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Using Earned Value Information to Predict Program Cancellation

2 September 2014

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Since 2001, 12 major defense acquisition programs (MDAPs) have been cancelled. Although each of these programs had problems with cost or schedule overruns (or both), there were other MDAPs that had similar problems and were not cancelled. Is it possible that program managers had information that might help determine which program was likely to survive and which was more likely to be cancelled? We employ a unique and rigorous statistical methodology to help program managers and their overseers understand and quantify the risk to their programs based on key earned value metrics. We compare programs that were cancelled to programs that had significant cost overruns but were not cancelled. We use survival analysis to investigate whether differences in key EV metrics reported for cancelled programs and ?troubled? but not cancelled programs can be used to model the probability of cancellation for MDAPs. Our most significant finding across models is that when there is high cost growth in the EAC reported by the contractor, programs run far larger risks of cancellation. We find less robust evidence that increases in PM estimates and high cost variance also can drive risk of program cancellation.

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Abstract

Since 2001, 12 major defense acquisition programs (MDAPs) have been cancelled. Although each of these programs had problems with cost or schedule overruns (or both), there were other MDAPs that had similar problems and were not cancelled. Is it possible that program managers had information that might help determine which program was likely to survive and which was more likely to be cancelled? We employ a unique and rigorous statistical methodology to help program managers and their overseers understand and quantify the risk to their programs based on key earned value metrics. We compare programs that were cancelled to programs that had significant cost overruns but were not cancelled. We use survival analysis to investigate whether differences in key EV metrics reported for cancelled programs and "troubled" but not cancelled programs can be used to model the probability of cancellation for MDAPs. Our most significant finding across models is that when there is high cost growth in the EAC reported by the contractor, programs run far larger risks of cancellation. We find less robust evidence that increases in PM estimates and high cost variance also can drive risk of program cancellation.

Keywords: Acquisition, Earned Value, Survival Analysis, Cost Growth.

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Introduction

Since 2001, 12 major defense acquisition programs (MDAPs) have been cancelled. Although each of these programs had problems with cost or schedule overruns (or both), there were other MDAPs that had similar problems and were not cancelled. Is it possible that program managers had information that might help determine which program was likely to survive and which was more likely to be cancelled?

MDAPs are programs designated by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD [AT&L]) as having an estimated eventual total expenditure for Research, Development, Test and Evaluation (RDT&E) of more than $365 million in fiscal year (FY) 2000 constant dollars or, for procurement, of more than $2.19 billion in FY 2000 constant dollars (Defense Acquisition University, 2012a).

Information about cost and schedule performance for MDAPs is provided to DoD using Earned Value Management (EVM). EVM is an integrated management approach that uses schedule, cost, and scope of work goals and measures progress towards achievement of these goals (Performance Assessments and Root Cause Analyses, 2013). It provides program management offices (PMOs) with information to measure progress against established baselines and is required for all MDAPs.

This paper employs unique and rigorous statistical methodology to help program managers and their overseers understand and quantify the risk to their programs based on key earned value metrics. It compares programs that were cancelled to programs with that had significant cost overruns but were not cancelled. We use survival analysis to investigate whether differences in key EV metrics reported for cancelled programs and “troubled” but not cancelled programs can be used to model the probability of cancellation for major acquisition programs.

Specifically, we look at unclassified MDAPs cancelled since 2001 and similar programs that could be described as “troubled” but not cancelled in the same period of time. MDAPs were chosen because they are statutorily required to report EV data. We use the EV data reported in the Defense Acquisition Executive Summaries (DAES) on the government’s Defense Acquisition Management Information Retrieval (DAMIR) website.

Literature Review

Most of the studies that have examined why MDAPs fail point to cost overruns as the primary cause. Reasons cited include (1) excessively low initial cost estimates (Government Accountability Office, 2009; Sipple, White, & Greiner, 2004), (2) expectation of cost overrun sharing causing firms to bid below cost estimate (Chen & Smith, 2001), (3) excessively low cost overrun estimates (Christensen, 1994), (4) technological immaturity (Dubos, Saleh, & Braun, 2007; Tyson, Harmon, & Utech, 1994), (5) unstable requirements (Augustine, 1997), and (6) overly optimistic schedules (Augustine 1997; Berteau et al., 2011).

Charette (2008) pointed out that defense acquisitions problems have existed for decades, but the economic scope has changed. To put the scope of defense spending in context, the DoD's 2013 portfolio of 80 MDAPs has a total estimated cost of $1.5 trillion (Government Accountability Office, 2014); Berteau et al. (2011) investigated the root cause of cost and schedule overruns and found that inaccurate cost estimates are associated with 40% of the accumulated cost overruns.

Many authors advocate the use of EVM as a tool to help program managers and decision makers monitor early signs of cost growth (see, for example, Kerzner, 2009 and Webb, 2003). Abba (1997) made it clear that the U.S. government and countries across the world have validated EVM as a highly effective program management tool. Christensen (1999) noted that EV provides program managers and contractors valuable insight into the cost and schedule status of the project and concluded through multiple studies that the estimate at completion (EAC) is one of the most critical values reported to PMs.

Extensive research and experience have convinced both Congress and USD(AT&L) to conclude that EVM is a highly effective program management tool (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2011; Weapon Systems Acquisition Reform Act, 2009). The Weapon Systems Acquisition Reform Act of 2009 created the Director, Performance Assessment and Root Cause Analysis (PARCA) (Weapon Systems Acquisition Reform Act, 2009). USD AT&L has made PARCA responsible for EVM performance, oversight, and governance and for leading EVM improvements across the DoD (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2011).

Numerous factors are responsible for program cancellation. While many programs are troubled, not all of them are cancelled. This paper investigates whether there are significant differences in Earned Value metrics between cancelled and non-cancelled programs, and whether these metrics can help predict the ultimate cancellation and timing of cancellation of programs. This paper hypothesizes that cancelled programs would have more unfavorable cumulative cost and schedule variances, greater cost growth in the estimate at completion (EAC), and more disparity between the contractor and program manager cost estimates.

