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**Enhancing the Enhanced Scenario-Based Method of Cost-
Risk Analysis**

16 November 2011

by

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Abstract

The current s-curve method of cost-risk analysis for major DoN acquisitions projects does not accurately estimate actual cost when the program reaches full-rate production. Another, sometimes more effective method of measuring cost risk, is the enhanced scenario-based method (eSBM) of risk analysis. The reason that cost estimations based on Milestone B costs are inaccurate is that little, if any, real information about the project is known at that point in the project. eSBM allows managers a less statistically tasking method of determining cost risk for a project, while still maintaining the requirements of the Weapons System Acquisitions Reform Act (WSARA) of 2009. In measuring the usefulness of eSBM, the key factors should focus on the acquisition strategy being used for the project and the time frame from Milestone B to later milestones. I hypothesized that different acquisition strategies will yield different levels of success in estimating cost risk for eSBM.



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LT Seth T. Hooper was born in Lansing, MI, and raised in the suburbs of Detroit. He received a Bachelor of Science in Electrical Engineering and a commission in the United States Navy through the STA-21 program from The Citadel in 2006. LT Hooper is a naval submarine officer who has more than 17 years of both enlisted and commissioned service.

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I. INTRODUCTION

A. BACKGROUND

The current method of choice for developing risk-adjusted cost estimates is the Monte Carlo simulation method, which sums probability-based cost distributions at the work breakdown structure (WBS) element level to produce a cumulative distribution for overall program cost. The confidence level from the cumulative distribution is the resulting “risk” for the estimated cost. This Monte Carlo method is also referred to within the cost-estimating community as the s-curve method of cost-risk analysis, and, although it is the current method of choice for developing risk-adjusted cost estimates, it leaves several of the following problems unmanaged:

1. Programs do not behave as the cost-estimation model had forecast. The cost risk becomes a second-order guess based on another guess.
2. This model does not bound possible risk areas on either high or low likelihood probability. By using this method, the left and right tails of the cumulative distribution are weighted equally with the mean.
3. The model assumes that the consequences for all unfavorable outcomes equally affect the cost model.
4. The model requires in-depth knowledge of statistical analysis and processes.

The s-curve method of cost-risk analysis for major Department of Defense (DoD) and Department of the Navy (DoN) acquisitions projects, so-called major defense acquisition programs (MDAPs), does not accurately estimate actual cost from the pre-Milestone B stages of the acquisitions process to the phase at which the program reaches full-rate production; thus, the s-curve method produces unreliable cost-risk analysis.

One of the reasons that cost estimates at Milestone B are inaccurate is that very little, if any, real information about the project is known other than the conceptual capabilities required. The enhanced scenario-based method (eSBM) makes risk assessments without the need for details about the program, while still



being grounded in historical facts and data. eSBM allows managers a less statistically taxing method of determining cost risk for a project.

B. PURPOSE

The key factors in measuring the usefulness of eSBM should be to focus on the acquisition strategy being used for the project and the time frame from Milestone B to later milestones. In this thesis, I hypothesized that different acquisition strategies yield different levels of variation in estimating cost risk for eSBM. Furthermore, I hypothesized that the longer a program takes to reach full-rate production from Milestone B, the more cost risk there is for that program.

The eSBM method is not meant to replace the use of statistical analysis to determine cost risk; it is intended to provide an alternative to the current standard. By having an additional method of risk analysis, cost estimators and program managers are provided with yet another risk profile with which to compare and measure risk.

C. THE QUESTION

No definitive research links the effects of acquisition strategy and/or program length to program cost risk and the Monte Carlo method of cost-risk analysis makes no attempt to factor in acquisition strategy or the time horizon for the program. On the other hand, the eSBM makes an effort to reduce statistical uncertainty in estimating costs and reducing the risk of cost overrun. However, it falls short in the areas of acquisition strategy and time horizon. I hypothesized that different acquisition strategies yield different levels of risk in estimating cost risk for eSBM.

D. WHO BENEFITS

More accurate risk analysis benefits every level of DoD decision-making. The following examples outline some of these benefits.



- By providing an accurate assessment of a program's cost risk, the senior acquisition managers and Milestone Decision Authorities (MDAs) will be able to manage program risk early on and avoid potentially overly risky programs. Having another cost-risk profile will allow for more rational debates during the analysis of alternatives (AOA) stage of the acquisition process. By weeding out programs with a high likelihood of failure, more funds will be available for other programs that are likely to succeed.
- Program executive offices (PEOs) and program managers (PMs) will be able to focus attention on areas of highest risk sooner in the program, thus detecting the potential effects on cost, schedule, and performance before problems arise. The more accurate cost-risk assessment also allows for realistic decisions about how to manage the program as a whole.
- Cost estimators would be provided with a method of analysis that is founded in historical data without the rigorous statistical analysis. Due to the complex statistical analysis methods needed to produce accurate Monte Carlo simulations, cost estimations are subject to additional scrutiny from statisticians. The eSBM method removes this statistical scrutiny while still maintaining the desired outcome in terms familiar to decision-makers.

In a dynamic world of fiscal constraints, accurate cost-estimating risk assessments are even more crucial.

E. THE NEXT STEPS

In the next chapter, I describe how the eSBM was developed, how its parameters were derived, and how it is used for cost-risk analysis. In that section, I include a description of the methods used to construct the coefficients of variation (CV) for the different cost drivers. Additionally, I explain how to translate the eSBM results into terms familiar to the acquisition community.

In this thesis, I present my research on how acquisition strategy and program length affect the cost-risk profile of MDAPs. In this research, I derived the cost growth factors (CGF) and coefficients of variation by using historical data. After the CVs were formulated, I tested them for validity and translated them into a cost-risk profile.



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II. LITERATURE REVIEW

A. INTRODUCTION

In 2005, Paul Garvey introduced the scenario-based method (SBM) as an alternative to the s-curve method of risk-adjusted cost estimation; he described it as an effective, less statistically intensive method of determining cost-risk analysis (Garvey, 2005). The Air Force introduced the SBM in the 2007 *Cost Risk and Uncertainty Handbook* as an acceptable method to calculate cost-estimate uncertainty (Air Force Cost Analysis Agency [AFCAA], 2007).

In order to meet the requirements of the Weapons System Acquisition Reform Act (WSARA) of 2009, the SBM would need to be able to produce confidence interval data that could be compared in the same manner as the s-curve analysis. Additionally, the new method would need to be coupled with historical data from previous defense acquisition programs. These requirements led to the development of the statistical SBM, which uses simple algebraic formulas and basic statistical processes to generate cost-risk curves. Flynn and Garvey (2011) conducted research on historical cost data to produce historically driven CVs, lending historical credibility to the statistical SBM. This historical data led to the eSBM.

