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Investigation into Engineering Change Order Costs and Appropriate Rules-of-thumb

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INVESTIGATION INTO ENGINEERING CHANGE ORDER COSTS AND APPROPRIATE RULES-OF-THUMB

THESIS

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Abstract

Engineering Change Orders (ECO) are technical requirements changes to existing contracts. To account for the potential increase in contract costs stemming from ECOs, current acquisition practice is to estimate a dollar value to hold in management reserve (MR) in case of ECO occurrence. Estimators often rely on rules-of-thumb when developing these estimates. Specifically, estimators use a 10% rule-of-thumb for estimating MR contract costs in the Development life cycle phase and a 5% rule-of-thumb for contracts in the Production or O&S life cycle phase. However, no empirical data supports or validates these 10% and 5% figures. Using a new data source, 2,434 contracts with ECOs were analyzed to determine the accuracy of the 10% and 5% rules-of-thumb as well as to determine if more accurate rules-of-thumb could be developed. Results suggest that if a contract is likely to have a positive ECO percentage, then 13.25%, 5.5%, and 13.5% rules-of-thumb are more appropriate for contracts in the Development, Production, and O&S life cycle phases respectively. Service, Contract Type, Commodity, Initial Program Size, and Schedule impact ECO percentages.

Acknowledgments

I acknowledge my wonderful wife and all the joy she has brought to my life. For her unwavering support that enables me to spend hours in a dark basement typing pages for this research. I thank God every day for allowing me to meet her as well as for His Plan of Happiness that allows me to live with her for eternity.

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INVESTIGATION INTO ENGINEERING CHANGE ORDER COSTS AND APPROPRIATE RULES-OF-THUMB

I. Introduction

The Department of Defense (DoD) has instructed cost estimators to include in their estimates an additional percentage of the total costs to be held in reserve as a buffer against the possibility of an Engineering Change Order (ECO) since at least 1983 (Gibson, 1983). Per the 1983 ECO Guidebook, a 10% estimate has provided reasonable coverage for the unanticipated requirements on many programs. The 1983 ECO Guidebook also provides suggestions for if/when to deviate from the 10%. However, no empirical data has been found that has shown the original derivation or substantiated the validity of the 10% figure. Practitioners have continued to anchor estimates to that 10% for Development contracts and have also used a general 5% rule-of-thumb for estimating reserve amounts on Production and Operations and Support (O&S) contracts.

An ECO is a tool used by management to direct a scope change to a contract (Defense Acquisition University, 2021). This scope change is typically technical. When estimating the total costs of a contract, it is common practice to add an additional percentage on top of the original cost to hold in reserve in case of cost growth due to ECOs. Due to cost growth associated with ECOs, it would be very beneficial to the government if accurate predictions could be made about the appropriate amount to hold in reserve. Reserving too much money limits the number of programs able to be funded. Reserving too little money puts a program at risk of being delayed or even cancelled.

The Government Accountability Office (GAO, 2008) determined that 63% of Major Defense Acquisition Programs (MDAPs) required contractual changes after system development. Such changes included administrative, engineering (also referred to as technical), and added non-technical work requirements changes. The same report showed that poorly-defined requirements in acquisition programs can create significant cost growth. Major defense programs that had requirement changes after initial system development experienced mean cost growth of 72% from initial estimate, while those that did not change requirements had only 11%.

To determine the driving causes of ECOs, Ellis et al. (2018) investigated the factors that corresponded with changing requirements along with their respective cost and schedule impact using data on contracts from the Cost Assessment Data Enterprise (CADE). Ellis et al. (2018) determined that approximately 20% of contracts in the CADE database contained ECOs. They also found that the 10% rule-of-thumb appeared to be an insufficient estimate 89% of the time when looking at overfunded management reserves and insufficient 9% of the time when looking at underfunded management reserves. The empirical model had a lower risk than the 10% rule-of-thumb of both under and over funding, indicating that the withhold percentage should be either larger or smaller than 10% depending on the characteristics of the contract.

Ellis et al.'s (2018) findings might be limited due to their database comprising of nearly 40% contracts from the F-18 Super Hornet program, though Ellis et al. (2018) conducted an inferential test for the effect of the F-18 and found it statistically insignificant (at the 0.05 level of significance). Although useful in identifying potential variables that could drive ECO costs, Ellis et al.'s research focused on regression analysis to derive ECO percentages rather than comparisons of the real-world data to current rule-of-thumb practices.

This research investigates the accuracy of the 10% and 5% rules-of-thumb. If necessary, it subsequently develops more appropriate rules-of-thumb for the percentage to be held in reserve in case of ECOs. In lieu of using regression, this analysis instead uses a non-parametric inferential tool of detecting differences in the locations of ECO percentages. Previous studies will be used to identify different variables that could potentially affect ECO percentages. If more accurate rules-of-thumb can be developed, the government may more adroitly estimate the additional amount to be held in reserve in case of ECOs. This could potentially enable the government to more appropriately manage its fiscal resources.

Background

In DoD acquisitions, the scope of work requested in a contract is finalized once the contract is awarded to a contractor. It is possible to change the established work in a contract, resulting in a contract modification or a change order. As opposed to an administrative or standard contract change, ECOs initiate a technical or engineering change. ECOs can be instigated by contractors, acquisition agents, or end users who see the need for a technical change (Defense Acquisition University, 2021). Chapter II discusses more detailed information on ECO classifications.

Despite the significant preparation required before contract award, the DoD and its subordinate military departments have frequently underestimated the cost of procuring new weapon systems. Upon analyzing major DoD programs, Arena et al. (2006) determined that these major programs experienced nearly 46% cost growth before Milestone B, which is the transition point from technology maturation to engineering and manufacturing development. They also determined that an additional 16% cost growth occurred by Milestone C, the transition point from engineering and manufacturing development to production and deployment. The Weapon System Acquisition Reform Act of 2009 was instituted by Congress to control such cost growth. The act created the Office of Cost Assessment and Program Evaluation (OSD-CAPE) to analyze the cost of defense programs at large.

In accordance with the Federal Acquisition Regulation (FAR) part 43, DoD estimates a dollar value to hold in reserve after the contract has been awarded. This withhold is known as the management reserve (MR). If an ECO is necessary, the withhold is to be used to pay for the additional costs. Many program managers consider the MR to be an ECO withhold amount.

The common practice in the past has been to add a baseline 10% of total costs to the estimate for development contracts and to add a baseline 5% of total costs to the estimate for production and O&S contracts to account for any potential ECOs. Derivations from these percentages are often questioned as potentially being inaccurate.

The Air Force currently uses three primary cost estimating guides: The Joint Agency Cost, Schedule, Risk, and Uncertainty Handbook (JA CSRUH), the Air Force Cost Analysis Handbook (AFCAH), and the GAO Cost Estimating and Assessment Guide. The cost estimating guidelines provided by each are overlapping and none of the guides provide an empirically based method for determining an appropriate dollar amount to hold in reserve. They also do not provide any information on variables that have been shown to drive differences in ECO costs.

Research Objectives

The main objectives of this research are threefold. The first is to verify whether or not the current 10% and 5% rules-of-thumb can provide a good general estimate of the amount to be held in reserve for ECOs. If the first research objective indicates that the 10% or 5% seems to be inaccurate, then the second objective is to develop more accurate rules-of-thumb to estimate the percentage increase in cost due to ECOs. In conjunction with research objective two, the third objective is to determine which factors, such as commodity type, contract type, or contract length, drive differences in ECO percentages and whether or not different rules-of-thumb could be applied based on these different factors.

Research Questions

1. How accurate are the current 10% rule-of-thumb for development and 5% rule-of-thumb for production in estimating ECO withhold amounts?
2. What is the most appropriate general rule-of-thumb to use to estimate ECO withhold amounts?
3. What factors could potentially change more specific rule-of-thumb percentage estimates?

Methodology

All data for this research were obtained directly from Technomics Inc. This database contained 11,481 unique contracts with their respective modifications (if any) and reasons for modification. Due to the nature of the available data, the analysis in this research is solely at the contract level as opposed to the program level.

We analyze the rules-of-thumb data using both descriptive measures and customary tests. We further analyze the data in more detail by breaking the data into different categorical variables and then conducting Kruskal-Wallis and Steel-Dwass non-parametric tests. We also analyze whether or not program size or schedule length could potentially influence the likelihood of a contract experiencing an ECO with a higher-than-average ECO percentage using Pearson's Chi-squared test as well as an odds ratio. For level of significance, you use both an alpha of 0.05

and 0.10 to account for significant and moderately significant findings, respectively. We discuss this further in Chapter III.

Summary

This research investigates whether or not the 10% and 5% rules-of-thumb for estimating ECO amounts are appropriate methods for cost estimation in the DoD and is broken into five different chapters. Chapter I is an introduction that includes a brief overview of the purpose of this research. Chapter II is the literature review which serves the purpose of re-examining and synthesizing previous literature on the topic of ECO estimation. This permits us to begin where others have left off while minimizing unnecessary overlaps in research. Chapter II also identifies gaps in the ECO research that this research is attempting to fill. Chapter III explains the methodology of this research and the process by which we tested the data and obtained our results. Chapter IV provides those results. Chapter V is the conclusion section where a comparison of our results to previous ECO research findings takes place. We also include in this chapter a discussion on the relevance of this research to the DoD acquisitions community and suggestions on future research topics related to this research.

II. Literature Review

In this chapter, we examine and review previous research into Engineering Change Orders (ECO). We begin by explicitly defining what ECOs are. We next explore the history of cost growth in the DoD. Since the focus of this research is on the impacts that ECOs have on cost growth, we then explain the role of ECOs in cost growth. We then review the research on the causes of ECOs at the program and the contract level as well as the current practices being used to manage ECOs to find potential factors that could affect a general rule-of-thumb as well as more specific rules-of-thumb.

Engineering Change Orders

In order to understand clearly what an ECO is, we must first have a working definition of an ECO. The Defense Acquisition Guidebook defines an ECO as:

> "The documentation by which a proposed engineering change is submitted to the responsible authority recommending that a change to an original item of equipment be considered, and the design or engineering change be incorporated into the article to modify, add to, delete, or supersede original parts." (Defense Acquisition University, 2021, pg. 5)

Our research was able to verify what was initially relayed by Ellis et al (2018), that the 10% rule-of-thumb is an inefficient cost estimating technique. ECOs can be better understood by breaking down each of the individual words: Engineering, Change, and Order.

Engineering

The Federal Acquisition Regulation (FAR) lists multiple different types of changes to contracts, among these are contracting, administrative, engineering, and transportation changes (FAR, 2021). The type of change requested in an ECO is an engineering change. These changes are technical and can include specifications and details on performance such as a modification to an aircraft payload design enabling more or less ordinance to be carried.

Change

The action being requested is a change to an already established contract. The FAR states only contracting officers acting within the scope of their authority are empowered to execute contract modifications on behalf of the Government. Generally, Government contracts contain a changes clause that permits the contracting officer to make unilateral changes, in designated areas, within the general scope of the contract without the contractor's consent. Once a change order is signed, the contractor is directed/permitted to make a change to the already established contract.

Order

An order is a directive or mandate to complete a task. In this case the order is to change an existing contract.

Combining the definitions and descriptions of the individual words, ECO can be defined as a directed technical change to an already existing contract. It is important to note that since change management is a non-DoD exclusive discipline, our definition of an ECO can also be called other names: Engineering Change Proposal, Engineering Change, Engineering Change Notice, and Engineering Change Request. To remain terminologically consistent with current practitioner verbiage on the topic, we use the phrase Engineering Change Order as the all-encompassing term for a technical requirement change for our research.

There are two types of ECO classifications: Major (Class I) and Minor (Class II). Table 1 shows the descriptions and primary differences between the two classifications of ECOs (Defense Acquisition University, 2021).

Table 1. ECO Classification Descriptions

Classification of ECO:	Major (Class I)	Minor (Class II)
Description:	An ECO proposing a change to approved configuration documentation for which the government is the Current Document Change Authority (CDCA) or that has been included in the contractor Statement of Work (SOW) by the tasking activity.	An ECO proposing a change to approved configuration documentation for which the Government is the CDCA or that has been included in the contractor SOW by the tasking activity and which is not a Class I.
Types of changes:	Larger cost, complexity, and/or impact changes to contracts.	Minor conflicts, typos, or other changes essentially correcting documentation to reflect the current actual configuration.
Dispositioning Responsibility:	A formal Configuration Control Board (CCB).	The government administrative contracting officer or the plant representative.

Class I ECOs can be initiated to a contract during any phase of the acquisition lifecycle including: Material Solution Analysis, Technology Development, Engineering and Manufacturing Development (EMD), and Production and Deployment. Figure 1 depicts these phases in the acquisition lifecycle as defined by DoD Instruction 5000.02. Milestone B, also known as the Development Decision, takes place at the end of the technology development phase. If a project receives approval at Milestone B, resources are committed to conduct development leading to production and fielding of the project (DoD Instruction 5000.02, 2015). Said in a simplified way, the Milestone B decision permits entry into the EMD phase. All of the data we use in our research involves ECOs taking place after Milestone B. As such, all of the contracts we analyze that entails ECOs experience them in either the Development, Production, or O&S phases of the acquisition lifecycle.

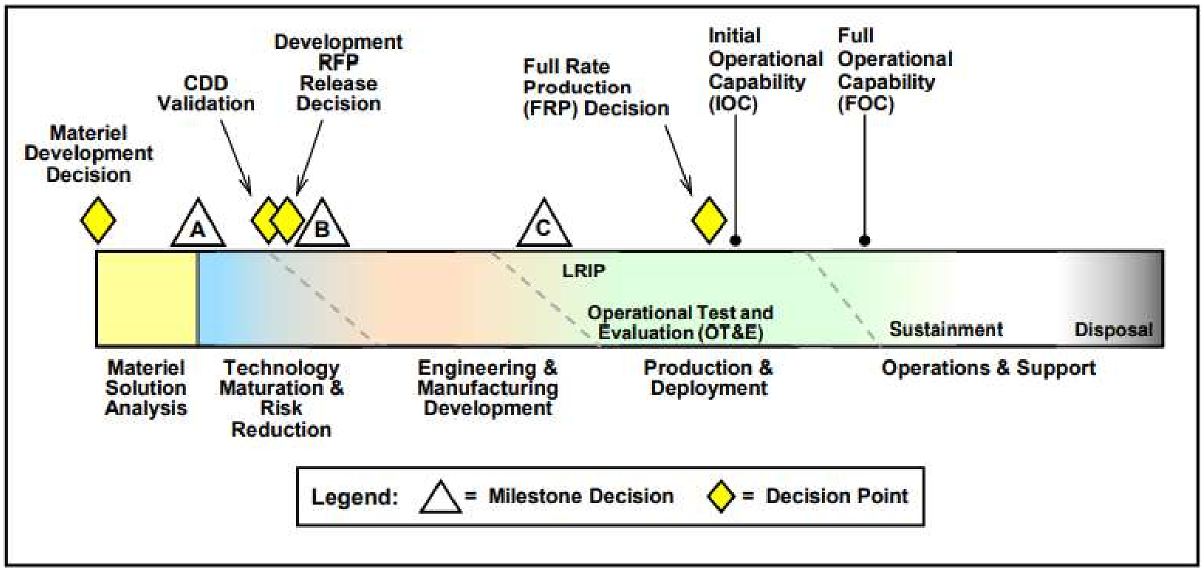

Figure 1. DoD Acquisition Lifecycle

History of Cost Growth in the DoD

The DoD has had an interest on the impacts of cost growth for most of the latter 20th and early 21st centuries. As part of a larger RAND corporation study that began in 1968, Arena et al. (2006) examined cost growth on weapons systems programs across the DoD. They primarily used data acquired via the Selected Acquisition Reports (SAR) prepared for presentation to Congress by all Major Defense Acquisition Programs (MDAP).

Arena et al.'s research reviewed 220 unique programs between the years 1968-2003. The metric they used to measure cost growth was the cost growth factor (CGF), which is defined as the ratio of the actual cost to the estimated costs. The estimated costs were defined as the most recent cost estimate on a project (so if in the EMD phase, the most recent cost estimate would be that at Milestone B). A CGF exceeding 1.0 implies that the actual cost was higher than the estimated cost – an overrun. A CGF of less than 1.0 indicates that the actual cost was lower than the estimate – also called an underrun (Arena et al. 2006). The estimate typically corresponded to a major acquisition decision milestone (such as Milestone B). Figure 2 shows the results of Arena et al.'s analysis on 68 programs that dealt with systems similar to those procured by the Air Force including aircraft, missiles, electronics, and software.

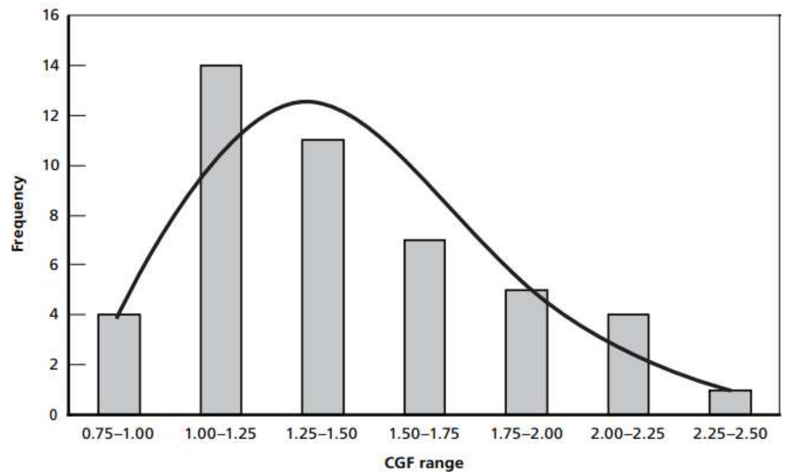

Figure 2. Distribution of Total Cost Growth from MS B Adjusted for Procurement Quantity Changes

Arena et al.'s analysis indicated a systemic problem of underestimating costs of MDAPs. The mean total cost growth for a completed program was 46 percent compared to the Milestone II (now referred to as Milestone B) estimate. The same programs averaged an additional 16 percent cost growth after Milestone III (Milestone C). The median CGF was 1.25, indicating a 25 percent cost growth over the Milestone II estimate.

Although identified as an issue, Arena et al. found few factors that correlated with their CGF. Program duration and commodity type may have been correlated with the CGF. Programs with longer durations had greater cost growth and electronics programs tended to have lower cost growth. They found no statistically significant correlation (at the 0.05 level) between branch of military and cost growth, though the Army seemed to have larger cost growth on MDAPs than the Navy or Air Force. This study indicates that program duration, commodity type, and branch of military are all potential predictors of cost growth, though Arena et al could not definitively state whether or not these variables had statistically significant correlations to cost growth. Our study tests each of these variables and their relationships to cost growth.

Overall, Arena et al.'s analysis showed about a 20 percent higher cost growth than a previous RAND study done in 1993, that had a CGF of around 1.04. They also concluded that cost growth does not disappear until three-quarters of the way through the system design, development, and production, at which point the system is well understood and a solid estimating basis is available. At this point, requirement changes also slow.

Kozlak et al. (2017) took a similar approach to Arena et al.'s research and found that a spike in program procurement costs occurs prior to First Flight, suggesting that there may be a difference in acquisitions costs between the life cycle phases. This study also identified three common predictors of cost growth: Bombers, Prototyping, and Electronic Upgrades; this suggests that commodity type may play a role in cost growth.

In another study on cost growth in the DoD D'Amico et al. (2018) found that the Development Test and Evaluation phase is a flag for high cost growth issues during a program lifecycle, which supports the findings of Kozlak et al. (2017) that different life cycle phases may have different factors that influence cost growth.

Further exemplifying the problem of cost growth in the DoD, Ben-Ari et al. (2010) researched the root cause behind cost and schedule delays for MDAPs based on a Government Accounting Office (GAO) study that showed in Fiscal Year (FY) 2008, 96 MDAPs went $296 billion over budget. Their research looked at programs that were at the initiation of an acquisition or beyond (normally Milestone B). They found that overly optimistic cost estimating was possibly responsible for cost growth.

The OSD has in the past developed reports related to cost growth. The principal staff element of the Secretary of Defense in the exercise of policy development, planning, resource management, fiscal, and program evaluation responsibilities is the Office of the Secretary of Defense (OSD). From 2013-2016, OSD released annual reports on the performance of the Defense Acquisition System. OSD also released partial updates in 2017, 2018, and 2020. Figure 3 depicts OSD's results from a study on cost growth from the 2020 partial update. OSD prefers to use the weighted cumulative growth metric to the unweighted as it accounts for the magnitude of the total dollar amount in each MDAP (i.e., programs costing larger dollar amounts will have more weight than those costing smaller amounts).

In 2019, the median weighted cost growth, defined as the percentage difference in actual cost vs estimated cost, was 74.55 percent. The median unweighted cost growth was 14.93 percent. Using the unweighted cost growth metric, OSD claims that the cumulative cost growth for Research, Development, Test, and Evaluation (RDT&E) has been stable since 2010. Median RDT&E program cost growth from 2017-2019 was less than 0.5 percent. OSD does acknowledge that on a dollar basis, cost growth has been increasing which is consistent with the results in Figure 3.

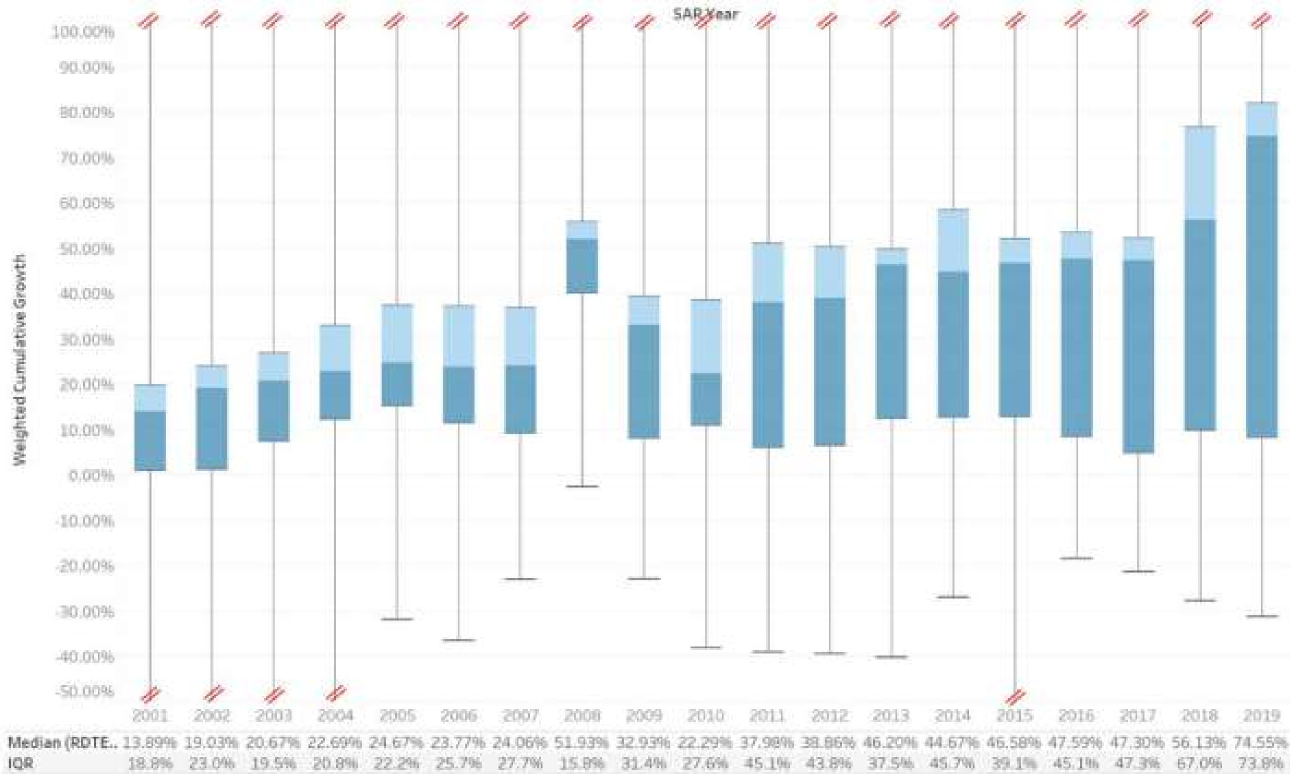

Figure 3. Weighted Cumulative Cost Growth on MDAPs

To understand the reasons for the large cost growth, programs should be looked at individually. For example, one of the programs driving the large mean weighted cost growth in 2019 is the acquisition of the F-35. The F-35 was required to have capabilities that were not currently in any other aircraft. This new development brought with it an increased technological risk. Numerous changes had to be done throughout the acquisition lifecycle in order to properly develop the F-35, increasing program costs significantly. Examples like the F-35 program could represent a major change in the program, not necessarily a program suffering from failure of execution even though both are classified as having a change in initial requirements.

Studies on cost growth in the DoD appear to show that the cost growth on programs that experience requirements changes tends to be much higher than 10%. These studies also indicate that Service, Commodity, and Schedule (program duration) may be correlated with cost growth. We analyze each of the three variables as part of our research.

ECOs Role in Cost Growth

ECOs, as discussed previously, are technical requirement changes in a program. Previous research has found that general requirement changes play a significant role in cost growth. Bolten et al. (2008) examined SAR inputs for 35 mature defense programs, where a program was considered to be mature if it was more than 90 percent complete. Although not specifically studying the effects of changing technical requirements, they found that on average 13 percent of cost growth could be attributed to general requirements changes (Bolten et al., 2008). This research also found that 41 percent of cost growth on procurement contracts could be attributed to a change in quantity on a contract, such as ordering more aircraft than originally planned. It is intuitive that changes in quantity would lead directly to overall cost growth.

The GAO in 2011 released a report detailing the reasons behind Nunn-McCurdy breaches since 1997. A minor Nunn-McCurdy breach occurs when the program acquisition unit cost (PAUC) or average procurement unit cost (APUC) increases by 25 percent or more over the current acquisition program baseline (APB) objective. A major Nunn-McCurdy breach occurs when the PAUC or APUC increases by 50 percent or more over the original APB. The GAO report examined the 74 unique program breaches since 1997 and found that 34 of them state changing requirements as a factor leading to their breach (GAO, 2011). Forty-one of the programs state that a change in quantity was a factor leading to their breach, backing the findings by Bolten et al (2018).

Programs that experience early cost growth have also been found to experience cost growth throughout the program's life cycle (Christensen and Templin, 2000). Programs that have already modified requirements will continue to modify requirements. Harmon and Arnold (2013) found that of the 16 development programs they analyzed, 11 had positive year-over-year cost growth due to unforeseen increases in capability requirements, though the small sample size leaves some doubt to their conclusions.

Potential Causes of ECOs

Program Level

We know that ECOs are related to cost growth so, similar to Ellis et al. (2018), we conjecture variables predicting cost growth may also help to predict ECO growth percentages. Trudelle et al. (2017) identified several variables to be predictive in determining if a program will experience limited cost and schedule growth. They found that Electronic System Programs, projected Milestone B to Initial Operational Capability (IOC) duration less than 58 months, and extra-large programs to be statistically significant. These three variables can be summarized as commodity type, schedule length, and project size. Thus, Trudelle et al.'s findings support Arena et al.'s (2006) report that electronics programs and programs with shorter schedules from Milestone B to IOC tend to experience cost growth. Transitively, we expect that electronics programs, programs with longer schedules, and smaller programs to have a lower likelihood of experiencing ECOs.

Contract type has also been found to relate to cost growth. Fixed price contracts (FFP) are typically used when a potential programs technology is mature and stable, whereas cost reimbursable contracts are used when there are relatively few known solutions. Due to their natures, we would expect cost growth to be lower on FFP contracts. Both Harmon and Arnold (2013) as well as Christensen and Templin (2000) conclude that contract type influences the executability of a contract, with FFP contracts typically being easier to execute. Cost reimbursement contracts were found to be more difficult to execute due to the higher uncertainty.

Thus far, we have investigated research that primarily focuses on the causes of cost growth at the program level. However, since a program is the summation of numerous smaller contracts, a look into the causes of cost growth at the contract level would be beneficial. This leads us into research on the contract level factors that could potentially predict ECOs.

Contract Level

Two recent studies were conducted with the intent of developing a method to predict both the likelihood of a contract experiencing an ECO as well as the appropriate amount to hold in reserve. Cordell (2017) found that Unmanned Aerial Vehicle (UAV), contract greater than $500 million, Navy, Army, Aircraft contract, FFP contract, Cost Plus Fixed Fee (CPFF) contract, and contracts less than $5 million were all significant variables in predicting ECOs. The study also found that contracts less than $5 million, FFP contracts, Munition commodity type, and Electronics and Missiles commodity type were significant predictive variables in determining an appropriate ECO withhold amount, with a base amount of 22.5 percent to be held in reserve (Cordell, 2017).

Ellis et al. (2018) analyzed 533 contracts with the intent to predict the likelihood of a contract experiencing an ECO as well as to determine the expected median percent increase in a baseline contract cost if an ECO was likely. They found the significant factors to be the initial contract cost and the number of line items on the contract. Specifically, Ellis et al.'s findings suggest that contracts starting off at less than $100 thousand may potentially be less likely to incur an ECO. Again, it appears that commodity type, schedule length, and project size are all potentially significant variables in determining ECO likelihood and cost growth.

Furthermore, they determined that the likelihood of an ECO and the additional amount incurred appeared to be independent of acquisition phase, branch of service, commodity, contract type, or any other factor except for the basic contract amount and the number of contract line items. They also developed a model that empirically estimated an appropriate dollar amount to hold in reserve in case of an ECO occurrence. The empirical model had a lower risk of both under and over funding. This empirical model estimated an ECO withhold that was too low 9.38% of the time compared to 9.57% of the time for the current practice of rule-of-thumb estimating. When looking at overfunding, the empirical model overfunded the ECO withhold 58.9% of the time as compared to 89.3% of the time by the current practice (Ellis 2018).

Current Methods of Managing ECOs

In 2014, the Air Force Cost Analysis Agency (AFCAA) hired Technomics to build a contracts database that bucketed contract overruns (cost growth) into three categories: cost, schedule, and technical. The following year the Air Force Life Cycle Management Center (AFLCMC) reviewed and coordinated with Technomics on the contract database. AFLCMC developed their own ECO factor under a notional exponential distribution and found that the mean management reserve should be around 18.75 percent. In 2017, Cordell (2017) used stepwise regression on the Technomics database and found the mean management reserve should be 22.5%.

The current practice within AFLCMC and AFCAA for estimating the amount to be held in management reserve (MR) in case of an ECO is to use a 10% rule-of-thumb for development contracts and a 5% rule-of-thumb for production contracts. It appears that the 10% and 5% rules-of-thumb were never developed empirically. Figure 4 shows a timeline of ECO studies and MR estimation techniques since 1980.

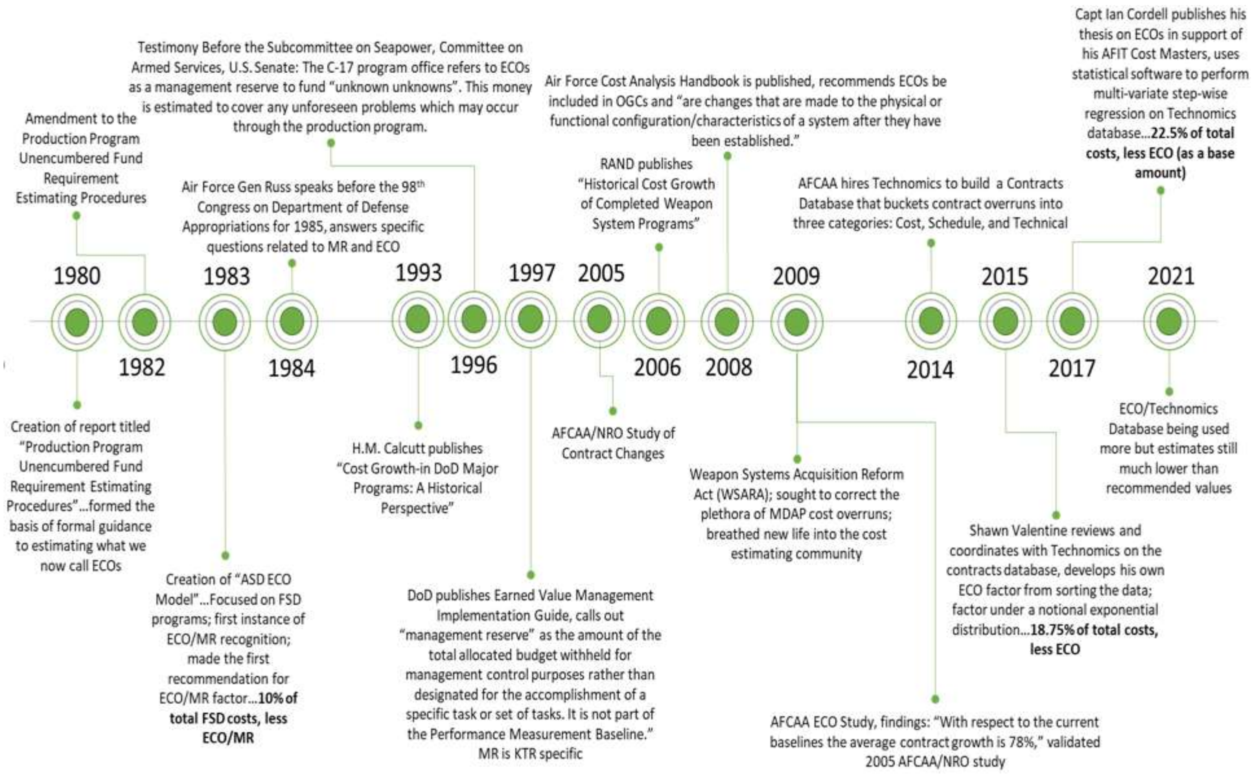

Figure 4. Timeline of ECOs in Cost Estimating

The first indication of the 10% rule-of-thumb appears in a 1983 Economic Change Orders Model Users Guide that instructs that MR for economic change orders should be 10% of the total costs because this value has provided reasonable coverage for the unanticipated requirements on many programs in recent years (Gibson, 1983). The guide does not provide any definition of reasonable or the exact number of programs. The guide also states that the 10% value originated during Congressional committee discussions of the proper MR amount for the B-1A program. The guide even places restrictions on going outside the 10%, stating that if an analyst departs from the 10% value, he or she should clearly document the reasons for the departure and how the value selected was derived. Newer guides have since been created, such as Mil-Handbook 61-B, but they do not contain any guidance on specific amounts to hold in management reserve. We were unable to find any source for the origin of the 5% rule-of-thumb and it appears that this rule morphed from the 10% rule when cost estimators realized that production and development contracts have different levels of risk for ECOs (S. Valentine, personal communication, 2021).

The current practice of using the 10% and 5% rules-of-thumb for AFLCMC and AFCAA is often producing estimates that are much lower than empirically recommended values. As with many large organizations, the Air Force seems resistant to change. Specifically, the practitioners may be unwilling to use a new tool (such as a regression model) to estimate ECO MR amounts. It may be beneficial to develop a new rule-of-thumb that is more accurate than the 10% and 5% rules if empirical analysis suggests that such percentages are currently inaccuarate.

Summary

Cost growth has been a fundamental aspect of DoD acquisitions and, unsurprisingly, there have been numerous studies done relating to cost growth. In more recent years, ECOs have been studied to determine their impact on cost growth. In this chapter, we relayed the history of cost growth in the DoD, defined specifically what ECOs are, discussed how ECOs relate to cost growth as well as potential causes of ECOs, and outlined current practices for managing ECOs. There seems to be some consistency in potential factors that could predict ECOs and cost growth (by percent over baseline). These factors include commodity type, schedule length, and project size. We aim to add to the understanding of factors relating to ECOs and cost growth. After reviewing the literature and the current practices of managing ECOs, we now know that prior research has not had a real effect on how the Air Force estimates ECO withholds. Specifically, the current 10% rule-of-thumb practice appears to be unchanged since at least 1983. This research seeks to develop a more accurate rule-of-thumb for practitioners to use in an aim to simplify the use of more accurate empirical information.

