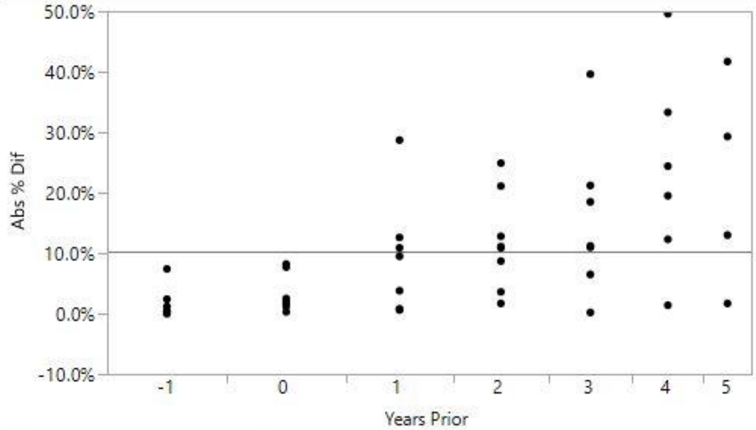
q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
2	1	3.44056	2.896197	1.18796	0.8990	0.121000	-0.34700	0.982000	
3	1	1.97802	2.773501	0.71319	0.9919	0.259000	-0.66700	1.137000	
5	4	0.41667	1.443376	0.28868	1.0000	0.023500	.	.	
2	0	0.23011	3.104073	0.07413	1.0000	0.020500	-1.24100	0.838000	
4	1	0.00000	3.049450	0.00000	1.0000	0.006000	.	.	
3	0	-0.10268	3.065902	-0.03349	1.0000	-0.033000	-1.43900	1.137000	
3	2	-0.23377	2.581150	-0.09057	1.0000	-0.015000	-1.21100	1.034000	
5	1	-0.28846	3.396831	-0.08492	1.0000	-0.030000	.	.	
4	0	-0.59375	3.524879	-0.16845	1.0000	-0.182000	.	.	
5	0	-0.84375	3.983191	-0.21183	1.0000	-0.099500	.	.	
2	-1	-0.94545	3.035627	-0.31145	0.9999	-0.125000	-1.36300	0.618000	
4	3	-0.95238	2.089277	-0.45584	0.9993	-0.164000	.	.	
5	3	-0.96429	2.195775	-0.43916	0.9995	-0.509500	.	.	
3	-1	-1.04762	2.971520	-0.35255	0.9998	-0.083000	-1.54000	1.130000	
5	-1	-1.41667	3.798986	-0.37291	0.9998	-0.241500	.	.	
4	-1	-1.60000	3.374646	-0.47412	0.9992	-0.215000	.	.	
1	0	-2.02163	3.171495	-0.63744	0.9956	-0.058500	-1.36500	0.372000	
4	2	-2.54545	2.724746	-0.93420	0.9671	-0.199000	.	.	
0	-1	-2.64792	3.255476	-0.81337	0.9837	-0.023500	-1.31900	1.148000	
5	2	-2.65909	2.993680	-0.88823	0.9744	-0.142000	.	.	
1	-1	-3.51795	3.114955	-1.12937	0.9192	-0.217000	-1.40200	0.365000	

Figure 39: Software Years Prior Statistical Test

Fit Group

Oneway Analysis of Abs % Dif By Years Prior



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
-1	10	110.000	275.000	11.0000	-3.665
0	10	183.000	275.000	18.3000	-2.038
1	9	252.000	247.500	28.0000	0.093
2	8	279.500	220.000	34.9375	1.437
3	7	244.500	192.500	34.9286	1.327
4	6	252.000	165.000	42.0000	2.382
5	4	164.000	110.000	41.0000	1.768

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
25.8427	6	0.0002*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

q*	Alpha
2.94832	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
2	-1	8.212500	2.529677	3.246462	0.0200*	0.104500	0.012000	0.2450000	
4	-1	7.333333	2.454927	2.987190	0.0447*	0.194000	-0.010000	0.4940000	
2	0	7.200000	2.528368	2.847686	0.0664	0.087000	-0.008000	0.2280000	
1	-1	6.650000	2.583303	2.574223	0.1339	0.076500	-0.007000	0.2740000	
4	0	6.266667	2.454927	2.552690	0.1409	0.191000	-0.063000	0.4920000	
3	-1	6.192857	2.480909	2.496205	0.1605	0.108500	-0.010000	0.3930000	
5	-1	6.125000	2.469428	2.480331	0.1663	0.174500	.	.	
3	0	5.464286	2.485494	2.198471	0.2962	0.104500	-0.023000	0.3840000	
5	0	4.900000	2.466701	1.986459	0.4233	0.169000	.	.	
0	-1	4.700000	2.631789	1.785857	0.5577	0.009000	-0.020000	0.0740000	
4	1	4.583333	2.357023	1.944544	0.4506	0.134500	-0.273000	0.4900000	
1	0	4.538889	2.583303	1.757010	0.5773	0.034500	-0.039000	0.2620000	
5	1	3.791667	2.340267	1.620185	0.6692	0.123000	.	.	
4	2	2.770833	2.259240	1.226445	0.8841	0.107000	.	.	
3	1	2.666667	2.397530	1.112256	0.9246	0.072000	-0.177000	0.3870000	
2	1	2.361111	2.452235	0.962841	0.9618	0.023000	-0.178000	0.2110000	
4	3	2.321429	2.166667	1.071429	0.9365	0.084000	.	.	
5	2	2.250000	2.204077	1.020836	0.9494	0.088000	.	.	
5	3	1.375000	2.078805	0.661438	0.9946	0.043000	.	.	
3	2	0.937500	2.314550	0.405046	0.9997	0.013000	-0.209000	0.3600000	
5	4	0.000000	1.954340	0.000000	1.0000	-0.018500	.	.	

