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Engineering Change Orders in Space Programs: "What Are The Odds?"

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ENGINEERING CHANGE ORDERS IN SPACE PROGRAMS:

WHAT ARE THE ODDS?

THESIS

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Abstract

There has been little empirical evidence and vague official guidance published to inform the Department of Defense (DOD) acquisition community on the cost growth effects of engineering change orders (ECO) on their programs. The information is especially scarce when it comes to understanding those effects in space programs. Utilizing previous research to our advantage, we explore factors that may explain ECO-related cost growth including program size, acquisition phase, the number of modifications to a contract, contract type, and specific space commodity assets. Using non-parametric analysis, contingency tables, and odds ratio tests, these were found to be significant factors (except acquisition phase) that could determine the likelihood of ECO-related growth at different percentage levels. This research aims to establish a reference point for future research into ECO-related cost growth and space commodities.

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I. Introduction

Background

Space Systems Command (SSC), formerly Space and Missile Systems Center (SMC), executes 85% of the Department of Defense (DOD)’s space budget and is responsible for developing, acquiring, equipping, fielding, and sustaining resilient space capabilities to meet the demands of the National Defense Strategy. These space systems provide critical capabilities that support the U.S. military, other U.S. government agencies, commercial partners, and the international community. These capabilities include spacelift operations, secure communications for troops around the globe, weather monitoring, navigational data for air, ground, and fleet operations, and detecting dangers such as ballistic missile launches and space debris (USSF Capabilities, 2021). The scale and complexity of initiating and sustaining these advanced capabilities present many challenges. The United States Government Accountability Office (GAO) found that the challenges DOD faces in its space acquisitions include schedule delays, multibillion-dollar increases, significant reductions in capabilities, and in some cases cancellations (Ludwigson, 2021). Another challenge that SSC must attempt to overcome is determining the appropriate resource allocations needed to support these space systems while minimizing cost growth.

Faced with these challenges are the SSC cost estimators who handle the command’s annual $9B budget. Part of their challenge is to track the expected and actual costs of each space program to ensure mission requirements are met within budget constraints. While changes are inevitable to programs, understanding what typically drives those changes is key to planning for and mitigating program impacts. In 2015, to find opportunities to control program cost growth, an Engineering Change Order (ECO) study was conducted by SSC on its space programs. The goal of the study was to develop a better understanding of ECO costs in three ways: 1) to identify the primary types of ECOs found in space programs, 2) to assess the contribution of each type of ECO to the total program cost, and 3) to discuss the possible implications of the findings for program managers and cost analysts. For this 2015 study, ECOs were defined as anything that changed the contract value. Space vehicle programs were analyzed in this study, specifically three development phase contracts and eight production phase contracts, resulting in ECO-related cost growth averages of 34.4% and 3.7%, respectively. They advised that future research should address factors that contribute to ECO related cost growth in space programs.

The objective of this paper is to determine what factors may cause ECO cost growth in SSC programs and at what magnitudes. We conduct an analysis of space program contracts with data current up to 2021. To do this, a non-parametric analysis approach was used to uncover the effects of factors that cause ECO-related cost growth.

Problem Statement

This research revisits previous studies to investigate the variables that contribute to ECOs in space programs. Using the 2021 data set, we can determine the most recent impacts of these factors on ECO-related cost growth. Currently it is unclear what factors have significant relationships with ECO-related cost growth in space programs. This analysis will provide insight for the space acquisition community to use when considering ECO cost growth effects into their cost estimates.

Research Objectives

1. What variables contribute to Engineering Change Orders (ECO) in Space Systems Command (SSC) programs?
2. What are the ECO growth tendencies for the contributing variables in SSC programs?
3. What are the current impacts of ECOs on cost growth in SSC programs?

Methodology

Previous cost growth and ECO related topics were visited to determine what factors cause ECO-related cost growth. We apply that knowledge to a modern database to discern what data can answer our research objectives. The data were filtered to focus strictly on Air Force space program elements and tested for relationships with ECO-related cost growth. We determined that a non-parametric analysis would be the best way to answer our research objectives.

Assumptions/Limitations

This research focuses primarily on Air Force space programs. A limitation to this research is that space programs also do not produce large quantities of products that would allow for robust data analysis. For example, a single satellite may be launched once in a few year span. Lower production of space products limits data analysis in comparison to larger data sets of defense requirements, such as producing hundreds of fighter planes or rifles for thousands of troops. Also, space programs may have extreme variability in contract values (this research covers contracts ranging from $100,000 to almost $7 billion) that makes it difficult for parametric analyses.

Implications

This research will serve as a key reference point for space programs and acquisition professionals that are involved with engineering change orders, The contract factors and ECOs relationships observed in this analysis can be used by decision makers and cost estimators during acquisition considerations. Amid those considerations, acquisition personnel will have insight on the tendencies caused by certain contract factors and use that awareness to mitigate cost growth. Moreover, this analysis supplements space program research, which is a subject that has limited empirical sources.

Summary

This research examines the effect of factors on ECO-related cost growth in SSC programs. Chapter II is the literature review. Chapter III then describes the data and methodology of this research. The chapter progressively presents the order in which the research was conducted, how the data were collected, and what analysis is derived from the data. In Chapter IV we discuss the results of non-parametric tests and their implications. Lastly, chapter V is the conclusion and discussion section. Here we summarize the findings, discuss how the findings are relevant to the acquisition community, and suggest future research topics.

II. Literature Review

Chapter Overview

In this chapter, we review literature associated with engineering change orders (ECO). The term “engineering change order” has interchangeable definitions in DOD acquisitions, so we first ascertain the appropriate interpretation. Then, we identify the current guidance regarding ECOs. Thirdly, we review previous studies for factors associated with ECO cost growth.

Background of Engineering Change Orders

Engineering Change Proposals and Orders

The terms “engineering change proposals” (ECP) and “engineering change orders” are commonly used interchangeably. According to the Defense Acquisition University (DAU) glossary, an ECP is “documentation that serves as a management tool to propose a configuration change to a CI [configuration item]” (2022). In order to make an engineering change, a proposal is initiated by either the government or the contractor (Engineering Change Proposal (ECP), 2021). After a series of reviews, an engineering change order (ECO) is established when the government and contractor approve the changes in the proposal.