III. Methodology

In this chapter, we discuss the process we use to analyze the variables we identified in Chapter II that may drive differences in ECO percentages. We begin by describing the database and its details as well as the procedures used to modify the dataset and correct for any errors that may be present. This first step is important because the original database required operose processing in order to be analyzed. We next describe the statistical tests we use to analyze the database and the standard we use to determine significance. Lastly, we conclude by describing our process of conducting those statistical tests.

Data

The data was retrieved on 07 October 2021 directly from Technomics. This database is comprised of basic contracts and their modifications. The database included a column for dollar amounts of each modification normalized for inflation to constant year (CY) 2020. The specific factors used by Technomics to normalize the dollar amounts come from the 2020 OSD inflation table. All values are in FY20 dollars. The normalization happens at the CLIN level. It utilizes the modification date to determine what fiscal year (FY) the money was obligated in; it does not use the FY found in the original contract's line of accounting. The inflation calculation is done by utilizing the modification date to determine which FY to use. A multiplier factor is then applied based on the appropriation. If the appropriation is not available, the service, phase, and commodity are used to determine the appropriate inflation factor to be applied.

The original database contains 11,481 unique contracts with their modifications. The total amount of rows in the original database was 226,515. A list of all the different programs contained in the database can be found in the Appendix. This original database was reduced in order to be made analyzable for our research and the specific reductions will be discussed later in this chapter. The Air Force and the Navy constituted a combined 92.6% of the total contracts in the database. The percentage of the contracts in the database for each service can be found in Figure 5. The vast majority (~73%) of the contracts were aircraft (including Other Aircraft, F/A-18, and F-16) related as can be seen in Table 2. The F/A 18 made up about 37% of the aircraft contracts and about 27% of the total contracts in the database. Figure 7 shows the number of contracts by aircraft.

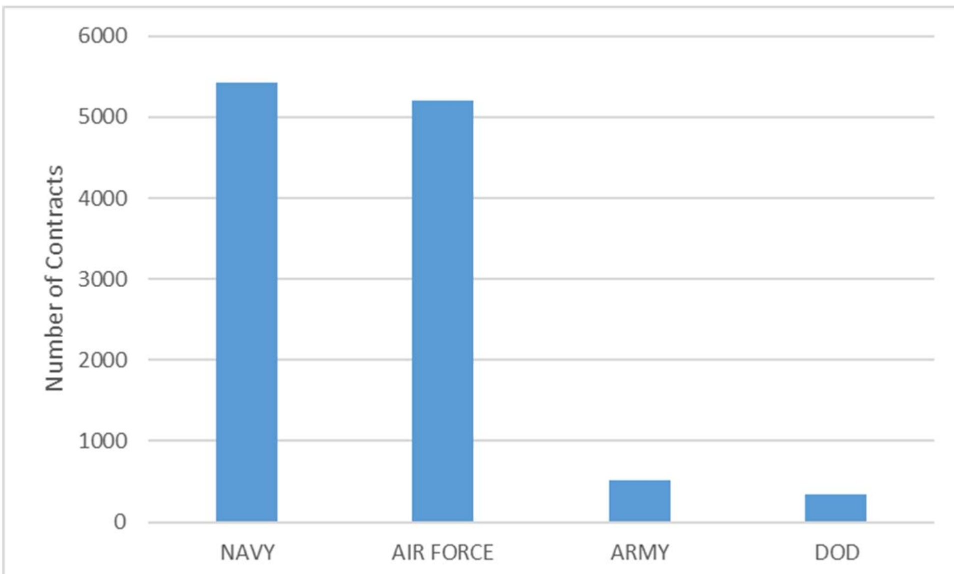

Figure 5. Number of Database Contracts by Branch of Service

Table 2. Database Contracts by Commodity

Commodity	Count	Percent of Total
OTHER AIRCRAFT	3397	29.59%
F/A-18	3113	27.11%
F-16	1831	15.95%
MISSILES	773	6.73%
AIS	543	4.73%
GROUND VEHICLE	533	4.64%
ORDNANCE	378	3.29%
UAV	335	2.92%
ELECTRONICS	295	2.57%
TARGETS/DRONES	121	1.05%
SPACE	79	0.69%
ENGINE	42	0.37%
DECOYS	22	0.19%
RADAR	7	0.06%
LASER	4	0.03%
GUN	3	0.03%
SHIP	3	0.03%
NON-LETHAL	2	0.02%

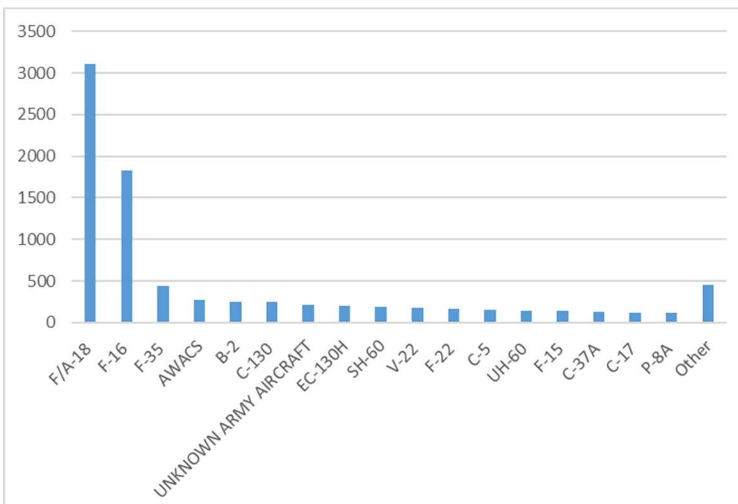

Figure 6. Number of Contracts by Aircraft

The database itself was originally created when the Defense Cost and Resource Center (DCaRC) commissioned Technomics Inc. to establish it. The database contains data on historical contracts, taken directly out of the DoD contracting system known as Electronic Document Access (EDA). EDA is an online resource in which government contracting agencies upload scanned copies of actual contractual documents (EDA, 2017). Technomics extracted information from EDA and placed it into an Excel database file. The raw data was obtained directly from Technomics, though a processed version of the data can also be found via CADE, which is more readily accessible by cost analysts DoD wide. We elected to obtain our data directly from Technomics because the formatting of the raw data they could provide was more easily processed compared to the CADE database though both databases relay the same information.

Technomics. is still the contracted entity maintaining and updating the data transfer from EDA to CADE. To the best of our knowledge, the contracts in the current database were not chosen by random. Each year, Technomics sends out a data call to cost agencies DoD wide asking for a list of contracts that analysts would like information on. Cost agencies then send their lists of contracts to Technomics who researches them in EDA and transfers the data to the CADE database. Technomics updates the CADE database on a quarterly basis. The purpose of the database is solely informational.

Of the contract modifications in the database, including the baselines, about 25% are technical in nature as depicted in Figure 7a. A baseline modification is defined as the original contract. Furthermore, when only looking at modification types (i.e. excluding the baselines) 41% of the modifications are technical in nature as depicted in Figure 7b. This means that about two-fifths of all modifications done to a contract in this database were technical, the highest of any modification type. This information should only increase the Air Force’s interest in management strategies for ECOs.

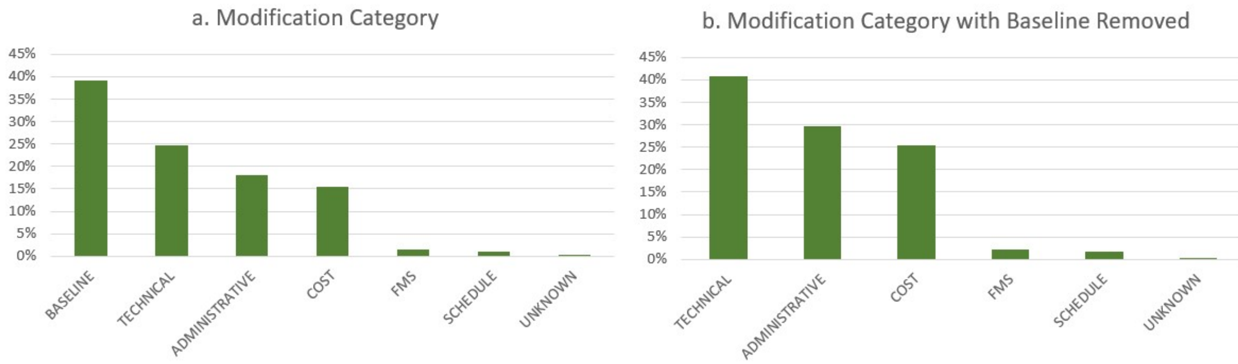

Figure 7a and 7b. Percent of Database Modifications that are Technical

Database Modifications

Three different processing actions were taken on the original database prior to finalizing the data before any descriptive or inferential analysis. These three actions reduced the dataset from 11,481 unique contracts to 2,434 unique contracts. The data was analyzed using both positive and negative ECO values, and then just the negative ECO values were excluded and the data was analyzed again. When only analyzing the Positive ECO percentages, the remaining contracts was reduced to 1,793. When analysis was performed on Schedule length, any contract missing modification dates or period of performance end dates was removed since this made it impossible to determine the length of the contract. The last two criteria in Table 3 are highlighted blue to identify them as exclusion steps for additional analysis performed. The inclusion criteria along with the number of contracts removed at each step can be found in Table 3.

Table 3. Inclusion Criteria for Analyzed Data - * and ** indicate exclusion steps taken on only select variables

Inclusion Criteria	Contracts Added	Contracts Removed	Contracts Remaining
Database from Technomics	11481		11481
Non-Technical Modifications		8537	2944
Blank Baseline or ECO Cost		12	2932
Absolute Value of ECO percentage > 100%		498	2434
*Negative ECO Percentage		641	1793
** Missing Dates		39	1754

Modification Type

There were seven different modification types in the original dataset: Technical, Foreign Military Sales (FMS), Baseline, Schedule, Cost, Administrative, and Unknown. The Air Force Cost Analysis Agency (AFCAA) defines Technical mods as an engineering change order dependent on an independent cost estimate method (AFCAA, 2009). The basis of this research is the comparison of the Technical modification amount to the baseline amount. As such, any non-technical modification was removed from the dataset with the exception of Baseline modifications. Technical modifications were compared to their respective baselines in order to calculate ECO percentages.

Blank Baseline or ECO Cost

The government cannot require a contractor to provide a product or service free of charge. As such, any contracts that had blank or zero dollar costs were removed from the dataset. Any contract with a blank ECO cost was also removed as that was considered missing information.

Appropriately Scoped Contracts

Logically, we would not expect a contract to more than double in cost if scoped correctly. The intent of our research was to provide realistic rules-of-thumb to cost estimators based on contracts that were properly scoped. If a contract contained an ECO that was more than 100% of its baseline cost in absolute value, it was determined to be uncommon and unrealistic and was removed from the dataset. As such, the results of this research only hold for sufficiently scoped and properly accounted for initial contract award. This removed 498 out of the remaining 2434 contracts, or about 20%. We here acknowledge that we are identifying a properly scoped contract as having an ECO no more than 100% in absolute value. This number may not be the best measure for properly scope contract and we recommend that future research look into the reasons behind contracts exceeding this 100% threshold.

Missing Date

The modification date and the period of performance end date allowed us to estimate the length of the contract. If either of the dates were not available, we could not estimate the contract length. Therefore, any contracts or modifications missing a date were removed.

Limitations

As with any research, there are mentionable limitations to our research. There may be selection bias in the population since Technomics adds contract information to the database based on interest from analysts. Additionally, there may be input errors in the database since Technomics was taking data from scanned copies of contracts and manually inputting them into the database.

The original database was sorted into 28 columns, with each column containing specific information on each basic contract or modification including contract type, dollar value of the basic contract or modification, quantity, and so on. Any missing or unknown values were recorded as blank cells. For our research the database was narrowed to 12 total variables shown in Table 4 and Table 5.

Table 4. Categorical Variables Remaining After Data Processing

Categorical Variable	Sub-Categories
Life-Cycle Phase	Development, Production, O&S
Service	Air Force, Army, DoD, Navy
Contract Type	Fixed, Cost, T&M, Unknown
Commodity	Other Aircraft, F-16, F/A-18, Missiles, Ground Vehicle, UAV, Space, Ordnance, AIS, Electronics, Engine, Targets/Drones, Decoys, Gun, Radar, Ship, Non-Lethal, Laser

Table 5. Continuous and Binary Variables Remaining After Data Processing

Continuous Variable	Range-Low	Range-High
Baseline Dollar Amount (Program Size)	$120.43	$26,180,003,415.94
ECO Dollar Amount	-$283,408,322.19	$10,115,580,960.74
ECO Percentage	-100%	100%
Schedule Length in Days	1	9891
Binary Variable	**Value 1**	**Value 2**
Baseline Amount > $1M	Yes	No
Baseline Amount > $2.5M	Yes	No
Schedule Length > 5 years	Yes	No
ECO Percentage Positive	Yes	No

Statistical Tests Performed

Once the dataset was processed and ready for analysis, multiple statistical tests were performed on the data. We first test to see whether or not the overall mean ECO percentage was equivalent to the 10% rule-of-thumb for Devlopement contracts or the 5% rule-of-thumb for Production and O&S contracts. Then, based on the findings from our literature review, we conduct additional tests to determine whether or not the mean ECO percentage differs based on the categorical variables of Commodity, Contract Type, or Service. We conclude our analysis by determining whether or not there is a greater likelihood that a contract would experience a larger ECO percentage based on program size or schedule length. For all tests, we assume that each individual observation in our dataset was independent of all the others. We use an alpha value of 0.05 to test for the statistical significance of each test. JMP Pro 12 was the software used to perform all statistical tests.

***t*-test**

The first statistical test we perform is a customary *t*-test. This test is performed on the entirety of the dataset to determine whether or not the mean ECO percentage is statistically equivalent to 10% or 5%. We note that if the sample size, n, is greater than 30 then the Central-

Limit Theorem is engaged and normality is not required. The null and alternative hypotheses for the *t*-test are below, where μ was the mean ECO percentage for our database.

$$H_0: \mu = 0.1$$

$$H_a: \mu \neq 0.1$$

Kruskal-Wallis Test

After determining whether or not the overall mean ECO percentage is different than 10%, we use our review of previous literature to determine if certain categorical variables can explain some of the variability in ECO percentages. For each of the categorical variables of Commodity, Contract Type, and Service we perform a Kruskal-Wallis test in order to determine if the ECO percentage location differs between any of the categories. For each Kruskal-Wallis test, the null and alternative hypotheses are:

H_0: The ECO percentage location is equivalent for each category

H_a: At least two categories have different ECO locations

Steel-Dwass

If the *p*-value is sufficiently low enough to reject the null hypothesis for any of the Kruskal-Wallis tests performed, then we conduct a Steel-Dwass test to determine between which categories the difference occurs. The Steel-Dwass test allows us to do multiple comparisons of locations in order to control for an overall Type I error.

Pearson's Chi-Squared Test and Odds Ratio

The last statistical tests we conduct are a Pearson's test of dependency with an associated odds ratio to determine whether or not there is a greater likelihood of a large ECO percentage occurring based on schedule length or on the project size of the initial contract (measured in dollars). For each Pearson Test, the independent variable is compared to the dependent variable of whether or not the ECO percentage is greater than the appropriate rule-of-thumb. We use 10% for Development contracts and 5% for Production and O&S contracts.

Sequence of Statistical Tests Performed

We first conduct an inferential test to determine if there is a difference in ECO percentage locations based on Life-Cycle Phase. We then divide the database into three smaller datasets using the three life cycle phases of Development, Production, and O&S. For each life cycle phase, we further divide the data into four separate data groups. This leaves us with a total of 12 data groups to be analyzed, found in Table 6. We perform analysis on five variables that our literature review indicates may influence ECO percentages for each of the 12 data groups: Service, Contract Type, Commodity, Program Size, and Schedule.

Alpha trimmed means are used in statistical analysis to reduce the effects of outliers. An alpha trimmed mean reduces the observations on both ends of the range of the database by a pre-selected percentage. For our research, the range of ECO percentages was -100% to 100% for each of the life cycle phases. We selected our alpha trimming factor by identifying large tails in the data and attempting to remove those tails to reduce outlier effects.

Table 6. Data Groups for Analysis

Life Cycle	Data Group	*n*
Development	All Technical Contracts	448
	Only Positive Technical Contracts	389
	1% Alpha Trimmed - All Technical Contracts	438
	1% Alpha Trimmed - Only Positive Technical Contracts	384
Production	All Technical Contracts	768
	Only Positive Technical Contracts	621
	2.5% Alpha Trimmed - All Technical Contracts	728
	2.5% Alpha Trimmed - Only Positive Technical Contracts	600
O&S	All Technical Contracts	1218
	Only Positive Technical Contracts	872
	F/A-18 Excluded, 2.5% Alpha Trimmed - All Technical Contracts	1000
	F/A-18 Excluded, 2.5% Alpha Trimmed - Only Positive Technical Contracts	762

Summary

In this chapter, we discussed the dataset we used for our analysis. We also discussed the different criteria we used to reduce the original dataset, the different datagroups we idientified for analysis, and the statistical tests we intend to perform. In Chapter IV, we perform those statistical tests and relay the results.

IV. Results

Our results section is split into four different phases: Life Cycle Phase testing, Development analysis, Production analysis, and Operations and Support (O&S) analysis. We begin by using statistical tests to determine whether or not there is a difference in ECO percentage locations between any of the three life cycle phases of Development, Production, and O&S. We then analyze each life cycle phase separately, initially using all of the negative and positive ECO percentages before analyzing just the positive ECO percentages in each life cycle phase. We then use alpha trimming to remove any potential outliers and reconduct the same tests to determine if there is consistency in our results. At the end of the analysis for each life cycle phase, we conclude with a multivariable analysis to determine if contracts with specific characteristics are more or less likely to incur positive ECO percentages.

Differences Between Life Cycle Phases

We start our analysis by determining whether or not the ECO percentage locations differ between the Development, Production, and O&S phases of the DoD acquisition lifecycle. Figure 8 shows a box plot of ECO percentages for each life cycle phase.

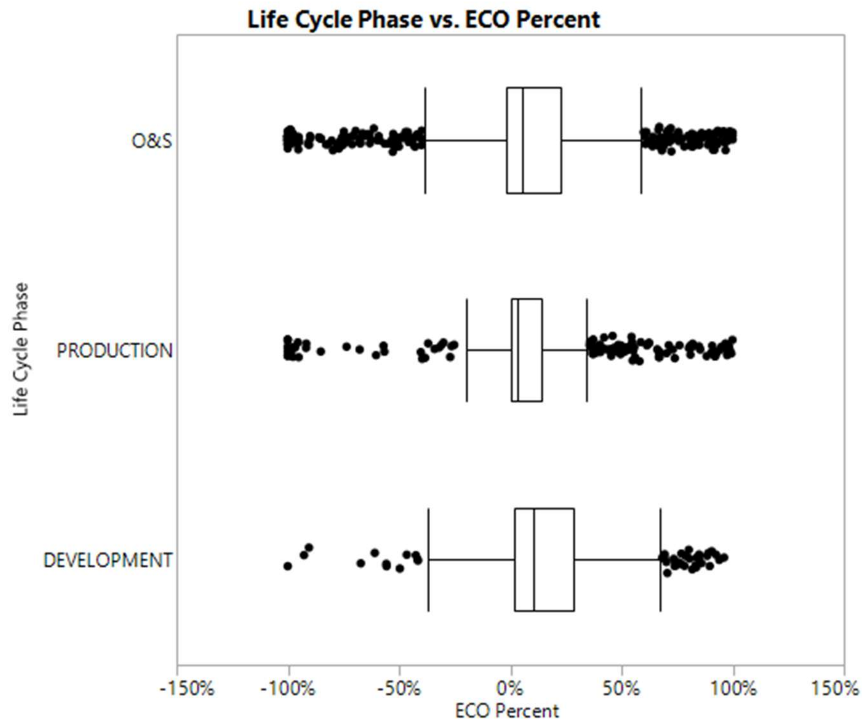

Figure 8. Box Plots of ECO Percentages by Life Cycle Phase for Technical Contracts

We perform a Kruskal-Wallis test that includes all of the negative and positive ECO percentages to determine if there is any statistical difference at the 0.05 level of significance. The results of this test are found in Table 7.

Table 7. Kruskal-Wallis Test Results for Life Cycle Phase, all Technical Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DEVELOPMENT	448	631648	545440	1409.93	6.416
O&S	1218	1442438	1482915	1184.27	-2.335
PRODUCTION	768	889310	935040	1157.96	-2.838

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
41.8260	2	<.0001*

The *p*-value is sufficiently low (less than the alpha value of 0.05), so we reject the null and conclude that there is a difference in ECO percentage locations between at least two of the life cycle phases. In order to determine which of the life cycle phases differ, we perform a Steel-Dwass test, the results of which can be found in Table 8.

Table 8. Steel-Dwass Results for Life Cycle Phase, all Technical Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
PRODUCTION	O&S	-13.568	26.42242	-0.51349	0.8648
PRODUCTION	DEVELOPMENT	-139.033	20.87651	-6.65978	<.0001*
O&S	DEVELOPMENT	-143.096	26.58173	-5.38323	<.0001*

The results from the Steel-Dwass test indicate that there is a difference in ECO percentage locations between Production and Development as well as between O&S and Development. The results also indicate that contracts in the Development phase tend to have the higher ECO percentage locations, followed by O&S, with Production having the smallest ECO percentage locations. This ordering aligns with common DoD acquisition belief that Development contracts tend to be riskier and have a higher chance of incurring ECOs.

We suspect that there may be differences in the results of our tests if we conduct them using only the positive ECO values. For this reason, we then exclude all of the negative ECO percentages from our dataset and conduct another Kruskal-Wallis test to determine whether or not there are differences in ECO percentage locations between any of the life cycle phases. Box plots of positive ECO percentages for each life cycle phase can be found in Figure 9. The results for the Kruskal-Wallis test on life cycle phases for positive ECO contracts can be found in Table 9.

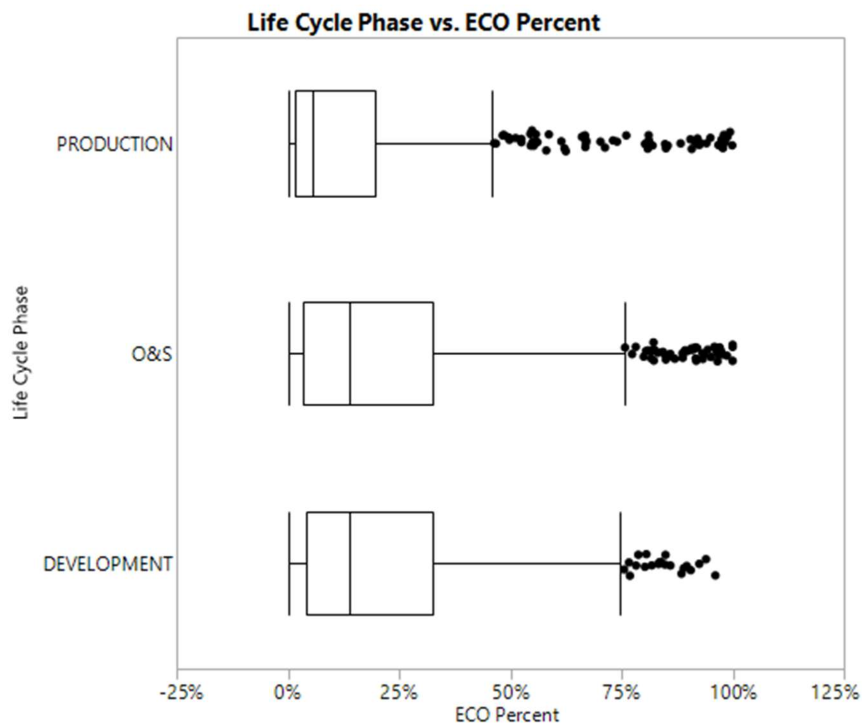

Figure 9. Box Plots of ECO Percentages by Life Cycle Phase for Positive ECO Technical Contracts

Table 9. Kruskal-Wallis Test Results for Life Cycle Phase, Positive ECO Technical Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DEVELOPMENT	389	398153	366049	1023.53	3.365
O&S	872	877428	820552	1006.22	4.842
PRODUCTION	620	494441	583420	797.49	-8.036

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
64.8457	2	<.0001*

The results of the Kruskal-Wallis test indicate that there is a difference in ECO percentage locations for at least two of the life cycle phases. We perform a Steel-Dwass test in order to determine between which pair of life cycle phases this difference occurs. The results of this Steel-Dwass test can be found in Table 10.

Table 10. Steel-Dwass Results for Life Cycle Phase, Positive ECO Technical Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
O&S	DEVELOPMENT	-9.335	22.20319	-0.42042	0.9072
PRODUCTION	DEVELOPMENT	-123.799	18.84851	-6.56810	<.0001*
PRODUCTION	O&S	-163.888	22.63299	-7.24113	<.0001*

When only looking at the positive ECO percentages, Development tends to have the highest ECO percentage locations, followed by O&S, with Production having the lowest ECO percentage locations. Again, this follows with common DoD acquisition beliefs. The results of the Steel-Dwass test indicate that there is a significant difference in ECO percentage locations between contracts in the Production and Development life cycle phases as well as between contracts in the Production and O&S phases. These findings differ from the findings that included both negative and positive ECO percentages.

Due to the differing results of the Kruskal-Wallis test conducted on just the positive ECO percentages when compared to the test conducted on negative and positive ECO percentages, we elect to analyze our dataset in three different groupings based on life cycle phase: Production, O&S, and Development. We analyze each data group with negative and positive ECO percentages included before excluding the negative ECO percentages and analyzing just the positive ECO percentages in each group.

Development Contracts

We begin our individual analysis on the life cycle phases beginning with Development. We start by analyzing all positive and negative ECO percentages before scaling down and looking at just the positive ECO percentages for Development contracts.

Positive and Negative ECO Percentages – Technical Development Contracts

A histogram of all the ECO percentage values can be seen in Figure 10. We test for whether or not the mean ECO percentage for Development contracts is equivalent to the 10% rule-of-thumb using a *t*-test of equivalence. We use the 10% rule-of-thumb as a comparison on Development contracts because that is the rule currently being used by practitioners for Development contracts. Summary statistics for this data group as well as the results of the *t*-test can be found in Table 11.

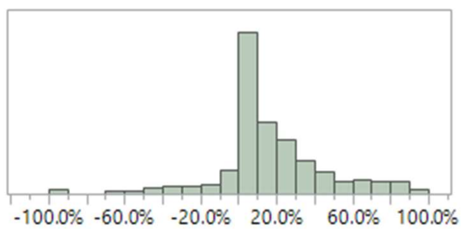

Figure 10. Histogram of ECO Percentages, Technical Development Contracts

Table 11. Summary Statistics and t-test for Technical Development Contracts

N	448
Mean	16.299%
Median	10.35%
Std Dev	27.886%
CV	1.7109186
IQR	26.525%
Compared to	10%
Test Statistic	4.7811
p-value	<.0001

We conclude from our test that the mean ECO percentage for all technical Development contracts is different than 10%, with our estimated mean being about 16.3%. However, it is important to note that the median ECO percentage for this data group was 10.35%, which is very close to the 10% rule-of-thumb.

Service

We next move into our analysis on the five different variables that may affect ECO percentages, beginning with Service. Figure 11 shows box plots of ECO percentages for each of the different services. We test for differences in ECO percentage locations between the Services using a Kruskal-Wallis test. The results of which can be found in Table 12. Our results indicate that there is no difference in the ECO percentage locations between any of the services. ECO percentage summary statistics can be found in Table 13.

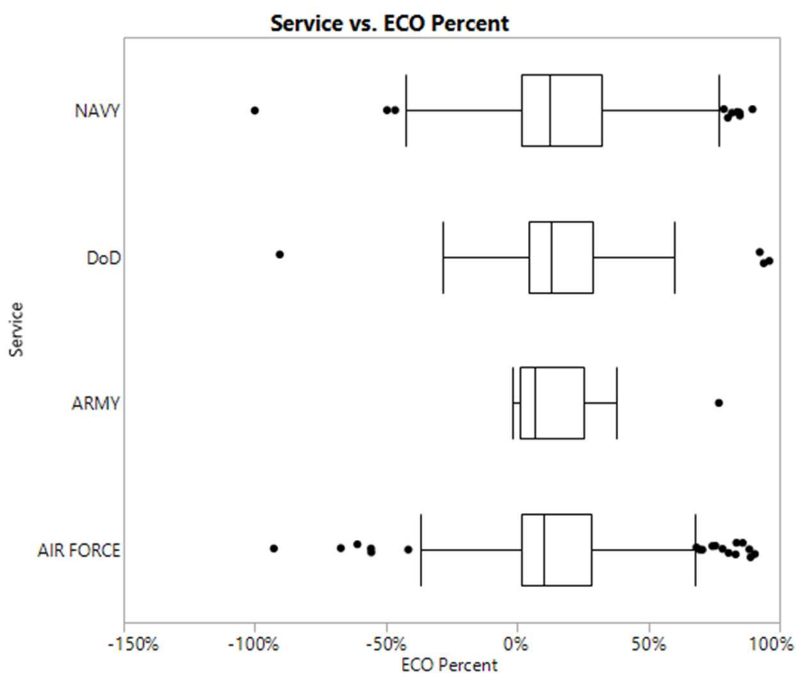

Figure 11. Box Plots of ECO Percentages by Service, Technical Development Contracts

Table 12. Kruskal-Wallis Test Results for Service, Technical Development Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	262	57569.5	58819.0	219.731	-0.925
ARMY	18	3636.50	4041.00	202.028	-0.751
DoD	26	6423.50	5837.00	247.058	0.915
NAVY	142	32946.5	31879.0	232.018	0.837

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.1658	3	0.5387

Table 13. ECO Percentage Summary Statistics by Service, Technical Development Contracts

	Air Force	Army	DoD	Navy
N	262	18	26	142
Mean	15.03%	14.73%	20.50%	18.08%
Median	9.85%	6.65%	12.65%	12.50%
Std Dev	26.03%	20.29%	38.44%	29.84%
CV	1.7320694	1.377095	1.874828	1.650426
IQR	26.48%	23.98%	24.05%	30.58%

Contract Type

We now test for whether or not there are differences in ECO percentage locations based on Contract Type. Figure 12 shows the different ECO percentage box plots for each of the Contract Types. We perform a Kruskal-Wallis test and conclude from the results in Table 14 that there are differences in ECO percentage locations between at least two of the Contract Types.

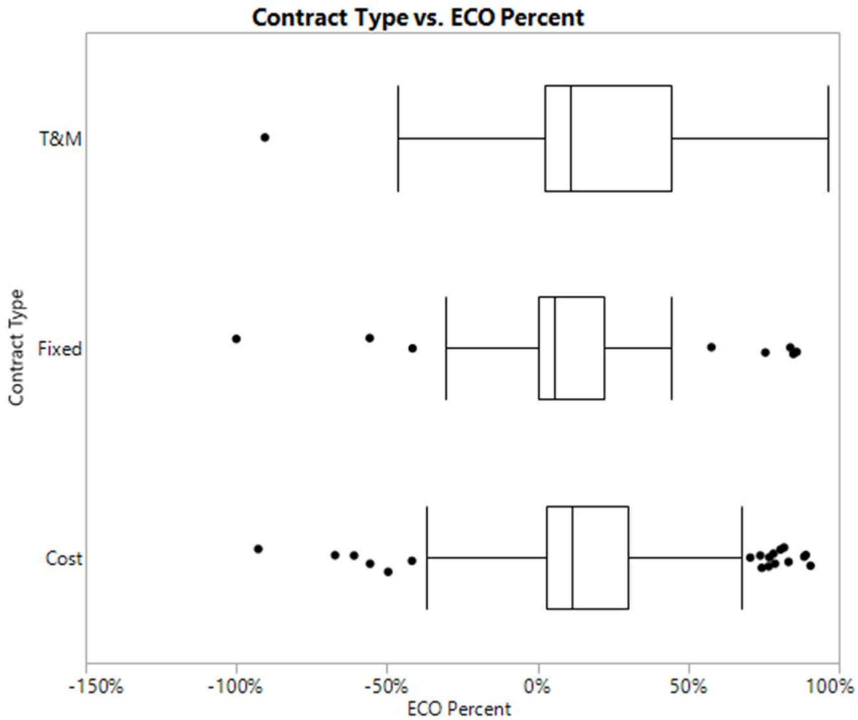

Figure 12. Box Plots of ECO Percentages by Contract Type, Technical Development Contracts – Excluded Unknown Contract Types (65, 14.5%, *n* = 448)

Table 14. Kruskal-Wallis Test Results for Contract Type, Technical Development Contracts – Excluded Unknown Contract Types (65, 14.5%, *n* = 448)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	251	50134.5	48192.0	199.739	1.886
Fixed	85	14022.5	16320.0	164.971	-2.551
T&M	47	9379.00	9024.00	199.553	0.499

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.5124	2	0.0385*

In order to determine between which pairs of Contract Types the difference in ECO percentage locations occurs, we perform a Steel-Dwass test. The results of our Steel-Dwass test found in Table 15 suggest that there is a difference in ECO percentage locations between Fixed and Cost contracts, with Fixed Contracts having lower ECO percentage locations. Summary statistics for each of the Contract Types can be seen in Table 16. Although T&M contracts have a higher mean ECO percentage than Cost contracts, they are not statistically significantly different than Fixed contracts. This is most likely due to the large IQR of the T&M contracts when compared to the IQR of the Cost contracts.

Table 15. Steel-Dwass Test Results for Contract Type, Technical Development Contracts – Excluded Unknown Contract Types (65, 14.5%, *n* = 448)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	10.2428	6.95254	1.47325	0.3038
T&M	Cost	1.1115	13.69527	0.08116	0.9964
Fixed	Cost	-31.2849	12.19022	-2.56639	0.0277*

Table 16. Summary Statistics for Contract Type, Technical Development Contracts – Excluded Unknown Contract Types (65, 14.5%, *n* = 448)

	Cost	Fixed	T&M
N	251	85	47
Mean	17.24%	10.20%	21.12%
Median	11.40%	5.70%	10.90%
Std Dev	26.39%	27.07%	39.93%
CV	1.5309734	2.653645	1.890392
IQR	26.90%	21.50%	42.10%

It is interesting to note that Fixed contracts have a mean ECO percentage of 10.2%, which is very close to the 10% rule-of-thumb. Comparatively, T&M and Cost contracts had much higher mean ECO percentages.

Commodity

The last descriptive variable we analyze in this data group is Commodity. Figure 13 shows the different box plots of ECO percentages for the Commodities. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations between any of the Commodities. The results of the Kruskal-Wallis test can be found in Table 17. We conclude from the results of our Kruskal-Wallis test that there is no difference in ECO percentage locations between any of the pairs of Commodities.

