Analyzing Cost Growth in Government Acquisitions

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Abstract

This paper studies a sampling of historical programs that have experienced varying levels of cost growth. The chief purpose is to identify (common) causes; thereby offering an opportunity to make recommendations that can mitigate those causes.

This paper examines a broad range of U.S. Government procurements, spanning:

- Technology domains that cover satellites, ships, land systems, command and control systems, etc.
- Department of Defense, National Aeronautics and Space Administration, Department of Homeland Security, and the Department of Energy government segments
- An epoch that starts as early as 1921 through the present

The analysis begins with collecting publicly available documentation regarding the contract performance on a plethora of programs. The analysis principally involves gathering causal data; parsing and collating the causes into a manageable set of codified bins; and examining the frequency of occurrence.

In the course of data collection/analysis, an assessment will be made with respect to the effectiveness of various acquisition reforms that have been instituted throughout the chronology under study. These recommendations as well as those that have been published within the causal documentation will also be collated and parsed.

The paper will conclude with a unified set of findings and recommendations.

Paper Overview

The purpose of this paper is to examine cost and schedule growth, and if possible, identify universal causal factors. This purpose is accomplished by examining a broad range of U.S. Government procurements, spanning a broad range of technologies, funding agencies, and nearly 90 years of acquisitions.

The intention is to review the surface of a broad range of Government sponsored procurements in order to detect systemic problems associated with the acquisition process. It is not our intention to:

- Perform an in-depth analysis on any particular acquisition,
- Accuse or criticize individual programs, companies and/or agencies,
- Highlight failures, or successes, of various Acquisition Reform activities.

Scope and Limitations

This paper focuses on U.S. Government sponsored acquisitions only. The foundation for this analysis is publicly available data. More specifically, nearly 80% of our references/data were drawn from one of three sources: 1) Government Accounting Office (GAO) Reports, 2) Congressional Budget Office (CBO) Reports, and 3) other U.S. Government published reports (e.g. Selected Acquisition Reports, or SARs). While these sources do bring to bear certain biases, we believe that these sources do remove significant error associated with data normalizing.

This paper looks at cost growth in relative terms only. As such, there is no measure of absolute cost or schedule growth. The analysis is founded on elementary statistics, namely: mean, median, minima, maxima, and skewness—assumed to be understood by the reader. JMP release 6.03 (SAS Institute, Inc.) was used for the analysis.

Overview of Analysis

The analysis uses basic statistics. Mini-tables summarize the data points and their associated parsing. Box plots (plots) are used to display the median growth and the growth variability associated with a particular funding agency and/or technology. A brief discussion providing commentary on findings and causes accompanies each plot. The paper concludes with a summary set of interpretations.

Before proceeding to the analysis, a brief discussion of definitions, reference material, and data collecting/parsing is warranted.

Definition of terms: Over the course of the literature research the authors have found a variety of terms used in association with cost growth. The term 'cost growth' is itself subject to dispute depending on the chosen reference plane. In one source, the cost growth reference is the budget estimate established at Milestone B

[McCrillis]. Another reference measured cost growth relative to the final budget [Christensen et. al.]. To avoid confusion, the following definitions apply within the context of this paper.

Cost Growth. Cost growth is a relative measure. That is, it is a percentage increase/decrease relative to a baseline. To the maximum extent possible, and to be consistent with the SARs, it is the cumulative measure of growth from Milestone B to the point at which the data source is published. It is calculated as follows:

$$Growth = \frac{Cumulative}{Baseline} - 1 \qquad \textbf{Eq 1:}$$

Funding Agencies. The research lead to the analysis of seven different agencies: 1) U.S. Army, 2) U.S. Air Force, 3) U.S. Navy, 4) Department of Defense (DoD), 5) Civil (99% are NASA programs), 6) Department of Homeland Security (DHS), and 7) Department of Energy (DoE). Parsing a particular program, or system acquisition, according to funding agency is explicitly defined by the source document. The authors have attempted to recognize "Joint" service programs as DoD programs—regardless of the particular arm of the DoD that leads the development and/or production. Sample programs include Joint Strike Fighter, Joint Tactical Radio System, and elements within the Missile Defense Agency (MDA).

Technologies. The parsing of programs, or systems, into categorical domains is usually straightforward, but there are instances where the categorization is more subjective. This arises mostly in system-of-systems type programs, e.g. Future Combat Systems (FCS—Ground Systems), or Integrated Deep Water System (IDWS—Ships). These programs are typically developing several different technologies. For instance, under the umbrella of FCS, Ground Systems, C4I components, and Aircraft elements are being developed. A problem arises related to the masking of the real technology driver under these system-of-systems type programs. If the literature was clear (rarely the case), an effort was made to separate these elements in order to more accurately assign the growth. The technology descriptions used in this paper are shown in Table-1.

Table-1. Technology Taxonomy Used in Analysis

Technology Domain	Description
Aircraft	New development aircraft as well as upgrade aircraft are included here. No distinction is made between manned and unmanned aircraft, or between fixed- and rotary-wing aircraft.
C4I	Programs and/or equipments associated with command, control, communications, computation, or information gathering sensors (e.g. radars). This category includes offensive and defensive electronics systems.
Ground Systems	Wheeled and tracked vehicles, towed and mobile artillery, and offensive and defensive gun systems are all included.
Missiles	Ground, sea, and air launched munitions, including all unpowered vehicles, e.g. bombs.
NBC	High energy physics laboratories and facilities, weapons disposal, hazardous waste cleanup, and de-militarization/disposal of chemical and nuclear systems.
Satellites	All unmanned orbiting systems. No distinction is made as to their intended mission or purpose.
Ships	All surface and subsurface assets. No distinction is made between combatants and non-combatants. Also, no distinction is made between propulsive fuel types, e.g. diesel or nuclear.
Space	Manned space programs as well as all launch vehicle and booster development programs.

Growth Causes. Many of the references provided a high-level description of the causes for growth in their respective programs. The SAR Summary Tables parse budget changes into seven categories, see Figure-1. These changes were viewed as consequences, rather than causes, unless explicit descriptions were provided elsewhere in the reports.

Figure-1. Excerpt from 2004 SAR Report

SELECTED ACQUISITION REPORTS (SARs) - HIGHLIGHTS
(As of December 31, 2004)

Changes Since Last Report:	
Economic	$ +32,127.1
Quantity	-24,478.7
Schedule	+20,112.9
Engineering	+35,203.8
Estimating	-6,603.4
Other	-722.4
Support	+3,977.1
Net Cost Change	$ +59,616.4

It is important to note that the identified causes do not necessarily translate into root causes. This is due primarily to the highly interrelated nature of the cost/growth drivers, Figure-2. Without detailed knowledge, or direct experience on a particular program, it is not possible to identify the true root causes. (i.e. Did the requirement drive the selection of an immature technology? Or did the lure of incorporating emerging technologies drive the requirements?) The authors did not assume the role of judge regarding how accurately the the sources documented the causes for cost/schedule growth. To the maximum extent possible, it was assumed that causes were, in fact, root causes. Table-2 portrays the Cause taxonomy used in this paper.

Figure-2. Interrelated Effects of Cost/Schedule Growth Drivers

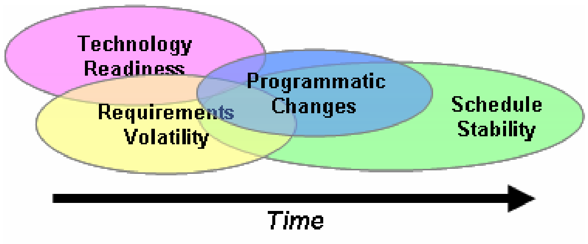
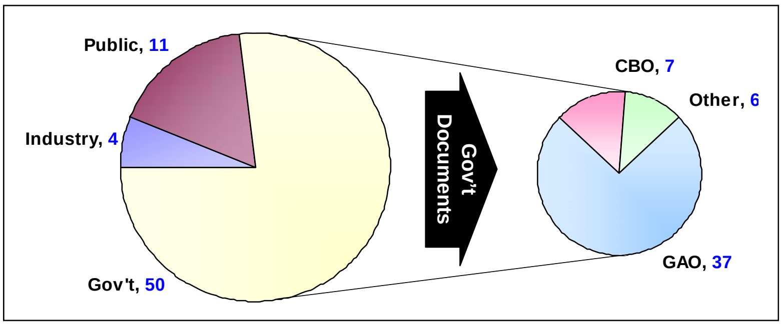


Table-2. Causal Descriptions Taxonomy Used in Analysis

Cause	Description
Technology Readiness	This issue has to do with introducing emerging technological capabilities: in some cases, before those capabilities are mature and their associated features, strengths, and burdens are well understood. The reference documentation is clear with respect to identifying technology readiness as a cause for cost and/or schedule growth.
Requirements Volatility	Requirements volatility is a multi-faceted problem. Volatility can arise when the requirements values fluctuate (i.e. threat changes, technology readiness). Volatility can also occur as a result of an abbreviated requirements definition phase for a program. In this case, the system advances to the next phase of program development with an immature, or incomplete, set of requirements. The reference documentation is clear with respect to identifying requirements issues as a cause for cost and/or schedule growth.
Programmatic Changes	This category captures such things as optimistic baseline cost estimates, attempts to minimize test programs, budget/schedule changes wrought by external forces, etc. This particular 'cause' captures references to what amounts to executive and management decisions. In most cases the documentation is clear in highlighting these decision-maker induced changes.
Schedule Stability	This category of growth causes is also bi-modal. As was suggested in the Requirements Volatility description, an overly aggressive or optimistic schedule usually backfires, leading to problems that result in program delays. In the other extreme, with the increase in functional/technical density and contractors as leads in System of Systems acquisitions, the gestation period for system development is also increasing. Some discernment was required to discover the schedule causes within the documentation.

