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Transaction Costs and Cost Breaches in Major Defense Acquisition Programs

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Abstract

Transaction costs associated with program management are a component of acquisition cost that is often overlooked when estimating the total costs of a DoD program. This research explores the possibility that transaction costs may be related to major defense acquisition program (MDAP) cost breaches. We examine the two questions: (1) Is there a relation between MDAP transaction costs and cost breaches? and (2) Are cost breaches related to the amount, or percentage of total costs, spent on MDAP transaction costs? Using systems engineering and program management (SE/PM) costs as a proxy for transaction costs, we analyze the level of SE/PM expenditures in MDAPs to determine whether a relationship exists between transaction costs and cost breaches. Contract type and program maturity are also considered. Logistic regression models are used to examine the occurrence of program breaches in MDAPs. We find a positive relationship that is significant at the 5% (p = .05) level between the likelihood of a cost breach occurring and estimate at completion SE/PM cost ratio. On average, for a 1% increase in the SE/PM cost ratio, there is a corresponding 0.8% increase in the likelihood that a cost breach will occur. When maturity and contract type are included in the model, the average effect of the SE/PM cost ratio on the likelihood of a cost breach increases to 1% for cost-plus contracts at a significance level of 10% (p = .10). Although SE/PM cost ratio and cost breaches are shown to be related, it cannot be assumed that transaction costs are a causal factor for cost breaches.

Keywords: transaction costs, cost breach, major defense acquisition program, MDAP, systems engineering, program management, SE/PM cost ratio

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Transaction Costs and Cost Breaches in Major Defense Acquisition Programs

Introduction

The Department of Defense (DoD) uses the acquisition process to provide support and services for military operations. Weapon system acquisitions fall into three categories: Acquisition Category (ACAT) I, II, or III. ACAT I programs are those estimated to have expenditures greater than $365 million in research, development, technology, and engineering (RDT&E) or $2.19 billion in procurement, including all planned increments, in fiscal year (FY) 2000 constant dollars; in addition, programs may be designated as ACAT I by the under secretary of defense for acquisition, technology and logistics (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics [OUSD(AT&L)], Enclosure 3, Table 1). ACAT I programs are commonly referred to as major defense acquisition programs (MDAPs). Acquisition programs that do not meet the requirements for ACAT I are categorized as ACAT II or III programs. This report focuses on cost overruns for ACAT I programs.

A 2011 Government Accountability Office (GAO) report stated that "inaccurate cost estimates are responsible for the strongest correlation with net cost growth changes and are associated with 40 percent of the accumulated cost overruns" (p. 2). A 2007 RAND study on the cost growth in DoD weapons systems analyzed total program and procurement cost growth for 46 programs. The study determined that the cost growth ratio across all programs was 1.46 more than the cost estimate for Milestone B (program initiation; Younossi et al, 2007, p. xvi). According to the GAO, active MDAPs in FY 2011 collectively experienced a cost growth of $74.4 billion. The size and frequency of cost overruns in MDAPs suggest that there may be a component of acquisition cost that is not fully considered in MDAP cost estimates.

This report examines transaction costs, a component of system cost that is not explicitly included in most cost estimates. Is there a relationship between transaction costs and cost overruns in MDAPs? A better understanding of this relationship could help explain the differences between actual and estimated costs in MDAPs, perhaps leading to more complete cost estimates and possibly improved forecasting of cost breaches.

To measure transaction costs, we use a proxy measure first suggested by Angelis, Dillard, Franck, and Melese in 2008 that includes systems engineering (SE) and program management (PM) costs reported by MDAP contractors. According to

MIL-STD-881C (DoD, 2011), *system engineering* is defined as “the technical and management efforts of directing and controlling a totally integrated engineering effort of a system or program” (p. 222), and *program management* is defined as “the business and administrative planning, organizing, directing, coordinating, controlling, and approval actions designated to accomplish overall program objectives, which are not associated with specific hardware elements and are not included in systems engineering” (p. 222).

A SE/PM ratio based on the total program cost is developed to allow comparison of transaction costs across different programs. For purposes of this study, a *cost overrun* is defined as a cost breach of 10% or greater as reported by the MDAP program manager. A cost breach occurs when program costs exceed the approved acquisition program baseline (APB).[1] It seems reasonable to assume that the SE/PM costs may increase as program managers respond to actual or anticipated increases in program costs. Can cost breaches be related to the amount of SE/PM cost in a program?

Department of Defense (DoD) Cost Estimation

Cost estimates provide the DoD, Congress, and program managers with the information needed to determine whether a program is affordable and cost-effective. A *good* cost estimate should provide a reasonable prediction of the costs associated with a program throughout its life cycle, to include research and development (R&D) costs, production and construction costs, operation and support costs, and retirement and disposal costs. Acquisition costs, which consist of the R&D costs and the production and construction costs, compose a significant portion of a program’s estimated life-cycle cost.

The Director, Cost Assessment and Program Evaluation (CAPE), within the Office of the Secretary of Defense (OSD) is responsible for overseeing DoD cost estimation policy and procedures and providing independent life-cycle cost estimates for MDAPs (Weapon Systems Acquisition Reform Act of 2009). A primary responsibility of the CAPE is to provide independent analytic advice to the secretary of defense on the cost-effectiveness of defense systems (Cost Assessment and Program Evaluation [CAPE], 2013a). *DoD Cost Analysis Guidance and Procedures* (DoD 5000.4-M) provides cost-estimating guidance for DoD programs (DoD, 1992). In addition to the independent life-cycle cost estimate, DoD Instruction 5000.2 and DoD 5000.2-M require that a program office estimate and DoD component cost analysis estimate also be performed (DoD, 1992, p. 8). These three estimates are

[1] The APB is the baseline that reflects the threshold and objective values for the minimum number of cost, schedule, and performance attributes that describe the program over its life cycle (Defense Acquisition University [DAU], 2011b).

based on the MDAP cost analysis requirements description (CARD), a document which provides an overview of the technical and programmatic features of an acquisition program. In accordance with DoDI 5000.02, Enclosure 4, Table 2, independent cost estimates for ACAT ID[2] programs must be provided by the Office of the Secretary of Defense Cost Analysis Improvement Group before entering the Technology Development phase (Milestone A), the Engineering and Manufacturing Development phase (Milestone B, or program initiation), the Production and Deployment phase (Milestone C), and the full-rate production decision review (OUSD[AT&L], 2008).

A 1972 GAO report titled *Theory and Practice of Cost Estimating for Major Acquisitions* noted that cost-estimating techniques across DoD programs were inconsistent in their level of detail and that the cost-estimating techniques used for DoD programs varied widely. The GAO believed these practices resulted in inaccurate, typically low, cost estimates which often led to cost overruns. Some of the problems noted by the GAO include the following:

- known costs had been excluded without adequate or valid justification;
- historical cost data used for computing estimates were sometimes invalid, unreliable, or unrepresentative;
- understanding the proper use of the estimates was hindered because the estimates were too low;
- readily retrievable cost data that could serve in computing cost estimates for new weapon systems were generally lacking; and
- organized and systematic efforts were not made to gather actual cost information to achieve comparability between data collected on various weapon systems or to see whether the cost data the contractors reported were accurate and consistent.

In response to these findings, the GAO developed a list of basic characteristics of credible cost estimates, which are still applicable today. Unfortunately, GAO reports continue to provide evidence of poor cost estimating in DoD programs (see, for example, GAO, 2011, 2012, and 2013). In 2009, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs* was published in an effort to help government managers improve acquisition cost estimates (GAO, 2009b).