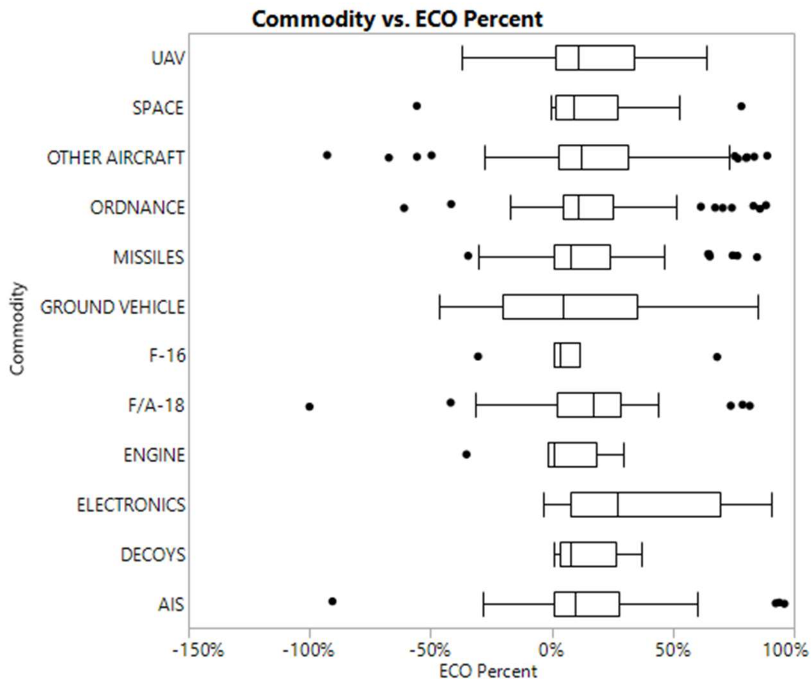

Figure 13. Box Plots of ECO Percentages by Commodity, Technical Development Contracts – Excluded Commodities < 5, (7, 1.6%, *n* = 448)

Table 17. Kruskal-Wallis Test Results for Commodity, Technical Development Contracts – Excluded Commodities < 5, (7, 1.6%, *n* = 448)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	29	6516.00	6409.00	224.690	0.161
DECOYS	5	1076.00	1105.00	215.200	-0.101
ELECTRONICS	13	3940.50	2873.00	303.115	2.357
ENGINE	8	1150.00	1768.00	143.750	-1.729
F/A-18	26	6110.50	5746.00	235.019	0.577
F-16	7	1178.00	1547.00	168.286	-1.102
GROUND VEHICLE	20	3808.50	4420.00	190.425	-1.097
MISSILES	74	15004.0	16354.0	202.757	-1.349
ORDNANCE	53	12477.0	11713.0	235.415	0.877
OTHER AIRCRAFT	161	36367.5	35581.0	225.885	0.610
SPACE	20	4279.50	4420.00	213.975	-0.251
UAV	25	5553.50	5525.00	222.140	0.045

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.5271	11	0.2603

Program Size

We now move our focus into the analysis of our binary variables, beginning with Program Size. We conducted ad hoc/posterior analysis to determine a place where a break point may occur. We ascertained that Development programs with a Baseline Cost greater than $2.5 million may have a decreased likelihood of incurring an ECO percent greater than 10% though this could be looked into further in future research in order to confirm our preliminary findings We conduct a Pearson's Chi-squared test of dependency in order to determine whether or not contracts with a baseline cost greater than $2.5 million have a different likelihood of incurring an ECO percentage greater than 10%. The results of our test can be found in Table 18.

Table 18. Pearson's Chi-Squared Test Results for Program Size, Technical Development Contracts

		ECO Percent > 10%	
Baseline Cost > $2.5M		No	Yes
	No	36	61
	Yes	184	167
Pearson *p*-value	0.0076		
Odds Ratio	Lower 95%	Upper 95%	
0.535638	0.337421	0.850297	

We conclude from these results that there is a difference in the likelihood of a contract incurring greater than a 10% ECO percentage based on whether or not that contract had a baseline cost greater than $2.5 million. A contract with a baseline cost less than $2.5 million is 1.87 (1/.535638 = 1.87) more likely to incur an ECO percentage greater than 10%.

Schedule

The second binary variable we analyze is Schedule. We again use a Pearson's Chi-squared test of dependency to determine whether or not there is a difference in the likelihood of a contract experiencing greater than a 10% ECO percentage based on whether or not that contract had a schedule longer than five years. We conclude from the results of our test in Table 19 that there is a difference in the likelihood. Specifically, a contract with a Schedule greater than five years is 3.5 times more likely to incur a ECO percentage greater than 10% than a contract with a Schedule less than five years.

Table 19. Pearson's Chi-Squared Test Results for Schedule, Technical Development Contracts – Excluded Blank Schedule Dates (101, 22.5%, *n* = 448)

	ECO Percent > 10%		
Schedule > 5 years		No	Yes
	No	143	164
	Yes	8	32
Pearson *p* -value	0.0014		
Odds Ratio	Lower 95%	Upper 95%	
3.487805	1.556948	7.813223	

Positive ECO Percentage - Technical Development Contracts

We now exclude all negative ECO percentages from our data group and look at just the positive ECO percentages on Technical Development contracts. Figure 14 shows a histogram of positive ECO percentages.

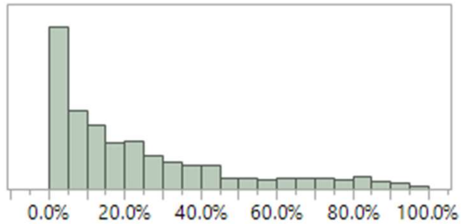

Figure 14. Histogram of ECO Percentages, Positive ECO Technical Development Contracts

We perform a *t*-test in order to determine if the mean ECO percentage on positive ECO Development contracts is different than the 10% rule-of-thumb. Our results in Table 20 indicate that the mean ECO percentage for positive ECO Development contracts is different than 10%, with an estimated mean more than twice that amount at 22.15%. The median ECO percentage was 13.9%

Table 20. Summary Statistics and t-test Results, Positive ECO Technical Development Contracts

N	389
Mean	22.146%
Median	13.90%
Std Dev	23.313%
CV	1.0527412
IQR	28.550%
Compared to	10%
Test Statistic	1.2750
p-value	<.0001

Service

We move into our variate analysis on positive ECO percentage Development contracts beginning with Service. Figure 15 shows box plots of positive ECO percentages for each

Service. We conduct a Kruskal-Wallis test and conclude from our results in Table 21 that there is no difference in ECO percentage locations between any of the Services.

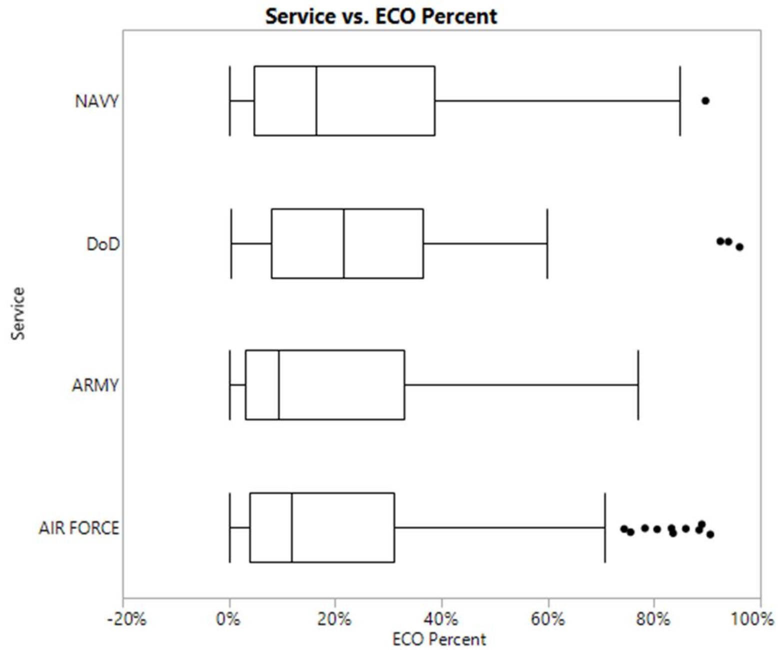

Figure 15. Box Plots of ECO Percentages by Service, Positive ECO Technical Development Contracts

Table 21. Kruskal-Wallis Test Results for Service, Positive ECO Technical Development Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	229	43100.5	44655.0	188.212	-1.424
ARMY	15	2617.00	2925.00	174.467	-0.720
DoD	22	4983.50	4290.00	226.523	1.353
NAVY	123	25154.0	23985.0	204.504	1.133

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.9430	3	0.2677

Contract Type

The next variable we analyze is Contract Type. Figure 16 shows the different box plots of positive ECO percentages for each of the Contract Types. We use a Kruskal-Wallis test to determine whether or not the ECO percentage locations differ between any of the different Contract Types. The results in Table 22 indicate that there is a difference in ECO percentage locations between at least two of the Contract Types.

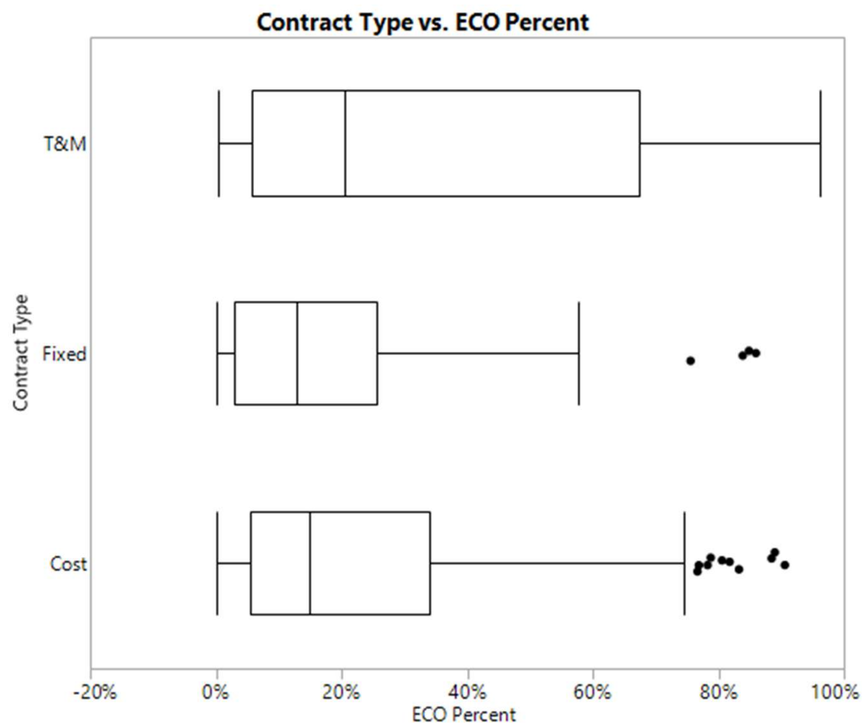

Figure 16. Box Plots of ECO Percentages by Contract Type, Positive ECO Technical Development Contracts – Excluded Unknown Contract Types (60, 15.4%, *n* = 389)

Table 22. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical Development Contracts – Excluded Unknown Contract Types (60, 15.4%, *n* = 389)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	224	37321.5	36960.0	166.614	0.449
Fixed	68	9862.50	11220.0	145.037	-1.942
T&M	37	7101.00	6105.00	191.919	1.826

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0234	2	0.0492*

We then conduct a Steel-Dwass test in order to identify between which pairs of Contract Types the difference in ECO percentage locations is occurring. The results in Table 23 of this test identify zero pairs of Contract Types that produce a *p*-value less than our alpha value of 0.05. However, it appears that T&M and Fixed Contract Types may potentially differ, with T&M having higher ECO percentage locations. This pair of Contract Types had a *p*-value of 0.059, which is slightly above the 0.05 alpha level. The summary statistics of positive ECO percentages for each Contract Type can be found in Table 24.

Table 23. Steel-Dwass Test Results for Contract Type, Positive ECO Technical Development Contracts – Excluded Unknown Contract Types (60, 15.4%, *n* = 389)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Cost	20.6426	13.39584	1.54097	0.2718
T&M	Fixed	14.1683	6.22132	2.27738	0.0590
Fixed	Cost	-19.4961	11.69068	-1.66766	0.2177

Table 24. ECO Percentage Summary Statistics Positive ECO Technical Development Contracts – Excluded Unknown Contract Types (60, 15.4%, *n* = 389)

	Cost	Fixed	T&M
N	224	68	37
Mean	22.27%	18.24%	33.71%
Median	14.80%	12.75%	20.40%
Std Dev	21.77%	20.76%	32.60%
CV	0.9773347	1.138196	0.967336
IQR	28.43%	22.68%	61.65%

Commodity

We now look for potential differences in ECO percentage locations based on Commodity. Figure 17 shows box plots of positive ECO percentages for each Commodity. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations between any of the Commodities. Our results in Table 25 indicate that there is no difference in ECO percentage locations between any of the pairs of Commodities.

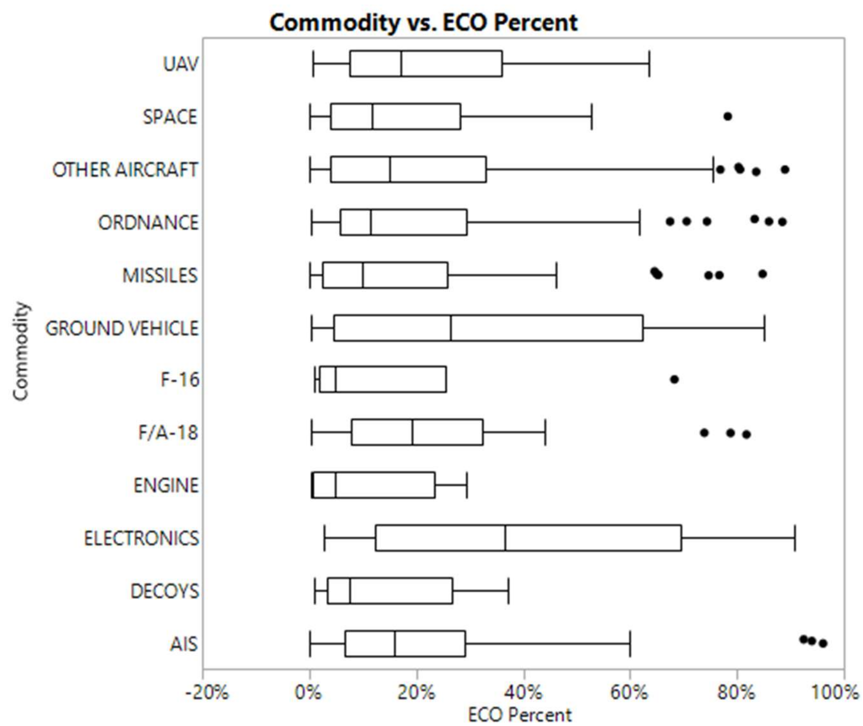

Figure 17. Box Plots of ECO Percentages by Commodity, Positive ECO Technical Development Contracts – Excluded Commodities < 5 (4, 1.02%, *n* = 389)

Table 25. Kruskal-Wallis Test Results for Commodity, Positive ECO Technical Development Contracts – Excluded Commodities < 5 (4, 1.02%, *n* = 389)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	24	5012.00	4632.00	208.833	0.719
DECOYS	5	796.000	965.000	159.200	-0.682
ELECTRONICS	12	3230.50	2316.00	269.208	2.409
ENGINE	6	759.500	1158.00	126.583	-1.472
F/A-18	22	4802.50	4246.00	218.295	1.097
F-16	6	823.500	1158.00	137.250	-1.235
GROUND VEHICLE	13	2902.50	2509.00	223.269	0.996
MISSILES	66	11050.5	12738.0	167.432	-2.050
ORDNANCE	50	9633.00	9650.00	192.660	-0.022
OTHER AIRCRAFT	143	27800.5	27599.0	194.409	0.191
SPACE	18	3217.00	3474.00	178.722	-0.556
UAV	20	4277.50	3860.00	213.875	0.861

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.8241	11	0.1132

Program Size

We next use a Pearson's Chi-squared test of dependency to determine whether or not a contract with a baseline cost greater than \$2.5 million effects the likelihood of that contract experiencing an ECO percentage greater than 10%. The results of this test in Table 26 indicate that there is a significant difference in the likelihood of a contract experiencing greater than a 10% ECO percentage based on whether or not that contract has a baseline cost greater than \$2.5 million. A contract with a baseline cost less than \$2.5 million is 2.56 (1/.391101 = 2.56) times more likely to incur an ECO percentage greater than 10%.

Table 26. Pearson's Chi-Squared Test Results for Program Size, Positive ECO Technical Development Contracts

	ECO Percent > 10%		
		No	Yes
Baseline Cost > \$2.5M	No	20	61
	Yes	140	167
Pearson *p*-value	0.0007		
Odds Ratio	Lower 95%	Upper 95%	
0.391101	0.225035	0.679717	

Schedule

The last variable we look at in this section is Schedule. The results of a Pearson's Chi-squared test found in Table 27 suggest that there is a difference in the likelihood of a contract experiencing an ECO percentage greater than 10% based on whether or not the Schedule is greater than 5 years. Specifically, a contract with a Schedule greater than 5 years is 4.64 times more likely to incur an ECO percentage greater than 10%.

Table 27. Pearson's Chi-Squared Test Results for Schedule, Positive ECO Technical Development Contracts – Blank Schedule Contracts Removed (69, 17.7%, n = 389)

	ECO Percent > 10%		
Schedule > 5 years		No	Yes
	No	119	164
	Yes	5	32
Pearson p-value	0.0008		
Odds Ratio	Lower 95%	Upper 95%	
4.643902	1.757578	12.2702	

Development Contracts Alpha Trimmed 1%

We now wish to determine whether or not outliers are having an effect on our results. To do this, we apply a 1% alpha trimming factor to our data group and re-conduct all of the same statistical tests. An alpha trimming factor of 1% reduces our data group by 5 observations on either end of the data, for a total reduction of 10 observations.

Positive and Negative ECO Technical Development Contracts – Alpha Trimmed 1%

A histogram of our reduced data group can be found in Figure 18. We notice that the tails of the histogram are smaller than the untrimmed equivalent from Figure 10. We conduct a t-test on our reduced data group and conclude from the results in Table 28 that the mean ECO percentage is different than the 10% rule-of-thumb, with our estimate being closer to 16.5%. The median of our data group is 10.35% which is very close to the rule-of-thumb. These results are consistent with those from the equivalent untrimmed analysis conducted earlier.

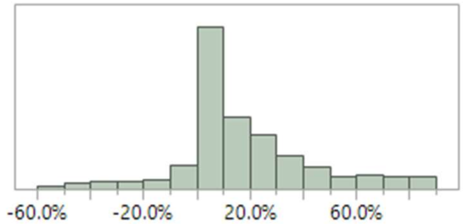

Figure 18. Histogram of ECO Percentages, Technical Development Contracts Alpha Trimmed 1%

Table 28. Summary Statistics and t-test Results, Technical Development Contracts Alpha Trimmed 1%

N	438
Mean	16.553%
Median	10.35%
Std Dev	24.798%
CV	1.4980288
IQR	25.975%
Compared to	10%
Test Statistic	5.5309
p -value	<.0001

Service

We move to the descriptive variable analysis beginning with the Service variable. Figure 19 shows the different ECO percentage box plots of our 1% trimmed data group for each Service. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations among any of the Services. The results of this test are seen in Table 29. We conclude from these results that there is no difference in ECO percentage locations between any of the Services in our 1% alpha trimmed data group. This result is consistent with the result in the untrimmed portion.

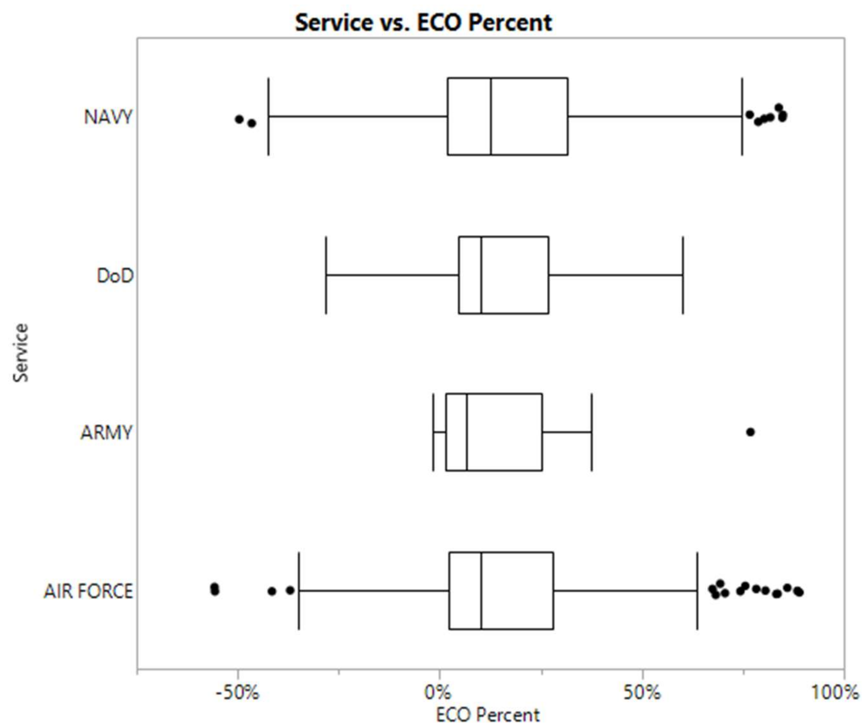

Figure 19. Box Plots of ECO Percentages by Service, Technical Development Contracts Alpha Trimmed 1%

Table 29. Kruskal-Wallis Test Results for Service, Technical Development Contracts Alpha Trimmed 1%

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	258	55823.5	56631.0	216.370	-0.619
ARMY	18	3546.50	3951.00	197.028	-0.768
DoD	22	4969.50	4829.00	225.886	0.242
NAVY	140	31801.5	30730.0	227.154	0.867

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.2928	3	0.7308

Contract Type

We next analyze if there are any differences in ECO percentage locations based on Contract Type. Figure 20 depicts box plots of ECO percentages for each Contract Type. The results of a Kruskal-Wallis test in Table 30 suggest that there are differences in ECO percentage locations between at least two of the Contract Types. In order to determine between which of the Contract Types that difference occurs, we then conduct a Steel-Dwass test, the results of which are located in Table 31.

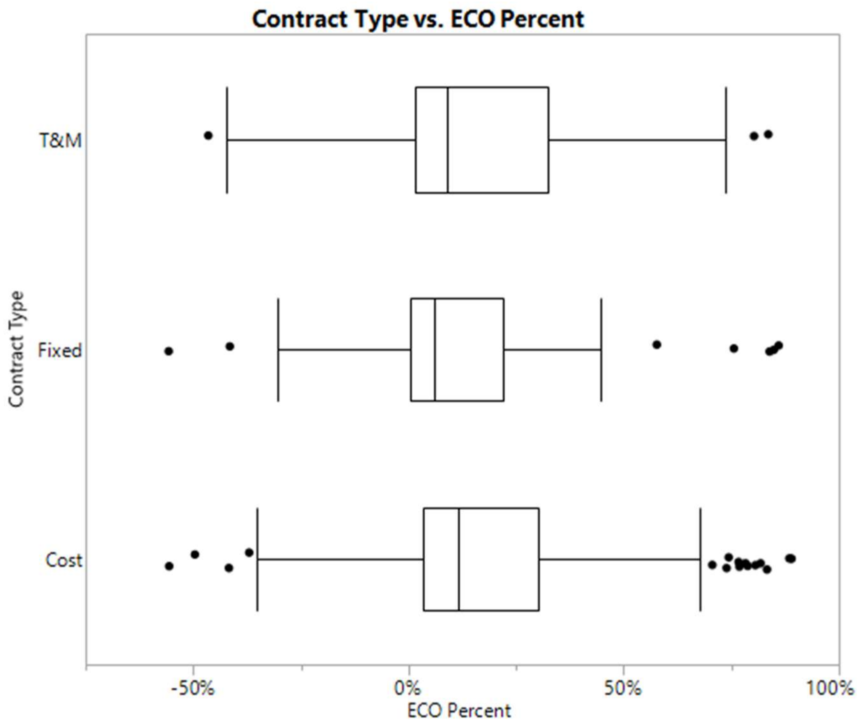

Figure 20. Box Plots of ECO Percentages by Contract Type, Technical Development Contracts Alpha Trimmed 1% - Excluded Unknown Contract Types (65, 14.8%, *n* = 438)

Table 30. Kruskal-Wallis Test Results for Contract Type, Technical Development Contracts Alpha Trimmed 1% - Excluded Unknown Contract Types (65, 14.8%, *n* = 438)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	247	48508.5	46189.0	196.391	2.355
Fixed	84	13601.5	15708.0	161.923	-2.421
T&M	42	7641.00	7854.00	181.929	-0.323

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.5108	2	0.0386*

Table 31. Steel-Dwass Test Results for Contract Type, Technical Development Contracts Alpha Trimmed 1% - Excluded Unknown Contract Types (65, 14.8%, *n* = 438)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	5.7321	6.90095	0.83063	0.6840
T&M	Cost	-10.4050	13.94851	-0.74596	0.7361
Fixed	Cost	-31.0293	12.08683	-2.56720	0.0277*

The results of our Steel-Dwass indicate that there is a difference in ECO percentage locations between Fixed and Cost Contract Types, with Fixed having lower ECO percentage locations than Cost Contract Types. This finding is consistent with the untrimmed findings on Contract Type. Summary statistics for ECO percentages of each of the Contract Types can be found in Table 32.

Table 32. ECO Percentage Summary Statistics by Contract Type, Technical Development Contracts Alpha Trimmed 1% - Excluded Unknown Contract Types (65, 14.8%, *n* = 438)

	Cost	Fixed	T&M
N	247	84	42
Mean	18.04%	11.51%	16.93%
Median	11.50%	5.85%	8.85%
Std Dev	24.13%	24.36%	31.01%
CV	1.3373191	2.11614	1.831652
IQR	26.70%	21.45%	30.88%

Commodity

We now look for differences in ECO percentage locations based on Commodity. Figure 21 shows ECO percentage box plots for each of the Commodities. We conduct a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations between any of the Commodities. The results of this Kruskal-Wallis test in Table 33 indicate that there are no differences in ECO percentage locations between any of the Commodities. These results are consistent with the untrimmed results.

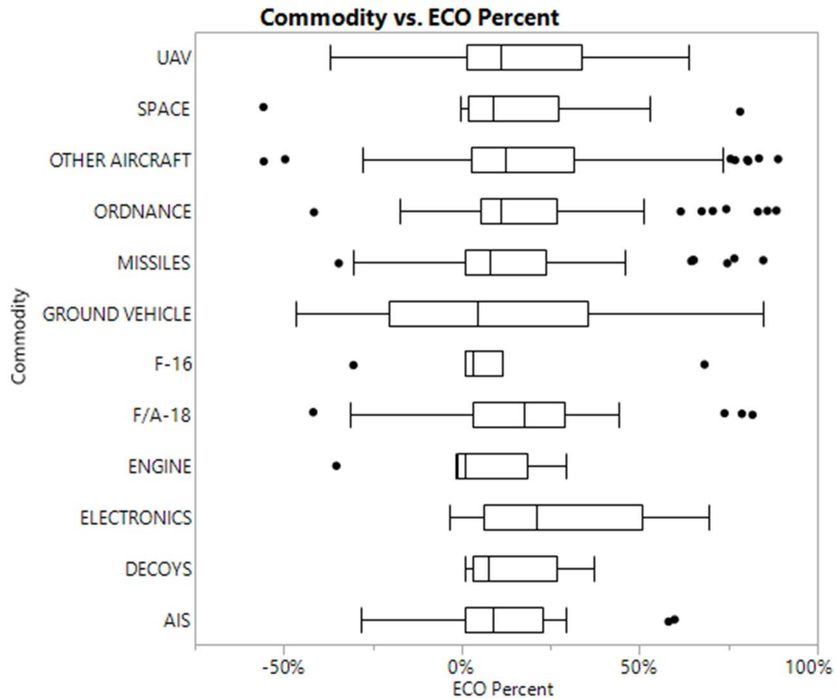

Figure 21. Box Plots of ECO Percentages by Commodity, Technical Development Contracts Alpha Trimmed 1% - Excluded Commodities < 5 (7, 1.6%, *n* = 438)

Table 33. Kruskal-Wallis Test Results for Commodity, Technical Development Contracts Alpha Trimmed 1% - Excluded Commodities < 5 (7, 1.6%, *n* = 438)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	25	5068.00	5400.00	202.720	-0.548
DECOYS	5	1051.00	1080.00	210.200	-0.103
ELECTRONICS	11	3010.50	2376.00	273.682	1.555
ENGINE	8	1110.00	1728.00	138.750	-1.769
F/A-18	25	5984.50	5400.00	239.380	0.966
F-16	7	1143.00	1512.00	163.286	-1.127
GROUND VEHICLE	20	3708.50	4320.00	185.425	-1.123
MISSILES	74	14634.0	15984.0	197.757	-1.384
ORDNANCE	52	12212.0	11232.0	234.846	1.163
OTHER AIRCRAFT	159	35566.5	34344.0	223.689	0.979
SPACE	20	4179.50	4320.00	208.975	-0.257
UAV	25	5428.50	5400.00	217.140	0.046

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.5195	11	0.3259

Program Size

We move to our binary variable analysis with Program Size. We conduct a Pearson's Chi-squared test of dependency and conclude from the results in Table 34 that there is a difference in the likelihood of a contract experiencing greater than a 10% ECO percentage based on whether or not that contract has a baseline cost greater than \$2.5 million. A contract with a baseline cost less than \$2.5 million is 1.85 (1/.54049 = 1.85) times more likely to incur an ECO percentage greater than 10%. This finding is consistent with the equivalent untrimmed finding.

Table 24. Pearson's Chi-Squared Test Results for Program Size, Technical Development Contracts Alpha Trimmed 1%

	ECO Percent > 10%		
		No	Yes
Baseline Cost > \$2.5M	No	35	59
	Yes	180	164
Pearson *p*-value	0.0095		
Odds Ratio	Lower 95%	Upper 95%	
0.54049	0.338264	0.863611	

Schedule

We analyze our second binary variable with another Pearson's Chi-squared test of dependency. The results of this test in Table 35 indicate that there is a difference in the likelihood of a contract experiencing a greater than 10% ECO percentage based on whether or not the contract's Schedule is greater than 5 years. Specifically, a contract with a Schedule greater than 5 years is 3.55 times more likely to incur an ECO percentage greater than 10%. This finding is consistent with the equivalent untrimmed finding.

Table 35. Pearson's Chi-Squared Test Results for Schedule, Technical Development Contracts Alpha Trimmed 1% - Excluded Blank Date Contracts (98, 22.4%, *n* = 438)

	ECO Percent > 10%		
Schedule > 5 years		No	Yes
	No	141	159
	Yes	8	32
Pearson *p* -value	0.0012		
Odds Ratio	Lower 95%	Upper 95%	
3.54717	1.582352	7.951715	

Positive ECO Technical Development Contracts - Alpha Trimmed 1%

The last portion of analysis we conduct is on just the positive ECO percentage Technical Development contracts that have been trimmed by 1%. A histogram of the ECO percentages for this data group can be found in Figure 22. We conduct a *t*-test to determine whether or not the mean ECO percentage is equivalent to 10%. Summary statistics of the positive ECO percentage 1% alpha trimmed Technical Development contracts as well as the results of the *t*-test are located in Table 36.

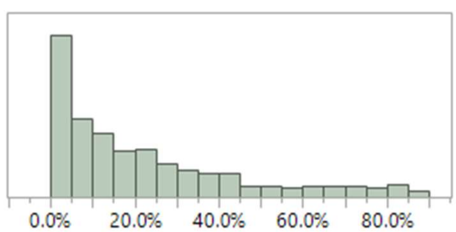

Figure 22. Histogram of ECO Percentages, Positive ECO Technical Development Contracts, Alpha Trimmed 1%

Table 36. Summary Statistics and t-test Results, Positive ECO Technical Development Contracts, Alpha Trimmed 1%

N	384
Mean	21.228%
Median	13.25%
Std Dev	22.021%
CV	1.0373495
IQR	27.425%
Compared to	10%
Test Statistic	9.9917
p -value	<.0001

The results of our *t*-test indicate that the mean ECO percentage of this data group is statistically different than the 10% rule-of-thumb, with an estimated mean of 21.228%. The median ECO percentage was 13.25%. These findings are consistent with the untrimmed findings.

Service

We first look at the Service variable to see if there are any differences in ECO percentage locations amongst the 1% alpha trimmed positive ECO percentage Development contracts. A box plot of positive ECO percentages is depicted in Figure 23. We perform a Kruskal-Wallis test to determine if there are differences in ECO percentage location between any of the Services. The results of this test in Table 37 indicate that there are no differences in ECO percentage locations between any of the Services. These findings are consistent with the equivalent untrimmed findings.

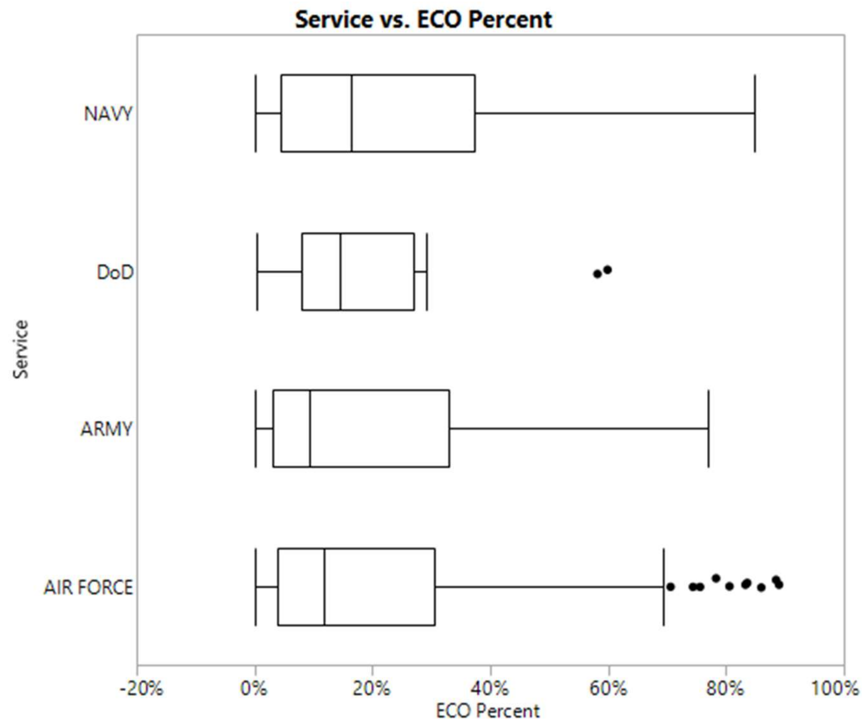

Figure 23. Box Plots of ECO Percentages by Service, Positive ECO Technical Development Contracts, Alpha Trimmed 1%

Table 37. Kruskal-Wallis Test Results for Service, Positive ECO Technical Development Contracts, Alpha Trimmed 1%

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	228	42714.5	43890.0	187.344	-1.100
ARMY	15	2617.00	2887.50	174.467	-0.641
DoD	19	3819.50	3657.50	201.026	0.342
NAVY	122	24769.0	23485.0	203.025	1.267

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.0969	3	0.5525

Contract Type

We next look at the Contract Type variable. Figure 24 shows box plots of positive ECO percentages trimmed 1% for each contract type. We perform a Kruskal-Wallis test to determine whether or not there are differences in ECO percentage locations between any of the contract types. The results of this Kruskal-Wallis test are found in Table 38. Unlike the untrimmed results, these trimmed results indicate that there is no difference in the ECO percentage locations between any of the services. This suggest that outliers may be having an influence on whether or not there is a difference in ECO percentage locations between Contract Types for positive ECO percentages.