Data. The authors, by design, depended chiefly on government documents. Of the 65 sources cited, 50 are from U.S. Government sources, as shown in Figure-3. These sources, particularly the GAO reports, provide greater assurance that the data are verifiable. Many of these reports depend on the SARs for their cost data; and therefore provide greater probability that costs have been correctly interpreted, parsed, and normalized. The four industry references include documents from Rockwell International and the RAND Corporation.

Figure-3. Quantification of Source Document Types



The document search intentionally spanned a wide time interval in order to examine how, or if, the causes have changed with the advance of time and technology. Figure-4 depicts the number of documents assessed relative to the year the report was published.

The data gathered in the study focused on cost and schedule growth: accordingly, cost and schedule data were gathered. As stated at the outset, this data was normalized, causing the absolute values for time and cost to become transparent. Production quantities were also gathered where appropriate. This data was used as an artifact related to the examination of production and average unit cost growth.

Figure-4. Distribution of Source Document Publishing Year

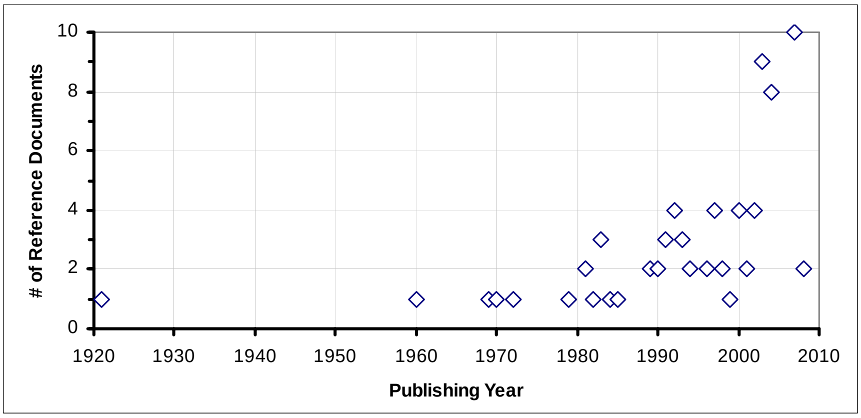


Figure-5 summarizes the data that were extracted from the reference material. Of the 433 points, approximately 50 points appear to be repetitive. That is, the program name is identical, or nearly identical. Within this subset, approximately 30 data points capture data on different metrics; while the remaining 20 data points capture duplicate measures—most often from a different snapshot in time. Of the sources reviewed, Figure-5 indicates the fact that only 15 programs were highlighted for operations and support (O&S) cost growth. Due to the shortage of data, O&S cost growth will not be assessed as part of this paper.

Figure-5. Cost Growth Data Points Parsed by Technology, Funding Agency, and Program Phase

	Funding Agencies								Program Phases			
	USA	USAF	USN	DoD	Civil	DHS	DoE	Total	NRE	Prdn	O&S	Total
Aircraft	17	44	38	4		5		108	45	59	4	108
Electronics	25	25	19	6		1		76	56	20		76
Ground Systems	26		6			1		33	17	15	1	33
Missiles	36	34	34	9				113	58	55		113
NBC				3			23	26		16	10	26
Satellites		15	1		2			18	9	9		18
Ships			41			6		47	22	25		47
Space		4			8			12	10	2		12
	104	122	139	22	10	13	23	433	217	201	15	433

The reader should also be aware that many more data points were reviewed but not added to the analyzed data set. These points reflected citations without a reference plane. For instance, there were numerous claims to 'X' number of years of schedule stretch-out, but with no baseline estimate of schedule.

Analysis

The ensuing data and analysis focus primarily on data tables and box plots. Many observations and deductions can be made directly from these figures. (A note of caution. In a few instances, the y-axis was truncated so that details of the plots would be readable. Also, due to the transfer of graphics from one application to another and some user scaling of the graphics to fit on the page, some distortion of the plots has been introduced.) The authors have added program names to the set of the more egregious outliers (> 90th percentile) that appear on each of the plots. Following the recurring and nonrecurring plots, a summary is made of the growth causes.

Nonrecurring (Development) Data: The following analysis is directed towards a program's nonrecurring development cost. A total of 241 programs/data points define the sample used in the analysis, which is summarized in Figure-6. The data indicates that the programs experience a mean cost growth of 49%; a median growth of 20%; with a weighted-average minimum of between -45% and -39%; a weighted-average maximum between 373% and 439%; and an aggregate skewness of 3.47.

Figure-6. Nonrecurring Cost Growth Data Points, Parsed by Technology and Funding Agency

NRE Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	63	0.53	0.31	-0.11	6.05	4.08
Civil (e.g. NASA)	9	2.59	2.34	0.11	5.64	0.40
Dept. of H/L Security	2	1.65	1.65	0.41	2.88	-
Dept. of Defense	13	0.42	0.44	-0.08	0.79	-0.64
U.S. Navy	80	0.25	0.08	-0.53	3.01	2.76
U.S. Air Force	74	0.43	0.18	-0.82	5.00	3.49
Total / Wtd Avg	241	0.49	0.20	-0.45	4.39	3.47

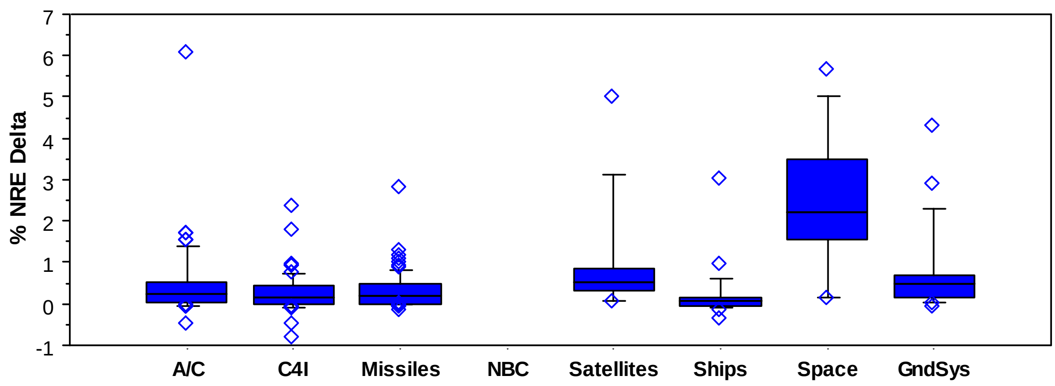
Weighted Average for Min and Max

NRE Data, Parsed by Technology

# Pts	Mean	Median	Min	Max	Skew	
52	0.48	0.25	-0.51	6.05	4.43	**Aircraft**
57	0.28	0.16	-0.82	2.32	1.84	**C4I**
19	0.76	0.48	-0.11	4.27	2.41	**Ground Systems**
70	0.32	0.18	-0.16	2.78	2.82	**Missiles**
10	0.97	0.54	0.03	5.00	2.84	**Satellites**
23	0.23	0.07	-0.37	3.01	3.65	**Ships**
10	2.47	2.23	0.11	5.64	0.35	**Space**
241	0.49	0.20	-0.39	3.73	3.47	**Total / Wtd Avg**

Figure-7 depicts the nonrecurring cost growth viewed relative to the eight technologies. Of immediate note is the absence of data associated with nuclear, biological, and chemical (NBC)–type programs. Also particularly noteworthy is the fact that the Space category tends to incur a higher median and minimum (always positive cost growth). The Space data is driven largely by the elements of the Space Shuttle development effort and the International Space Station. These were geographically distributed system-of-systems programs, with complex management structures, and were pushing the technology envelope on a number of different fronts.

Figure-7. Plot of Nonrecurring Cost Growth versus Technology



Outlier Summary

Aircraft:	UH-60L Modification Program (Army, 605%)
Satellites:	Conical Microwave Imager Sounder Program (USAF, 500%)
Ships:	DDX Ship Program (Navy, 301%)
Space:	Space Shuttle Solid Rocket Booster Program (NASA, 564%)
Grnd System:	Light Weight Howitzer Program (Army, 427%)

Figure-8 lists the NRE cost growth causes parsed by technology. The summary row indicates that the Technology Readiness and Requirements Volatility dominate the causes for NRE cost growth. The research also indicates that the Satellite and NBC technologies tend to document more ardently the significance of issues related to Requirements Volatility and Technology Maturity.