B. WEAPONS SYSTEM ACQUISITION REFORM ACT OF 2009

In 2009, Congress passed the WSARA into law in an effort to provide better oversight and direction in the acquisition of defense programs. This law is intended “to improve the organization and procedures of the Department of Defense for the acquisition of major weapon systems” (Weapons System Acquisition Reform Act [WSARA], 2009, Introduction). With respect to cost estimation, the new law imposed two important requirements:

1. The director of the Cost Assessment and Program Evaluation (CAPE) shall “issue guidance relating to the proper selection of confidence levels in cost estimates generally, and specifically, for the proper selection of confidence levels in cost estimates for major defense



acquisition programs and major automated information system programs” (WSARA, 2009, § 101, subsection 2334(a)).

2. The director shall also “disclose in accordance with paragraph (2) the confidence level used in establishing a cost estimate for a major defense acquisition program or major automated information system program, the rationale for selecting such confidence level, and, if such confidence level is less than 80 percent, the justification for selecting a confidence level of less than 80 percent” (WSARA, 2009, § 101, subsection 2334(d)).

These two requirements drive the need to alter the SBM of cost estimation into a more statistically driven method. In Sections C and D of this chapter, I discuss the basic form of the SBM and the enhancements needed to comply with the WSARA.

C. SBM

1. Non-Statistical SBM

The non-statistical SBM method analyzes the risks of various aspects of a project in a realistic manner in the opinion of the program manager and the experts conducting the analysis. This method brings to light all possible and reasonable risks for a program and discards the extreme outlier scenarios. Figure 1 illustrates the non-statistical SBM, and in subsequent paragraphs, I fully explain each step in the method.

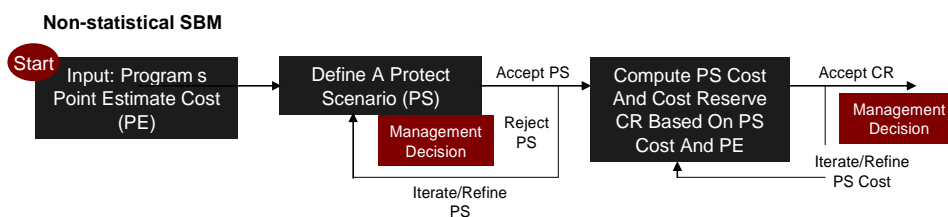


Figure 1. A Non-Statistical SBM
(Flynn & Garvey, 2011, p. 7)

The first step in this method is to add the estimates of all the elements from the work breakdown structure (WBS) as the program is defined in the program



manager's cost analysis requirements description (CARD). This sum of all the elements of the WBS is not adjusted for risk or uncertainty. The cost estimated from this step is called the program's point estimate (PE).

The second step is to define the program's protect scenario (PS). In this step, managers and analysts define the sources of major known areas of risk or uncertainty that have the potential to impact the cost estimate. This PS should not include worst-case or unrealistic scenarios, but should include the areas in which managers should focus their attention. Once the PS is accepted, the cost associated with the scenario is estimated to determine the program's PS cost.

The difference between the PE and the PS costs is defined as the program's cost reserve (CR), as illustrated in Equation 1. By increasing the program's PS cost, the CR also increases. Conversely, if the PE increases, the CR will be reduced by the same amount.

$$CR = PS\ Cost - PE \quad (1)$$

Analysts are then able to conduct a sensitivity analysis of the PS cost and CR in order to improve the model. Once the model has been completed, the program office and cost estimators can finalize all estimates and generate all of the required reports.

2. Statistical SBM

The statistical SBM expands the non-statistical method by using the original PE and the addition of two inputs. These inputs are the probability that PE will not be exceeded (α_{PE}) and the coefficient of variation of program cost. By using the outputs from the non-statistical SBM, basic algebra, and simple statistical analysis, the basic SBM can be transformed to produce a cumulative distribution curve that is similar to the traditional s-curve methods.

The analysts provide the probability that the PE cost will not be exceeded (α_{PE}) and the coefficient of variation (CV) of program cost. The probability that the



PE will not be achieved is based on the historical data and judgment of the PM and the cost estimators. The CV is based solely on the historical data from previous programs. Figure 2 shows the steps of the statistical SMB process.

Inputs for statistical SBM include the following:

- a. Point estimate (x_{PE})
- b. Probability PE will not be exceeded (α_{PE})
- c. Coefficient of variation (CV)

Statistical SBM

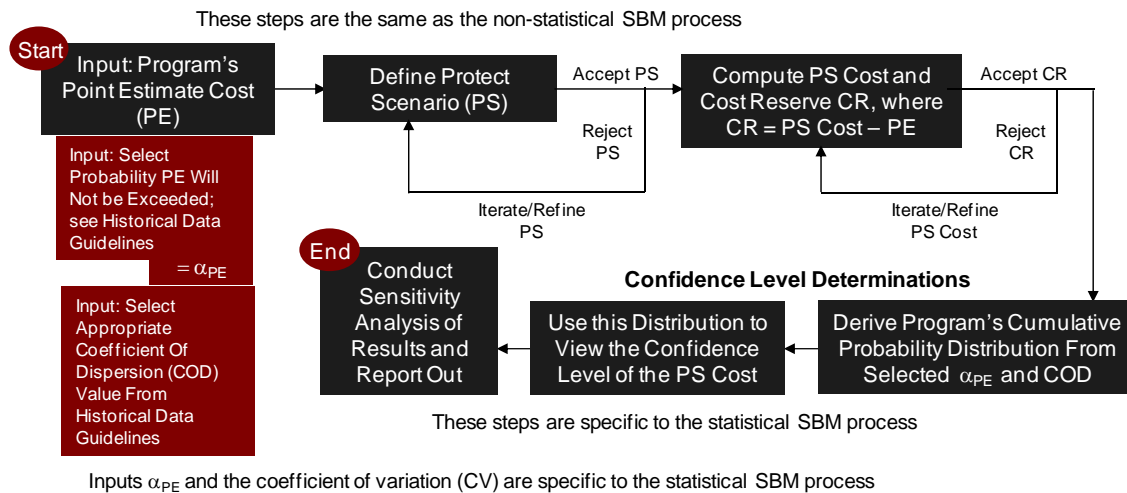


Figure 2. Statistical SBM
(Flynn & Garvey, 2011, p. 9)

The CV of a probability distribution is the ratio of the distribution's standard deviation to its mean. Equation 2 illustrates the calculation for determining a CV. The CV lets cost estimators and analysts produce the probability distribution function (PDF) and cumulative distribution function (CDF).

$$CV = D = \frac{\sigma}{\mu} \quad (2)$$

Two variations to the statistical SBM account for the difference between normal and lognormal probability distributions (Flynn & Garvey, 2011, pp.10–11). Equations 3–6 illustrate how the statistical SBM inputs are used to calculate the program's mean cost and cost standard deviation.