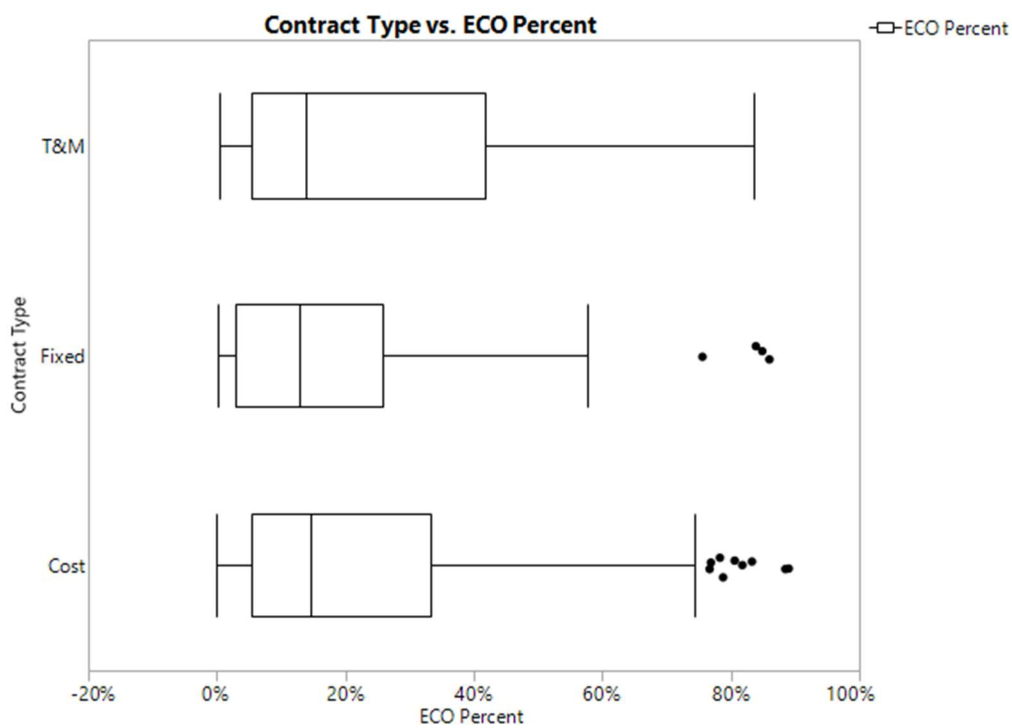

Figure 24. Box Plots of ECO Percentages by Contract Type, Positive ECO Technical Development Contracts, Alpha Trimmed 1% - Excluded Unknown Contract Types (60, 15.6%, *n* = 384)

Table 38. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical Development Contracts, Alpha Trimmed 1% - Excluded Unknown Contract Types (60, 15.6%, *n* = 384)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	223	36995.5	36237.5	165.899	0.970
Fixed	68	9862.50	11050.0	145.037	-1.729
T&M	33	5792.00	5362.50	175.515	0.841

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.2940	2	0.1926

Commodity

The last descriptive variable we analyze is Commodity. Figure 25 shows box plots of 1% alpha trimmed positive ECO percentages for each commodity. We use a Kruskal-Wallis test and conclude from the results of that test in Table 39 that there is no difference in ECO percentage locations between any of the Commodities. These findings are consistent with the untrimmed equivalent findings.

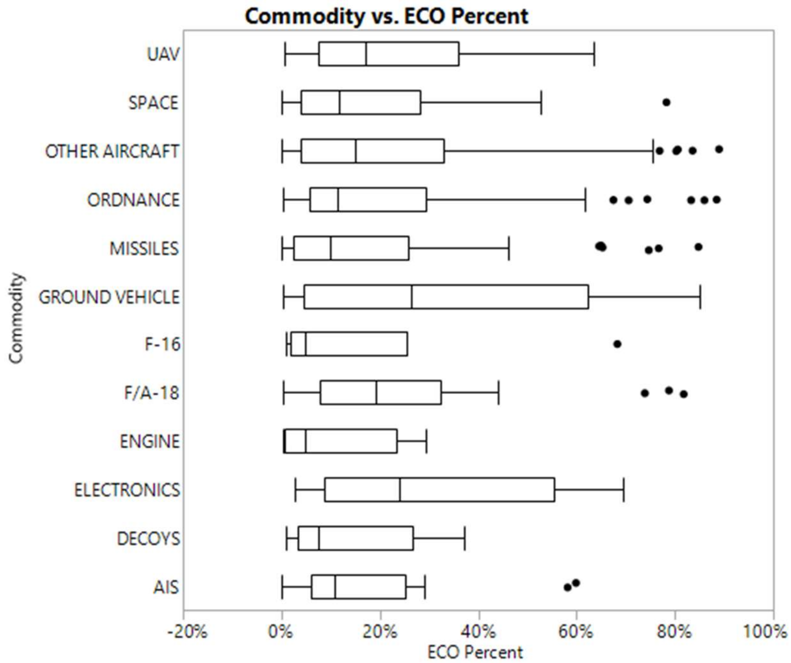

Figure 25. Box Plots of ECO Percentages by Commodity, Positive ECO Technical Development Contracts, Alpha Trimmed 1% - Excluded Commodities < 5 (4, 1.04%, *n* = 384)

Table 39. Kruskal-Wallis Test Results for Commodity, Positive ECO Technical Development Contracts, Alpha Trimmed 1% - Excluded Commodities < 5 (4, 1.04%, *n* = 384)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	21	3860.00	4000.50	183.810	-0.286
DECOYS	5	796.000	952.500	159.200	-0.639
ELECTRONICS	10	2467.50	1905.00	246.750	1.640
ENGINE	6	759.500	1143.00	126.583	-1.435
F/A-18	22	4802.50	4191.00	218.295	1.222
F-16	6	823.500	1143.00	137.250	-1.195
GROUND VEHICLE	13	2902.50	2476.50	223.269	1.093
MISSILES	66	11050.5	12573.0	167.432	-1.876
ORDNANCE	50	9633.00	9525.00	192.660	0.149
OTHER AIRCRAFT	143	27800.5	27241.5	194.409	0.538
SPACE	18	3217.00	3429.00	178.722	-0.465
UAV	20	4277.50	3810.00	213.875	0.977

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.3387	11	0.2718

Program Size

We move to our binary variable analysis by looking at Program Size. We conduct a Pearson's Chi-squared test of dependency and conclude from the results in Table 40 that there may is a difference in the likelihood of a contract experiencing an ECO percentage greater than 10% based on whether or not that contract has a baseline cost greater than $2.5 million. Specifically, a contract with a baseline cost less than $2.5 million is 2.52 (1/.397094 = 2.52) times as more likely to incur an ECO percentage greater than 10%. These findings are consistent with the untrimmed equivalent findings.

Table 40. Pearson's Chi-Squared Test Results for Program Size, Positive ECO Technical Development Contracts, Alpha Trimmed 1%

	ECO Percent > 10%		
		No	Yes
Baseline Cost > $2.5M	No	20	59
	Yes	140	164
Pearson *p* -value	0.0009		
Odds Ratio	Lower 95%	Upper 95%	
0.397094	0.227957	0.691727	

Schedule

The last variable we analyze is Schedule. Table 41 shows the results of a Pearson's Chi-squared test of dependency for Schedule. The results indicate that a contract is 4.79 times more likely to incur an ECO percentage greater than 10% if that contract has a Schedule longer than five years. This finding is consistent with the untrimmed finding.

Table 41. Pearson's Chi-Squared Test Results for Schedule, Positive ECO Technical Development Contracts, Alpha Trimmed 1% - Excluded Blank Date Contracts (69, 17.97%, n = 384)

	ECO Percent > 10%		
Schedule > 5 years		No	Yes
	No	119	159
	Yes	5	32
Pearson p-value	0.0006		
Odds Ratio	Lower 95%	Upper 95%	
4.789937	1.812161	12.66085	

Summary of Results of Analysis on Technical Development Contracts

We summarize our findings for Technical Production Contracts in Table 42 and Table 43. All results refer to ECO percentage locations. We note that the findings are consistent between the untrimmed and trimmed data sets with the exception of the results on Contract Type for the positive ECO percentage only.

Table 42. Summary of Results on Negative and Positive ECO Percentage Technical Development Contracts

	All Development	1% Alpha Trimmed Development	Are Findings Consistent?
t-test	Significantly Different than 10%	Significantly Different than 10%	Yes
Service	No Significant Difference	No Significant Difference	Yes
Contract Type	Fixed < Cost	Fixed < Cost	Yes
Commodity	No Significant Difference	No Significant Difference	Yes
Program Size	Contracts with Baseline > $2.5M 0.54 times as likely to incure ECO > 10%	Contracts with Baseline > $2.5M 0.54 times as likely to incure ECO > 10%	Yes
Schedule	Significantly Different Likelihood, Odds Ratio = 3.5	Significantly Different Likelihood, Odds Ratio = 4.8	Yes

Table 43. Summary of Results on Positive ECO Percentage Technical Development Contracts

	Development Positive ECO Only	Development Positive Only-1% Alpha Trimmed	Are Findings Consistent?
t-test	Significantly Different than 10%	Significantly Different than 10%	Yes
Service	No Significant Differences	No Significant Differences	Yes
Contract Type	T&M potentially > Fixed	No Significant Differences	No
Commodity	No Significant Differences	No Significant Differences	Yes
Program Size	Contracts with Baseline > $2.5M 0.39 times as likely to incure ECO > 10%	Contracts with Baseline > $2.5M 0.4 times as likely to incure ECO > 10%	Yes
Schedule	Significantly Different Likelihood, Odds Ratio = 4.64	Significantly Different Likelihood, Odds Ratio = 4.79	Yes

Part of our analysis in this section indicated that there may be a difference between Development contracts when looking at just the positive ECO percentages versus when looking at both positive and negative ECO percentages. In order to provide practitioners with a better idea of when to take into account our results from this section, we also conduct multiple Pearson's Chi-squared tests for dependency with associated odds ratios. The results of the tests for each variable can be found in Table 44. Only results with *p*-values less than 0.1 are shown. The red values are those whose *p*-values are less than our alpha value of 0.05.

Table 44. Significant Pearson's Chi-Squared Test for Dependency Results with Odds Ratios of Incurring a Positive ECO Percentage on Technical Development Contracts

Data Group	Variable	*p*-value	Odds Ratio of Experiencing Positive ECO
All Development Contracts	Contract Type = Cost	0.0137	2.05
	Contract Type = Fixed	0.0928	0.58
	Commodity = Ground Vehicle	0.0026	0.25
	Commodity = Ordnance	0.0928	2.69
1% Alpha Trimmed Development Contracts	Contract Type = Cost	0.0092	2.2
	Contract Type = Fixed	0.0846	0.57
	Commodity = Ground Vehicle	0.0013	0.23
	Commodity = Ordnance	0.0523	3.8

Production Contracts

Negative and Positive ECO Technical Production Contracts

We first look at the negative and positive ECO percentages for Production contracts. Figure 26 shows a histogram of the ECO percentages for Production contracts. We first determine whether or not the mean ECO percentage for Production Contracts differs from the 5% rule-of-thumb being used in practice. In order to do this, we perform a *t*-test where the null hypothesis centers around 5% and the alternative is not equal to 5%. Table 45 provides summary statistics of ECO percentages for the Production contracts data group as well as the results of the *t*-test.

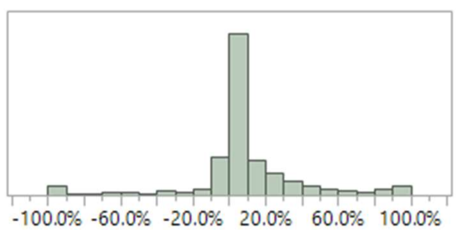

Figure 26. Distribution of ECO Percentages, Technical Production Contracts

Table 45. Summary Statistics and *t*-test results for all Technical Production Contracts

N	768
Mean	8.802%
Median	3.50%
Std Dev	28.638%
CV	3.2534527
IQR	14.050%
Compared to	5%
Test Statistic	3.6796
p-value	0.0002

The *p*-value for the *t*-test is sufficiently low to reject the null hypothesis. We conclude that the mean ECO percentage for Production contracts is different than 5%, with our estimate being closer to 8.8%. It is notable that the median ECO percentage is 3.5%, which suggests to us that there could be serious outliers that are affecting the mean. We address this potential issue using alpha-trimmed means in a later section of our analysis.

We now use the information found in our literature review to see what variables might be driving the differences in ECO percentage locations. We test for differences within five variables: Service, Contract Type, Commodity, Program Size, and Schedule.

Service

Figure 27 shows box plots of ECO percentages by Service. In this case, DoD was excluded from the analysis as only 1 contract fell under the DoD Service component. We use a Kruskal-Wallis test to determine if the ECO percentage location differs between any of the services. The results of this test can be found in Table 46. The IQR for the Army data appears to be much narrower than for that of the Navy or the Air Force.

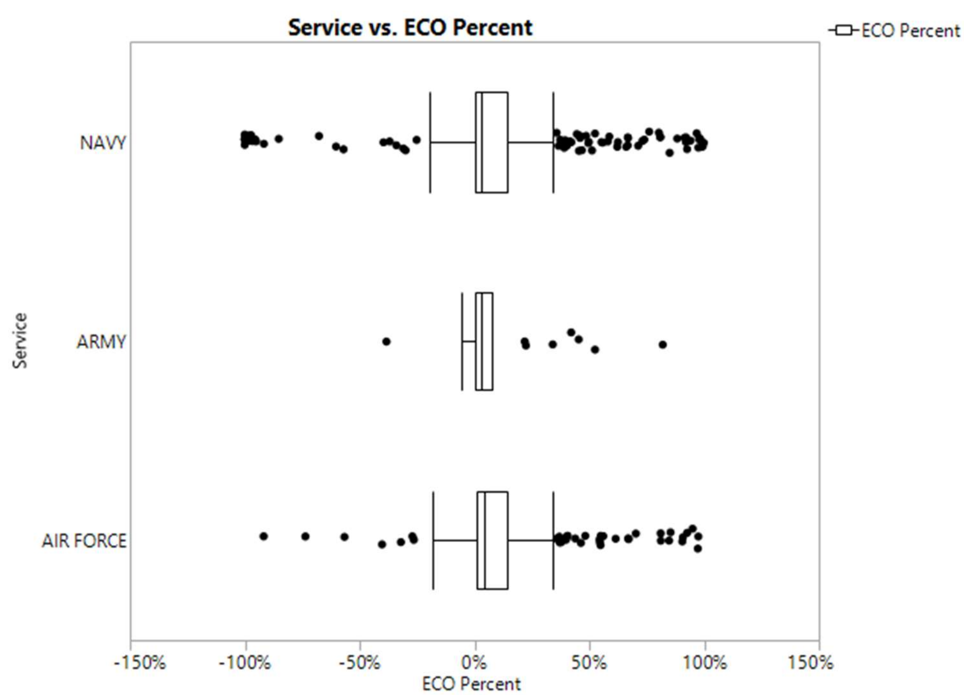

Figure 27. Box Plots of ECO Percentages by Service for Technical Production Contracts

Table 46. Kruskal-Wallis Test Results for Service, Technical Production Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	326	133739	125184	410.242	2.820
ARMY	31	11488.0	11904.0	370.581	-0.344
NAVY	410	149301	157440	364.149	-2.659

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.9794	2	0.0185*

The *p*-value is sufficiently low to reject the null. We expect there to be a difference in ECO percentage locations between at least two of the Services. We conduct a Steel-Dwass test to determine between which pairs of Services the difference in ECO percentage locations lies. The results of this test can be found in Table 47. The results of the Steel-Dwass test indicate that there is a difference in ECO percentage locations between Navy and Air Force Production contracts, with Navy having lower ECO percentage locations than the Air Force. Table 48 shows the summary statistics of ECO percentages broken down by service.

Table 47. Steel-Dwass Results for Service, Technical Production Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
NAVY	ARMY	-5.6556	23.73877	-0.23824	0.9692
ARMY	AIR FORCE	-20.4535	19.39572	-1.05454	0.5424
NAVY	AIR FORCE	-43.9144	15.77613	-2.78360	0.0149*

Table 48. Summary Statistics of ECO Percentages by Service, Technical Production Contracts

	Air Force	Army	Navy
N	326	31	410
Mean	10.91%	9.90%	7.03%
Median	4.30%	2.70%	2.95%
Std Dev	21.90%	21.78%	33.40%
CV	2.0071749	2.199751	4.749482
IQR	13.73%	7.80%	14.00%

Contract Type

The next variable we examine is Contract Type. We exclude the unknown Contract Type from our analysis as we cannot determine which contract types they represent due to missing data. Figure 28 shows box plots of ECO percentages by Contract Type.

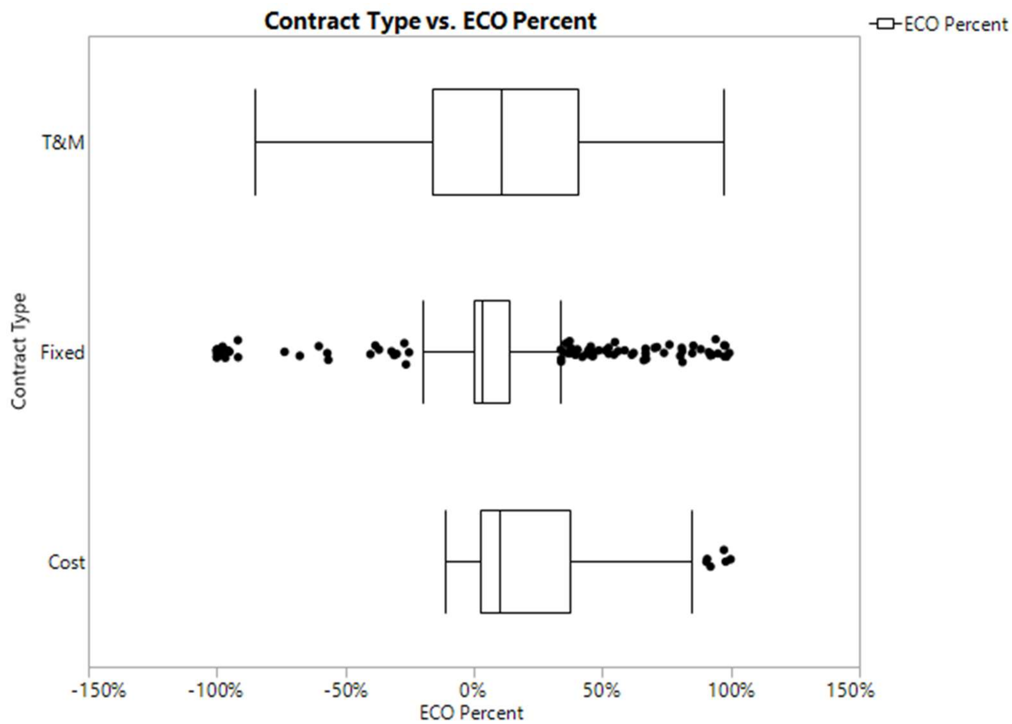

Figure 28. Box Plots of ECO Percentages by Contract Type for Technical Production Contracts - EXCLUDED Unknown Contract Types (95, *n* = 673)

We perform a Kruskal-Wallis test to determine if there is a difference in ECO percentage location between the different contract types. The results in Table 49 indicate that there is a difference in ECO percentage location between at least two of the contract types.

Table 49. Kruskal-Wallis Test Results for Contract Type, Technical Production Contracts - EXCLUDED Unknown Contract Types (95, *n* = 673)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	75	31751.0	25275.0	423.347	4.080
Fixed	582	189357	196134	325.355	-3.929
T&M	16	5693.50	5392.00	355.844	0.392

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
17.0329	2	0.0002*

We then conduct a Steel-Dwass test to find between which contract types there is a difference in ECO percentage locations. The results of this Steel-Dwass test in Table 50 indicate that there is a difference in ECO percentage locations between Fixed and Cost contract types, with Fixed contract types having a lower ECO percentage location than Cost contract types for Production contracts. These results make intuitive sense in the fact that we would expect Fixed contract types to have lower risk and to have well-defined requirements when compared to Cost contract types. Table 51 provides the ECO percentage summary statistics broken down by Contract Type.

Table 50. Steel-Dwass Results for Contract Type, Technical Production Contracts - EXCLUDED Unknown Contract Types (95, *n* = 673)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	24.9167	43.78006	0.56913	0.8366
T&M	Cost	-6.5596	7.27356	-0.90184	0.6391
Fixed	Cost	-96.1568	23.28487	-4.12958	0.0001*

Table 51. Summary Statistics of ECO Percentages by Contract Type, Technical Production Contracts - EXCLUDED Unknown Contract Types (95, *n* = 673)

	Cost	Fixed	T&M
N	75	582	16
Mean	23.64%	6.95%	9.12%
Median	10.20%	3.00%	10.35%
Std Dev	30.62%	29.04%	43.09%
CV	1.2952069	4.178081	4.725927
IQR	34.70%	13.43%	56.53%

Commodity Type

The last categorical variable we examine is Commodity Type. Box plots of ECO percentages for each commodity type can be found in Figure 29. We conduct a Kruskal-Wallis test to determine if there is a difference in ECO percentage locations based on Commodity Type. The results of this test can be found in Table 52.

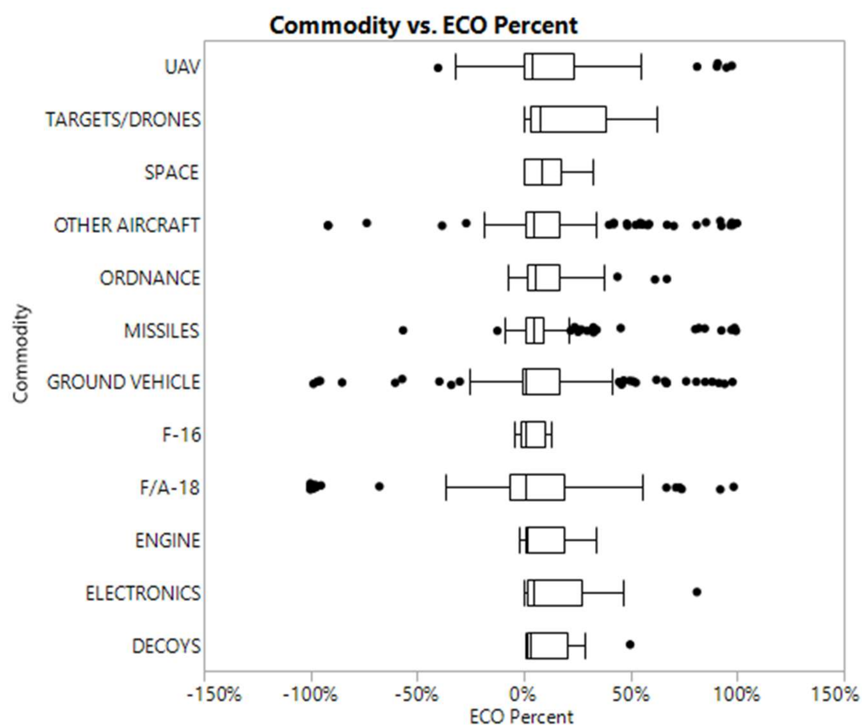

Figure 29. Box Plots of ECO Percentages by Commodity Type for Technical Production Contracts

Table 52. Kruskal-Wallis Test Results for Commodity Type, Technical Production Contracts– Excluded Commodities < 5 (7, 0.009%, *n* = 761)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DECOYS	11	4662.00	4191.00	423.818	0.650
ELECTRONICS	13	5876.50	4953.00	452.038	1.175
ENGINE	14	5111.50	5334.00	365.107	-0.272
F/A-18	71	22923.0	27051.0	322.859	-2.340
F-16	8	2222.50	3048.00	277.813	-1.334
GROUND VEHICLE	178	59322.0	67818.0	333.270	-3.310
MISSILES	152	59825.0	57912.0	393.586	0.789
ORDNANCE	62	26883.5	23622.0	433.605	1.966
OTHER AIRCRAFT	160	66153.5	60960.0	413.459	2.102
SPACE	15	6626.00	5715.00	441.733	1.080
TARGETS/DRONES	9	4429.50	3429.00	492.167	1.525
UAV	68	25906.0	25908.0	380.971	-0.001

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
27.9555	11	0.0033*

The *p*-value is sufficiently low and we conclude that there is a difference in ECO percentage locations between at least two of the Commodity Types. We conduct a Steel-Dwass test to find which pairs of Commodity Types differ. The results can be found in Table 53.

Table 53. Steel-Dwass Test Results for Commodity Type, Technical Production Contracts–Excluded Commodities < 5 (7, 0.009%, *n* = 761)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
OTHER AIRCRAFT	GROUND VEHICLE	35.5980	10.64463	3.34422	0.0394*
TARGETS/DRONES	GROUND VEHICLE	35.4273	18.49019	1.91600	0.7495
OTHER AIRCRAFT	F-16	30.9750	17.62123	1.75782	0.8408
ORDNANCE	GROUND VEHICLE	30.6850	10.23730	2.99737	0.1091
MISSILES	GROUND VEHICLE	29.0836	10.53587	2.76043	0.1972
MISSILES	F-16	26.5132	16.80498	1.57770	0.9174
SPACE	GROUND VEHICLE	26.3478	15.01525	1.75473	0.8424
OTHER AIRCRAFT	F/A-18	25.6011	9.52908	2.68663	0.2327
TARGETS/DRONES	MISSILES	24.7738	15.99243	1.54909	0.9267
MISSILES	F/A-18	20.4155	9.27369	2.20144	0.5485
TARGETS/DRONES	OTHER AIRCRAFT	18.4844	16.76181	1.10277	0.9946
ORDNANCE	F/A-18	16.8138	6.69759	2.51043	0.3331
ORDNANCE	F-16	15.8065	7.64392	2.06785	0.6460
TARGETS/DRONES	F/A-18	14.8983	8.21802	1.81288	0.8113
ORDNANCE	MISSILES	14.5218	9.33031	1.55641	0.9244
SPACE	MISSILES	14.2463	13.08478	1.08877	0.9952
UAV	GROUND VEHICLE	14.0641	10.14347	1.38652	0.9663
OTHER AIRCRAFT	ENGINE	13.2442	14.03873	0.94340	0.9987
SPACE	F/A-18	11.4667	7.09244	1.61674	0.9034
UAV	F/A-18	11.1707	6.83194	1.63507	0.8963
UAV	F-16	9.7794	8.25352	1.18488	0.9902
GROUND VEHICLE	F-16	9.4045	19.45515	0.48339	1.0000
OTHER AIRCRAFT	MISSILES	8.9995	10.21718	0.88082	0.9993
MISSILES	ENGINE	8.8539	13.42304	0.65960	1.0000
ORDNANCE	ENGINE	8.6682	6.53274	1.32689	0.9758
GROUND VEHICLE	F/A-18	7.3983	10.10876	0.73187	0.9999
SPACE	OTHER AIRCRAFT	6.4896	13.67968	0.47440	1.0000
TARGETS/DRONES	ORDNANCE	5.9803	7.36094	0.81244	0.9997
SPACE	F-16	5.0792	2.96562	1.71268	0.8629
TARGETS/DRONES	F-16	4.4861	2.45223	1.82940	0.8020
TARGETS/DRONES	ENGINE	4.4722	2.89630	1.54412	0.9283
TARGETS/DRONES	DECOYS	3.5354	2.65808	1.33004	0.9754
SPACE	ENGINE	2.1405	3.16143	0.67706	0.9999
ORDNANCE	DECOYS	2.0337	6.94042	0.29303	1.0000
TARGETS/DRONES	SPACE	1.5111	2.97429	0.50806	1.0000
TARGETS/DRONES	ELECTRONICS	1.4103	2.81501	0.50098	1.0000
UAV	ENGINE	1.0336	6.98878	0.14790	1.0000
SPACE	DECOYS	0.9455	3.03355	0.31167	1.0000
ELECTRONICS	DECOYS	0.9231	2.89620	0.31872	1.0000
SPACE	ORDNANCE	0.4554	6.43589	0.07076	1.0000
SPACE	ELECTRONICS	-0.2154	3.11239	-0.06920	1.0000
OTHER AIRCRAFT	DECOYS	-1.3602	15.43100	-0.08815	1.0000
F-16	F/A-18	-2.3644	8.55390	-0.27642	1.0000
ORDNANCE	ELECTRONICS	-2.6985	6.64744	-0.40595	1.0000
ENGINE	DECOYS	-3.2468	2.96192	-1.09616	0.9949
F-16	ENGINE	-3.4375	2.87391	-1.19611	0.9894
ENGINE	ELECTRONICS	-3.8571	3.05435	-1.26284	0.9835
UAV	MISSILES	-4.0122	9.28593	-0.43207	1.0000
F-16	DECOYS	-4.4261	2.61479	-1.69273	0.8720
UAV	DECOYS	-4.4358	7.45755	-0.59481	1.0000
OTHER AIRCRAFT	ORDNANCE	-5.5388	9.60808	-0.57647	1.0000
F/A-18	ENGINE	-5.6011	7.21400	-0.77642	0.9998
F-16	ELECTRONICS	-5.6538	2.78729	-2.02844	0.6739
UAV	SPACE	-6.0216	6.87514	-0.87585	0.9993
MISSILES	DECOYS	-6.7267	14.73557	-0.45649	1.0000
UAV	ELECTRONICS	-7.3761	7.12112	-1.03581	0.9969
UAV	ORDNANCE	-7.8937	6.61452	-1.19340	0.9896
OTHER AIRCRAFT	ELECTRONICS	-8.8579	14.44366	-0.61327	1.0000
UAV	OTHER AIRCRAFT	-9.2415	9.54838	-0.96787	0.9983
UAV	TARGETS/DRONES	-10.1283	7.93498	-1.27641	0.9821
F/A-18	DECOYS	-11.1293	7.71293	-1.44294	0.9550
MISSILES	ELECTRONICS	-12.3165	13.80445	-0.89222	0.9992
F/A-18	ELECTRONICS	-12.8321	7.35517	-1.74463	0.8474
GROUND VEHICLE	ENGINE	-13.7143	15.42282	-0.88922	0.9992
GROUND VEHICLE	DECOYS	-23.7457	16.99385	-1.39731	0.9643
GROUND VEHICLE	ELECTRONICS	-29.7973	15.88026	-1.87637	0.7742

The results of our Steel-Dwass test indicate that there is a difference in ECO percentage locations between Other Aircraft and Ground Vehicle, with Other Aircraft having higher ECO percentage locations than Ground Vehicle. We note that F-16 and F/A-18 contracts were not flagged as being different.

Program Size

We now move to conducting our analysis on two binary variables, starting with Program Size. We conducted ad hoc/posterior/posterior analysis to determine a place where a break point may occur. We ascertained that programs with a Baseline Cost greater than $1 million may have an increased likelihood of incurring an ECO percent greater than 5% though this could be looked into further in future research in order to confirm our preliminary findings.

We perform a Pearson's Chi-Squared test of dependence in order to determine if a program with a baseline cost greater than $1 million has a different likelihood of incurring an ECO percentage greater than the 5% rule-of-thumb. The results in Table 54 indicate that there could potentially be a moderate difference in the likelihood of a contract incurring an ECO percentage greater than 5% based on whether or not that contract had a baseline cost over or under $100 million. A contract with a baseline cost greater than $1 million may be 1.5 times more likely to incur an ECO percentage greater than 5%.

Table 54. Pearson's Chi-Squared Test Results for Program Size, Technical Production Contracts

	ECO Percent > 5%		
Baseline Cost > $1M		No	Yes
	No	57	30
	Yes	379	302
Pearson *p*-value	0.0803		
Odds Ratio	Lower 95%	Upper 95%	
1.513984	0.948874	2.415651	

Schedule

The second binary variable we analyze is Schedule. We defined schedule as the time from Baseline Contract creation through either Period of Performance (PoP) end date or the last modification date, whichever came later. We used a Schedule length of 5 years as our break point since DoD appropriations can last up to 5 years at the maximum for typical contracts before expiring.

We conduct a Pearson's Chi-Squared test of dependency to determine whether or not there is a different likelihood of a contract experiencing an ECO percentage larger than 5% based on whether or not the contract lasts more or less than 5 years. The results of this test as well as the odds ratio can be found in Table 55.

Table 55. Pearson's Chi-Squared Test Results and Odds Ratio for Schedule, Technical Production Contracts

	ECO Percent > 5%		
Schedule > 5 years		No	Yes
	No	275	257
	Yes	36	52
Pearson *p*-value	0.0609		
Odds Ratio	Lower 95%	Upper 95%	
1.545612	0.977957	2.442761	

Our results indicate that there may be a moderate difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not that contract has a schedule greater than 5 years. Specifically, our results indicate that if a contract lasts for more than 5 years, it is 1.5 times more likely to experience an ECO percentage greater than 5%.

Positive ECO Technical Production Contracts

From our previous analysis on differences in ECO percentage locations based on Life Cycle Phase, we know that the results of the different variables may change based on whether or not we are analyzing both positive and negative ECO percentages or just positive ECO percentages. For this reason, we conduct the same tests using just the Positive ECO percentages. A histogram of the positive ECO percentages for technical production contracts can be found in Figure 30.

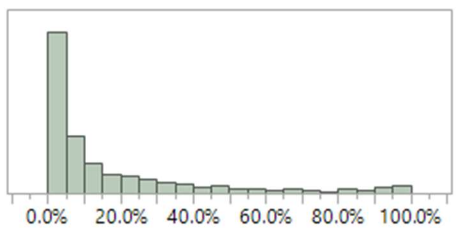

Figure 30. Histogram of ECO percentages, Positive ECO Technical Production Contracts

We begin by conducting a *t*-test to determine whether the mean ECO percentage for positive ECO production contracts is statistically different than 5% or not. The summary statistics for positive ECO percentage technical production contracts and the results of the *t*-test can be found in Table 56.

Table 56. Summary Statistics and t-test Results for Positive ECO Technical Production Contracts

N	620
Mean	15.708%
Median	5.50%
Std Dev	22.715%
CV	1.446043
IQR	17.950%
Compared to	5%
Test Statistic	11.7382
p -value	<.0001

The *t*-test results indicate that the mean ECO percentage is statistically different than 5%, with our estimate being closer to 15.7%.

Service

We now conduct statistical analysis on the same variables using only positive ECO percentages. Figure 31 depicts box plots of positive ECO percentages based on Service.

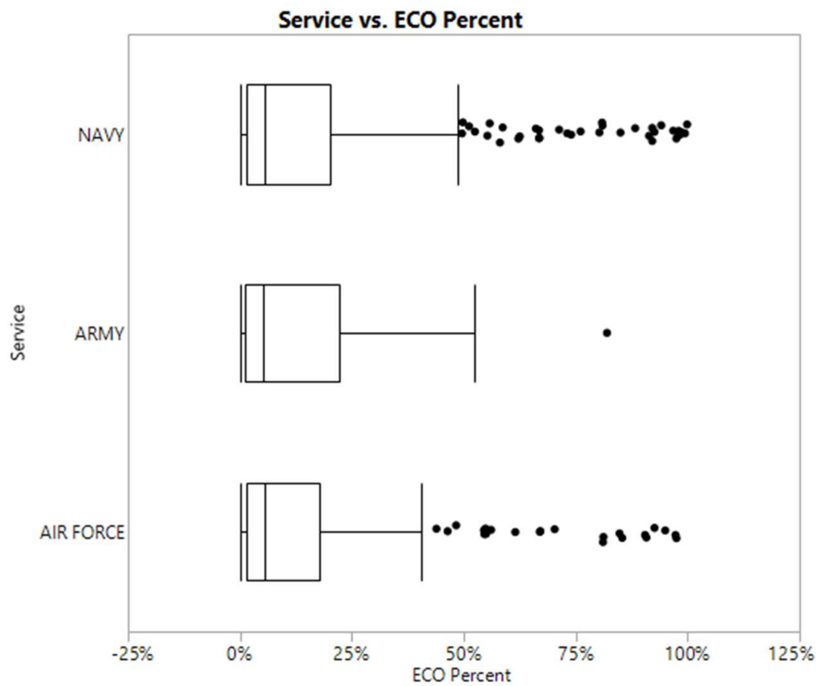

Figure 31. Box Plots of ECO Percentages by Service, Positive ECO Technical Production Contracts

We perform a Kruskal-Wallis Test to determine if there is a difference in ECO percentage locations based on Service. The results in Table 57 indicate that there is no difference in ECO percentage locations based on Service.

Table 57. Kruskal-Wallis Test Results for Service, Positive ECO Technical Production Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	287	88137.5	88970.0	307.099	-0.375
ARMY	25	7202.00	7750.00	288.080	-0.625
NAVY	307	96550.5	95170.0	314.497	0.620

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.6453	2	0.7242

Contract Type

We move on to the next variable, Contract Type. Box plots of the positive ECO percentages by Contract Type can be found in Figure 32. We perform a Kruskal-Wallis test to see if there are differences in ECO percentage locations between any of the Contract Types. The results in Table 58 indicate that there is a difference in ECO percentage location between at least two of the Contract Types.