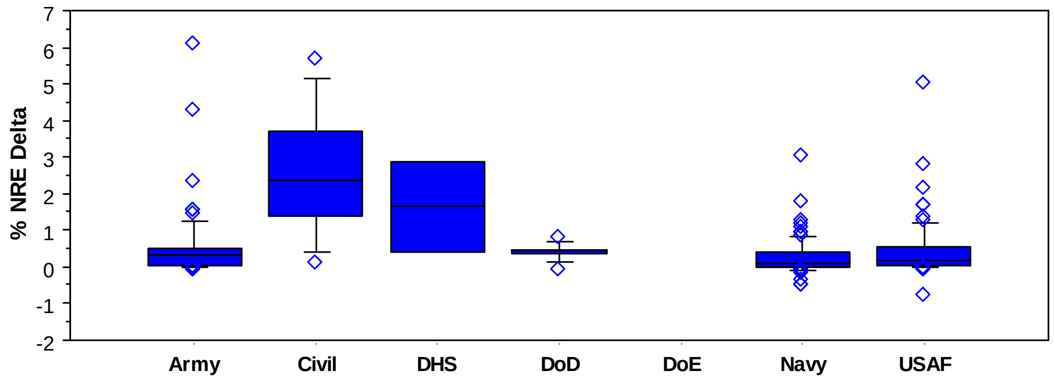
Figure-8. Causes of Nonrecurring Cost Growth Parsed by Technology

	Growth Causes			
Technology	**Req'ts**	**Schedule**	**Program-matics**	**Tech Maturity**
Aircraft	5	1	2	5
C4I	6	1	2	2
Missiles	5	2	2	5
NBC	9	2	4	5
Satellites	10	0	3	9
Ships	4	1	1	0
Space	4	1	1	2
Ground Systems	5	2	2	4
	48	**10**	**17**	**32**

Government Agency Parsing: Figure-9 depicts nonrecurring cost growth as viewed relative to the seven U.S. Government funding agencies. As with the NBC–type programs, data representing the Department of Energy

NRE costs was not immediately available to the authors. Not surprising is the fact that the 'Civil' agency (dominated by NASA) has the highest median growth—as NASA is nearly a synonym for the Space technology.

Figure-9. Plot of Nonrecurring Cost Growth versus Funding Agency



<u>Outlier Summary</u>

Army: UH-60L Modification Program (Aircraft, 605%), Light Weight Howitzer Program (Grnd System, 427%)
Civil: Space Shuttle Solid Rocket Booster Program (Space, 564%)
Navy: DDX Ship Program (Ships, 301%)
Air Force: Conical Microwave Imager Sounder Program (Satellites, 500%)

Schedule Analysis: Nonrecurring schedule growth was examined in addition to cost growth. 95 programs/data points constitute the set of points used in the analysis, which are summarized in Figure-10. The Figure indicates that the programs experience a mean schedule growth of 23%; a median growth of 16%; with a weighted-average minimum of between -16% and -9%; a weighted-average maximum between 107% and 117%; and an aggregate skewness of 1.69.

Figure-10. Nonrecurring Schedule Growth Data Points, Parsed by Technology and Funding Agency

Schedule Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	26	0.25	0.25	-0.12	1.18	1.77
Dept. of H/L Security	11	0.18	0.00	-0.33	1.25	1.16
Dept. of Defense	1	0.29	0.29	0.29	0.29	-
Dept. of Energy						
U.S. Navy	30	0.17	0.09	-0.01	0.86	1.64
U.S. Air Force	27	0.31	0.16	-0.05	1.50	1.73
Total / Wtd Avg	95	0.23	0.16	-0.09	1.17	1.69

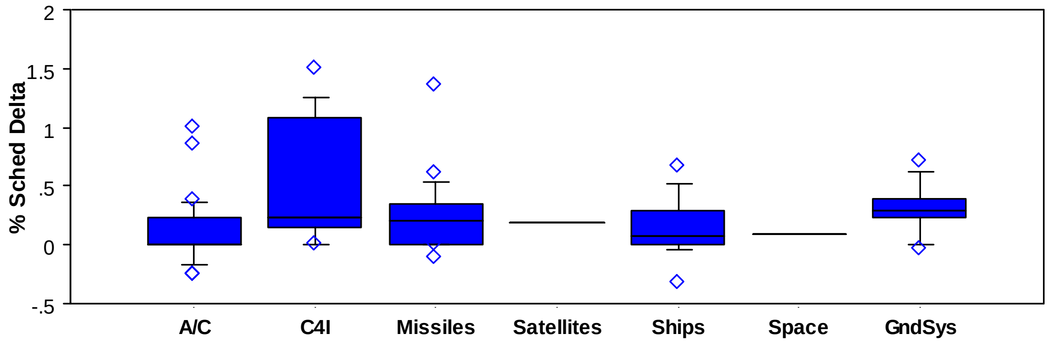
Weighted Average for Min and Max

Schedule Data, Parsed by Technology

# Pts	Mean	Median	Min	Max	Skew	
29	0.11	0.00	-0.25	1.00	1.80	Aircraft
15	0.51	0.23	0.00	1.50	0.86	C4I
10	0.31	0.29	-0.04	0.70	0.12	Ground Systems
25	0.24	0.20	-0.12	1.36	2.15	Missiles
						NBC
1	0.18	0.18	0.18	0.18	-	Satellites
14	0.14	0.08	-0.33	0.67	0.46	Ships
1	0.08	0.08	0.08	0.08	-	Space
95	0.23	0.16	-0.16	1.07	1.69	Total / Wtd Avg

Figure-11 depicts the schedule growth associated with development programs relative to seven technology types (Officially, the NBC programs had no data points for NRE schedule. There is published schedule data for DoE and NBC-type programs, however it is booked in the recurring production phase.) From a purely schedule perspective, most of the technologies have a fairly narrow distribution. C4I-type programs are distinguished as having the greatest interquartile range. This can be attributed to a strong dependence on software development.

Figure-11. Plot of Nonrecurring Schedule Growth versus Technology

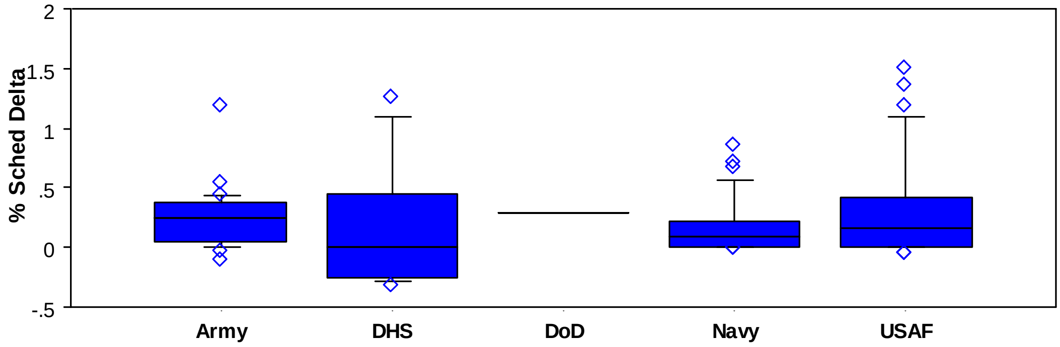


Outlier Summary

Aircraft: IDWS Vertical Unmanned Aerial Vehicle (DHS, 100%), MH-53 (USN, 86%)
C4I: Worldwide Military Command and Control System (USAF, 150%)
Missiles: Advanced Medium Range Air-to-Air Missile (USAF, 136%)

Figure-12 illustrates Schedule growth, parsed by funding agency. The programs identified as outliers in Figure-11 tend to appear as outliers for each of the funding sources. The DHS plot has the greatest interquartile range; however, it should be noted that most of these data points are elements of the Integrated Deep Water System which is still in acquisition.

Figure-12. Plot of Nonrecurring Schedule Growth versus Funding Agency



Outlier Summary

Army: TACFIRE Program (C4I, 118%)
DHS: Rescue 21 Program (C4I, 125%)
Navy: MH-53 (Aircraft, 86%)
Air Force: Worldwide Military Command and Control System (C4I, 150%), Advanced Medium Range Air-to-Air Missile (Missiles, 136%)

Recurring Production Data: For the recurring production data, two different metrics are assessed: total production program costs and average unit costs. With respect to the total production costs, 225 program data points define the set of points used in the analysis; while 186 points define the set used to examine AUC behavior. These data are summarized in Figure-13. It is immediately apparent in this Figure that analysis is not possible for Space systems, nor for the Civil and DHS funding agencies. The Figure indicates that the programs experience a mean total production growth of 42%, a median of 10%, with a weighted-average minimum of between -34% and -36%, a weighted-average maximum between 330% and 358%, and an aggregate skewness of 3.09. Similarly, the mean AUC growth is 61%; a median of 6%, with a weighted-average minimum of between -57% and -65%, and a weighted-average maximum between 649% and 866%, and an aggregate skewness of 4.22.