Normal Probability Equations

$$\mu_{\text{cost}_{pgm}} = x_{PE} - z_{PE} \frac{D(x_{PE})}{1 + D(z_{PE})} \quad (3)$$

$$\sigma_{\text{Cost}_{pgm}} = \frac{D(x_{PE})}{1 + D(z_{PE})} \quad (4)$$

Lognormal Probability Equations

$$\mu_{\ln \text{cost}_{pgm}} = \ln x_{PE} - z_{PE} \sqrt{\ln(1 + D^2)} \quad (5)$$

$$\sigma_{\ln \text{Cost}_{pgm}} = \sqrt{\ln(1 + D^2)} \quad (6)$$

The lognormal mean and standard deviation require conversion from log-dollars to dollars by Equations 7 and 8 (Garvey, 2005).

$$\mu_{\text{Cost}_{pgm}} = e^{\mu_{\ln \text{Cost}_{pgm}} + \frac{1}{2} \sigma_{\ln \text{Cost}_{pgm}}^2} \quad (7)$$

$$\sigma_{\text{Cost}_{pgm}} = \sqrt{e^{2\mu_{\ln \text{Cost}_{pgm}} + \sigma_{\ln \text{Cost}_{pgm}}^2} (e^{\sigma_{\ln \text{Cost}_{pgm}}^2} - 1)} \quad (8)$$

Analysts are now able to conduct a sensitivity analysis of the model by altering the α_{PE} and the CV. Alterations can create steeper or shallower slopes to the CDF, as well as shift the mean of the function. These alterations to the SBM allow cost estimators to produce reports that are similar to the widely accepted s-curve outputs.

D. NAVAL CENTER FOR COST ANALYSIS STUDY AND THE ENHANCED SBM

In Section C, I demonstrated the methods necessary to produce confidence intervals and CDFs for the SBM. Alterations to the α_{PE} and the CV allow cost



estimators to produce reports that are similar to the widely accepted s-curve outputs. The issue of how to ground the SBM in historical data still remains problematic.

In 2011, Flynn and Garvey conducted research of historical costs across all realms of DoD acquisitions in order to integrate historical data into the SBM. The research focused on determining the appropriate value for the program's α_{PE} and CV.

The Flynn and Garvey study (2011) derived a value of $\alpha_{PE} = 0.34$ for programs at Milestone B based on a historical CV equal to 0.51. Similar findings were noted in the 2007 RAND report (Younossi, 2007), which noted a $\alpha_{PE} = 0.09$ based on an implied CV = 0.26 at Milestone B. These two reports give analysts a bounded region of α_{PE} to work within. Now that a historical value range for the α_{PE} has been derived, the only input left to consider is the CV.

In the Flynn and Garvey study (2011), research focused on determining what actually drives the value of the CV for various programs. Their first conjecture was that cost growth factors (CGFs) have been historically consistent. The researchers found routine underestimation of cost within the DoD. The second conjecture was that CVs decreased throughout the acquisition process. The researchers confirmed this assumption of decreasing CVs as programs progressed through the acquisition life cycle. The third conjecture was that CVs were equivalent in all acquisition programs, regardless of platform. Again, the researchers proved this assumption to be true, especially from early milestones, such as Milestone B. The fourth conjecture was that CVs would be lower if they were adjusted to account for quantity changes and actual inflation. Again, the Naval Center for Cost Analysis (NCCA) researchers supported this assumption based on historical data. The fifth conjecture was that duration would have no effect on the CV. The researchers found no evidence to support this assumption; the data actually suggested quite the opposite (Flynn & Garvey, 2011).



E. SUMMARY

The possibility of producing historically based cost estimates with minimal statistical analysis has driven the desire for a new method of cost estimation. For any new method to be useful in the cost-estimating community, it would, as a minimum, have to meet the requirements of the WSARA (2009). The non-statistical SBM produces a cost-estimation method that is bounded by a scenario agreed upon by the program management team; it also derives the program's PE. The program management team's PE is coupled to a probability of achieving the estimated PE and a coefficient of variation to allow for statistically adjusted cost estimates. During Flynn and Garvey's (2011) study of program cost estimates, the eSBM gained the historical perspective necessary to achieve credibility with other cost estimators. The evolution of the SBM into the eSBM has revealed an all-new possibility of risk-adjusted cost estimation.



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III. METHODS OF ANALYSIS

A. NCCA HISTORICAL DATABASE

1. How the Database Was Created

The cornerstone of any research project is the collectable data. The NCCA collected and organized raw data from 100 Selected Acquisitions Reports (SARs). The SARs were mostly historical DoN major acquisition programs that were at various stages of completion (Flynn & Garvey, 2011). The database organized cost data in the following categories: current-year and then-year values, quantity adjustments, information on platform type, milestone cost estimates, and annual program cost updates. By creating a well-functioning database, the NCCA established the groundwork for further analysis.

2. Assumptions Used in the Database

From a managerial standpoint, the SAR is the best source of data for a program. The two key cost estimates present in the SAR are the Baseline Estimate (BE) and the Current Estimate (CE). Although the cost estimates in the SAR are not perfect, numerous cost studies have indicated that the SAR is the best source for comprehensive program data (Flynn & Garvey, 2011, p. 21). For the NCCA research, as well as for follow-on research, the BE is used as the initial cost estimate, and the CE of the last SAR for a program is used as the final actual cost. As stated by Flynn and Garvey (2011) in the eSBM,

based on an analysis of 10 programs in our database dating from the 1990s, there is little difference between the SAR BE, the program office estimate, and the Independent Cost Estimate (ICE) conducted either by the Naval Center for Cost Analysis (NCCA) or the Office of the Secretary of Defense (OSD). (p. 21)

B. NCCA ANALYSIS METHOD

In order to determine the CGF, the NCCA study used the ratio of BE to CE. As stated in Equation 2 (Chapter II), the CV is the ratio between the sample



standard deviation and the sample mean. For the different hypotheses in the NCCA study, the mean and standard deviation for each set of CGFs was calculated to determine the applicable CV.

1. Acquisition Milestone Adjustment

In the NCCA study, researchers calculated the CGF at Milestones A, B, and C for all programs in the database, regardless of platform or type. They then plotted the results, which revealed a lognormal distribution of CGFs for Milestones B and C. There was insufficient data to determine the distribution for data at Milestone A. The researchers used a statistical analogy to determine the approximate CVs for Milestone A. After calculating the CGFs for each program, researchers then calculated the CV for each program using both quantity and non-quantity adjustments for base- and then-year dollars. They then plotted the mean and range for CVs at Milestones A, B, and C to reveal lower CVs for the later milestones. The more accurate cost estimation can be explained by technology maturation as well as by clearer information about program parameters. It is noted in the NCCA study that the range of the CVs narrowed at the later milestones. Figure 3 illustrates the results of this analysis.