Earned Value Management

Earned Value Management is a widely accepted industry best practice that is used commercially and in the DoD to manage programs. It is an integrated management approach that uses schedule, cost, and scope of work goals and measures progress towards achievement of these goals (Performance Assessments and Root Cause Analyses, 2013). It is a critical tool for engineering management and oversight of acquisition (Defense Acquisition University, 2012a).

In simplest terms, EVM is a procedure for understanding, assessing, and quantifying what a contractor is achieving with contract dollars and to predict future performance. It works by establishing an integrated baseline that is developed from the work defined in the work breakdown structure and its associated time-phased budget. As work is performed, its corresponding budget ("earned value") can be measured against the integrated baseline. Cost and schedule variances can be calculated and analyzed. These variances can help management determine if a project is ahead or behind schedule and above or below budget, and where to focus additional resources to remedy the problem.

EVM Statutes, Policy, and DoD Implementation

EVM evolved during the 1990s from service unique cost and schedule performance criteria called the Cost/Schedule Control System Criteria (C/SCSC) into a set of 32 industry-owned guidelines called the Earned Value Management System (EVMS; Defense Acquisition University, 2012b). The requirement for MDAPs to use EVM is stipulated in three laws:

- Government Performance and Results Act of 1993 (GPRA)
- Federal Acquisition Streamlining Act of 1994 Title V (FASA)
- Clinger–Cohen Act of 1996

These acts provide the legal basis for the policies implementing EVM. At the executive branch level, the primary policy document governing EVM is the Office of Management and Budget (OMB) Circular A-11, Part 7, *Capital Programming Guide*, which requires the use of EVM or some similar system "for risk and program management of capital asset acquisition" and "to establish cost, schedule, and performance goals for major acquisitions and then achieve on average, 90% of these goals" (Office of Management and Budget, 2006). The DoD, as an agency of the federal government, has issued its own directives—the DoDD 5000.01 (Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics

[OUSD(AT&L)], 2007) and DoDI 5000.02 (OUSD[AT&L], 2008)—to address the statutory and regulatory requirements of acquisition of all military systems. These documents along with the Federal Acquisitions Regulation (FARs) and the Defense Federal Acquisitions Regulation (DFARs) provide the explicit requirements[1] for use of EVM in DoD MDAPs.

The Weapon Systems Reform Act of 2009 created the PARCA and charged the organization with conducting and overseeing performance assessments and root cause analyses for MDAPs (Weapon System Acquisition Reform Act, 2009). PARCA's assessments evaluate the cost, schedule, and performance requirements relative to current metrics (Defense Acquisition University 2012a). Additionally, PARCA is the policy holder for EV; they are responsible for the implementation and use of EVM across the DoD and for evaluating the utility of performance metrics used to measure cost, schedule, and performance of MDAPs (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2011).

In a recent DoD memorandum entitled "Earned Value Management Systems Performance, Oversight, and Governance," the USD(AT&L) provided direction to improve the effectiveness of EV across the DoD. Specifically, he reemphasized that EVM must be applied in a disciplined manner and that the data provided by EVM must be accurate, reliable and timely (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2011). The Defense Contract Management Agency's (DCMA) is responsible for EVM System compliance within the DoD. (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2011). In this role, DCMA conducts EVMS reviews of all MDAPs to ensure compliance of EV standards. The DCMA's Earned Value Management Implementation Guide (EVMIG) is the DoD's principle guidance document for EV.

EVM Reporting Requirements

The three primary vehicles for reporting EVM information are (1) Selected Acquisition Reports (SARs) to Congress,[2] (2) Defense Acquisition Executive Summary (DAES)[3] reports to senior level DoD decision-makers[4], and (3) the

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[1] Current DoD regulation and policy requires EVMS on cost or incentive contracts, subcontracts, and intra- government work agreements valued at or greater than 20 million in then-year dollars. For efforts exceeding 50 million in then-year dollars, the EVMS must be validated or accepted by the Defense Contract Management Agency (Defense Acquisition University 2012a).

[2] DoD must submit Selected Acquisition Reports (SARs) for all MDAPs annually. The frequency is increased should the MDAP fail to achieve certain performance thresholds contained in 10 USC § 2432—Selected Acquisition Reports. The SARs enable USD(AT&L) to meet statutory reporting requirements of all MDAPs to Congress (Defense Acquisition University 2012a).

[3] DAESs are submitted quarterly or monthly depending on whether certain performance thresholds are met. The DAES process enables the USD(AT&L) to fulfill statutory requirements to manage and oversee MDAPs. The goal of the DAES process is to facilitate communication between, and provide feedback to, key stakeholders in OSD, the Joint Staff, the Components, and Program Offices. It is

Integrated Program Management Report (IPMR)[5] to program managers. The goal of all of these reports is to facilitate communication between and provide feedback to key stakeholders in Congress, DoD, and the program offices. Typically, the EV data for MDAPs is reported monthly by the contractor in Contract Performance Reports (formats 1 through 5)[6] and in the IPMR for use by internal program management. A portion of this data is included monthly in the DAES database, quarterly in the formal DAES reports for use by DoD executives, and annually in the SARs for use by Congress.[7] The DAES reports are the source documents for EV data in this research.

Earned Value Terminology

The following definitions are necessary to understand the analysis and findings of this report. The definitions come from the *EVMIG* (Defense Contract Management Agency 2006) and the *Defense Acquisition University Glossary of Defense Acquisition and Terms* (DAU, 2009).[8]

- Budgeted Cost of Work Scheduled (BCWS or "planned value"): the sum of the budgets for all work scheduled to be accomplished with a given time period. Also called the Performance Measurement Baseline (PMB). $BCWS_{CUM}$ represents the cumulative BCWS at a certain point of the contract.
- Actual Cost of Work Performed (ACWP or "actual costs"): the costs actually incurred and recorded in accomplishing the work performed within a given time period. $ACWP_{CUM}$ represents the cumulative ACWP at a certain point of the contract.
- Budgeted Cost of Work Performed (BCWP or "earned value"): the value of completed work in terms of the work's assigned budget. BCWPCUM represents the cumulative BCWP at a certain point of the contract.

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important to note that the DAES is an internal management system meant to fulfill the needs of senior Department of Defense executives and is NOT for general public consumption (Defense Acquisition University 2012a).