Engineering change orders in DOD acquisition may have analogous definitions among various agencies using the term. In a 2015 (ECO) study by the Space and Missiles Systems Center (SMC), an ECO is interpreted as any modifications to a contract that changes contract value (SMC/FMC, 2015). According to James Ellis et.al., (2018), an “engineering change proposal [ECP] is a scope change to a contract, usually technical in nature” which is synonymous with the definition for engineering change orders. Referencing an ECO study by Technomics, Inc., the previous definitions of an ECP and ECO can be classified as a “technical” variable that encompasses modifications to a contract including new scopes, descopes, weight, software, discrete, and unanticipated changes (2021). Considering all the various definitions, we ascertain that the term "ECO" is defined as technical modifications to a contract that may or may not incur a cost.

Cost Growth

To further understand ECOs and the monetary implications on contracts, it is important to understand that it is one of many factors that induces cost growth in contracts. Cost growth as defined by Arena et al. "is the term used for the increase of the actual (or final) cost of acquiring a system or capability relative to the value estimated…growth could be positive (costs underestimated) or negative (costs overestimated)" (2006, p. 1). In context, this thesis analyzes the growth of the baseline dollar values of contracts versus the induction of costs from ECOs. "ECO-related cost growth" is a term that is referenced throughout this thesis that is defined as the cost growth caused strictly by ECOs in space program contracts.

Inconsistent Guidance to Handle ECO-Related Cost Growth

There is a theme of inconsistent guidance throughout DOD acquisition history, which is applicable to ECOs and a similar budgetary tool known as management reserves (MR). Christensen and Templin state that "a management reserve is an amount of the total allocated budget (TAB) withheld by contractors for management control purposes…its purpose is to provide an adequate budget for in-scope but unanticipated work on the contract" (2000). The inconsistent guidance theme is detectable at least up to four decades prior to this research when Peter Woodward addressed the absence of universal DOD policy on how to establish MRs or to account for uncertainty. Woodward states that "there are no generalized…management techniques that apply to every situation…the universal risk model which applies to every situation and all services, as well as every kind of system, does not exist" (1983, pp. 107-108).

In the decade following, Kevin Gould researched MR budgets descriptions by contractors, and found that it lacked a “detailed methodology necessary to develop and establish an accurate [MR] budget” (1995, p. 44). This is evidence of inconsistent guidance extending through the years. Gould’s and Woodward’s research served as the precursor for the work of David Christensen and Carl Templin who used their insights to establish a method that detects “statistically significant factors in the median MR budget percentage across contract categories…military services…and acquisition phases” (2000, p. 191). This theme concerning lack of guidance and methodologies to calculate MRs are comparable to the issues of accounting for ECO-related cost growth.

ECOs are mentioned in official DOD acquisition guidance. However, there is seldom any that establishes a standard to account for ECO-related cost growth in cost estimates. Guidance from the Air Force Cost Risk and Uncertainty Analysis Handbook (CRUH) (2007) provides some guidance on ECOs:

> ECOs are the result of controlled, approved changes to the requirement or the design. It is extremely rare for a project to proceed through the acquisition cycles without a single ECO. In any case, the ECO cost element is not meant to be catchall for potential system cost growth and it is therefore not acceptable to use it as a wedge for additional risk dollars. (p. 30).

The Joint Agency Cost Schedule Risk and Uncertainty Handbook (JA CSRUH) advises that “cost elements for engineering changes such as Engineering Change Orders (ECO) are not meant to be the catchall for potential system cost growth or a place to allocate probability adjustment dollars. It is, therefore, not acceptable to use the ECO cost element to increase management reserve or as a substitute for uncertainty analysis (2014, p. 40). Seven years between the two versions, and neither provide a methodology to account for ECO-related cost growth.

NASA's Cost Estimating Handbook (2015) provides an alternative approach and uses unallocated future expenses (UFE), which is interpreted to be similar to DOD's ECO term (p. 27). An estimate of a UFE is generated through a cost risk assessment, which takes into account cost drivers and risk inputs from program stakeholders and runs that information through a risk model. These risk models may be a combination of probabilistic cost estimates and sensitivity analyses that generate a UFE estimate (National Aeronautics and Space Administration, 2015, p. 28) These UFE estimates could be included in the overall cost estimate in order to provide decision makers an understanding of additional funding required for a contract's baseline budget. NASA's handbook does not designate a specific factor that adds to a baseline budget in order to account for UFEs (or ECOs in the DODs case) but may provide a starting point to include it in the overall estimate.

As NASA would suggest, there are risk models that the DOD may undertake to account for ECO-related cost growth. However, the challenge for the DOD acquisition personnel is to determine what risk factors do cause an increase in ECOs. A risk model is not performed in this thesis as the data is unsuitable, however a non-parametric method is discussed in chapter III, which describes how it may detect how certain variables affect ECO-related cost growth in space program contracts.

Causes and Impacts ECO Cost Growth

Factors That Cause ECO Cost Growth

Previous studies on ECO-related cost growth provide the starting points for this research exploration into what factors may cause ECO-related growth in space programs. Program size or (basic contract costs) is one factor that has been statistically significant to affect ECO-related cost growth (Arena, et al., 2006; Cordell, et al.,2017; Ellis, et al., 2018). Another considered factor is acquisition phases, but phase has typically turned out as not statistically significant (Christensen & Templin, 2000; Ellis, et al., 2018). Additionally, contract types were previously studied for ECO-related cost growth effects (Christensen & Templin, 2000; Cordell, et al. 2017; Ellis, et al., 2018). We use these factors to inform the independent variables of our space program analysis discussed in chapter III and IV, contingent on the availability of information in our dataset.

Impacts of ECO Cost Growth

These previous studies reported results regarding the cost growth effects of ECOs on contracts. Christensen's research detected that MRs accounted for 16% increase of total contract value, with most results falling in between 5% and 10% (Christensen & Templin, 2000). Of contracts that contain ECOs, Cordell (2017) found the baseline increased by 22.5%. These indicators provide insight on what ECO-related growth to expect on a wide range of programs, and we explore how it compares in space programs. This analysis uses available data on space programs to detect what variables affect ECO-related growth and to what degree.