Figure 40: UAV Years Prior Statistical Test

Summary

Initial analysis of the linear interpolation of the percent budget change indicates that there's sign of underspending in the earlier stages of acquisition programs' life cycle. Then, looking at the cumulative budget change in relation to the cumulative percent schedule, with the two outlier programs B2-RMP and SDB II accounted for, the timing of budget changes has been shifted more towards the end of acquisition programs' life cycle. Next, an analysis of the S-curve suggests that, overall, acquisition programs tend to reach 60% of total program budget around the 50% schedule mark. However, it is more accurate to say that there's no one size fit all solution for each of the program types and cost analysts will have to be mindful of the characteristics of the programs they are performing estimates for. Finally, the years-prior analysis indicates that, overall, estimates tend to be more accurate when performed within two years of the budget year. The next chapter connects these results to their respective research questions and discusses limitations and potential follow-on research.

V. Conclusions and Recommendations

Chapter Overview

In this chapter, we draw the connection between the findings in Chapter 4 to our research questions. We also discuss the limitations of our research along with recommendations for follow-on research

Research Questions Answered

1. What curves best fit changes in the RDT&E budget of a program?

From an overall perspective, after accounting for the two outlier programs, it seems that a linear curve would adequately fits the RDT&E budget for most programs. However, there is enough variations between different commodity types and even within commodity types that it seems the best practice would be for the cost analyst to make this determination on a case-by-case basis relying on available data.

2. When do budget estimates change and what can be associated with those changes?

There is no general answer that would not overlook significant nuances for different commodity types. However, from the results, after excluding the B2-RMP and SDB II programs as outliers, budget changes seem to occur most towards the latter half of a program’s development cycle. We suspect this is mostly due to changes in requirement scope causing fluctuations in both the estimates and the actual budgets.

3. How different is the rate of change amongst the type of programs?

Budget changes for each commodity type are very different from one another and even for programs within a commodity type. These changes can fit a linear curve, a quadratic curve, or an exponential curve. Once again, it behooves the cost analysts to make judgements based on the characteristics of the program they are estimating.

4. ***How should the S-curve be applied for RDT&E budget for different program types when looking at the time between MSB and IOC?***

   Our analysis of the S-curve suggests that, overall, acquisition programs tend to reach 60% of total program budget around the 50% schedule mark. However, this does not account for the effect of the growth of the total program budget every year. Additionally, there's no one solution for each of the program types and cost analysts will have to be mindful of the programs they are performing estimates for.

5. ***What specific recommendations can the USAF have for different types of program to minimize these estimate variations?***

   From our analysis of the years-prior estimates, as an estimate gets closer to the budget year, the error is reduced. Specifically, our statistical tests show that if estimates are performed more than two years out, there's a high chance that the actual amount needed will be off by 25.74% or more. Perhaps the USAF should run a pilot program to test if performing time-phase estimate for no more than two years out would allow for more flexibility in budget planning as well as getting more accurate estimates.

Limitations

Our first limitation would be the size of the sample for some of our analysis such as determining which functions (linear, exponential, etc.) would best reflect budget changes. This limitation also prevents us from making any meaningful generalization regarding UAV programs as we were only able to obtain data for the Global Hawk program. The second limitation has to do with significant changes to a program budget data for a given FY long after that data is recorded for that FY.

The final limitations are inherent with using SARs as our data, which consists of the following (Younossi et al., 2007):

- The unfeasibility of analysis on major subsystem since data is rolled up and reported at the levels of annual development funding, Military Construction (MILCON) funding, and Operations &Maintenance (O&M) funding.
- Program baselines and system configurations evolve over time making it difficult to analyze cost growth.
- Changes in report requirements and guidelines. This makes comparing SARs across time periods challenging.
- There's inconsistency of the allocation of cost growth among different programs in each of the SAR cost variance category.
- SARs are not required for all programs
- The initial estimates in the SAR are consistent with the program's early budget which may not reflect the most realistic cost estimate as well as any issues related to underspending.

Recommendations for Future Research

For future researches, we recommend looking into Software programs and collect more data on UAV programs to determine if there would be similar results. Our findings from the years-prior analysis for software was so different from the rest of the commodity types that we suspect Software programs might carry some inherent cost characteristics that are very different from other commodity types.

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14. ABSTRACT

As fiscal resources become more limited due to the expanding range of mission needs, accurate cost estimating and budgeting have become more important than ever before. Accurate cost estimates allow the Department of Defense (DoD) to budget with confidence and to effectively communicate its needs to Congress. This research looks to analyze estimates from Air Force's programs using Milestone B and Initial Operational Capability as the analysis window. Initial analysis of the linear interpolation of the percent budget change indicates that there's a sign of underspending in the earlier stages of acquisition programs' development cycle. Additionally, looking at the cumulative budget change in relation to the cumulative percent schedule, with the two outlier programs B2-RMP and SDB II accounted for, significant budget changes tend to occur near the end of acquisition programs' life cycle, particularly around the 70% - 80% schedule mark and on. Then, an analysis of the S-curve suggests that, overall, acquisition programs tend to reach 60% of total program budget around the 50% schedule mark. Finally, the years-prior analysis indicates that, overall, estimates tend to be more accurate when performed within two years of the budget year.

15. SUBJECT TERMS

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