[4] For the remainder of this study the general collective term "DoD executives," "DoD officials," or "senior level DoD decision makers" refers to USD(AT&L), Program Executive Office (PEO), the Milestone Decision Authority (MDA), and their associated staffs.

[5] The IPMR provides performance data that is used to identify problems early in the contract and forecast future contract performance (Defense Acquisition University, 2012a).

[6] Contract Performance Reports formats 1 through 5 are prepared by the contractor and are the primary means for reporting contract performance data. Their periodicity is typically monthly unless tailored for specific program.

[7] These periodicities are subject to change based on the program.

[8] Except where specific citation is made in this section, it is to be assumed that the definition came from one of these two sources.

- Schedule Variance (SV): the algebraic difference between earned value and the budget (SV = BCWP – BCWS). A positive value is a favorable condition (ahead of schedule) while a negative value is unfavorable (behind schedule).
- Schedule Variance Percentage (SV%): indicates how much ahead or behind schedule the project is in terms of percentage. A positive value is a favorable condition (percent ahead of schedule) while a negative value is unfavorable (percent behind schedule). It may be expressed as a value for aspecific period of time or for cumulative to date. SV% = (SV/BCWS) × 100 (TutorialsPoint, 2013).
- Schedule Performance Index (SPI): EV performance factor representing schedule efficiency. Calculated by dividing the Budgeted Cost for Work Performed (BCWP) by the Budgeted Cost for Work Scheduled (BCWS). This metric is one of the performance factors used in EAC calculations.
- Cost Variance (CV): the algebraic difference between earned value and actual cost (CV = BCWP – ACWP). A positive value indicates a favorable condition (under budget) and a negative value indicates an unfavorable condition (over budget).
- Cost Variance Percentage (CV%): indicates how much over or under budget the project is in terms of percentage. It indicates how much less or more money has been used to complete the work as planned in terms of percentage. A positive value is a favorable condition (percent under budget) while a negative value is unfavorable (percent over budget). It may be expressed as a value for a specific period of time or for cumulative to date. CV % = (CV/BCWP) × 100 (TutorialsPoint, 2013).
- Cost Performance Index (CPI): EV performance factor representing cost efficiency. Calculated by dividing the Budgeted Cost for Work Performed (BCWP) by the Actual Cost of Work Performed. This metric is one of the performance factors used in EAC calculations.
- Budget at Completion (BAC): The sum of all budgets established for the contract. BAC is a term that may also be applied to lower levels, such as the PMB or at the control account level.
- Estimate at Completion (EAC): the estimated total cost for all authorized work. Equal to the sum of actual costs to date (including all

allocable indirect costs), plus the estimated costs to completion (estimate to complete).

- Estimate to Complete (ETC): estimate of costs to complete all work from a given point in time to the end of the contract.
- Variance reset: when a contract's cost and/or schedule variances are reset to zero. This is done to improve managerial control over the work remaining on a contract.

When the BCWS, ACWP, and BCWP are obtained for a period, numerous additional EV metrics can be calculated including the SPI, SV%, CPI, CV%, ETC, and EAC, that are helpful to understand how the program is performing and to predict future performance based on the contract's past performance. Figure 1 illustrates the relationship of BCWS, ACWP, and BCWP for a project that is over-budget (ACWP>BCWP) and behind schedule (BCWP<BCWS).

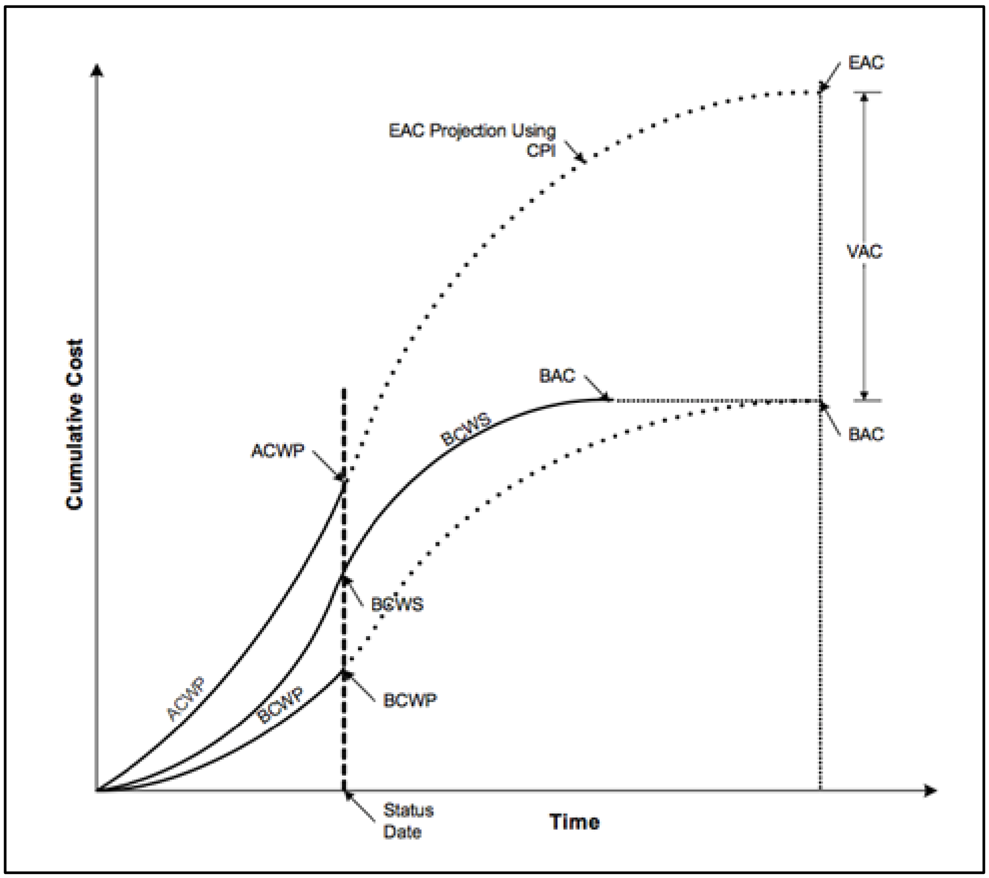

Figure 1. Graphical Depiction of EV Metrics for a Sample Project
(Vargas, 2009)