Summary

Within this chapter, we have established a basic understanding of ECOs and its associated effects within the DOD acquisition process. Despite the minimal guidance established to determine cost growth effects on contracts caused by ECOs, previous studies explored various factors that form the basis for our analysis. Continuing to improve the availability of knowledge of preceding studies, this analysis aims to provide a reference point for future studies to consider when performing ECO-related cost growth research in space programs.

III. Data and Methodology

Chapter Overview

The purpose of this chapter is to describe the sources of data and explain the methods used for analysis of the research questions. We will describe how the data was collected, how it was processed, and the development of our research variables. Additionally, inclusion and exclusion criteria, dummy variable creation, and data validation tests will be discussed. Throughout data validation and analysis, we use an alpha threshold of 0.10 when examining p-values, due the exploratory nature of this research. After the finalized database has been fully explained, we will describe the methods used to address our research questions.

Data Collection

The dataset selected to analyze the research questions was a less processed version of the Contracts Database Suite of Tools (KDB) available on the Cost Assessment Data Enterprise (CADE) website. The less processed version is in a flat file format and includes Base Year 2020 (BY20) dollars, making it more compatible with statistical software and more suitable for our research objectives. This tool, maintained by Technomics, contains DOD contract information across all the services and numerous commodities. Our research dataset will be referred to as "the KDB database" hereafter.

Understanding the KDB Database

This database has over 200,000 lines of data and each line contains information regarding a contract within the DOD acquisition system. The 24 variables included in the KDB database are listed and described in Table 1. Additional information for the KDB database variables can be found in Appendix A.

Table 1

Description of KDB Database Variables

KDB Database Variables	Basic Description
Service	Air Force, Army, Navy, DOD
Commodity	Type of product
Program Name	Name of program/commodity
Phase	Acquisition phase (Development, Production, O&S)
Contract Type	Fixed, Cost, and other types of contracts
Contractor	Name of contractor
Contractor Location	Location of contractor
Contract #	Assigned contract number
Mod #	Modification number for the contract
Mod Category	Category that modification is classified as (Baseline, Administrative, Cost, Schedule, Technical, Other)
Mod Desc	Description of modification
Lot Description	Description of the lot
Tech Category	Subcategory of "Mod Category"
CLIN	Contract line number in a contract
Adj Dollars	Dollar values in Base Year 2020 for modification
Qty	Quantity
Mod Date	Date modification started
PoP End Date	Period of performance end date
Inflation Index	Ranges from 1-18
Dollars	Dollar value of original modification
Initial	Notation for initial/basic contract modification
Index	Number for line item in data
Comments	No comments available
AppropriationCode	Appropriation code of funds

Preliminary Data Processing

The entire KDB database had 226,516 lines of DOD contract modifications, which were then trimmed to 6,805 lines, including only space programs within the Air Force (Table 2). These modification lines contain the variables stated in Table 1, and are consolidated per unique contract in order to be analyzed. There are 75 unique Air Force Space contracts in the KDB database used for this analysis.

Table 2

Summary of KDB Database

Database Elements	Lines of Data
Entire KDB Database	226,516
Other than SPACE Commodity	218,883
Other than USAF SPACE Commodity	244
Other than Acquisition Phase - Development or Production	584
Remaining Lines of Data for Analysis	6,805

Database Elements	Unique Contracts
Entire KDB Database	11,481
Other than SPACE Commodity	11,402
Other than USAF SPACE Commodity	1
Other thanAcquisition Phase - Development or Production	3
Remaining Unique Contracts for Analysis	75

Variables of interest that were essential to this analysis are listed in Table 3. The following variables were removed from the analysis: Contractor, Contractor Location, Inflation Index, Index, and Appropriation Code. These variables were removed before any formal analysis was done, as the focus of this research did not include the scope of the possible effects of private contractors, inflation, or appropriations in relation to ECOs. The Index variable was also excluded as it was simply meant for database tracking. We added an additional variable (commodity asset) that divided the “Space” commodity into separate groups for analysis (Space, Ground, and Launch Vehicles). These variables would form the basis of the independent variables used in the analysis described in Chapter IV.

Table 3

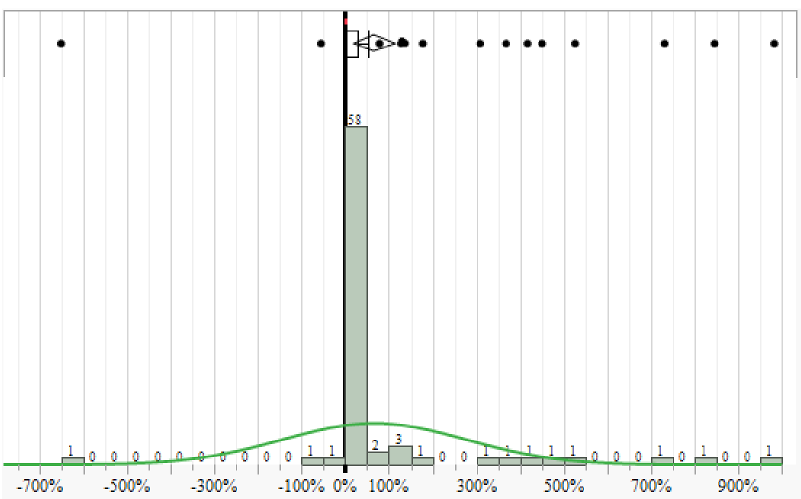
KDB Database Variables Used in Analysis

Database Variables			Added Variables
Service	Tech Category		Commodity Asset
Commodity	CLIN		
Program Name	Adj Dollars		Removed Variables
Phase	Qty		Contractor
Contract #	Mod Date		Contractor Location
Mod #	PoP End Date		Inflation Index
Mod Category	Dollars		Index
Mod Desc	Initial		AppropriationCode
Lot Description	Contract Type		
Comments			

Engineering change order growth was calculated as the sum of all technical modifications (classified as an ECO), divided by the contract's baseline cost. Figure 1 displays the ECO percent growth of these contracts in a histogram and its summary statistics. These descriptive statistics clearly show that this data is not normal. Specifically, the Anderson-Darling Normality test value (p-value <0.0001) confirms that this data is not normal as we reject the null hypothesis at an alpha of 0.10. Thus, this data is not suited for a parametric analysis. Therefore, we used non-parametric methods for this analysis.