Figure-13. Recurring Production and Average Unit Cost Growth Data Points, Parsed by Technology and Funding Agency

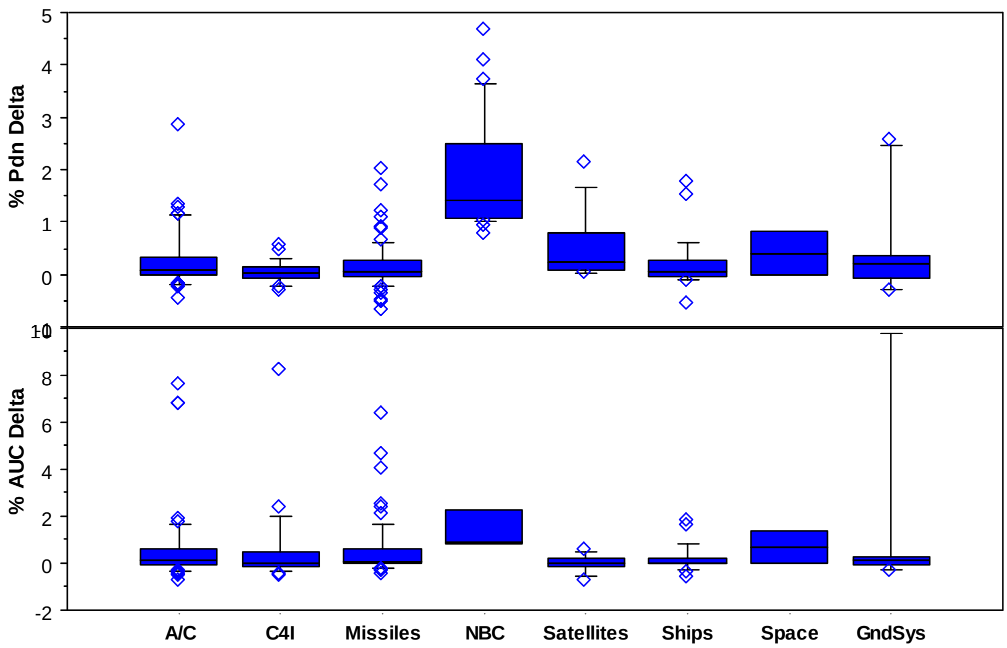
	Production Data, Parsed by Technology						AUC Data, Parsed by Technology					
	# Pts	Mean	Median	Min	Max	Skew	# Pts	Mean	Median	Min	Max	Skew
Aircraft	57	0.34	0.08	-0.47	6.54	29.47	53	0.66	0.13	-0.77	7.59	3.24
C4I	25	0.04	0.01	-0.33	0.54	0.36	24	0.55	0.02	-0.53	8.18	3.85
Ground Systems	14	0.44	0.19	-0.32	2.57	2.59	12	1.82	0.11	-0.33	13.11	2.29
Missiles	68	0.15	0.04	-0.70	2.00	5.92	62	0.53	0.07	-0.50	6.38	3.02
NBC	26	1.83	1.40	0.76	4.65	0.91	3	1.46	0.93	0.76	2.69	1.69
Satellites	9	0.54	0.24	0.02	2.13	3.60	8	0.01	0.03	-0.73	0.58	-0.73
Ships	24	0.19	0.04	-0.56	1.76	5.23	22	0.17	0.03	-0.62	1.79	1.96
Space	2	0.41	0.41	0.00	0.81	-	2	0.69	0.69	0.00	1.38	-
Total / Wtd Avg	225	0.42	0.10	-0.36	3.30	3.09	186	0.42	0.06	-0.57	6.49	4.22

	Production Data, Parsed by Agency						AUC Data, Parsed by Agency					
	# Pts	Mean	Median	Min	Max	Skew	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	54	0.26	0.05	-0.53	2.84	2.36	51	0.90	0.05	-0.45	13.11	3.44
Civil (e.g. NASA)	1	2.13	2.13	2.13	2.13	-						
Dept. of H/L Security	1	0.41	0.41	0.41	0.41	-						
Dept. of Defense	13	0.55	0.30	-0.15	2.69	2.48	8	0.81	0.61	-0.35	2.69	1.16
Dept. of Energy	23	1.88	1.50	1.00	4.65	1.37						
U.S. Navy	76	0.15	0.04	-0.70	1.76	1.96	73	0.39	0.04	-0.77	7.59	4.43
U.S. Air Force	57	0.29	0.04	-0.31	6.54	5.62	54	0.59	0.06	-0.73	6.77	3.10
Total / Wtd Avg	225	0.42	0.10	-0.34	3.58	3.09	186	0.42	0.06	-0.65	8.66	4.22

Weighted Average for Min and Max

Technology Parsing: Figure-14 depicts recurring and average unit (AUC) cost growth relative to the eight technologies. The NBC–type programs experience the greatest total recurring and AUC cost growth, while all other technology domains are relatively close to the median. The causes for these significant differences are driven primarily by new technology issues associated with the construction of new high-energy physics facilities, and with disposal of hazardous materials and chemicals. Also particularly noteworthy is the wide AUC distribution of the Ground System category. The top whisker, representing the 90th percentile, actually has a point above it for the Army Light Armored Vehicle program.

Figure-14. Plot of Recurring Production and Average Unit Cost Growth versus Technology



<u>**Production Outliers**</u>

Aircraft:	C-130J Modification Program (Air Force, 654%)
Missiles:	Patriot Missile Program (Army, 250%), Wide Area Antiarmor Munitions (USAF, 169%)
NBC:	Weapons Destruction (DoE, 465%), Hanford Waste Cleanup (DoE, 407%)
Satellites:	GOES I – M (USAF, 213%)
Grnd System:	Land Warrior Program (Army, 257%)

AUC Outliers

Aircraft: F-14J Modification Program (Navy, 759%), C-17 Program (USAF, 675%)
C4I: Army Data Distribution System Program (Army, 812%)
Missiles: Roland Missile Program (Army, 638%), Standard Missile II (Navy, 464%)
Grnd System: LAV Program (Army, 1311%), DIVAD Program (Army, 801%)

Figure-15 lists the Recurring cost growth causes parsed by technology as enumerated by the references. The summary row clearly depicts that Programmatic issues dominate the causes for recurring cost growth. Under Programmatic Changes, aircraft and missile growth causes are dominated by changes (reductions) in the baseline quantities. For the NBC programs, regulatory issues related to constructing high-energy physics laboratories or building facilities for storing/disposing/inerting NBC products or byproducts drive cost growth. The Programmatic Changes for satellite technologies tend to focus on high-level program management issues related to credible baseline estimates (by both contractors and government), stable budgets, and a stable industrial base.

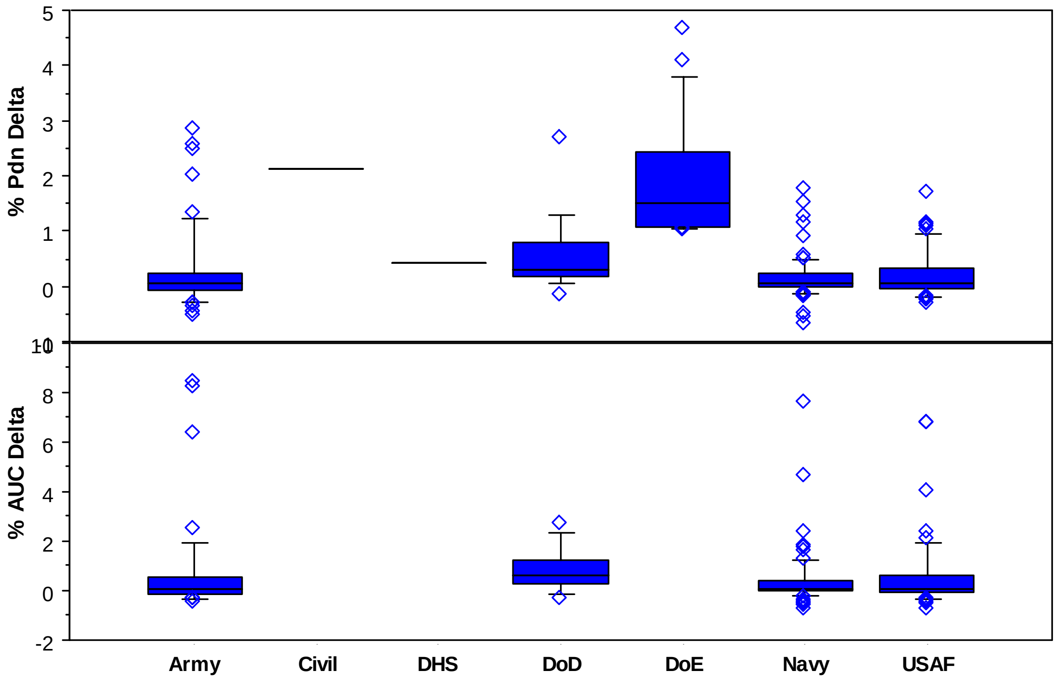
Figure-15. Causes of Recurring Cost Growth Parsed by Technology and Cause

	Growth Causes			
	Req'ts	Schedule	Program-matics	Tech Maturity
Aircraft	0	0	6	1
C4I	1	2	4	0
Missiles	0	5	6	0
NBC	1	4	9	0
Satellites	1	0	6	1
Ships	0	1	3	0
Space	0	1	3	0
Ground Systems	1	4	4	0
	4	**17**	**41**	**2**

Government Agency Parsing: Figure-16 depicts the total recurring production and AUC cost growth relative to the seven funding agencies. DHS, DoE and Civil agencies had no data for AUC; while Civil and DHS had only a single point for total production costs.

As stated earlier, with the DoE having 'ownership' of most of the NBC–type programs, it is not surprising that the DoE total production cost growth is roughly 5-times the aggregate median. The causes for these significant differences are driven primarily by new technology issues associated with both the construction of new high-energy physics facilities and with hazardous/chemical disposal.