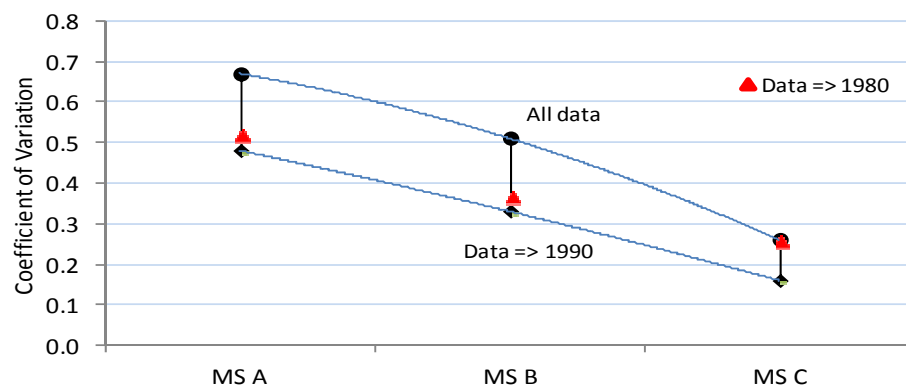


Figure 3. Benchmark CVs by Acquisition Milestone—Quantity Adjusted in Then-Year Dollars
(Flynn & Garvey, 2011, p. 28)



2. Platform Homogeneity

In the NCCA study, researchers also analyzed the difference in cost growth between platforms. For this part of the study, researchers separated the CGFs by program type. The type categories included ships and subs, aircraft, missiles, electronics, and other. Researchers calculated the mean and variance for each category to allow for an analysis across categories. The surprising finding of this portion of the study was that the CGFs were consistent across platforms and categories. At both Milestones B and C, the CGFs were within the 5% alpha confidence level. This finding proved that there is significant homogeneity between programs. Figures 4 and 5 illustrate the relationship of CGF to platform type at Milestones B and C.

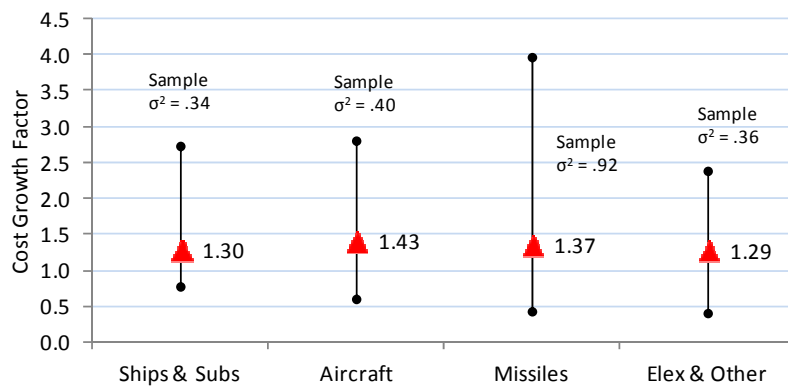


Figure 4. Milestone B: CGF Means and Variances (Quantity Adjusted in Then-Year Dollars)
(Flynn & Garvey, 2011, p. 24)



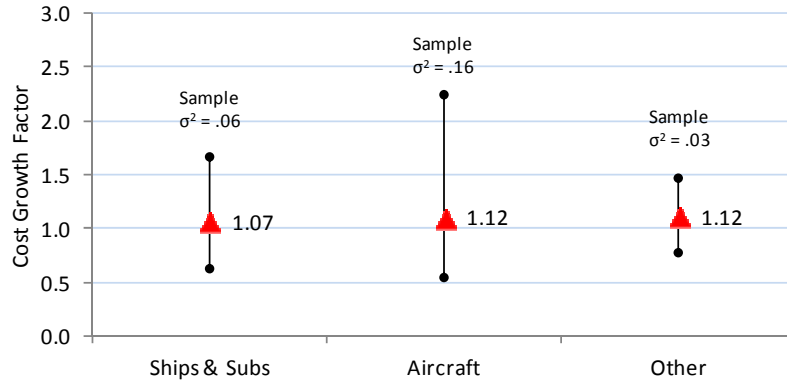


Figure 5. Milestone C: CGF Means and Variances (Quantity Adjusted in Then-Year Dollars)
(Flynn & Garvey, 2011, p. 27)

3. Quantity Normalization

To account for changes in the quantity of items being procured, researchers in the NCCA study analyzed the CV first without adjustment for changes in quantity and then made adjustments for changes in quantity. It was no surprise that the adjusted CVs were lower than the unadjusted CVs. It is the opinion of the NCCA researchers that “changes in acquisition quantity from a program baseline are generally regarded as beyond the purview of the cost analyst” (Flynn & Garvey, 2011, p. 22). The researchers conducted the quantity adjustment in two manners to determine whether the adjustment method had any effect on the calculated CVs. First, researchers scaled the BE to account for the actual number produced or acquired; next, they normalized the CE to reflect the actual cost if the original quantity was delivered. The differences between the two methods proved to be insignificant; however, the differences between the quantity-adjusted and the non-quantity-adjusted CVs were significant.

4. Inflation Normalization

Although SARs are adjusted to inflation, the values used are predicted inflation rates, not the actual rates observed during the time period covered by the program’s life cycle. Inflation rates are promulgated by the OSD to ensure that there is a standard set of inflation values used across all areas of the DoD. The problem



arises when the actual rates are drastically different than the predicted rates from OSD. An example of drastic differences between the two rates occurred during the Carter administration when the observed rate was nearly 10.7%, whereas the OSD was forecasting rates between 3% and 4% (Flynn & Garvey, 2011). By the time the OSD began to change the rates, inflation was on the decline and the OSD rates overestimated inflation during the Reagan administration (Flynn & Garvey, 2011). The researchers of the NCCA study calculated CVs using the original inflation rates and also using the actual historical inflation rates. Once again, they confirmed the expected effect of lower CVs for the historical inflation-adjusted estimates.

C. METHOD FOR ACQUISITION STRATEGY CV ANALYSIS

For my analysis of the effect of acquisition strategy on the CGF and CV, I placed each SAR in a category corresponding to the type of acquisition strategy used to procure the item. Once the programs were separated into their respective acquisition strategies, I computed each category's standard deviation and mean. From the mean and standard deviation, I was able to calculate the CV for each acquisition strategy. To ensure that the changes in the CGF and CV were not due to factors other than the acquisition strategy, I adjusted the values for the BE and CE to account for changes in quantity and for historical inflation rates.

D. METHOD FOR PROGRAM-LENGTH CV ANALYSIS

To analyze the effect of program length on the CV, I measured each program's total length and added the data to the NCCA database. I calculated the CGF for each program and then plotted the CGF against the program life span. Once the CGFs were plotted with respect to time, I determined the mean and standard deviation for the entire sample set so that I could derive an overall CV for program length.

I also segregated the CGF into three general time frames. The time frames were short acquisition lengths (< 5 years), average acquisition lengths (sample average +/- one standard deviation), and long acquisition lengths (> one standard



deviation longer than the average). For each category, I then had a CV calculated to determine a relationship between the program length and the expected CV. I adjusted the values for the BE and CE to account for changes in quantity and for historical inflation rates to ensure that the effects of the variation were due to program length and not inflation or quantity changes.