Cost estimates are expected to change and presumably become more accurate as a program matures. These refinements are largely due to lessening

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[2] The "D" refers to the Defense Acquisition Board (DAB), which advises the USD(AT&L) at major decision points.

uncertainty surrounding the specific program requirements and technology and more certainty regarding actual costs as expenditures are incurred. To ensure a realistic cost estimate, it is important that the estimate be periodically reevaluated and updated to account for requirements changes, actual cost expenditures, and the latest version of the program's schedule (GAO, 2009b, p. 37). The GAO stated that

> relying on a standard process that emphasizes pinning down the technical scope of the work, communicating the basis on which the estimate is built, identifying the quality of the data, determining the level of risk, and thoroughly documenting the effort should result in cost estimates that are defensible, consistent, and trustworthy. (GAO, 2009b, p. 12)

Cost Breaches in Major Defense Acquisition Programs

Controlling cost growth for MDAPs has been problematic in the DoD for many years (Arena, Leonard, Murray, & Younossi, 2006). Selected Acquisition Reports (SARs) were introduced in 1967 to better monitor MDAP performance. The information found in the SAR provides the DoD and Congress a summary of the MDAP's ability to meet cost, performance, and schedule objectives agreed upon by the program manager and defense acquisition executive. If a program exceeds an established cost threshold, a breach has occurred and the program manager must provide an explanation in the SAR (which is generally brief) of how or why the cost breach occurred. The default threshold value for a cost breach is 10% cost growth over the acquisition program baseline (usually the original cost estimate approved at program initiation). The various types of cost breaches and their cost appropriation categories are explained later in this section.

In 1981, Senator Samuel Nunn and Congressman David McCurdy introduced the Nunn–McCurdy Amendment (10 U.S.C. § 2433, 2006) in an effort to control MDAP cost growth by holding the DoD accountable to Congress for management of program costs. The Nunn–McCurdy Amendment became law with the FY 1983 Department of Defense Authorization Act (1982), which establishes consequences for MDAPs which exceed cost thresholds. These consequences include that the secretary of defense provide Congress with program cost estimates using original and current requirements, as well as certification to Congress that the unit costs are reasonable and that the management structure of the program is adequate to control future costs (GAO, 2009b, pp. 310–311).

Types of Cost Breaches in the DoD

There are six categories of appropriations where cost breaches often occur: average procurement unit cost (APUC); program acquisition unit cost (PAUC);

procurement; RDT&E; military construction (MILCON); and acquisition-related operations and maintenance (O&M). Each of these cost breach categories was included in the data set for this study. The following definitions are from the Defense Acquisition University (DAU) Glossary (DAU, 2011b) and the DAMIR SAR Data Entry Instructions (OUSD[AT&L], 2011).

AverageProcurement Unit Cost (APUC)

Average Procurement Unit Cost (APUC) is the unit cost that equals the program acquisition cost (the sum of all procurement funds) divided by the total number of fully configured end items to be procured. For unit cost reporting and APB breach purposes, the APUC is calculated in base-year dollars. Base-year dollars are calculated by using the currently approved APB.

Program Acquisition Unit Cost (PAUC)

Program Acquisition Unit Cost (PAUC) is the unit cost that equals the total program acquisition cost (including development, procurement and construction) divided by the program acquisition quantity (i.e., the total number of fully configured end items). For unit cost reporting and APB breach purposes, the PAUC is calculated in base-year dollars. Base-year dollars are calculated by using the currently approved APB.

Procurement

Procurement appropriations fund those acquisition programs that have been approved for production (to include low-rate initial production [LRIP] of acquisition objective quantities) and all costs integral and necessary to deliver a useful end item intended for operational use or inventory upon delivery (DAU, 2011b).

Research, Development, Testing, and Evaluation (RDT&E)

RDT&E appropriations fund the efforts performed by contractors and government activities required for the R&D of equipment, material, computer application software, and their test and evaluation (T&E) including initial operational test and evaluation (IOT&E) and live fire test and evaluation (LFT&E). RDT&E also funds the operation of dedicated R&D installation activities for the conduct of R&D programs (DAU, 2011b).

Military Construction (MILCON)

MILCON appropriations fund major projects such as bases, schools, missile storage facilities, maintenance facilities, medical/dental clinics, libraries, and military family housing (DAU, 2011b). Military construction costs include only those projects that directly support and are uniquely identified with the subject program (DAMIR, 2011).

Acquisition Operations and Maintenance (O&M)

Acquisition Operations and Maintenance (O&M) appropriations fund expenses such as civilian salaries, travel, minor construction projects, operating military forces, training and education, depot maintenance, stock funds, and base operations support (DAU, 2011b). Acquisition-related O&M costs may include acquisition costs which, in special cases, have been funded by O&M (DAMIR, 2011).

Measuring Cost Breaches in the DoD

A cost threshold breach is considered to occur when cost expenditures exceed the approved baseline cost estimate for an MDAP—also known as the APB. The initial APB cost estimate is established early in the acquisition phase when there may be a considerable amount of uncertainty about specific requirements and technology. In some cases that estimate should to be revised due changes in mission requirements, technology development, or other circumstances. This results in a rebaselining of the program, which must be officially approved by the milestone decision authority.[3] The initial APB is referred to as the original baseline, and for a rebaselined program, the revised APB is called the current baseline. If an MDAP has been officially rebaselined, cost breaches are measured relative to the current baseline.

Nunn–McCurdy legislation is the current federal law used to monitor and control MDAP cost growth. There have been changes to the Nunn–McCurdy Act over the years, most notably in FY 2006 and FY 2009. In 2006, the original baseline estimate was established as a threshold for measuring cost growth. This prevents a program from rebaselining simply to avoid a Nunn–McCurdy cost threshold breach. In 2009, Congress endorsed a requirement that any program with a critical breach (defined below) is presumed terminated unless that program has been certified by the Secretary of Defense.[4]

Nunn–McCurdy cost threshold breaches, or cost overruns, are based on original cost estimates for PAUC and APUC at project completion and in the case of a program which has rebaselined, cost threshold breaches are also based on the current (i.e., rebaselined) cost estimate for PAUC and APUC at project completion. For the purposes of this report, a cost breach is any cost breach reported in the SAR that is greater than or equal to 10% above the APB. The type of cost threshold breach and the APB baseline that it is compared against is shown in Table 1.

[3] More information about the rebaselining process can be found in DoD Instruction 5000.02, Enclosure 4, Table 6 (OUSD[AT&L], 2008).

[4] More information about MDAP certification requirements can be found in Public Law 111–23 (Weapon Systems Acquisition Reform Act of 2009, 2009); DoDI 5000.02 (OUSD[AT&L], 2008); and *Defense Acquisition Guidebook*, Chapter 10 (DAU, 2011a).

Table 1. **Nunn–McCurdy Cost Breach Thresholds**

	APB Breach (RDT&E, Procurement, MILCON, O&M)	Nunn–McCurdy Significant Breach (PAUC & APUC)	Nunn–McCurdy Critical Breach
Current Baseline Estimate	10%	+15%	+25%
Original Baseline Estimate	N/A	+30%	+50%

Figure 1 can be used to illustrate cost overrun calculations. The total allocated budget is the sum of all of the budgets for work on a contract plus the management reserve (an amount withheld by the program manager for risk management purposes). The budgeted cost of work performed (BCWP) represents the total amount budgeted for work packages that are open or completed at any given point in time. The budgeted cost of work scheduled (BCWS) represents the total amount budgeted for the work that was scheduled for completion at a given point in time. The BCWS line represents the contract's overall time-phased budget plan and will equal the program baseline or budget at completion (BAC) on the date all work is scheduled to finish (completion date). The actual cost of work performed (ACWP) is the sum of actual costs that have been incurred to accomplish the work performed as of a point in time.