Calculating EAC

EAC is used to determine whether sufficient funds are available to cover the cost of the contract at completion. A common way for programs to calculate their EAC is by using formulas that use contractor's efficiency to date as measured by the CPI and SPI. Equation 1 illustrates that EAC is equal to the amount of money already spent on the contract or Actual Cost of Work Performed (ACWP) plus the amount of money it will take to complete the contract or the Estimate to Complete (ETC).

$$EAC = ACWP + ETC \tag{1}$$

The ACWP is an accounting figure reported monthly by the contractor in the CPRs. The ETC on the other hand is a forecast that can be calculated in numerous ways. The generic formula for calculating ETC is contained in Equation 2:

$$ETC = \frac{BAC - BCWP_{cum}}{Index} \tag{2}$$

Use of different performance indices results in different EAC forecasts. The two indices used primarily in the DoD (but not mandated) are cost performance index and composite index. Use of these indices results in the EAC_{CPI}, referred to as the "best case" EAC, and the $EAC_{Composite}$, which is called the "worst case" EAC ("DAU Gold Card–July 2012," 2012). These EAC values are reported as best and worst case EACs in the monthly DAES reports.

(1) Best Case EAC. The best case approach for calculating EAC involves using the current CPI of the program as the performance index. It assumes that the rest of the work remaining will be done according to the same cost efficiency recorded to date. Equation 3 depicts this relationship:

$$ETC_{CPI} = \frac{BAC - BCWP_{cum}}{CPI} \tag{3}$$

Substituting ETCCPI into Equation 1 results in the EAC_{CPI} expression in Equation 4.

$$EAC_{CPI} = ACWP + \frac{BAC - BCWP_{cum}}{CPI} \tag{4}$$

(2) Worst Case EAC. The worst case approach for calculating EAC involves using a composite performance index called the schedule cost index (SCI). Equation 5 shows the SCI expression.

$$SCI = SPI \times CPI \tag{5}$$

It assumes that the rest of the future work will follow the cost efficiency determined by the cost performance index (CPI), as well as the schedule efficiency determined by the scheduled performance index, generating the SCI. Equation 6 depicts this relationship:

$$ETC = \frac{BAC - BCWP_{cum}}{SCI} \tag{6}$$

This approach incorporates a tendency for programs to perform with CPIs and SPIs less than one (an indication of inefficiency). The product of two indices less than one has the compounding effect of raising the ETC more than using the CPI alone and consequently results in a higher EAC forecasts than the best case approach (see Equation 7).

$$EAC = ACWP + \frac{BAC - CDWP_{cum}}{SCI} \tag{7}$$

This study uses the earned value data reported in the Defense Acquisition Executive Summaries (DAES) on the government's Defense Acquisition Management Information Retrieval (DAMIR) website. DAMIR is a DoD initiative that streamlines acquisition management and oversight by leveraging numerous government databases into one central repository. The DAMIR databases used in this study were the Selected Acquisition Report (SAR) and the Services' Defense Acquisition Executive Summary (DAES). The DAES information contains some of the earned value data from the contract performance reports (DD Forms 2734/1–5, APR 2005) on a nearly monthly basis (not all EV data available in the CPR formats 1–5 is available for study). The SARs, in the most extreme case, are published three times per year, but more typically are published once annually and do not contain sufficient EV data for meaningful analysis in this study; however, the SAR is useful because it provides background information on each program and some explanations of program actions taken. The analysis reported in this thesis is based almost exclusively on the DAES data because of the frequency and quality of the EV data provided in DAES.

Program Selection

Since 2001, 12 MDAPs were cancelled before they could field an operational system (Harrison, 2011). These programs are listed in Table 1. Of the 12 cancelled programs, DAMIR earned value data was available for the eight programs annotated with an asterisk. These eight programs made up the cancelled programs sample of this study.

Table 1. Major Programs Cancelled Since 2001 Without Fielding Any Operational Systems
(adapted from Harrison, 2011)

Program Name	Sunk Cost (in billions of then-year dollars)	Source
Future Combat Systems (FCS)*	$18.1 B	September 2008 SAR
Comanche*	$7.9 B	December 2003 SAR
National Polar-orbiting Operational Environmental Satellite System (NPOESS)*	$5.8B	December 2009 SAR
VH-71 Presidential Helicopter*	$3.7B	September 2008 SAR
Expeditionary Fighting Vehicle (EFV)*	$3.3B	December 2010 SAR
Transformational SATCOM (TSAT)	$3.2B	Annual Budget Justification Document
Crusader*	$2.2B	December 2001 SAR
Advanced SEAL Delivery System (ASDS)	$0.6B	December 2005 SAR
Armed Reconnaissance Helicopter (ARH)*	$0.5B	September 2008 SAR
Aerial Common Sensor (ACS)*	$0.4B	December 2005 SAR
CG(x) Next Generation Cruiser	$0.2B	Annual Budget Justification Document
CSAR-X	$0.2 B	Annual Budget Justification Document
* Program used in this study		

Conceivably, more can be learned by comparing cancelled programs to fellow troubled programs than by comparison to on-track programs. One would expect the on-track programs to outperform the cancelled programs in most, if not all, earned value performance metrics. For this study we define a troubled program as a program that experienced consecutive unfavorable (negative) cumulative cost or schedule variance percentages greater than 10%. The selection criterion used for the comparison sample of the non-cancelled programs was three-fold: (1) the program was not cancelled, (2) earned value data was available for the major program, and (3) the program had to be troubled (as defined above).

Eight programs were selected from the 90 active programs in DAMIR for use as a control group. The programs are organized by service on DAMIR and then alphabetized within the service. The first row of each service was analyzed until eight programs that met the criteria were obtained. The first eight non-cancelled programs that met the criteria for troubled programs were chosen as the comparison sample of non-cancelled programs. These programs are listed Table 2.