Figure 1

SSC Contracts – Histogram, Summary Statistics, and Goodness of Fit Test



Summary Statistics

Mean	0.6645513
Std Dev	2.1075213
N	75
Minimum	-6.49947
Maximum	9.81052
Median	0.01281
Mode	0
Range	16.30999

All Modes

Modes	Count
0	28

Goodness-of-Fit Test

	A2	Prob > A2
Anderson-Darling	15.422306	<.0001*

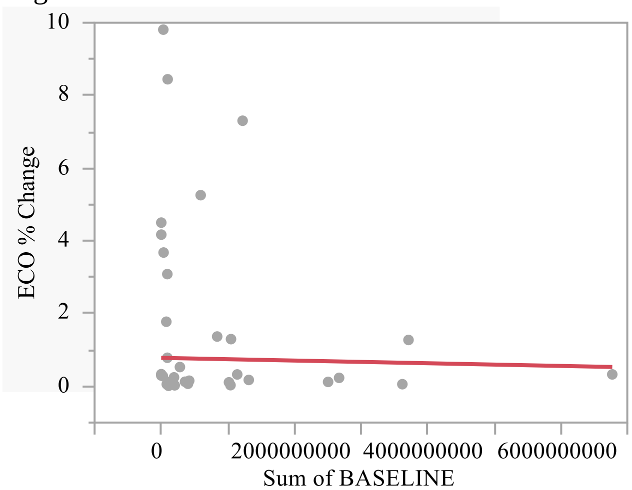
Ordinary Least Squares Regression Tests

We investigated the possibility of doing parametric testing on the data, and found the data to be inconclusive in various ordinary least squares (OLS) regression tests. We tested 74 unique contracts ECO-related cost growth percentage (DV) against baseline dollar amounts, which resulted in an r-square value of less than 0.01 and overall F-test value of 0.86 (Figure 2). It is important to recognize that 28 of these contracts had ECO growth of zero percent, and three contracts had negative ECO growth. We then tested 39 unique contracts for ECO-related cost growth percentages between 0.01 to 35 percent, and that test resulted in an r-square value of 0.02 and overall F-test value of 0.35 (Figure 3). This supports that non-parametric analysis may be appropriate to conduct analysis on this dataset, as parametric testing did not elicit any significant relationships.

Figure 2

OLS Regression on 74 Unique Contracts (ECO % Change by Contract Baseline Dollar Value)

Regression Plot



Summary of Fit

RSquare	0.000417
RSquare Adj	-0.01347
Root Mean Square Error	1.959838
Mean of Response	0.761362
Observations (or Sum Wgts)	74

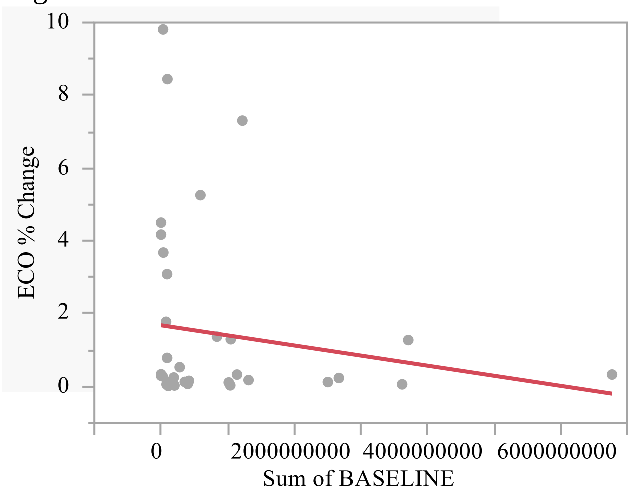
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.11549	0.11549	0.0301
Error	72	276.54957	3.84097	Prob > F
C. Total	73	276.66506		0.8628

Figure 3

OLS Regression on 39 Unique Contracts (ECO % Change by Contract Baseline Dollar Value)

Regression Plot



Summary of Fit

RSquare	0.023175
RSquare Adj	-0.00323
Root Mean Square Error	2.497377
Mean of Response	1.45893
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5.47486	5.47486	0.8778
Error	37	230.76504	6.23689	Prob > F
C. Total	38	236.23990		0.3549

To prepare the data for non-parametric analysis, the variables were arranged into dichotomous variables. We looked for natural breakpoints in the data that would meet the statistical conditions for contingency tests. If the criteria for the variable was met in the data, the response in the analysis is a "1," otherwise a "0." The variables created are displayed in Table 4. As for independent variables (IV),"Baseline" variables represent a contract baseline dollar value being less than or greater than a threshold (i.e., "Baseline <$2.5M" with a response of "1" indicating a contract whose baseline dollar value is less than $2,500,000). Other dichotomous variables created include “Phase – Development” and “Phase – Production,” “ECO modifications” counts the number of modifications in a contract that were considered as an ECO less than or greater than a threshold. “Contract Type - Fixed” or “Contract Type - Cost” are variables that represent a contract that was either established on a fixed cost basis or cost basis. The variables with a “ConType” description are contract types that are either Firm-Fixed Price (FFP), Fixed-Price Incentive (FPI), Cost-Plus Fixed Fee (CPFF), Cost-Plus Incentive Fee (CPIF,) or Cost-Plus Award Fee (CPAF). For the final set of IVs, are contracts that were determined to be of a Space, Ground, or Launch Vehicle program in the Air Force. Finally, for our dependent variables (DV), “ECO>X%” represents if a contract had an ECO percent change in cost greater than a determined threshold (e.g., ECO >5% is a contract that had cost growth of greater than 5% due to ECOs).