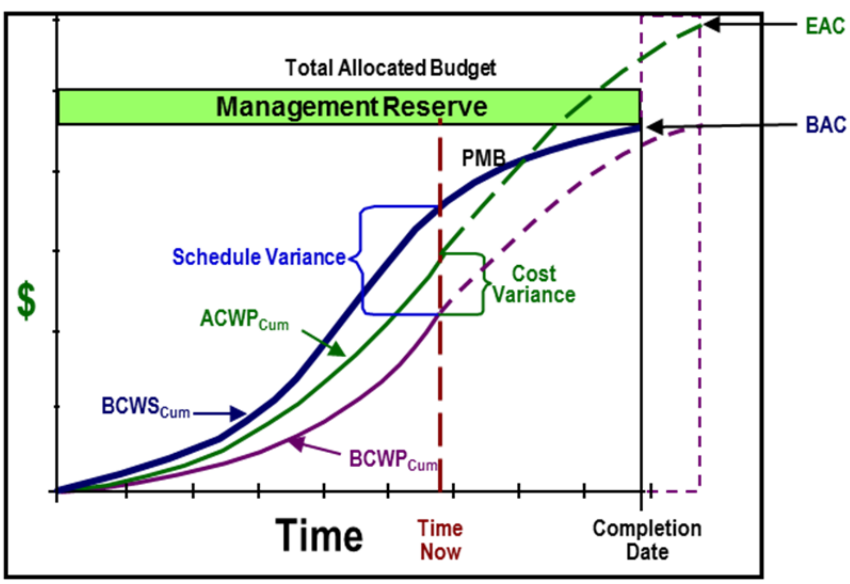

Figure 1. Earned Value Management
(DAU, 2014)

The estimate at completion (EAC) is the sum of the ACWP and the estimate to completion (ETC) for the remaining work. The ETC can be calculated using the cost performance index (CPI) and the schedule performance index (SPI). The CPI is calculated by dividing BCWP by ACWP and is a measure of cost efficiency. The SPI is calculated by dividing BCWP by BCWS and is a measure of schedule efficiency. The formula for calculating ETC is

$$ETC = (BAC - BCWP) / (CPI * SPI) \quad (1)$$

When the EAC, a cost estimate for the total cost of the contract, is higher than the BAC, the baseline cost estimate of the contract, a cost overrun is projected. To calculate the expected cost overrun the current cost estimate must be revised to incorporate actual costs (ACWP). This adjusted EAC is then compared to the BAC, the acquisition program baseline for the contract. The percentage of cost overrun projected can be calculated using the following equation:

$$\text{Projected \% Cost Overrun} = \left[\frac{EAC}{BAC} \times 100\right] - 100 \quad (2)$$

Figure 1 also illustrates the cost and schedule overruns for a contract or series of contracts at project completion. The actual completion date is often delayed when there are cost overruns.[5] A revised completion date is shown by the dashed line on the far right of the graph. At this revised completion date, the cost difference between ACWP (no longer EAC because work is complete) and BAC is determined, and this delta defines the final size of the cost overrun. The actual cost overrun calculation can be made using a similar formula:

$$\text{Actual \% Cost Overrun} = \left[\frac{ACWP}{BAC} \times 100\right] - 100 \quad (3)$$

Transaction Costs

Transaction costs are the costs associated with "source selection, periodic competition and renegotiation, contract negotiation and management, performance measuring and monitoring and dispute resolutions" (Angelis et al., 2008, p.3). Transaction costs are driven by the complexity and riskiness of the work to be accomplished. Thus, transaction costs represent a cost of doing business that may not be completely captured in standard work breakdown structure (WBS) estimates. There are three generally accepted categories of transaction costs: search and information costs; bargaining and decision costs; and policing and enforcement

[5] In many instances, contracts exhibit a relation between cost and schedule performance. For example, program managers may increase the man-hours allocation of a project in order to meet a schedule deadline. An increase in man-hours allocation, and particularly if the work effort qualifies as overtime pay, may cause project costs to increase.

costs (Johnson, 2005). To illustrate these cost categories, Biggs (2013) described the non-monetary exchanges which occur during the marketing and purchase of a home. The prospective homeowners are working with a realtor to find an acceptable home based on its physical location, size, and other intrinsic characteristics (search and information costs). The prospective homeowners will then negotiate between their realtor and the seller's realtor to determine a purchasing price for the home (bargaining and decision costs). Last, if the home was purchased using money that was borrowed from a mortgage lender, the mortgage company will ensure that the buyers are upholding their end of the agreement by paying the monthly mortgage bill (policing and enforcement costs). Although they are not often captured in the accounting records, the time and effort associated with these three types of transactions represent real costs to the organization.

In general, a program has two types of costs: production costs and transaction costs. Production costs are usually captured in the WBS, but transaction costs may not be adequately captured in the WBS. Because traditional cost estimates are based on the production costs found in the WBS, they do not explicitly include transaction costs (Angelis et al., 2008). Coordination costs include search and information costs; bargaining and decision costs; and policing and enforcement costs. These costs are affected by market competition (contestability), asset specificity, and the recurrence or frequency of a transaction. Asset specificity, a manufacturer's specialization in the production of a system or machine, may result in the government becoming reliant on a sole provider and may lead to opportunistic behavior by the manufacturer. Motivation costs are those costs which promote productive efforts and provide incentives to encourage investment, as well as those costs which deter unproductive bargaining and opportunistic behavior. Motivation costs are impacted by the complexity of the contract, the uncertainty or amount of risk that a contract presents, and the contract type. For more information about transaction costs see *Applying Insights from Transaction Cost Economics (TCE) to Improve DoD Cost Estimation* (Angelis, Dillard, Franck, & Melese, 2007).

Measuring Transaction Costs in the DoD

Transaction costs are difficult to measure because they are not easily identified and seldom captured in the accounting records. In previous research, Angelis et al. (2008) examined how transaction costs might be captured in the cost estimates of DoD acquisition programs. To test the hypothesis that the traditional WBS approach may overlook some important variables resulting in low initial cost estimates, we should compare cost estimates for systems that included significant transaction costs with those of systems that did not include significant transaction costs. The first problem is to find a way to measure transaction costs in acquisition programs. Angelis et al. (2008) identified a number of issues with DoD program management cost data reported for major weapon systems and found that program office data collected for major weapon systems is not well suited for developing a cost model that includes transaction cost variables. As an alternate approach, they explored using contractor program management data from Cost Data Summary Reports (DD form 1921) and suggested using the Systems Engineering/Program Management (SE/PM) category as a proxy for transaction costs.

The SE/PM cost seems an appropriate proxy for transaction costs because program management costs and transaction costs are both defined, in part, as costs associated with contract management, performance measurement, and oversight activities. Due to differences in program accounting practices and varying interpretations for classifying costs as Systems Engineering or Program Management, it is prudent to collect the sum of SE and PM costs to ensure that all the appropriate costs are included in the data gathered.

The SE/PM cost values used in this report are extracted from the WBS line item values for EAC SE/PM cost, which are listed on the Cost Data Summary Report (CDSR), DD Form 1921. The EAC SE/PM cost is the projected SE/PM cost at contract completion. The SE/PM costs are inclusive of the total contract costs less the contractor’s profit/loss or fees.

The SE/PM Cost Ratio

This study uses the SE/PM cost ratio for a program (the ratio of SE/PM costs divided by total program costs as shown in Equation 4), which specifies the proportion of total program costs that are dedicated to managing, integrating, and directing the program:

$$\text{SE / PM Cost Ratio} = \frac{\text{SE / PM Costs}}{\text{Total Cost}} \tag{4}$$

The numerator of the SE/PM cost ratio is the sum of SE and PM cost expenditures, and the denominator is total program expenditures. A ratio is calculated to provide a perspective on the relative magnitude of SE/PM expenditures as well as to allow for comparison across different programs.