Table 2. Comparison Sample of Troubled Non-Cancelled Major Programs
(Hodgson, 2013)

Program Name
H1 Upgrades
Joint Precision Approach and Landing System (JPALS)
CH-53K
Global Positioning System (GPS) III
Joint High Speed Vessel (JHSV)
PATRIOT Advanced Capability-3 (PAC-3) System
UH-60M
Joint Primary Aircraft Training System (JPATS)

This study hypothesized that the variables presented in Table 3 were the most likely differentiators of cancelled programs. In order to sufficiently analyze the hypotheses that these variables are different in cancelled programs, the following EV data was collected for each program:

- Cost variance percentage
- Schedule variance percentage
- Program Manager's Estimate at Completion (PM EAC)
- Contractor's Estimate at Completion
- Cost variance resets
- Schedule variance resets

Table 3. Variables Used in Analysis
(Hodgson. 2013)

Independent Variables
Cost Variance %
Cost Variance % at 25% completion
Cost Variance % at 50% completion
Schedule Variance %
Schedule Variance % at 25% completion
Schedule Variance % at 50% completion
Cost Growth (PM Estimate at Completion)
Cost Growth (PM Estimate at Completion) at 25% completion
Cost Growth (PM Estimate at Completion) at 50% completion
Cost Growth (Contractor Estimate at Completion)
Cost Growth (Contractor Estimate at Completion) at 25% completion
Cost Growth (Contractor Estimate at Completion) at 50% completion
Difference between Contractor and Program Manager's EAC
Difference between Contractor and Program Manager's EAC (0-25%)
Difference between Contractor and Program Manager's EAC (26-50%)
Difference between Contractor and Program Manager's EAC (51-75%)
Cost Variance Reset Frequency
Schedule Variance Reset Frequency

Contract Selection

All MDAPs have multiple contracts for each phase of the weapons systems development to handle different components and functions of systems acquisition. To maintain consistency between the samples, the largest Engineering and Manufacturing Development phase contract was used for each program. The available raw data for the variables for each program's largest EMD contract was extracted from the DAMIR site under the "Earned Value" tab using the "Cumulative" and "Summary" reports. While the DAES reports are missing some data, sufficient data existed for each program to conduct the analysis.

Cost Variance Percentage

The cost variance percentages were extracted from every CPR available in the DAES reports. Hodgson (2013) calculated the mean and medians presented in Table 4. We note that the overall median and mean CV% of non-cancelled programs is more unfavorable than the cancelled programs, which suggests that the non-cancelled programs are at least as "troubled" as their cancelled counterpart. Additionally, it suggests that CV% may not be a discriminating variable in a program's survival.

Table 4. CV Percentage Means and Medians of All Programs in Study
(Hodgson, 2013)

Cancelled program	Median CV%	Mean CV%	Std. Dev.	Non-cancelled program	Median CV%	Mean CV%	Std. Dev.
VH-71	0.12	-1.31	4.75	H1 Upgrades	-0.97	-2.66	7.16
FCS	0.58	0.63	1.38	JPALS	-6.28	-6.99	2.54
Comanche	-4.59	-4.31	3.45	CH-53K	-0.97	-1.50	4.02
NPOESS	-3.23	-4.58	4.90	GPS III	-5.62	-7.77	4.82
EFV	-6.93	-7.14	3.44	JHSV	-24.37	-24.64	13.09
Crusader	-1.94	-3.03	3.31	PAC-3	-5.54	-8.20	3.58
Armed Recon Helo	-4.58	-8.73	9.58	UH-60M	-5.47	-4.26	4.03
ACS	-1.94	-5.47	11.05	JPATS	-9.54	-8.13	12.50
Overall	-2.59	-4.24		Overall	-5.58	-8.02	

Hodgson (2013) used the same CV% data to examine the impact of the timing of cost variance percentages on program cancellation at the 25% and 50% completion points of the contract. For these two completion points, the average of the CV% within +/- 5% of the respective completion points was used for the CV% of each program. Tables 5 and 6 contain the CV% at these completion points for the sampled cancelled and non-cancelled programs (note: data for VH-71 and ACS were not available in DAES for these contract completion points).

Table 5. Cancelled Programs' CV Percentages at 25% and 50% Contract Completion Points
(Hodgson, 2013)

Cancelled program	CV% at 25% Contract Completion Point	CV% at 50% Contract Completion Point
VH-71		-13.01
FCS	1.12	-1.07
Comanche	-9.07	-4.96
NPOESS	1.11	-1.34
EFV	-13.19	-4.31
Crusader	-5.47	-6.16
Armed Recon Helo	-6.18	-21.37
ACS		
Median	-5.82	-4.96
Mean	-5.28	-7.46

Table 6. Non-Cancelled Programs' CV Percentages at 25% and 50% Contract Completion Points
(Hodgson, 2013)

Non-cancelled program	CV% at 25% Contract Completion Point	CV% at 50% Contract Completion Point
H1 Upgrades	-11.13	-9.78
JPALS	-4.30	-6.19
CH-53K	-1.23	-5.16
GPS III	-4.55	-12.49
JHSV	-7.78	-10.96
PAC-3	-6.33	-8.15
UH-60M	7.84	-1.51
JPATS	14.85	-11.29
Median	-4.42	-8.96
Mean	-1.58	-8.19

On average, cancelled programs in the study had more unfavorable CV% at the later stages of the contract; however, the median CV% appears to improve from 25% to 50% completion point. Table 6 shows that both the mean and median CV% becomes more unfavorable over time for the sampled non-cancelled programs. When comparing the mean CV% between cancelled and non-cancelled programs in Tables 5 and 6, cancelled programs maintain worse CV% at the 25% completion point, but slightly more favorable at the 50% completion point. These observations are not intuitive and make drawing any initial conclusions difficult.

Schedule Variance Percentage

The schedule variance percentages were extracted and compiled from every available CPR in the DAES reports. Hodgson (2013) calculated the mean and median for each program presented in Table 7. The mean SV percentage is slightly more unfavorable (more negative) in cancelled programs while the cancelled programs' median SV% is slightly less unfavorable.