Figure-16. Plot of Recurring Production and Average Unit Cost Growth versus Funding Agency



Production Outliers

Army: CH-47F Modification Program (285%), Light Weight Howitzer Program (245%)
DoD: Chemical Demilitarization – Newport (269%)
DoE: Weapons Destruction (465%), Hanford Waste Cleanup (407%)
Navy: Waste Transfer Facility (DoE, 200%)
Air Force: Advanced Medium Range Air-to-Air Missile (USAF, 136%)

AUC Outliers

Army: LAV Program (1311%), Army Data Distribution System Program (812%), Sergeant York Division Air Defense Program (801%)
Navy: F-14J Modification Program (759%), Standard Missile II (464%)
Air Force: C-17 Program (675%), Advanced Medium Range Air-to-Air Missile (400%)

Technology Analysis with Respect to Funding Agencies

Three technologies had enough data points to compare and contrast their relative performance between funding agencies: Aircraft, C4I and Missiles. The analysis within this section involves looking at all the metrics simultaneously. This analysis simply compares the respective funding agencies to see if there are significant differences between their growth statistics.

Aircraft Data Summary: As indicated in Figure-17, the total number of discrete data points ranges from 36 (schedule growth) to 57 (total production cost growth). Most metrics have at least one funding agency that is vacant (DHS) and each metric also has a funding agency that has less than 5 data points (DoD).

Figure-17. Aircraft NRE, Production, AUC and Schedule Growth Data Points, Parsed by Funding Agency

NRE Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	9	1.19	0.50	-0.03	6.05	2.53
Dept. of H/L Security						
Dept. of Defense	3	0.47	0.46	0.42	0.52	0.81
U.S. Navy	21	0.14	0.06	-0.51	0.92	0.96
U.S. Air Force	19	0.52	0.29	-0.09	1.66	0.99
Total / Wtd Avg	52	0.48	0.25	-0.22	2.06	4.43

Schedule Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	4	0.20	0.20	0.00	0.38	-0.22
Dept. of H/L Security	5	0.05	-0.25	-0.25	1.00	2.03
Dept. of Defense	1	0.29	0.29	0.29	0.29	-
U.S. Navy	11	0.13	0.00	-0.01	0.86	2.60
U.S. Air Force	8	0.06	0.00	-0.05	0.25	0.88
Total / Wtd Avg	29	0.11	0.00	-0.05	0.63	1.80

Production Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	10	0.51	0.19	-0.47	2.84	1.98
Dept. of H/L Security						
Dept. of Defense	2	0.16	0.16	0.10	0.23	-
U.S. Navy	22	0.21	0.08	-0.21	1.25	1.83
U.S. Air Force	23	0.41	0.02	-0.25	6.54	4.30
Total / Wtd Avg	57	0.34	0.08	-0.26	3.63	4.99

AUC Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	10	0.46	0.26	-0.45	1.59	0.33
Dept. of H/L Security						
Dept. of Defense	1	0.28	0.28	0.28	0.28	-
U.S. Navy	21	0.65	0.13	-0.77	7.59	3.69
U.S. Air Force	21	0.78	0.10	-0.42	6.77	2.69
Total / Wtd Avg	53	0.66	0.13	-0.55	6.00	3.24

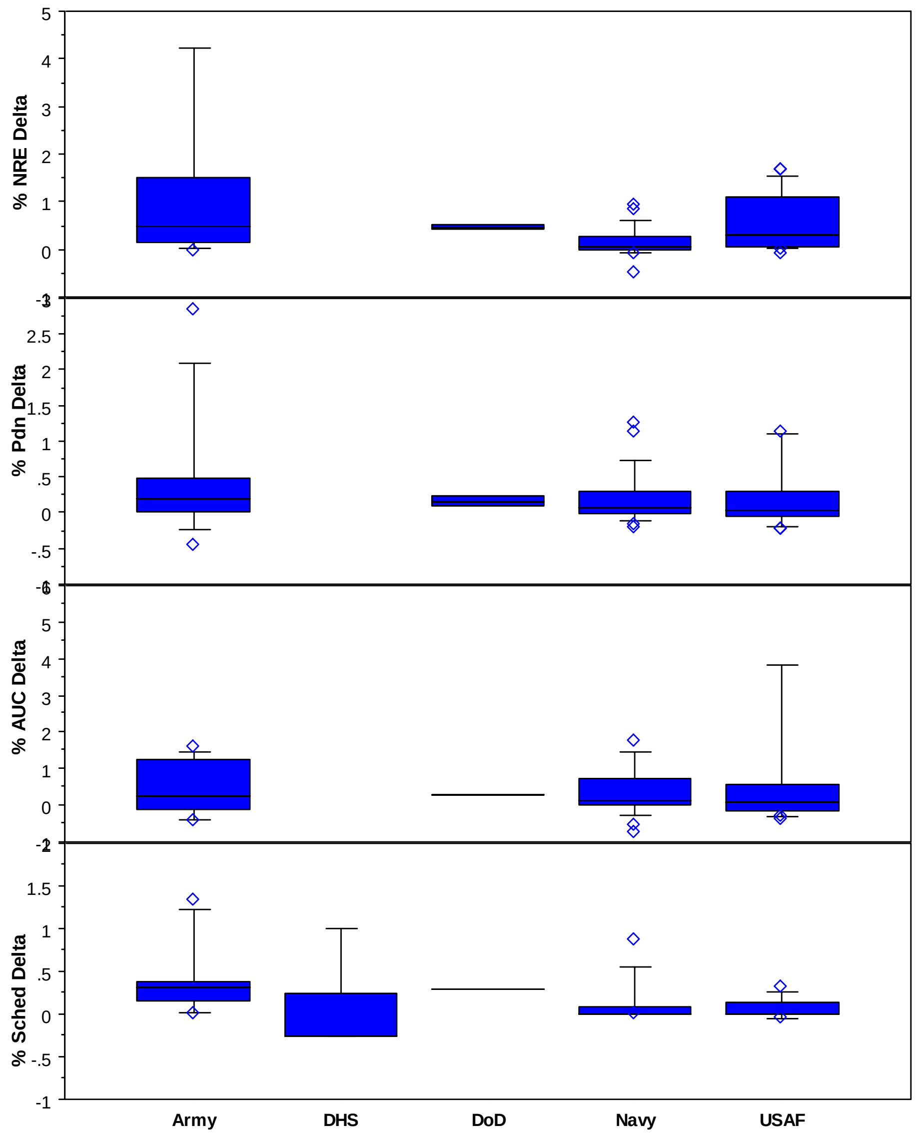
Weighted Average for Min and Max

Figure-18 shows the plots for the four Aircraft metrics parsed by funding agency. As indicated in Figure 13, the DoD data portrayed in the plots are not useful for analysis. First, there are too few points, and secondly the points represent relatively new/immature programs: Joint Strike Fighter, and Joint Tactical UAV. Similarly, the DHS data depicted in the Schedule growth plot are related to all the aircraft procurements in the IDWS program. These four IDWS aircraft types are still in the acquisitions process.

Outlier Summary

NRE: UH-60L Upgrade Program (Army, 605%)
Prdn: CH-47F Upgrade Program (Army, 285%)
AUC: F-14D Upgrade Program (Navy, 759%), C-17 Program (USAF, 675%), C-130H Upgrade Program (677%)
Schedule: AH-66 Comanche Program (Army, 132%)

Figure-18. Plot of Aircraft NRE, Production, AUC and Schedule Growth, Parsed by Funding Agency



C4I Data Summary: As indicated in Figure-19, the total number of discrete data points ranges from 20 (schedule growth) to 57 (NRE cost growth). All metrics have at least one funding agency that is vacant (DHS), while AUC has two vacancies, including DoD. The Schedule metric, with only nine total points, was omitted from the analysis.

Figure-19. C4I NRE, Production, AUC and Schedule Growth Data Points, Parsed by Funding Agency

NRE Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	18	0.33	0.05	-0.09	2.32	2.49
Dept. of H/L Security						
Dept. of Defense	6	0.44	0.44	0.16	0.69	-0.34
U.S. Navy	13	0.27	0.16	-0.53	1.75	1.74
U.S. Air Force	20	0.19	0.14	-0.82	0.89	-0.52
Total / Wtd Avg	57	0.28	0.16	-0.42	1.52	1.84

Schedule Data, Parsed by Agency

# Pts	Mean	Median	Min	Max	Skew
Insufficient Data					

Production Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	10	-0.03	-0.02	-0.33	0.45	0.87
Dept. of H/L Security						
Dept. of Defense	1	0.19	0.19	0.19	0.19	-
U.S. Navy	7	0.03	0.01	-0.18	0.24	0.20
U.S. Air Force	7	0.12	0.08	-0.24	0.54	0.45
Total / Wtd Avg	25	0.04	0.01	-0.24	0.41	0.49