Table 4

Variables Used for Non-parametric Analysis

Independent Variables	Dependent Variables
Baseline < $2.5M	ECO>0%
Baseline >$2.5M	ECO>5%
Baseline > $50M	ECO>10%
Baseline >$100M	ECO>20%
Baseline > $500M	ECO>100%
Baseline > $1B	
Phase - Development	
Phase - Production	
< 5 ECO Modifications	
> 5 ECO Modifications	
> 20 ECO Modifications	
Contract Type - Fixed	
Contract Type - Cost-Plus	
ConType FFP	
ConType FPI	
ConType CPFF	
ConType CPIF	
ConType CPAF	
Asset - Space	
Asset - Ground	
Asset - Launch Vehicle	

Methods for Non-parametric Analysis

Once the data set was prepared, we conducted three non-parametric tests to evaluate if there were any statistically significant relationships in the model. To determine a statistical relationship, the resulting p-value of these would have to be less than an alpha threshold of 0.10 due to the exploratory in nature of this research and lack of peer-reviewed evidence. We first conducted the Wilcoxon and Kruskal-Wallis tests to examine if there was a relationship between ECO percent change (a continuous dependent variable) and nominal independent variables (IVs).

An example of these test results for the “Commodity Assets” IV is shown in Figure 4. This example highlights that the p-value is 0.0018, which indicates a significant relationship between commodity assets and ECO-related cost growth.

Figure 4

Example. Wilcoxon and Kruskal-Wallis Test Significant Result on Commodity Assets

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean
GROUND	21	1043.50	798.000	49.6905
LAUNCH VEHICLE	34	991.000	1292.00	29.1471
SPACE	20	815.500	760.000	40.7750

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.6330	2	0.0018*

Secondly, we created contingency tables that would investigate statistical significance between two categorical variables, with ECO-related cost growth as the DV. The conditions to determine a statistical significance from the contingency table are that 1) all expected counts of the two variables must be greater than one, 2) no more than 25% of the expected counts will be less than five, and 3) the p-value satisfies the alternate hypothesis. Lastly, an odds ratio was computed to evaluate likelihood of the significant relationship between the two categorical variables tested in the contingency table. Odds ratio values indicate a likelihood relationship based off the distance from the value of one. Those values that resulted in less than one indicated lesser likelihood of the relationship between the two categorical variables tested, while values greater than one indicated the greater likelihood of that relationship. For example, a value of 0.20 would describe an 80% lesser likelihood (0.20 subtracted from 1.00) of an occurrence between a contract variable and ECO-related cost growth; a value of 1.50 would indicate a 50% greater likelihood (1.00 subtracted from 1.50) of an occurrence between a contract variable and ECO-related cost growth. An example of the conditions that must be met for contingency tables and odds ratio tests are displayed in the boxes shown in Figure 5 (more likely relationship) and Figure 6 (less likely relationship). To interpret these results, Figure 5 has a p-value of 0.0030 and odds ratio value of 6.46, which indicates there is a significant relationship between "ground commodity assets" and ECO-related cost growth; also the odds ratio value indicates that it is six times as likely for ECO-related cost growth to occur in "ground commodity asset" contracts. With all these tests completed, we discuss the significant findings of these results and its implications in chapter IV.

Figure 5

Example. Contingency Table and Odds Ratio Results for More Likely Relationship

Contingency Table

ECO>0%

GROUND	Count / Expected	0	1	Total
	0.00	28 22.32	26 31.68	54
	1.00	3 8.68	18 12.32	21
	Total	31	44	75

Tests

N	DF	-LogLike	RSquare (U)
75	1	4.8483164	0.0953

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	9.697	0.0018*
Pearson	8.799	0.0030*

Odds Ratio

Odds Ratio	Lower 95%	Upper 95%
6.461538	1.702562	24.52273

Figure 6

Example. Contingency Table and Odds Ratio Results for Less Likely Relationship

Contingency Table

ECO>0%

LAUNCH VEHICLE	Count / Expected	0	1	Total
0.00	Count	9	32	41
	Expected	16.9467	24.0533	
1.00	Count	22	12	34
	Expected	14.0533	19.9467	
Total		31	44	75

Tests

N	DF	-LogLike	RSquare (U)
75	1	7.2013326	0.1416

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	14.403	0.0001*
Pearson	14.011	0.0002*

Odds Ratio

Odds Ratio	Lower 95%	Upper 95%
0.153409	0.055286	0.425685

Summary

The data and methodology described in this chapter form the basis for this ECO analysis of Air Force space programs. By processing the data with the appropriate inclusion and exclusion criteria, relevant variables are formed and can be tested among 75 unique contracts. Due to the nature of the data being exploratory, p-values less than 0.10 reject our null hypotheses.. We conducted non-parametric tests to investigate any statistically significant relationships within the data. In chapter IV, we report the results of this analysis and reveal what ECO-related cost growth relationships are found.

IV. Analysis and Results

Chapter Overview

In this chapter we present the results from the data and methodology discussed in chapter III. The Kruskal-Wallis and Wilcoxon test revealed that the "Acquisition Phase" and "Contract Type" categories, respectively, were the exceptions to a significant relationship regarding Engineering Change Order (ECO)-related cost growth. However, when "Contract Type" was subdivided into FFP, CPFF, etc., the Kruskal-Wallis test revealed that there is a significant relationship with an exploratory p-value of less than 0.10. Having completed these tests, contingency tables and odds ratio tests were then conducted to determine any significant relationships of the variables regarding ECO-related cost growth.

Wilcoxon and Kruskal-Wallis Test Results

We performed the Wilcoxon and Kruskal-Wallis tests on the categorical variables against the continuous variable (of ECO-related cost growth) to determine any significant relationships. Table 5 displays the p-values of the categorical variables when tested against the ECO-related cost growth continuous variable. All categorical variables, with two exceptions, resulted in significant relationships when set to an alpha of 0.10. The two exceptions to a possible relation to ECO-related cost growth were the "Acquisition Phase" and "Contract Type" variables, with their p-values exceeding the alpha 0.10 threshold. These results are insightful when detecting if there is an ECO-related cost growth relationship with a particular variable. By using this information, we proceed to test these relationships in odds ratio tests to evaluate the likelihood of its occurrence.