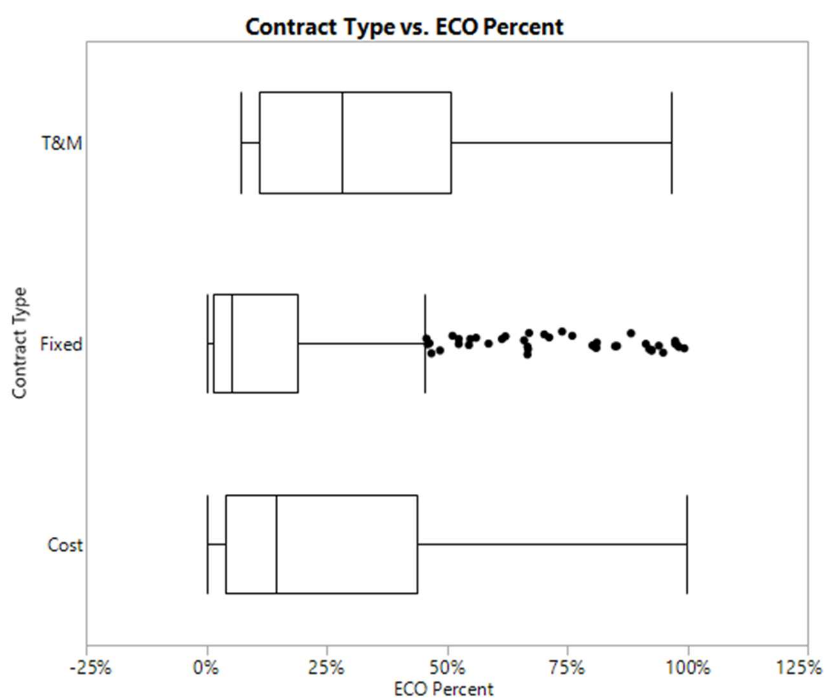

Figure 32. Box Plots of ECO Percentages by Contract Type, Positive ECO Technical Production Contracts

Table 58. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical Production Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	65	21838.0	17322.5	335.969	3.889
Fixed	457	115881	121791	253.569	-4.789
T&M	10	4059.00	2665.00	405.900	2.894

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
24.7359	2	<.0001*

We then conduct a Steel-Dwass test and conclude that there is a difference in ECO percentage locations between Time and Materials (T&M) and Fixed contract types as well as a difference in ECO percentage locations between Fixed and Cost contract types. T&M has the highest ECO percentage location, followed by Cost, with Fixed contract types having the lowest ECO percentage location. These results can be found in Table 59. ECO percentage summary statistics broken down by contract type can be found in Table 60.

Table 59. Steel-Dwass Test Results for Contract Type, Positive ECO Technical Production Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	133.815	43.13744	3.10207	0.0055*
T&M	Cost	9.635	7.40301	1.30145	0.3943
Fixed	Cost	-80.817	19.99341	-4.04220	0.0002*

Table 60. Summary Statistics by Contract Type, Positive ECO Technical Production Contracts

	Cost	Fixed	T&M
N	65	457	10
Mean	28.11%	14.81%	33.98%
Median	14.40%	5.40%	28.25%
Std Dev	30.49%	21.59%	28.24%
CV	1.084918	1.45832	0.830975
IQR	39.90%	17.70%	39.75%

Commodity

We next conduct an analysis on potential differences based on Commodity. Figure 33 shows box plots of positive ECO percentages for each Commodity. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations between at least two different commodities. Based on the results in Table 61 we conclude that there is not a statistical difference in ECO percentage locations between any of the commodities.

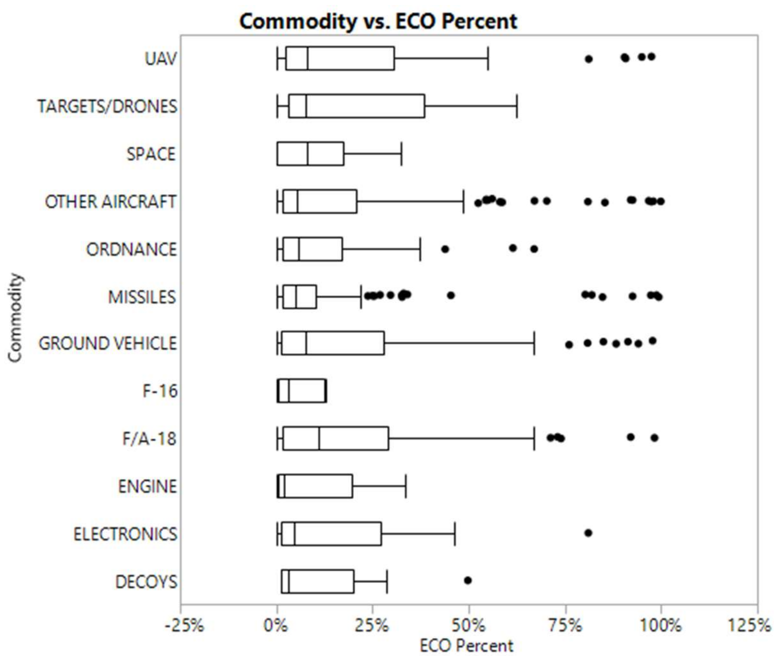

Figure 33. Box Plots of ECO Percentages by Commodity Type for Positive ECO Technical Production Contracts

Table 61. Kruskal-Wallis Test Results for Commodity, Positive ECO Technical Production Contracts – Excluded Commodities < 5 (7, 0.011%, *n* = 620)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DECOYS	11	3034.00	3377.00	275.818	-0.588
ELECTRONICS	13	3952.50	3991.00	304.038	-0.060
ENGINE	13	3097.00	3991.00	238.231	-1.414
F/A-18	44	15123.5	13508.0	343.716	1.427
F-16	5	1203.00	1535.00	240.600	-0.841
GROUND VEHICLE	116	37359.5	35612.0	322.065	1.017
MISSILES	136	38130.5	41752.0	280.371	-1.988
ORDNANCE	60	17892.0	18420.0	298.200	-0.405
OTHER AIRCRAFT	142	43858.0	43594.0	308.859	0.142
SPACE	15	4411.00	4605.00	294.067	-0.286
TARGETS/DRONES	9	3097.50	2763.00	344.167	0.633
UAV	49	17032.5	15043.0	347.602	1.673

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.0297	11	0.3614

Program Size

We next perform a Pearson's Chi-Squared test of dependency on our Program Size binary variable to determine whether or not there is a greater likelihood of a contract incurring an ECO percentage greater than 5% based on whether or not the contract's baseline cost was greater than $1 million. The results can be found in Table 62.

Table 62. Pearson's Chi-Squared Test Results for Program Size, Positive ECO Technical Production Contracts

	ECO Percent > 5%		
		No	Yes
Baseline Cost > $1M	No	2	30
	Yes	286	302
Pearson *p*-value	<.0001		
Odds Ratio	Lower 95%	Upper 95%	
0.070396	0.016671	0.297258	

The results indicate that there is a statistically significant difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not that contract had a baseline cost greater than $1 million. A contract with a baseline cost less than $1 million is 14.2 times (1/.070396 = 14.2) more likely to incur an ECO percentage greater than 5%.

Schedule

The last statistical test we perform on positive ECO percentage production contracts is a Pearson's Chi-Squared test on Schedule. The results of this test can be found in Table 63. Based on these results, we conclude that there is not a statistically significant difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not that contract had a scheduled greater than 5 years.

Table 63. Pearson's Chi-Squared Test Results and Odds Ratio for Schedule, Positive ECO Technical Production Contracts

	ECO Percent > 5%		
Schedule > 5 years		No	Yes
	No	204	257
	Yes	32	52
Pearson *p*-value	0.295		

Technical Production Contracts – Alpha Trimmed 2.5%

In order to determine the robustness of our results, we now decide to apply alpha trimmed means in order to eliminate outliers that could potentially be skewing our results with respect to the means. For Production contracts, we apply a 2.5% alpha trimmed mean. This 2.5% reduces our observations by 40, with 20 being removed from each side. We now conduct the exact same analysis using the negative and positive ECO percentage and then using just the positive ECO percentages.

Positive and Negative ECO Production Contracts – Alpha Trimmed 2.5%

A histogram of ECO percentages after applying the 2.5% trimming factor can be seen in Figure 34. When compared to the untrimmed histogram from Figure 26, it is clear that there are no longer large bumps in the tails of the distribution.

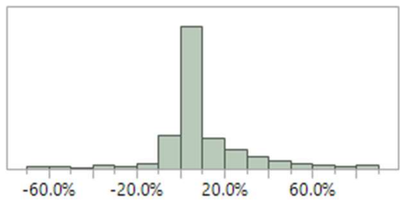

Figure 34. Histogram of ECO Percentages, 2.5% Alpha Trimmed Technical Production Contracts

We conduct a *t*-test to determine if the mean ECO percentage is different from 5% for the trimmed data group. The results from this *t*-test along with ECO percentage summary statistics for the trimmed data group can be found in Table 64. Based on these results, we conclude that the mean ECO percentage is statistically different than 5%, with our estimate being closer to 9.3%.

Table 64. Summary Statistics and t-test Results for 2.5% Alpha Trimmed Technical Production Contracts

N	728
Mean	9.312%
Median	3.50%
Std Dev	18.892%
CV	2.0287149
IQR	12.700%
Compared to	5%
Test Statistic	6.1587
p -value	<.0001

Service

We now conduct our analysis on the different variables, beginning with Service. Figure 35 shows the alpha trimmed ECO percentage box plots for each service. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO percentage locations between any of the Services. Our results in Table 65 indicate that there is a difference in ECO percentage locations between at least two of the services.

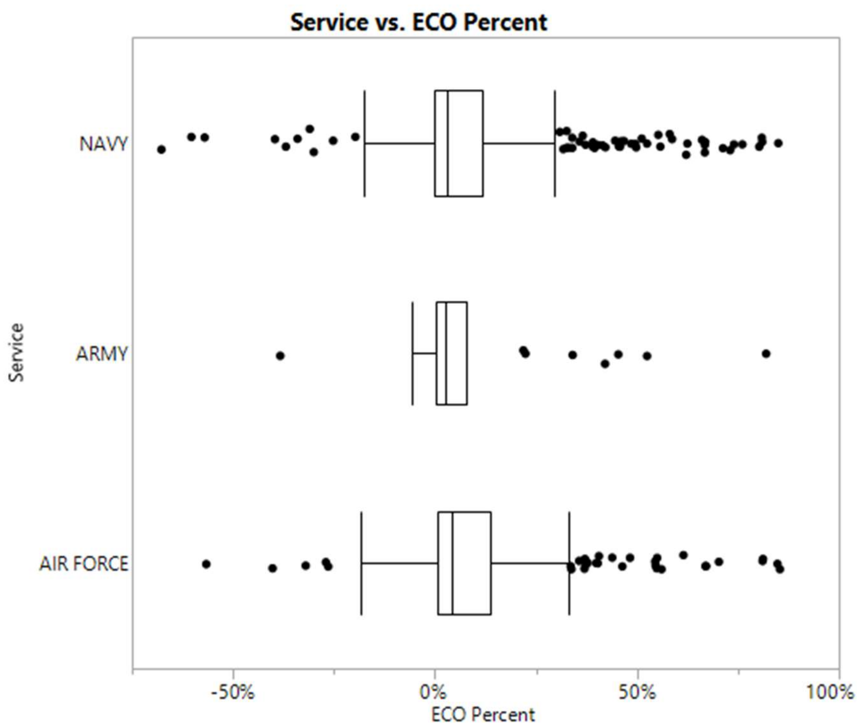

Figure 35. Box Plots of ECO percentages by Service, 2.5% Alpha Trimmed Technical Production Contracts

Table 65. Kruskal-Wallis Test Results for Service, 2.5% Alpha Trimmed Technical Production Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	318	122812	115752	386.201	2.513
ARMY	31	10868.0	11284.0	350.581	-0.363
NAVY	378	130948	137592	346.423	-2.348

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.3289	2	0.0422*

We then perform a Steel-Dwass test and conclude from the results in Table 66 that there is a difference in ECO Percentage locations between the Navy and the Air Force, with the Navy having lower ECO percentage locations than the Air Force. This result is consistent with our untrimmed findings. ECO percentage summary statistics broken down by Service can be found in Table 67.

Table 66. Steel-Dwass Test Results for Service, 2.5% Alpha Trimmed Technical Production Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
NAVY	ARMY	-3.5253	22.08332	-0.15963	0.9860
ARMY	AIR FORCE	-18.3032	18.98232	-0.96422	0.5995
NAVY	AIR FORCE	-37.8792	15.29863	-2.47599	0.0355*

Table 67. ECO Percentage Summary Statistics by Service, 2.5% Alpha Trimmed Technical Production Contracts

	Air Force	Army	Navy
N	318	31	378
Mean	9.93%	9.90%	8.73%
Median	4.15%	2.70%	3.10%
Std Dev	17.44%	21.78%	19.85%
CV	1.7559849	2.199751	2.273485
IQR	13.10%	7.80%	11.83%

Contract Type

We move on to our analysis for Contract Type on the alpha trimmed negative and positive ECO percentage Production contracts. Figure 36 show box plots of trimmed ECO percentages for the different Contract Types. We conduct a Kruskal-Wallis test and find that there is a difference in ECO percentage locations between at least two of the Contract Types. The results of the Kruskal-Wallis test can be found in Table 68. We then perform a Steel-Dwass test to determine between which of the Contract Types the difference in ECO percentage locations occurs. The results of this test are found in Table 69.

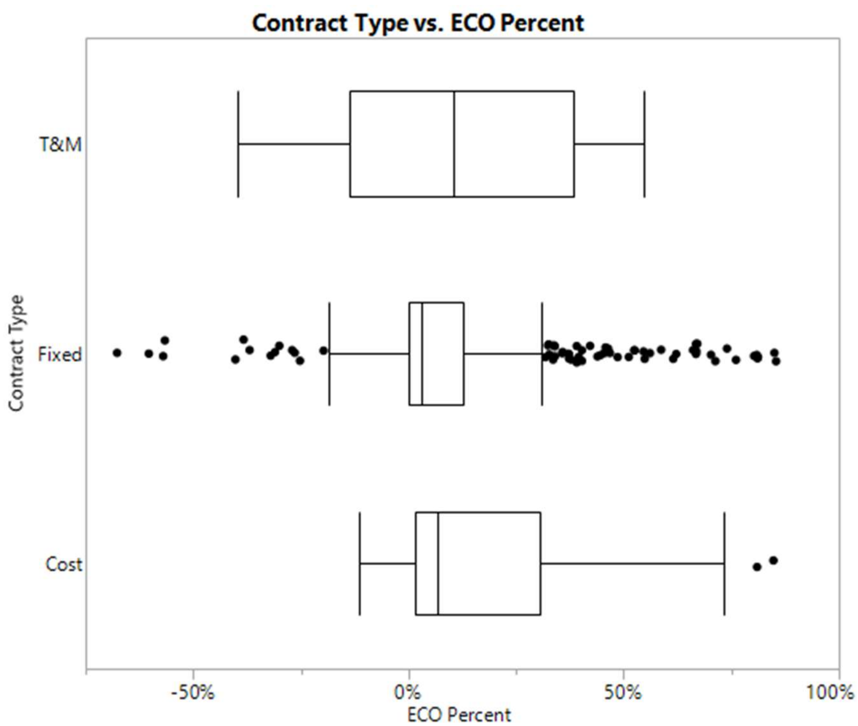

Figure 36. Box Plots of ECO percentages by Contract Type, 2.5% Alpha Trimmed Technical Production Contracts

Table 68. Kruskal-Wallis Test Results for Contract Type, 2.5% Alpha Trimmed Technical Production Contracts – Excluded Unknown Contract Types (94, 12.9%, n = 728)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	69	26389.5	21907.5	382.457	3.120
Fixed	551	170176	174943	308.849	-3.064
T&M	14	4729.50	4445.00	337.821	0.419

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.0803	2	0.0065*

Table 69. Steel-Dwass Test Results for Contract Type, 2.5% Alpha Trimmed Technical Production Contracts – Excluded Unknown Contract Types (94, 12.9%, n = 728)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	23.8774	44.17697	0.54049	0.8513
T&M	Cost	-3.5657	7.06528	-0.50468	0.8691
Fixed	Cost	-72.3977	22.87289	-3.16522	0.0044*

Based on these results, we conclude that there is a difference in ECO percentage locations between Fixed and Cost contracts, with Fixed having lower ECO percentage locations than Cost. These results are consistent with the untrimmed results. Summary statistics broken down by contract type can be found in Table 70.

Table 70. ECO Percentage Summary Statistics by Contract Type, 2.5% Alpha Trimmed Technical Production Contracts

	Cost	Fixed	T&M
N	69	551	14
Mean	17.46%	8.61%	9.59%
Median	6.90%	3.10%	10.35%
Std Dev	23.10%	18.66%	29.44%
CV	1.3236177	2.168212	3.069311
IQR	29.00%	12.50%	51.98%

Commodity

We now analyze the differences in ECO percentages based on commodity. Figure 37 depicts box plots of alpha trimmed ECO percentages for each commodity. We perform a Kruskal-Wallis Test to determine if there is a difference in ECO percentage locations between at least two of the commodities. The results of this test can be found in Table 71. Based on these results we conclude that there may be a difference in ECO percentage locations between at least two of the Commodities.

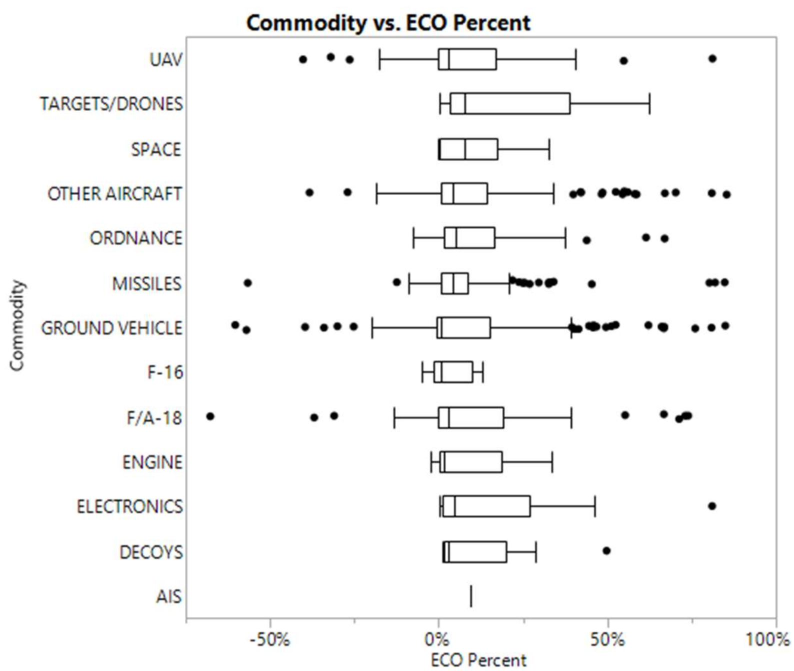

Figure 37. Box Plots of ECO percentages by Commodity, 2.5% Alpha Trimmed Technical Production Contracts

Table 71. Kruskal-Wallis Test Results for Commodity, 2.5% Alpha Trimmed Technical Production Contracts – Excluded Commodities < 5 (7, 0.0097%, *n* = 721)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	1	501.500	361.500	501.500	0.669
DECOYS	11	4445.00	3976.50	404.091	0.682
ELECTRONICS	13	5621.50	4699.50	432.423	1.237
ENGINE	14	4835.50	5061.00	345.393	-0.291
F/A-18	56	20222.0	20244.0	361.107	-0.014
F-16	8	2064.50	2892.00	258.063	-1.410
GROUND VEHICLE	170	52922.5	61455.0	311.309	-3.588
MISSILES	148	53876.5	53502.0	364.030	0.165
ORDNANCE	62	25667.0	22413.0	413.984	2.072
OTHER AIRCRAFT	151	58608.0	54586.5	388.132	1.764
SPACE	15	6333.00	5422.50	422.200	1.138
TARGETS/DRONES	9	4252.50	3253.50	472.500	1.606
UAV	64	21653.5	23136.0	338.336	-0.930

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
25.3303	12	0.0133*

We next conduct a Steel-Dwass test to determine which pairs of Commodities have different ECO percentage locations. The results can be found in Table 72. Our results show that none of the pairs has a *p*-value that is less than the alpha value of 0.05. However, the *p*-value for the pair of Other Aircraft and Ground Vehicle is 0.054 which is very close to the alpha value. For this reason, we conclude that there may be some difference in ECO percentage locations between Other Aircraft and Ground Vehicle, with Other Aircraft having higher ECO percentage locations than Ground Vehicle. These findings are relatively consistent with the untrimmed findings.

Table 72. Steel-Dwass Test Results for Commodity, 2.5% Alpha Trimmed Technical Production Contracts – Excluded Commodities < 5 (7, 0.0097%, n = 721)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
TARGETS/DRONES	GROUND VEHICLE	35.5075	17.72097	2.00370	0.7308
OTHER AIRCRAFT	GROUND VEHICLE	34.1195	10.37767	3.28778	0.0540
ORDNANCE	GROUND VEHICLE	31.0581	9.95665	3.11933	0.0888
OTHER AIRCRAFT	F-16	29.4834	16.70353	1.76510	0.8670
TARGETS/DRONES	MISSILES	26.9328	15.60801	1.72558	0.8846
SPACE	GROUND VEHICLE	26.4441	14.42040	1.83380	0.8329
MISSILES	GROUND VEHICLE	25.6764	10.33564	2.48425	0.3849
MISSILES	F-16	24.4409	16.39712	1.49056	0.9585
TARGETS/DRONES	OTHER AIRCRAFT	20.1325	15.89684	1.26644	0.9890
ORDNANCE	MISSILES	17.4733	9.19206	1.90091	0.7953
SPACE	MISSILES	16.4836	12.78769	1.28902	0.9872
ORDNANCE	F-16	15.8065	7.64392	2.06785	0.6869
OTHER AIRCRAFT	ENGINE	11.6686	13.34641	0.87429	0.9997
OTHER AIRCRAFT	MISSILES	10.5696	9.99990	1.05697	0.9979
GROUND VEHICLE	F-16	9.4235	18.63912	0.50558	1.0000
TARGETS/DRONES	F/A-18	8.9633	6.78985	1.32010	0.9843
ORDNANCE	ENGINE	8.6682	6.53274	1.32689	0.9836
SPACE	OTHER AIRCRAFT	8.1717	13.01115	0.62806	1.0000
UAV	F-16	7.5938	7.84754	0.96766	0.9991
UAV	GROUND VEHICLE	7.3985	9.92649	0.74533	0.9999
ORDNANCE	F/A-18	7.3240	6.30582	1.16147	0.9949
OTHER AIRCRAFT	F/A-18	7.0624	9.37144	0.75361	0.9999
MISSILES	ENGINE	6.6848	13.11539	0.50969	1.0000
TARGETS/DRONES	ORDNANCE	5.9803	7.36094	0.81244	0.9999
SPACE	F-16	5.0792	2.96562	1.71268	0.8900
SPACE	F/A-18	5.0292	5.99999	0.83820	0.9998
TARGETS/DRONES	F-16	4.4861	2.45223	1.82940	0.8352
TARGETS/DRONES	ENGINE	4.4722	2.89630	1.54412	0.9461
TARGETS/DRONES	DECOYS	3.5354	2.65808	1.33004	0.9833
SPACE	ENGINE	2.1405	3.16143	0.67706	1.0000
ORDNANCE	DECOYS	2.0337	6.94042	0.29303	1.0000
TARGETS/DRONES	SPACE	1.5111	2.97429	0.50806	1.0000
TARGETS/DRONES	ELECTRONICS	1.4103	2.81501	0.50098	1.0000
SPACE	DECOYS	0.9455	3.03355	0.31167	1.0000
F/A-18	ENGINE	0.9375	6.08030	0.15419	1.0000
ELECTRONICS	DECOYS	0.9231	2.89620	0.31872	1.0000
MISSILES	F/A-18	0.8369	9.26103	0.09036	1.0000
SPACE	ORDNANCE	0.4554	6.43589	0.07076	1.0000
SPACE	AIS	0.0000	4.89898	0.00000	1.0000
SPACE	ELECTRONICS	-0.2154	3.11239	-0.06920	1.0000
ELECTRONICS	AIS	-1.0769	4.34122	-0.24807	1.0000
TARGETS/DRONES	AIS	-1.1111	3.19142	-0.34816	1.0000
UAV	ENGINE	-1.3058	6.68520	-0.19533	1.0000
F-16	AIS	-1.6875	2.90474	-0.58095	1.0000
DECOYS	AIS	-2.1818	3.76588	-0.57937	1.0000
ENGINE	AIS	-2.6786	4.62083	-0.57967	1.0000
ORDNANCE	ELECTRONICS	-2.6985	6.64744	-0.40595	1.0000
OTHER AIRCRAFT	DECOYS	-2.9747	14.64909	-0.20306	1.0000
ENGINE	DECOYS	-3.2468	2.96192	-1.09616	0.9970
UAV	F/A-18	-3.3147	6.36456	-0.52081	1.0000
F-16	ENGINE	-3.4375	2.87391	-1.19611	0.9934
ENGINE	ELECTRONICS	-3.8571	3.05435	-1.26284	0.9893
F-16	DECOYS	-4.4261	2.61479	-1.69273	0.8981
F/A-18	DECOYS	-4.9489	6.42560	-0.77018	0.9999
F-16	ELECTRONICS	-5.6538	2.78729	-2.02844	0.7141
F/A-18	ELECTRONICS	-6.5872	6.17598	-1.06659	0.9977
F/A-18	AIS	-6.6161	16.74465	-0.39512	1.0000
UAV	DECOYS	-6.8182	7.11297	-0.95856	0.9992
ORDNANCE	AIS	-7.1129	18.47354	-0.38503	1.0000
OTHER AIRCRAFT	ORDNANCE	-7.7469	9.29579	-0.83338	0.9998
UAV	MISSILES	-7.8672	9.17666	-0.85730	0.9997
UAV	SPACE	-8.5583	6.58253	-1.30016	0.9862
F-16	F/A-18	-8.7143	7.03667	-1.23841	0.9909
MISSILES	DECOYS	-8.8876	14.38808	-0.61771	1.0000
UAV	ELECTRONICS	-9.8564	6.80541	-1.44831	0.9667
OTHER AIRCRAFT	ELECTRONICS	-10.5267	13.72493	-0.76698	0.9999
UAV	AIS	-11.6797	19.05294	-0.61301	1.0000
UAV	ORDNANCE	-12.0665	6.50657	-1.85451	0.8217
UAV	TARGETS/DRONES	-12.4835	7.55278	-1.65284	0.9130
GROUND VEHICLE	ENGINE	-13.7613	14.80697	-0.92938	0.9994
GROUND VEHICLE	F/A-18	-14.1962	10.07317	-1.40931	0.9732
UAV	OTHER AIRCRAFT	-14.3830	9.27844	-1.55016	0.9445
MISSILES	ELECTRONICS	-14.5185	13.48506	-1.07663	0.9975
GROUND VEHICLE	DECOYS	-23.8107	16.29844	-1.46092	0.9644
OTHER AIRCRAFT	AIS	-26.1722	44.16587	-0.59259	1.0000
GROUND VEHICLE	ELECTRONICS	-29.8928	15.24094	-1.96135	0.7583
GROUND VEHICLE	AIS	-33.6971	49.64552	-0.67875	1.0000
MISSILES	AIS	-41.7804	43.29828	-0.96494	0.9991

Program Size

We next move to our first binary variable, Program Size. We conduct a Pearson's Chi-Squared test of dependency to determine if there is a different likelihood of incurring and ECO percentage greater than 5% based on whether or not a contract has a baseline cost greater than $1 million. The results in Table 73 show that there is no significant difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not the contract's baseline cost was greater than $1 million. These findings are different than the equivalent untrimmed findings.

Table 73. Pearson's Chi-Squared Test Results for Program Size, 2.5% Alpha Trimmed Technical Production Contracts

		ECO Percent > 5%	
		No	Yes
Baseline Cost > $1M	No	41	23
	Yes	375	289
Pearson *p*-value	0.2415		

Schedule

We now test for differences in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not the Contract length was greater than 5 years using a Pearson's Chi-Squared test of dependency. The results can be found in Table 74. From these results, we conclude that there may be a difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not the Contract length was greater than 5 years. Specifically, if a contract has a schedule greater than 5 years, it may be

1.55 times more likely to incur an ECO percentage greater than 5%.These findings are consistent with the untrimmed findings.

Table 74. Pearson's Chi-Squared Test Results for Schedule, 2.5% Alpha Trimmed Technical Production Contracts

		ECO Percent > 5%	
		No	Yes
Schedule > 5 years	No	267	244
	Yes	36	51
Pearson *p*-value	0.0608		
Odds Ratio	Lower 95%	Upper 95%	
1.550205	0.978023	2.457136	

Positive ECO Technical Production Contracts – Alpha Trimmed 2.5%

We now conduct analysis on just the positive ECO percentages of our 2.5% alpha-trimmed data group. Figure 38 shows the histogram of positive ECO percentages for the 2.5% alpha trimmed technical production contracts.

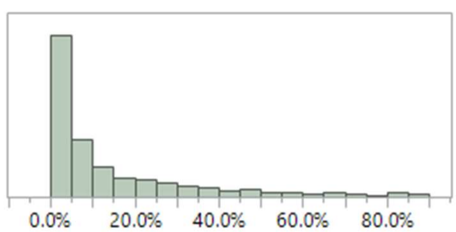

Figure 38. Histogram of Positive ECO Percentages, 2.5% Alpha Trimmed Technical Production Contracts

We use a *t*-test to determine whether or not the mean ECO percentage is different than 5%. The results of this *t*-test and the 2.5% alpha trimmed positive ECO percentage summary statistics can be found in Table 75. From these results, we conclude that that the mean ECO percentage is different than 5%, with our estimate being about 13.06%.

Table 75. Summary Statistics and *t*-test Results for 2.5% Alpha Trimmed Positive ECO Technical Production Contracts

N	600
Mean	13.064%
Median	5.30%
Std Dev	17.767%
CV	1.3599976
IQR	16.075%
Compared to	5%
Test Statistic	11.1174
p-value	<.0001

Service

We now look at the Service variable to determine whether or not there are differences in ECO percentage locations between the services for the 2.5% alpha trimmed positive ECO percentage only data group. Figure 39 shows box plots of the 2.5% alpha trimmed positive ECO percentage Production contracts for each service. We perform a Kruskal-Wallis test and the results found in Table 76 indicate that there is no difference in ECO percentage locations between the services. This finding is consistent with the untrimmed finding.

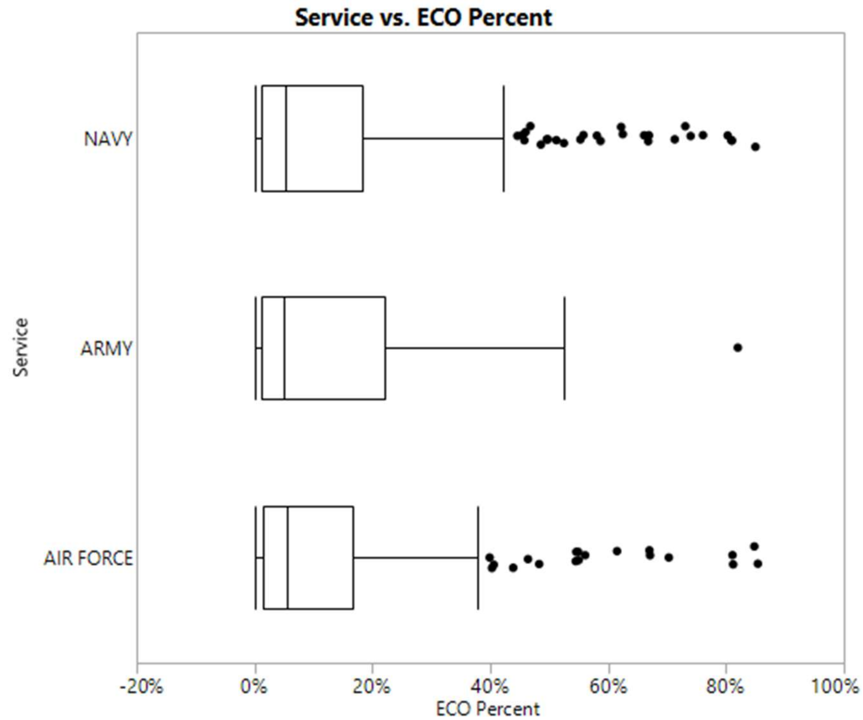

Figure 39. Box Plots of ECO Percentages by Service, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts

Table 76. Kruskal-Wallis Test Results for Service, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	281	84495.5	84300.0	300.696	0.092
ARMY	25	7202.00	7500.00	288.080	-0.351
NAVY	293	88002.5	87900.0	300.350	0.048

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.1244	2	0.9397

Contract Type

We move on to our analysis for Contract Type. Figure 40 shows the box plots of the 2.5% alpha trimmed positive ECO percentages by Contract Type. We perform a Kruskal-Wallis test to determine whether or not there are differences in ECO percentage locations between the

Contract Types. The results of this test can be found in Table 77. We conclude from these results that there may be a statistical difference in ECO percentage locations between at least two of the Contract Types.

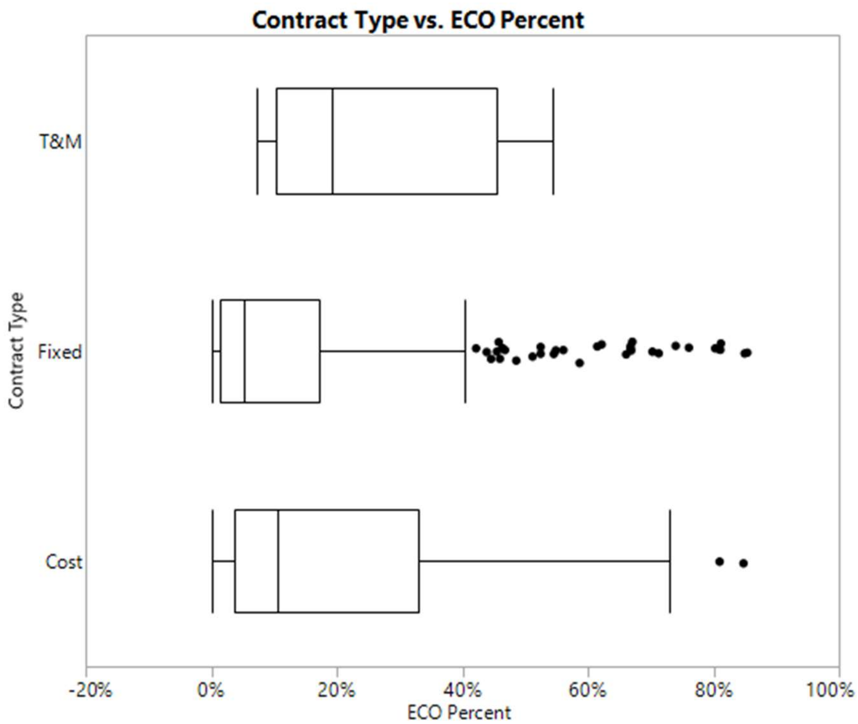

Figure 40. Box Plots of ECO Percentages by Contract Type, 2.5% Alpha Trimmed Positive ECO Production Contracts – Excluded Unknown Contract Types (87, 14.5%, *n* = 600)

Table 77. Kruskal-Wallis Test Results for Contract Type, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts - Excluded Unknown Contract Types (87, 14.5%, *n* = 600)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	59	18702.5	15163.0	316.992	3.304
Fixed	445	109604	114365	246.300	-4.182
T&M	9	3535.00	2313.00	392.778	2.771

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.5358	2	<.0001*

We perform a Steel-Dwass test and find that there is a difference in ECO percentage locations between T&M and Fixed Contract Types as well as between Fixed and Cost Contract Types. These results are shown in Table 78. Specifically, T&M contracts have the highest ECO percentage locations, followed by Cost, with Fixed Contract Types having the lowest ECO percentage locations. These findings are consistent with the equivalent untrimmed findings. ECO percentage summary statistics can be found in Table 79 broken down by contract type for these findings.