E. SUMMARY

The NCCA database of over 100 SARs, spanning the last four decades, is the single best resource of data on historical cost. The key assumption used in the NCCA study was that the SAR BE would be used as the program's initial cost estimate, and that the CE would be used as the program's final cost. To normalize the initial estimates, the BE would have to be adjusted to account for changes in quantity and changes in actual inflation from the estimated inflation rates used in the cost-estimation process. A ratio of the BE and the CE were used to calculate the program's CGF. The NCCA researchers calculated the CV for various combinations of CGFs to determine the appropriate CV to use in the eSBM. Additional research still needs to be conducted regarding acquisition strategy and overall program length. Comparing the CGFs for the different acquisition strategies and program lengths will provide further insight into the drivers for program CVs.



IV. ANALYSIS

A. INTRODUCTION

In this section, I describe the findings for my analysis of program length and acquisition strategy. Section B, in which I discuss program length, is divided into three parts: all programs, completed programs, and ongoing programs. Section C, in which I discuss acquisition strategy, illustrates the problems with correlating any one acquisition strategy with a CGF.

B. PROGRAM LENGTH

I conducted the data analysis for program length to determine a correlation between program length and CGFs. I grouped the programs into two different categories: completed and ongoing. Additionally, I developed a third group of programs to include all programs. In the following sections, I discuss the findings for the claim that the longer the program's length, the more cost growth can be expected.

1. All Programs

I used the *all programs* group as the control to determine any difference between the findings of Flynn and Garvey (2011) and my follow-on research. The sample data that I used included 50 Milestone B cost estimates. To verify Flynn and Garvey's results, I re-did the analysis for CGFs and CVs for all programs. My results were the exact same as those illustrated in Flynn and Garvey's 2011 eSBM paper. Their findings made a clear connection between the CGF and the quantity adjustment. Table 1 illustrates the Milestone B CGFs and CVs for all programs. Additionally, the relationship between base-year and then-year adjustments illustrates the relationship between the CGF and inflation for the same programs.



Table 1. Cost Growth Factors and CVs at Milestone B (All Programs)
(Flynn & Garvey, 2011, p. 22)

Cost Growth Factors & CVs for All DON MDAPs at MS B; n = 50				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year\$	Then-Year\$	Base-Year\$	Then-Year\$
Mean	1.49	1.86	1.24	1.36
Standard Deviation	0.94	1.61	0.44	0.69
CV	0.63	0.87	0.36	0.51

I analyzed the relationship between the CGF and program length for all programs. I assumed that no further schedule or performance growth would occur for the programs that were still ongoing. I conducted a regression analysis on all 50 programs. The most effective regression was the linear regression for all four cases: non-quantity-adjusted base-year dollars and then-year dollars, and quantity-adjusted base-year dollars and then-year dollars. Figures 6 and 7 illustrate the linear regression for all four cases. Figure 6 shows a slight correlation between CGFs and program length for the non-quantity-adjusted cases. The correlation is not as evident for the quantity-adjusted cases, as is shown in Figure 7.

The regression results for all four cases yielded insignificant results in determining a correlation between CGFs and program length. The results were insignificant at the 90% level, leading me to reject the hypothesis that there is correlation between the two variables. That is, I concluded that there is no correlation between the two variables. The analysis also failed the *F* test and *t* test, confirming the lack of correlation. The *R*-squared and adjusted-*R*-squared results for the non-quantity regression had a minimal significance; however, once quantity



adjustments were made, there was no longer any noticeable significance. These results deny the claim that program length has any effect on program cost growth.