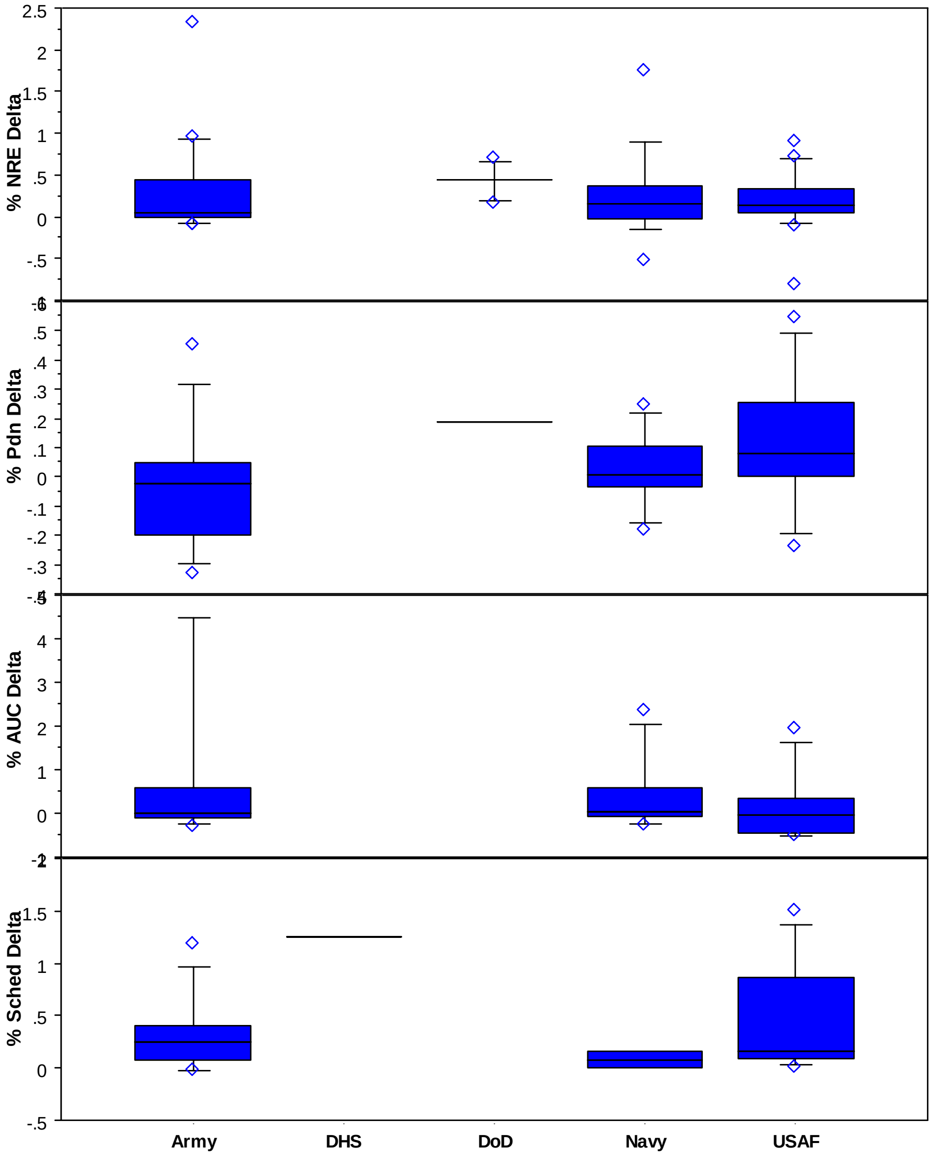
AUC Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	10	0.94	0.02	-0.30	8.18	3.05
Dept. of H/L Security						
Dept. of Defense						
U.S. Navy	7	0.41	0.03	-0.26	2.35	2.09
U.S. Air Force	7	0.15	-0.03	-0.53	1.93	1.86
Total / Wtd Avg	24	0.56	0.02	-0.36	4.66	3.85

Weighted Average for Min and Max

Figure-20 shows the plots for the four C4I metrics parsed by funding agency. As indicated in Figure-19, the DoD and DHS data portrayed in the plots are not useful for analysis.

Figure-20. Plot of C4I NRE, Production, AUC and Schedule Growth, Parsed by Funding Agency



<u>Outlier Summary</u>

NRE: Maneuver Control System (Army, 233%), Virtual At Sea Training Program (Navy, 175%)

Prdn: Global Broadcast System (USAF, 54%), Suite of advanced infrared countermeasures systems which include the Advanced Threat Infrared Countermeasures (ATIRCM) and the Common Missile Warning System (CMWS) programs (Army, 45%)

AUC: Army Data Distribution System (Army, 818%), Relocatable Over-the-Horizon Radar (Navy, 236%), Over-The-Horizon-Backscatter Radar (OTH-B) program (USAF, 193%)

Schedule: Worldwide Military Command and Control System (USAF, 150%), TACFIRE program (Army, 118%)

Missile Data Summary

As indicated in Figure-21, the total number of discrete data points ranges from 40 (schedule growth) to 70 (NRE cost growth). The DoD has less than 5 data points associated with each metric except for total production cost growth (7 data points).

Figure-22 shows the plots for the four Missile metrics parsed by funding agency. As indicated earlier, analysis related to the DoD data is potentially only viable on the total Production metric. However, while Figure 17 depicts 7 distinct points for Production growth, 2 points come from different periods on the Peacekeeper program, 2 points come from GMD, and 1 point comes from a "collective-set" of unnamed programs. Therefore, the analysis should be restricted to the Army, Air Force, and Navy missile programs. Although it is interesting to note that the DoD behavior is typically within one standard deviation of the aggregate median, for all metrics, despite the small sample size.

The Air Force Production outlier is the Wide Area Antiarmor Munitions (WAAM) Program. In the early 1980s, "The present WAAM program consists of the: (1) Antiarmor Cluster Munition, which is in full scale development; (2) Extended Range Antiarmor Munition, which recently completed the validation phase; and (3) Wasp, which is in its third year of the validation phase." [GAO/C-MASAD-83-12] The GAO recommended cancellation of this program in 1983, because it was 18 months behind schedule and estimates through production had risen to over $800M with anticipated growth exceeding $6B.

Figure-21. Missile NRE, Production, AUC and Schedule Growth Data Points, Parsed by Funding Agency

NRE Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	21	0.32	0.32	0.00	0.97	0.81
Dept. of Defense	4	0.35	0.33	-0.08	0.79	0.16
U.S. Navy	21	0.35	0.19	-0.16	1.26	0.93
U.S. Air Force	24	0.29	0.06	-0.10	2.78	3.34
Total / Wtd Avg	70	0.32	0.18	-0.09	1.67	2.82

Schedule Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	7	0.13	0.04	-0.12	0.37	0.15
Dept. of Defense						
U.S. Navy	8	0.16	0.17	0.00	0.46	0.68
U.S. Air Force	10	0.37	0.27	0.00	1.36	1.62
Total / Wtd Avg	25	0.24	0.20	-0.03	0.79	2.15

Production Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	23	0.16	0.07	-0.53	2.00	2.47
Dept. of Defense	7	0.32	0.30	-0.15	0.85	0.32
U.S. Navy	20	0.08	0.05	-0.70	0.90	-0.07
U.S. Air Force	18	0.16	0.00	-0.31	1.69	2.19
Total / Wtd Avg	68	0.15	0.04	-0.48	1.47	1.97

AUC Data, Parsed by Agency

	# Pts	Mean	Median	Min	Max	Skew
U.S. Army	22	0.49	0.06	-0.37	6.38	3.49
Dept. of Defense	4	0.47	0.35	-0.35	1.51	0.84
U.S. Navy	19	0.39	0.04	-0.50	4.64	3.58
U.S. Air Force	17	0.76	0.20	-0.13	4.00	1.79
Total / Wtd Avg	62	0.53	0.07	-0.34	4.88	3.03

Weighted Average for Min and Max

With respect to the AUC metric, the Army outlier at 638% is the US Roland missile program, which was cancelled before it went into full rate production. The Air Force outlier at 4.00x the baseline estimate was the Advanced Medium-Range Air-to-Air Missile (AMRAAM); while the Navy outlier is the Standard Missile II program.

<u>Outlier Summary</u>

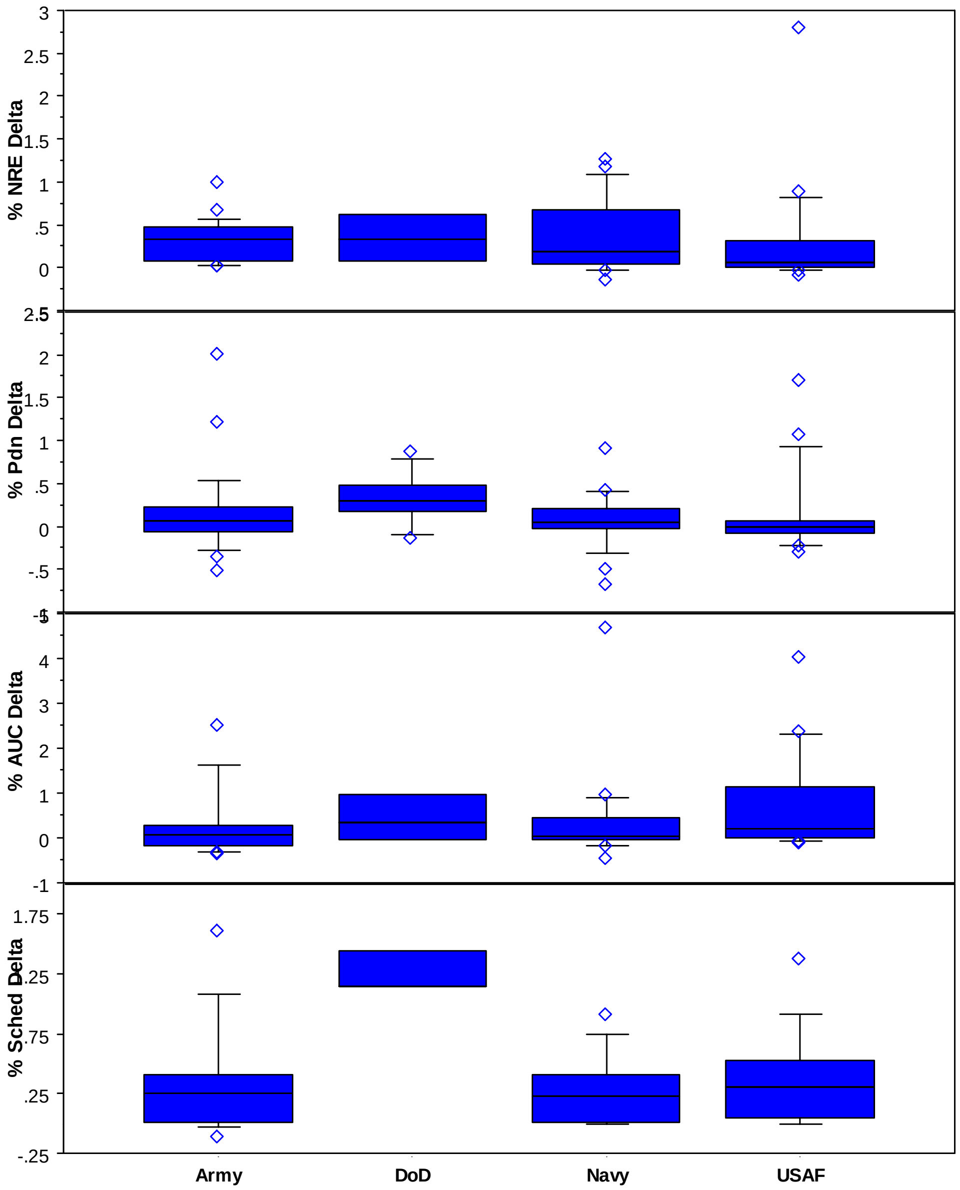
NRE: Short Range Missile Program (USAF, 278%)