Our hypothesis is that a higher SE/PM cost ratio is related to future cost threshold breaches. Our assumption is that programs with higher SE/PM cost ratios are in riskier contractual relationships and have higher transaction costs and will experience more cost overruns than those programs with lower SE/PM cost ratios. Categorizing an SE/PM cost ratio as high or low is a judgment call. There does not appear to be a directed standard or normal-practice SE/PM cost ratio definition across MDAPs. One reason that the SE/PM cost ratios may vary is due to the type of weapon system. Another reason SE/PM cost ratios differ between MDAPs, and sometimes across contracts within the same MDAPs, is due to subjective interpretations among contractors (and program managers) about the definition of SE/PM costs and non-uniform standards regarding which costs qualify to be categorized as SE/PM costs (Stem, Boito, & Younossi, 2006).

This study analyzes the SE/PM cost ratio of MDAPs looking for potential correlation between the SE/PM ratios and cost breaches. Determining the nature of any potential relationship between the SE/PM cost ratio and the number of cost breaches experienced by a program will test the hypothesis that programs with higher SE/PM cost ratios will experience more cost overruns than programs with lower SE/PM cost ratios.

Other Explanatory Variables

While the SE/PM cost ratio was the focus of our research, we acknowledge that there are likely many other variables that are related to cost overruns (e.g., GAO, 2011). Although it was not within the scope of this research to test other explanatory variables, we did record maturity and contract type for each of the programs selected for this study because the information was easily obtained from the documents we examined.

As a program develops, it seems reasonable to assume that the uncertainty surrounding the program's cost is reduced, and therefore we should expect to see fewer cost breaches in older programs. However, age by itself is not sufficient to compare different programs, since programs have different expected durations (schedules). A better metric is the program's maturity, based on the design and technology readiness of the system. In this study, program maturity is measured by the time elapsed since Milestone B, the entry point into the Engineering and Manufacturing Development phase. For a program to receive approval to begin Milestone B in the DoD, the design and technology associated with the system must be considered "mature".[6] This requirement provides some assurance that we are comparing programs in approximately the same stage of development or maturity, thus minimizing differences that might be explained more by the acquisition phase or technology readiness than by other factors such as the SE/PM cost ratio.

The type of contract used for a program is an indication of the perceived level of risk associated with the execution of the contract. As the level of performance risk increases, the risk of cost overruns also increases and the amount of cost risk that the contractor is willing to assume tends to decrease. Contract types differ in how

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[6] Milestone B approval authorizes an MDAP to enter the Engineering and Manufacturing Development phase of the acquisition process. Statutory requirements for MDAPs to achieve Milestone B approval are found in 10 U.S.C. § 2366b. These requirements include that the program is certified by the milestone decision authority to be affordable, fully funded through the Future Years Defense Program (FYDP), and that the cost and schedule estimates are reasonable.

the cost risk is shared between the government and the contractor. In a firm fixed-price contract, there is no cost sharing between the government and the contractor, and the contractor has full responsibility for the performance costs and resulting profit (or loss). In a cost-plus contract, a share ratio based on the contract cost and the contractor's fee (profit) is negotiated so that the contractor has a pre-determined responsibility for the performance costs, which will directly affect the fee (profit). In the case of both contract types, incentives may be offered in which the contractor's responsibility for the performance costs and the profit or fee incentives offered are tailored to the uncertainties involved in contract performance (FAR, 2005). By including contract type in our analysis, we can account for basic cost risk differences recognized by both the government and the contractor at the onset of the program.

Hypothesis

Many studies (e.g., Bolten, Leonard, Arena, Younossi, & Sollinger, 2008) have examined cost growth in DoD programs, yet little research has been done on the relationship between transaction costs and cost overruns as suggested by Angelis et al. in 2008. A 2006 RAND study established that MDAP SE/PM costs vary between programs depending on the program type (Stem et al., 2006), and Angelis et al. (2008) suggested using the SE/PM cost as a proxy for transaction costs to examine the relationship between transaction costs and cost overruns.

This study seeks to determine the nature of any potential relationship between transaction costs (using the SE/PM cost ratio as a proxy) and the likelihood of cost breaches experienced by a program. The hypothesis is that programs with higher SE/PM cost ratios are more likely to experience cost breaches than programs with lower SE/PM cost ratios. This is based on the assumption that higher SE/PM cost ratios are related to riskier contractual relationships since more time, effort, and resources are expended to meet performance and schedule deadlines when compared to less risky contracts. Programs with higher transaction costs may experience more cost breaches as a result of those transaction costs not being accounted for in the original cost estimate.

The influence diagram in Figure 2 describes the interactions between factors that may be associated with the occurrence of a cost breach. There are likely many other variables which affect cost breaches, but the variables identified in this influence diagram (i.e., SE/PM cost ratio, program maturity, and contract type) are shown because they can be represented with the data collected. The dashed lines in Figure 2 represent factors that one cannot observe or does not know how to observe and must be dealt with qualitatively or by using proxies. The solid lines represent factors that can be quantitatively evaluated. While the risk and complexity of a program may directly contribute to a cost overrun, the SE/PM efforts and the contract type can influence the magnitude and frequency of cost overruns as measured by cost breaches. Figure 2 indicates that program maturity influences the risk and complexity associated with a program. Many will associate maturity with the technology readiness level, but we quantify *maturity* as the time in years since program initiation or Milestone B, which assumes a certain level of technology readiness. Figure 2 also indicates that the risk and complexity of the MDAP will guide program managers and contractors in their selection of an appropriate contract type which in turn can influence the government's exposure to cost overruns. It is also likely that the risk and complexity of a program will drive the level of monitoring and negotiation (transaction costs) required to manage the program and that riskier, more complex programs will require higher levels of transaction costs, which may contribute to cost overruns.

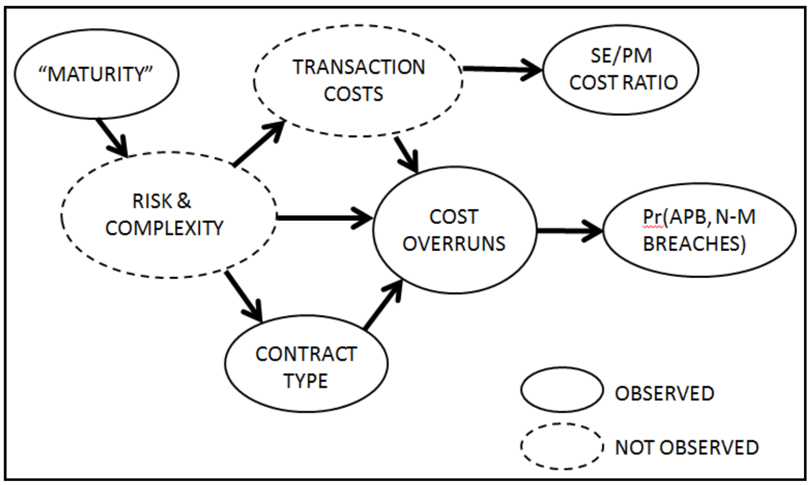

Figure 2. Cost Breach Influence Diagram

Because transaction costs are difficult to quantify, the SE/PM cost ratio can be used as a proxy to help understand the contribution of transaction costs to a program's cost overruns and subsequently the probability of the program having a cost breach. Of course, not all cost overruns are considered cost breaches. Current estimates which exceed the estimated cost of a program by any amount are considered a cost overrun. Cost breaches result when the amount of the cost overrun exceeds certain parameters defined by regulation. There are two types of cost breaches: APB and Nunn–McCurdy breaches. In order for a program to incur an APB breach, estimated program expenditures must be greater than the APB estimate at completion (EAC) by at least 10%. If the difference is 15% or more, it is a Nunn–McCurdy breach. In this report, a default value of 10% cost overrun constitutes a cost breach threshold.

