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ENGINEERING CHANGE ORDERS AND THEIR IMPACT ON DOD ACQUISITION CONTRACTS

THESIS

Ian S. Cordell, Captain, USAF

AFIT-ENC-MS-17-M-180

DEPARTMENT OF THE AIR FORCE
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ENGINEERING CHANGE ORDERS AND THEIR IMPACT ON DOD ACQUISITION CONTRACTS

THESIS

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In Partial Fulfillment of the Requirements for the

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Ian S. Cordell, B.S.

Captain, USAF

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Engineering Change Orders and Their Impact on DoD Acquisition Contracts

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Abstract

Cost growth is a problem DoD wide. Cost Estimators attempt to remedy this problem by accounting for uncertainty in the estimates they complete. They use tools such as Engineering Change Orders (ECO's) to account for the uncertainty, by applying a percentage to the final amount estimated. The following research gives the acquisition community a more precise tool to predict whether a DoD Acquisition Contract will have an Engineering Change Order, which can then be used also during programmatic cost estimating, and also a method for predicting the proper amount of ECO to apply when certain variables are present. The study used both logistic and multiple regression to accomplish this. For both types of regression a stepwise approach was adopted for the response. For the Logistic Regression the Y variable was that an ECO was present and the significant predictor variables were: UAV, >500M (dollars), Navy, Army, Aircraft, Firm Fixed Price (FFP), Cost Plus Fixed Fee (CPFF) and <5M (dollars). The final model was 85% predictive. The multiple regression modeled the expected ECO percent change (less than 100% of baseline). Predictive variables included: <5M, FFP, Munition, Electronics and Missiles, along with a base amount of 22% ECO. This model was more exploratory in nature due to the extreme variability present in ECO percent changes.

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Ian S. Cordell

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I. Introduction

General Issue

When it comes to budget decisions for the Department of Defense (DoD), cost estimates drive the amount of funding placed on all contract types. The accuracy of cost estimates is imperative so as to ensure the proper amount of money is set aside by Congress to acquire the weapon systems and platforms needed to complete the U.S. military missions. Furthermore, cost estimates are what drive the Acquisition Program Baseline (APB), which is the determined amount of funds allocated to an acquisition program. Historically, these estimates have been wrought with inaccuracies due to cost-overruns and mission creep. Cost overruns refer to going over the budget, and mission creep refers to added features that come with added costs to budget baselines.

Cost overruns repeatedly show that estimates are predicted too low in comparison to the actual execution cost for an acquisition programs. According to DeNeve, "inaccurate cost estimates are a recurrent problem for Department of Defense (DoD) acquisition programs, with cost overruns exceeding billions of dollars each year. These estimate errors hinder the ability of the DoD to assess the affordability of future programs and properly allocate resources to existing programs (DeNeve, 2014, ii)." With the DoD operating in a more fiscally constrained environment due to shrinking budgets and sequestration, the accuracy of estimates created by the Air Force Life Cycle Management Center (AFLCMC), Air Force Cost Analysis Agency (AFCAA), and similar agencies from other branches of the military are now an essential topic of discussion.

In order to purchase any item, however, a contract must be set in place because contracts are the means by which programs are carried out and executed. A significant aspect of any contract is the cost estimate associated with the specific item(s) a program desires to acquire. When accomplishing cost estimates, agencies do their best to find programs who previously purchased similar items as a reference point for the new item they want to purchase. This is oftentimes a reasonably accurate approach to account for existing items. However, due to the ever improving and evolving weapons systems, there are also unknowns that must be taken into account.

One of the main methods the DoD implements into both the development cost and the production cost estimates are Engineering Change Orders (ECOs). ECOs are blanket percentage amounts added into the cost that the estimate compiles. As a rule of thumb, for development cost estimates, a ten percent cost is added to the estimate; whereas, for production estimates, a five percent cost is added. A recent study conducted by Valentine (2015) indicated that the ten percent charge added to estimates for development may not be accurate: "The ECO factor for Air Force, cost-type development contracts tend to follow a probability distribution" (Valentine, 2015, 34). That study was the basis for this thesis; Valentine acknowledges more research is required into ECO's to make them into an accurate measure.

Problem Statement

Cost estimating methods are limited to the accepted standards that are already set in place. The overall ECO percentages that are applied to programs are never altered, even if programs go over budget and need to be re-baselined. Even when ECO

percentages are applied, the length of the contract or the type of system being acquired is not considered. Even though there are historical inaccuracies on initial cost estimating as well as a tendency for contracts to go over their intended amounts, ECOs remain either overlooked or not even considered as a source of cost growth

Research Objective

This thesis focuses on ECOs and the actual historical funding that was spent over the course of a contract as a result of specified engineering changes. The purpose of this research is to establish proper resource allocations and affordability estimates that can be implemented early on in the Major Defense Acquisition Programs (MDAPs) process. Our objective is to either find a better way to account for ECOs, other than a set standard percentage, or find a more appropriate percentage to add to an estimate, one that will properly capture the desired item to be procured. Factors that may influence the proper application of ECOs include service branch, type of acquisition program, and length of program. The purpose of this thesis is move ECOs from a mere placeholder to a valuable tool at the Department of Defense's (DoD's) disposal.

Investigative Questions

These are the questions our research desires to answer:

1. How can logistic regression incorporate common variables to accurately predict whether a contract will contain an ECO?
2. Using a multiple regression model, what is the appropriate percentage to be applied to cost contracts based off of certain common variables that will accurately depict the proper amount of ECOs?

Methodology

This study concentrated on as many DoD acquisition contracts as possible, to include a wide spectrum of various programs and weapon systems. This was accomplished under the assumption that in order for DoD mandated programs to execute properly, contracts must be seen as the building blocks. The contracts considered in this thesis are from all four major branches of the military, both development and production type contracts. However, it should be noted that only historical contracts that have already been executed will be examined.

The beginning phase of this study involved acquiring data from a Defense Cost and Resource Center (DCaRC) database created by a company called Techonomics. This data base contains historical contract information, to include: initial award amount, total baseline, award plus baseline growth, cost growth, schedule related costs, and most importantly, technical costs, which denote the ECO amount.

Once the data was obtained and compiled, statistical software such as JMP® or Excel were used to model techniques to detect patterns and statistical significances. To be specific two different regression were completed; first a Logistic Regression was run in order to predict whether a contact would contain ECO and Multiple Regression was then performed to predict the percent, on the contracts where ECO was present.

Assumptions and Limitations

The contracts were retrieved from the Technomics Database; while they were collected in “no particular order”, they do not technically make up a random sample. Only Acquisitions Category (ACAT) Level I programs were analyzed in this thesis.

Furthermore, only executed contracts as well as unclassified contracts were considered for this study.

Summary

In order for contracts to reflect the precise end amount, it is important to ensure that each method that go into a cost estimate is accurate. The current approach of predicting the amount of ECO based on two single-blanket amounts, in reality, may not be the best way to ensure accuracy of the amount placed on contracts.

With this problem in mind, Chapter 2 delves into our literature review, which identifies further reasons for implementing an ECO percentage as well as to ascertain some of the reasons and implications for inaccurate cost estimates. The literature review provides the basis with which we approached our data collection and methodologies discussed in Chapter 3. In Chapter 4, we present the two different regression analyses results in addition to validating our various findings. Lastly, Chapter 5 provides our conclusions from the study and possible follow-on research for future researchers.

II. Literature Review

Introduction

The process to acquire a new weapon system is lengthy and consists of numerous components. Accurate cost estimates that properly represent the cost of the components is important in order to capture the right amount of resources. Oftentimes cost estimates have been very inaccurate, causing numerous programs to exceed their allotted budgets. This act of going over budget is referred to as "cost overruns." The purpose of this chapter is to summarize previous research that has been accomplished regarding cost overruns and their impact on DoD acquisition programs. Chapter 2 also analyzes the different methods of dealing with uncertainties and how risk can lead to cost overruns.

One major component of cost overruns is covering the cost of unknowns or risks, such as technological advances or failures that cause changes in engineering. These costs are often covered by what is called a management reserve (MR). MRs are a certain portion of the program's budget that is set aside to be used for changes that may come into play that are considered within the scope of a project. The specific nomenclature for these within-scope changes in engineering or technological design is referred to as Engineering Change Orders (ECOs). The unknowns are referred to as uncertainty, and the more unknowns, the more ECOs are possible. Similarly, MR's are "an important part of effective planning and control on defense contracts. Presumably, contracts with greater risk (uncertainty) will have a need for a greater MR budget" (Christensen, 2000, 191). If ECO's can more accurately be predicted they can lead to a more accurate application of MR's throughout the estimating and contracting processes.

To initiate our thesis and meet our objectives, we start by looking at previous research accomplished in the acquisition arena. First, we look at cost overruns and cost growth to seek evidence of historical issues. Second, we examine management reserves and more specifically, how they attempt to account for risk and uncertainties. Third, we explore ECOs and what impact they have on MRs, which can lead to cost overruns.

Cost Overruns

To begin, we bring attention to the problem of cost growth. Research conducted by Arena, Leonard, Murray, and Younossi (2006) studied weapon system cost growth across all branches of the military. Their primary source for acquiring data was via Selected Acquisition Reports (SAR), which were prepared by all major defense acquisition programs (MDAPs) to be presented to Congress. Overall their research reviewed 220 programs from 1968-2003. The study measured cost growth using the current cost estimate for the program as a ratio to the percent of a prior cost estimate. Their research found that the final program cost was 46 percent higher than Milestone II (Milestone B, Figure 1) estimate, and 16 percent higher than Milestone III (Milestone C, Figure 1). The cost growth was shown to be 20 percent higher than the previous similar study conducted by their research group the RAND Corporation. Their study concluded that the DOD and Military Departments largely underestimated the cost of purchasing new weapons systems. We utilized this study to demonstrate how, historically, DoD cost estimates are inaccurate and much lower than the final cost of a material development's life.

Ben-Ari, Berterau, Hofbauer, and Sanders (2010), is the next research used to exemplify the problem of cost growth. Ben-Ari et al.(2010) researched the root cause behind cost and schedules delays for MDAPs). Their research was based on a

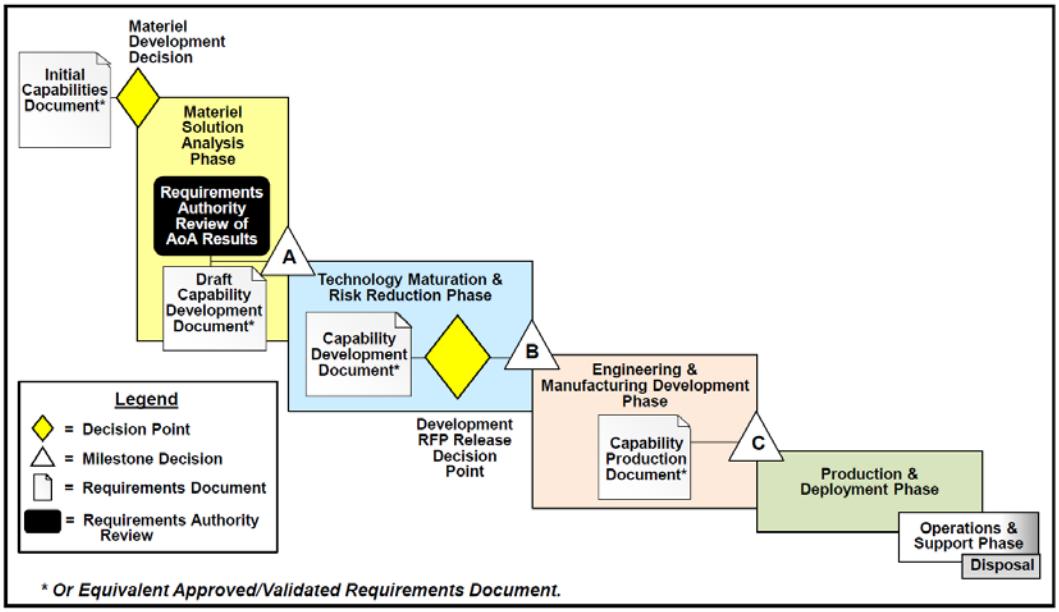


Figure 1 Acquisition Process, USD (AT&L). (2015, January 7). Department of Defense Instruction 5000.02.

Government Accounting Office (GAO) study that showed in FY2008 the 96 MDAPs went $296 billion dollars over budget. For the purpose of our research, this study was used study to emphasize the problem cost overruns in the DoD.

To complete this study Ben-Ari et al. (2010) examined several variables to determine what may contribute to cost overruns. The variables were “realism of baseline program cost estimates, government management and oversight, the role of contractors and lead military services, levels of competition, and contract structures” (Ben-Ari et al., 2010, 14). They examined three data sources: SARs, Federal Procurement Data Systems (FPDS) and Department of Defense Budget Documents. Next, they looked at programs

that were in Milestone B or beyond which is “normally the initiation of an acquisition program. This common starting point ensured that only programs in a relatively mature acquisition phase are compared” (Ben-Ari et al., 2010, 14). Ben-Ari et al., (2010) found that cost estimating was responsible for cost overruns by being overly optimistic. They found that time-costs were not impactful on cost overruns and that most of the patterns have other secondary or tertiary factors explaining cost overruns. They then suggested using more rigorous quantitative and qualitative research to find the root causes, which we attempted with our study.

To further examine this issue we look at an article by the GAO (2011). In 2011 the GAO Director Sullivan made a statement before the Committee on Homeland Security and Governmental Affairs on the trend in Nunn-McCurdy breaches, factors responsible for trends in the breaches, and tools besides Nunn-McCurdy that could be used to minimize cost-overruns. Nunn-McCurdy breaches occur when a programs unit cost exceeds certain thresholds. When this occurs congress must be notified. Sullivan stated that “Nunn-McCurdy breaches are often the result of multiple, interrelated factors. Our analysis of DOD data and SARs showed that the primary reasons cited for the unit cost growth that led to Nunn-McCurdy breaches were engineering and design issues, schedule issues, and quantity changes” (2011, 4). This is significant for the purpose of our study. Engineering/design issues were the most cited as a cause of the breach, with fifty citations, the next closest was scheduling issues, which had forty-four citations. (Figure 2).