Table 78. Steel-Dwass Test Results for Contract Type, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts - Excluded Unknown Contract Types (87, 14.5%, *n* = 600)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	129.228	44.17023	2.92569	0.0096*
T&M	Cost	10.373	7.07586	1.46595	0.3074
Fixed	Cost	-69.500	20.17657	-3.44461	0.0017*

Table 79. ECO Percentage Summary Statistics by Contract Type, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts - Excluded Unknown Contract Types (87, 14.5%, *n* = 600)

	Cost	Fixed	T&M
N	59	445	9
Mean	21.33%	12.65%	27.00%
Median	10.60%	5.10%	19.20%
Std Dev	22.77%	17.36%	18.68%
CV	1.0673437	1.371973	0.69177
IQR	29.40%	16.00%	35.20%

Commodity

The last categorical variable we analyze in this data group is commodity. Figure 41 shows the 2.5% alpha trimmed positive ECO percentage box plots for each of the commodity types. We conduct a Kruskal-Wallis test and conclude from the results in Table 80 that there is no difference in ECO percentage locations between any of the commodities. These findings are consistent with the untrimmed findings.

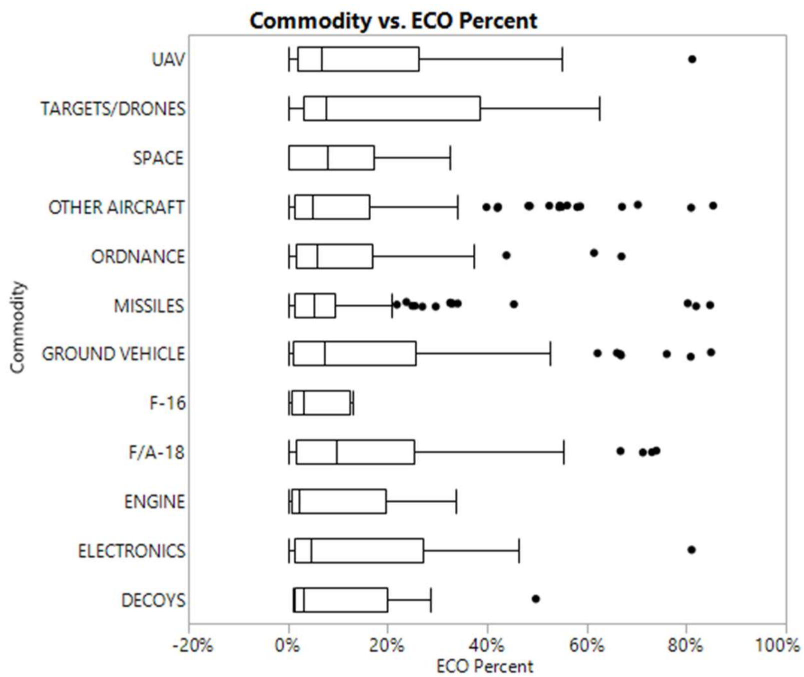

Figure 41. Box Plots of ECO Percentages by Commodity, 2.5% Alpha Trimmed Positive ECO Production Contracts – Excluded Commodities < 5 (7, .012%, *n* = 600)

Table 80. Kruskal-Wallis Test Results for Commodity, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts – Excluded Commodities < 5 (7, .012%, *n* = 600)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DECOYS	11	3034.00	3267.00	275.818	-0.413
ELECTRONICS	13	3952.50	3861.00	304.038	0.149
ENGINE	13	3097.00	3861.00	238.231	-1.250
F/A-18	42	13915.0	12474.0	331.310	1.346
F-16	5	1203.00	1485.00	240.600	-0.738
GROUND VEHICLE	112	34958.5	33264.0	312.129	1.037
MISSILES	132	35702.0	39204.0	270.470	-2.018
ORDNANCE	60	17892.0	17820.0	298.200	0.057
OTHER AIRCRAFT	136	40226.5	40392.0	295.783	-0.094
SPACE	15	4411.00	4455.00	294.067	-0.066
TARGETS/DRONES	9	3097.50	2673.00	344.167	0.831
UAV	45	14632.0	13365.0	325.156	1.146

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.8973	11	0.5396

Program Size

We conduct an analysis on Program Size to determine if there is a different likelihood of a contract experiencing greater than a 5% ECO percentage based on whether or not the contract's baseline cost is greater than $1 million. The results of our Pearson's Chi-Squared test of dependency are found in Table 81. From these results we conclude that there is a difference in the likelihood of a contract experiencing greater than a 5% ECO percentage based on whether or not the contract's baseline cost is greater than $1 million. These findings are consistent with the untrimmed findings. A contract with a baseline cost less than $1 million is 10.8 times (1/.092391 = 10.8) as likely to incur an ECO percentage greater than 5%.

Table 81. Pearson's Chi-Squared Test Results for Program Size, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts

	ECO Percent > 5%		
Baseline Cost > $1M		No	Yes
	No	2	23
	Yes	272	289
Pearson *p* -value	<.0001		
Odds Ratio	Lower 95%	Upper 95%	
0.092391	0.021578	0.395596	

Schedule

The last statistical test we conduct regarding production contracts is a Pearson's Chi-Squared test of dependency to determine whether or not there is a different likelihood of a contract incurring an ECO percentage greater than 5% based on whether or not the contract length is greater than 5 years. The results of this test can be found in Table 82. We conclude from these results that there is no statistical difference in the likelihood of a contract experiencing greater than a 5% ECO percentage based on whether or not that contract's schedule is greater than 5 years.

Table 82. Pearson's Chi-Squared Test Results for Schedule, 2.5% Alpha Trimmed Positive ECO Technical Production Contracts

	ECO Percent > 5%		
Schedule > 5 years		No	Yes
	No	204	244
	Yes	32	51
Pearson *p* -value	0.2397		

Summary of Findings for Technical Production Contracts

We summarize our findings for Technical Production Contracts in Table 83 and Table 84. All results refer to ECO percentage locations. We note that the findings are consistent between the untrimmed and trimmed data sets.

Table 83. Summary of Results of Tests for Significant Differences, All Technical Production Contracts

	All Production	2.5% Alpha Trimmed All Production	Are Findings Consistent?
t-test	Significantly different than 5%	Significantly different than 5%	Yes
Service	Navy < Air Force	Navy < Air Force	Yes
Contract Type	Fixed < Cost	Fixed < Cost	Yes
Commodity	Ground Vehicle < Other Aircraft	Ground Vehicle is potentially < Other Aircraft	Yes
Program Size	Contracts with Baseline > $1M 1.5 times more likely to incure ECO > 5%	No Significant Difference	No
Schedule	No Significant Difference	No Significant Difference	Yes

Table 84. Summary of Results of Tests for Significant Differences, Positive ECO Percentage Technical Production Contracts

	Production Positive ECO Only	Production Positive ECO - 2.5% Alpha Trimmed	Are Findings Consistent?
t-test	Significantly different than 5%	Significantly different than 5%	Yes
Service	No Significant Differences	No Significant Differences	Yes
Contract Type	T&M > Fixed, Fixed < Cost	T&M > Fixed, Fixed < Cost	Yes
Commodity	No Significant Differences	No Significant Differences	Yes
Program Size	Contracts with Baseline > $1M 0.07 times as likely to incure ECO > 5%	Contracts with Baseline > $1M 0.09 times as likely to incure ECO > 5%	Yes
Schedule	No Significant Differences	No Significant Differences	Yes

In order to aid practitioners in using our findings for technical Production contracts, we also want to know what the likelihood of incurring a positive ECO percentage would be for each of the different variables. To do this, we conduct a Pearson's Chi-squared test for dependency with an associated odds ratio. The results of the tests for each variable can be found in Table 85. Only results with p-values less than 0.1 are shown. The red values are those whose p-values are less than our alpha value of 0.05.

Table 85. Significant Pearson's Chi-Squared Test for Dependency Results with Odds Ratios of Incurring a Positive ECO Percentage on Technical Production Contracts

Data Group	Variable	*p* -value	Odds Ratio of Experiencing Positive ECO
All Production Contracts	Service = Navy	<.0001	0.43
	Service = Air Force	<.0001	2.42
	Contract Type = Cost	0.0855	1.82
	Commodity = F/A-18	<.0001	0.35
	Commodity = Missiles	<.0001	2.35
	Commodity = Ground Vehicle	<.0001	0.32
	Commodity = Other Aircraft	0.0032	2.18
	Commodity = UAV	0.0637	0.59
	Baseline Program Size > $1M	<.0001	10.87
	Schedule > 5 years	0.019	3.23
Alpha Trimmed Production Con	Service = Navy	<.0001	0.45
	Service = Air Force	<.0001	2.31
	Commodity = Ground Vehicle	<.0001	0.25
	Commodity = Other Aircraft	0.0038	2.19
	Commodity = Missiles	0.0027	2.3
	Commodity = Ordnance	0.0023	5.2
	Commodity = UAV	0.0318	0.54
	Baseline Program Size > $1M	<.0001	8.5
	Schedule > 5 years	0.0114	3.51

The results in Table 85 could be useful for practitioners to use when estimating how likely it is that their program will experience positive ECO growth. For example, if a contract is for a Missiles commodity, it is 2.35 times more likely to experience a positive ECO percentage than a non-Missiles commodity. Conversely, an F/A-18 contract is only 0.35 times as likely to experience a positive ECO percentage as a non-F/A-18 contract.

O&S Contracts

Having completed our analysis on the Technical Production contracts, we now shift our focus to Technical Operations and Support (O&S) contracts. We follow the same line of analysis as we did in analyzing the Technical Production contracts.

Negative and Positive ECO Technical O&S Contracts

A histogram of the ECO percentages for Technical O&S contracts can be found in Figure 42. We conduct a *t*-test on this data group to determine if the mean ECO percentage is equivalent to the 5% rule-of-thumb for O&S contracts. Summary statistics for Technical O&S contracts as well as the results of the *t*-test can be seen in Table 86.

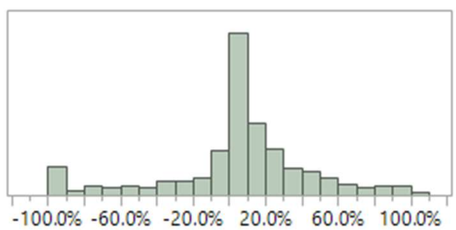

Figure 42. Histogram of ECO Percentages, Technical O&S Contracts

Table 86. Summary Statistics and t-test Results, Technical O&S Contracts

N	1218
Mean	4.795%
Median	5.20%
Std Dev	39.535%
CV	8.2450865
IQR	24.650%
Compared to	5%
Test Statistic	-0.1814
p-value	0.8561

The *p*-value for the *t*-test is much larger than our 0.05 level of significance. We conclude that for all Technical O&S contracts, the mean ECO percentage is not statistically different than 5%. The mean of this data group was 4.8% and the median was less than half a percentage point higher than the mean at 5.2%.

Service

We now conduct analysis to determine whether or not there is a difference in ECO percentage locations based on Service within Technical O&S contracts. Figure 43 depicts box plots of ECO percentages based on Service. We perform a Kruskal-Wallis test to determine whether or not the ECO percentage locations differ between any of the Services. The results of this Kruskal-Wallis test can be found in Table 87.

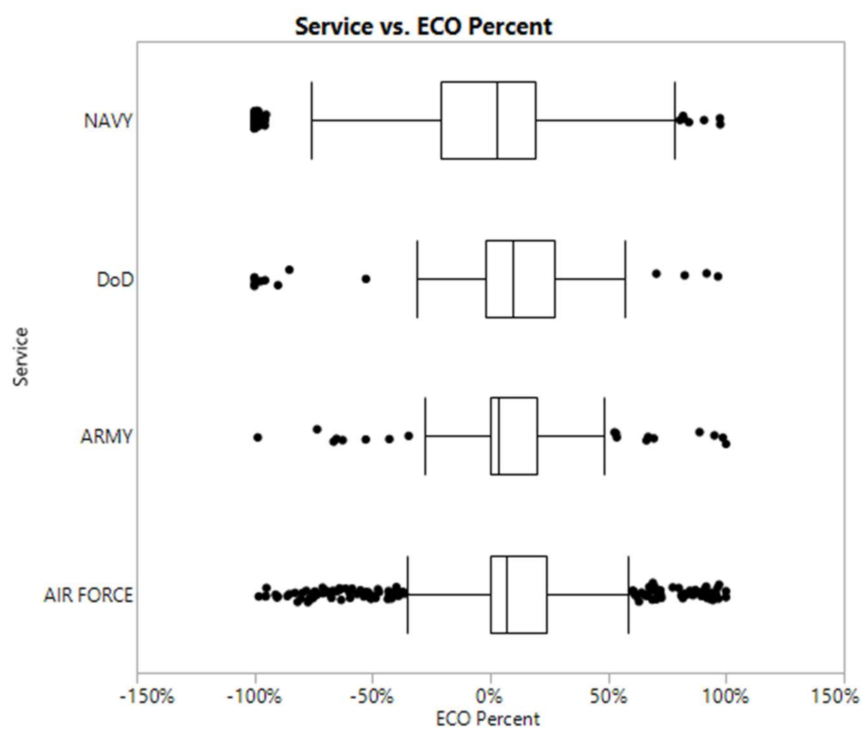

Figure 43. Box Plots of ECO Percentages by Service, Technical O&S Contracts

Table 87. Kruskal-Wallis Test Results for Service, Technical O&S Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	726	462585	442497	637.169	3.335
ARMY	95	56725.5	57902.5	597.111	-0.357
DoD	98	63149.0	59731.0	644.378	1.023
NAVY	299	159912	182241	534.823	-4.226

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.0508	3	0.0003*

We see that the Kruskal-Wallis test results indicate that there is a difference in ECO percentage locations between at least two of the services. We perform a Steel-Dwass test to determine between which pairs of Services the difference in ECO percentage locations lies. The results of this Steel-Dwass test are found in Table 88.

Table 88. Steel-Dwass Test Results for Service, Technical O&S Contracts

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
DoD	ARMY	7.7013	8.04231	0.95760	0.7735
DoD	AIR FORCE	5.7502	25.61400	0.22449	0.9960
NAVY	ARMY	-22.0199	13.40879	-1.64220	0.3549
ARMY	AIR FORCE	-28.4797	25.87336	-1.10073	0.6891
NAVY	DoD	-34.5285	13.35167	-2.58608	0.0478*
NAVY	AIR FORCE	-85.8959	20.34192	-4.22261	0.0001*

The results indicate that there is a difference in ECO percentage locations between Navy and DoD, with Navy having lower ECO percentage locations than DoD. There is also a difference between Navy and Air Force, with Navy having lower ECO percentage locations. Table 89 shows the ECO percentage summary statistics for each service. We note that Navy contracts actually have a negative mean ECO percentage for Technical O&S contracts.

Table 89. ECO Percentage Summary Statistics by Service, Technical O&S Contracts

	Air Force	Army	DoD	Navy
N	726	95	98	299
Mean	9.08%	8.43%	6.85%	-7.43%
Median	6.60%	3.10%	9.60%	2.40%
Std Dev	34.52%	33.69%	39.06%	49.29%
CV	3.8017621	3.996441	5.70219	6.633917
IQR	23.95%	19.80%	28.55%	40.30%

Contract Type

We next move on to our analysis of Contract Type. Figure 44 shows box plots of ECO percentages based on Contract Type. We conduct a Kruskal-Wallis test to determine whether there is a difference in ECO percentage locations between at least two of the contract types. The results of this test in Table 90 indicate that there is a difference between at least two of the contract types. In order to determine between which pairs of contract types the difference occurs, we then perform a Steel-Dwass test, the results of which are found in Table 91.

The results of our Steel-Dwass test indicate that there is a difference in ECO percentage locations between T&M and Fixed contracts with T&M having higher ECO percentage locations as well as a difference between T&M and Cost contracts, with T&M having higher ECO percentage locations. There is no statistical difference in ECO percentage locations between Fixed and Cost contracts. ECO percentage summary statistics for each contract type can be found in Table 92.

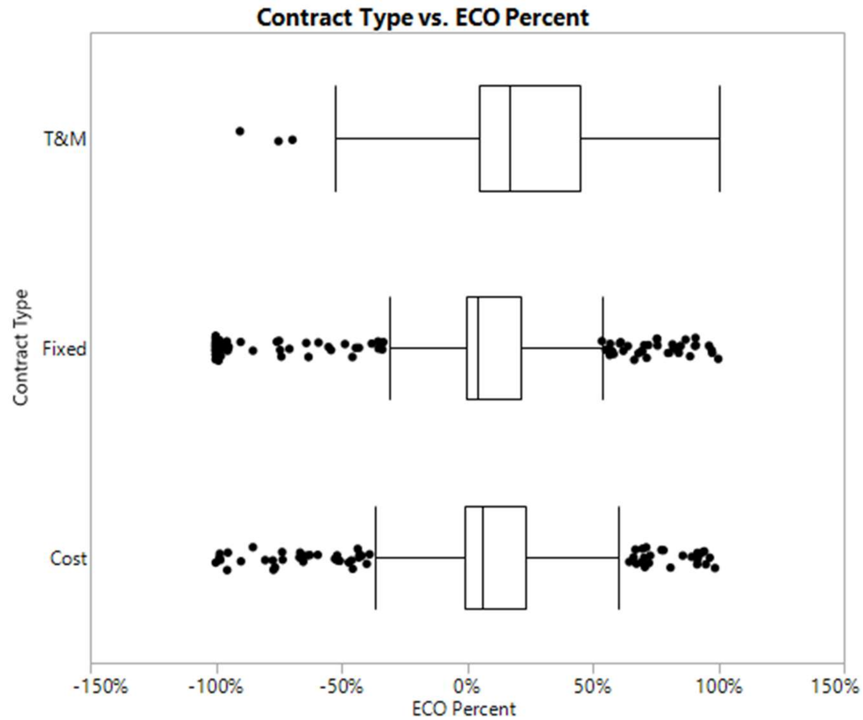

Figure 44. Box Plots of ECO Percentages by Contract Type, Technical O&S Contracts – Unknown Contract Types Removed (103, 8.5%, n = 1218)

Table 90. Kruskal-Wallis Test Results for Contract Type, Technical O&S Contracts – Unknown Contract Types Removed (103, 8.5%, n = 1218)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	432	238787	241056	552.748	-0.433
Fixed	547	287074	305226	524.815	-3.377
T&M	136	96309.0	75888.0	708.154	5.803

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
35.4960	2	<.0001*

Table 91. Steel-Dwass Test Results for Contract Type, Technical O&S Contracts – Unknown Contract Types Removed (103, 8.5%, *n* = 1218)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	111.537	18.90463	5.89996	<.0001*
T&M	Cost	79.967	16.13611	4.95577	<.0001*
Fixed	Cost	-24.868	18.19934	-1.36643	0.3586

Table 92. ECO Percentage Summary Statistics by Contract Type, Technical O&S Contracts - Unknown Contract Types Removed (103, 8.5%, *n* = 1218)

	Cost	Fixed	T&M
N	432	547	136
Mean	8.40%	2.15%	24.07%
Median	5.90%	4.10%	16.75%
Std Dev	33.35%	42.26%	34.52%
CV	3.9681959	19.65618	1.434221
IQR	24.38%	21.60%	40.65%

Commodity

The next variable we look to analyze is Commodity. Figure 45 shows the box plots of ECO percentages for the different Commodities. We conduct a Kruskal-Wallis test and conclude from the results in Table 93 that there is a difference in ECO percentage locations between at least two of the Commodities. We conduct a Steel-Dwass test and conclude that there is a difference in ECO percentage locations between ten pairs of commodities, indicated by red text in Table 94.

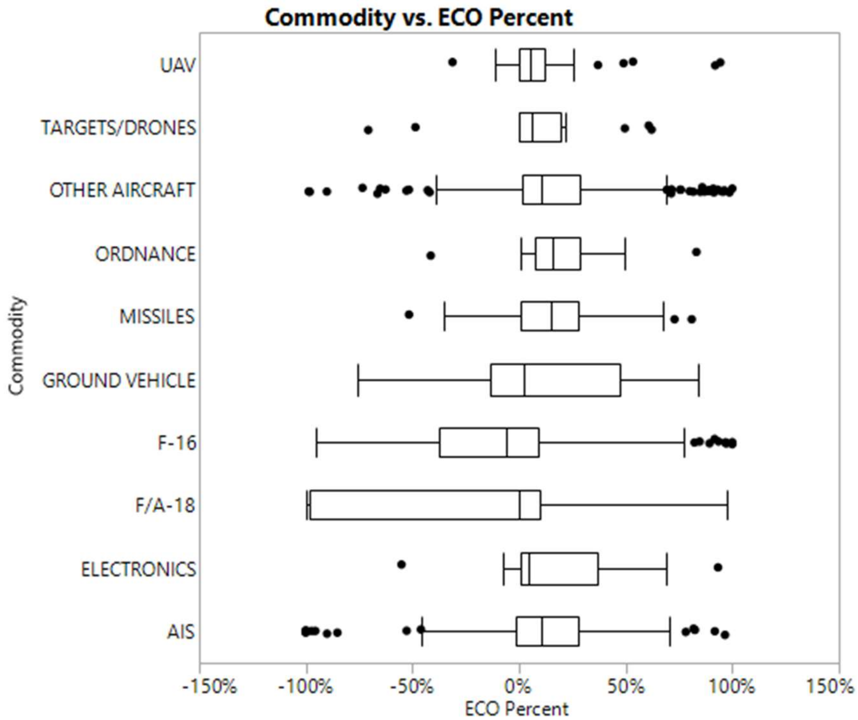

Figure 45. Box Plots of ECO Percentages by Commodity, Technical O&S Contracts – Excluded Commodities < 5 (6, .49%, *n* = 1218)

Table 93. Kruskal-Wallis Test Results for Commodity, Technical O&S Contracts – Excluded Commodities < 5 (6, .49%, *n* = 1218)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	137	89458.0	83090.5	652.978	1.650
ELECTRONICS	24	16290.0	14556.0	678.750	1.021
F/A-18	164	70822.0	99466.0	431.841	-6.872
F-16	220	93933.5	133430	426.970	-8.409
GROUND VEHICLE	22	12846.5	13343.0	583.932	-0.305
MISSILES	60	42311.0	36390.0	705.183	2.240
ORDNANCE	21	16704.5	12736.5	795.452	2.495
OTHER AIRCRAFT	508	358317	308102	705.348	8.352
TARGETS/DRONES	16	10055.0	9704.00	628.438	0.252
UAV	40	24340.5	24260.0	608.513	0.037

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
153.7195	9	<.0001*

Table 94. Steel-Dwass Test Results for Commodity, Technical O&S Contracts – Excluded Commodities < 5 (6, .49%, *n* = 1218)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
OTHER AIRCRAFT	F-16	173.229	16.97286	10.2062	<.0001*
OTHER AIRCRAFT	F/A-18	144.338	17.43425	8.2790	<.0001*
ORDNANCE	F-16	68.622	15.92242	4.3098	0.0007*
MISSILES	F-16	65.005	11.79306	5.5121	<.0001*
UAV	F-16	51.764	12.92576	4.0047	0.0025*
OTHER AIRCRAFT	GROUND VEHICLE	51.739	33.34884	1.5514	0.8711
ORDNANCE	F/A-18	50.628	12.38141	4.0890	0.0018*
MISSILES	F/A-18	47.361	9.76464	4.8503	<.0001*
TARGETS/DRONES	F-16	41.535	17.67745	2.3496	0.3568
UAV	F/A-18	31.906	10.39181	3.0703	0.0659
TARGETS/DRONES	F/A-18	30.114	13.61166	2.2124	0.4481
GROUND VEHICLE	F-16	29.150	15.65314	1.8622	0.6948
OTHER AIRCRAFT	AIS	25.797	17.93851	1.4381	0.9154
GROUND VEHICLE	F/A-18	24.152	12.19525	1.9805	0.6129
ORDNANCE	AIS	17.135	10.72222	1.5980	0.8496
OTHER AIRCRAFT	ELECTRONICS	13.112	32.10974	0.4084	1.0000
F-16	F/A-18	11.627	11.44773	1.0157	0.9914
MISSILES	AIS	8.532	8.82590	0.9667	0.9940
MISSILES	GROUND VEHICLE	7.051	5.93536	1.1879	0.9743
ORDNANCE	MISSILES	6.075	5.96467	1.0185	0.9912
ORDNANCE	GROUND VEHICLE	5.631	3.83074	1.4699	0.9041
ORDNANCE	ELECTRONICS	5.000	3.92425	1.2741	0.9595
UAV	GROUND VEHICLE	4.263	4.78878	0.8901	0.9968
ELECTRONICS	AIS	4.040	10.31611	0.3916	1.0000
TARGETS/DRONES	GROUND VEHICLE	1.511	3.65115	0.4139	1.0000
MISSILES	ELECTRONICS	1.283	5.89057	0.2179	1.0000
TARGETS/DRONES	ELECTRONICS	-1.198	3.77255	-0.3175	1.0000
OTHER AIRCRAFT	MISSILES	-1.556	22.40247	-0.0695	1.0000
UAV	TARGETS/DRONES	-1.794	4.82433	-0.3718	1.0000
TARGETS/DRONES	AIS	-3.141	11.70649	-0.2683	1.0000
UAV	ELECTRONICS	-3.300	4.80702	-0.6865	0.9996
GROUND VEHICLE	ELECTRONICS	-3.964	3.96174	-1.0006	0.9923
TARGETS/DRONES	MISSILES	-5.542	6.21247	-0.8920	0.9967
TARGETS/DRONES	ORDNANCE	-6.387	3.59176	-1.7782	0.7492
GROUND VEHICLE	AIS	-8.467	10.57515	-0.8006	0.9986
UAV	AIS	-8.527	9.20861	-0.9260	0.9957
UAV	MISSILES	-9.250	5.92159	-1.5621	0.8664
UAV	ORDNANCE	-12.890	4.78398	-2.6944	0.1757
TARGETS/DRONES	OTHER AIRCRAFT	-35.909	38.44314	-0.9341	0.9954
F/A-18	ELECTRONICS	-36.110	11.86535	-3.0433	0.0712
OTHER AIRCRAFT	ORDNANCE	-46.959	34.03712	-1.3797	0.9337
F/A-18	AIS	-52.784	10.06582	-5.2438	<.0001*
F-16	ELECTRONICS	-53.883	15.17258	-3.5514	0.0141*
UAV	OTHER AIRCRAFT	-54.557	26.00192	-2.0982	0.5287
F-16	AIS	-65.045	11.23165	-5.7912	<.0001*

Our results indicate that F-16 contracts have lower ECO percentage locations than Other Aircraft, Ordnance, Missiles, UAV, Electronics, and AIS contracts. Furthermore, F/A-18 contracts have lower ECO percentage locations than Other Aircraft, Ordnance, Missiles, and AIS contracts. From these results, it appears that F-16 and F/A-18 contracts are different than many other commodities, though they do not differ statistically from each other. Since the F/A-18 is a

Navy program, it is very likely the cause of the mean ECO percentage for the Navy being negative.

Program Size

We move to our analysis on the first binary variable within Technical O&S contracts. Our ad hoc/posterior analysis indicated that contracts with a baseline of $1 million may be the break point. We perform a Pearson's Chi-Squared test of dependency to determine whether or not there is a difference in the likelihood of a contract experiencing an ECO percentage higher than 5% based on whether or not that contract had baseline cost greater than $1 million. The results of this test can be found in Table 95.

Table 95. Pearson's Chi-Squared Test Results for Program Size, Technical O&S Contracts

	ECO Percent > 5%		
Baseline Cost > $1M		No	Yes
	No	255	175
	Yes	350	438
Pearson *p*-value	<.0001		
Odds Ratio	Lower 95%	Upper 95%	
1.82351	1.43694	2.314076	

Our results indicate that there is a difference in the likelihood of a contract experiencing an ECO percentage higher than 5% based on whether or not that contract had baseline cost greater than $1 million. Contracts with a baseline cost greater than $1 million were 1.8 times more likely to incur an ECO percentage greater than 5%.

Schedule

The second binary variable we analyze is Schedule. As with Production contracts, we use a Schedule length of 5 years as our break point in determining whether or not there is a higher likelihood of a contract incurring an ECO percentage higher than 5%. The results of our Pearson's Chi-Squared test for dependency can be found in Table 96.

Table 96. Pearson's Chi-Squared Test Results for Schedule, Technical O&S Contracts – Blank Dates Excluded (431, 35.3%, *n* = 1218)

	ECO Percent > 5%		
Schedule > 5 years		No	Yes
	No	261	499
	Yes	5	22
Pearson *p*-value	0.0876		
Odds Ratio	Lower 95%	Upper 95%	
2.301403	0.861579	6.147379	

Our results indicate that there may be a difference in the likelihood of a contract experiencing an ECO percentage greater than 5% based on whether or not that contract's schedule is greater than 5 years. Specifically, a contract with a Schedule greater than 5 years could potentially be 2.3 times more likely to incur an ECO percentage greater than 5%.

Positive ECO Technical O&S Contracts

We now exclude all negative ECO percentage contracts and re-conduct our analysis on the five different variables using only the positive ECO percentage Technical O&S contracts. Figure 46 shows a histogram of these ECO percentages.

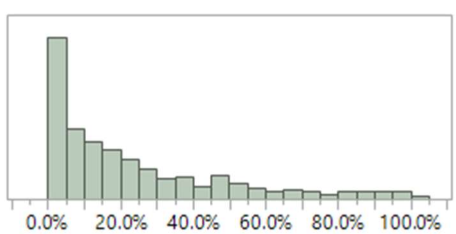

Figure 46. Histogram of ECO Percentages, Positive ECO Technical O&S Contracts

We perform a *t*-test to determine if the mean ECO percentage differs from 5% looking at just the positive ECO percentages. Summary statistics and the results of this test can be found in Table 97. From these results we conclude that the mean ECO percentage for Positive ECO Technical O&S contracts differs from the 5% rule-of-thumb, with our mean estimate being closer to 22% with a median of 14%.

Table 97. Summary Statistics and t-test Results, Positive ECO Technical O&S Contracts

N	872
Mean	22.313%
Median	14.00%
Std Dev	24.122%
CV	1.0810526
IQR	28.850%
Compared to	5%
Test Statistic	21.1947
p -value	<.0001

Service

We move to our analysis of the five different variables within Positive ECO Technical O&S contracts, beginning with Service. Figure 47 shows ECO percentage box plots for the different services. We conduct a Kruskal-Wallis test to determine whether or not there is a difference in ECO locations between any of the Services. The results of this test can be found in Table 98. The results from our Kruskal-Wallis test indicate that there is no statistically significant difference in ECO percentage locations based on Service.

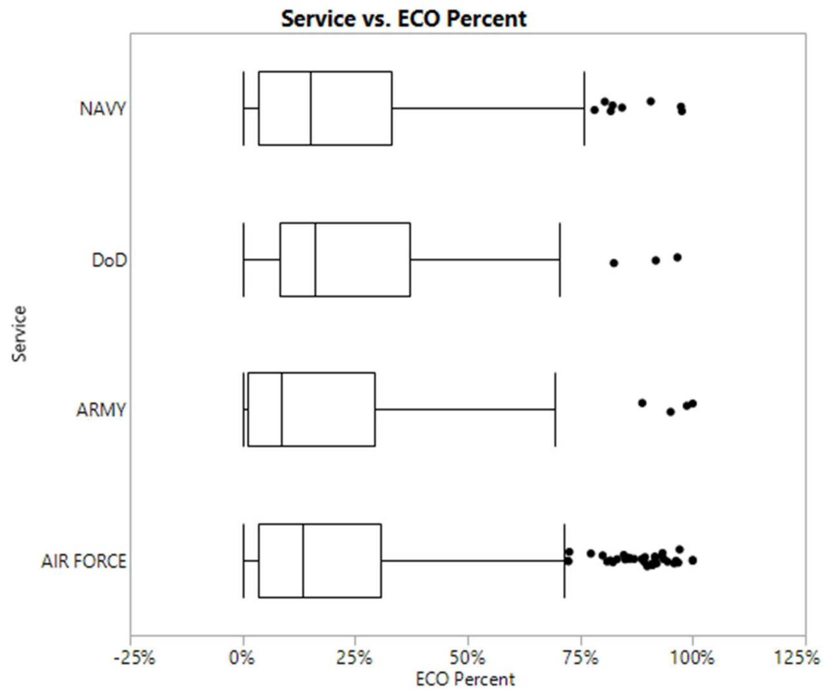

Figure 47. Box Plots of ECO Percentages by Service, Positive ECO Technical O&S Contracts

Table 98. Kruskal-Wallis Test Results for Service, Positive ECO Technical O&S Contracts

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	551	239487	240512	434.641	-0.285
ARMY	70	27261.5	30555.0	389.450	-1.629
DoD	69	33499.0	30118.5	485.493	1.684
NAVY	182	80380.5	79443.0	441.651	0.310

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.1598	3	0.1605

Contract Type

We now analyze Contract Type to determine if there are any differences. Figure 48 shows the different ECO percentage box plots based on Contract Type. We conduct a Kruskal-Wallis test and conclude from the results in Table 99 that there is a difference in ECO percentage locations between at least two of the Contract Types. We perform a Steel-Dwass test to find between which pairs of Contract Types this difference lies. The results of our Steel-Dwass test can be found in Table 100.

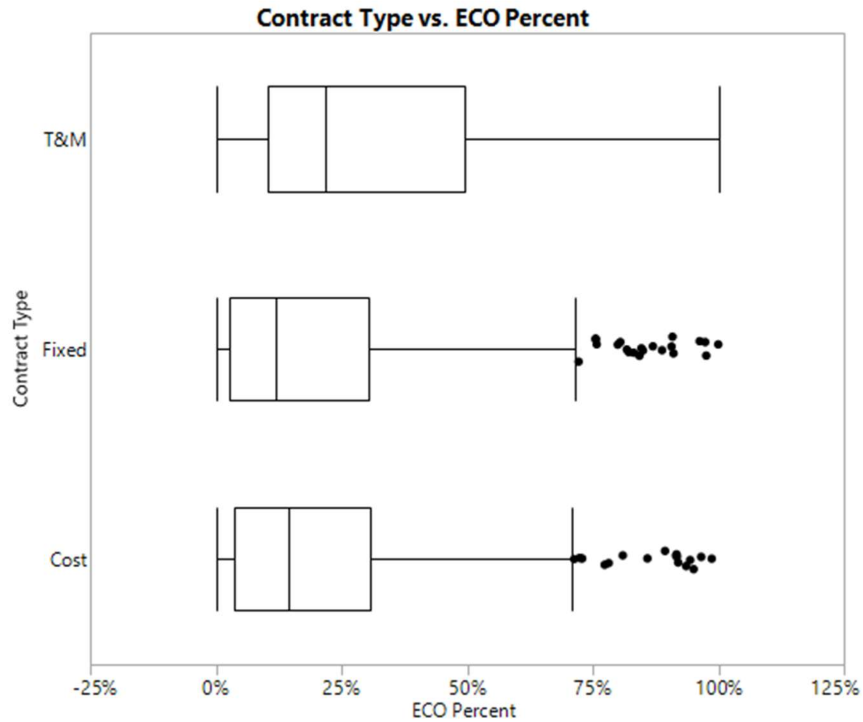

Figure 48. Box Plots of ECO Percentages by Contract Type, Positive ECO Technical O&S Contracts – Excluded Unknown Contract Type (42, 4.8%, *n* = 872)

Table 99. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical O&S Contracts - Excluded Unknown Contract Type (42, 4.8%, *n* = 872)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	317	130727	131714	412.386	-0.294
Fixed	394	154399	163707	391.874	-2.699
T&M	119	59740.0	49444.5	502.017	4.253

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.3774	2	<.0001*

Table 100. Steel-Dwass Test Results for Contract Type, Positive ECO Technical O&S Contracts - Excluded Unknown Contract Type (42, 4.8%, *n* = 872)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	67.5579	15.50523	4.35710	<.0001*
T&M	Cost	47.6187	13.54649	3.51521	0.0004*
Fixed	Cost	-17.8351	15.49644	-1.15091	0.2498

These results indicate that there is a difference in ECO percentage locations between T&M and Fixed Contracts, with T&M having higher ECO percentage locations. There is also a statistically significant difference between the ECO percentage locations of T&M and Cost contracts, with T&M being higher. Table 101 shows the summary statistics of each of the contract types.