In this study, we examine how the SE/PM ratio is related to the probability of incurring a cost breach as defined above. The null hypothesis of this research states that better incorporation of transaction costs into cost estimates will not significantly affect the ability of an MDAP to operate within its approved financial constraints as measured by cost breaches.

Data Sources

This study used two major data sources to develop the SE/PM ratio: Selected Acquisition Reports (SARs) and the cost and software data reporting system (CSDR). The data sources are discussed in the following sections.

Selected Acquisition Reports

The SAR is a single report which contains details of critical parameters of an MDAP or major automated information system (MAIS), to include the responsible office, threshold breaches, schedule, performance, current contracts, and cost details. SARs must be submitted on an annual basis and occasionally at quarterly intervals. The Defense Acquisition Management Information Retrieval (DAMIR) system provides electronic copies in PDF format for active and inactive MDAPs. SARs contain threshold breach data and a brief explanation delineating the cause of the cost breach.

MDAPs typically require several contracts to be executed, often concurrently. SARs provide information for the overall program and not for individual contracts. A SAR may list a single contract or many contracts for a single MDAP. In addition, not all contracts for a program may be included in the SAR. The current contract section of the SAR only includes "the six largest, currently active contracts (excluding subcontracts) that exceed $40 million in Then-Year dollars" (DAMIR, 2011). This means that for MDAPs listing more than one contract in a SAR, if there is a threshold breach it is often difficult to determine which contract(s) caused the threshold breach.

Because threshold breaches are associated with contract estimates, it is important to identify which contract is responsible for a threshold breach. To facilitate our analysis, only MDAPs which listed one contract in the Contracts section of the SAR were selected for our study. In addition, most programs which featured contracts with effort numbers were excluded because the effort number in DAMIR does not always accurately correspond to the contract effort number in the DCARC database.

According to DoD guidance, "SAR termination will be considered when 90% of expected program deliveries or 90% of planned acquisition expenditures have been made, or when Selected Acquisition Reporting criteria are no longer met" (DAMIR, 2011). This means that the active MDAPs found in DAMIR are between the beginning of the Engineering and Manufacturing Development phase (Milestone B) and 90% complete. Inactive MDAPs that are at least 90% complete are no longer required to submit SARs. There are many instances where the final SAR for an MDAP indicates that the program is more than 90% complete, but not 100% complete. The use of data which may only be 90% complete is presumed acceptable based on the following assumptions:

- 90% of delivered product probably accounts for more than 90% of expenditures.
- Experience indicates that after 90% of the budget has been expended, the remaining 10% of the expenditures have already been committed.

SARs provide relatively high-level contract cost information. For this reason, it was decided that DAMIR would be used solely for the threshold breach data contained in the SARs.

In addition to cost threshold breaches, the SAR indicates the time since program initiation at Milestone B, which was used in this study to indicate program maturity. Although the time elapsed since Milestone B for a contract may not always accurately represent the amount of time that an MDAP has been in existence, it was valid for the more recent contracts applicable to the program.

Cost and Software Data Reporting System

The program cost data found in the DD Form 1921 (Cost Data Summary Report, CDSR) provided by the Defense Cost and Resource Center (DCARC) in the Defense Automated Cost Information Management System (DACIMS) database contains significantly more contract detail than the SARs. DCARC, an entity of the Office of the Secretary of Defense Cost Assessment and Program Evaluation (OSD CAPE) organization, collects current and historical cost and resource data for MDAPs and MAISs. These cost and resource data are used by government cost analysts to develop cost estimates for government programs (CAPE, 2013b).

The work breakdown structure (WBS) format of the CDSR allows us to obtain information on SE and PM costs. The Cost and Software Data Reporting (CSDR) library in DACIMS contains folders of active and inactive MDAP contract data sorted by weapons system types. From the CDSR we can extract the line item costs that we need for the SE/PM cost ratio calculation. Within a single contract, it is not unusual to find cost data for both the prime vendor and subcontractors. To simplify the data collection process, only the cost data provided by the prime contractor were recorded for further analysis. The type of contract used for the program was also obtained from the CDSRs. Programs were noted as having either firm fixed price type contracts or cost-plus type contracts.[7]

[7] A cost-plus contract is a type of contract that provides for payment to the contractor of allowable costs incurred in the performance of the contract, to the extent prescribed in the contract. This type of

Data Selection[8]

As noted above, cost threshold breach information categorized by appropriation was available from SARs in DAMIR and the expenditure items required to calculate the SE/PM cost ratios were available from the CDSRs found in DACIMS. The MDAPs used for this study were not randomly selected, and not all MDAPs contained in either DACIMS or DAMIR were selected for analysis. Inclusion of MDAPs in this study was based on the availability of relevant data from the two databases, DAMIR and DACIMS. Discrepancies between the two databases often precluded an MDAP from consideration.

If an MDAP has a cost threshold breach but the contract is not listed in both databases (DACIMS and DAMIR), it is excluded from the data set. This is because we need to know the SE/PM cost ratios for the year when the cost threshold breach occurred in order to understand the relationship between a breach and the SE/PM cost ratio. For an MDAP with no cost threshold breaches, using the SE/PM cost ratios for the contracts that are available in the DACIMS database can be done without fear of missing a cost threshold breach.

In many cases, the cost information contained in DAMIR does not match the cost information contained DACIMS for the same contract. Cost data as reported in the SAR are from the perspective of the government representative, or program manager, while cost data contained in the CDSR are reported by the contractor, which may account for some of the observed differences. In addition, the CDSR and SAR are usually submitted at different times. To eliminate the cost difference between the two databases, all cost data were retrieved from the DACIMS library (CDSR) and threshold breach data were obtained solely from the DAMIR database (SAR).

The contractor work breakdown structure (CWBS) dictionary contains a description of the technical and cost data for the CWBS elements within the contract. Because different contractors have slightly different definitions for SE/PM costs, the costs reported in the SE/PM category may differ from contract to contract. By utilizing the CWBS it is possible, albeit tedious, to ensure to a high degree of

contract establishes an estimate of total cost for the purpose of obligating of funds and establishes a ceiling that the contractor may not exceed without prior approval of the contracting officer (CO). A firm fixed price contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. This type of contract places upon the contractor maximum risk and full responsibility for all costs and resulting profit or loss. It provides maximum incentive for the contractor to control costs and imposes a minimum administrative burden on the government (DAU, 2011b).

[8] For a more detailed discussion of methodology for collecting data, see Biggs (2013), especially the appendix.

confidence that the SE/PM costs between contracts in this study are based on the same types of WBS elements and reasonably comparable.

Contract data provided in the CDSR can be initial, interim, or final cost information and are submitted according to the contract CDSR plan approved for each program. As a result, the frequency of submission for cost data documents across different MDAPs varies considerably. To ensure that the cost data collected from the CDSR apply to approximately the same period that a cost breach is reported in the SAR, the reporting periods for the two documents were verified to be within the same calendar year. Otherwise, the program was excluded from the data set. A total of 32 MDAPs representing Air Force, Army, Navy, and Joint programs since 1988 were included in this study and are listed in the appendix.

Methodology[9]

This research uses binary, clustered, and panel data. Any type of cost breach, APB cost breach or Nunn–McCurdy cost breach, is considered the binary-outcome dependent variable in this analysis: cost breach or no cost breach in a given calendar year. The data are clustered based on the different types of programs included in the data set (e.g., ship building, aircraft development), and observations were collected for a program over a period of years creating panel data (SE/PM cost data ratio calculations were recorded by year for each program). There are three independent or explanatory variables that were included in the analysis: EAC SE/PM cost ratio, time since program initiation (maturity), and program contract type (fixed price or cost-plus). While the exact nature of the relationship between cost threshold breaches and these explanatory variables is unknown, it is reasonable to suppose that the explanatory variables influence the cost performance of the MDAPs in some manner.