Sullivan (2011,6) states, “to put programs in a position to minimize the risk of cost growth, DOD must use the tools available to it to establish programs in which there

is a match between requirements and resources—including funding— from the start and execute those programs using knowledge-based acquisition practices." This tool as

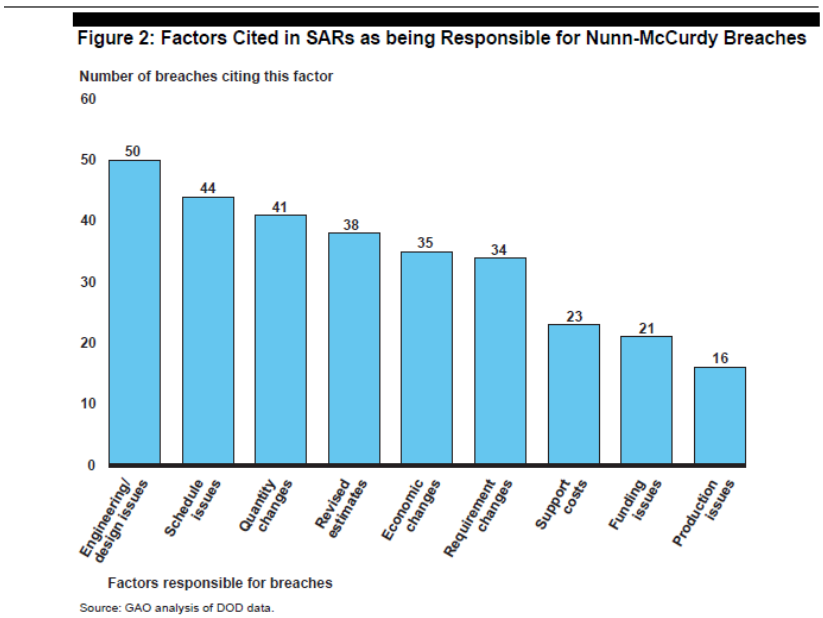


Figure 2 Factors Cited in SARs as being Responsible for Nunn-McCurdy Breaches, Sullivan (2011)

described by Director Sullivan is what ECOs can and should be used for. Sullivan's article demonstrated the commonality of cost overruns and the need for devices such as ECOs for the DoD to reign in cost-overruns.

Through Calcutt's study (1993), we were able to further address the causes of cost overruns. Calcutt (1993) studied the history of cost growth in the DoD. He acknowledged a large portion of the growth resulted from improperly accounting for uncertainty and risk. He created several recommendations, but his fourth suggestion is the most relevant to our research. Calcutt was interested in looking "further into MRs to study the impacts of them on other programs and what total would be required" (Calcutt 1993,5). Although this study only briefly mentions MRs, it does place an importance on them, along with the importance of keeping costs under control. Calcutt also mentioned how the overrun

problem could become emphasized with shrinking budgets. He describes how companies will agree to lower amounts of contracts just to win them, which would in turn lead to cost overruns as contracts are actually executed.

Throughout these studies, the researcher's emphasis is on inaccurate cost estimating and the impacts that not estimating correctly can have upon scarce financial resources. As found in previous studies, uncertainty is a very large portion of what leads to cost overruns. This concept is exemplified by Frank Husic (1968) when he described cost estimating relationships (CER). In his research he expounded upon the fact that each piece of the estimate is comprised of smaller pieces, all of which must be accurate in order for the overall estimate to be accurate. Husic notes that "for each of a multitude of other important inputs, similar decisions are made, and a single aggregate cost is obtained as the output of the cost model" (Husic, 1968, 4). Husic is implying that after all of the decisions are made, the smaller pieces are put together for a cost estimate. This is a key component to our study. The ECO is currently a small piece but it can have a very large impact on the final number.

Management Reserve

Tools are set in place, such as MRs, to act as pieces to the overall estimate. Kevin Gould (1995) offers an in-depth analysis of the usage of MRs in the DoD budgeting procedures. Gould describes MRs as a budget that "is held in a reserve account controlled by the contractor project manager and is intended for management control purposes rather than designated for the accomplishment of a specific task or set of tasks" (Gould 1995, 2). He goes on to describe the necessity for such an allotment so as to create an incentive for doing a job efficiently and using the MR to account for in-scope

unanticipated growth changes. He found three methods for developing the MR: non-participative, participative, and a combination of the two. Non-participative includes funds put in by upper-management, participative was done by lower levels, and a combination is simply using both methods together.

To analyze MR usage, Gould's methodology included a sample of five contractor system descriptions. Once he reviewed each description and compared the methods and procedures used by particular contractors with whom interviewed, he then looked for correlations. The interviews consisted of phone interviews, which were transcribed and verified by interviewees for completeness. After conducting his interviews and correlations, Gould found that no prescribed format existed by which contractors applied MRs; instead, he typically found that less than one page of the system description was dedicated to the development of the MR. This led to a confusing way of developing the MR, which he feels should be very straight forward. For the purpose of our research, Gould showed that no industry accepted method of accounting exists for unknowns or risk using an MR.

While MR's are a tool used by estimators, they are not without problems. Some of these issues are addressed by Woodard (1983) who was critical of the method used by the DoD to account for risk and uncertainty in establishing budget baselines. He began his study by emphasizing the impact of inaccurate estimates on scarce resources: "Presently DoD is faced with the same problems of how to accurately estimate costs and control cost growth. Funds are limited and DoD has to compete with other increasing needs of the nation such as social welfare programs, energy, etc."(1983, 5). Within his research,

Woodward (1983, 5) only focused on development costs and attempted to answer three questions:

1. Should MR's be visible?
2. Should a better approach be implemented estimate risk?
3. Does another problem cause this uncertainty that has not been discussed?

Woodward looked at the normal techniques of expert opinion, analogy, parametric, and a method of breaking down a project into segments. He called this method "Industrial Engineering Approach,". After looking at risk, he then talked about different methods of looking into uncertainty. In his findings, Woodward (1983) concluded that three areas need to be considered regarding the management of risk and uncertainty: methodology, techniques, and databases. He found that no universal DoD policy occurred to establish MRs or account for uncertainty. He discussed how this is a political issue that needs to be formally recognized and standardized. He proposed that the DoD had an issue where MRs were hidden to keep costs below certain levels, when instead MRs should be transparent. Woodward also noted that "better risk management techniques are needed rather than just developing more mathematical techniques to quantify risk" (1983, 108). What Woodward describes here is that besides simply adding mathematics techniques, more robust data must be applied that may be more qualitative real word correlations, such as analogous programs or similar contracting methods and how much they expanded in the past.

Christensen and Templin (2000) further emphasized MRs analysis in their research. This study began by defining an MR's purpose as providing "an adequate budget for in-scope but unanticipated work on the contract. As a contract proceeds to

completion, an unanticipated, in-scope work is identified, an MR budget is allocated to that work" (Christensen and Templin, 2000, 910). This is similar to Gould's definition (1995, 191) of an MR with DoD Policy Documents: "the primary purpose of an MR budget is a reserve forum certainties related to in-scope but unforeseen work" (DoD, 1997, 12). However, where Christensen's study differs from Gould (1993) is that he sought to quantify an amount that should be applied to management reserves, instead of looking for patterns in a qualitative method.

To quantify the amount required for a management reserve, Christensen and Templin, (2000) relied on descriptive statistics. They focused on the uncertainty of projects, where more uncertainty had more MR budget and less uncertainty had less MR budget. Christensen and Templin. (2000, 196) started their research with 3 hypotheses:

- H_{1o}: Median MR percent development > Median MR percent production contracts

- H_{1a}: Median MR percent development contracts < Median MR percent production contracts

- H_{2o}: Median MR percent price contracts > Median MR percent cost contracts

- H_{2a}: Median MR percent price contracts < Median MR percent cost contracts

- H_{3o}: Median MR percent Army = Median MR percent Air Force =Median MR percent Navy contracts

- H_{3a}: Median MR percent Army ≠ Median MR percent Air Force ≠ Median MR percent Navy contracts

The data used to conduct these tests was pulled from a monthly cost and schedule database maintained by the Office of the Undersecretary of Defense for Acquisition Technology and Logistics (OUSD AT&L), (Appendix B).

In the summary of their findings, Christensen and Templin (2000, 199) had mixed results for their hypotheses. Their first hypothesis looked at the median MR between production and development contracts and found that development was higher, but the results were not statistically significant. Null 1 could not be rejected. For Hypothesis 2, the median MR percent on fixed-price contracts was greater than the firm on cost equals reimbursable. The difference was significant so they rejected the null. The null Hypothesis 3 was also rejected, demonstrating that the MR budget is sensitive to the branch managing the contract. Christensen's study was vital to the research we conduct as they looked at the big picture of total MRs; whereas, our study looked at one component of MRs, being that of ECOs. The difference being that ECO's focus on engineering changes, and MRs look at all uncertainty within scope of a contract.

Engineering Change Orders

To focus in specifically on ECOs, we looked at an NRO Cost Group (2005) study that was one of the first to focus on engineering changes and their impact on the final bottom line of an independent cost estimate (IDE). This study was limited, but it shed light on the issues surrounding how much should be included in an estimate to best compensate for

The NRO Cost Group analyzed 21 space related programs that ranged from 4 million dollars to 4 billion dollars. In this study, engineering change orders are referred to as "engineering change proposals," but they are the same by definition. The research

showed that, of the expected cost growth contained in the program, approximately 20%-30% would be for new technical scope, which contained the ECOs. Some total cost growth can be as much as 200%, which indicates that the majority of the growth is not solely contained in ECOs; however, a large portion is reflected in them and if the ECO's are not accurate than the overall accuracy will be lower, even if variables other than ECO's also caused cost growth.

Another study conducted by Valentine (2015) set out to analyze the effect of ECOs on cost growth. He narrowed his search to an Air Force specific contract type. Valentine noted that "the purpose of this study is to develop an estimating technique to account for the additional costs associated with Engineering Change Orders (ECOs) for cost-type development contracts" (Valentine 2015, 3). He used a data base that was contracted from the Defense Cost and Resource Center (DCARC), which compiled finished contracts. The contracts were then separated into four different categories as, Initial Award, Total Baseline, Cost and Technical. Initial Award was calculated to show the cost of the contract at award; The Total Baseline was analyzed to show the initial award plus the base cost growth; Cost denoted the cost overruns; and Technical showed the ECO costs added to the original baseline.

Next, Valentine created a probability distribution with the conditional probability where an ECO is greater than 0. To derive an accurate distribution, outliers were removed. Then, the ECO was divided by total contract value. After his analysis, Valentine (2015) found that "the ECO factor for Air Force, cost-type development contracts tends to follow a probability distribution where the frequency is higher for

lower ECO factors and gradually declines as the ECO factors increase" (3). He then recommends three follow-on research ideas:

- Determining why so many development contracts have $0 ECO
- Determining why some contracts exhibit extraordinary ECO growth
- Determining if ECO factor study may prove even more relevant with respect to procurement contracts

This is similar to the basis for our study, except we investigated:

1. Is it possible to predict whether a contract will have an ECO or not?

2. Where an ECO is present, can an accurate percentage be applied to cost estimates or contract amounts that will accurately depict the proper amount of ECO Growth throughout the life of the contract?

Summary

In this Literature Review we reviewed previously completed research that focused on cost overruns and their impact on DoD acquisition programs. We showed how cost overruns have a negative effect on the DoD by tying up funds that could be allocated in a more efficient manner. Additionally, we show how different organizations have attempted to reign in the cost growth, and we attempt another method to assist in this. We also found studies representing MR uses and procedures to account for uncertainties and risk, by adding on certain amounts to the bottom line of estimates to account for these unseen amounts. Finally ECOs were observed to illustrate how they can be a useful tool to account for unknowns, along with how some preliminary studies have shown the inaccuracies of current ECO usage. In the next chapter, we explain the methodology used to define correlations between ECOs in DoD Contracts.

III. Methodology

The purpose of Chapter 3 is to explain the methodology used in this thesis. We begin our discussion with our problem statement as well as the source of the data. This includes limitations and the methods to choose and organize the data. Next, we define our variables that correspond to our research questions and objectives. Third, we discuss the regression methods both linear and multiple along with the outcomes of the regression. Finally, we discuss the application of multiple regression analysis. This final application serves as the statistical basis for predicting the usage of ECOs along with the proper percentage amounts that should be added onto estimates.

Problem Statement

As stated in Chapter 1 cost estimating methods are currently limited to the accepted standards that are in place. The overall ECOs percentages applied remain the same even when programs go over budget. While some ECO's have zero ECO and some have a very large amount, the same blanket assumption is placed upon all total amounts, which skews the average. Also, the length of the contract or type of system being acquired is not considered in applying the ECO percentages. Despite historical shortcomings across the board on initial cost estimating, the system for developing ECOs has not changed.

Database

The data derived for this study came from the database of a company called Technomics. The database was commissioned by the Defense Cost and Resource Center (DCaRC). It contains historical contracts, taken directly out of the Electronic Database

Access (EDA), that were compiled into a usable form. This was more useful than current contracts because the amounts are not subject to change. While this makes the data more usable, it does not take into effect current funding situations. This could come into play during the initial budgeting of more recent contracts. This data is limited by the historical aspect as well as the reliance on Technomics properly archiving the data without altering it from the original source, EDA. EDA is a website that contains the electronic copy of government documents, including DoD contracts, which were used in this research.

The database is broken down into a usable tool called the "Interactive Contract Database and Analysis Tool." The tool is divided into several search options, which are found under the contract growth factors. The contract information features a selection for the branch of service: Army, Navy, Air Force, or Marine Corp. The contract growth factor features the production phase: development, production, or operations and support (O&S). Another option includes Commodity, which is the type of weapon system. The last selection under that search option is Contract Type, which are the type of contracts used for the weapon system (Appendix B).

For our research, the database was narrowed to ten categories. The first 3 identify the program: Contract Number, Description, and Program. Next are the headlines that are important to our research. Initial Award is the amount that is originally provided to fund a program. Baseline Growth is how much the contract grew in the life of the program. Total Baseline is the amount added together. Lastly, Technical is the key to this study.

The column labeled "Technical" is the most important piece of our study as it represents the amount spent on the programs ECOs. The Air Force Cost Analysis Agency (AFCAA) defines Technical as an "engineering change order or proposal dependent on

ICE (Independent Cost Estimate) method" (2009, 5). The comparison of the Technical amount compared to the original and baseline, is the basis for this research (Appendix C).