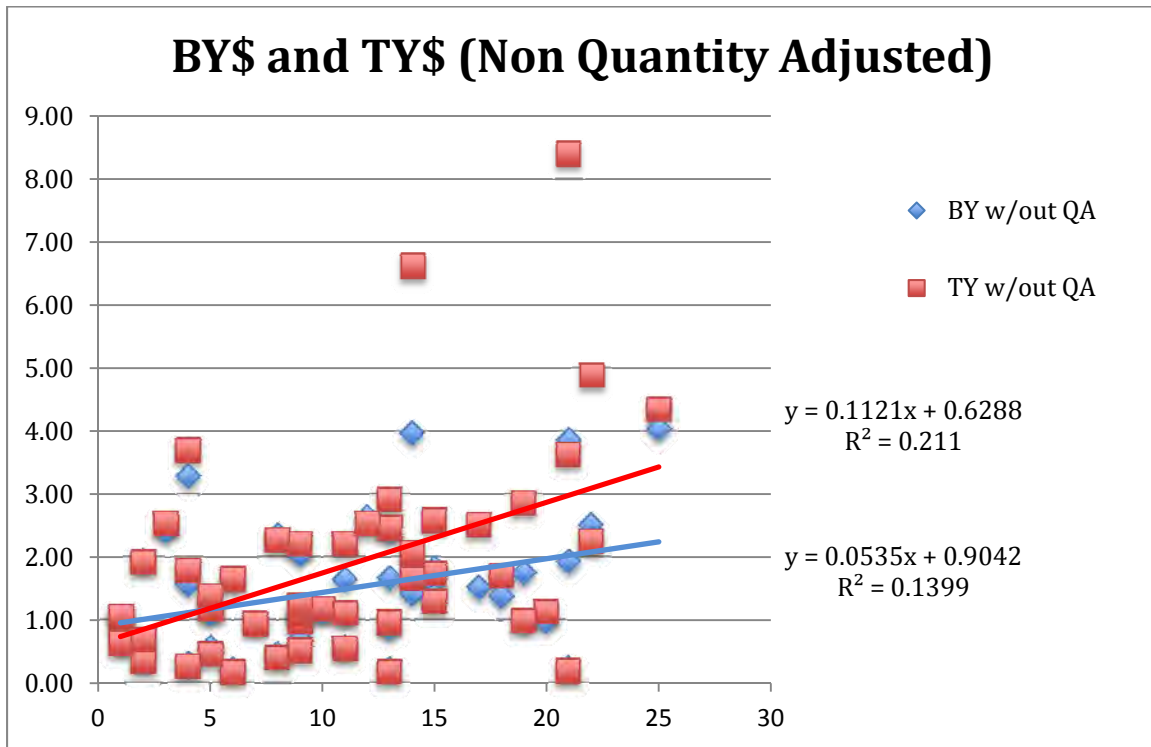


Figure 6. All Programs Non-Quantity-Adjusted Linear Regression



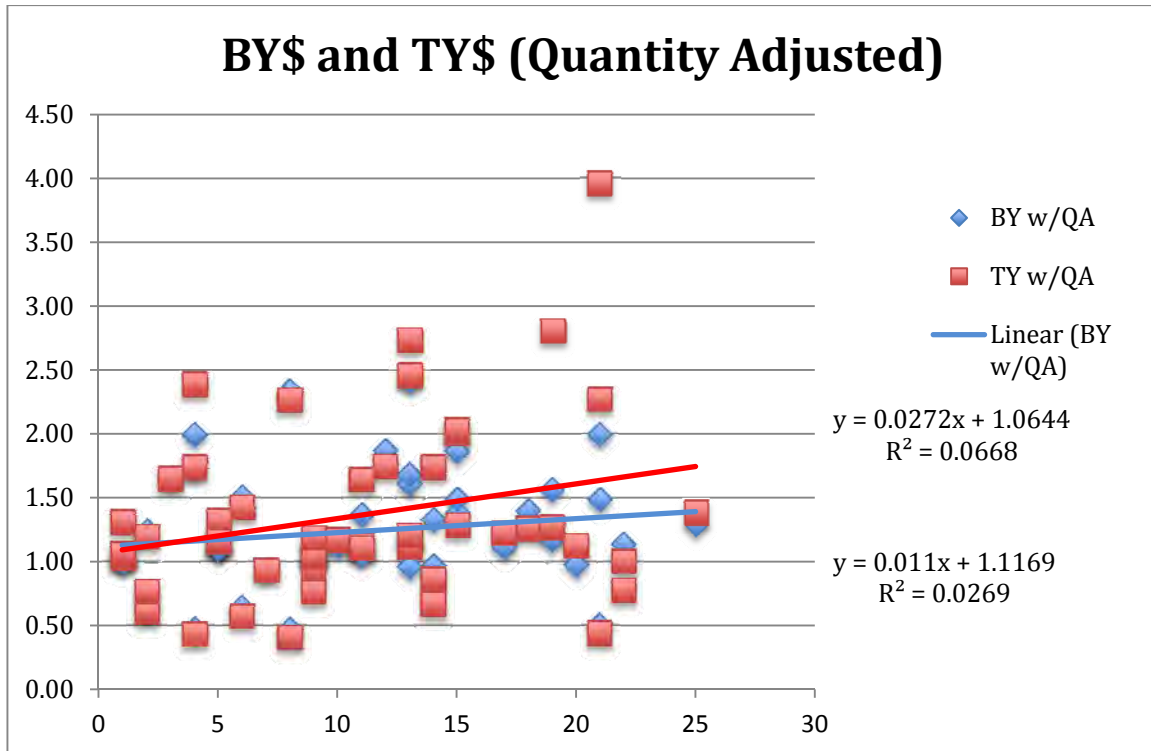


Figure 7. All Programs Quantity-Adjusted Linear Regression

2. Completed Programs

For the completed programs, the only assumption I made was that there were no outstanding costs. This is a fair assumption considering the amount of time that had elapsed for a majority of the completed programs. My first task was to conduct a regression analysis of the CGFs for all completed programs, using the Milestone B estimates against the program length. I set up the analysis to conduct all the normal regressions to include linear, exponential, and logarithmic regressions to produce the most significant regression result. The linear regression produced the most significant results for both quantity-adjusted and non-quantity-adjusted values of base-year dollars and then-year dollars. Figures 8 and 9 illustrate the linear regressions between the program length, on the x-axis, and the CGF, on the y-axis. Figure 8 suggests only minor significance to the claim that program length has some effect on the CGF; however, once the program was adjusted for quantity changes, the value for *R*-squared was reduced to an insignificant value, as illustrated in Figure 9. The adjusted *R*-squared values revealed an even lower significance for the



relation between the CGF and the program length to claim that program length has an effect on CGFs for completed programs. The non-quantity-adjusted values produced results with modest correlation, but that were still not above the 90% confidence level. Once I ran the correlations for quantity-adjusted CGFs, the correlation became even worse: all four analyses failed both the *F* test and *t* test for significance. I rejected the claim that program length affects cost growth for completed programs at the Milestone B cost estimate.