To discover a possible relation between the SE/PM cost ratio and cost breaches, we could start with an ordinary least squares (OLS) regression model, where SE/PM is the independent variable and cost breach is the dependent variable. To incorporate maturity and contract type as additional explanatory variables, a multiple regression model makes sense. However, it has already been established that we are analyzing clustered panel data and that the average SE/PM costs differ by program types (see Stem et al., 2006). Thus, a single SE/PM cost ratio value that would indicate a cost breach may be of little use to a program manager since there is no accounting for the variance across program types.

Perhaps instead of finding a single SE/PM cost ratio that would presumably alert program managers to possibility of an APB or Nunn–McCurdy cost breach, it would be more helpful to provide program managers with an indication of the risk of

[9] For a more detailed study of regression analysis methodology, see Biggs (2013).

incurring a cost breach. To do this, we use a logistic regression model, or a maximum likelihood estimator such as logit, which uses the natural logarithm of the odds ratio. This model is appropriate because it is designed for use with binary-outcome dependent variables. Additionally, a fixed effects logit model adjusts for bias introduced by omitted explanatory variables within the clustered panel data, and a population averaged logit model is appropriate for examining across clusters of panel data.

In this study, the pooled OLS regression serves as the baseline model. The data are considered pooled because it uses all of the data observations assuming they are independent. Unfortunately this assumption skews the calculated standard errors for the data. We employ one of several maximum likelihood estimators and panel data techniques to address this problem.

The standard logit model is presented in Equation 5, where P_{it} represents the probability that at a specific time an MDAP breaches a cost threshold, β_{it} is the vector of regression coefficient which represents the association of cost breaches and the explanatory variable to a unit change in the independent variable (SE/PM cost ratio) and x represents the explanatory variable for the respective MDAP.

$$\text{Log}\left(P_{it} \;/\; 1 - P_{it}\right) \;=\; \beta_{it}x \tag{5}$$

The fixed effects (conditional) logit model, which accounts for dependence of the observations within a group, modifies the basic logit model and is presented in Equation 6. In this equation, α represents a set of fixed constants for each MDAP in the group. This model can be considered to describe the impact of short-run changes, (i.e., that a change in the SE/PM cost ratio for an MDAP will change its probability of breaching a cost threshold).

$$\text{Log}\left(P_{it} \;/\; 1 - P_{it}\right) \;=\; \alpha \;+\; \beta_{it}x \tag{6}$$

Finally, the relationship between SE/PM cost ratio and cost breach was modeled using a population averaged logit model. Unlike the fixed effects method that looks *within* programs for changes in the SE/PM cost ratio, the population averaged method looks *across* programs to measure changes in the SE/PM cost ratio. Therefore, in the population averaged logit model, α in Equation 6 represents a set of averaged constants for MDAPs across program groups. The population averaged method is most useful for measuring long-run effects, (i.e., measuring whether programs with high average SE/PM cost ratios are more likely to experience a cost breach).

Results

For the 32 programs included in this study, Figure 3 shows the total number of cost breaches reported for each program compared to the program's average SE/PM cost ratio.

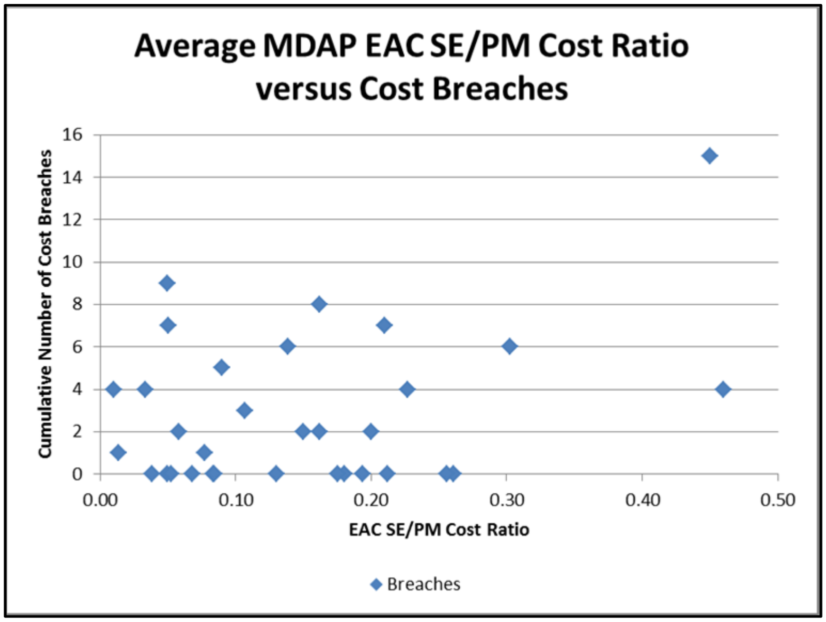

Figure 3. MDAP EAC SE/PM Cost Ratio Versus Cost Breaches
(Biggs, 2013)

It appears that more than half of the MDAPs maintain an EAC SE/PM cost ratio of 0.20 or less and have experienced less than two cost breaches since 1998. Furthermore, it can be inferred that most of the programs have experienced at least one cost breach and these inferences seems to confirm a recent RAND report which found that most MDAPs' actual costs exceeded baseline cost estimates (Arena et al., 2006).[10]

Observations of the MDAP SE/PM cost ratios in this report seem to concur with the RAND study which suggests that trends in SE/PM costs vary across MDAPs (Stem et al., 2006). For this reason, it is challenging to identify relationships between SE/PM costs and cost breaches. The average EAC SE/PM cost ratio for the sample data set of 32 MDAPs is 0.16. This suggests that on average, program managers of the MDAPs studied in this report spent 16% of their budgets on systems engineering and program management activities. Recall that the systems engineering and program management costs are used as proxy measures of the transaction costs required to administer and to manage the MDAP.

[10] For most of the programs reviewed, actual costs exceeded the baseline cost estimate established at Milestone II (program initiation), as measured by the cost growth factor (Arena et al., 2006).

A histogram of the EAC SE/PM cost ratios observed in this study is shown in Figure 4. From this histogram we can observe that while most observed ratios varied between 0.05 and 0.35, there do appear to be two outliers having values of 0.50.

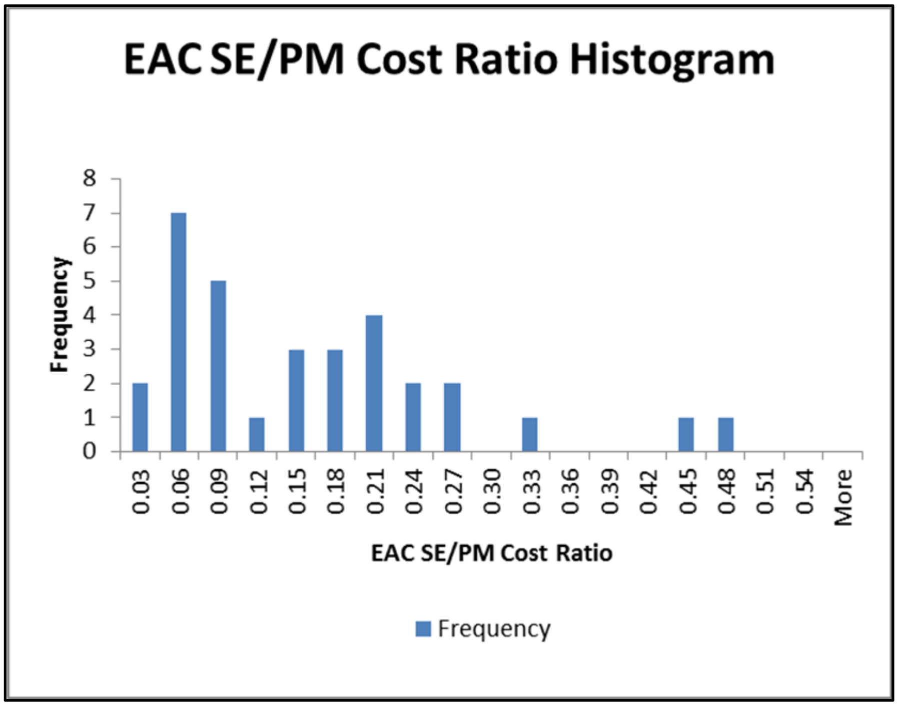

Figure 4. EAC SE/PM Cost Ratio Histogram for MDAPs
(Biggs, 2013)
Note. Study data from Biggs is available on request.