Table 101. ECO Percentage Summary Statistics by Contract Type, Positive ECO Technical O&S Contracts - Excluded Unknown Contract Type (42, 4.8%, *n* = 872)

	Cost	Fixed	T&M
N	317	394	119
Mean	21.93%	20.74%	31.58%
Median	14.60%	11.80%	21.80%
Std Dev	23.29%	23.25%	28.29%
CV	1.0617413	1.12091	0.895696
IQR	26.90%	27.50%	39.20%

Commodity

We transition to our analysis based on Commodity for the Positive ECO Technical O&S Contracts. Figure 49 shows box plots of ECO percentages for each of the Commodities. We perform a Kruskal-Wallis test to determine whether or not there is a difference in ECO locations amongst any of the Commodities. Our results are in Table 102. These results indicate that there is no difference in ECO locations based on Commodity.

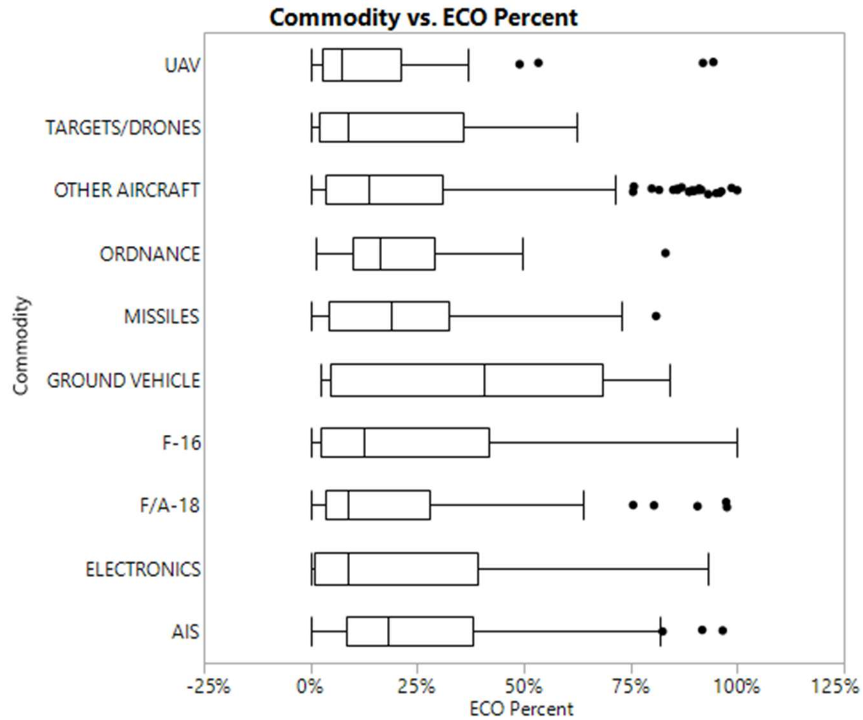

Figure 49. Box Plots of ECO Percentages by Commodity, Positive ECO Technical O&S Contracts – Excluded Commodities < 5 (5, 0.57%, *n* = 872)

Table 102. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical O&S Contracts - Excluded Commodities < 5 (5, 0.57%, *n* = 872)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	97	47691.5	42098.0	491.665	2.406
ELECTRONICS	22	8344.50	9548.00	379.295	-1.037
F/A-18	83	33781.0	36022.0	407.000	-1.033
F-16	94	40637.0	40796.0	432.309	-0.069
GROUND VEHICLE	12	6786.50	5208.00	565.542	1.832
MISSILES	50	22785.5	21700.0	455.710	0.631
ORDNANCE	20	9667.50	8680.00	483.375	0.892
OTHER AIRCRAFT	445	190306	193130	427.653	-0.766
TARGETS/DRONES	13	5033.00	5642.00	387.154	-0.679
UAV	31	11246.0	13454.0	362.774	-1.612

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
14.8754	9	0.0944

Program Size

We next conduct a Pearson's Chi-Squared test of dependency to determine whether or not there is a different likelihood of a contract incurring an ECO percentage greater than 5% based on whether or not the original baseline contract amount was greater than $1 million. The results of this test are found in Table 103 and indicate that there is a difference in the likelihood of a contract incurring and ECO percentage greater than 5% based on whether or not the contract baseline amount was greater than $1million. Specifically, a positive ECO Technical O&S contract with a baseline cost over $1 million is only 0..34 times as likely to incur an ECO percentage greater than 5% as a contract with a baseline less than $1 million. Said differently, a positive ECO Technical O&S contract with a baseline cost less than $1 million is 2.97 times more likely to incur an ECO percentage greater than 5%.

Table 103. Pearson's Chi-Squared Test Results for Program Size, Positive ECO Technical O&S Contracts

	ECO Percent > 5%		
Baseline Cost > $1M		No	Yes
	No	30	175
	Yes	223	438
Pearson *p*-value	<.0001		
Odds Ratio	Lower 95%	Upper 95%	
0.336707	0.221339	0.512209	

Schedule

Our last test for the untrimmed positive ECO Technical O&S contracts is a Pearson's Chi-Squared test of dependency based on Schedule. We conclude from the results in Table 104 that there is no difference in the likelihood of a positive ECO Technical O&S contract incurring an ECO percentage greater than 5% based on whether or not its schedule is greater than 5 years.

Table 104. Pearson's Chi-Squared Test Results for Schedule, Positive ECO Technical O&S Contracts

	ECO Percent > 5%		
		No	Yes
Schedule > 5 years	No	180	499
	Yes	4	22
Pearson *p*-value	0.2049		

Technical O&S Contracts – F/A-18 Contracts Removed and Alpha Trimmed 2.5%

When examining our original O&S data, we notice that F/A-18 contracts are largely concentrated in the negative tail of the ECO percentages as can be seen in Figure 50. Due to potential influence exerted on our results by this large grouping of F/A-18 contracts in the negative tail as well as other potential highly influential outliers, we now exclude all F/A-18 contracts and apply a 2.5% alpha trimming factor to reduce our data group.

The exclusion of the F/A-18 contracts removes 164 contracts from our data group, the histogram of this data group after the F/A-18 contracts are removed can be found in Figure 51. The 2.5% trimming factor further reduces our data group by 27 observations from each side of the dataset, for a total of 218 observations removed. A histogram of the data group after the exclusion of the F/A-18 contracts and the 2.5% trimming factor can be seen in Figure 52. When compared to Figure 42, the histogram of ECO percentages in Figure 52 has no explicitly large peaks in the tails, which suggests that there were large outliers in the untrimmed dataset.

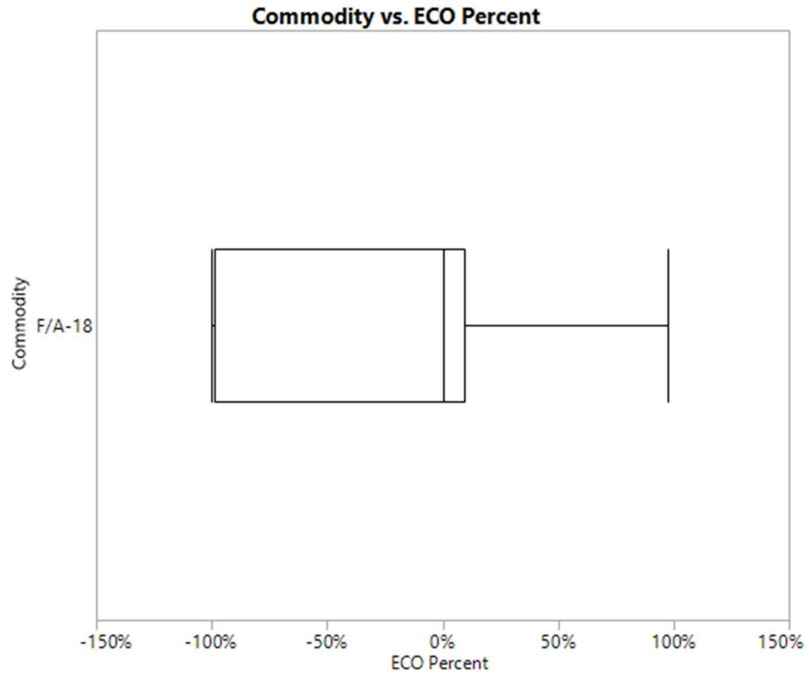

Figure 50. Box Plot of ECO Percentages for F/A-18 Contracts, Technical O&S Contracts

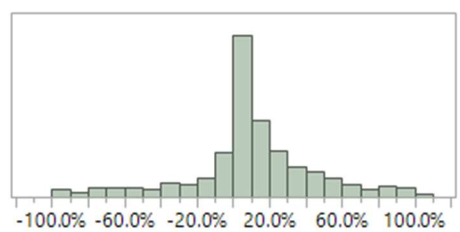

Figure 51. Histogram of ECO Percentages, Technical O&S Contracts Excluding F/A-18 Contracts

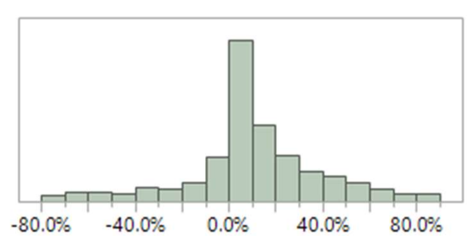

Figure 52. Histogram of ECO Percentages, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

We conduct a *t*-test to determine whether or not the mean ECO percentage is statistically different than the 5% rule-of-thumb. Summary statistics for the data group with just the F/A-18 contracts removed can be found in Table 105. Summary statistics of the data group excluding the F/A-18 contracts and applying the 2.5% alpha trimmed Technical O&S ECO percentages as well as the results of the *t*-test can be found in Table 106. We conclude from our results that the mean ECO percentage for 2.5% alpha trimmed Technical O&S contracts excluding F/A-18 contracts is different than 5%, with our estimate being about 9.3%. The results of both *t*-tests differ from the results of the untrimmed *t*-test.

Table 105. Summary Statistics and *t*-test Results, Technical O&S Contracts Excluding F/A-18 Contracts

N	1054
Mean	9.304%
Median	6.60%
Std Dev	34.298%
CV	3.6861849
IQR	24.100%
Compared to	5%
Test Statistic	4.0745
p -value	<.0001

Table 106. Summary Statistics and *t*-test Results, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

N	1000
Mean	9.690%
Median	6.60%
Std Dev	28.031%
CV	2.8929048
IQR	22.600%
Compared to	5%
Test Statistic	5.2905
p -value	<.0001

Service

We now analyze the data group with the F/A-18 contracts removed and the 2.5% trimming factor applied for the different variables. We begin with our analysis on the Service variable. Box plots of ECO percentages by Service can be found in Figure 53.

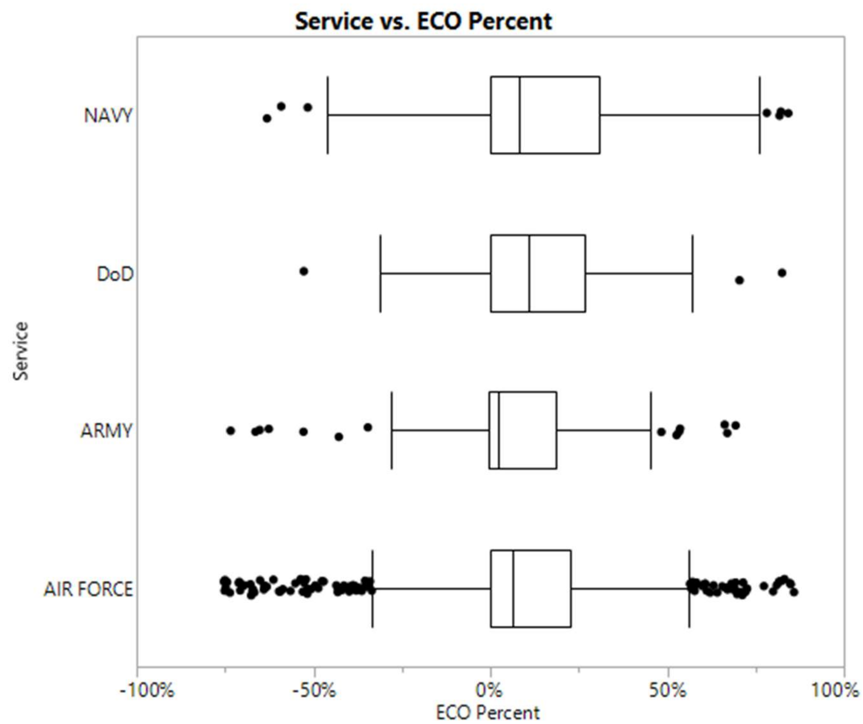

Figure 53. Box Plots of ECO Percentages by Service, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

We perform a Kruskal-Wallis test and conclude from the test results in Table 107 that there is no difference in ECO percentage locations between the Services. These results differ from those of the untrimmed results, leading us to believe that outliers may have a significant impact on our analysis. Table 108 shows summary statistics of the ECO percentages by Service. We note that the Navy no longer has a negative mean ECO percentage.

Table 107. Kruskal-Wallis Test Results for Service, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	688	342371	344344	497.632	-0.466
ARMY	90	40114.0	45045.0	445.711	-1.886
DoD	88	47899.0	44044.0	544.307	1.490
NAVY	134	70116.0	67067.0	523.254	0.980

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.1629	3	0.1039

Table 108. Summary Statistics of ECO Percentages by Service, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

	Air Force	Army	DoD	Navy
N	688	90	88	134
Mean	8.87%	5.74%	14.21%	13.59%
Median	6.40%	2.25%	11.05%	8.30%
Std Dev	28.61%	26.83%	22.25%	28.71%
CV	3.2266704	4.674922	1.565855	2.11225
IQR	22.35%	19.08%	26.65%	30.83%

Contract Type

We next conduct our analysis on the different Contract Types. Box plots of ECO percentages for each contract type can be found in Figure 54. We perform a Kruskal-Wallis test to determine if there is a difference in ECO percentage locations between any of the different Contract Types. Based on the results of this test found in Table 109 we conclude that there is a difference in ECO percentage locations between at least two of the contract types.

We then perform a Steel-Dwass test to determine between which pairs of Contract Types the difference in ECO percentage locations lies. We conclude from the results in Table 110 that there is a difference in ECO percentage locations between T&M and Cost contracts, with T&M

being higher. There is also a difference in ECO percentage locations between T&M and Fixed contracts, with T&M being higher. These results are consistent with the equivalent untrimmed results. Summary statistics of ECO percentages for each contract type can be found in Table 111.

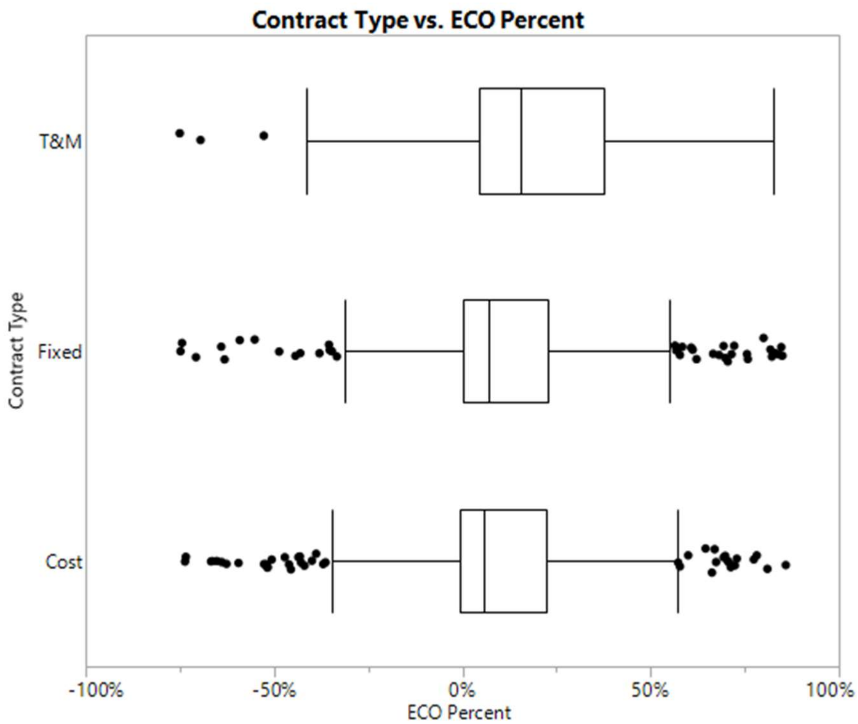

Figure 54. Box Plots of ECO Percentages by Contract Type, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (87, 8.7%, *n* = 1000)

Table 109. Kruskal-Wallis Test Results for Contract Type, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (87, 8.7%, *n* = 1000)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	383	164481	175031	429.453	-2.683
Fixed	412	187892	188284	456.049	-0.099
T&M	118	64868.5	53926.0	549.733	4.094

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
18.7773	2	<.0001*

Table 110. Steel-Dwass Test Results for Contract Type, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (87, 8.7%, *n* = 1000)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Cost	63.61993	15.24244	4.173868	<.0001*
T&M	Fixed	56.71641	15.98940	3.547126	0.0011*
Fixed	Cost	24.23602	16.29959	1.486910	0.2972

Table 111. ECO Percentage Summary Statistics by Contract Type, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (87, 8.7%, *n* = 1000)

	Cost	Fixed	T&M
N	383	412	118
Mean	8.94%	12.78%	19.89%
Median	5.90%	6.90%	15.40%
Std Dev	27.20%	24.72%	28.00%
CV	3.0435881	1.933633	1.407286
IQR	23.10%	22.30%	33.13%

Commodity

We now look at the different Commodities to see if there are any differences in their ECO percentage locations. Figure 55 depicts box plots of ECO percentages for each of the different Commodities. We perform a Kruskal-Wallis test to determine if there are differences in ECO percentage locations between any of the Commodities. The results of this test can be found in Table 112. We conclude from the Kruskal-Wallis test results that there is a difference in ECO percentage locations between at least two of the commodities. We then perform a Steel-Dwass test to determine between which pairs of Commodities there is a difference in ECO percentage locations. The results of this test can be found in Table 113.

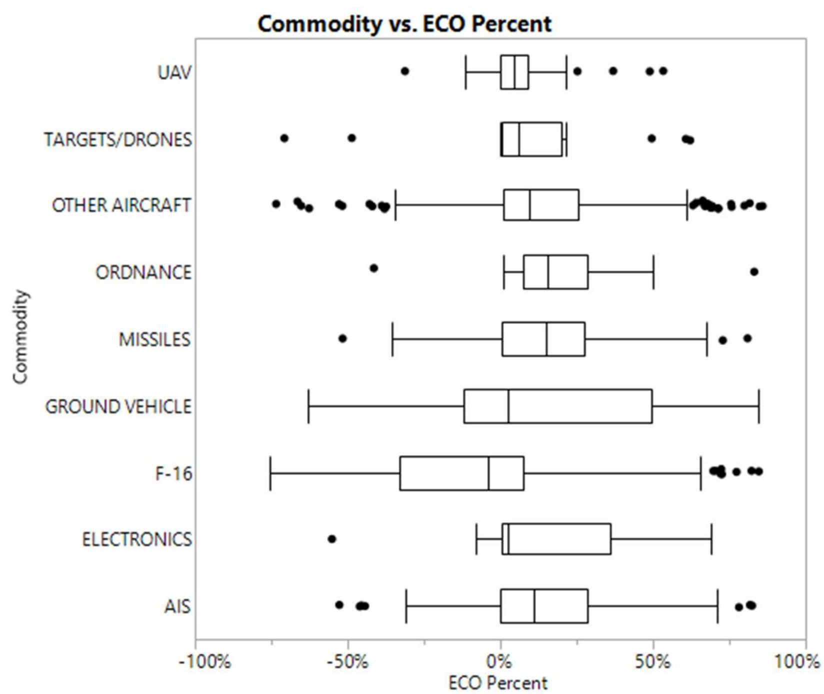

Figure 55. Box Plots of ECO Percentages by Commodity, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (6, 0.6%, *n* = 1000)

Table 112. Kruskal-Wallis Test Results for Commodity, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (6, 0.6%, *n* = 1000)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	127	68722.0	63182.5	541.118	1.833
ELECTRONICS	23	11908.5	11442.5	517.761	0.342
F-16	198	61910.0	98505.0	312.677	-10.123
GROUND VEHICLE	21	9979.50	10447.5	475.214	-0.359
MISSILES	60	33690.0	29850.0	561.500	1.781
ORDNANCE	21	13472.5	10447.5	641.548	2.324
OTHER AIRCRAFT	490	270025	243775	551.071	5.801
TARGETS/DRONES	16	7871.50	7960.00	491.969	-0.077
UAV	38	16936.0	18905.0	445.684	-1.134

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
111.8142	8	<.0001*

Table 113. Steel-Dwass Test Results for Commodity, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (6, 0.6%, *n* = 1000)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
OTHER AIRCRAFT	F-16	165.841	16.73669	9.90884	<.0001*
ORDNANCE	F-16	64.863	14.54177	4.46043	0.0003*
MISSILES	F-16	61.340	10.99668	5.57806	<.0001*
UAV	F-16	43.568	12.09105	3.60331	0.0095*
TARGETS/DRONES	F-16	37.524	16.09325	2.33168	0.3228
OTHER AIRCRAFT	GROUND VEHICLE	35.457	32.90395	1.07760	0.9775
GROUND VEHICLE	F-16	31.286	14.54178	2.15144	0.4380
OTHER AIRCRAFT	ELECTRONICS	18.731	31.62531	0.59228	0.9996
ORDNANCE	AIS	13.818	10.09821	1.36834	0.9098
ORDNANCE	MISSILES	6.075	5.96467	1.01850	0.9842
ORDNANCE	ELECTRONICS	6.058	3.87672	1.56265	0.8251
MISSILES	GROUND VEHICLE	5.368	5.96467	0.89994	0.9930
OTHER AIRCRAFT	AIS	4.952	17.74929	0.27902	1.0000
ORDNANCE	GROUND VEHICLE	4.762	3.78594	1.25779	0.9432
MISSILES	AIS	4.319	8.47889	0.50940	0.9999
MISSILES	ELECTRONICS	3.128	5.91052	0.52915	0.9998
UAV	GROUND VEHICLE	1.442	4.67013	0.30871	1.0000
TARGETS/DRONES	GROUND VEHICLE	0.661	3.59176	0.18395	1.0000
TARGETS/DRONES	ELECTRONICS	-0.371	3.71120	-0.09995	1.0000
GROUND VEHICLE	ELECTRONICS	-2.095	3.87685	-0.54045	0.9998
ELECTRONICS	AIS	-2.722	9.84495	-0.27645	1.0000
UAV	TARGETS/DRONES	-3.242	4.68840	-0.69145	0.9989
UAV	ELECTRONICS	-3.734	4.68964	-0.79622	0.9970
TARGETS/DRONES	MISSILES	-5.542	6.21247	-0.89202	0.9934
TARGETS/DRONES	ORDNANCE	-6.387	3.59176	-1.77821	0.6968
TARGETS/DRONES	AIS	-6.545	10.98884	-0.59558	0.9996
OTHER AIRCRAFT	MISSILES	-8.297	21.73516	-0.38172	1.0000
GROUND VEHICLE	AIS	-9.045	10.09825	-0.89574	0.9932
UAV	MISSILES	-12.121	5.89465	-2.05628	0.5037
UAV	ORDNANCE	-14.676	4.67013	-3.14254	0.0442*
UAV	AIS	-17.539	8.83378	-1.98549	0.5536
TARGETS/DRONES	OTHER AIRCRAFT	-29.753	37.14455	-0.80101	0.9969
F-16	ELECTRONICS	-47.024	14.08555	-3.33848	0.0238*
OTHER AIRCRAFT	ORDNANCE	-53.285	32.90394	-1.61941	0.7944
UAV	OTHER AIRCRAFT	-64.993	25.69043	-2.52987	0.2175
F-16	AIS	-72.907	10.68224	-6.82508	<.0001*

Our results indicate that the ECO percentage location is lower for F-16 than for Other Aircraft, Ordnance, Missiles, UAV, Electronics, and AIS. These results are consistent with the untrimmed results. There is also a difference in ECO percentage locations between UAV and Ordnance, with UAV having lower ECO percentage locations, which is a difference from the results of the untrimmed data group.

Program Size

We move to analyzing our binary variables, beginning with Program Size. Table 114 shows the results of the Pearson's Chi-Squared test of dependency for Program Size. We conclude from these results that there is a difference in the likelihood of a Technical O&S Contract experiencing an ECO percentage greater than 5% based on whether or not the baseline cost was greater than $1 million. A contract with a baseline cost over $1 million is 1.45 times more likely to incur an ECO percentage greater than 5%. This result is consistent with the equivalent result in the untrimmed data group.

Table 114. Pearson's Chi-Squared Test Results for Program Size, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

		ECO Percent > 5%	
		No	Yes
Baseline Cost > $1M	No	160	141
	Yes	307	392
Pearson *p*-value	0.0072		
Odds Ratio	Lower 95%	Upper 95%	
1.448934	1.104726	1.900389	

Schedule

We next conduct a Pearson's Chi-Squared test of dependency for Schedule. The results in Table 115 indicate that there is no difference in the likelihood of a Technical O&S contract incurring an ECO percentage greater than 5% based on whether or not the contract's schedule exceeds five years. This result may differ slightly from the result of the untrimmed data group.

Table 115. Pearson's Chi-Squared Test Results for Program Size, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Blank Date Contracts (324, 32.4%, *n* = 1000)

		ECO Percent > 5%	
		No	Yes
Schedule > 5 years	No	219	433
	Yes	5	19
Pearson *p* -value	0.1923		

Positive ECO Technical O&S Contracts – F/A-18 Contracts Removed and Alpha Trimmed 2.5%

The last section of analysis on Technical O&S contracts is conducted on just the Positive ECO percentage contracts after removing all F/A-18 contracts and applying the 2.5% trimming factor. Figure 56 shows a histogram of the positive ECO percentages for this data group.

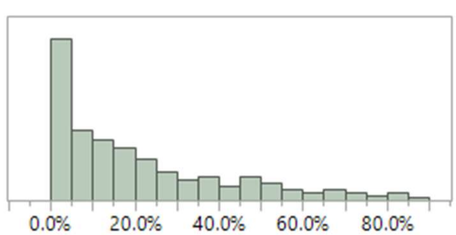

Figure 56. Histogram of ECO Percentages, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

We perform a *t*-test and determine from the results in Table 116 that the mean ECO percentage differs from 5%, with our estimate being closer to 20%. These results are consistent with the untrimmed results.

Table 116. Summary Statistics and t-test Results, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

N	762
Mean	20.076%
Median	13.50%
Std Dev	20.522%
CV	1.0222312
IQR	26.600%
Compared to	5%
Test Statistic	20.2785
p -value	<.0001

Service

We next conduct analysis to determine if there are any differences in ECO locations based on Service. Figure 57 shows box plots of positive ECO percentages for each Service. We conduct a Kruskal-Wallis test and conclude from the results in Table 117 that there is a difference in ECO percentage locations between at least two of the Services.

We then perform a Steel-Dwass test and find that there is a difference in ECO percentage locations between Navy and Army, with Navy having higher ECO percentage locations. There is also a difference between DoD and Army, with DoD having higher ECO percentage locations as can be seen in Table 118. Table 119 shows the summary statistics for each Service. These results differ from those results in the equivalent untrimmed analysis.

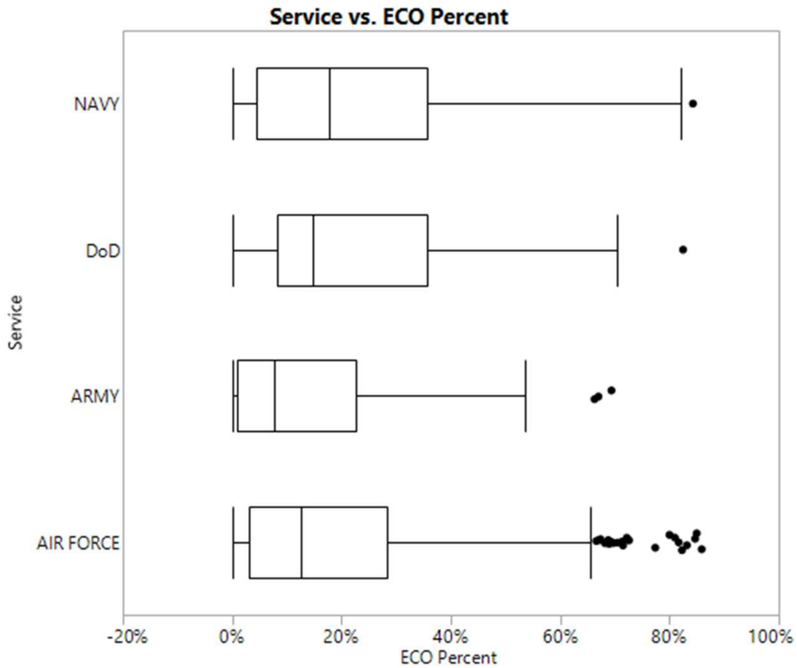

Figure 57. Box Plots of ECO Percentages by Service, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

Table 117. Kruskal-Wallis Test Results for Service, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIR FORCE	530	199036	202195	375.540	-1.130
ARMY	66	21400.5	25179.0	324.250	-2.211
DoD	67	28514.0	25560.5	425.582	1.716
NAVY	99	41752.5	37768.5	421.742	1.950

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.8501	3	0.0126*

Table 118. Steel-Dwass Test Results for Service, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
DoD	AIR FORCE	39.6095	22.36399	1.77113	0.2873
NAVY	AIR FORCE	38.2291	19.89596	1.92145	0.2189
NAVY	ARMY	19.8990	7.59162	2.62118	0.0435*
DoD	ARMY	18.1213	6.68321	2.71147	0.0339*
NAVY	DoD	0.1376	7.60344	0.01810	1.0000
ARMY	AIR FORCE	-40.6619	22.47612	-1.80912	0.2689

Table 119. ECO Percentage Summary Statistics by Service, Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

	Air Force	Army	DoD	Navy
N	530	66	67	99
Mean	19.51%	16.13%	21.96%	24.46%
Median	12.60%	7.60%	14.80%	17.80%
Std Dev	20.26%	19.08%	18.53%	23.43%
CV	1.0383069	1.182354	0.843834	0.95765
IQR	25.23%	21.80%	27.30%	31.40%

Contract Type

The next descriptive variable we analyze is Contract Type. Figure 58 shows box plots of positive ECO percentages for each Contract Type. We perform a Kruskal-Wallis test and conclude that there is a difference in ECO percentage locations between at least two of the Contract Types. The results of the Kruskal-Wallis test can be found in Table 120.

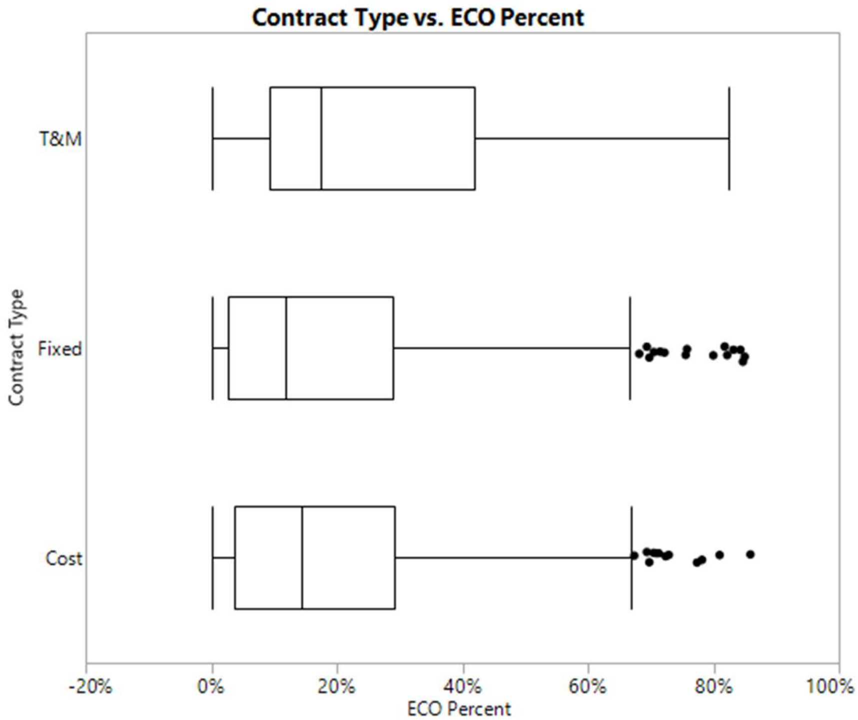

Figure 58. Box Plots of ECO Percentages by Contract Type, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (39, 5.1%, n = 762)

Table 120. Kruskal-Wallis Test Results for Contract Type, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (39, 5.1%, n = 762)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Cost	283	102164	102446	361.002	-0.103
Fixed	337	115559	121994	342.905	-2.297
T&M	103	44003.5	37286.0	427.218	3.422

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.8673	2	0.0016*

We then perform a Steel-Dwass test and conclude from our findings in Table 121 that there is a difference in ECO percentage locations between T&M and Fixed contracts, with T&M

being higher as well as between T&M and Cost contracts, with T&M again having higher ECO percentage locations. These findings are consistent with the findings from the equivalent analysis done on the untrimmed data group. Table 122 shows the positive ECO percentage summary statistics for each of the Contract Types.

Table 121. Steel-Dwass Test Results for Contract Type, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (39, 5.1%, *n* = 762)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
T&M	Fixed	50.7107	14.31653	3.54211	0.0012*
T&M	Cost	35.9661	12.83904	2.80131	0.0141*
Fixed	Cost	-15.8200	14.44202	-1.09541	0.5169

Table 122. ECO Percentage Summary Statistics by Contract Type, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Unknown Contract Types (39, 5.1%, *n* = 762)

	Cost	Fixed	T&M
N	283	337	103
Mean	19.98%	19.21%	26.31%
Median	14.50%	11.90%	17.50%
Std Dev	19.87%	20.72%	22.09%
CV	0.9945869	1.078809	0.839835
IQR	25.40%	26.05%	32.60%

Commodity

The last descriptive variable we look at during our O&S analysis is Commodity. Figure 59 shows box plots of positive ECO percentages for each Commodity. We conduct a Kruskal-Wallis test to determine if there are differences in ECO percentage locations between any of the

Commodities. Our results can be found in Table 85. We conclude from these results that there is a difference in ECO percentage locations between at least two of the Commodities.