Table 5

Summary – Wilcoxon and Kruskal-Wallis Test Results

Wilcoxon Test Results

Category Variables	p-Value
Baseline < $2.5M	0.013*
Baseline >$2.5M	0.013*
Baseline > $50M	0.003*
Baseline >$100M	0.019*
Baseline > $500M	0.003*
Baseline > $1B	0.010*
< 5 ECO Modifications	<0.001*
> 5 ECO Modifications	<0.001*
> 20 ECO Modifications	<0.001*
Contract Type	0.892

Note: * are significant P-values of 0.05 or less
** are significant P-values of 0.10 or less

Kruskal-Wallis Test Results

Category Variables	p-Value
Acquisition Phase	0.344
Contract Type (Individual)	0.085**
Commodity	0.002*

Note: * are significant P-values of 0.05 or less
** are significant P-values of 0.10 or less

Contingency Table and Odds Ratio Test Results

We conducted contingency tables and odds ratios tests on these relationships with categorical variables, which produced results that provide supplementary information to understand the ECO-related cost growth in Air Force space programs. Throughout this section the number of contracts associated with each variable, number of contracts that meet both categorical variable conditions, and odds ratios are presented in tables.

Table 6

Number of Contracts and Median ECO % by Contract Baseline Dollar Amount

	Number of Contracts and Median ECO % Change in Contract Variable									
	ECO>0% (n=44)		ECO>5% (n=33)		ECO>10% (n=29)		ECO>20% (n=22)		ECO>100% (n=12)	
Independent Variables	n	Median	n	Median	n	Median	n	Median	n	Median
Baseline < $2.5M (n=18)	4	225.11%	4	225.11%	4	225.11%	4	225.11%	2	433.08%
Baseline >$2.5M (n=57)	40	15.25%	29	27.85%	25	32.55%	18	128.44%	10	338.14%
Baseline > $50M (n=47)	37	12.37%	26	23.72%	22	32.49%	15	127.30%	8	242.98%
Baseline >$100M (n=37)	31	11.90%	20	22.77%	18	23.72%	11	52.79%	5	136.72%
Baseline > $500M (n=16)	15	23.05%	12	32.49%	11	32.55%	8	128.44%	5	136.72%
Baseline > $1B (n=13)	13	17.29%	10	27.74%	9	32.43%	6	79.92%	3	129.59%

Table 7

Odds Ratios of ECO % Variables by Contract Baseline Dollar Amount

	ECO % Growth in Contract Variable				
Independent Variables	ECO>0% (n=44)	ECO>5% (n=33)	ECO>10% (n=29)	ECO>20% (n=22)	ECO>100% (n=12)
Baseline < $2.5M (n=18)	0.12*	0.28*	0.37**	0.62	0.59
Baseline >$2.5M (n=57)	8.24*	3.63*	2.73**	1.62	1.70
Baseline > $50M (n=47)	11.10*	3.71*	2.64**	1.41	1.23
Baseline >$100M (n=37)	9.94*	2.26**	2.33**	1.04	0.69
Baseline > $500M (n=16)	15.52*	5.43*	5.01*	3.21*	3.38**
Baseline > $1B (n=13)	NA	5.65*	4.73*	2.46	1.77

Baseline dollar values were grouped into categorical variables according to their size. Table 6 displays the number of contracts and median ECO-related cost growth percentages as grouped by their size. The odds ratio test computed these baseline variables with different percentage levels of categorical variables for ECO-related cost growth. The results (Table 7) show that contracts less than 2.5 million dollars were less likely to see ECO-related cost growth, especially between 0% and 10%. Generally, the results indicate that larger contracts (>$500M) were more likely to have ECO-related growth. In fact, contracts with a baseline dollar value of greater than 500 million were significant at all ECO-related cost growth variables.

Table 8

Number of Contracts and Median ECO % by Acquisition Phase

	Number of Contracts and Median ECO % Change in Contract Variable									
	ECO>0% (n=44)		ECO>5% (n=33)		ECO>10% (n=29)		ECO>20% (n=22)		ECO>100% (n=12)	
Independent Variables	n	Median	n	Median	n	Median	n	Median	n	Median
Phase - Development (m=50)	26	26.11%	20	42.98%	18	65.55%	15	127.30%	8	338.14%
Phase - Production (n=25)	18	13.55%	13	23.05%	11	32.43%	7	136.72%	4	628.03%

Table 9

Odds Ratios of ECO % Variables by Acquisition Phase

	ECO % Growth in Contract Variable				
	ECO>0% (n=44)	ECO>5% (n=33)	ECO>10% (n=29)	ECO>20% (n=22)	ECO>100% (n=12)
Independent Variables					
Phase - Development (n=50)	0.42**	0.62	0.72	1.10	1.00
Phase - Production (n=25)	2.37**	1.63	1.40	0.91	1.00

Table 8 displays the number of contracts and median ECO-related cost growth percentages grouped by acquisition phase. Previously, the Wilcoxon test signaled that there were no significant relationships between the acquisition phase variables and ECO-related cost growth. However, Table 9 displays that the contingency table tests resulted in a possible relationship between these two categorical variables at the ECO greater than 0% variable, then are indicated as non-significant at the rest of the levels. Our findings indicate that development phase contracts are less likely to incur ECO-related cost growth, whereas production phase contracts are more likely to incur ECO-related cost growth.