SE/PM Cost Ratios

To understand the results of our analysis, it will be helpful to consider the following linear model used to explore the effect of the independent variables on cost breaches:

$$Y = \alpha + \beta_0 X_0 + \beta_i X_i. \quad (7)$$

For this linear model, β_o is the regression coefficient that will be associated with the independent variable (EAC SE/PM cost ratio), and β_i is the regression coefficient that will be associated with all other explanatory variables. The dependent variable, Y, represents the likelihood of a cost breach occurring. The constant α represents the value of the probability of a cost breach occurring when there are no explanatory variables (X_i) and EAC SE/PM cost ratio (X_0) is zero (Hutcheson, 2011). Accordingly, for the first series of data tests, the equation for the model being tested is

$$Y = \alpha + \beta_0 X_0 \quad (8)$$

$$X_0 = \text{EAC SE/PM cost ratio}$$

The hypothesis being tested is that the probability of a program sustaining a cost threshold breach is related to the EAC SE/PM cost ratio of the MDAP. The null hypothesis is that there is no relation between the probability of a cost threshold breach and the EAC SE/PM cost ratio and that the model has no explanatory power.

The results of the regression models based on the SE/PM ratio are shown in Table 2. The OLS regression and logit population averaged regression models indicate a positive relationship that is significant at the 5% level (p = .05) between EAC SE/PM cost ratio and the likelihood of a cost breach occurring. Since we established in the previous chapter that the OLS regression does not adequately model the data and the logit fixed effects (FE) model is not significant, only the logit population averaged (PA) regression results are further examined.

Table 2. Impact of EAC SE/PM Ratio on Likelihood of Cost Breach

EQUATION	VARIABLES	OLS Breach (X_0)	Logit-FE Breach (X_0)	Logit-PA Breach (X_0)
	EAC SE/PM Cost Ratio (β_0)	1.097** (0.421)	-9.238 (7.825)	4.006** (2.021)
	Constant (α)	0.143* (0.0789)		-1.473*** (0.454)
	Number of Observations	84	39	84
	R-squared Statistic	0.079		
	Number of Programs	32	11	32

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Average Marginal Effect in PA model is .8

ME @ EAC=0.1 0.76
ME @ EAC=0.2 0.90
ME @ EAC=0.3 0.98
ME @ EAC=0.4 1.00

The marginal effect of the logit population averaged model shows that, based on *across* programs observations, for every unit change in EAC SE/PM, the log odds rise in the probability of a cost breach occurring is 0.80. This means that for every 1% increase or decrease in the EAC SE/PM cost ratio, there is an average increase or decrease of 0.8% in the probability of a program sustaining a cost threshold breach. In logistic regression, the value of the marginal effect is not constant and must be interpreted accordingly. For example, in Table 2 when the EAC SE/PM cost ratio is

0.1, the marginal effect on the likelihood of a cost threshold breach is 0.76. When the EAC SE/PM cost ratio is equal to 0.1, a 1% increase in the EAC SE/PM cost ratio will positively correspond to a 0.76% increase in the likelihood of a cost threshold breach occurring.

It is interesting to note that the logit fixed effects model which looks within programs does not show correlation between EAC SE/PM and cost breaches. This seems to suggest that *within* a program the likelihood of a program incurring a cost threshold breach cannot be associated to the EAC SE/PM cost ratio.

The logit population averaged model provides a long-term look across programs and yields statistically significant results for associating cost breaches to EAC SE/PM cost ratio. The across programs look can be interpreted as indiscriminately considering all DoD MDAPs in the data set, regardless of the program's affiliation with a specific service or weapons type. The results suggest that, in general, the probability of a cost breach occurring is related to the EAC SE/PM cost ratio.

Figure 5 illustrates the relationship between EAC SE/PM cost ratio and the likelihood of cost breaches for the population averaged model.

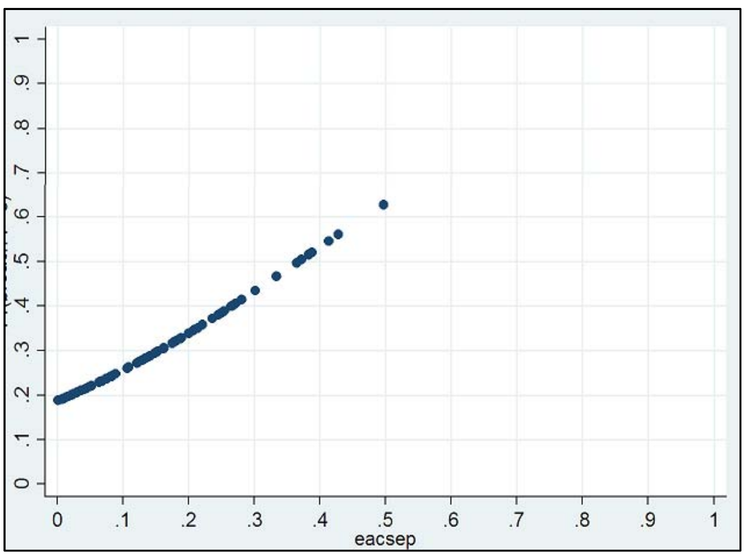

Figure 5. Cost Breach Versus SE/PM Logistic Regression S-Curve
(Biggs, 2013)

The regression s-curve in Figure 5 indicates that an increase or decrease in the EAC SE/PM cost ratio is associated with a corresponding increase or decrease in the probability of a cost breach occurring.

SE/PM Cost Ratios and Program Maturity

The program maturity, considered in this report to be the length of time (in years) since the requisite program contracts entered Milestone B, was used to expand the model. We are interested in the impact of EAC SE/PM cost ratio on the likelihood of a cost breach occurring while including the explanatory variable *Log Maturity*, the logarithm of the maturity variable (taking the natural log of maturity helps to linearize the relation of maturity to cost breaches in this model):

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1 \quad (9)$$

X_0 = EAC SE/PM Cost Ratio

X_1 = Log Maturity

The null hypothesis is that there is no relation of cost breaches with EAC SE/PM cost ratio and program maturity as defined in this report. The analysis is modeled by logit fixed effects and logit population averaged models and the resulting impact of the explanatory variable Log Maturity is displayed in Table 3.

Table 3. Impact of EAC SE/PM With Log Maturity

VARIABLES	Logit-FE (X_i)	Logit-PA (X_i)
Log Maturity (β_1)	0.429	0.350
	(0.877)	(0.302)
EAC SE/PM Cost Ratio (β_0)	-8.826	4.449**
	(7.897)	(1.907)
Constant (α)		-2.193***
		(0.752)
Number of Observations	39	84
Number of Programs	11	32

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Average marginal effect in PA of Log maturity is 0.7 and EAC SE/PM Cost Ratio is 0.89

ME @ EAC=0.1 0.83
ME @ EAC=0.2 0.99
ME @ EAC=0.3 1.08
ME @ EAC=0.4 1.08

While maturity does not have a statistically significant effect in any of the models, the SE/PM ratio is significant at the 5% (p = .05) level in the logit population averaged (PA) model. The average marginal effect of the EAC SE/PM cost ratio is 0.89, which means that a one unit (1%) change in the EAC SE/PM cost ratio of an MDAP will result in a 0.89% change in the likelihood of an MDAP incurring a cost breach. The practical interpretation of these results may be that SE/PM costs become a larger percentage of the total program costs due to the proactive or reactive actions of the program manager to avoid a cost threshold breach. Thus, there is evidence to suggest that the SE/PM cost ratio may be an indicator of cost troubles.