Prdn: Original Patriot Missile Program (Army, 200%), Wide Area Antiarmor Munitions Program (USAF, 169%)

AUC: US Roland Missile Program (Army, 638%), Standard Missile II Program (USN, 464%), Medium-Range Air-to-Air Missile (USAF, 400%)

Schedule: Hellfire Missile Program (Army, 160%)

Figure-22. Plot of Missile NRE, Production, AUC and Schedule Growth, Parsed by Funding Agency



Summary of Technology Analysis

In general, the median values and even the interquartile ranges across all metrics, tend to be relatively consistent. This reveals that the system acquisition process is relatively equally employed by all funding agencies. Also, given the shrinkage of the industrial base over time, it also reinforces that the contractors are also are also consistently applying the appropriate and similar government and commercial processes across the procurements, regardless of who is funding the procurement.

Figure-23 summarizes the funding agencies' performance with respect to the three technology domains using the four metrics. The value (1 through 5) in any given cell represents the ranking of the particular funding agency relative to the other funding agencies, for the given technology (a score of '1' represents the greatest growth in that particular metric, in a given technology; and a '5' represents the lowest growth, or in some instances a lack of measurement.). The grey-shaded row represents a composite score while the bottom row for each metric provides a relative ranking for each funding agency relative to the metric indicated. Again, a '1' represents greatest growth. This particular instantiation of the analysis is independent of time. So the only conclusions that can be drawn from these particular tables are that the Army, at some point in time, experienced the greatest overall growth percentage (rankings of 1, 1, 2, 2); the Navy, by the same token, experienced the least growth (rankings of 3, 3, 3, 1); and the Air Force tended to be between the Army and Navy (rankings of 1, 2, 2, 3).

Also, as discussed in the Production Data Analysis section, these overall rankings tend to support the hypothesis that programs generally attempt to minimize overall program growth by reducing the quantity of systems that are procured. While this tends to keep the overall budget in check, one result is that the unit costs for the items procured tend to increase (as the production start-up costs get amortized across fewer systems). This is seen by looking at the Navy's production ranking ('3', representing lowest total production growth) and comparing to the Navy's unit cost ranking ('1', representing the greatest unit cost growth). The converse appears to be true in the rankings as well. The Air Force has a total production cost growth ranking of '1' (the greatest growth) and yet the Air Force unit cost ranking is '3' (the least growth).

Figure-23. Funding Agencies Relative Rankings Associated with Aircraft, Missile, and C4I System Acquisitions

NRE Cost Growth Ranking

	# Pts	USA	DHS	DoD	USN	USAF
Aircraft	52	1	N/A	N/A	3	2
C4I	57	1	N/A	4	2	3
Missiles	70	3	N/A	N/A	2	1
		1.78	5.00	4.68	2.29	1.93
Relative Ranking		1	N/A	N/A	3	2

NRE Schedule Growth Ranking

	# Pts	USA	DHS	DoD	USN	USAF
Aircraft	36	1	2	N/A	3	4
C4I	20	2	N/A	N/A	N/A	1
Missiles	40	1	N/A	N/A	3	2
		1.32	4.13	5.00	3.64	2.26
Relative Ranking		1	N/A	N/A	3	2

Production Cost Growth Ranking

	# Pts	USA	DHS	DoD	USN	USAF
Aircraft	57	2	N/A	N/A	3	1
C4I	25	2	N/A	N/A	3	1
Missiles	68	1	N/A	4	3	2
		1.55	5.00	4.55	3.00	1.45
Relative Ranking		2	N/A	N/A	3	1

AUC Cost Growth Ranking

	# Pts	USA	DHS	DoD	USN	USAF
Aircraft	53	3	N/A	N/A	1	2
C4I	24	1	N/A	N/A	2	3
Missiles	62	1	N/A	N/A	2	3
		1.76	5.00	5.00	1.62	2.62
Relative Ranking		2	N/A	N/A	1	3

Summary and Interpretation of Findings

The summary of findings and interpretation of the analysis are presented in the order discussed in the paper. The initial discussion focuses on nonrecurring cost/schedule. It is followed by recurring production, and concluding with brief remarks concerning the analysis of the three technologies, parsed by funding agency.

The nonrecurring cost growth analysis revealed that the composite growth for all types of technologies is approximately 50% (the median value at approximately 30%, see Figure-6), with an aggregate skewness statistic of 3.47 (see Figure-24 histogram) which suggests a moderate probability of even higher cost growth: with a documented growth that exceeds 600% (Figure-6). By the same token, the aggregate nonrecurring schedule growth has a mean of approximately 25%, with an aggregate skewness statistic of 1.46 (see Figure-24 histogram), suggesting only a minor probability of a schedule stretch-out. Together, these data suggest that nonrecurring cost growth occurs most frequently, not because the schedule is perturbed, but because either the original nonrecurring estimates were underestimated or the complexity of the program (requirements challenges or aggressive pursuit of technology) was under estimated. Figure-25 was developed from data contained in [Drezner, et. al., 1996]. This graph, based on modern programs (post-1980s) indicates that there is a point after which reducing the duration of the requirements development and risk reduction phase (pre-SDD phases) of a program is detrimental to overall program costs. Conversely, Figure-26 depicts the gestation period behavior for programs (artillery and aircraft) since the late 1800s. When the total time to define, develop and field a system is less than 3-4 years, the authors believe that the probability of seeing cost and schedule growth with the magnitudes seen in modern data is significantly reduced. Alternatively, it is easy to grasp the opportunity, and therefore the probability, for significant cost growth when development programs last 10-years or more.