Table 7. SV Percentage Means and Medians of All Programs in Study
(Hodgson, 2013)

Cancelled program	Median SV%	Mean SV%	Std. Dev.	Non-cancelled program	Median SV%	Mean SV%	Std. Dev.
VH-71	-1.94	-2.20	1.13	H1 Upgrades	-1.24	-2.67	2.74
FCS	-0.91	-0.94	0.45	JPALS	-2.31	-2.31	1.14
Comanche	-2.19	-2.10	1.75	CH-53K	-2.73	-3.16	2.59
NPOESS	-1.01	-4.44	6.79	GPS III	-3.41	-3.76	2.47
EFV	-3.71	-3.82	1.74	JHSV	-6.07	-6.05	2.47
Crusader	-0.98	-3.24	4.72	PAC-3	-1.85	-3.33	4.28
Armed Recon Helo	-19.78	-16.30	11.89	UH-60M	-7.86	-8.70	4.35
ACS	-5.86	-9.93	10.44	JPATS	-6.23	-6.19	5.69
Overall	-2.06	-5.37		Overall	-3.07	-4.52	

To analyze the timing of schedule variances and their potential effect on cancellation, Hodgson (2013) used the same SV% data. For the 25% and 50% completion points of the contract, the average of the SV% within +/- 5% of these completion points was used for the SV% of each program. Tables 8 and 9 contain the SV% at these completion points for the sampled cancelled and non-cancelled program.

Table 8. Cancelled Programs' SV Percentages at 25% and 50% Contract Completion Points
(Hodgson, 2013)

Cancelled program	SV% at 25% Contract Completion Point	SV% at 50% Contract Completion Point
VH-71		
FCS	-0.93	-0.93
Comanche	-4.20	
NPOESS	-5.56	-0.36
EFV	-6.80	-4.44
Crusader	-10.51	-11.39
Armed Recon Helo	-30.98	-20.71
ACS		
Median	-6.18	-4.44
Mean	-9.83	-7.56

Table 9. Non-Cancelled Programs' SV Percentages at 25% and 50% Contract Completion Points
(Hodgson, 2013)

Non-cancelled program	SV% at 25% Contract Completion Point	SV% at 50% Contract Completion Point
H1 Upgrades	-3.68	-3.08
JPALS	-3.31	-3.41
CH-53K	-1.52	-0.55
GPS III	-1.72	-6.03
JHSV	-8.99	-5.49
PAC-3	-16.13	-5.32
UH-60M	-25.63	-7.22
JPATS	-6.10	-6.77
Median	-4.89	-5.41
Mean	-8.38	-4.73

Table 8 suggests that on average cancelled programs have more favorable SV% at the later stages of the contract. Table 9 shows that while the mean SV% seems to improve over time, the median SV% becomes more unfavorable for the sampled non-cancelled programs. When comparing the mean and median SV% between cancelled and non-cancelled programs in Tables 9 and 10, cancelled programs maintain worse SV% at the 25% completion point. There is conflicting evidence between the mean and median SV% at the 50% point. Again, these general observations based on very small sample sizes make drawing initial conclusions challenging.

Cost Growth

To analyze cost growth as a potential discriminating variable, Hodgson (2013) recorded the program manager estimate at completion and contractor EACs for every CPR. Initially the cumulative cost growth, that is, the difference between the EAC at the beginning of the contract and the current EAC would seem the logical metric. However, due to changes in the program baseline ("re-baselining") during the course of the contract, the cumulative cost growth did not prove a consistent measure from program to program. When a program experiences significant cost growth or schedule delays, it is not uncommon for the program manager to request that it be "re-baselined." This gives the program a fresh start, and leads to a new "beginning" EAC. One possible way to handle the effect of re-baselining is to consider the re-baselined program a new program. This method was discarded because it was difficult to determine in some cases when or if a program had been re-baselined (and in some cases the EAC would go down without any evidence of re-baselining).

Alternatively, it is possible to ignore the re-baselined EAC and continue to calculate the difference between the original EAC and the current EAC. Doing so is problematic however, as it fails to recognize that some programs are re-baselined due to changes in scope or requirements, so that the observed cost growth is not indicative of program health, but merely a reflection of legitimate changes in program scope. Since the objective of this research was to find variables that may predict program cancellation, measuring the difference between the original EAC and the new EAC could be misleading.

To address the difficulties mentioned above, a cost growth metric was constructed by Hodgson (2013) to facilitate comparison of programs. The purpose of the metric is to measure the cumulative effect of marginal changes in the EAC. This metric has the advantage that it is less distorted by re-baselining yet still captures the overall effect of increases in the EAC from the beginning of the program to the current period. The metric for both PM EAC and contractor EAC was calculated using Equation 8:

$$EAC\ Growth\%_{present} = EAC\ Growth\%_{past} + \frac{EAC_{present} - EAC_{past}}{EAC_{past}} \qquad (8)$$

This constructed metric provides a conservative estimate of the cost growth experienced by a program, while eliminating the problems caused by re-baselining. This metric is hereafter referred to as “cost growth.” Note that the cumulative cost growth percentage (computed by taking the difference between the current EAC and the original EAC and dividing the difference by the original EAC) will always be higher than the “cost growth” metric.

For the 25% and 50% contract completion points, the average cost growths within +/- 5% of 25% and 50% completion points, respectively, were computed by Hodgson (2013) and used for the cost growth of each program. The total cost growths and cost growths at 25% and 50% completion points were calculated for all programs in the study and are presented in Tables 10 through 13. Where data is missing, it is because it was unavailable in DAES.