Table 10

Number of Contracts and Median ECO % by Number of ECO Modifications in Contracts

	Number of Contracts and Median ECO % Change in Contract Variable									
	ECO>0% (n=44)		ECO>5% (n=33)		ECO>10% (n=29)		ECO>20% (n=22)		ECO>100% (n=12)	
Independent Variables	n	Median	n	Median	n	Median	n	Median	n	Median
Less than 5 ECO Modifications (n=48)	18	9.35%	11	27.49%	9	29.45%	6	55.74%	2	433.56%
Greater than 5 ECO Modifications (n=25)	24	32.49%	22	42.67%	20	90.05%	16	133.15%	10	338.14%
Greater than 20 ECO Modifications (n=14)	14	42.67%	14	42.67%	13	52.79%	9	129.59%	6	252.26%

Table 11

Odds Ratios of ECO % Variables by Number of ECO Modifications in Contracts

	ECO % Growth in Contract Variable				
Independent Variables	ECO>0% (n=44)	ECO>5% (n=33)	ECO>10% (n=29)	ECO>20% (n=22)	ECO>100% (n=12)
Less than 5 ECO Modifications (n=48)	0.02*	0.07*	0.08*	0.10*	0.07
Greater than 5 ECO Modifications (n=25)	36.00*	26.00*	18.22*	13.03*	16.00*
Greater than 20 ECO Modifications (n=14)	NA	NA	36.56*	6.65*	6.88*

Table 10 displays the number of contracts and median ECO-related cost growth percentages as grouped by the amount of ECO modifications in a contract. Results shown in Table 11 reveal a large difference in the likelihood of ECO growth between contracts with less than 5 ECO modifications (less likely) and those with greater than 5 ECO modifications (more likely). This is an expected outcome, of course, but may have implications for decision-makers.

Table 12

Number of Contracts and Median ECO % by Contract Type

	Number of Contracts and Median ECO % Change in Contract Variable									
	ECO>0% (n=44)		ECO>5% (n=33)		ECO>10% (n=29)		ECO>20% (n=22)		ECO>100% (n=12)	
Independent Variables	n	Median	n	Median	n	Median	n	Median	n	Median
Contract Type - Fixed (n=28)	19	10.76%	11	15.19%	10	16.24%	4	787.46%	3	844.50%
Contract Type - Cost(n=47)	25	32.86%	22	42.98%	19	78.31%	18	102.80%	9	308.48%
ConType FFP (n=24)	16	11.33%	10	16.24%	9	17.29%	4	787.46%	3	844.50%
ConType FPI (n=4)	3	2.90%	1	11.90%	1	11.90%	0	NA	0	NA
ConType CPFF (n=27)	9	31.31%	8	31.31%	8	31.31%	8	31.31%	2	433.56%
ConType CPIF (n=12)	9	55.43%	8	78.31%	3	129.59%	8	153.53%	2	242.98%
ConType CPAF (n=8)	10	75.18%	9	127.30%	8	132.01%	6	132.01%	4	136.72%

Table 13

Odds Ratios of ECO % Variables by Contract Type

	ECO % Growth in Contract Variable				
Independent Variables	ECO>0% (n=44)	ECO>5% (n=33)	ECO>10% (n=29)	ECO>20% (n=22)	ECO>100% (n=12)
Contract Type - Fixed (n=28)	2.19	0.81	0.90	0.29*	0.54
Contract Type – Cost (n=47)	0.46	1.23	1.11	3.45*	1.85
ConType FFP (n=24)	1.64	0.87	0.93	0.37**	0.67
ConType FPI (n=4)	NA	0.63	0.79	0.00	0.00
ConType CPFF (n=27)	0.16*	0.35*	0.50	0.94	0.28
ConType CPIF (n=12)	4.26**	4.88*	2.61	2.94**	3.44**
ConType CPAF (n=8)	2.29	2.32	1.68	2.72	3.87**

Contract types were tested at the aggregated and individual contract types. Table 12 displays the number of contracts and median ECO-related cost growth percentages as grouped by contract type. Table 13 displays the results of the contingency table and odds ratio tests. When tested for the contract types related to fixed price contracts, odds ratio values at all percentage levels described a possible relationship in which ECO-related cost growth was less likely to occur but was only significant when tested for ECO percentage change of greater than 20 percent. Contract types related to a cost contract was significant at the zero percent and greater than 20% ECO percentage change levels, describing a relationship that the variable is more likely to incur ECO-related cost growth. We also tested odds ratios for the five individual contract types, which resulted in three types that had statistical significance. Firm-fixed price (FFP) contracts exhibited odds ratio values to suggest a less likely relationship with ECO-related cost growth but was only significant at the greater than 20% percentage level. Cost plus fixed fee (CPFF) contracts odds ratio values suggested less likely to incur ECO-related cost growth and tested for significance in relation to ECO growth of greater than zero percent and 5 percent. Cost plus incentive fee (CPIF) contracts suggested more likely to incur ECO-related cost growth, with greater than zero percent, 5%, 20%, and 100% having statistical significance. Cost plus award fee (CPAF) contracts also had statistical significance of more likely odds for ECO-related cost growth to occur at 100% levels or more. Considering all tests on these contract types, analysis on individual contract types is best suited to understand the relationships at a granular level. Odds ratios of fixed price contract models did indicate that these types of contracts elicit less likely incurrence of ECO-related cost growth, while cost contract models will elicit a more likely relationship instead. These indications may provide insight for acquisitions professionals when determining cost estimates that include ECO-related cost growth predictions.

Table 14

Number of Contracts and Median ECO % by Commodity Asset

	Number of Contracts and Median ECO % Change in Contract Variable									
	ECO>0% (n=44)		ECO>5% (n=33)		ECO>10% (n=29)		ECO>20% (n=22)		ECO>100% (n=12)	
Independent Variables	n	Median	n	Median	n	Median	n	Median	n	Median
Asset – Space Vehicle (n=20)	14	14.83%	12	24.92%	11	32.55%	6	102.80%	3	525.63%
Asset - Ground (n=21)	18	23.44%	14	31.31%	12	81.38%	10	153.53%	6	338.14%
Asset – Launch Vehicle (n=34)	12	15.46%	7	32.43%	6	84.58%	6	84.58%	3	730.42%

Table 15

Odds Ratios of ECO % Variables by Commodity Asset

	ECO % Growth in Contract Variable				
	ECO>0% (n=44)	ECO>5% (n=33)	ECO>10% (n=29)	ECO>20% (n=22)	ECO>100% (n=12)
Independent Variables					
Asset – Space Vehicle (n=20)	1.94	2.43**	2.51**	1.04	0.90
Asset - Ground (n=21)	6.46*	3.68*	2.90*	3.18*	3.20**
Asset – Launch Vehicle (n=34)	0.15*	0.15*	0.17*	0.33*	0.34

Table 14 displays the number of contracts and median ECO-related cost growth percentages as grouped by commodity asset. Of the different space commodity assets depicted in Table 15, odds ratio values indicated that launch vehicle contracts were unlikely to incur ECO cost change increases between zero percent and at least 20 percent. Contracts in the space vehicle asset were more likely to incur ECO-related cost growth and were significant between the five percent and greater than 10% variables. Ground asset related contracts were more likely to incur ECO-related cost growth between the zero percent and through 100% variables. These results are useful when understanding all space commodity programs at a granular level, as the three assets do perform different missions and ECO-related cost growth could vary.