Once the data was accessed it was first normalized to Base Year 2017 to ensure all of the amounts accounted for the same amount due to inflation. Next it was moved from Technomics Database to Excel where if/then statements were used to find the presence of variables. After the variables were sorted out, they were imported into the JMP System in order to be analyzed. Care was taken to ensure the data was not altered in any way during the transfer process, which included double checks and spot checks of the data before and after moving it. In total, 3,399 contracts were analyzed.

After the data was moved into JMP, it was divided by branch of service, commodity type, contract type, and whether it was a development contract or a production contract. We converted these to binary variables with a "1" being assigned to the presence of the variable and a "0" if not. We divided the data as such to better differentiate between variables. Even though these divisions were sufficient for our research, it can be noted that the operators at Technomics used the EDA to find and break down the contracts by purpose and further read through the contract in order to separate out the reasons for the cost growth. (Appendix E)

Hypotheses

This thesis contains a two-pronged approach to predicting ECO's in the DoD. First, a logistic regression model was developed to establish whether an ECO was present in the criteria contained within a contract. Second, a multiple regression model was built in order to predict the percentage of an ECO, once the presence of an ECO is detected.

Logistic Regression

The function form of the logistic model appears as:

$$g(x) = \frac{e^{f(x)}}{e^{f(x)} + 1}$$

where

$$f(x) = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p$$

Our Logistic Regression data needed to be separated into binary variables. In total there were 34 predictor variables (see Appendix E for a detailed description) among our four categories of branch, commodity, production phase, and contract type and Positive ECO Yes/No. We represent a positive ECO with a "1" being given for a "yes," while a negative or no ECO is coded with a "0". Two addition binary variables were added on top of the ones provided by Technomics. The first was an additional dichotomous variable for contracts under 5 Million dollars and the second variable was for all contracts over 500 Million. These were both added after it was observed that they might be statistically significant. After the dichotomous variables were added, a random number was assigned to each contract and the random numbers were put in order from largest to smallest. The first 680 were removed from the analysis, composing 20% of the database for validation, leaving 80% available for analysis.

Analysis Conducted

A mixed stepwise procedure was run on the 80% analysis set of variables where the ECO/Yes variable was the "Y Variable" and the X Variable was a comparison of all

of the binary variables with an α of 0.10. This produced a fit model consisting of the common model effect of the branch, commodity, contract types, and bucket variables. We then tested the model to see how well it performed using an α of 0.1, due to the exploratory nature of the analysis. The Odds Ratio or OR was analyzed for the significant variables, which an OR equal to 1 indicates the explanatory variable does not affect the odds of a program experiencing an ECO. An OR > 1 implies a higher odds of an ECO, while an OR < 1 suggests a lower odds of experiencing an ECO (Szumilas, 2010). With respect to the confidence interval of an odds ratio, either the lower or upper confidence bound is used to estimate the precision of the OR. In practice, this bound is often used as a proxy for the presence of statistical significance if it does not overlap the null value (e.g., OR = 1) (Szumilas, 2010).

Next the Receiver Operator Characteristic or ROC curve was run, containing the Area under the Curve (AUC) were compared to test the model. "ROC plot displays the performance of a binary classification method with continuous or discrete ordinal output. It shows the sensitivity (the proportion of correctly classified positive observations) and specificity (the proportion of correctly classified negative observations) as the output threshold is moved over the range of all possible values. ROC curves do not depend on class probabilities, facilitating their interpretation and comparison across different data sets…. In the ROC context, the AUC measures the performance of a classifier and is frequently applied for method comparison. A higher AUC means a better classification (Robin, 2011)".

The AUC indicates the sorting efficiency of a model with a value of 0.5 indicating merely random chance and a value of 1.0 indicating perfect prediction capabilities

(Gaudard, Ramsey, & Stephens, 2006). The AUC is a single measure of the overall discrimination ability of a test. In general, an AUC that is greater than 0.8 suggests that the diagnostics test has good discriminatory power (McPherson & Pincus, 2016: 80). The AUC was then bootstrapped 1000 times to generate a CI to assess the over-all accuracy of the model. This technique called bootstrapping (Efron & Tibshirani, 1994) presents a 90% confidence interval for the AUC value for the logistic regression model; this interval provides the user predictive limitations of the model.

Finally the 80% analysis set of data was run through the probability formula to predict the 'yes' result, which was later compared to the actual 'yes' variables where ECO's were present. The agreement between the two was then shown in a distribution and compared to the 20% that had been previously separated as a crosscheck

Logistic Regression Results

After enacting the methodology discussed in earlier, we arrived at the model presented in Tables 1-4. The Logistic Regression was found to reliably predict whether or not an ECO will be present with approximately an 81% accuracy rate. These results were tested using the Effects Summary, Parameter Estimates, and Effect Likelihood tests from the fit model (Table 3). A whole model p-value of <.0001, is much less than the pre-established limit of .1 as stated previously (Table 2), along with the individual P-values of the variables shown on the Effect Summary in the same table. The Effects Likelihood Ratio Tests result in demonstrating the productiveness of the variables from Greatest to least, with the greatest being X_1 and the least being X_8 (Table 1.)

Table 1 Variables with P Values

X Value	Variable Description	P-Value
X_1	Contract amount is < 5M Dollars	<0.0001
X_2	Contract is a Firm Fixed Price	<0.0001
X_3	Contract consists of a Commodity of Aircraft	<0.0001
X_4	Contract amount is > 500M Dollars	<0.0001
X_5	Contract is an Army Contract	<0.0001
X_6	Contract is a Navy Contract	<0.0001
X_7	Contract consists of a Commodity of UAV	<0.0001
X_8	Contract is a Cost Plus Fixed Fee Contract	0.0009

Next, the Odds Ratio or OR reinforces the variables that show a positive influence on the outcome as being over 1 and those that show a negative outcome as being below 1 (Table 5). Another indicator that this model is a good predictor of whether or not an ECO will be present in a contract is that of the ROC AUC. Our model shows an AUC of .8860 (Figure 3), which is considered good to borderline excellent as it is close to 90%. The 1000 bootstrap iterations reveal an average AUC of. 0.887 with a 95% C.I. of (.87, .90), (Figure 4) and reinforces the significant result.

Table 2 Whole Model Test

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	548.0892	8	1096.178	<.0001*
Full	981.4624			
Reduced	1529.5516			

The model further demonstrates its accuracy through a graphical distribution of the agreement between the true binary 1 Yes Response and the predict response. Using the 80% analysis file, the model properly predicted the outcome 83% of the time. Additionally, when using the 20% analysis crosscheck, the model predicted the outcome

81% of the time (Figure 5). After analyzing the Data, the selected formula was derived from the parameter model estimates and provides a working example of our model. The working outputs also validate the influence of each variable as a predictor. The likelihood follows the formula: (Table 1 and Table 5)

$$\text{ECO is present} = \frac{e^{(2.14-1.02X_1-2.78X_2-.62X_3-1.88X_4-1.04X_5-1.38X_6-.62X_7-2.28X_8)}}{1+e^{(2.14-1.02X_1-2.78X_2-.62X_3-1.88X_4-1.04X_5-1.38X_6-.62X_7-2.28X_8)}}$$

Table 3 Effects Test/P-Values

Effects Likelihood Ratio Tests				
Source	**Nparm**	**DF**	**L-R ChiSquare**	**Prob>ChiSq**
UAV	1	1	19.3240262	<.0001*
>500M	1	1	70.6220125	<.0001*
Navy	1	1	20.8205073	<.0001*
Army	1	1	25.8933553	<.0001*
Aircraft	1	1	59.8551842	<.0001*
FFP	1	1	71.8381697	<.0001*
CPFF	1	1	11.0573064	0.0009*
<5M	1	1	408.865564	<.0001*

l

Table 4 Odds Ratio

Unit Odds Ratio				
Term	**Odds Ratio**	**Lower 95%**	**Upper 95%**	**Reciprocal**
UAV	0.359959	0.226466	0.568625	2.7780972
>500M	16.05503	7.252851	42.82052	0.0622858
Navy	0.53527	0.40943	0.699719	1.8682176
Army	0.152588	0.067345	0.325468	6.5535973
Aircraft	0.354032	0.271516	0.460836	2.824602
FFP	0.252695	0.183773	0.346938	3.9573323
CPFF	0.538307	0.372705	0.775773	1.8576754
<5M	0.10194	0.080671	0.128331	9.809653

Also Table 5 contains the ChiSquare output, which shows the strongest association. The <5M variable is the most dominant with a ChiSquare Score of 372.03, and the FFP is the second most dominant with a score of 72.10. The least dominant is CPFF with a score of 10.98.

Table 5 Parameter Estimates

Parameter Estimates				
Term	**Estimate**	**Std Error**	**ChiSquare**	**Prob>ChiSq**
Intercept[0]	2.14021125	0.1755113	148.70	<.0001*
UAV	-1.0217662	0.2345743	18.97	<.0001*
>500M	2.77602209	0.445714	38.79	<.0001*
Navy	-0.6249848	0.1366438	20.92	<.0001*
Army	-1.8800141	0.4000996	22.08	<.0001*
Aircraft	-1.0383675	0.134888	59.26	<.0001*
FFP	-1.3755701	0.1620023	72.10	<.0001*
CPFF	-0.6193259	0.1869091	10.98	0.0009*
<5M	-2.2833669	0.1183822	372.03	<.0001*

Receiver Operating Characteristic

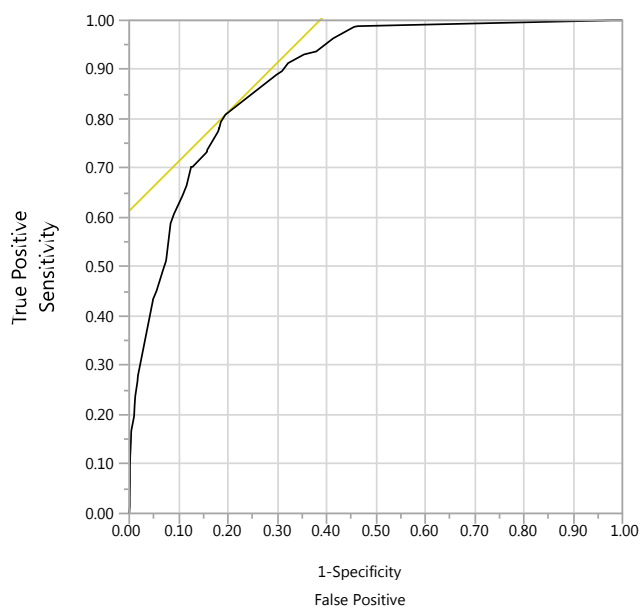
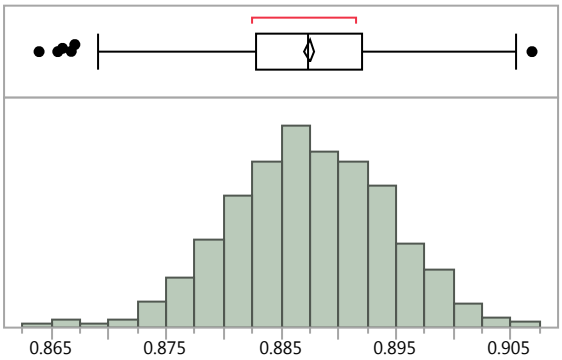


Figure 3 ROC Curve

Boot Strapping



Summary Statistics

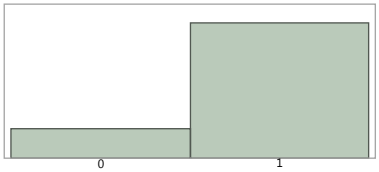
Mean	0.8874497
Std Dev	0.0066915
Std Err Mean	0.0002116
Upper 95% Mean	0.8878649
Lower 95% Mean	0.8870345
N	1000

Confidence Limits

Coverage	Pct Lower	Pct Upper
0.95	0.87408	0.90012
0.90	0.8764	0.89838
0.80	0.87883	0.89602
0.50	0.8829	0.89212

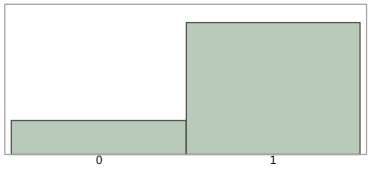
Figure 4 Bootstrapping

80% Analysis Agreement



Level	Count	Prob
0	464	0.17059
1	2256	0.82941
Total	2720	1.00000

20% Analysis CrossCheck



Level	Count	Prob
0	136	0.20029
1	543	0.79971
Total	679	1.00000

Figure 5 Predicted Percentage

Multiple Regression

The Multiple Regression gave us an answer we believe to be reliable; however, due to the unaccounted variance in the form of the low R^2, lack of normality, and constant variance, lends toward the conclusion that the multiple regression "exploratory" may be necessary to ensure the accuracy of the result.

Analysis Conducted

When setting up our multiple regression model, any contract that contained a positive ECO was pulled out of the total data set to make sure that the negative or zero amounts did not overly influence the outcomes. Afterwards, a new variable was added where the ECO Amount was divided by the Total Baseline amount to give a numeric representation of what percentage the ECO has upon the Total Baseline Amount. This resulted in 850 of the 3399 being selected. To eliminate outliers those contracts where ECO percentages surpassed 100% of the original Baseline Amount were excluded. These were determined to be special case situations such as the MRAP program which was brought on by a need and funded using a UCA or undefinitized contracting action, which is essentially a blank check. The need for the MRAP in tactical environment to combat IED's and save coalition lives created a scenario where contracting rules were bent. Another example is the B-2 Sprint Contract where the initial statement of work did not contain the full scope of the program. After removed those extreme percentages who met this criteria, 674 remained for analysis.

The next step was to run a stepwise procedure to produce a fit model with the percentage of the ECO to Baseline as the Y variable and the same X variables from before. The output formula from the statistically significant variables is:

$$f(x) = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p$$

After the regression was run and we obtained the diagnostic results, we then ran through the Cooks-D Test to test for influential data points. "Cook's Distance is commonly used in multiple regression analysis to interpret each data point's influence on the regression results and can easily highlight outliers through a graphical interface and a corresponding

"score" for each data point between 0 and 1. An overly-influential data point can be potentially harmful in a regression model, due to the fact that it over-fits the regression output to include that one instance. In essence, it influences the model to behave more like the one observed outcome than the population as a whole. When utilizing Cook's Distance, we are alerted to any possible points which need to be analyzed more closely by a score of between .1 and .5. (Cook, 1977).