Figure-24. Histograms for Nonrecurring Cost and Schedule Growth

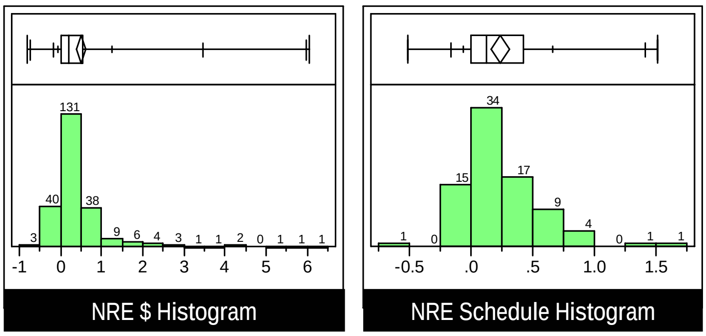


Figure-25. RAND Study Highlights Importance of Activities Preceding Milestone B

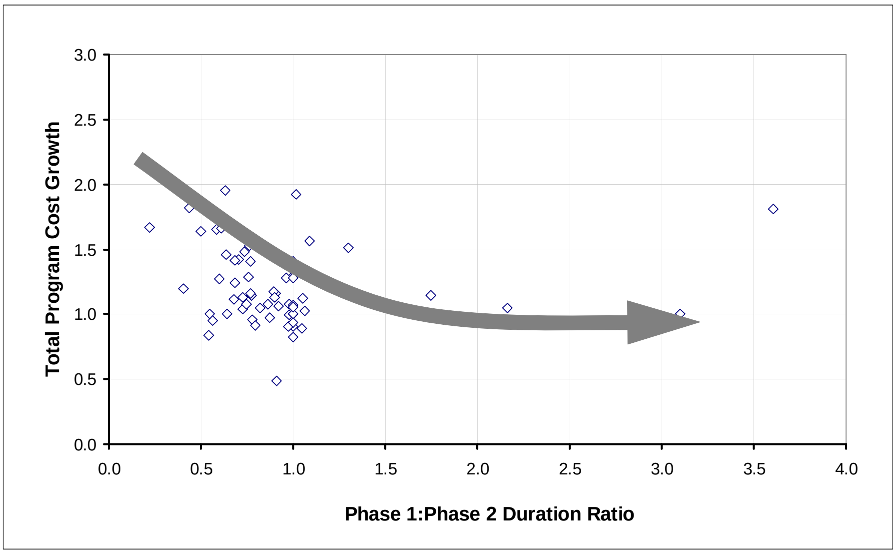
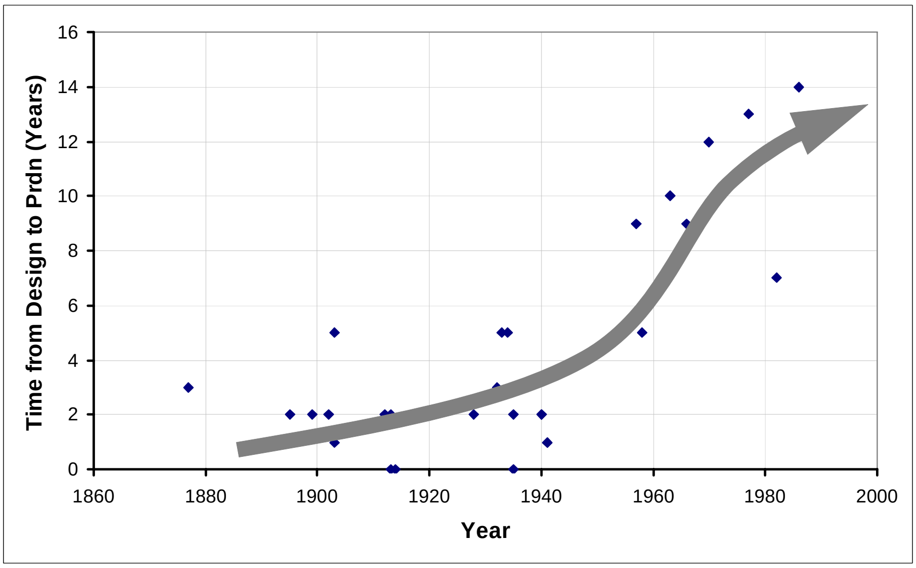


Figure-26. The Time to Develop and Field Systems Is Exceedingly Long

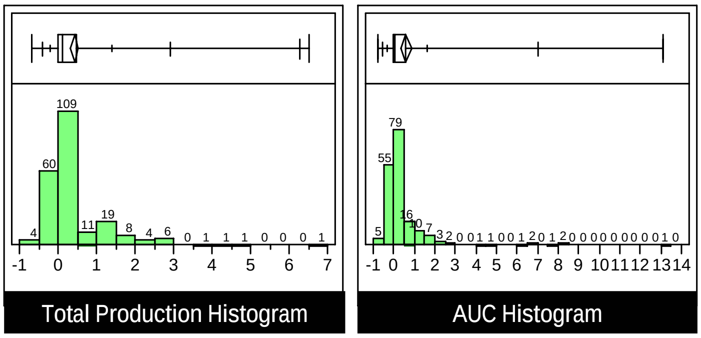


The recurring production growth analysis underscores a couple of interesting findings. The analysis of total production reveals a mean growth of approximately 42% (a median of approximately 10%), with a aggregate skewness statistic of 3.09 (see Figure-27 histogram). In contrast, the analysis of the system AUC indicates the potential for higher growth. The mean growth is approximately 61% (with a median value of just 6%), but the aggregate skewness statistic has a value of 4.2 (see Figure-27 histogram). These two metrics (AUC and total production) examined collectively suggest the following. Programs place a higher priority on controlling total production cost rather than controlling AUC. This is confirmed by Dr. Kenneth Oscar, the Acting Assistant Secretary of the Army for Acquisition, Logistics, and Technology (January 2001 through March 2002), who suggested (tongue-in-cheek)

> "Since we always wind up buying half or less of the quantity we originally say we need, we should always set up the factory or production process to build half of whatever amount we originally think we're going to buy." He argued this rule would make sense because what tends to drive costs "is not the production but rather the upfront production investment." [Christopher H. Hanks, et. al.]

A close look at the scales presented in Figures-15 and -16, reveals that the AUC growth scale is almost twice the Total Production growth scale. This was confirmed again, when the three technologies were examined separately. The DoD's Analysis of Alternatives (AoA) process is intended not only to compare competing concepts and to identify the features/requirements of future/candidate weapons systems, but also to quantify the service needs, which would include an estimate of the quantity of systems required. This raises a couple of opposing questions. Are the services at risk of not meeting their mission needs and objectives when the quantity of procured systems is reduced in order to control total production costs? Or, is there a flaw in the AoA process that allows services to over-inflate their true needs?

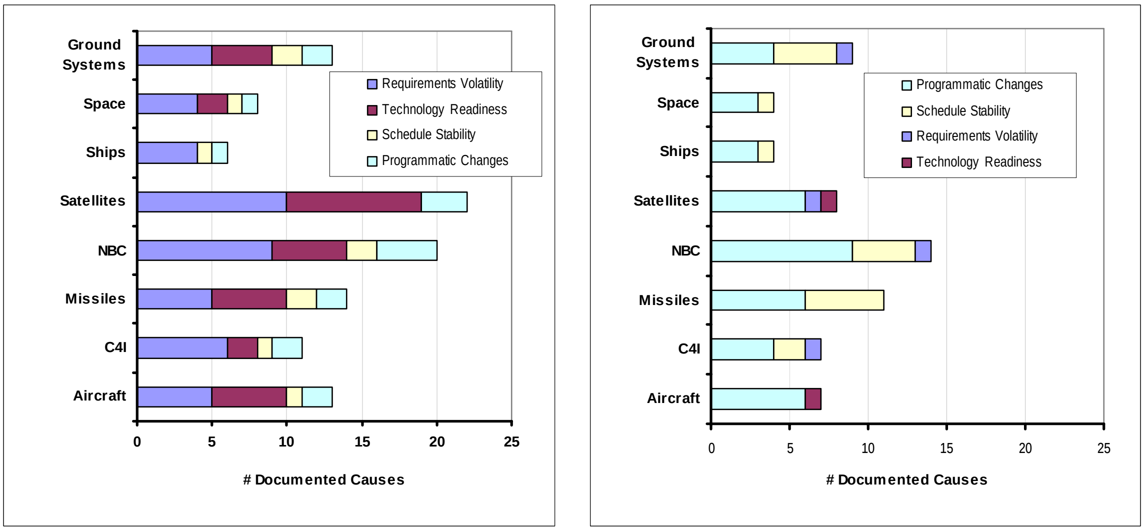
Figure-27. Histograms for Recurring Production and AUC Growth



The separate Technologies analysis with respect to funding agencies, confirms that the services tend to manage to Total Program Cost, thereby allowing AUC to grow. This analysis also highlighted that the converse also tends to be true. The Air Force data in Figure-23 provides evidence that they tend to manage AUC, allowing total program production costs to "float".

Figure-23 depicts the contrast between nonrecurring and recurring program phases with respect to causes of cost and schedule growth. During program development, Technology Readiness and Requirements Volatility dominate the causes for cost and schedule growth. These causes are evident in relatively equal proportion in all technology domains.

Figure-23. The Documented Causes of Growth are Distinct for Development and Production



Furthermore, the impacts of Technology Readiness and Requirements Volatility issues extend beyond program development. These NRE causes/drivers influence not only the (in)ability of a program to maintain production phase cost schedule targets, but also have cost and readiness consequences during the operations phase of a program.

> "DOD is spending more on operating and support costs for its weapon systems than it planned. We found three primary reasons for the high cost of operating and supporting DOD's fielded weapon systems. These were (1) little or no attention to the trade-offs between readiness goals and the cost of achieving them when setting the key parameters for weapon systems; (2) the use of immature technologies during product development and delays in acquiring knowledge about the design and its reliability until late in development, or in some cases, production; and (3) insufficient data on the operations and maintenance costs and actions for fielded systems that would allow improvements in products currently in development." [GAO-03-57]

Programmatic Changes eclipse all other drivers during a program's production phase. Unlike the NRE causes, which appear relatively consistently across the various technologies, the recurring/production growth causes appear to be more dependent on the particular technology. Properly "calibrated" expectations (cost and schedule estimates, customer-contractor-subcontractor relationships) and stability of procurement budgets, quantities, and interdependent technologies/program elements are a frequently occurring subset of technology-dependent growth causes that must be confronted.

Summary of Recommendations

The authors are not in a position to make policy recommendations that would mitigate the above listed causes or their consequences. However, given the documented life cycle cost consequences (extending beyond the NRE growth documented herein) of Requirements Volatility and Technology Readiness, it would appear that increased emphasis in up-front and thorough requirements analysis is still warranted. In parallel, a strict adherence to employing only mature and/or well understood technologies will also yield savings that reach well beyond system development.

With respect to this analysis, we offer the following recommendations to extend this body of work.

1. Trace acquisition cost/schedule growth over time (possibly by technology)
2. Research operations and support cost growth over time (possibly by technology)
3. Use the SARs as a starting reference, and in a more detailed analysis, trace programs year by year, from inception through production
4. Examine the relationship between development growth and production growth

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