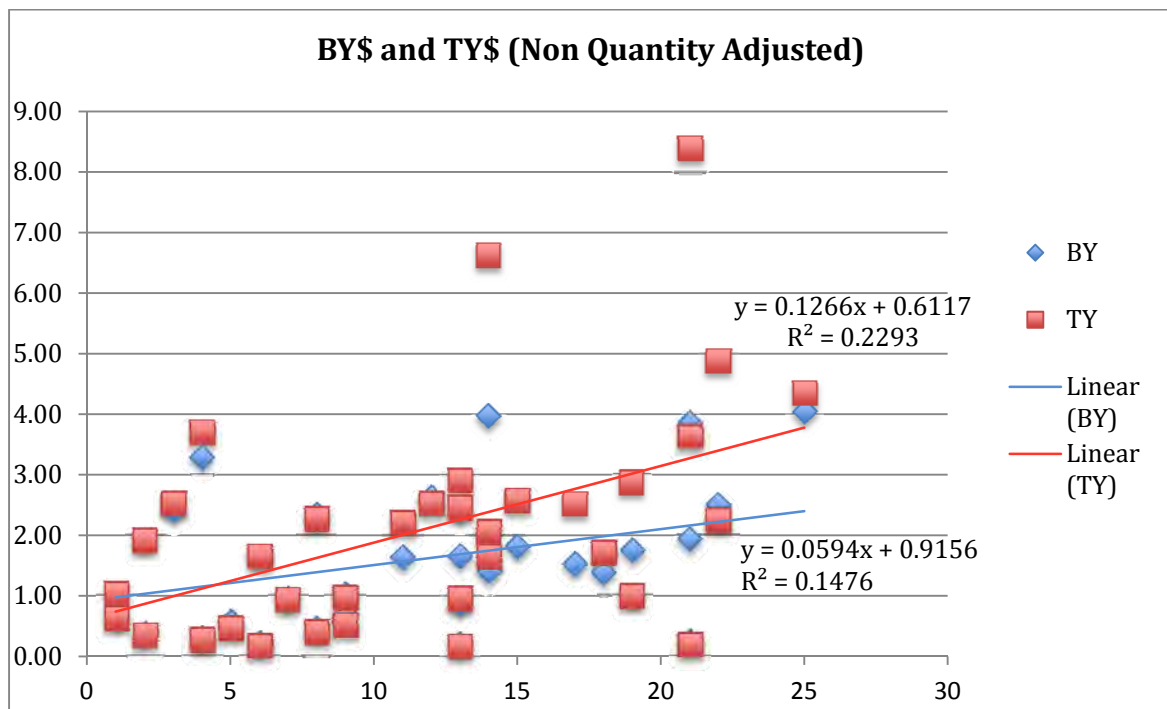


Figure 8. Completed Programs Non-Quantity-Adjusted Linear Regression



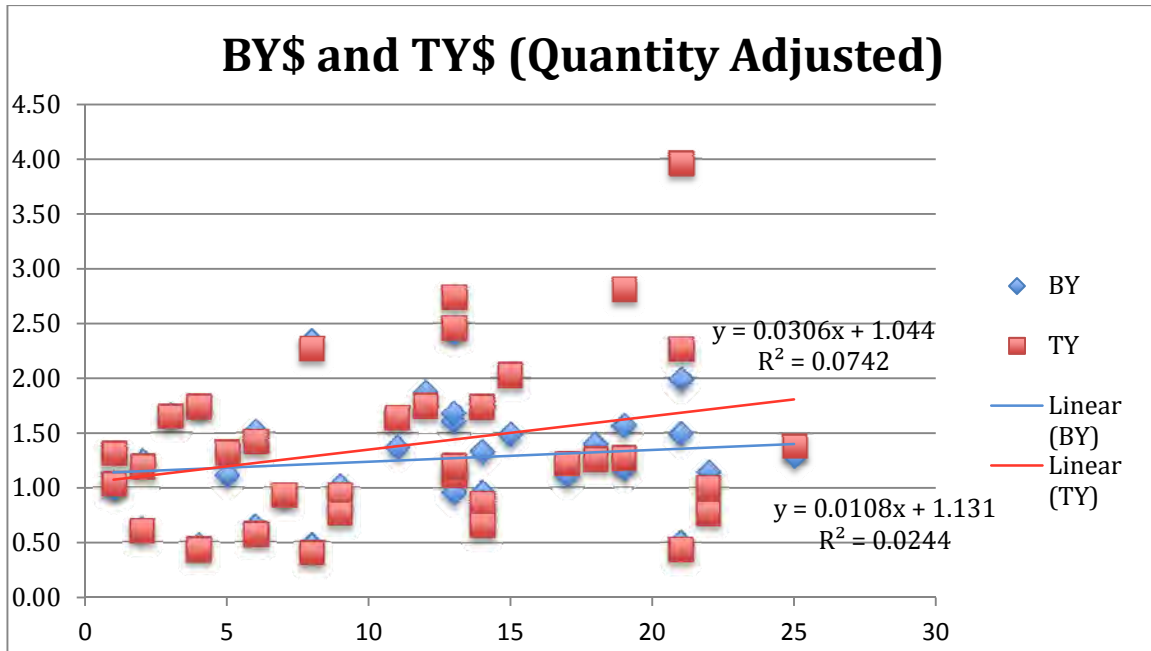


Figure 9. Completed Programs Quantity-Adjusted Linear Regression

The next analysis I conducted was to determine the average CGF and CV for the completed programs. Table 2 illustrates the CGFs and CVs for the completed programs from the Milestone B estimates. These values are consistent with Flynn and Garvey’s (2011) findings, as illustrated in Table 1. My findings validated the claim that changes in program quantity play the most significant role in determining cost growth. The results of the completed programs produced more significant results than the results of all programs due to the removal of the ongoing programs.



Table 2. Cost Growth Factors and CVs at Milestone B (All Programs)

Cost Growth Factors & CVs for Completed DON MDAPs at MS B; n = 35				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year\$	Then-Year\$	Base-Year\$	Then-Year\$
Mean	1.61	2.10	1.26	1.40
Standard Deviation	1.07	1.84	0.48	0.78
CV	0.66	0.87	0.38	0.56

3. Ongoing Programs

The results for ongoing programs revealed a negative relationship between CGFs and program length. The negative cost growth for ongoing programs was unexpected and counterintuitive to the results of the completed programs. Programs with the most time remaining until completion have lower CGFs. Also, the differences between non-quantity-adjusted and quantity-adjusted CGFs are not as obvious because many of the programs have yet to be affected by quantity drawdowns. Additionally, many of the programs have not been in existence long enough for the effects of inflation to become relevant. Figures 10 and 11 show the negative relationship between CGFs and program length for ongoing programs. The regressions for the ongoing programs also showed large standard errors and low adjusted *R*-squared values. There was some significance at the 90% confidence level for all four cases; however, there were only 10 observations that reduced the reliability of these findings. Once again, the findings of this research contradict the claim that program length has any effect on cost growth.