Summary

We have gained valuable insight in understanding the relationships between contract variables and ECO-related cost growth. These statistical relationships are summarized in Table 16, which provides a comprehensive view of all the variables that may induce ECO-related cost growth. Further implications of these relationships and how they answer our research questions are provided in chapter V.

Table 16

Summary – Significant ECO Growth Variables by Likelihood

Variables (High Likelihood)	ECO>0%	ECO>5%	ECO>10%	ECO>20%	ECO>100%
Baseline >$2.5M	X	X	X		
Baseline > $50M	X	X	X		
Baseline >$100M	X	X	X		
Baseline > $500M	X	X	X	X	X
Baseline > $1B		X	X	X	
Greater than 5 ECO Modifications	X	X	X	X	X
Greater than 20 ECO Modifications			X	X	X
Contract Type - Cost				X	
ConType CPIF	X	X		X	X
ConType CPAF					X
Asset - Space Vehicle		X	X		
Asset - Ground	X	X	X	X	X

Variables (Less Likelihood)	ECO>0%	ECO>5%	ECO>10%	ECO>20%	ECO>100%
Baseline < $2.5M	X	X	X		
< 5 ECO Modifications	X	X	X	X	
Contract Type - Fixed				X	
ConType FFP				X	
ConType CPFF	X	X			
Asset - Launch Vehicle	X	X	X	X	

V. Conclusions and Recommendations

Chapter Overview

In this chapter, we discuss conclusions of the analysis, provide suggestions for future research, and explain the implications this research has for the acquisition community. Understanding the process of using previous studies (chapter II), working through establishing a baseline for analysis (chapter III), and exploring the results (chapter IV) will be a source for the acquisition community to evaluate and utilize when ECO and space programs are the topic of discussion.

Conclusions of Research

Engineering change order-related cost growth in space programs tends to be associated with the size of a contract, how many modifications occur, the type of contract, and the type of asset. Similar to the results of previous studies, smaller contracts and less technical modifications suggest a lesser likelihood of ECO-related cost growth, while vice-versa is suggested for larger contracts and more technical modifications. Another important detail is that contract types with a firm-fixed price basis are associated with less likelihood of ECO-related cost growth, whereas cost based contracts tend to have high likelihood of ECO-related cost growth. Moreover, space vehicle and ground asset programs may be more likely to experience ECO growth, whereas launch vehicle programs may be less likely to experience ECO growth.

The implications of this research establishes an empirical reference point for use in future research and analysis involving ECO factors on space program cost growth. The odds ratio values of the significant variables revealed in this research indicate the tendencies of ECO-related cost growth. This will be useful in decision making with the ability to anticipate and mitigate ECO-related cost growth. Another implication is that the KDB database is a tool that could be used for cost estimates and data analysis that is easily accessible and presents agile feedback.

Recommendations for Future Research

As the space acquisition environment is unique, future research is warranted to explore and establish further understanding of ECO growth in that context. By using the KDB database further exploration into cost growth into the other types of modifications (i.e., administrative, schedule) is possible. The advantage of doing so will reveal a holistic view for potential cost growth in space programs and allows decision makers the flexibility to optimize decisions related to cost. Furthermore, analysis of the sub-level of technical/ECO modifications may provide insight on a micro-level to understand the effects of certain actions and how it affects cost growth.

Summary

The results from this analysis form the foundation for future exploration of ECO-related cost growth in Air Force space programs. It will also serve as a potential reference to those involved in the acquisition process that are concerned with ECO-related cost growth. Continuing to increase the knowledge base of cost estimators (especially in space programs) benefit the acquisition community to aid in cost estimation and budgetary decisions.

Appendix A

Information Contained in KDB Database Variables

Service	Commodity	Phase	Contract Type	Mod Category	Tech Category
NAVY	GROUND VEHICLE	PRODUCTION	FFP	BASELINE	Basic
ARMY	MISSILES	O&S	CPFF	FMS	IATCO
DoD	AIRCRAFT	DEVELOPMENT	N/A	TECHNICAL	PME
AIR FORCE	AIS		FPI	COST	TRAINING
	SPACE		CPIF	ADMINISTRATIVE	NRE
	DECOYS		CPAF	SCHEDULE	Spt. Eqt.
	ORDNANCE		COST	UNKNOWN	O&S
	TARGETS/DRONES		T&M		DATA
	ELECTRONICS		FPAF		PoP
	RADAR		OTH		SPARES
	UAV		FP-EPA		SE/PM
	ENGINE				STE
	LASER				Admin
	NON-LETHAL				CLIN Shift
	GUN				Definitization
	SHIP				Predefined
					Award Fee
					New Scope
					ECP
					Descope
					Option
					Correction
					Long Lead
					Overrun
					EPA
					Missing Mod
					Slip
					Discrete
					Rephasing
					Software
					Funding
					Unanticipated
					Underrun
					Final
					Weight
					OTB

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14. ABSTRACT

There has been little empirical evidence and vague official guidance published to inform the Department of Defense (DOD) acquisition community on the cost growth effects of engineering change orders (ECO) on their programs. The information is especially scarce when it comes to understanding those effects in space programs. Utilizing previous research to our advantage, we explore factors that may explain ECO-related cost growth including program size, acquisition phase, the number of modifications to a contract, contract type, and specific space commodity assets. Using non-parametric analysis, contingency tables, and odds ratio tests, these were found to be significant factors (except acquisition phase) that could determine the likelihood of ECO-related growth at different percentage levels. This research aims to establish a reference point for future research into ECO-related cost growth and space commodities.

15. SUBJECT TERMS

Engineering change order, Space, Cost growth, Non-parametric analysis

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