Variance Inflation Factors (VIF) scores were checked to look for multi-collinearity. The VIF measures how much multicollinearity has increased the variance of an estimate, meaning that it measures and indicates the magnitude that a single predictor variable influences the outcome of a multiple-regression model (Stine, 1995). Next, the residuals produced from the regression were tested for normality using the Shapiro-Wilk Test. The null hypothesis for the S-W test is that the residuals from our model are normally distributed; the alternative hypothesis is that they are not. We test this at a threshold of $\alpha = .05$. If the p-value for the test is larger than .05, then we satisfy the assumption of normality for our models (Neter et al., 1996:111). Constant variance was tested using the Breusch Pagan Test. The second of the two key assumptions of any multiple regression model is that it contains constant variance. The Breusch-Pagan (B-P) test is used to statistically prove whether residuals exhibit constant variance or not.

Multiple Regression Results

A fit model was conducted using the 674 responses, with the Percentage of ECO under 100% as the Y variable and the X variable being the 34 stated as before (Appendix E). The fit models output included an analysis of Variance, and Parameter estimates, including the VIF Scores shown as in (Table 7). Next Cooks-D was used to show that

none of the points had undue influence on the model (Figure 7). The final test of the diagnostics was the Studentized Residuals (Figure 8), which showed than none of that residuals contained more than 3 standard deviations from the mean. An overall ANOVA P value of <.00001, along with the previously stated test initially indicate a good model. If these diagnostics held true the output predictive model looks like this from the parameter Estimate (Table7):

$$f(x) = (22.46\%) + (18.4\%)X_1 - (5.7\%)X_2 - (11.4)X_3 - (7.0\%)X_4 + (14.6\%)X_5$$

This is telling us that 22.46% should be the base amount of ECO placed upon contracts that show they most likely will have an ECO based on the Logistic Model Equation, plus or minus the percentages of the variables above. However this is where the accuracy of the model stopped and the "noise" from the many variables, influence on the model began to show.

Table 6 Significant Variables

X Value	Variable Description	P-Value
X_1	Contract consists of a Commodity of Electronics	0.00710
X_2	Contract consists of a Commodity of Missiles	0.00770
X_3	Contract consists of a Commodity of Munitions	0.00270
X_4	Contract is a Firm Fixed Price	0.00010
X_5	Contract amount is < 5M Dollars	<0.00001

To begin with, the variance explained by the R^2 was a mere .13 (Figure 8), this meant that a large portion of the data relation to the numbers went unaccounted for. Also, as expected the regression model failed normality using the Shapiro-Wilk test (Figure 8). The expectation going in was that this test of Normality was going to fail, simply based on the amounts and how the contract amounts vary so much and how the

amounts of ECO go from 0% to over 90% without any indication. There are a decent amount around the 20% margin which should show us that that is a safe amount, however there are too many variables that do not fit into the mold, that Normality is not met. Finally the assumption of constant variance was failed using the Breusch Pagan test (Appendix F) with a p-value of .0 e-21. This goes hand in hand with the normality tests being failed; if a model is not normally distributed the constant variance is usually not present either. Table 7 also demonstrates the t Ratio which represents the variables that are the most and least dominant of the significant variables. In this case the most dominant is the variable of <5M with a t Ratio of 6.81 and the least most dominant variable is FFP with a t Ratio of -3.86.

Table 7 P-Value/Parameter Estimates

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	5.243683	1.04874	19.3060
Error	668	36.287053	0.05432	**Prob > F**
C. Total	673	41.530736		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	0.2246312	0.015988	14.05	<.0001*	.
Electronics	0.1843034	0.068196	2.70	0.0071*	1.0090594
Missiles	-0.057143	0.02138	-2.67	0.0077*	1.0355453
Munitions	-0.114471	0.038027	-3.01	0.0027*	1.0250289
FFP	-0.070095	0.01817	-3.86	0.0001*	1.011097
<5M	0.1460461	0.021445	6.81	<.0001*	1.0150336

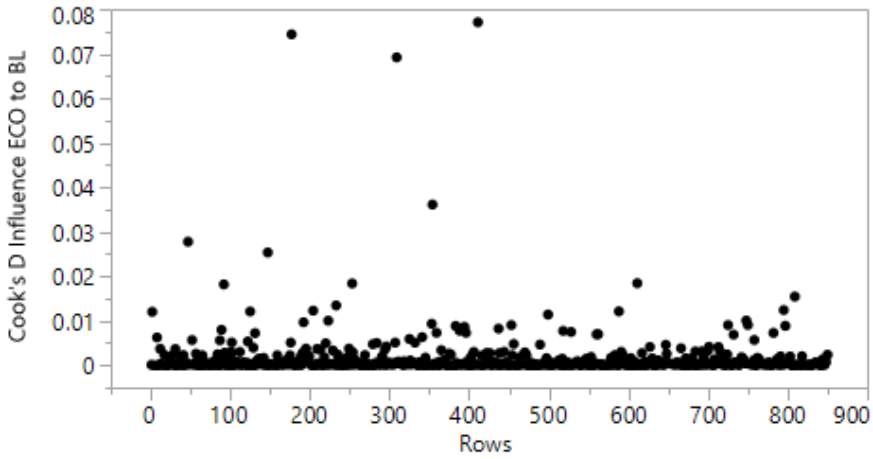


Figure 6 Cooks D

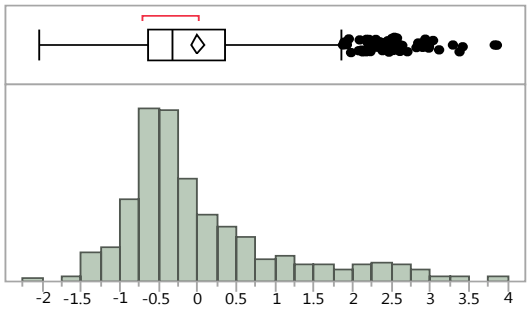
Studentized Residuals	Summary Statistics	
	Mean	-8.813e-6
	Std Dev	1.0010934
	Std Err Mean	0.0385607
	Upper 95% Mean	0.0757049
	Lower 95% Mean	-0.075723
	N	674

Figure 7 Studentized Residuals

Summary

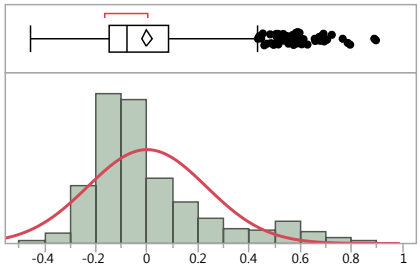
In this chapter we first discussed the source of the data, and how it was taken from its original form and separated off for analysis. Second we discussed the variables being analyzed and how they were divided up. Third, we discussed the methods used to analyze the variables. We first attempted to predict whether a contract would have an ECO and the accuracy of this prediction. Next we discussed the second regression we ran, the multiple regression to see what percentage of ECO should be applied to the contract, along the various methods used to verify the results of the tests. After all of the

predictors could be derived along with some of the predictors requiring more analysis into their original causes, designating them as exploratory analysis.

Summary of Fit

RSquare	0.12626
RSquare Adj	0.11972
Root Mean Square Error	0.233071
Mean of Response	0.202018
Observations (or Sum Wgts)	674

Goodness of Fit



Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.515e-17	-0.017562	0.0175618
Dispersion	σ	0.2322033	0.2204342	0.2453099

-2log(Likelihood) = -56.5424931787367

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.864027	<.0001*

Figure 8 Fit Tests

IV. Chapter Conclusions and Recommendations.

Introduction

The intent of this chapter is to explain our findings and make recommendations for future research in the field of ECO's so as to answer any questions remaining after this study. The major outcome from our analysis will hopefully shed light on the concept of the Engineering Change Order and how it can drastically affect both cost and cost growth in the DoD Acquisition Contracts and Programs as a whole. First, we revisit the research questions of this study to validate the outcomes versus the intent of this undertaking. Next, we describe the limitations of this study, and how future studies may be able to overcome them. Finally we conclude with a brief summary of what this study accomplished.

Research Questions Answered

1. *How can logistic regression incorporate common variables to accurately predict whether a contract will contain an ECO?*

Regarding the final model created and the data that was available through the Technomics Contract Database, the answer is yes. Applying certain variables that are statistically significant can be used with 81% accuracy to predict whether or not a contract will have an ECO attached to it. All the necessary variables should be known by the contracting personnel during the creation of the contract.

2. *Using a multiple regression model, what is the appropriate percentage to be applied to cost contracts based off of certain common variables that will accurately depict the proper amount of ECOs?*

With respect to the final model created in the previous chapter the answer is yes; however, more exploration into this data will be required to ensure the accuracy of the model. Due to the noise created b narrowing of the binary variables, this is described in greater detail under limitations.

Some similar variables appear both as significant for the logistic regression and the multiple regression; those are contracts which have a baseline amount of less than 5 Million dollars and those that are Firm Fixed Price. The first point is supported by a finding from Dameron (2001), "Contract Data mimics patterns in SAR data in the shape of the cost growth distribution and trends for tolerance of cost growth, i.e., higher cost growth for smaller programs". While the smaller contracts are significant they are negatively correlated, thus have less of a chance of having an ECO. This makes sense in that the contracts that have a small amount probably do not cover a lot of different variables and or line items; thus there are less reasons or opportunities for them to expand. However if they do contain an ECO for some reason they will have an extra 14.6% than the already recommended 22.5%; in that if they do have an ECO it will be a much larger percentage, such as Dameron (2001), found. Basically, if a 1 Million Dollar Contract grows by 1 Million then that is 100% growth, while if a 10 Million Dollar Contract Grows by 1 Million then it is only 1% cost growth.

Likewise, a FFP would less reason to have an ECO present or a reason to have an expansion of the final amount in that there is no incentive to keep the amount low, in the rigidity of the contract. Therefore without an incentive the only way to get more money is to expand the scope, which can will entail an ECO if growth is deemed necessary. FFP contract by their nature do not adjust to pricing changes or profitability by the contractor.

These while less likely to occur, are subject to alterations after the fact instead of in the process of the contract itself, such as a cost plus fixed fee contract, where the contractor would have incentive to keep the cost low during actual process of the contract.

As for similarities to previously studies, for comparison, Valentine (2009) found that that development ECO should be above 20%; we concur with this assessment. However, along with looking at only Air Force cost contracts, Valentine separated Production from Development contracts. This study looked into separating this during out regression tests. We held Production and Development as variables and they did not register as significant, therefore we did not separate them for the analysis.

Limitations

We recognize this study contains several limitations. First, the sample of contracts used for the analysis are not completely random. Even though the contracts are collected for analysis without prejudice, as long as they are ACAT 1 and already fully accomplished, they still were personally requested, thereby making them not completely random. While it is impossible to collect all of the historical contract in the DoD, this sample was useful for analysis. There are several other reasons for extreme ECO growth, based on the few contracts sampled. On two of the sampled contracts, the scope of the effort was not inherent in the initial statement of work; this caused the contract to be expanded exponentially. Another contract began as a small support contract, but ECO's became the tools used as the scope of the program changed and CLINs were added as the project expanded. Another contract started as a service type and it is unknown why the contract was funded with 3600 money, which is the code for Air Force Research and

Development dollars, instead of Information Support, which should be coded as 3400 or Operations and Maintenance. This resulted in additional noise due to improper classification of funds.

Second, while the reasons for cost growth are widely accepted categories by the DoD, there are multiple reasons for them to occur, which skews the data immensely. For instance, ECO's alone have 18 variables (Appendix G), or reasons why it is classified as an ECO, but this would require going through each contract individually and finding the exact reason for the growth. This variability accounts for additional "noise," which make the data have an extremely wide range. The numerous variables that go into each category for cost growth must also be considered in order to get a full picture on why percentages are so vast.

Along those same lines contracts are developed at different times for different reasons. Contracts like the MRAP were created in a hurry using a barely legal Un-differentiated Contact Action or UCA, which is almost a blank check and that program resulted in almost 220000% ECO. So another variable that should be examined is the urgency behind a contract, or to be more specific, more of its "story"; this is often not a measurable data point, but has a huge impact on total amounts. If more of the story is able to be told it is very possible that contracts could in fact be a great source for predicting variability. But, the classification of ECO should be broken down further into sub-ECO's in order to make sure for example, ECO's added due to mission creep, as in the program getting more capabilities are not the same as a software update required by the manufacturer. Both are necessary and both can be considered ECO's; however,

mission creep has a much larger impact on the overall bottom line. Reading into the story is the key to cost estimating.

Future Research

- A case study, using EDA to further dive into the exact reasons for cost growth without classifying them into the larger more accepted “blanket reasons” for cost growth. This should build fewer (based on the time constraints of sifting through contracts) but much more precise data points and thus re-accomplishing the multiple regression above.
- A study looking in the time ECO’s are applied into programs life cycles, and if that has an impact on the growth.
- A numeric study of management reserves, it seems like a large portion of DoD Special Program Offices (SPO’s), simply place the ECO’s into MR’s so a study into the accuracy of MR’s over time and what impacts ECO’s have on them.

Summary

In conclusion, we completed our research by discussing the findings, placing emphasis on the relevancy of the findings, and presenting its usefulness in a real work setting. Second, we described the studies shortcomings and limitations as well as their impact on the results. Next, we described possible future research for the field regarding ECO’s and cost growth, which may overcome some of the elements that held this specific study back.

We recommend the use of the logistic regression tool to predict whether or not a contract will need an ECO to be factored into its creation. This can be important as to

even if the correct amount may not be readily available the programs that show that they will have an ECO can be monitored more closely than those that do not. We can offer a guideline as to the amount, which is that of 22.5% as a base amount plus the other variables. With further research, our model, could be substantiated. But for the moment, we designate it as exploratory. We recommend the contracting personnel do their own research to determine their specific program's ECO amount due to the lack of ability to verify our models accuracy.