Table 10. Cost Growth for Cancelled Programs (PM EAC)
(Hodgson, 2013)

Cancelled program	Total Cost Growth (PMEAC)	at 25% Contract Completion Point	at 50% Contract Completion Point
VH-71	-36.64%		
FCS	55.28%	41.11%	47.23%
Comanche	93.48%	55.81%	
NPOESS	113.52%	25.13%	88.25%
EFV	86.31%	6.16%	23.15%
Crusader	399.29%	337.04%	258.43%
Armed Recon Helo	151.21%	-0.51%	23.92%
ACS	22.31%		
Median	89.90%	33.12%	47.23%
Mean	110.60%	77.46%	88.19%

Table 11. Cost Growth for Non-Cancelled Programs (PM EAC)
(Hodgson, 2013)

Non-cancelled program	Total Cost Growth (PMEAC)	at 25% Contract Completion Point	at 50% Contract Completion Point
H1 Upgrades	109.49%	20.99%	45.93%
JPALS	20.00%	0.72%	2.86%
CH-53K	33.03%	0.00%	0.01%
GPS III	-2.01%	0.00%	-0.04%
JHSV	27.17%	2.74%	2.74%
PAC-3	67.63%	-4.88%	30.01%
UH-60M	83.12%	0.00%	70.81%
JPATS	58.51%	30.62%	66.56%
Median	45.77%	0.36%	16.43%
Mean	49.62%	6.27%	27.36%

Table 12. Cost Growth for Cancelled Programs (Contractor EAC)
(Hodgson, 2013)

Cancelled program	Total Cost Growth (Contractor EAC)	at 25% Contract Completion Point	at 50% Contract Completion Point
VH-71	20.04%		
FCS	55.30%	41.28%	50.04%
Comanche	98.81%	55.96%	
NPOESS	118.13%	24.02%	92.87%
EFV	84.54%	3.08%	27.86%
Crusader	393.44%	329.59%	338.79%
Armed Recon Helo	143.95%	-0.51%	52.83%
ACS	21.60%		
Median	91.68%	32.65%	52.83%
Mean	116.98%	75.57%	112.48%

Table 13. Cost Growth for Non-Cancelled Programs (Contractor EAC)

Non-cancelled program	Total Cost Growth (Contractor EAC)	at 25% Contract Completion Point	at 50% Contract Completion Point
H1 Upgrades	106.23%	19.49%	43.27%
JPALS	24.28%	2.45%	9.74%
CH-53K	37.65%	21.83%	32.14%
GPS III	0.60%	3.92%	17.82%
JHSV	27.05%	0.00%	2.06%
PAC-3	66.71%	-9.20%	22.86%
UH-60M	5.00%	0.00%	0.00%
JPATS	56.99%	5.13%	102.77%
Median	32.35%	3.19%	20.34%
Mean	40.56%	5.45%	28.83%

We can make some general observations from Tables 11 through 14. As expected, regardless of estimate type, the cost growth metric increases as programs progress. In addition, cost growth appears to be significantly higher in cancelled programs than in the non-cancelled counterparts. Moreover, the data appears to show that the there are fewer differences in program manager and contractor estimates in non-cancelled programs and that the greatest difference in estimates appears to occur at the 50% completion point of cancelled programs.

Differences in the Estimates at Completion

To investigate the potential effect the differences between the two estimates may have on cancellation, Hodgson (2013) first normalized the differences. The calculation to normalize the differences is based on the PM EAC and Contractor EAC values reported in each program's CPR in the DAES report. To normalize the differences for program comparison, the magnitude of the difference is divided by its corresponding program manager's estimate at completion for each program. For example, if the program manager's estimate at completion was $5,000 and the contractor's estimate at completion was $4,500 at a certain contract completion percentage, the difference between the two estimates is $500 and the normalized difference is $500/$5,000 or 0.10.

The data were organized into the following four periods to study the potential effects of the timing of the difference: (1) total normalized difference, (2) normalized difference from 0–25% contract completion point, (3) normalized difference from 26–50% contract completion point, and (4) normalized difference from 51–75% contract completion point. The median total EAC difference and averages of the three periods' EACs were calculated for each program in the study and are presented in Tables 14 and 15. The cells of the table that remain empty did not have sufficient data for analysis.

Table 14. Normalized Differences in Program Manager and Contractor EAC for Cancelled Programs
(Hodgson, 2013)

Cancelled program	Total EAC Difference*	EAC Difference (from 0-25%)	EAC Difference (from 26-50%)	EAC Difference (from 51-76%)
VH-71	38.31%			32.16%
FCS	0.00%	0.00%	0.00%	0.00%
Comanche	3.77%	4.99%	5.87%	
NPOESS	3.07%	18.69%	12.01%	3.13%
EFV SDD1	1.39%	1.16%	2.51%	2.04%
Crusader	1.28%		1.19%	1.49%
Armed Recon Helo	0.00%	0.00%	0.61%	2.68%
ACS	2.80%	5.19%		
Median	2.09%	3.08%	1.85%	2.36%
Mean	6.33%	5.01%	3.70%	6.92%
* Median EAC Difference				

Table 15. Normalized Differences in Program Manager and Contractor EAC for Non-Cancelled Programs
(Hodgson, 2013)

Non-cancelled program	Total EAC Difference*	EAC Difference (from 0-25%)	EAC Difference (from 26-50%)	EAC Difference (from 51-76%)
H1 Upgrades	0.77%	0.15%	1.52%	5.34%
JPALS	2.34%	3.00%	4.49%	3.11%
CH-53K	7.24%	6.46%	9.36%	6.31%
GPS III	8.82%	9.67%	9.55%	9.11%
JHSV	0.13%	0.00%	4.51%	1.02%
PAC-3	0.87%	0.00%	1.23%	4.63%
UH-60M	4.67%	0.00%	1.16%	6.34%
JPATS	5.37%	8.37%	11.56%	2.31%
Median	3.51%	1.57%	4.50%	4.98%
Mean	3.78%	3.45%	5.42%	4.77%
* Median EAC Difference				

The medians and means tell two different stories in this case. A comparison of the medians reveals that the EAC difference is worse (greater) in non-cancelled programs for all but the 0–25% group, whereas, a comparison of the means suggests that cancelled programs have worse EAC differences in all groups but the 26–50%. Conclusions cannot be made from simply comparing the means and medians in this way, but it is useful in providing a general sense of how the difference in estimates may effect cancellation.

Methodology

To understand how cancelled programs, and non-cancelled but troubled programs differ from each other, we examine differences in earned value metrics. The challenge we face is that the small number of programs limits our sample size and our ability to use parametric methods. Using methodology that works for small sample sizes, Hodgson (2013) examined whether cancelled and non-cancelled programs are different on average in terms of their earned value metrics. We look at whether we can use earned value metrics to predict the probability of failure, and we look at whether over time, the risk of program failure changes.