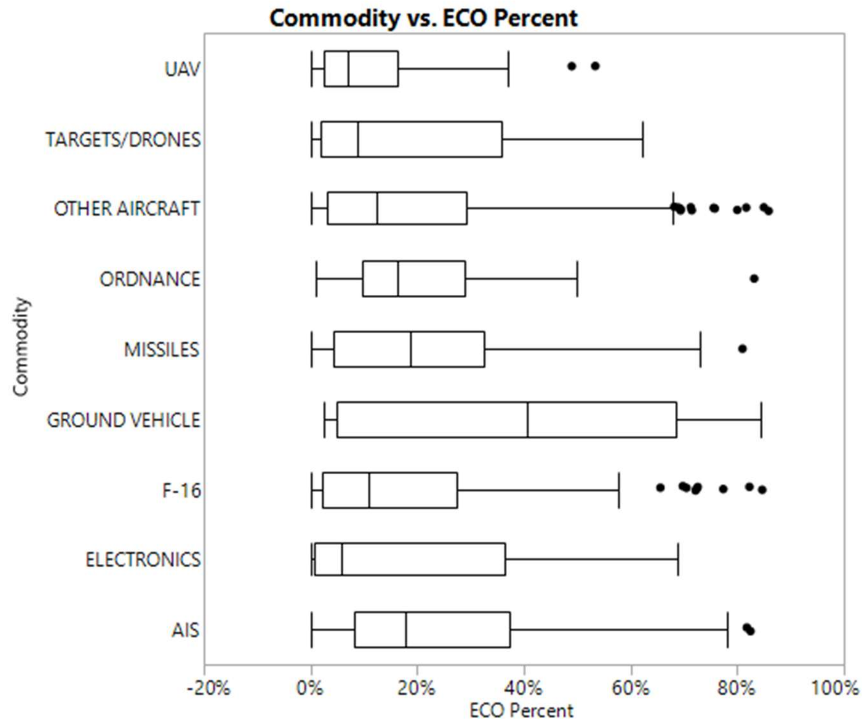

Figure 59. Box Plots of ECO Percentages by Commodity, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (5, 0.66%, *n* = 762)

We conduct a Steel-Dwass test and conclude that there is a difference in ECO percentage locations between UAV and AIS Commodity types, with UAV having lower ECO percentage locations than AIS. These results can be found in Table 123, and they differ from the untrimmed results.

Table 123. Kruskal-Wallis Test Results for Commodity, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (5, 0.66%, *n* = 762)

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AIS	95	41264.5	36005.0	434.363	2.639
ELECTRONICS	21	6749.50	7959.00	321.405	-1.224
F-16	87	31158.0	32973.0	358.138	-0.946
GROUND VEHICLE	12	6107.50	4548.00	508.958	2.075
MISSILES	50	20492.0	18950.0	409.840	1.032
ORDNANCE	20	8677.50	7580.00	433.875	1.137
OTHER AIRCRAFT	430	159407	162970	370.714	-1.195
TARGETS/DRONES	13	4516.00	4927.00	347.385	-0.525
UAV	29	8531.00	10991.0	294.172	-2.130

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
20.0847	8	0.0100*

Table 124. Steel-Dwass Test Results for Commodity, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Commodities < 5 (5, 0.66%, *n* = 762)

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
OTHER AIRCRAFT	ELECTRONICS	29.0428	29.12715	0.99710	0.9863
GROUND VEHICLE	F-16	18.0647	8.84422	2.04254	0.5133
GROUND VEHICLE	AIS	12.6241	9.50692	1.32789	0.9232
ORDNANCE	F-16	11.3457	7.69486	1.47445	0.8676
OTHER AIRCRAFT	F-16	9.0382	17.56137	0.51466	0.9999
MISSILES	F-16	8.3775	7.04356	1.18938	0.9590
GROUND VEHICLE	ELECTRONICS	7.7917	3.49886	2.22692	0.3879
MISSILES	ELECTRONICS	6.9986	5.36633	1.30416	0.9305
F-16	ELECTRONICS	6.5616	7.61433	0.86174	0.9948
ORDNANCE	ELECTRONICS	5.5643	3.74244	1.48681	0.8621
TARGETS/DRONES	ELECTRONICS	1.7436	3.51351	0.49625	0.9999
ORDNANCE	MISSILES	1.6450	5.38411	0.30553	1.0000
UAV	ELECTRONICS	0.3284	4.17621	0.07864	1.0000
ORDNANCE	AIS	-0.6355	8.20247	-0.07748	1.0000
TARGETS/DRONES	F-16	-1.3263	8.62591	-0.15375	1.0000
UAV	TARGETS/DRONES	-2.8966	4.09454	-0.70742	0.9987
MISSILES	AIS	-3.4800	7.33825	-0.47423	0.9999
ORDNANCE	GROUND VEHICLE	-4.0667	3.42540	-1.18721	0.9594
TARGETS/DRONES	ORDNANCE	-4.3154	3.44461	-1.25279	0.9445
TARGETS/DRONES	GROUND VEHICLE	-4.9679	2.94571	-1.68650	0.7551
TARGETS/DRONES	MISSILES	-5.1854	5.70579	-0.90879	0.9926
UAV	F-16	-7.7011	7.21034	-1.06807	0.9787
MISSILES	GROUND VEHICLE	-9.0417	5.79913	-1.55914	0.8270
UAV	GROUND VEHICLE	-9.6020	4.11159	-2.33535	0.3207
UAV	ORDNANCE	-10.7716	4.15303	-2.59366	0.1890
UAV	MISSILES	-11.9317	5.35625	-2.22763	0.3875
TARGETS/DRONES	AIS	-12.1992	9.26175	-1.31716	0.9266
TARGETS/DRONES	OTHER AIRCRAFT	-13.9478	36.04015	-0.38701	1.0000
ELECTRONICS	AIS	-15.9900	8.10912	-1.97185	0.5632
F-16	AIS	-17.8917	7.81755	-2.28866	0.3489
OTHER AIRCRAFT	MISSILES	-25.0940	20.72489	-1.21081	0.9544
UAV	AIS	-25.4976	7.62449	-3.34418	0.0234*
OTHER AIRCRAFT	ORDNANCE	-37.1512	29.74746	-1.24889	0.9455
OTHER AIRCRAFT	AIS	-44.6346	17.19715	-2.59547	0.1883
UAV	OTHER AIRCRAFT	-46.8570	25.44812	-1.84128	0.6544
OTHER AIRCRAFT	GROUND VEHICLE	-80.5622	37.38498	-2.15494	0.4356

Program Size

We next use a Pearson's Chi-Squared test of dependency to determine if differences in Program Size could change the likelihood of an ECO percentage greater than 5% occurring. The results of this test in Table 125 suggest that there is a difference in the likelihood of a positive Technical O&S contract experiencing greater than 5% ECO percent growth based on whether or not the contract's baseline cost was greater than $100 million. Specifically, a contract with a baseline cost less than $1 million is 2.75 (1/.363235 = 2.75) times more likely to experience an ECO percentage greater than 5% than a contract with a baseline cost more than $1 million. This result is consistent with the untrimmed result.

Table 125. Pearson's Chi-Squared Test Results for Program Size, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5%

	ECO Percent > 5%		
		No	Yes
Baseline Cost > $1M	No	26	141
	Yes	199	392
Pearson *p*-value	<.0001		
Odds Ratio	Lower 95%	Upper 95%	
0.363235	0.231199	0.570675	

Schedule

The final test we conduct in our analysis of O&S contracts is a Pearson's Chi-Squared test of dependency on Schedule. We conclude from our results in Table 126 that there is no difference in the likelihood of a contract incurring an ECO percentage greater than 5% based on whether or not that contract had a Schedule length greater than five years. These results are consistent with those of the untrimmed equivalent.

Table 126. Pearson's Chi-Squared Test Results for Schedule, Positive ECO Technical O&S Contracts Excluding F/A-18 Contracts, Alpha Trimmed 2.5% - Excluded Blank Date Contracts (148, 19.4%, *n* = 762)

		ECO Percent > 5%	
		No	Yes
Schedule > 5 years	No	158	433
	Yes	4	19
Pearson *p*-value	0.3185		

Summary of Findings for Technical O&S Contracts

The results of all the analysis we conduct on Technical O&S contracts can be found in Table 127 and Table 128. We note that there were multiple differences between the untrimmed and trimmed analysis.

Table 127. Summary of Results from Analysis on All Technical O&S Contracts

	All O&S	Excluded F/A-18 and 2.5% Alpha Trimmed	Are Findings Consistent?
t-test	Not Signficantly different than 5%	Significantly different than 5%	No
Service	Navy < DoD, Navy < Air Force	No Significant Difference	No
Contract Type	T&M > Fixed, T&M > Cost	T&M > Fixed, T&M > Cost	Yes
Commodity	F-16 and F/A-18 < 4 other Commodities	F-16 < 4 other commodities, UAV < Ordnance	Partially
Program Size	Contracts with Baseline > $1M 1.8 times more likely to incure ECO > 5%	Contracts with Baseline > $1M 1.45 times more likely to incure ECO > 5%	Yes
Schedule	Possible Moderate Difference	No Significant Difference	Partially

Table 128. Summary of Results from Analysis on Positive ECO Technical O&S Contracts

	O&S Positive ECO Only	O&S Positive Only-Excluding F/A-18 and 2.5% Alpha Trimmed	Are Findings Consistent?
t-test	Significantly Different than 5%	Significantly Different than 5%	Yes
Service	No Significant Differences	Navy > Army, DoD > Army	No
Contract Type	T&M > Fixed, T&M > Cost	T&M > Fixed, T&M > Cost	Yes
Commodity	No Significant Differences	UAV < AIS	No
Program Size	Contracts with Baseline > $1M 0.34 as likely to incure ECO > 5%	Contracts with Baseline > $1M 0.36 times as likely to incure ECO > 5%	Yes
Schedule	No Significant Differences	No Significant Differences	Yes

In an effort to assist practitioners in using our results, we now conduct analysis on each of the variables to determine the likelihood of incurring a positive ECO percentage. We use a

Pearson's Chi-Squared test of dependency to determine whether or not the categories in each variable have a different likelihood of incurring a positive ECO percentage. The significant results of our analysis can be found in Table 129. We note that of the F/A-18 Technical O&S contracts, 83 out of 164 of the contracts had negative ECO percentages.

Table 129. Significant Pearson's Chi-Squared Test for Dependency Results with Odds Ratios of Incurring a Positive ECO Percentage on Technical O&S Contracts

Data Group	Variable	*p*-value	Odds Ratio of Experiencing Positive ECO
All O&S Contracts	Service = Navy	<.0001	0.51
	Service = Air Force	<.0001	1.68
	Contract Type = Fixed	0.0521	0.77
	Contract Type = T&M	0.0001	2.72
	Commodity = Electronics	0.0244	4.58
	Commodity = F/A-18	<.0001	0.34
	Commodity = F-16	<.0001	0.22
	Commodity = Ground Vehicle	0.0852	0.48
	Commodity = Ordnance	0.0137	8.32
	Commodity = Other Aircraft	<.0001	4.66
	Baseline Program Size > $1M	<.0001	5.72
Excluded F/A-18, 2.5% Alpha Trimmed O&S Contracts	Contract Type = Cost	0.0007	0.58
	Contract Type = Fixed	0.0865	1.33
	Contract Type = T&M	0.0151	2.0
	Commodity = Electronics	0.0783	3.43
	Commodity = F-16	<.0001	0.15
	Commodity = Ground Vehicle	0.0443	0.42
	Commodity = Ordnance	0.0352	6.55
	Commodity = Other Aircraft	<.0001	3.8
	Baseline Program Size > $1M	<.0001	4.39

V. Conclusions and Recommendations

The intent of this chapter is to discuss our relevant findings from Chapter IV, the limitations and implications of those findings, and how future researchers can potentially build upon our findings. We began our research with the hope of providing cost estimators with useful rules-of-thumb to consider when developing estimates for the amount to be held in management reserve in case of ECO occurrence. Consequently, we also provide tables with variables that could impact the appropriate amount to be held in MR. If used properly, the findings of this research have the potential to enable cost analysts and program managers to expeditiously develop better MR estimates, especially in the absence of analogous programs.

Five key conclusions can be drawn from our findings. One, it is evident from the results of our research that one general rule-of-thumb to estimate an appropriate percentage to be held in reserve in case of ECO occurrence cannot be established. Two, the appropriate ECO percentage differs by life-cycle phase. Three, it appears that the variables of Service, Contract Type, Commodity, Program Size, and Schedule all have some degree of influence on the appropriate percentage to hold in reserve in case of ECO occurrence. Four, within each life cycle phase, the appropriate ECO percentage to hold in reserve differs by whether or not that ECO percentage is likely to be positive. Five, if practitioners want to use rules-of-thumb, it is important to know the different factors that increase the likelihood of a contract incurring a positive ECO percentage.

Tables 130 and 131 provide the results of the *t*-tests using the appropriate rule-of-thumb as the comparison value for each of the different data groups. In only 1 out of 12 tests was the estimated mean ECO percentage found to be statistically non-different than the current rule-of-thumb practice and this was for all Technical O&S contracts. However, our analysis showed that the F/A-18 was having a large effect on the ECO percentages within O&S contracts. As such, when F/A-18 contracts were excluded from the data, the results indicated that the mean ECO percentage for the 12 data groups was statistically different than the rules-of-thumb. We also highlight that the results when analyzing just the positive ECO percentages differ considerably from those that include the negative ECO percentages.

Table 130. Summary of Results on Current Rule-of-Thumb Accuracy, Technical Contracts - * indicates not statistically different than rule-of-thumb

Life Cycle Phase	Current Rule-of-Thumb	Estimated Mean ECO % - All Values	Estimated Median ECO % - All Values	Estimated Mean ECO % - Only Positive ECO Percentages	Estimated Median ECO % - Only Positive ECO Percentages	Percent of Contracts with Positive ECO
Development	10%	16.30%	10.35%	22.15%	13.90%	86.83%
Production	5%	8.80%	3.05%	15.71%	5.50%	80.73%
O&S	5%	4.8%*	5.20%	22.31%	14.00%	71.59%

Table 131. Summary of Results for *t*-tests on Current Rule-of-Thumb Accuracy, Technical Contracts, Outliers Alpha Trimmed

Life Cycle Phase	Current Rule-of-Thumb	Estimated Mean ECO % - All Values	Estimated Median ECO % - All Values	Estimated Mean ECO % - Only Positive ECO Percentages	Estimated Median ECO % - Only Positive ECO Percentages
Development	10%	16.55%	10.35%	21.23%	13.25%
Production	5%	9.31%	3.50%	13.06%	5.30%
O&S	5%	9.69%	6.60%	20.08%	13.50%

From our literature, we found that five variables may have some influence on ECO percentage: Service, Contract Type, Commodity, Program Size, and Schedule. We analyzed each of these variables within each life cycle phase and found that they all have some impact on ECO percentages. Table 132 and 133 indicate which of the variables were significant in each data group. Both Contract Type and Program Size were found to be significant factors in determining ECO percentages in 11 out of the 12 data groups. This leads us to conclude that of the five variables we analyzed, Contract Type and Program Size are the most commonly influential variables in determining ECO percentages. Therefore, these should be accounted for when developing MR estimates.

Table 132. Summary of Variables that Influence ECO Percentages by Life Cycle Phase, All Technical Contracts

	All Technical Contracts			Alpha Trimmed Technical Contracts		
	Development	Production	O&S	Development	Production	O&S
Service		x	x		x	
Contract Type	x	x	x	x	x	x
Commodity		x	x		x	x
Program Size	x	x	x	x		x
Schedule	x		m	x		

x - indicates significant variable (*p-value < 0.05)*
m - indicates moderately signficant variable (0.05 < *p* -value < 0.1)

Table 133. Summary of Variables that Influence ECO Percentages by Life Cycle Phase, Positive ECO Percentage Technical Contracts

	Positive ECO Technical Contracts			Alpha Trimmed Positive ECO Technical Contracts		
	Development	Production	O&S	Development	Production	O&S
Service						x
Contract Type	x	x	x		x	x
Commodity						x
Program Size	x	x	x	x	x	x
Schedule	x			x		

x - indicates significant variable (p-value < 0.05)

The Program Size variable was a binary variable created by performing ad hoc/posterior analysis in order to find a break point that may be influential in differentiating between ECO percentages. In order to be transparent with our analysis and our findings, we include in Figure 60 a graph of the different Odds Ratios of a program exceeding its associated rule-of-thumb value based on six different baseline values: $1 million, $2.5 million, $5 million, $10 million, $25 million, and $50 million. We also include in Figure 61 a graph of the different Odds Ratios of a program incurring a positive ECO percentage based on the same six baseline values. In both graphs, the Odds Ratios for the different data groups move towards convergence as the program baseline threshold amount increases.

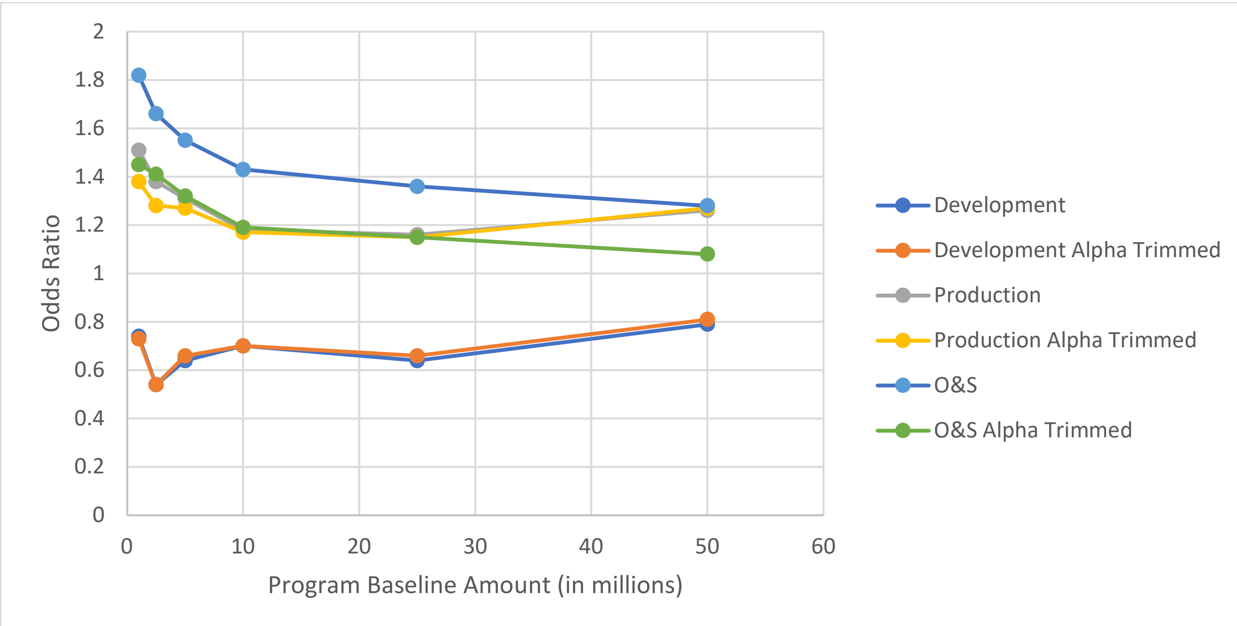

Figure 60. Scatterplot of Odds Ratios for the Likelihood of Exceeding Associated Rule-of-Thumb Percentage by Program Baseline Amount

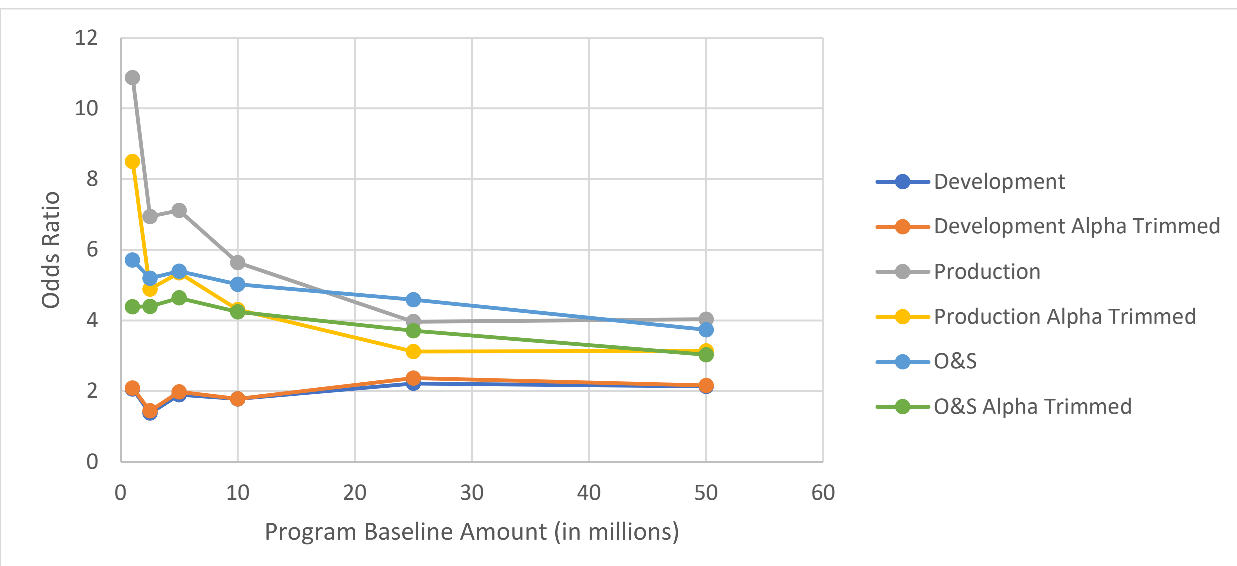

Figure 61. Scatterplot of Odds Ratios for the Likelihood of Incurring Positive ECO Percentage by Program Baseline Amount

Proposed Rules-of-Thumb

As stated earlier, our results indicate that no one rule-of-thumb should be used to estimate the amount to be held in MR in case of ECO. Our results also highlight that the mean ECO percentage differs significantly when looking at just positive ECO percentages versus when taking into account negative ECO percentages as well. For these reasons, we suggest that if a rule-of-thumb is to be used, a four-tiered approach should be taken. First, the life cycle phase of the contract should be considered. Second, characteristics of the contract should be reviewed to determine whether or not there is an increased likelihood of incurring a positive ECO percentage. Third, a rule-of-thumb percentage should be chosen as a starting point. Fourth, characteristics of the contract should be reviewed to determine whether to adjust the estimate upward, downward, or not at all.

At least 71% of the contracts that we analyzed in each life cycle phase incurred positive ECO percentages. For this reason, we recommend using the results from our analysis on positive ECO percentage contracts for all estimates excluding those that display characteristics with increased odds of experiencing negative ECO percentages when applying a rule-of-thumb. Tables 134, 135, and 136 provide the four-tiered approach we recommend for developing MR estimates. We propose using the results of our alpha-trimmed analyses to develop estimates due to the potentially significant impact of outliers. For our analysis on O&S contracts we removed F/A-18 contracts during the alpha-trimming process. For this reason, the suggestions in Table 136 should not be used if estimating F/A-18 contracts.

Table 134. Flowchart for Estimating ECO MR Amount, Development Contracts

1. Does Contract Have ANY of the Following Characteristics?	2a.If yes, start estimate at:	3. If Contract has the Following Characteristics	3a. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
Contract Type = Fixed	10.35%	Contract Type = Cost	Upward	1.5%
Commodity = Ground Vehicle		Schedule > 5 years	Upward	11%
		Initial Program Size > $2.5M	Downward	-1.3%
		Initial Program Size < $2.5M	Upward	12%
	2b. If no, start estimate at:	3. If Contract has the Following Characteristics	3b. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
	13.25%	Schedule > 5 years	Upward	13.4%
		Initial Program Size < $2.5M	Upward	18%
		Initial Program Size > $2.5M	Downward	-2%

Table 135. Flowchart for Estimating ECO MR Amount, Production Contracts

1. Does Contract Have ANY of the Following Characteristics?	2a.If yes, start estimate at:	3. If Contract has the Following Characteristics	3a. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
Service = Navy	3.50%	Service = Air Force	Upward	0.6%
Commodity = Ground Vehicle		Contract Type = Cost	Upward	3.4%
Commodity = UAV		Contract Type = Fixed	Downward	-0.5%
		Commodity = Other Aircraft	Upward	0.5%
	2b. If no, start estimate at:	3. If Contract has the Following Characteristics	3b. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
	5.50%	Contract Type = T&M	Upward	14.7%
		Contract Type = Cost	Upward	5.5%
		Initial Program Size < $1M	Upward	18.6%

Table 136. Flowchart for Estimating ECO MR Amount, O&S Contracts

1. Does Contract Have ANY of the Following Characteristics?	2a.If yes, start estimate at:	3. If Contract has the Following Characteristics	3a. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
Contract Type = Cost	6.60%	Contract Type = T&M	Upward	8.8%
Commodity = F-16		Contract Type = Fixed	Upward	0.3%
Commodity = Ground Vehicle		Commodity = UAV	Downward	-2.1%
		Commodity = Ordnance	Upward	9%
		Initial Program Size > $1M	Upward	1.3%
		Initial Program Size < $1M	Downward	-3.1%
	2b. If no, start estimate at:	3. If Contract has the Following Characteristics	3b. Direction to Adjust Estimate	Suggested Percentage Point Adjustment
	13.50%	Service = Navy	Upward	4.3%
		Service = Army	Downward	-5.4%
		Service = DoD	Upward	1.3%
		Contract Type = T&M	Upward	4%
		Commodity = UAV	Downward	-6.6%
		Commodity = AIS	Upward	4.3%
		Initial Program Size > $1M	Downward	-1.8%
		Initial Program Size < $1M	Upward	5.4%

If a contract has multiple characteristics listed in column 3 of the flowcharts, then the suggested percentage point adjustments in the last column of each of the flowcharts will be averaged (not summed). For example, if trying to calculate an appropriate ECO percentage estimate for a Fixed contract in the Development phase with a Schedule greater than 5 years and an initial contract cost greater than $2.5 million the appropriate ECO percentage estimate would be 10.35% + (11%-1.3%)/2 = 15.2%. We suggest that the estimates from the flowchart should be used as an initial point estimate for developing ECO percentage estimates and should not be treated as an exact estimate. Cost estimator should use prior knowledge and other tools that they have to deviate from this point estimate when necessary.

The initial point estimates in the second column of each table were determined by finding the median ECO percentage for that particular data group. For example, the point estimate of 10.35% in column 2a of Table 134 was the median ECO percentage for all negative and positive technical Development Contracts. The point estimate of 13.25% in column 2b of Table 134 was the median ECO percentage for just the positive ECO percentage technical Development contracts. The suggested percentage point adjustment in each table was determined by finding the difference between the applicable point estimate and the median ECO percentage for contracts with the specified characteristic. For example, the suggested percentage point adjustment of 1.5% in column 5 of Table 134 was derived by finding the median ECO percentage of technical development contracts with a Cost contract type (11.85%) and subtracting the point estimate (10.35%).

We again acknowledge that there is no one-size-fits-all rule-of-thumb that can be used to estimate appropriate amounts to hold in MR in case of ECO. Even when dividing the data into the different life cycles, there are still variables that appear to drive differences in ECO percentages. Our research indicates that the suggestions from our flowcharts will lead to more accurate MR estimates. However, when feasible, contracts should be analyzed in a variety of ways to develop the most accurate estimates possible.

Comparison to Previous Research

When compared to the 1983 ECO Guidebook (Gibson, 1983) from which the original 10% rule-of-thumb deviated, our findings suggest that ECO percentage estimates should often be higher than 10%. Our results suggest that ECO percentage estimates have been underestimating the true ECO percentages by using the 10% rule of thumb.

Our findings have also been consistent with previous studies on potential causes of ECOs that found that Service, Contract Type, Commodity Type, Program Size, and Schedule may play a role in ECO percentages.

Future Research

Our analysis indicated that there was a relatively substantial number of contracts, approximately 23%, that experienced negative ECO percentages. This drove a significant difference between the mean ECO percentages of the Positive ECO percentage data groups when compared to the data groups that included the negative ECO percentages. For this reason, we recommend that further research be conducted into the variables that influence whether a contract experiences positive or negative ECO growth at the CLIN level.

We acknowledge our use of ad hoc/posterior analysis to find an appropriate break point for our Program Size variable. We suggest that future research look into the effects that a program's initial size has on the likelihood of ECO occurrence as well as the size of the cost growth increase should an ECO occur. It also may be more beneficial to practitioners if ECO percentages were analyzed based on acquisition category (ACAT) instead of arbitrary program size dollar figures.

In our analysis, we removed any contracts that had ECO percentages greater than 100% in absolute value. It may be beneficial to know the different variables that may influence contracts to exceed this 100% threshold. It may also be beneficial to analyze whether or not the number of ECOs on a single contract has any influence on overall ECO percentages.

Lastly, we suggest future analysis use EVM data to develop ECO percentage estimates to compare to the results found in our analysis. If the results were similar, this would further validate the results of our analysis.

Appendix: Department of Defense Programs Used in Database

3DELRR (3DELRR - Three-Dimensional Expeditionary Long-Range Radar)
ADM-141C (ITALD)
ADM-160 (Miniature Air-Launched Decoy)
ADS (Active Denial System)
AEHF (AEHF Advanced Extremely High Frequency (AEHF) Satellite Program)
AGM-130 (AGM-130A)
AGM-142 (Have Nap)
AGM-154A (JSOW (Baseline) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant)
AGM-154C (JSOW (Unitary) - Joint Stand-Off Weapon Baseline Variant and Unitary Warhead Variant)
AGM-158 (JASSM (JASSM/JASSM-ER) Joint Air-to-Surface Standoff Missile)
AGM-169 (JCM - Joint Common Missile (AGM-169))
AGM-65 (AGM-65 (Maverick))
AGM-84 (AGM-84; RGM-84; UGM-84 (Harpoon SLAM ER))
AGM-86A/B/C/D (AGM-86 (Air-Launched Cruise Missile (ALCM)))
AGM-88 (AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program)
AGM-88E (AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program)
AH-1
AH-64
AHLTA (AHLTA - Armed Forces Health Longitudinal Technology Application)
AIM-120 (AMRAAM - Advanced Medium Range Air-to-Air Missile)
AIM-7 (AIM-7; RIM-7 (Sparrow; Sea Sparrow))
AIM-9 (AIM-9X - Air-to-Air Missile Upgrade)
AN/AAR-57 CMWS (Common Missile Warning System)
AQM-37 (AQM-37 (Target Drone))
ASIP (Advanced Special Improvement Models)
AV-8B
AWACS
AWS (AEGIS - MK 7 Advanced Shipboard Weapon System)
B-1
B-2
B-52 CONECT (B-52 Stratofortress Combat Network Communications Technology)
B-52H
B-61 Tailkit (B61 Mod 12 Life Extension Program Tailkit Assembly)
BGM-109 (BGM-109 (Gryphon (Ground-Launched Cruise Missile)))
BQM-167 (Skeeter)
BQM-34 (Firebee)
BQM-74 (Chukar)
BTERM (Ballistic Trajectory Extended Range Munition)
C-12U
C-12V

C-130
C-17
C-37A
C-40A
C-5
CBU-105 (Sensor Fuzed Weapon)
CBU-97 (CBU-97 (Sensor Fused Weapon (SFW)))
CH-47
CH-53
CHAMP (Champ)
CHCS (Composite Health Care System)
CIWS (Close in Weapons System)
CV-22
DCAPES (Deliberate Crisis Action Planning and Execution Segments INC 2B)
DCGS-N (DCGS Navy - Distributed Common Ground System Navy)
DDG 51 (DDG 51- Arleigh Burke Class Guided Missile Destroyer)
DEAMS (Defense Enterprise Accounting Management System)
E-2D
E-3A
EA-18G
EC-130H
EELV (EELV - Evolved Expendable Launch Vehicle)
EPS (Enhanced Polar System)
Essentris (Essentris)
EX-171 (ERM - Extended Range Munition)
F/A-18
F-119 (F-22 Engine)
F-135 (F-35 Engine)
F-136 (F-35 Engine)
F-15
F-15 AN/ALQ-135 (Electronic Countermeasure)
F-15 ATP (Advanced Targeting Pod)
F-16
F-22
F-35
FAB-T (FAB-T – Family of Beyond Line-of-Sight Terminals)
FMTV (FMTV - Family of Medium Tactical Vehicles)
GBU-12 (Paveway II)
GBU-15 (Guided Bomb Unit 15)
GBU-24 (Paveway III)
GBU-28 (Bunker Buster)
GBU-39 (SDB I Small Diameter Bomb Increment I)
GBU-53/B (SDB II Small Diameter Bomb, Increment II)
GCSS-MC (Global Combat Support Systems - Marine Corps)
GPS III (Global Positioning System III)

GPS OCX (GPS OCX - Global Positioning System Next Generation Operational Control System)
GQM-163 (Coyote)
GQM-173 (Multi Stage Supersonic Target)
H-1
HCMC 130
HH-60
HMMWV (HMMWV - High Mobility Multi-Purpose Wheeled Vehicle)
IDECM (IDECM - Integrated Defensive Electronic Countermeasures)
JAGM (JAGM Joint Air-to-Ground Missile)
JDAM (JDAM - Joint Direct Attack Munition)
JLTV (JLTV Joint Lightweight Tactical Vehicle)
JPALS (JPALS - Joint Precision Approach and Landing System)
JPATS
KC-46A
LAIRCM (LAIRCM - Department of the Navy Large Aircraft Infrared Countermeasure)
LRASM (Long Range Anti-Ship Missile)
LVSR (LVSR - Logistics Vehicle System Replacement)
LW155 (Light Weight Howitzer 155 mm)
MC-130J
MGM-140 (ATACMS)
MH-139
MH-60R
MHS (Military Health System)
MIDS-LVT (MIDS Multi-Functional Information Distribution System (Includes Low Volume Terminal and JTRS))
MIM-104A/B/C/D (PATRIOT)
MIM-104F (PAC-3 - Patriot Advanced Capability 3)
MQ-1 (MQ-1B UAS Predator)
MQ-4C (MQ-4C Triton (Formerly BAMS))
MQ-9 (MQ-9 Reaper)
MRAP (Joint MRAP - Joint Mine Resistant Ambush Protected Vehicles)
MTVR (MTVR - Medium Tactical Vehicle Replacement)
MUOS (Mobile User Objective System)
NAVSTAR GPS (NAVSTAR GPS - Global Positioning System)
P-8A
PIM (PIM - Paladin Integrated Management)
QF-4 (FSAT)
RATTLERS (Rattlers)
RIM-116 (RAM BLK 2)
RIM-116A (RAM BLK 0)
RIM-116B (RAM BLK 1)
RIM-161 (SM-3 - Standard Missile 3)
RIM-162 (ESSM - Evolved Sea Sparrow Missile)
RIM-174 (SM-6 Standard Missile-6)
RIM-66 (RIM-66 (Standard Missile 1 (SM-1 MR)))

RQ-4 (Global Hawk (RQ-4A/B) - High Altitude Endurance Unmanned Aircraft System)
RQ-7B SHADOW TUAS (Tactical Unmanned Aircraft System)
RUR-5 ASROC (VLA Missile)
SAFE (Structural Appraisal of Fatigue Effects)
SBIRS (Space-Based Infrared System)
SBSS B10 (Space-Based Space Surveillance Block 10)
SH-60/HH-60H/MH-60 (Sikorsky Seahawk)
SLAM-ER (Standoff Land Attack Missle - Extended Response)
SLAMRAAM (Surface Launched Advanced Medium-Range Air-to-Air Missle)
Space Fence (Space Fence Inc 1)
T-45
UH-1
UH-60
UH-72
UNKNOWN ARMY AIRCRAFT
UNKNOWN ARMY UAV (Unknown Army UAV)
Unknown Navy Aircraft
Unknown Navy Electronics (Unknown Navy Electronics)
Unknown Navy Engine (Unknown Navy Engine)
V-22
WCMD (Wind Corrected Munitions Dispenser)
WGS (WGS Wideband Global SATCOM Program)
WSF (Weather Satellite Follow-on (WSF))

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14. ABSTRACT
Engineering Change Orders (ECO) are technical requirements changes to existing contracts. To account for the potential increase in contract costs stemming from ECOs, current acquisition practice is to estimate a dollar value to hold in management reserve (MR) in case of ECO occurrence. Estimators often rely on rules-of-thumb when developing these estimates. Specifically, estimators use a 10% rule-of-thumb for estimating MR contract costs in the Development life cycle phase and a 5% rule-of-thumb for contracts in the Production or O&S life cycle phase. However, no empirical data supports or validates these 10% and 5% figures. Using a new data source, 2,434 contracts with ECOs were analyzed to determine the accuracy of the 10% and 5% rules-of-thumb as well as to determine if more accurate rules-of-thumb could be developed. Results suggest that if a contract is likely to have a positive ECO percentage, then 13.25%, 5.5%, and 13.5% rules-of-thumb are more appropriate for contracts in the Development, Production, and O&S life cycle phases respectively. Service, Contract Type, Commodity, Initial Program Size, and Schedule impact ECO percentages.

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