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Appendix A

AF Life Cycle Management Center

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ECO Study and Analysis

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Briefing Overview

AFLCMC… Providing the Warfighter's Edge

- Purpose
- Overarching assumptions
- Interactive Contract Database & Analysis Tool
- Determining the dataset
- Modeling the data
- Fitting a model to the data
  - Exponential distribution
  - Exponential distribution fitness
- Risk assessment example
- Study results

2

Purpose

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- **The purpose of this study is to develop an estimating technique to account for the additional costs associated with Engineering Change Orders (ECOs) for cost-type development contracts**

3

Overarching Assumptions

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- **Dollars are in Base Year 2014**
- **Data was collected from the Interactive Contract Database & Analysis Tool**
  - **Tool developed by Technomics, Inc. and accessible through Defense Cost and Resource Center (DCaRC)**
  - **Department of Defense *owns* the database**
  - **Contracts are from ACAT I programs**
- **Study focuses on ECO as it relates to Air Force, *cost-type* development contracts**
  - **The techniques utilized in this study can be applied to procurement contracts as well**
  - **Methods may apply to numerous queries within the Contract Database & Analysis Tool and not limited to the query presented in this briefing**

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Contract Database Tool

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Contract Database Tool

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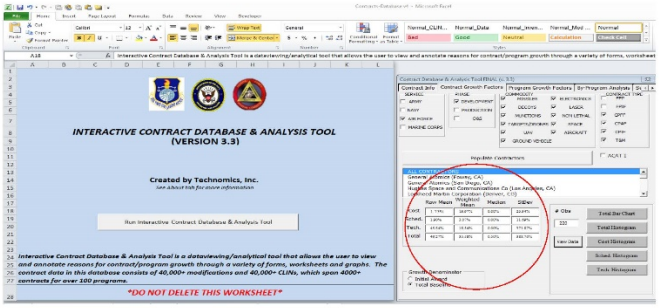
- **Extracted statistics from the query are identified by the red circle**



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Contract Database Tool

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- **Table below shows statistics for Cost, Schedule, and Technical (ECO) changes to a contract with respect to a contract's Total Baseline**
- **Raw Mean and StDev assume each contract is of an equal proportion**
- **Weighted Mean assumes a weighted proportion with respect to each contract's Total Baseline**
  - **Total Baseline denotes Initial Award cost plus Baseline Growth cost**
  - **This can be changed and shown with respect to Initial Award**

	Raw Mean	Weighted Mean	Median	StDev
Cost	1.75%	13.97%	0.00%	25.34%
Sched.	1.90%	3.07%	0.00%	11.69%
Tech.	45.84%	18.54%	0.00%	371.87%
Total	49.27%	35.58%	0.50%	388.76%

Growth Denominator
- Initial Award
- Total Baseline

Obs: 220

View Data

Total Bar Chart

Total Histogram

Cost Histogram

Sched. Histogram

Tech. Histogram

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- **The Tech. StDev statistic requires further explanation:**
  - **StDev assumes each contract is of an equal proportion**
    - **It is not a weighted StDev**
  - **StDev is the empirical standard deviation with no assumption made regarding the data's underlying distribution**
    - **Because relatively few contracts have negative ECO and there is a relatively high Stdev, the data is probably not uniformly or normally distributed**
    - **Common sense implies the underlying ECO/Total Baseline distribution is highly skewed—to the right in this case**
      - **Right skewness implies a heavy right tail**

	Raw Mean	Weighted Mean	Median	StDev
Cost	1.75%	13.97%	0.00%	25.34%
Sched.	1.90%	3.07%	0.00%	11.69%
Tech.	45.84%	18.54%	0.00%	371.87%
Total	49.27%	35.58%	0.50%	388.76%

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- Initial Award
- Total Baseline

Obs: 220

View Data

Total Bar Chart

Total Histogram

Cost Histogram

Sched. Histogram

Tech. Histogram

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Contract Database Tool

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- **Select the *View Data* option to export the data to a worksheet within the workbook model**

Contract Database Tool

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- **The data below is an excerpt of the aforementioned query**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Contract #	Description	Lead Service	Commodity	Program	Phase	Contract Type	Contractor	ACAT	Initial Award	Baseline Growth	Total Baseline	Cost	Schedule
2	F33657-99-D-0026-0052	Advancing technologies/capabilities that address	AIR FORCE	AIRCRAFT	B-2 DMS	DEVELOPMENT	CPIF	Northrop Grumman Corporation (Palmdale, CA)	ACAT I	$880,807	$ -	$880,807	$1,884,266	$809,4
3	F33657-99-D-0026-0053	B-2 Defensive Management System (DMS) Technolog	AIR FORCE	AIRCRAFT	B-2 DMS	DEVELOPMENT	CPIF	Northrop Grumman Corporation (Palmdale, CA)	ACAT I	$55,974,261	$ -	$55,974,261	$ -	$ -
4	F33657-99-D-0026-0020	EHF SATCOM Program Component Advanced Develop	AIR FORCE	AIRCRAFT	B-2 EHF Inc 1	DEVELOPMENT	CPAF	Northrop Grumman Corporation (Palmdale, CA)	ACAT I	$30,697,529	$94,134,806	$104,812,335	$17,316,354	$ -
5	F33657-99-D-0026-0028	EHF SATCOM Computer Upgrade Program Increment	AIR FORCE	AIRCRAFT	B-2 EHF Inc 1	DEVELOPMENT	CPAF	Northrop Grumman Corporation (Palmdale, CA)	ACAT I	$203,278,995	$43,716,531	$246,995,526	($918,799)	$ -
6	F33657-99-D-0026-0023	RMP System Development and Demonstration	AIR FORCE	AIRCRAFT	B-2 RMP	DEVELOPMENT	CPAF	Northrop Grumman Corporation (Palmdale, CA)	ACAT I	$409,126,962	$13,879,892	$423,006,853	$22,397,834	$ -
7	F33657-02-C-2000	RELIABILITY ENHANCEMENT AND REVENUE PROGRAM	AIR FORCE	AIRCRAFT	GALAXY (C-5)	DEVELOPMENT	CPAF	Lockheed Martin Corporation (Marietta, GA)	ACAT I	$1,414,441,474	($188,606,579)	$1,224,834,899	$180,322,833	$ -
8	F33657-98-C-0006	AVIONICS MODERNIZATION PROGRAM (AMP)	AIR FORCE	AIRCRAFT	GALAXY (C-5)	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Marietta, GA)	ACAT I	$518,739,623	$123,787,051	$642,526,674	$191,074,022	$4,563,-
9	F33657-02-C-0009-0003	SYSTEMS ENGINEERING AND PROGRAM MANAGEMENT	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$79,408,467	$9,184,606	$88,593,073	($4,263,203)	$ -
10	F33657-02-C-0009-0002	SPIRAL 2 PHASE B - DESIGN	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPIAF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$84,092,183	($18,192,286)	$65,888,897	($496,278)	$ -
11	F33657-02-C-0009-0003	4TH GENERATION RADAR DEVELOPMENT TEST PHASE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$128,541,148	($7,605,112)	$120,936,036	$40,509,668	$ -
12	F33657-02-C-0009-0007	REPLACEMENT TEST AIRCRAFT	AIR FORCE	AIRCRAFT	[illegible]	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$34,858,752	$94,763,767	$129,622,519	$1,270,924	$ -
13	F33657-02-C-0009-0008	GUN (INSERT) CFE DEFRAGMENTATION	AIR FORCE	AIRCRAFT	[illegible]	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$4,009,686	($1,057,821)	$3,027,867	($1,149,179)	$ -
14	F33657-02-C-0009-0012	ENHANCED COMMON INTEGRATED PROCESSOR	AIR FORCE	AIRCRAFT	[illegible]	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$25,704,383	$ -	$25,704,383	($2,359,930)	$ -
15	F33657-02-C-0009-0013	FLEXIBLE EMBEDDED TRAINING	AIR FORCE	AIRCRAFT	[illegible]	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$3,018,036	$ -	$3,018,036	($158,823)	$ -
16	F33657-02-C-0009-0014	COMBINED TEST FORCE INFRASTRUCTURE	AIR FORCE	AIRCRAFT	[illegible]	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$34,110,563	$92,999,745	$127,110,308	($27,118,846)	$ -
17	F33657-02-C-0009-0015	INTER/INTRA FLIGHT DATA LINK (IFDL) EXTENDED BAND	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$3,623,246	($1,755,825)	$1,867,420	($250,539)	$ -
18	F33657-02-C-0009-0016	SPIRAL 2A, PHASE B, DESIGN	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPAF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$50,231,569	$51,269,949	$101,501,518	($2,461,576)	$ -
19	F33657-02-C-0009-0017	CAPABILITY DELIVERY, DV ENG, PROG MGT, AND INTEG	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$123,291,647	$ -	$123,291,647	($43,224,310)	$ -
20	F33657-02-C-0009-0019	SPIRAL 2 PHASES C/D/E - DEVELOPMENT TEST, INTEGRA	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$14,508,146	$91,454,759	$105,962,904	($983,008)	$ -
21	F33657-02-C-0009-0021	LAB INFRASTRUCTURE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$7,602,204	$136,388,594	$143,990,798	($1,999,937)	$ -
22	F33657-02-C-0009-0022	PALM (KLE) PHASE E CONCURRENCY MODS	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$46,028,613	$14,685,221	$60,714,846	($3,545,075)	$ -
23	F33657-02-C-0009-0023	DISTRIBUTED MISSION OPERATIONS - PHASE A AND B	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$23,960,187	$468,969	$24,429,737	$ -	$ -
24	F33657-02-C-0009-0024	STRUCTURE REPORT	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPAF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$69,841,192	$8,765,948	$78,607,140	($2,442,755)	$ -
25	F33657-02-C-0009-0025	RELIABILITY AND MAINTAINABILITY MATURATION PROG	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$48,880,390	$ -	$48,880,390	$ -	$ -
26	F33657-02-C-0009-0026	S/W SUPPORT INFRASTRUCTURE DEV & LIMITED IMPLE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$3,281,816	$107,204,346	$110,486,164	($1,796,351)	$ -
27	F33657-02-C-0009-0027	VIRTUAL AIR COMBAT SIMULATOR (VACS)	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$2,137,878	$ -	$2,137,878	($182,892)	$ -
28	F33657-02-C-0009-0028	ENHANCED STORES MGMT SYSTEM (ESMS) DESIGN/INTE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPAF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$93,105,683	$53,894,937	$147,000,620	$14,408,026	$ -
29	F33657-02-C-0009-0029	CHASE SUPPORT	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	T&M	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$1,929,941	$34,995,989	$36,925,932	$5,476,904	$ -
30	F33657-02-C-0009-0030	PRE/PKG EVALUATIONS	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$6,172,656	$8,887,345	$15,060,003	($229,500)	$ -
31	F33657-02-C-0009-0031	SPIRAL 3A MODERNIZATION, PHASE C-D	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPIF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$215,871,363	$292,735,847	$508,586,010	$27,116,433	$ -
32	F33657-02-C-0009-0034	ORDER THROUGHPUT	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$18,378,961	$19,922,460	$31,296,421	$ -	$ -
33	F33657-02-C-0009-0036	Program Integration, Requirements Analysis, and Sy	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$229,652,489	($8,910,717)	$220,941,748	($11,289,233)	$ -
34	F33657-02-C-0009-0037	LAB INFRASTRUCTURE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$95,487,725	$102,662,558	$198,150,283	($12,079,454)	$24,115,-
35	F33657-02-C-0009-0038	COMBINED TEST FORCE INFRASTRUCTURE	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$69,444,664	$93,230,866	$162,675,029	($10,143,428)	$ -
36	F33657-02-C-0009-0041	ELECTRONIC WARFARE USEFUL LOADS COMPUTION (E	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$8,438,938	($1,461,872)	$7,093,288	$9,877,279	$ -
37	F33657-02-C-0009-0044	RELIABILITY AND MAINTAINABILITY MATURATION PROG	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$23,478,011	$122,702,735	$146,181,746	$31,304,840	$ -
38	F33657-02-C-0009-0046	DISTRIBUTED MISSION OPERATIONS - PHASES C/D/E	AIR FORCE	AIRCRAFT	RAPTOR (F-22)	DEVELOPMENT	CPFF	Lockheed Martin Corporation (Fort Worth, TX)	ACAT I	$52,071,647	$7,315,144	$59,386,792	$5,816,342	$ -

Contract Database Tool

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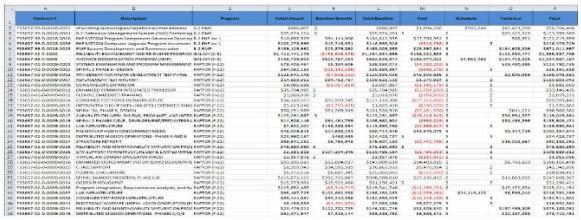
- **The worksheet below shows some of the data extracted for this study**
  - **Initial Award denotes contract cost at contract award**
  - **Total Baseline denotes Initial Award cost plus Baseline Growth cost**
  - **Cost denotes cost overruns**
  - **Schedule denotes schedule-related costs**
  - **Technical denotes ECO-type costs**