SE/PM Cost Ratios, Program Maturity, and Contract Type

Finally, we examine the impact of the type of contract on the likelihood of a cost breach occurring. The null hypothesis of this analysis is that there is no relation between cost breaches and EAC SE/PM cost ratio, log maturity, and MDAP contract type. The linear equation model that analyzes the impact of EAC SE/PM on the likelihood of a cost breach occurring while including the explanatory variables Log Maturity and MDAP contract type is

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1 + \beta_2 X_2 \quad (10)$$

X_0 = EAC SE/PM Cost Ratio

X_1 = Log Maturity

X_2 = Contract Type

For this model, firm-fixed price contracts have $\beta_2 = 0$, and cost-plus contracts have $\beta_2 = 1$.

Table 4 shows the marginal effects of the independent and explanatory variables for programs with fixed price and cost-plus contracts. In this model, the effect of maturity was statistically significant at the 5% ($p = .05$) level and effect of the EAC SE/PM cost ratio was significant at the 10% ($p = .10$) level for programs with cost-plus contracts. For cost-plus contract programs, the average marginal effect of Log Maturity is 0.21, and for EAC SE/PM cost ratio is 1.00. This means that for a one unit (1%) change in the Log Maturity the likelihood of a cost breach occurring will change by 0.21%, and for a one unit (1%) change in the EAC SE/PM cost ratio the likelihood of a cost breach occurring will change by 1%.

Table 4. Logistic Regression With Log Maturity and Contract Type

VARIABLES	Logit PA (X_i) "Fixed Price" (β_2=0)	Logit PA (X_i) "Cost Plus" (β_2=1)
Log Maturity (β_1)	-0.0967	1.115**
	(0.586)	(0.553)
EAC SE/PM (β_0)	-2.121	5.172*
Cost Ratio	(4.665)	(2.846)
Constant (α)	-0.906	-3.255***
	(1.346)	(1.214)
Number of Observations	37	41
Number of Programs	15	16

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Including ME for the type 1 model only
Average marginal effect in PA of Log maturity is .21, and EACSEP is 1.00

ME @ EAC=0.1 0.94
ME @ EAC=0.2 1.08
ME @ EAC=0.3 1.12
ME @ EAC=0.4 1.07

In summary, we looked at the SE/PM cost ratios, maturity, contract type, and cost breaches for 32 MDAPs during the period of 1998 to 2011. Based on the results of the analysis, using the population averaged logit model to look across programs seems most useful. This is probably due to the population averaged model making longer term observations, whereas the fixed effects model is making short-term observations. We find a positive relationship that is significant at the 5% (p = .05) level between the likelihood of a cost breach occurring and the EAC SE/PM cost ratio. On average, for a 1% increase in the SE/PM cost ratio there is a corresponding 0.80% increase in the likelihood that a cost breach will occur. For cost-plus contracts, the effect of maturity was statistically significant at the 5% (p = .05) level and the model had the largest average marginal effects of EAC SE/PM cost ratio, with a 1% increase in the EAC SE/PM cost ratio corresponding to a 1% increase in the likelihood of a cost breach at a significance level of 10% (p = .10).

Conclusions

This research is based on the assumption that there are real costs (transaction costs) associated with managing and monitoring an MDAP which may not be accounted for in traditional cost estimates. This study tried to determine (1) if there is a correlation between these transaction costs and acquisition cost threshold breaches; and (2) if cost threshold breaches are related to the *amount*, or proportion of total costs, that are spent on program transaction costs. The data set included major defense acquisition programs (MDAPs) with 10% (or greater) cost threshold breaches. Logit population averaged regression analysis yielded statistically significant results for the EAC SE/PM cost ratio by itself and for Log Maturity and

EAC SE/PM cost ratio in programs with cost-plus contracts. These contracts exhibited relationships between (1) the estimate at completion (EAC) system engineering/program management (SE/PM) cost ratio and the likelihood of a cost breach occurring; and (2) the log maturity and the likelihood of a cost breach occurring.

The results show that as the EAC SE/PM cost ratio rises there is a statistically significant corresponding increase in the probability of a cost threshold breach occurring. This provides answers to both of these research questions. First, the statistically significant correspondence between the variables infers that correlation exists. Second, the relation between cost threshold breaches and the amount of transaction costs is confirmed because as the relative amount of transaction costs for an MDAP increases, the likelihood of the occurrence of a cost threshold breach also increases.

If the original cost estimate did not account for transaction costs and those transaction costs are high, it is possible the missing (i.e., unestimated) transaction costs are contributing to the cost overrun. In other words, if transaction costs are high and they were not part of the program baseline or BAC, then they may account for at least part of the difference between the BAC and the estimate at completion (EAC) which may eventually lead to a cost breach. However, the correlation found in our analysis does not suggest causality, but merely that a relationship exists.

It is reasonable to assume that the SE/PM cost ratio is a symptom associated with risky, complex programs. Higher transactions may be the result of program management activities intended to reduce risk in complex programs, which by their nature are more likely to experience cost overruns. Just like the temperature of a patient can indicate an infection, the temperature itself is not the cause of the infection. Rather, the body’s efforts to fight the infection cause the temperature to increase. The doctor measures the patient’s temperature to evaluate the probability of an infection. In a similar fashion, program managers may be able to measure the SE/PM cost ratio to assess the probability of a cost breach.

Understanding the significance of transaction costs in life-cycle cost estimation may lead to better life-cycle cost estimates for MDAPs. In addition, understanding the relationship between the SEPM cost ratio and cost breaches could help program managers understand and potentially predict possible cost overruns, which may lead to better cost risk management in DoD acquisitions.

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Appendix

PROGRAMS SELECTED FOR STUDY

Active Electronically Scanned Array (AESA) Radar

AIM-9X/Short Range Air-to-Air Missile

AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)

Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)

AN/WQR-3, Advanced Deployable System (ADS)

Apache Block IIIA Remanufacture (AB3A REMANUFACTURE)

AV-8B/Attack, V/STOL, Close Air Support (Harrier II+ Remanufacture)

B-2 Radar Modernization Program

Cobra Judy Replacement (Cobra Judy Replacement)

EA-18G Growler (EA-18G)

Expeditionary Fighting Vehicle (EFV)

E-3 AWACS Radar System Improvement Program (RSIP)

E-2C Reproduction

Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)

Family of Medium Tactical Vehicles (FMTV)

Guided Multiple Launch Rocket System/DPICM/Unitary/Alternative Warhead (GMLRS/GMLRS AW)

Joint Common Missile (JCM)

Joint Tactical Radio System Ground Mobile Radio (formerly Cluster 1)

(JTRS GMR)

Longbow Hellfire—subsystem of the AH-64 Apache Weapon System

LHA Replacement Amphibious Assault Ship

MQ-4C Unmanned Aircraft System Broad Area Maritime Surveillance (MQ-4C UAS BAMS)

Multi-Platform Radar Technology Insertion Program (MP-RTIP)

National Polar-Orbiting Operational Environmental Satellite System (NPOESS)

Presidential Helicopter Replacement (VH-71) Program

P-8A Poseidon

Sense and Destroy Armor (SADARM)

Small Diameter Bomb Increment II (SDB II)

Space Based Infrared System (SBIRS) High Program

Standard Missile (SM)–2 Block IV

Stryker Family of Vehicles (STRYKER)

UH-72A Light Utility Helicopter (LUH)

Warfighter Information Network–Tactical (WIN-T)

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