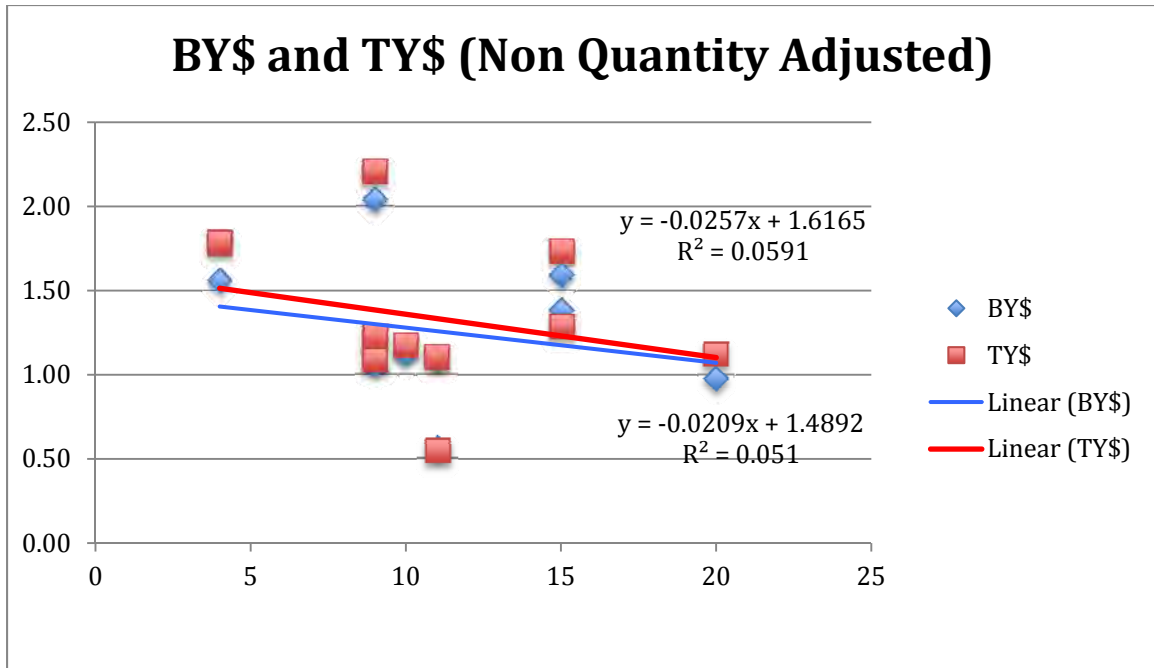


Figure 10. Ongoing Programs Non-Quantity-Adjusted Linear Regression

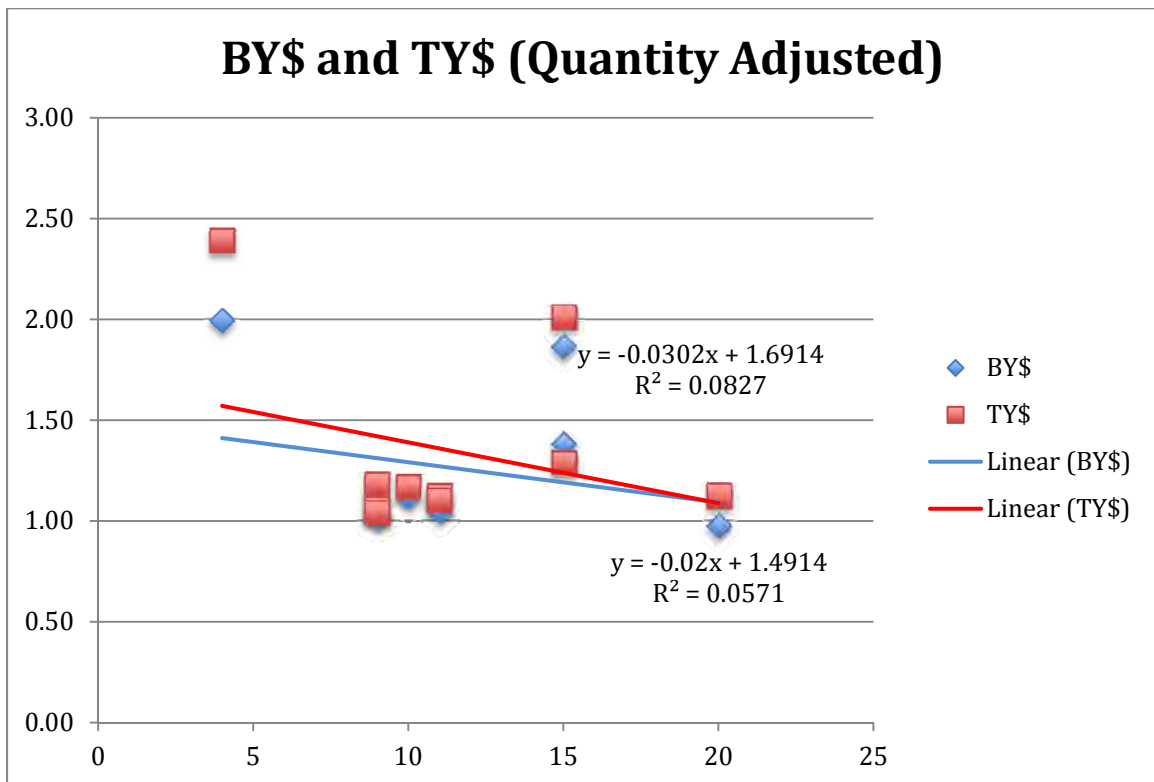


Figure 11. Ongoing Programs Quantity-Adjusted Linear Regression



Table 3 shows the average CGFs and CVs for the ongoing programs. Even for the ongoing programs, the CGFs and CVs for the quantity-adjusted values were within the range of the completed program threshold.

Table 3. Cost Growth Factors and CVs at Milestone B (Ongoing Programs)

Cost Growth Factors & CVs for All DON MDAPs at MS B; n = 10				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year\$	Then-Year\$	Base-Year\$	Then-Year\$
Mean	1.25	1.33	1.27	1.35
Standard Deviation	0.41	0.46	0.37	0.46
CV	0.32	0.35	0.29	0.34

C. ACQUISITION STRATEGY

1. Types of Acquisition Strategies

The analysis of acquisition strategy resulted in more questions and no definitive answers. The problem with relating any one acquisition strategy to a CGF is the complexity of the acquisition system and modern program management. Program managers use a mixture of contract types during the Milestone B and beyond the contracts negotiation stage. For the current ongoing programs, each program uses a mixture of firm-fixed-price (FFP), fixed-price-incentive-fee (FPIF), cost-plus-fixed-fee (CPFF), cost-plus-incentive-fee (CPIF), and cost-plus-award-fee (CPAF) contract types. The problem of assigning an acquisition strategy to a single contract type becomes more difficult when the issue of awards and incentive fees is taken into account. Awards and incentives are written into contracts at the beginning but not awarded until contract completion.



2. Continuation of Research

The next step in trying to determine how acquisition strategy affects cost growth is to break down cost growth for each contract type into individual CGFs. Once the individual CGFs have been determined, they can be weighted to account for the relative amount each contract contributes to the total program cost. Breaking down the programs to the next lowest level allows for further insight into the drivers of cost growth.

D. SUMMARY

To the 95th percentile confidence level, I have rejected the hypothesis that as program length increases so does the CGF. Furthermore, the findings of this research have confirmed the findings of the NCCA study on CGFs and historical CVs. The analysis of program length yielded no significant relationship between the program length and CGFs. The analysis of program length reiterated the effects of quantity changes on CGFs as a significant driver for cost growth. Additionally, the effects of inflation on program cost growth continue to plague the cost-estimation community. Neither the changes in quantity nor the changes in inflation rates are under the control of the cost estimators; however, these changes must be accounted for in the cost-risk profile.



V. CONCLUSION

A. SUMMARY

In Chapter I, I discussed the basis for this research and the issue of risk-adjusted cost estimation using the Monte Carlo simulation method. The defining issues with cost estimation at Milestone B include the uncertainty of a clear program direction, the difficult statistical processes, and the unbounded reality of possible consequences. These difficulties led to the need for a new method of calculating risk-adjusted cost estimation. A new method would be beneficial to everyone involved in the acquisition process, from the MDA to the cost estimators.

In Chapter II, Literature Review, I described Paul Garvey and Brian Flynn's (2011) findings as a more effective method of risk-adjusted cost estimation. This chapter started with the necessary requirements defined in the WSARA (2009). This act tasks the director of CAPE with issuing guidance on the appropriate confidence intervals to be used and with justifying their use if that level is below the 80% threshold. Garvey's (2005) SBM provided the framework for a simplified method of risk-adjusted cost estimation using the statistical SBM. Flynn and Garvey's (2011) study on CGFs and CVs led to enhancements in the SBM that aligned the new eSBM with the requirements of the WSARA (2009).

Chapter III, Methods of Analysis, included two parts: what has been done in the past and what this thesis does differently. The NCCA study brought to light the issues of inaccurate inflation estimates and quantity adjustments as significant reasons for cost growth. The NCCA study also debunked the theory that there are secular differences in cost growth across program types. The methods used in this thesis were aimed at relating cost growth to program length and acquisition strategy.

I based my analysis in this thesis on two hypotheses: first, cost growth increases as program length increases; and, second, different acquisition strategies yield different rates of cost growth. I rejected the first hypothesis with a high degree



of confidence because I noted no correlation between program length and CGF. My analysis of program length did, however, further support Flynn and Garvey's (2011) findings that inflation and quantity adjustment are the most significant sources of cost growth. During my analysis of the second hypothesis, I discovered that no single acquisition strategy is used in contracting an MDAP. The complexity of acquisition strategy made the second hypothesis impossible to validate in the manner that I illustrated.

B. RECOMMENDATIONS

I recommend two main areas for continued research on historical cost growth and potential cost drivers.

The first major area that needs to be researched is in contract management and in the methods used as possible cost drivers. This area should include a breakdown of each program to the contract level to determine the cost growth for different contract types, and then the contract types across programs could be compared as potential links to cost growth.

The second area in which research could be beneficial is the effect of awards and incentives on cost growth. An analysis of what percentage of cost growth is accounted for in awards and incentives could lend insight into how to more accurately estimate awards and incentives for MDAPs.

Other areas in which research is still needed in the risk-adjusted cost-estimation arena include

1. how the eSBM compares to the Monte Carlo simulation at later milestones, and
2. how to account for and eliminate PM bias during the cost-estimation process.



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- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
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- Managing the Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21st-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting



Financial Management

- Acquisitions via Leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning
- Capital Budgeting for the DoD
- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-term Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness



- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)
- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
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