	A	B	C	I	K	L	M	N	O	P
1	Contract #	Description	Program	Initial Award	Baseline Growth	Total Baseline	Cost	Schedule	Technical	Total
2	FA8727-05-D-0010-0017	Advanced Planning and Scheduling Services Support Services	E-3 FMP	$660,007	$	$660,007	$3,294,350	$503,544	$47,415,500	$51,213,394
3	FA8727-05-D-0010-0001	ELT Tactical Management System (TMS) Training	E-3 FMP	$55,974,353	$	$55,974,353	$	$	$55,455,329	$55,455,329
4	FA8727-05-D-0010-0002	Tactical Management System (TMS) Training	E-3 FMP	$1,000,000	$92,113,000	$93,113,000	$17,556,561	$	$	$17,556,561
5	FA8727-05-D-0010-0006	AWACS/JSTARS Computer Upgrade Program Increment 1	E-3 BMP Inc 1	$120,270,944	$15,718,551	$135,989,504	$914,750	$	$56,971	$971,721
6	FA8727-05-D-0010-0019	RSIP System Development and Demonstration	E-3 RSIP	$108,129,982	$23,878,082	$132,008,065	$23,987,861	$	$181,808,508	$205,796,369
7	FA8727-05-D-0000	RELIABILITY ENHANCEMENT AND RE-ENGINE PROGRAM (REALIGNED)	E-3	$1,111,111,176	$130,878,978	$1,241,990,154	$108,111,999	$	$110,880,177	$218,992,176
8	FA8727-05-C-0009	PERSONS MODERNIZATION PROGRAM (MOP)	B52	$108,738,823	$123,787,253	$232,526,077	$188,071,023	$1,992,765	$181,112,828	$191,104,593
9	FA8727-05-C-0010-0001	SPECIAL PROJECT OFFICE PROGRAM MANAGEMENT	B52	$1,000,000	$1,000,000	$2,000,000	$1,000,000	$	$49,780,666	$50,780,666
10	FA8727-02-C-0009-0001	SPECIAL PHASE II - ORDER	B-1 FMP (F-22)	$64,062,142	$24,931,295	$89,000,437	$99,992,178	$	$	$99,992,178
11	FA8727-02-C-0009-0004	PRI-GENERATION PRIME UNSALVAGEABLE TEST ITEMS	B-1 FMP (F-22)	$120,871,179	$7,959,110	$128,830,289	$74,323,909	$	$2,909,292	$77,233,201
12	FA8727-02-C-0009-0005	SUPPLIER DEPOT SUPPORT	B-1 FMP (F-22)	$1,000,000	$91,758,797	$92,758,797	$1,000,000	$	$	$1,000,000
13	FA8727-02-C-0009-0006	SUPPLIER DEPOT SUPPORT	B-1 FMP (F-22)	$4,000,000	$3,000,000	$7,000,000	$3,000,000	$	$	$3,000,000
14	FA8727-02-C-0009-0013	ENHANCED COMMON INTEGRATED PROCESSOR	B-1 FMP (F-22)	$25,704,395	$	$25,704,395	$11,550,000	$	$	$11,550,000
15	FA8727-02-C-0009-0015	TECHNICAL ASSISTANCE (Training)	B-1 FMP (F-22)	$2,000,000	$	$2,000,000	$750,000	$	$	$750,000
16	FA8727-02-C-0009-0016	FORWARD FIT STORE ENGINEERING COUNT	B-1 FMP (F-22)	$94,000,000	$92,000,000	$186,000,000	$0	$	$	$0
17	FA8727-02-C-0009-0017	ENGINEERING SUPPORT FOR FIELD CONTRACTS Notes	B-1 FMP (F-22)	$1,000,000	$1,000,000	$2,000,000	$1,000,000	$	$	$1,000,000
18	FA8727-02-D-0009-0014	SPIRAL 3A, PHASE B, OPTION	B-1 FMP (F-22)	$50,747,504	$51,729,545	$102,476,949	$25,181,996	$	$661,273	$26,843,269
19	FA8727-02-D-0009-0017	FLIGHT LIFETIME SUPPL - EXTRUS, PROD SUPP, AUG SERVS	B-1 FMP (F-22)	$139,241,687	$	$139,241,687	($28,118,939)	$	$92,961,557	$64,842,618
20	FA8727-02-D-0009-0018	SPIRAL 3A, PHASE B, OPTION - SPIRAL 3A MAINTENANCE SUPPORT	B-1 FMP (F-22)	$41,000,000	$61,161,798	$102,161,798	$41,000,000	$	$61,166,568	$102,166,568
21	FA8727-02-D-0009-0011	LIVE FIRE OPERATIONS	B-1 FMP (F-22)	$7,800,000	$138,858,581	$146,658,581	$15,000,015	$	$	$15,000,015
22	FA8727-02-D-0009-0022	PHASE DEEP-AGED ENGINEERING NEEDS	B-1 FMP (F-22)	$96,009,819	$11,888,283	$107,713,016	$30,610,078	$	$6,517,728	$37,127,806
23	FA8727-02-D-0009-0023	STRUCTURE BETTER OPERATIONS - PHASE A AND B	B-1 FMP (F-22)	$38,000,000	$2,000,000	$40,000,000	$	$	$	$0
24	FA8727-02-D-0009-0024	STRUCTURE BETTER OPERATIONS	B-1 FMP (F-22)	$89,811,282	$8,796,878	$98,608,160	$12,772,195	$	$38,018,287	$50,790,482
25	FA8727-02-D-0009-0026	RELIABILITY AND MAINTAINABILITY IMPLEMENTATION PROG	B-1 FMP (F-22)	$78,000,000	$	$78,000,000	$	$	$	$78,000,000
26	FA8727-02-D-0009-0028	ATP SUPPORT TO PRODUCTION AND R & D TEST SUPPORT	B-1 FMP (F-22)	$6,000,000	$107,409,478	$113,409,478	$18,799,493	$	$	$18,799,493
27	FA8727-02-D-0009-0032	VIRTUAL AIR DEPARTMENT SIMULATOR (VADS)	B-1 FMP (F-22)	$6,557,878	$	$6,557,878	$100,000	$	$	$100,000
28	FA8727-02-D-0009-0033	SUPPLIER DEPOT SUPPORT FOR SUPPLIER DEPOT	B-1 FMP (F-22)	$1,000,000	$10,000,000	$11,000,000	$1,000,000	$	$6,792,022	$7,792,022
29	FA8727-02-D-0009-0012	C-MAC IMPROVE	B-1 FMP (F-22)	$6,000,000	$20,000,000	$26,000,000	$5,470,004	$	$	$5,470,004
30	FA8727-02-D-0009-0030	FLIGHT LINE UPGRADE	B-1 FMP (F-22)	$6,172,028	$6,000,000	$12,000,000	$10,000,000	$	$	$10,000,000
31	FA8727-02-D-0009-0031	ENGINE CONTROL SYSTEM (ECS) PI MOD KIT	B-1 FMP (F-22)	$2,000,000	$10,000,000	$12,000,000	$17,136,413	$	$11,603,205	$28,739,618
32	FA8727-02-D-0009-0034	DEDICATED DEPOT SUPPORT	B-1 FMP (F-22)	$25,575,951	$25,925,400	$51,501,351	$	$	$	$0
33	FA8727-02-D-0009-0036	Program Integration, Requirements analysis, and Sp	B-1 FMP (F-22)	$104,892,489	($4,516,737)	$100,375,752	($12,199,191)	$	$37,172,852	$24,973,661
34	FA8727-02-D-0009-0037	LIFE CYCLE MANAGEMENT	B-1 FMP (F-22)	$86,447,448	$102,882,488	$189,329,936	($12,198,191)	$35,318,439	$6,848,618	$30,000,866
35	FA8727-02-D-0009-0038	LIGHTWEIGHT FIXTURE CARRIER LIFE CYCLE	B-1 FMP (F-22)	$86,000,000	$84,000,000	$170,000,000	($18,000,000)	$	$	$(18,000,000)
36	FA8727-02-D-0009-0039	ELECTRICAL WORKING GROUP - LOCKS COMPLETION (P)	B-1 FMP (F-22)	$20,196,856	$12,000,000	$32,196,856	$8,272,276	$	$187,798,928	$196,071,204
37	FA8727-02-D-0009-0040	RELIABILITY AND MAINTAINABILITY VERIFICATION PROG	B-1 FMP (F-22)	$20,179,211	$122,702,759	$142,881,970	$33,928,870	$	$32,187,992	$66,116,862
38	FA8727-02-D-0009-0014	DEPP BLIND MISSION OPERATIONS - PHASE C/D/E	B-1 FMP (F-22)	$92,071,417	$7,318,111	$99,389,792	$8,000,812	$		$8,000,812

11

Contract Database Tool

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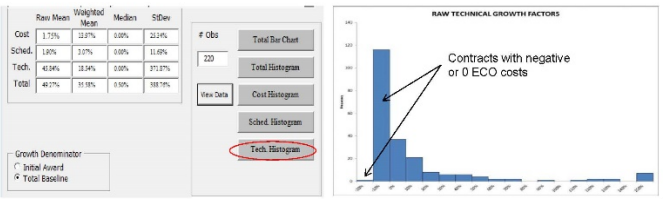
- **The histogram provides insight into the underlying distribution of the data**
  - **Histogram depicts ECO/Total Baseline**
  - **Data appears to follow an exponential or pareto distribution**
- **A potential concern exists with contracts containing no ECO: 54% of the contracts contain negative or zero ECO**



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Contract Database Tool

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- Recommend creating a distribution that assumes a contract will add some degree of ECO
  - We are essentially creating a conditional probability distribution: the conditional probability distribution of ECO given ECO is greater than 0
- To create this distribution, the analyst extracted the data and removed those entries with negative or zero ECO
- Contracts that have doubled due to ECO growth are excluded from the dataset
  - These contracts typically have extreme ECO values relative to the baseline contract and do not aid in determining a more practical ECO factor
- Analyst then divided ECO by total contract value to-date (ECO/Total Baseline was not utilized)
  - Contracts included in database are completed contracts

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Contract Database Tool

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- The ECO % of a contract requires conversion to an ECO factor to make it more useful to cost analysts
  - Thus, the analyst should convert the ECO% of total contract cost to a factor
    - The conversion equation is: ECO factor = $\frac{ECO\ \%\ of\ contract\ cost}{(1 - ECO\%\ of\ contract\ cost)}$
    - So a contract with an ECO cost of the total contract totaling 20% would have an ECO factor of 25%
    - Another approach is as follows:
      - Contract Total Excluding ECO= $100M
      - ECO = ECO Factor * Contract Total Excluding ECO = $25M
      - Contract Total = Contract Total Excluding ECO + ECO = $100M + $25M
      - ECO % of Contract Cost = $\frac{ECO}{Contract\ Total} = \frac{\$25M}{\$125M} = 20\%$
      - ECO Factor = $\frac{ECO}{Contract\ Total - ECO} = 25\%$
      - So, Contract Total = (1 + ECO Factor) * (Contract Total Excluding ECO)
      - Contract Total = (1.25%) * ($100M) = $125M
  - ECO can be thought of as a growth factor applied to the risk-loaded contract estimate
    - Bear in mind, the risk-loaded contract does not include ECO prior to applying the ECO factor

14

Determining the Dataset

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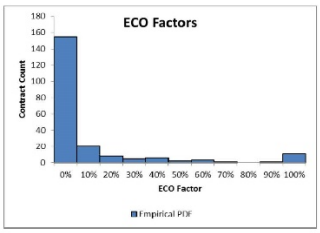
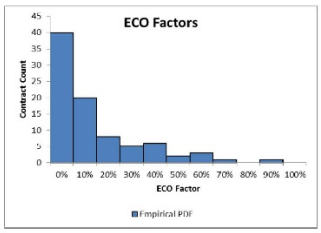
- Below is the histogram of the ECO factors for the initial query that includes all data points
- Histogram includes all contracts: negative ECO, $0 ECO, and extreme ECO % contracts

- The histogram below includes the following adjustments to the data
  - Negative or $0 ECO contracts are removed
  - Contracts that have doubled due to ECO are excluded
- The intent of the truncated data is to model the most probable ECO factors
  - Derived ECO factor is not intended to model extreme ECO % contracts





15

Determining the Dataset

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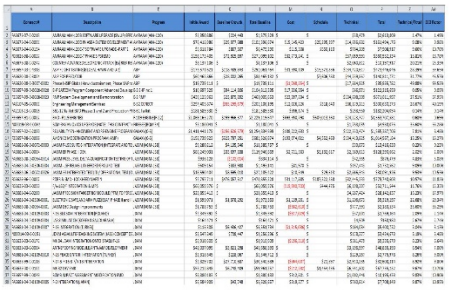
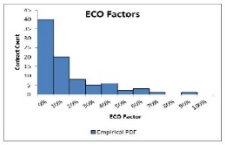
- **Below is an excerpt of the utilized dataset and accompanying population statistics**



Statistics	ECO Factor	Exponential Distribution
Minimum	0.0548%	0.0000%
Maximum	99.52%	∞
Mean	18.75%	18.75%
Second Moment	0.07	0.07
Stdev	19.92%	18.75%
Count	86	86



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Modeling the Data

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- **Next step is to derive a probability distribution that models the conditional empirical distribution**
  - **Find a distribution whose accompanying parameters fit the empirical data *well***
- **Analyst chose the exponential distribution**
  - **Intuitive and easy to use**
  - **Matches the data well without the analyst needing to solve for numerous parameters**
  - **Some statistical packages will fit the empirical data to distributions; however, the software may fit unique distributions to the data that may not be practical for cost estimating purposes**

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Fitted Model: Exponential Distribution

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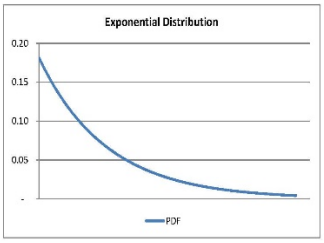
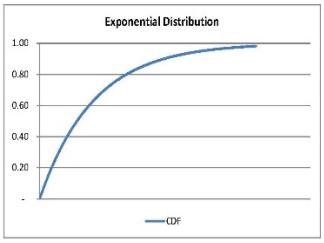
- **f(x) =** $\frac{e^{-\frac{x}{\theta}}}{\theta}$
- **F(X) =** $1 - e^{-\frac{x}{\theta}}$
- **Theta (θ) parameter completely defines the exponential distribution**
  - **Theta is equivalent to the mean**





18

Fitted Model: Exponential Distribution

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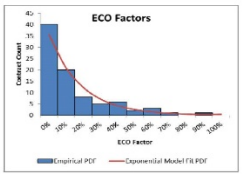
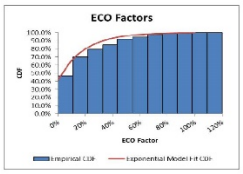
- **Utilize the mean of the empirical data to estimate the theta parameter of the exponential distribution**
  - **Method of moments or maximum likelihood (both yield the same result)**
    - **Percentile matching is another technique—not utilized in this study**
  - **Mean of data is approximately 18.75% (implies theta parameter is 18.75%)**
  - **Estimator of theta is unbiased, which is a statistically desirable characteristic**
- **f(x) =** $\frac{e^{-\frac{x}{.1875}}}{.1875}$
- **F(X) =** $1 - e^{-\frac{x}{.1875}}$

Replace θ in the equations with .1875

- **Fitted model is shown below for both the PDF and CDF**
- **Chi-squared test implies the fit is statistically valid**