Building on the differences observed in Mann-Whitney by Hodgson (2013), we want to estimate the probability of program cancellation based on earned value metrics. In most applications where the dependent variable is binary, maximum likelihood techniques such as Logit or Probit are used instead of OLS because they constrain the outcome probability to be less than 100% and more than 0%, where linear models can estimate probabilities outside these bounds. Probit and logit better handle dichotomous variables by using an iterative optimization routine to maximize a log likelihood function (Kennedy, 2003).

Unfortunately, maximum likelihood estimators like logit are generally unreliable when samples are small (Statistical Consulting Group, 2014). Maximum likelihood estimators suffers from bias when sample sizes are small or the ratio of 1s to 0s is skewed, a tendency exacerbated by the inclusion of many explanatory variables (Long, 1997). Exact logit is the prescribed solution in the case of small sample sizes, where traditional maximum likelihood estimation is undesirable as it produces inconsistent results (Hart & Clark, 1999). As we only have 16 observations, in addition to exact logistic we limit the inclusion of explanatory variables to include them one at time. Exact logistic returns the log odds of the outcome variable as a linear model of the predictor variables. We can interpret the coefficients as odds ratios meaning the coefficient is essentially a multiplier.

Secondly, we consider program survival using parametric survival analysis. We can think of program survival as sick patient survival over time after treatment. In this analysis we look at time in four periods—between 0–25% complete, 25%–50% complete, 50%–75% complete, and 75–100% complete to evaluate the impact of program development and earned value metrics over the program's development on the probability of cancellation. We model this parametrically with proportional hazard functions using an exponential model, which keeps time neutral.

We cannot use all variables together in the same models—schedule variance is highly correlated with cost variance, and estimate at completion growth of both contractors and program managers are too highly correlated with each other. Schedule variance is also too highly correlated with both EAC growths figures. Thus we break down our analysis into single variable models and then add cost variance to the EAC at completion variance models as a control

Results

Exact Logistics

Using exact logistic we measured the impact of seven EV metrics on the probability of troubled program cancellation testing each variable separately. The results are shown in Table 16. We show the coefficients for each model along with the standard deviation (in parentheses). Asterisks indicate significant results. The model score is a chi-squared score and the p value beneath it gives the overall significance of the model. Not surprisingly, as these are univariate models—the models with significant p are also the models with a significant model score.

Table 16. Exact Logistics Models for EV Metrics

	MODELS						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cost Variance	1.33*						
	(0.084)						
Cost Variance Reset Frequency		1.64					
		(0.73)					
Schedule Variance			0.973				
			(0.919)				
Schedule Variance Reset Freq				0.827			
				(1)			
Cost Growth PM EAC					2.68		
					(0.23)		
Cost Growth Contractor EAC						8.74*	
						(0.05)	
Contractor and PM EAC Diff							26.7
							(0.92)
observations	16	16	16	16	16	16	16
model score	2.4	0.48	0.06	0.09	1.56	2.65	0.3
p value	0.08	0.73	0.92	1	0.23	0.05	0.92

The coefficients for exact logit give a multiplier for the likelihood of program cancellation. We find that the cost growth based on the contractor's estimate is a significant indicator of program cancellation. Programs with one hundred percent cost growth are 8.74 times more likely to experience program cancellation. In other words, a 10% cost growth increases the chances of a program being cancelled by 73%. We also find that programs with high but positive cost variance are more likely to suffer program cancellation. Specifically, programs with 100% positive cost variance are 33% more likely to experience a cancellation. Both of these results are statistically significant at the 10% level.

Hazard Function

We next use Hazard functions to look at the risks to programs over their maturity from their EV metrics. The results are shown in Table 17.

Table 17. Hazard Functions for EV Metrics

	Models					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES						
Schedule Variance	0.0222					
	(0.0614)					
Cost Variance		0.0472			0.0493	0.0514
		(0.0410)			(0.0462)	(0.0458)
Cost Growth Contractor EAC			0.540**		0.535**	
			(0.256)		(0.255)	
Cost Growth PM EAC				0.511*		0.502*
				(0.266)		(0.265)
Constant	-1.718***	-1.598***	-2.179***	-2.230***	-1.941***	-1.976***
	(0.459)	(0.378)	(0.463)	(0.460)	(0.477)	(0.476)
Observations	50	50	46	50	46	50

Looking at the hazard functions, we find that cost and schedule variance are less important predictors than cost growth based on contractor or program manager estimates at completion which are significant at 5% and 10% levels respectively. To understand the impact of any factor on the hazard of program cancellation we exponentiate the coefficient which gives us a hazard ratio or multiplier. Here a 100 percentage point change in estimate at completion leads to a 65% to 75% increase in the likelihood of cancellation, or a 10% increase in the estimate would lead to a 6.5% to 7.5% increase in the likelihood of program cancellation with or without controlling for cost variance.

Conclusions

This research investigated whether there are differences in the key earned value metrics of cancelled and troubled non- cancelled programs, and whether these metrics can help predict the likelihood of program cancellation. Hodgson (2013) found that cancelled and non-cancelled programs do vary across their EVM characteristics. We expanded his work by examining the data with two more sophisticated techniques, exact logit and hazard analysis.

Our most significant finding across models is that when there is high cost growth in the EAC reported by the contractor, programs run far larger risks of cancellation. This may be because contractors have more insight into their cost structures and are better able to predict EAC, or it may be that program managers are reluctant to increase their EAC given the consequences they would face under the Nunn–McCurdy Act.[9] We find less robust evidence that increases in PM estimates and high cost variance also can drive risk of program cancellation.

We note that the cost growth metric (Equation 8) was developed by Hodgson (2013) and is not reported as EVM data. Given the significance of this metric in predicting program cancellation, we recommend program managers consider using this metric to monitor expected cost growth.

[9] The Nunn–McCurdy Act (10 U.S.C. § 2433) requires that DoD report to Congress whenever an MDAP experiences cost overruns that exceed certain thresholds. The purpose of the act is to help control cost growth in major defense systems by holding the appropriate Pentagon officials and defense contractors publicly accountable and responsible for managing costs.

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