Statistics	ECO Factor	Exponential Distribution
Minimum	0.0548%	0.0000%
Maximum	99.52%	∞
Mean	18.75%	18.75%
Second Moment	0.07	0.07
Stdev	19.92%	18.75%
Count	86	86
Chi-Square Statistic		7.88
Chi-Square Critical Value @ 5% CI		16.92

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Fitted Model: Exponential Distribution Fitness

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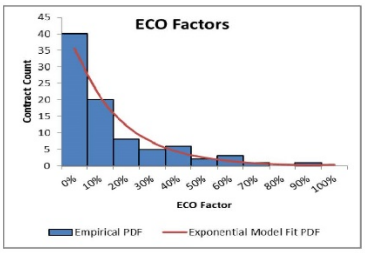
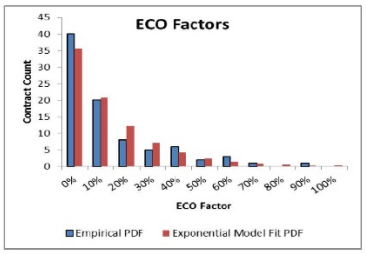
- **Observe graphically how well the exponential distribution models the underlying empirical data**
- **Both graphs below depict the probability density function (PDF)**





20

Fitted Model: Exponential Distribution Fitness

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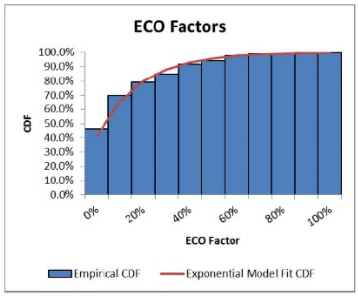
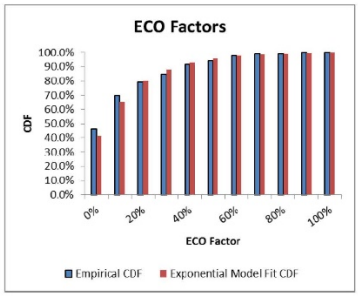
- **The graphs below depict the cumulative distribution function (CDF) of the empirical data and the fitted model**





21

Fitted Model: Exponential Distribution Fitness

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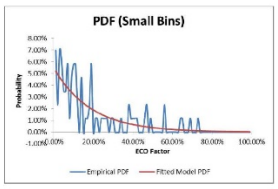
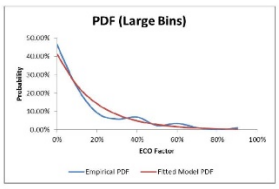
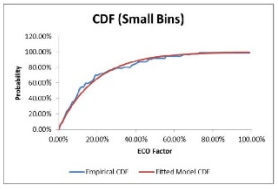
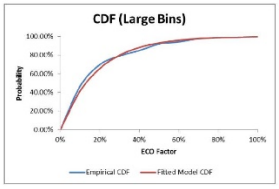
- **The tables below depict the PDF and CDF of the empirical data versus the fitted model with small and then large bin sizes**
- **The parameter theta is not dependent on bin size, so these tables merely provide a graphical description of how well the model fits the empirical data**









22

Fitted Model: Exponential Distribution Fitness

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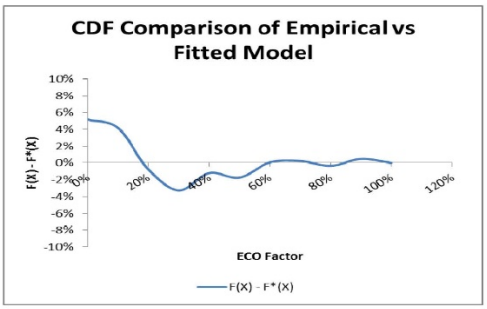
- **The graph below shows the empirical CDF minus the fitted CDF**
- **The depiction shows the amount of error between the empirical CDF and the fitted CDF**
  - **Bear in mind, this is with respect to bucketed data**



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Fitted Model: Exponential Distribution Fitness

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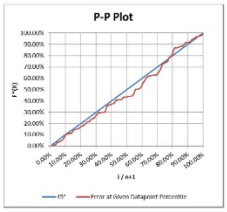
- **Although it is beneficial to see how well the fit is with respect to bins, it is also important to determine how well the fit is with respect to the individual data points**
  - **The graph below is a probability plot (p-p plot) graph and shows how well the fit is with respect to distinct values**
  - **In order for a distribution to have a good fit, the ordered data should lie close to the 45° line because the ith data point should be approximately $\frac{i}{n+1}$ of the way through the distribution**
  - **For example, at the median of the empirical data, the fitted model should be at the 50th percentile**
    - **For the fitted model, it is at about the 44th percentile**
    - **Therefore, the fitted model is underestimating the empirical data with respect ECO factors at the median**



24

Fitted Model: Exponential Distribution Fitness

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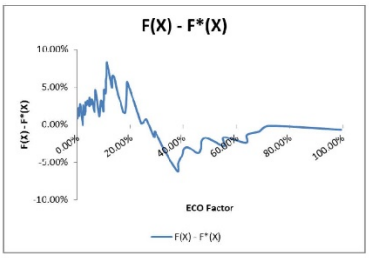
- Another way to show the fit regarding the distinct ECO factors for the empirical data versus the fitted model is to compare the difference in the CDFs at each data point
- The depiction below shows the difference in CDF values of the empirical and fitted model
- The exponential model underestimates the lower ECO factors until the ECO factors are above about 28%; then the exponential model begins to slightly overestimates the ECO factors



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Risk Assessment Example

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- The following charts provide examples of how to use the results of this study within a cost estimate
- The estimates utilize Crystal Ball, a software program capable of performing Monte Carlo simulations, to assess the risk inherent within each estimate
  - The first estimate uses 18.75% as the ECO factor but does not assume it follows any specific distribution
  - The second estimate uses 18.75% as the ECO factor but assumes the ECO factor follows an exponential distribution

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Risk Assessment Example

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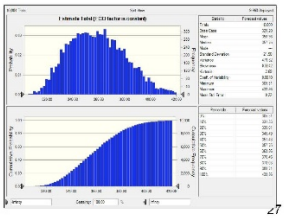
- Below is a rudimentary estimate
- The green cells are assumptions that follow triangular distributions
- Payload is assumed to be a fixed cost with no associated risk
- Notice that the ECO factor is a constant; its value does not fluctuate
  - The ECO amount will change, however; it will fluctuate with respect to the contract total (excluding the ECO portion)
  - ECO is approximately 15.79% of the contract total (including ECO) at the point estimate

Estimate assumes ECO factor is a constant

WBS	ELEMENT	Point	Assumptions	MIN	ML	MAX	Mean	Estimate
1.00	Total	329.20						329.20
1.01	Airframe	136.30	136.30	129.49	136.30	184.01		136.30
1.02	Propulsion	99.87	99.87	84.89	99.87	139.82		99.87
1.03	Payload	15.85	15.85	15.85	15.85	15.85		15.85
1.04	Data	25.20	10.00%	10.00%	10.00%	11.00%		25.20
1.05	ECO Factor	51.98	18.75%				18.75%	51.98



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Risk Assessment Example

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- For the second example, the estimate will remain the same as the first except the ECO factor assumption
  - The ECO factor will be assumed to follow an exponential distribution
- The following charts show how to assign an exponential distribution to the ECO factor

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Risk Assessment Example

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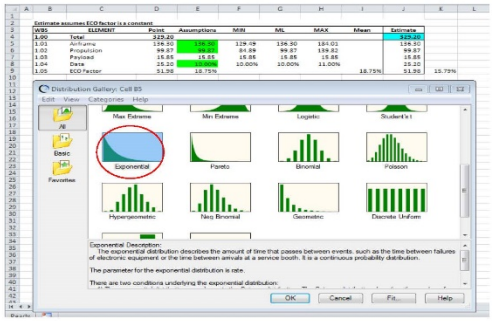
- As stated earlier, we first assume the estimate remains the same as on the prior chart; however, the ECO factor will follow an exponential distribution
- The ECO factor will now change with each simulation
- Both the ECO factor and the simulated contract size will now impact the ECO cost
- The screenshot below shows how to select the exponential distribution for the ECO factor *assumption* in Crystal Ball



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Risk Assessment Example

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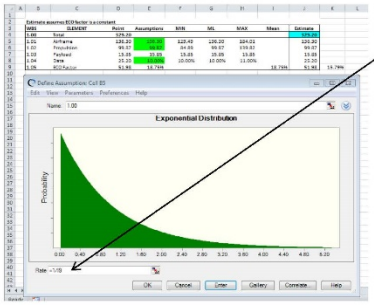
- Crystal Ball requires the exponential distribution's parameter to be input as a rate; therefore, the user must input 1/(ECO factor)
  - Crystal Ball utilizes the form f(x) = $\lambda e^{-x\lambda}$ for the exponential distribution
  - This implies that λ is equal to 1/ θ or 1/.1875
  - Click the *OK* icon when complete
  - Re-run simulation



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Risk Assessment Example

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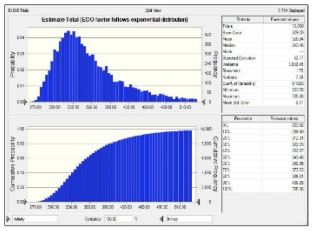
- **Below are both the inputs of the estimate and the Forecast**
- **The assumptions from the prior model are all the same except for the ECO factor assumption**
- **The ECO factor is no longer a constant in this model; its value fluctuates**
- **Notice the high degree of right-skewness**
  - **This model suggests there is an increased probability of experiencing high ECO costs on the development contract**
  - **ECO is approximately 15.79% of the contract total (including ECO) at the point estimate**

Estimate assumes ECO factor follows and exponential distribution

WBS	ELEMENT	Point	Assumptions	MIN	ML	MAX	Mean	Estimate
1.00	Total	329.20						332.20
1.01	Airframe	136.30	136.30	129.49	136.30	184.01		136.30
1.02	Propulsion	99.87	99.87	84.89	99.87	139.82		99.87
1.03	Payload	15.85	15.85	15.85	15.85	15.85		15.85
1.04	Data	25.20	10.00%	10.00%	10.00%	11.00%		25.20
1.05	ECO Factor	51.98	18.75%				18.75%	51.98



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Risk Assessment Comparison

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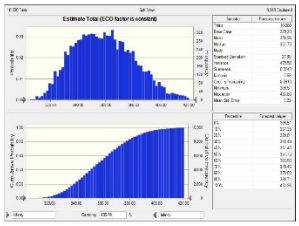
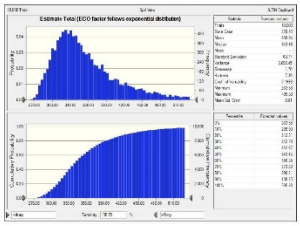
- **ECO factor is constant**
  - **Estimate distribution almost resembles a normal distribution with very little skewness: very light right tail**
  - **Probabilities of higher cost programs are not as prevalent under this methodology**
  - **Estimate assumes a cost of over $430M is near impossible**
  - **Coefficient of variation (CV) = 6.1%**
- **ECO factor follows an exponential distribution**
  - **Distribution has a high degree of positive skewness: very heavy right tail**
  - **Estimate follows more of a lognormal distribution**
  - **The high skewness hints at a high probability of cases where program costs are higher than anticipated when compared to the former model**
  - **Estimate suggests a program cost of over $430M has a 15% probability of occurring**
  - **Coefficient of variation (CV) = 16.9%**





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Review of Steps

U.S. AIR FORCE

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1) Create relevant query in Contract Database Tool
2) Extract data to Excel and remove $0 ECO contracts
3) Calculate the ECO factors for each contract
4) Remove those ECO factors that exceed 100 percent
5) Compute the average of the ECO factors in order to estimate the theta parameter of the exponential distribution
6) Integrate the ECO factor into the estimate by multiplying it by the total contract costs of the estimate
7) Create an assumption for the ECO factor within the Crystal Ball simulation by assuming ECO follows an exponential distribution with parameter equal to 1/theta
8) Run simulation and interpret forecast results

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Study Results

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- The ECO factor for Air Force, *cost-type* development contracts tends to follow a probability distribution where the frequency is higher for lower ECO factors and gradually declines as the ECO factors increase
- The corresponding distribution is exponential in nature; however, other distributions are capable of modeling this behavior
  - This study has focused on using the exponential distribution to model ECO factors due to its simplicity and its ability to fit the empirical data well for this particular query
- This briefing demonstrated how the exponential distribution is utilized within a cost estimating framework
- A risk assessment comparison was also conducted comparing an estimate whose ECO factor was constant against an estimate whose ECO followed an exponential distribution
- This approach to estimating an appropriate ECO factor can be applied to different contract queries within the Contract Database & Analysis Tool—if the data follows the above-mentioned trend

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U.S. AIR FORCE

Additional Studies

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- **Further analysis will focus on understanding the underlying dataset**
  - **Determining why so many development contracts have $0 ECO**
  - **Determining why some contracts exhibit extraordinary ECO growth**
    - **Potential Undefinitized Contract Award (UCA) ECOs, etc.**
  - **ECO factor study may prove even more relevant with respect to procurement contracts**

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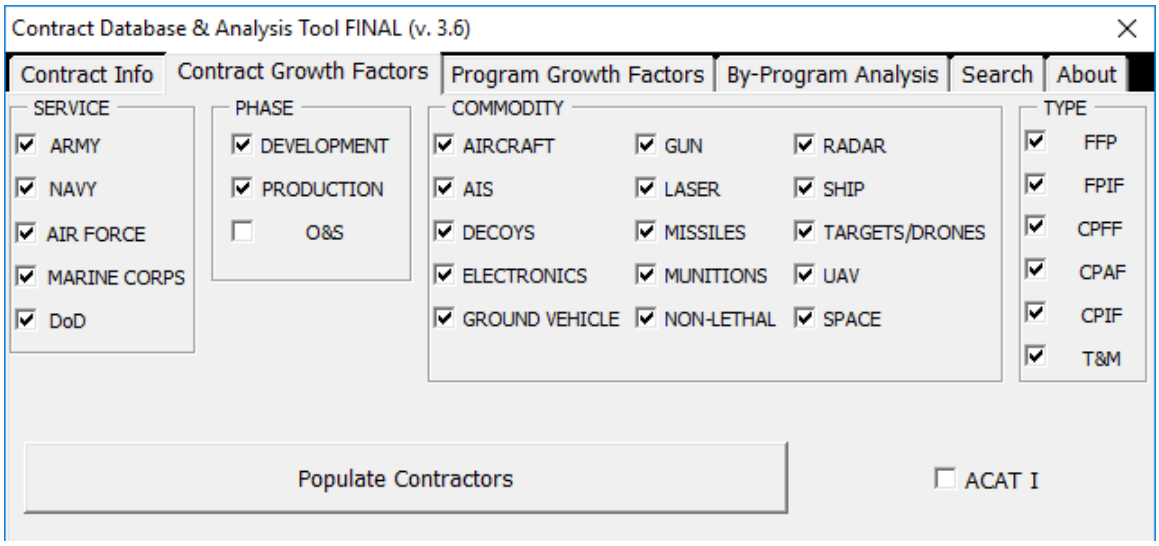
Appendix B

Table 1. Management Reserve Budget

		Management Reserve Budget (Percent)						Percentiles							Total Allocated Budget ($ Millions)				
Qtr.	Category	N	Mean	Median	Max	Min.	SD*	5th	10th	25th	50th	75th	90th	95th	Mean	Median	Max.	Min.	SD*
1	Develop	78	4.3	3.9	26.3	0.0	4.8	0.0	0.0	0.0	3.9	6.9	10.4	11.0	208	87	2523	12	326
	Produce	202	3.9	2.5	28.3	0.0	4.3	0.0	0.0	0.3	2.5	6.4	10.0	12.4	317	156	3020	5	413
	Cost	70	3.5	2.2	26.3	0.0	4.5	0.0	0.0	0.0	2.2	5.1	8.1	9.9	255	123	1478	12	295
	Price	210	4.2	3.0	28.3	0.0	4.5	0.0	0.0	0.2	3.0	6.9	10.4	12.4	297	142	3020	5	421
	Army	58	3.9	2.8	15.2	0.0	4.2	0.0	0.0	0.0	2.8	7.1	9.8	12.7	146	87	842	9	174
	Air Force	109	5.3	4.5	16.1	0.0	3.8	0.0	0.0	2.5	4.5	8.3	10.5	12.1	230	107	2823	10	388
	Navy	113	2.9	1.2	28.3	0.0	4.9	0.0	0.0	0.0	1.2	3.3	7.9	12.0	413	307	3020	5	443
	All	280	4.0	2.8	28.3	0.0	4.5	0.0	0.0	0.2	2.8	6.5	10.1	12.2	286	137	3020	5	394
2	Develop	98	4.8	4.2	24.2	0.0	4.6	0.0	0.0	0.6	4.2	7.4	10.9	12.7	209	86	3779	7	433
	Produce	234	4.1	3.0	18.7	0.0	3.9	0.0	0.0	0.9	3.0	6.1	9.6	12.3	345	167	3041	10	436
	Cost	82	3.8	3.1	24.2	0.0	4.2	0.0	0.0	0.5	3.1	5.5	7.8	11.3	228	96	1498	12	290
	Price	250	4.5	3.5	18.7	0.0	4.1	0.0	0.0	0.9	3.5	6.8	10.8	12.4	330	151	3779	7	476
	Army	72	3.8	3.0	12.3	0.0	3.5	0.0	0.0	0.5	3.0	5.9	9.2	11.4	155	93	851	7	174
	Air Force	125	5.8	5.1	16.4	0.0	3.9	0.0	1.3	2.5	5.1	7.9	11.6	13.4	274	112	3779	10	486
	Navy	135	3.2	1.5	24.2	0.0	4.3	0.0	0.0	0.3	1.5	4.6	7.6	12.1	413	218	3041	14	465
	All	332	4.3	3.4	24.2	0.0	4.1	0.0	0.0	0.9	3.4	6.6	10.4	12.4	305	143	3779	7	439
3	Develop	109	4.0	3.0	18.4	0.0	3.5	0.0	0.0	1.2	3.0	6.2	9.0	10.8	260	93	3899	7	560
	Produce	260	3.6	2.5	20.9	0.0	3.5	0.0	0.1	0.8	2.5	5.2	8.8	10.9	347	176	3080	14	430
	Cost	85	3.2	2.2	18.4	0.0	3.3	0.0	0.0	0.9	2.2	4.9	7.2	9.9	260	100	3899	11	479
	Price	284	3.8	2.7	20.9	0.0	3.6	0.0	0.1	1.0	2.7	5.9	9.0	11.0	339	158	3779	7	471
	Army	75	3.9	2.8	18.4	0.0	3.8	0.0	0.0	0.9	2.8	6.3	9.0	11.5	159	105	850	7	180
	Air Force	144	4.6	4.0	15.2	0.0	3.4	0.0	0.5	1.9	4.0	6.7	9.7	11.3	301	135	3779	14	478
	Navy	150	2.7	1.7	20.9	0.0	3.3	0.0	0.0	0.6	1.7	3.7	7.2	8.9	422	202	3899	16	542
	All	369	3.7	2.6	20.9	0.0	3.5	0.0	0.0	1.0	2.6	5.5	8.8	10.8	321.1	149	3899	7	473
4	Develop	106	3.1	2.0	12.7	0.0	2.9	0.0	0.0	1.0	2.0	5.0	7.3	9.0	300	109	3901	7	611
	Produce	276	3.1	1.9	20.2	0.0	3.5	0.0	0.0	0.4	1.9	4.5	8.1	10.1	346	163	6956	4	558
	Cost	93	2.3	1.6	12.7	0.0	2.6	0.0	0.0	0.3	1.6	3.2	5.2	8.8	275	105	3901	4	520
	Price	289	3.3	2.2	20.2	0.0	3.5	0.0	0.0	0.5	2.2	5.3	8.3	9.9	352	161	6956	7	588
	Army	77	2.5	1.8	11.8	0.0	2.7	0.0	0.0	0.2	1.8	3.8	6.5	8.7	160	111	850	4	175
	Air Force	144	4.0	3.4	14.5	0.0	3.4	0.0	0.0	1.0	3.4	6.1	9.1	11.2	358	159	6956	14	707
	Navy	161	2.6	1.4	20.2	0.0	3.3	0.0	0.0	0.4	1.4	3.5	7.1	9.7	394	161	3901	9	548
	All	382	3.1	2.0	20.2	0.0	3.3	0.0	0.0	0.5	2.0	4.5	7.8	9.7	333	150	6956	4	573

* Standard deviation.

Appendix C


Contract Database & Analysis Tool FINAL (v. 3.6)
Contract Info
Contract Growth Factors
Program Growth Factors
By-Program Analysis
Search
About
SERVICE
ARMY
NAVY
AIR FORCE
MARINE CORPS
DoD
PHASE
DEVELOPMENT
PRODUCTION
O&S
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AIS
DECOYS
ELECTRONICS
GROUND VEHICLE
GUN
LASER
MISSILES
MUNITIONS
NON-LETHAL
RADAR
SHIP
TARGETS/DRONES
UAV
SPACE
TYPE
FFP
FPIF
CPFF
CPAF
CPIF
T&M
Populate Contractors
ACAT I

Appendix D

Contract #	Lead Service	Commodity	Program	Phase	Contract Type	Initial Award	Baseline Growth	Total Baseline	Technical	Total
F09603-01-D-00	AIR FORCE	AIRCRAFT	C-130 (HERCULE	DEVELOPMENT	FFP	$704,220	$	$704,220	$	$704,220
F09603-01-D-00	AIR FORCE	AIRCRAFT	C-130 (HERCULE	DEVELOPMENT	FFP	$908,740	$	$908,740	$	$908,740
F09603-01-D-00	AIR FORCE	AIRCRAFT	C-130 (HERCULE	DEVELOPMENT	FFP	$4,999,879	$	$4,999,879	$	$4,159,335
F33657-00-C-00	AIR FORCE	AIRCRAFT	C-5 (GALAXY)	DEVELOPMENT	FFP	$20,606,205	($1,468,913)	$19,137,291	($52,885)	$35,385,364
F33657-01-C-20	AIR FORCE	AIRCRAFT	C-5 (GALAXY)	DEVELOPMENT	FFP	$28,186,512	$	$28,186,512	$	$28,186,512
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$126,610,048	($923,586)	$125,686,461	$	$125,686,461
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$6,201,047	($2,651,850)	$3,549,197	$	$3,549,197
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$83,115,923	($12,985,649)	$70,130,275	$611,036	$69,251,591
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$835,089	($252,822)	$582,267	$	$582,267
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$41,152,766	($6,122,843)	$35,029,924	$	$24,490,455
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$405,403	$	$405,403	$126,757	$532,160
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$3,244,520	$3,339,214	$6,583,733	$	$6,583,733
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$1,497,764	$	$1,497,764	$1,518,432	$3,016,196
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$39,355,523	$38,299,686	$77,655,209	$	$77,037,662
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$20,482,524	($1,409,567)	$19,072,957	$76,748,983	$99,343,713
F33657-02-D-00	AIR FORCE	AIRCRAFT	F-22 (RAPTOR)	DEVELOPMENT	FFP	$2,325,864	$	$2,325,864	$	$2,325,864
F08635-01-C-01	AIR FORCE	TARGETS/DRON	QF-16 (AST)	DEVELOPMENT	FFP	$43,491	$355,252	$398,742	$	$398,742
F08635-01-C-01	AIR FORCE	TARGETS/DRON	QF-16 (AST)	DEVELOPMENT	FFP	$22,967	$422,820	$445,787	$	$445,787
F08635-01-C-01	AIR FORCE	TARGETS/DRON	QF-16 (AST)	DEVELOPMENT	FFP	$24,912	$359,747	$384,659	$	$384,659

Appendix E

Binary Variables:

Branch: 1 for yes 0 for no.

- **Air Force**
- **Navy**
- **Marine Corp**
- **Army**
- **DoD**

Commodity: 1 if present 0 if not

- **Aircraft**
- **AIS**
- **Decoy**
- **Electronics**
- **Ground Vehicle**
- **Gun**
- **Laser**
- **Missiles**
- **Munitions**
- **Non-Lethal**
- **Radar**
- **Ship**
- **Target/Drones**
- **Space**

Contract Type

- **FFP-Firm Fixed Price**
- **FPIF-Fixed Price Incentive Fee**
- **CPFF-Cost Plus Fixed Fee**
- **CPIF-Cost Plus Incentive Fee**
- **T&M- Time and Materials**
- **Cost- Cost of Contract**

Numeric Variable

- **<%5M-If Contract is less than 5 Million receives 1 if not 0**
- **>500M-If Contract is greater than 5 Million receives 1 if not 0**

Appendix F

Breusch-Pagan Test	
α =	0.1
n =	674
Model Df =	5
SSE =	36.128
SSM (Residuals Squared) =	.621
T.S. =	107.122
p-value =	**1.661 E-21**

Appendix G

Explanations

Mod Category: Technical

The Technical mod category is for all modifications where *unanticipated* scope changes impact the contract value.

All Modifications that are Technical and are also within a production contract MUST have a Technical category (see next slide)

- **Instances of Technical Mod Categories:**
  - Adding CLINs that were ***not anticipated*** to be included in the scope of the contract, i.e. not mentioned in BASIC contract, SOW, or SAR (This usually results in a change in the SOW)
  - Adding and ***exercising options that were not included in the BASIC*** contract
  - Exercising ***"Reserved" CLIN*** (Non-Option)
  - ***Increase/decrease of quantity*** of an existing CLIN that results in change in contract value
  - Unanticipated Engineering Change Proposals ***(ECPs)***, Request for Waivers ***(RFWs)***, and Request for Deviations ***(RFDs)***
  - ***Definitization of any Technical changes*** (i.e., a CLIN was added with a NTE value and later that value was definitized- both of these mods would be classified as Technical)
  - Correction to ***Typographical Error of Technical Changes***
  - ***Value changes when a CLIN is split*** into subCLINs (generally Technical)
  - Decrease in contract value because of a ***defect*** (delivered product is not up to standard so Government reduces price of contract)

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Descriptions

Technical Categories

- **PME (Prime Mission Equipment)**
  - Change in scope that deals with the main item procured in the contract: If contract is for radars, and a mod adds more radars, the tech category is PME
  - Includes all mods that can be directly mapped to the PME *except* NRE (i.e., recurring engineering for PME is PME, but non-recurring engineering for PME is NRE)
  - Ex: For a contract that is for 8x10 displays, a mod description that says, "Procures one additional 8X10 display for E/A-18G" would be classified as PME
- **SE/PM (Systems Engineering/Program Management)**
  - Ex: Incorporate Cost of Software Data Reports (CSDR)
  - Ex: Adds funding (and cost) to Sustaining Engineering for completion of the Physical Configuration Audit
  - Ex: Add CLIN 0019AP and fund for Government Industry Logistics Support Program
- **STE (System Test and Evaluation)**
- **Spt. Eqt. (Support Equipment)**
- **NRE (Non-Recurring Engineering)**
- **IATCO (Integration, Assembly, Test, and Check-out)**
  - Ex: Incorporate Joint Helmet Mounted Cueing System GFE to CFE kits
- **Training**
- **Data**
- **Spares**

6

REPORT DOCUMENTATION PAGE

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14. ABSTRACT
Cost growth is a problem DoD wide. Cost Estimators attempt to remedy this problem by accounting for uncertainty in the estimates they complete. They use tools such as Engineering Change Orders (ECO's) to account for the uncertainty, by applying a percentage to the final amount estimated. The following research gives the acquisition community a more precise tool to predict whether a DoD Acquisition Contract will have an Engineering Change Order, which can then be used also during programmatic cost estimating, and also a method for predicting the proper amount of ECO to apply when certain variables are present. The study used both logistic and multiple regression to accomplish this. For both types of regression a stepwise approach was adopted for the response. For the Logistic Regression the Y variable was that an ECO was present and the significant predictor variables were: UAV, >500M (dollars), Navy, Army, Aircraft, Firm Fixed Price (FFP), Cost Plus Fixed Fee (CPFF) and <5M (dollars). The final model was 85% predictive. The multiple regression modeled the expected ECO percent change (less than 100% of baseline). Predictive variables included: <5M, FFP, Munition, Electronics and Missiles, along with a base amount of 22% ECO. This model was more exploratory in nature due to the extreme variability present in ECO percent changes.

15. SUBJECT TERMS
Engineering change order, management reserve, logistic regression, multiple regression.

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